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A Social and Ecological Approach to Mosquito Species Distribution Across Land Use in Bangor, Maine

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A SOCIAL AND ECOLOGICAL APPROACH TO MOSQUITO SPECIES DISTRIBUTION
ACROSS LAND USE IN BANGOR, MAINE

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Mosquitoes are ubiquitous pests and infectious disease vectors. However, not all mosquito species bite humans, or are competent pathogen vectors between bloodmeal hosts. Along with climatic variables like temperature and rainfall, mosquito species distribution is determined by aquatic habitat availability for juvenile mosquito development, and terrestrial habitat and host availability for adult mosquitoes. There is variation in the preferred aquatic habitat for gravid female oviposition and subsequent larval development. Some mosquito species' oviposition and development are associated with ephemeral water sources (e.g., floodplains), others prefer more permanent water sources (e.g., bogs or vernal pools). Other mosquitoes have evolved to occupy small, artificial water containers (e.g., buckets, tires) that are associated with human-dominated areas. These environmental factors are impacted by human processes like agriculture and urbanization and affect human exposure to mosquitoes and mosquito-borne diseases (MBD). Human exposure is also affected by mosquito control (e.g., spraying pesticides, emptying water containers) or personal protective behaviors (e.g., using mosquito repellent, wearing protective clothing). This interaction of human and environmental factors that affect mosquito habitat allows us to approach this system using a social-ecological systems (SES) framework. Social-ecological approaches call for the components within a system and the relationships between them to be examined from an integrated perspective including cultural, political, economic and ecological viewpoints across spatial scales. The One Health framework is an SES which considers the health of animals, humans and the environment as interconnected and dependent on one another. The ecology of vector-borne diseases, and mosquito ecology specifically, are relevant topics for application of the One Health model due to the interactions of human and environmental variables. In this thesis, mosquito species distribution was examined at 40 sites across an urban to rural gradient and recreational parks in Bangor, Maine to understand how mosquito distribution is affected by land use in this region. Additionally, a Knowledge, Attitudes and Practices survey was distributed among participants at the 30 residential study sites to understand factors that affect engagement in mosquito control and personal protective behaviors. A mosquito habitat assessment was conducted at each participant's property to integrate the analysis of social and ecological variables. Results show that mosquito abundance was significantly different across land use categories. Mosquito abundance was highest in recreational parks and rural residential areas. Among residential categories, rural sites had the most nuisance species mosquitoes, and the least vector species mosquitoes. Urban residential sites had the lowest mosquito abundance, but highest vector species abundance. Participant knowledge level was not associated with the amount of aquatic habitat suitable for larval mosquitoes, and participants were likely report mosquitoes as a nuisance on their properties, but unlikely to engage in control practices. These results indicate a possible mismatch between mosquito exposure, mosquito perceptions and engagement in control behaviors, which warrants further study. This thesis adds to a limited body of literature which examine mosquitoes from a social and ecological perspective in the United States, and this integrated perspective is

important for understanding, protecting, and improving public health issues related to mosquitoes.

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LIST OF ABBREVIATIONS

BI: Bretau Index

EEEV: Eastern Equine Encephalitis Virus

HI: House Index

JCV: Jamestown Canyon Virus

KAP: Knowledge Attitude and Practice

LUC: Land use category

MBD: Mosquito-borne disease

SES: Social-ecological systems

TPB: Theory of Planned Behavior

US: United States

VBD: Vector-borne disease

WNV: West Nile Virus

CHAPTER 1

MOSQUITO DISTRIBUTIONS AS A CASE FOR SOCIAL-ECOLOGICAL INVESTIGATION IN THE NORTHEAST US AND INTRODUCTION TO THE THESIS

Socio-ecological systems (SES) involve human and environmental variables which interact in complex ways and feedback to each other at overlapping scales (Zinstagg et al 2011). In SES theory, it is assumed that both social and ecological components within the system are complex and adaptive; the components and their interactions in an SES are not necessarily static through time nor across scales, making them difficult to model using traditional approaches (Aguirre 2019). SES thinking allows for a system to be broken down into social, cultural, economic, and/or environmental components at population to molecular scales, and for the connections and relationships between these components to be described from an integrated perspective (Richter et al 2015). The first research areas to employ SES theory were those investigating the resilience and sustainability of coupled human and natural ecosystems (Walker et al 2002), but since has been applied to food systems (e.g., agriculture, aquaculture), environmental justice issues (e.g., water and land access, climate change), and public health (e.g., emerging and zoonotic infectious disease, environmental contamination) as reviewed by Zinstagg (2011). SES theory allows researchers to consider bidirectionally linked human and environmental systems at varying scales, and studies which integrate these two systems have revealed new patterns such as feedback loops, tipping points and time lags between variables which are not detected with traditional approaches from social or environmental sciences on their own (Berkes et al. 2000). Inherently, SES approaches require that researchers not rely on heavily siloed, disciplinary training but instead consider a holistic, often transdisciplinary perspective which bridges barriers to system-based research (Aguirre 2019). SES is a common language that can be applied across many contexts, allowing for increased collaboration across social and environmental sciences on complex problems (Kadykalo et al 2022; Waltner-Toews 2017).

An interdisciplinary research approach born from SES theory is the One Health framework. One Health is the notion that human, animal and environmental health are inextricably related and should be considered holistically. Humans have long protected human and animal health and observed the link between health and the environment (Mi et al. 2016), but more recently the idea has been used formally as a research framework. One Health grew out of a succession of research models including Ecosystem Health, Conservation Medicine, and EcoHealth and later expanding to Planetary Health and GeoHealth (Aguirre et al., 2012, Almada et al., 2017; Wilcox et al., 2012; 2019; Whitmee et al., 2015), all aiming to integrate biophysical and social sciences to address modern problems in global health. One Health gained popularity in international research, particularly after 2010, when a report by the Food and Agriculture Organization of the United Nations, the World Health Organization of the United Nations, and the World Organization for Animal Health called for coordinated One Health collaborations to address growing global social-ecological issues (Aguirre 2019). Zinstagg (2011) reviews systems approaches to health and recommends a specific health model within SES, such as One Health, including both qualitative and quantitative methods to unravel complex interactions between human, animal and environmental variables. The One Health approach has been applied to health SES at local, national, and global scales with the goal of improving and protecting the health of people, animals and the environment. It has been used to investigate health SES relationships related to climate change, antibiotic resistance, food safety, food security, and most notably, zoonotic infectious diseases (Gibbs 2014). The One Health approach was pivotal in the global response to the threat of highly pathogenic avian influenza in 2006 with outcomes of interdisciplinary international collaboration including a framework for the control of future non-human influenzas (Gibbs 2014, World Bank 2010). Other infectious and zoonotic disease systems have benefitted from a One Health approach as well (Lebov et al. 2017). For example, consider Ebola virus, which has caused ten outbreaks in the Democratic Republic of Congo (DRC). With support from the WHO, health officials in the DRC have implemented Ebola virus response measures based in social, environmental and veterinary sciences, such as safe and dignified burials, human and wildlife screening and improved environmental conditions to help limit transmission and future spillover (Sikakulya et al 2020). Additionally, the One Health approach has been effectively applied to the rabies disease system in Latin America, where mass canine vaccinations and screenings, along with educational campaigns were crucial for the decline of canine-mediated human rabies (Cleaveland et al. 2014). More recently, the One Health approach has also been applied to the COVID-19 pandemic, where human health surveillance, veterinary surveillance and educational campaigns at regional, national and international levels were crucial for the pandemic response (Bonilla-Aldana et al. 2020; Trilla 2020).

Vector-borne zoonotic diseases (VBD) account for 17% of total global infections (WHO 2020), and the innate health SES they encompass are ideal contexts to apply the One Health approach. Figure 1, adapted from Benneli and Duggan (2018), shows a conceptual diagram of how the One Health approach encompassing human, animals, and the environment, fits within an SES. In the system illustrated by the figure, arthropod vectors, which feed on human and animal hosts and are tightly coupled with environmental conditions, allowing for transmission of VBD across a landscape. The interaction between social and ecological variables is in these health SES are complex; human institutions, policies, and behaviors mediate environmental changes such as anthropogenic climate change, urbanization, and agriculture which in turn affects vector distribution and risk of VBD emergence and transmission (Altizer et al 2013, Patts 2004, Franklinos 2019). Mosquito-borne diseases (MBD) are the VBD that cause the highest global morbidity and mortality, and mosquitoes are referred to as the world's deadliest animal due to the number of pathogens they can transmit and the number of people that are killed by mosquito borne disease each year (Rakotoarinia 2022). Indeed, the One Health approach has been used internationally to identify important social-ecological factors in MBD systems such as Dengue, chikungunya, and Zika viruses (Velosa 2022), and Aguirre (2019) argues that effective global malaria control and prevention require a collaborative and transdisciplinary approach, such as One Health.

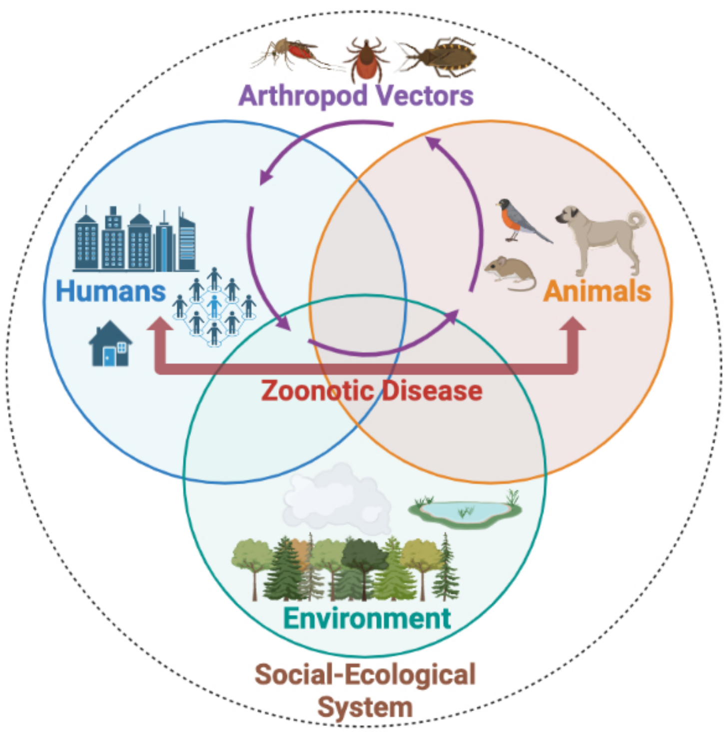

Figure 1. Conceptual figure adapted from Benelli and Duggan (2018) depicting the social-ecological system that comprises One Health within the context of VBD. Vector-borne zoonotic diseases are transmitted between humans and animals via of the bite of an infected arthropod vector. Environmental conditions facilitate transmission by providing vector habitat and allow for human, animal and vector contact. Created with BioRender.com

The One Health approach to MDB health SES has been more commonly adopted for practice in developing areas closer to the tropic zone, where MBD are more common and a bigger threat to public health. For example, a One Health approach to MBD in Panama City revealed that outreach programs should be targeted for elderly residents of low socioeconomic status, and residents with pets in the home (Whiteman et al. 2018). In Northern Thailand, where Dengue fever is of public health concern, housewives were documented to report the lowest knowledge and engagement in prevention practices but were also most likely to be at risk for disease transmission while working in and around the home (van Benthem 2002). Additionally, in malaria endemic regions of India, illiteracy and tribal affiliation were associated with low malaria knowledge, and high epidemiological risk, indicating a need for coordinated national and local interventions in both education and environmental conditions (Sharma et al. 2007).

In North America, the SES approach is less common in MBD systems, despite several MBDs emerging and re-emerging across the continent, including West Nile Virus (WNV), LaCrosse Encephalitis Virus, and Jamestown Canyon Virus (Petersen et al. 2019). Additionally, due to their tight coupling with human-mediated environments, mosquitoes are also important to consider in their role as a pest and human nuisance in North America. Previous SES mosquito research in the US has shown that higher mosquito control behaviors are reported from residents in Washington D.C. neighborhoods with high socioeconomic status and neighborhoods with lower socioeconomic status were more likely to report lower motivation in engage in control behaviors. Similarly, older age and higher socioeconomic status in Baltimore and Washington D.C. increases resident mosquito knowledge and increases likelihood of self-reporting for engagement in larval mosquito control (Parker 2019). Additionally, lower socioeconomic status in in these cities is associated with higher mosquito production (LaDeau 2013) and Dowling et al

(2013) reported more observations of potential larval habitat in lower socioeconomic status in Washington D.C. neighborhoods. However, in upstate New York, resident perception of WNV was significantly associated with engagement in mosquito control measures and the number of containers positive for mosquito larvae on their property, but resident knowledge of WNV was not significantly associated (Tuiten et al. 2009). Lastly in New Orleans, Louisiana Moise et al. (2022) report low resident knowledge of the relationship between mosquito production and discarded water containers, such as used tires. More research integrating human and environmental factors of mosquito distributions in the U.S. is necessary to understand how these complex systems interact and to protect public health, particularly in rural regions where mosquito SES research is even less common.

The purpose of this thesis is to explore the distribution of mosquitoes along a rural-urban gradient in Bangor, Maine through an integration of approaches from social and biophysical sciences. The questions driving this thesis are: how do residential land use zones affect adult mosquito distribution and larval mosquito habitat? What do residents on these properties know about mosquitoes, their habitat, and reduction or protection measures?

In the second chapter of the thesis, I describe a natural experiment designed to capture a fine scale of mosquito distribution across a small city. Adult mosquito collections occurred weekly across 40 sites. Thirty sites were residential properties spanning a land zoning gradient from urban residential to rural residential and 10 sites were within city recreational forests. By collecting weekly mosquito data at residential properties and recreational areas we were able to understand the types of mosquitoes that people are exposed to at their homes and while they recreate in public areas in Bangor. In addition to the collections, residential properties were surveyed for larval mosquito habitat in the form of water containers and property residents participated in a questionnaire. The aim of the second chapter is to present an integrated approach to investigating ecological and social dimensions of mosquito distribution. In the third chapter of the thesis, I discuss the resident survey in further depth by describing the theoretical basis, questionnaire design, and additional results. The survey results describe the observed relationships between participant knowledge, attitudes and behaviors surrounding mosquitoes and mosquito borne diseases. The aim of this thesis is to add to the growing body of research of using integrated methods to approach complex human problems, such as those presented by mosquitoes. By combining entomological and social assessments, we provide more context in the understanding of VBD SES like MBD systems and inform, improve and protect public health.

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CHAPTER 2

A SOCIAL-ECOLOGICAL APPROACH TO THE DISTRIBUTION OF VECTOR, NUISANCE AND ARTIFICIAL CONTAINER BREEDING MOSQUITO SPECIES: DIFFERENCES AMONG RESIDENTIAL LAND USE TYPES

ABSTRACT

Mosquito abundance and distribution is related to environmental variables like temperature, rainfall and land cover which shape available aquatic habitat for mosquito oviposition and juvenile development. As land cover changes over rural-urban gradients, mosquito species composition species richness decreases via decreased heterogeneity in habitat availability. Many mosquito species rely on ephemeral or permanent water sources, like floodplains and forest habitats. However, certain species have evolved to occupy urban niches and artificial aquatic habitats associated with urbanization and human-dominated environments, like tires or storm drain infrastructure. These species also adapted to urban habitats by using human hosts for bloodmeals and may transmit zoonotic pathogens. Mosquito habitat and subsequent human exposure to mosquitoes are affected by broad-scale environmental and human processes. At a finer scale, human behaviors also affect exposure. In this study, mosquitoes were collected at 40 sites across a rural-urban gradient and recreational parks in Bangor, Maine, and a juvenile habitat assessment was conducted on the 30 residential properties. Additionally, a Knowledge, Attitudes and Practice survey was distributed to residents to understand factors that determine engagement in mosquito control and personal protective behaviors. Mosquito and nuisance species abundance was highest in recreational and rural sites. Vector species abundance was highest at urban sites. Knowledge was not correlated with the number of container habitats on resident properties. Mosquitoes were reported as a nuisance, but residents were not likely to engage in control

practices. This study adds valuable information to the growing body of social-ecological approaches to mosquitoes in the United States.

Introduction

Mosquito species distributions and the risk of human exposure to mosquitoes as disease vectors and nuisance pests are driven by complex social and environmental dynamics. Due to human creation and modifications of mosquito habitats and subsequent human interactions with mosquitoes, mosquito distributions can be approached as products of a social-ecological system, in which social and ecological factors interact and feedback to each other at various spatial scales (Colding and Barthel 2019). Social dynamics and human activities at large scales (e.g., urbanization, globalization, commercial and residential development) and small scales (e.g., human decisions about property and landscape management, and personal protective behaviors) affect mosquito ecology through the alteration of available mosquito habitat (Bowden et al., 2011; Gratz, 1999). Some disease vector species have spread across the globe as a result of these human processes. *Aedes aegypti*, the primary vector of dengue, Chikungunya, and Zika viruses, is a particularly relevant example, having been introduced from its origin in sub-Saharan Africa across the Americas and into Asia and Australia via human movement due colonization and trade, likely during the 1600s (reviewed by Powell and Tabachnick, 2013). More recently, *Aedes albopictus*, another anthrophilic disease vector mosquito, was introduced in the US in the 1980s, likely via used tires imported from the mosquito's native range in northern Asia (Moore and Mitchell 1997).

The distributions of mosquito species, which may be disease vectors, biting pests, or both, is a consequence of the available aquatic habitat for oviposition and larval development and terrestrial habitat to support adult mosquitoes (Reiskind et al. 2017, Wilke et al. 2019). It is of public health and pest management interest to integrate the investigation of ecological and social drivers of mosquito species distributions to understand disease risk implications across regional landscapes, where human behavior can contribute to and change in response to the abundance of mosquitoes. Previous studies that explicitly integrate social and biophysical drivers of mosquito distributions at the residential scale are limited. While more common in countries with a higher mosquito-borne disease (MBD) burden, the first Unites States (US) study that reports integrating household social and entomological data collection found that perceptions, but not knowledge, of West Nile Virus (WNV) were related to the presence of larvae-positive containers on properties among participants in suburban upstate New York (Tuiten et al. 2009). A subsequent study integrating social science surveys and entomological assessments was conducted in the Baltimore-Washington, D.C. metropolitan area. Among Baltimore, MD and Washington, D.C. residents, Dowling et al. (2013) found that reported engagement in mosquito larvae source reduction was correlated with lower observations of *Culex pipiens* and *Ae. albopictus* larvae-positive containers on participant properties. It is important to continue to unravel this social and biophysical link at varying spatial scales and across diverse US regions to add context to our understanding of mosquito distributions and the implications for public health and pest management.

In the northeastern US mosquitoes are both pests and vectors of disease. In the state of Maine specifically, there are more than 45 documented mosquito species, and while about half of these species have been shown to be competent disease vectors in laboratory and experimental studies, several species are recognized as key amplifying and bridge vectors of zoonotic pathogens. WNV, first reported in New York in 1999, has become endemic in the two decades since its introduction and is the most common MBD in the US (Ronca et al. 2021). In the

Northeast US, WNV is maintained in enzootic and epizootic cycles by *Culex restuans, Cx, pipiens*, and *Cx. salinarious*, with the latter two species serving as the main bridge vectors of WNV to humans in this region (Andreadis 2004). Eastern Equine Encephalitis Virus (EEEV) is predominantly vectored by *Culiseta melanura* (McMillan et al 2020). EEEV is primarily maintained in an avian enzootic cycle, but occasionally EEEV cases spillover into livestock and humans (Andreadis et al. 2013). Jamestown Canyon Virus (JCV) is vectored by several boreal mosquito species, notably univoltine *Aedes/Ochlerotatus* species, such as *Aedes vexans* and *Ochlerotatus canadensis* (McMillan et al 2020, Andreadis, Thomas & Shepherd 2005; Crans 2004). The reservoir hosts of JCV in the Northeast are white-tailed deer, and although human cases are generally rare, the increase in cases in recent decades is of public health concern (Andreadis et al 2008). In addition to their ability to transmit diseases, more than half of the mosquito species in this region are known to be aggressive human-biters, notably, *Aedes japonicus,* and *Och. canadensis* (Holman et al. 2006). Studies have documented that residents and visitors in the Northeast perceive mosquitoes as nuisance pests, including a study conducted in New Jersey in which 59.5% of resident participants reported that mosquitoes prevented their enjoyment of outdoor activities (Halasa et al. 2014). Additionally, in survey research conducted at Acadia National Park, Maine, 60% of park visitors indicated that they perceived increased presence of mosquitoes to be an important impact of climate change within the park (De Urioste-Stone 2016).

Human exposure to mosquitoes is in part a consequence of mosquito species distributions in a landscape, which is driven largely by environmental factors. The distribution of mosquito species in a landscape varies as a function of land cover, and human land use patterns can alter the risk of mosquito-borne disease. (Franklinos et al. 2019, Ortiz et al. 2022). For example, clearcutting of tropical forests for the purpose of palm oil plantations is associated with higher risk of malaria transmission in Papua, New Guinea (Pluess et al. 2009). In New Haven, CT, *Cx. pipiens*, the primary vector of WNV to humans, is more associated with urban land use compared *Culex* species that only act as enzootic vectors (Brown et al. 2008). Reduced landscape heterogeneity in urban landscapes has also been associated with low mosquito species diversity in Chicago, IL, where WNV infection rates in *Cx. pipiens* increased in flat landscapes with high impervious surface cover (Chavez et al 2011). More broadly, reviews studies have examined how water retention systems, deforestation, agricultural development, and urbanization have been associated with risk of MBD transmission on a global scale (Norris 2004).

Mosquito species distributions are dependent on the types of available habitat for mosquito breeding due to differences in the oviposition habitat preferences of gravid female mosquitoes. For example, oviposition by some species such as *Cx. pipiens*, is associated with artificial human-made containers of water such as storm drain infrastructure, trash cans, and garden equipment in urban environments (Marini et al. 2020, Leisnham et al. 2021). Other urban mosquitoes, like *Ae. albopictus* and *Ae. aegypti* are more associated with smaller artificial human-made containers like planters, buckets and tarps (Carrieri 2003, LaDeau et al. 2013) Other species, like *Cs. melanura* and *Coquillettidia perturbans*, are associated with oviposition in natural aquatic habitat such as rural wetland or floodplain landscapes (Gaugler, et al., 2013; Skaff et al., 2017, Bowden et al. 2011). In general, species diversity tends to be lower in urban habitats compared to rural habitats due to higher concentration of impervious surface cover, limited diversity of breeding habitat, and higher temperatures, (de Valdez 2017, Gardner et al. 2014, LaDeau et al., 2013, Zettle et al 2022). Urban environments also tend to have a higher density of vector species compared to rural environments due to the availability of suitable habitat that disease vectors such as *Cx. pipiens* have evolved to occupy in niches of human-dominated environments, such as in buckets, tires or storm drain infrastructure (Becker et al., 2014). Human behaviors, such as those which affect larval mosquito habitat sources, can also impact mosquito abundance, species distributions and exposure to mosquitoes in a landscape, particularly at spatial scales, as fine as the household level (Brown et al., 2014).

In turn, the abundance and species distributions of mosquitoes may also affect human behavior and interaction with the landscape (Tangena et al., 2017). In residential neighborhoods, household mosquito abundance can be driven not only by landscape context but also by behaviors in the form of household management practices, such as emptying artificial water containers (Pai et al., 2005). While reducing mosquito abundance through removal or modification of habitat is an option on one's private residence, human exposure to mosquitoes and mosquito bites also occurs in recreational outdoor settings, like wooded areas that support large mosquito populations. This exposure to mosquitoes can be altered by preventative health behaviors such as use of protective clothing, personal repellent, or avoiding the outdoors altogether (Prabaningrum et al. 2020). Individuals decide whether to engage in these mosquito control or exposure behaviors based on personal experience with and knowledge of mosquitoes, positive or negative attitudes surrounding effectiveness, and perceptions of social norms (Bosnjak et al 2020). Additionally, exposure to mosquitoes in areas of recreation may influence individuals' perceptions and engagement in control practices at home, and vice versa. These dynamics of human-decision making can be measured using approaches from quantitative social sciences, such as the design and dissemination of theory-based surveys.

This study aimed to document mosquito species distributions over residential land use categories and is novel in its application of integrated biophysical and social science methodology in a dominantly rural landscape. The study had two main objectives, first to assess whether there are differences in a) mosquito abundance**,** b) vector species abundance, c) nuisance species abundance, or d) artificial container breeding species abundance across residential land use categories (LUC) in Bangor, Maine; and second, to investigate Bangor, Maine residents' knowledge, attitudes, and practices surrounding mosquito control and prevention behaviors, and the relationship between reported behaviors, observed mosquitoes and available mosquito habitat.

Methods

Site Selection and Property Recruitment

We conducted our study on residential properties and recreational forests in Bangor, Maine (44.80° N, 68.77° W), a US city of 34.26mi^2 and a population of 31,191 with a population density of 927 people per square mile according to 2021 US Census Bureau data. The city of Bangor and the urban to rural gradient it encompasses is a novel case for the study of mosquito species distributions due its location in the largely rural and forested state of Maine, which has no statewide mosquito control program. To assess the relationship between mosquito distributions and land use we selected 40 sites throughout Bangor for data collection. Thirty of the sites were randomly selected residential properties along an urban to rural gradient, with 10 sites from each of the following residential LUC: urban residential, low-density residential, and rural residential. Residential land parcel data were acquired from the Bangor City Planning Office. To understand the types of mosquitoes that Bangor residents are exposed to in public areas, an additional 10 sites were selected within recreational city forests: two within Brown Woods, three within Essex Woods, and five within Bangor City Forest. Participants were recruited from the randomly selected residential properties by approaching property owners with a request to participate in the study. If property owners from the randomly selected list were not home, or otherwise unable to participate, we instead recruited a neighboring property within the same land use category.

Mosquito Trapping

Mosquitoes were trapped from the week of 6/07/2021 through the week of 9/06/2021, for a total of 14 consecutive trapping weeks. Mosquitoes were trapped weekly at all 40 sites. Sites were randomly assigned to one of four groups, with one group sampled each of the four trap nights every week. Each week the sampling order was randomly determined. One of each gravid and light traps were set at each site. Traps were set between the hours of 1500-1100 on four trap nights each week. CDC Gravid Traps (catalog #6545-01-457-5511, John W. Hock Company, Florida, USA) were baited with 1 gallon of grass-clipping infused tap water, which was allowed to infuse for 24-48 hours prior to deployment. Gravid traps were placed on the ground near low vegetation in a shaded area. Unbaited CDC Miniature Light Traps (catalog #3740-01-106-0091, John W. Hock Company, Florida) were hung on a tree branch 4.5-5ft. Upon collection, mosquito traps were immediately placed in freezers at -30C to maintain sample integrity for identification. Mosquitoes were sorted from bycatch and sexed. Males and females were counted, and females were identified to species using a dichotomous key (Andreadis et al 2005). All identified mosquitoes were categorized by property as vector vs non-vector species, nuisance vs non-nuisance species and artificial container breeding vs non-artificial container species (Table 1). The number of vector species, nuisance species and artificial container breeding species collected were calculated for each property. Mosquito abundance was calculated as the average number of mosquitoes collected each week at each site. For the recreational forest LUC, only abundance data are reported due to the large number of specimens. Additionally, temperature (°C) and relative humidity (%) were monitored at each mosquito collection site. Microclimate conditions were recorded using BlueMaestro TempoDisc™ Dataloggers (catalog #DSCTHD001, Blue Maestro, London, UK), deployed on tree branches at breast height. Dataloggers were programmed to collect data hourly and data were offloaded weekly during mosquito trap collection.

Table 1. Mosquito species classification used in analysis based on literature review (Holman et al. 2006, Andreadis et al. 2005, Crans 2004)

Species	Vector- EEE	Vector- JCV	Vector- WNV	Nuisance	Artificial Container Breeding
Aedes abserratus	-	X	-	X	-
Aedes cinereus	X	X	X	X	-
Aedes thibaulti	-	-	-	X	-
Aedes vexans	X	X	X	X	-
Anopheles punctipennis	X	X	X	X	X
Anopheles quadrimaculatus	X	-	X	X	X
Anopheles sp.	X	-	X	-	-
Anopheles walkeri	X	X	X	-	-
Coquillettidia perturbans	X	X	X	X	-
Culex sp.	X	-	X	-	X
Culiseta melanura	X	-	X	-	-
Culiseta morsitans	X	X	-	-	-
Culiseta sp.	X	-	-	-	-
Ochlerotatus aurifer	-	X	-	X	-
Ochlerotatus canadensis	X	X	X	X	-
Ochlerotatus cantator	X	X	X	X	-
Ochlerotatus communis	-	X	-	X	-
Ochlerotatus dorsalis	-	-	-	X	X
Ochlerotatus excrucians	-	X	-	X	-
Ochlerotatus hendersoni	-	-	-	X	X
Ochlerotatus intrudens	-	-	-	X	-
Ochlerotatus japonicus	-	-	X	X	X

Table 1 (CONT.)					
Ochlerotatus provocans	-	X	-	X	-
Ochlerotatus punctor	-	-	-	X	-
Ochlerotatus triseriatus	X	X	X	X	X
Ochlerotatus trivittatus	X	X	X	X	X
Psorophora ferox	X	X	X	X	-
Uranotaenia sapphirina	X	-	X	X	-
Wyeomyia smithii	-	-	-	-	-

Larval Habitat Assessment

To explore a potential mechanism to explain adult mosquito abundance, all participant properties were assessed once for potential larval mosquito habitat, and presence of juvenile mosquitoes within those habitats. Any natural (e.g., trees holes) or artificial (e.g., tires, bird baths, children's toys) vessel that could support water collection was observed and recorded. The estimated volume of the container, container type category, and whether the container was positive for juvenile mosquito presence was recorded. Container type was categorized by function (e.g., ornamental, recreational). Larval habitat assessments occurred from the week of 7/12/2021 through the week of 8/23/2021. Assessments occurred on days when the latest precipitation event occurred at least 2-4 days prior to avoid a bias towards observation of larvae-positive containers.

Survey Design and Institutional Review Board Approval

A Knowledge, Attitudes, and Practices (KAP) survey was distributed to all 30 property participants under the University of Maine Institutional Review Board protocol no. 2021_07_07. The KAP survey was designed based on constructs and relationships as described in the Theory of Planned Behavior (Azjen 1991) to understand behaviors related to mosquito control and protection that property participants engage in and the factors that determine those behaviors. The factors include five constructs measured by the survey: knowledge, attitudes, subjective norms, perceived behavioral control and practices. The knowledge construct was composed of right/wrong survey questions addressing knowledge of mosquitoes and mosquito-borne disease systems. The attitudes, subjective norms, perceived behavioral control and practices constructs were comprised of questions addressing feelings about different types of mosquito control and protection practices and intentions to perform mosquito control and protection practices. Questions addressing sociodemographic items were also included. To promote higher KAP survey response rates, we used a mixed-mode survey approach (Dillman 2016). Participants first received an email with study details directing them to an online survey via Qualtrics. Participants were reminded twice via email and once via phone to complete the survey, and a paper version of the survey was available if participants had limited internet access. Participants completed the survey between 9/28/2021 and 3/22/2022.

Data Analysis

To test the hypotheses that there are differences in a) mosquito abundance, b) vector species abundance, c) nuisance species abundance, or d) artificial container breeding species abundance across residential LUC, data were analyzed using R version 4.2.1 (R Core Team 2022). For each response variable, ANOVA tests were conducted using hurdle models due to zero-inflated data (pscl package; Jackman, Klieber and Zeileis 2008). Hurdle models consist of two parts for analyzing zero-inflated data and are particularly relevant for count data analysis. The first portion is a binomial model in which presence versus absence during each data collection is modeled. The second portion of the analysis is the conditional run, which models the data given that a count was present. For the response variables in this study, the first portion of the analysis modeled whether mosquitoes were collected at each site each week, and the second portion modeled the number of mosquitoes collected on weeks when mosquitoes were present at each site (Feng 2021). Model predictors included fixed effects of LUC, site ID, and week of collection. Temperature and rainfall were included as covariates in the models due to their established associations with mosquito abundance. For significant ANOVA models, pairwise comparisons among means for land use categories were conducted using a Tukey's test for significant differences (emmeans package; Lenth 2022). Mosquito abundance metrics for each LUC were calculated as the average number of mosquitoes collected each trap night on properties from each LUC.

Participant knowledge was measured through answers to the KAP survey knowledge questions. Answers were scored as +1 for correct answers, and -1 for incorrect answers. Knowledge question scores were aggregated into a single score, and knowledge scores were further categorized in High, Mid, and Low levels of knowledge. Analysis of the correlation between resident knowledge scores and presence of larval habitat containers on resident properties was conducted using Kendall's Tau statistic in R (stats package; R Core Team 2022). Established measures of mosquito container habitat, the house index and Bretau index were calculated for each LUC. The House Index (HI) is calculated as the $N_{Houses\ Positive}/N_{Houses\ Observed}$, or the number of houses with containers positive for juveniles divided by the total number of houses observed. The Bretau Index (BI) is calculated as $N_{Containers\ Positive}/N_{Houses\ Observed}$ or the number of containers found positive for mosquito juveniles divided by the total number of houses observed. (Sanchez et al. 2010, Focks 2003)

Results

Mosquito Summary

Over the course of the study, 16,582 mosquitoes were collected, including male mosquitoes and those which were unidentifiable due to poor condition. The total numbers of female, male and unidentifiable mosquitoes are detailed in Table 2. Overall, mosquitoes were most abundant in the forest sites (9,736), followed by rural residential sites (3,294), urban residential sites (1,801), and low-density residential sites (1,751) (Fig 2). Species data are only reported for residential sites and for female mosquitoes that were identifiable to genus (N = 4694). The most abundant species, accounting for 43.89% (N= 2060) of total mosquitoes captured across sites, were *Cx. restuans and Cx. pipiens*, followed by *Cq. perturbans* accounting for 16.68% (N = 783), *Cs. moristans* and *Ae. japonicus* comprising 8.69% (N = 408) and 8.54% (N = 401), respectively. The remaining 22% of the identifiable female mosquitoes captured were comprised of 23 species across 5 genera, for a total of 27 species across 9 genera identified (Table 3).

Table 2. Number of female, male and unidentifiable mosquitoes collected across residential land use categories in Bangor, Maine

	Rural			Low-Density			Urban Residential			Grand Total		
	Gravid	Light	Total	Gravid	Light	Total	Gravid	Light	Total	Gravid	Light	Total
Total Mosquitoes	1464	734	2198	1008	505	1513	1425	157	1582	3897	1396	5293
Identifiable Female Mosquitoes	1317	624	1941	877	458	1335	1291	127	1418	3485	1209	4694
Male mosquitoes	25	90	115	7	26	33	12	24	36	44	140	184
Unidentifiable mosquitoes	122	20	142	124	21	145	122	6	128	368	47	415

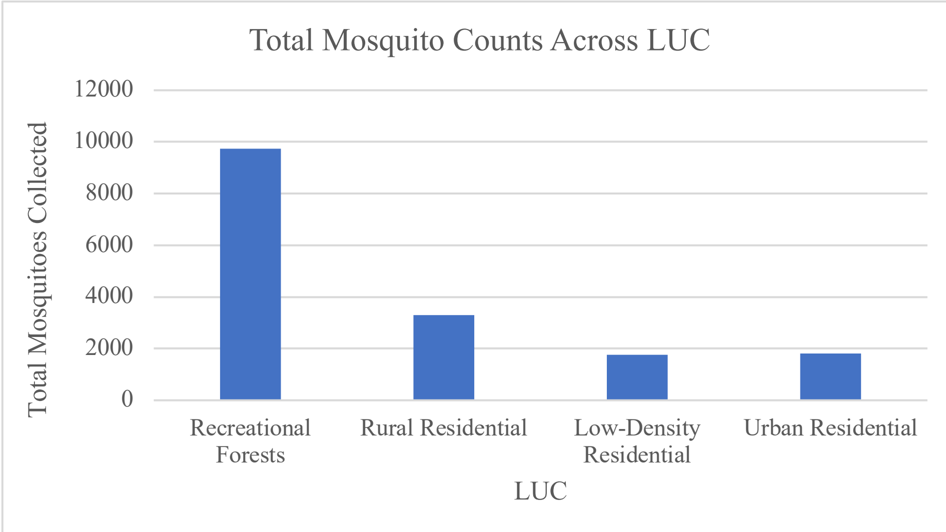

Figure 2. Total mosquitoes captured in each LUC in gravid and light traps

Table 3. Summary of mosquito species collected across residential land use categories in Bangor, Maine

	Rural			Low-Density			Urban			Grand Total		
Species	Gravid	Light	Total	Gravid	Light	Total	Gravid	Light	Total	Gravid	Light	Total
Aedes abserratus	3	0	3	0	0	0	4	0	4	7	0	7
Aedes cinereus	10	21	31	3	3	6	0	1	1	13	25	38
Aedes thibaulti	2	0	2	0	0	0	0	0	0	2	0	2
Aedes vexans	28	11	39	21	7	28	8	12	20	57	30	87
Aedes/Ochlerotatus sp.	9	1	10	16	0	16	1	0	1	26	1	27
Anopheles punctipennis	18	45	63	8	23	31	13	6	19	39	74	113
Anopheles quadrimaculatus	13	9	22	7	37	44	5	2	7	25	48	73
Anopheles sp.	1	0	1	0	0	0	0	0	0	1	0	1
Anopheles walkeri	1	14	15	2	18	20	0	1	1	3	33	36
Coquillettidia perturbans	227	213	440	101	170	271	45	27	72	373	410	783
Culex sp.	675	28	703	362	67	429	887	41	928	1924	136	2060
Culiseta melanura	25	31	56	66	20	86	56	8	64	147	59	206
Culiseta morsitans	74	173	247	44	81	125	25	11	36	143	265	408
Culiseta sp.	2	0	2	0	0	0	2	0	2	4	0	4
Ochlerotatus aurifer	3	3	6	32	5	37	7	0	7	42	8	50
Ochlerotatus canadensis	24	3	27	35	0	35	22	0	22	81	3	84
Ochlerotatus cantator	0	8	8	3	1	4	2	1	3	5	10	15
Ochlerotatus communis	0	0	0	1	0	1	0	0	0	1	0	1
Ochlerotatus dorsalis	0	0	0	1	0	1	0	0	0	1	0	1
Ochlerotatus excrucians	16	1	17	20	0	20	20	0	20	56	1	57
Ochlerotatus hendersoni	1	0	1	1	1	2	2	0	2	4	1	5

Table 3. (CONT.)												
Ochlerotatus intrudens	47	15	62	0	3	3	1	1	2	48	19	67
Ochlerotatus japonicus	81	2	83	142	7	149	165	4	169	388	13	401
Ochlerotatus provocans	4	9	13	0	1	1	3	1	4	7	11	18
Ochlerotatus punctor	1	8	9	2	0	2	0	0	0	3	8	11
Ochlerotatus triseriatus	24	6	30	4	1	5	19	5	24	47	12	59
Ochlerotatus trivittatus	2	3	5	5	0	5	1	0	1	8	3	11
Psorophora ferox	28	13	41	0	12	12	5	0	5	33	25	58
Uranotaenia sapphirina	1	3	4	1	1	2	2	2	4	4	6	10
Wyeomyia smithii	0	1	0	0	0	0	0	0	0	0	1	1
Totals	1320	621	1940	877	458	1335	1295	123	1418	3492	1202	4694

Mosquito diversity and abundance

Results of the Shannon's Diversity Index (Table 4) show that species diversity was lowest in urban sites than observed in low-density or rural sites. Additionally, results show that equity, or evenness, of species diversity was also lowest at urban sites, and highest at rural sites.

In the conditional run of the hurdle model, when mosquitoes were present, land use category was associated with a significant difference in mosquito abundance per trap night in gravid traps (Table 5). Mosquito abundance in gravid traps differed significantly between each land use category (Fig 3). The highest mean number of mosquitoes were captured at rural residential sites, followed by forested sites and urban residential sites, and the least number of mosquitoes were captured in gravid traps at low-density residential. For light traps, the conditional model indicates significant differences in mosquito abundance between land use categories (Table 5). The highest mean number of mosquitoes were trapped at recreational forest sites, followed by rural, low density and urban residential sites (Fig. 4).

Table 4. Shannon's Diversity and Equity Indices for Mosquito Species Diversity Across LUC		
Residential Land Use Category	Shannon's Diversity Index (H)	Shannon's Equity Index (H/H_{max})
Rural	2.09	0.61
Low-Density	2.17	0.64
Urban	1.41	0.41

Table 5: Hurdle Model Comparison of Weekly Trap Night Mosquito Abundance in Gravid and Light Traps Across Residential Land Use Category. Asterisk indicates significance at p<.05

Trap	Effect	Estimate	SE	Z	P-Value
Gravid	Zero-Inflated Model				
	Intercept	-4.459	1.920	-2.323	0.020*
	Land Use Category (Rural/Low Density)	0.877	0.505	1.737	0.082
	Land Use Category (Urban/Low Density)	1.062	0.541	1.962	0.050*
	Property	0.010	0.025	0.412	0.681
	Week	0.180	0.087	2.078	0.038*
	Temperature	0.261	0.107	2.439	0.015*
	Precipitation	-0.081	0.937	-0.086	0.931
	Conditional Model				
	Intercept	1.871	0.130	14.343	1.18E-46*
	Land Use Category (Rural/Low Density)	0.357	0.042	8.426	3.58E-17*
	Land Use Category (Urban/Low Density)	0.312	0.042	7.423	1.15E-13*
	Property	-0.017	0.002	-9.029	1.73E-19*
	Week	0.057	0.006	9.736	2.12E-22*
	Temperature	0.024	0.006	3.863	0.00011*
	Precipitation	-0.691	0.070	-9.878	5.20E-23*
Light	Zero-Inflated Model				
	Intercept	-1.681	1.035	-1.624	0.104
	Land Use Category (Rural/Low Density)	0.711	0.351	2.026	0.043*
	Land Use Category (Urban/Low Density)	-0.668	0.315	-2.117	0.034*
	Property	-0.010	0.016	-0.622	0.534
	Week	0.129	0.049	2.624	0.0087*
	Temperature	0.093	0.053	1.757	0.079*
	Precipitation	-0.385	0.442	-0.871	0.384
	Conditional Model				
	Intercept	-0.075	0.197	-0.383	0.702
	Land Use Category (Rural/Low Density)	0.377	0.058	6.561	5.34E-11*
	Land Use Category (Urban/Low Density)	-0.717	0.084	-8.511	1.72E-17*
	Property	-0.018	0.003	-6.235	4.52E-10*

Table 5. (CONT.)

	Week	-0.029	0.009	-3.366	0.000764*
	Temperature	0.122	0.009	14.127	2.58E-45*
	Precipitation	0.070	0.087	0.808	0.419

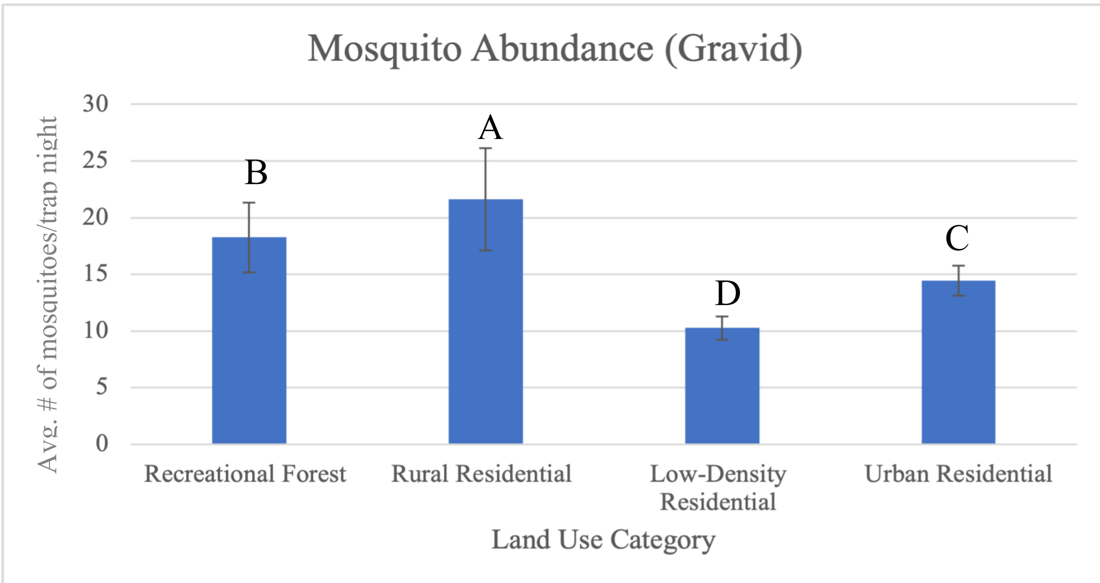

Figure 3. Mean abundance in mosquitoes captured per trap night across LUC in gravid traps

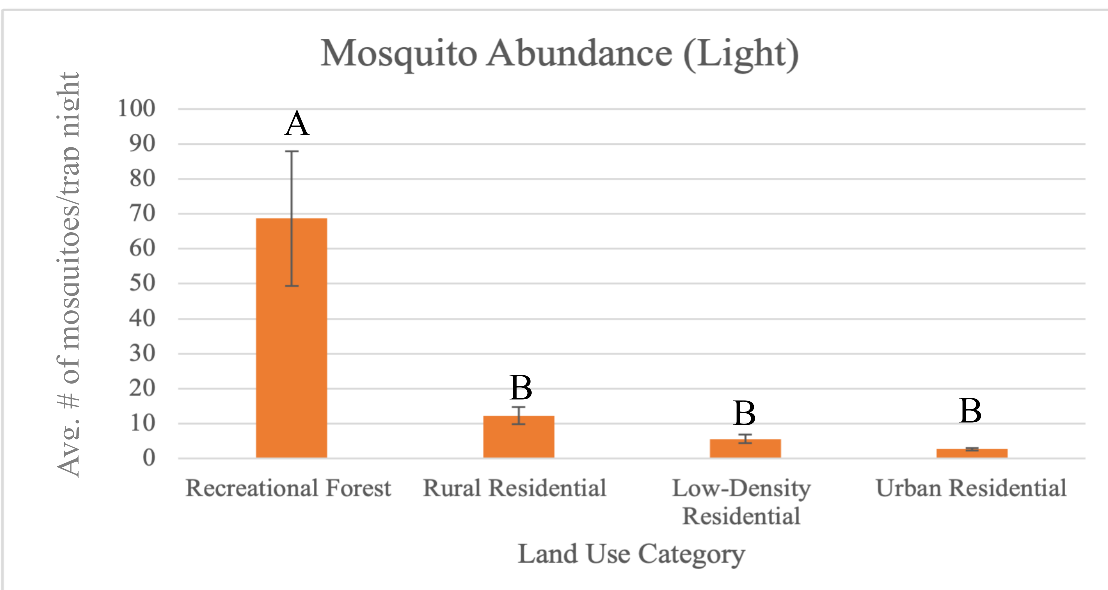

Figure 4. Mean abundance in mosquitoes captured per trap night across LUC in light traps

Vector species mosquito abundance

West Nile Virus vector species

When mosquitoes were present, there were differences in the mean abundance of WNV vectors (i.e., *Cx. pipiens, Cx. restuans, Och. japonicus,* etc) trapped in gravid traps between residential land use categories (Table 6). The highest mean number of WNV vectors were captured at urban residential sites and rural residential and the lowest mean number of WNV vectors were trapped in gravid traps at low-density residential sites (Fig 5). In light traps, the conditional model shows a relationship between residential land use categories and the mean number of WNV vectors collected. (Table 6). The highest mean number of WNV vectors in light traps were captured at rural residential sites, followed by low-density residential and the lowest mean number at urban residential sites (Fig 6).

Table 6: Hurdle Model Comparison of Weekly Trap Night WNV Vector Mosquito Abundance in Gravid and Light Traps Across Residential Land Use Category. Asterisk indicates significance at p<.05.

Trap	Effect	Estimate	SE	Z	P
Gravid	Zero-Inflated Model				
	Intercept	-3.340	1.512	-2.209	0.027*
	Land Use Category (Rural/Low Density)	0.640	0.443	1.446	0.148
	Land Use Category (Urban/Low Density)	0.864	0.470	1.838	0.066
	Property	0.024	0.022	1.082	0.279
	Week	0.202	0.075	2.711	0.0067*
	Temperature	0.182	0.081	2.242	0.025*
	Precipitation	-1.316	0.578	-2.276	0.023*
	Conditional Model				
	Intercept	1.493	0.154	9.710	2.73E-22*
	Land Use Category (Rural/Low Density)	0.209	0.050	4.147	3.37E-05*
	Land Use Category (Urban/Low Density)	0.313	0.048	6.458	1.06E-10*
	Property	-0.013	0.002	-5.917	3.29E-09*
	Week	0.050	0.007	7.269	3.62E-13*
	Temperature	0.030	0.007	4.127	3.68E-05*
	Precipitation	-0.785	0.094	-8.332	7.95E-17*

Table 6. (CONT).						
Light	Zero-Inflated Model					
		Intercept	-3.029	1.034	-2.930	0.0034*
		Land Use Category (Rural/Low Density)	0.785	0.331	2.369	0.018*
		Land Use Category (Urban/Low Density)	-1.072	0.318	-3.371	0.00075*
		Property	-0.003	0.015	-0.223	0.823
		Week	0.125	0.048	2.595	0.0095
		Temperature	0.138	0.052	2.636	0.0084*
		Precipitation	-0.526	0.431	-1.222	0.222
	Conditional Model					
		Intercept	-0.362	0.242	-1.497	0.134
		Land Use Category (Rural/Low Density)	0.200	0.066	3.017	0.0026*
		Land Use Category (Urban/Low Density)	-1.196	0.125	-9.591	8.74E-22*
		Property	-0.021	0.004	-5.788	7.12E-09*
		Week	-0.072	0.010	-6.958	3.44E-12*
		Temperature	0.145	0.010	14.530	7.84E-48*
		Precipitation	0.174	0.103	1.679	0.093

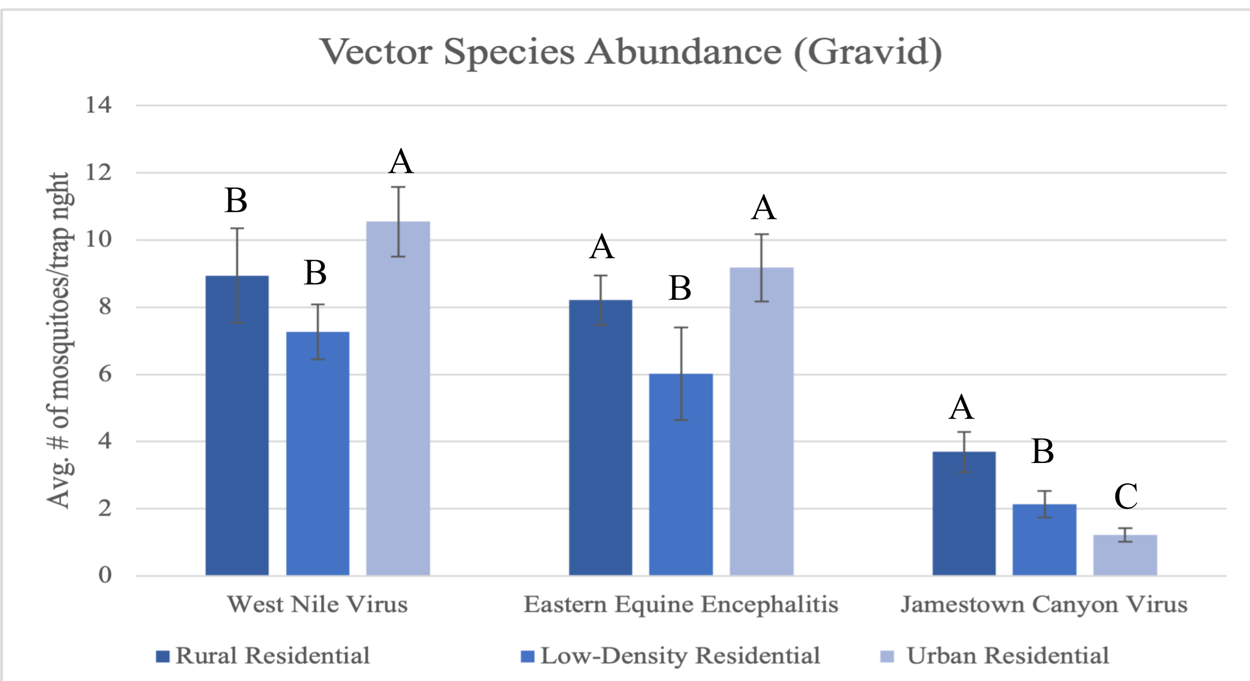

Figure 5. Mean abundance in vector mosquitoes captured per trap night across LUC in gravid traps

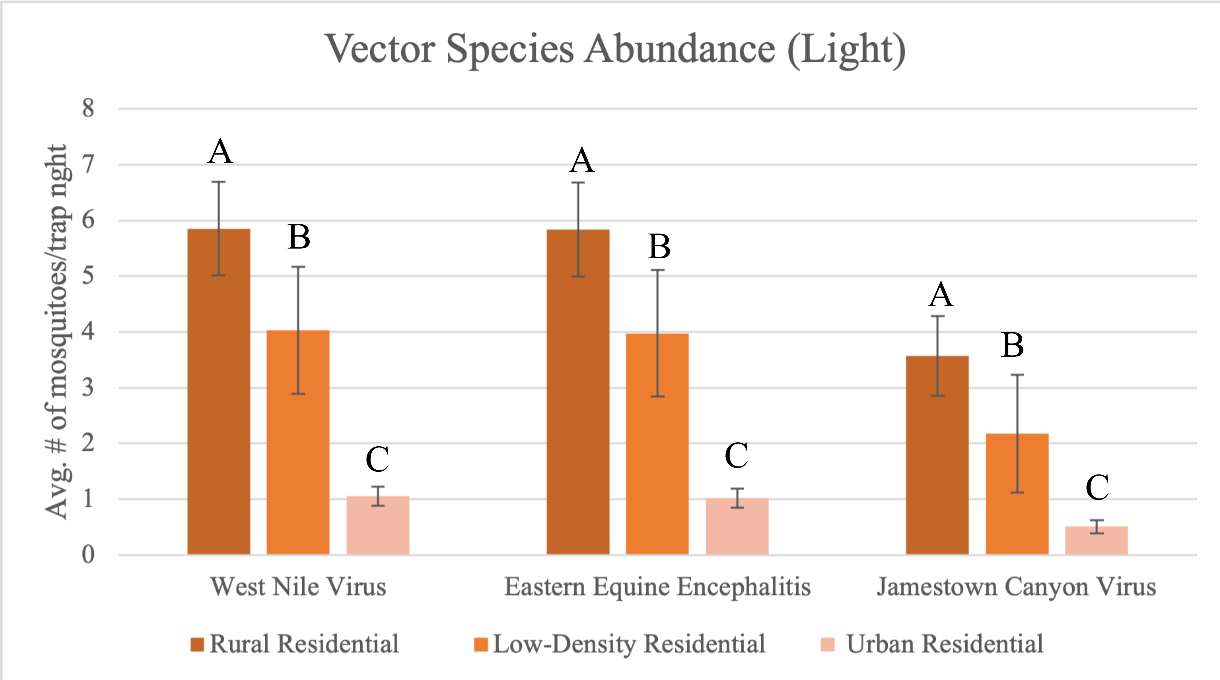

Figure 6. Mean abundance in vector mosquitoes captured per trap night across LUC in light traps

Eastern Equine Encephalitis Virus vector species

For the mean number of EEEV vectors (i.e., *Cs. melanura, Cs. mortisans, Ae. vexans,* etc.) captured in gravid traps there were significant differences between residential land use categories in the conditional model (Table 7). The highest mean number of EEEV vectors in gravid traps were captured at urban residential and rural residential sites and the lowest at low-density residential sites (Fig 5). In light traps, using the conditional model, the mean number of EEEV vectors captured per trap night differed across residential land use (Table 7). The highest mean number of EEEV vectors were captured at rural residential sites, followed by low-density residential sites, and the lowest number of EEEV vectors were captured in light traps at urban residential sites (Fig 6).

Table 7: Hurdle Model Comparison of Weekly Trap Night EEE Vector Mosquito Abundance in Gravid and Light Traps Across Residential Land Use Category. Asterisk indicates significance at p<.05.

Trap	Effect	Estimate	SE	Z	P
Gravid	Zero-Inflated Model				
	Intercept	-2.730	1.315	-2.077	0.038*
	Land Use Category (Rural/Low Density)	0.811	0.404	2.006	0.045*
	Land Use Category (Urban/Low Density)	1.118	0.436	2.566	0.010*
	Property	0.011	0.020	0.528	0.597
	Week	0.202	0.066	3.074	0.0021*
	Temperature	0.138	0.068	2.019	0.043*
	Precipitation	-1.188	0.532	-2.235	0.025*
	Conditional Model				
	Intercept	1.681	0.163	10.324	5.50E-25*
	Land Use Category (Rural/Low Density)	0.236	0.054	4.395	1.11E-05*
	Land Use Category (Urban/Low Density)	0.290	0.052	5.553	2.82E-08*
	Property	-0.014	0.002	-6.055	1.40E-09*
	Week	0.032	0.007	4.384	1.17E-05*
	Temperature	0.023	0.008	3.047	0.0023*
	Precipitation	-0.909	0.111	-8.230	1.88E-16*
Light	Zero-Inflated Model				
	Intercept	-3.029	1.034	-2.930	0.0034*
	Land Use Category (Rural/Low Density)	0.785	0.331	2.369	0.018*
	Land Use Category (Urban/Low Density)	-1.072	0.318	-3.371	0.00075*
	Property	-0.003	0.015	-0.223	0.823
	Week	0.125	0.048	2.595	0.0095*
	Temperature	0.138	0.052	2.636	0.0084*
	Precipitation	-0.526	0.431	-1.222	0.222
	Conditional Model				
	Intercept	-0.318	0.242	-1.313	0.189
	Land Use Category (Rural/Low Density)	0.210	0.067	3.150	0.0016*
	Land Use Category (Urban/Low Density)	-1.235	0.128	-9.642	5.31E-22*
	Property	-0.021	0.004	-5.701	1.19E-08*
	Week	-0.076	0.010	-7.350	1.98E-13*
	Temperature	0.143	0.010	14.347	1.12E-46*
	Precipitation	0.195	0.104	1.886	0.059

Jamestown Canyon Virus vector species

In the conditional model of mean JCV vector species (i.e., *Och. excrucians, Och. communis, Ae. abserratus,* etc.) abundance in gravid traps, there was significant differences between residential land use categories (Table 8). Based on Tukey's test, the highest number of JCV vectors in gravid traps were captured at rural residential sites, followed by low-density residential sites, with the lowest mean number of JCV vectors in gravid traps captured at urban residential sites (Fig 5). For the mean number of JCV vectors captured in light traps, the conditional model shows significant differences between residential land use categories (Table 8). The most JCV vector mosquitoes captured in light traps were at rural residential sites, followed by low-density residential sites, and the lowest mean number of JCV vectors in light traps were captured at urban residential sites (Fig 6).

Table 8: Hurdle Model Comparison of Weekly Trap Night JCV Vector Mosquito Abundance in Gravid and Light Traps Across Residential Land Use Category. Asterisk indicates significance at p<.05.

Trap	Effect	Estimate	SE	Z	P
Gravid	Zero-Inflated Model				
	Intercept	-1.016	0.961	-1.057	0.290
	Land Use Category (Rural/Low Density)	0.499	0.312	1.601	0.109
	Land Use Category (Urban/Low Density)	-0.371	0.310	-1.197	0.231
	Property	-0.028	0.015	-1.918	0.055
	Week	0.229	0.047	4.909	9.16E-07*
	Temperature	0.007	0.048	0.151	0.880
	Precipitation	-0.958	0.418	-2.292	0.022*
	Conditional Model				
	Intercept	2.131	0.309	6.896	5.35E-12*
	Land Use Category (Rural/Low Density)	0.391	0.088	4.414	1.01E-05*
	Land Use Category (Urban/Low Density)	-0.535	0.121	-4.432	9.32E-06*
	Property	-0.028	0.004	-6.282	3.34E-10*
	Week	0.036	0.015	2.378	0.017*
	Temperature	-0.019	0.015	-1.308	0.191
	Precipitation	-1.123	0.234	-4.803	1.56E-06*

Table 8. (CONT)					
Light	Zero-Inflated Model				
	Intercept	-2.734	1.099	-2.487	0.013*
	Land Use Category (Rural/Low Density)	1.005	0.326	3.084	0.0020*
	Land Use Category (Urban/Low Density)	-1.013	0.360	-2.811	0.0049*
	Property	-0.013	0.016	-0.864	0.387
	Week	0.254	0.053	4.827	1.38E-06*
	Temperature	0.040	0.054	0.728	0.467
	Precipitation	-0.550	0.447	-1.231	0.218
	Conditional Model				
	Intercept	-0.718	0.332	-2.163	0.031*
	Land Use Category (Rural/Low Density)	0.253	0.093	2.727	0.0064*
	Land Use Category (Urban/Low Density)	-1.154	0.184	-6.275	3.50E-10*
	Property	-0.038	0.005	-7.178	7.08E-13*
	Week	-0.138	0.013	-10.384	2.93E-25*
	Temperature	0.182	0.014	13.152	1.66E-39*
	Precipitation	0.320	0.135	2.376	0.018*

Nuisance species mosquito abundance

Mean abundance of nuisance species mosquito in gravid traps was significantly different between residential land use categories (Table 9). The residential land use category with the highest mean abundance of nuisance mosquitoes in gravid trap was rural, followed by low-density residential, and the lowest mean number of nuisance mosquitoes captured in gravid traps was at urban residential sites (Fig 7). For nuisance mosquitoes captured in light traps, the conditional model shows a significant difference between residential land use (Table 9). Based The most nuisance species mosquitoes in light traps were captured at rural residential sites, followed by low-density residential sites, and the lowest mean number of nuisance mosquitoes captured in light trap was at urban residential sites (Fig 8).

Table 9: Hurdle Model Comparison of Weekly Trap Night Nuisance Mosquito Abundance in Gravid and Light Traps Across Residential Land Use Category. Asterisk indicates significance at p<.05.

Trap	Effect	Estimate	SE	Z	P
Gravid	Zero-Inflated Model				
	Intercept	-2.881	1.017	-2.832	0.0046*
	Land Use Category (Rural/Low Density)	0.171	0.341	0.500	0.617
	Land Use Category (Urban/Low Density)	0.011	0.336	0.033	0.973
	Property	-0.010	0.016	-0.606	0.544
	Week	0.293	0.052	5.636	1.74E-08*
	Temperature	0.102	0.050	2.067	0.039*
	Precipitation	-1.150	0.438	-2.626	0.0087*
	Conditional Model				
	Intercept	1.693	0.255	6.651	2.92E-11*
	Land Use Category (Rural/Low Density)	0.363	0.072	5.027	4.99E-07*
	Land Use Category (Urban/Low Density)	-0.335	0.085	-3.942	8.07E-05*
	Property	-0.025	0.004	-7.062	1.64E-12*
	Week	0.078	0.012	6.237	4.47E-10*
	Temperature	-0.007	0.012	-0.535	0.593
	Precipitation	-0.699	0.144	-4.854	1.21E-06*
Light	Zero-Inflated Model				
	Intercept	-3.503	1.115	-3.143	0.0017*
	Land Use Category (Rural/Low Density)	0.989	0.334	2.958	0.0031*
	Land Use Category (Urban/Low Density)	-1.070	0.360	-2.971	0.0030*
	Property	-0.015	0.016	-0.948	0.343
	Week	0.285	0.054	5.296	1.18E-07*
	Temperature	0.076	0.054	1.412	0.158
	Precipitation	-0.736	0.451	-1.633	0.103
	Conditional Model				
	Intercept	-0.559	0.329	-1.701	0.089
	Land Use Category (Rural/Low Density)	0.244	0.088	2.778	0.0055*
	Land Use Category (Urban/Low Density)	-1.094	0.172	-6.367	1.92E-10*
	Property	-0.041	0.005	-8.077	6.66E-16*
	Week	-0.123	0.013	-9.448	3.45E-21*
	Temperature	0.172	0.014	12.468	1.12E-35*
	Precipitation	0.487	0.117	4.154	3.26E-05*

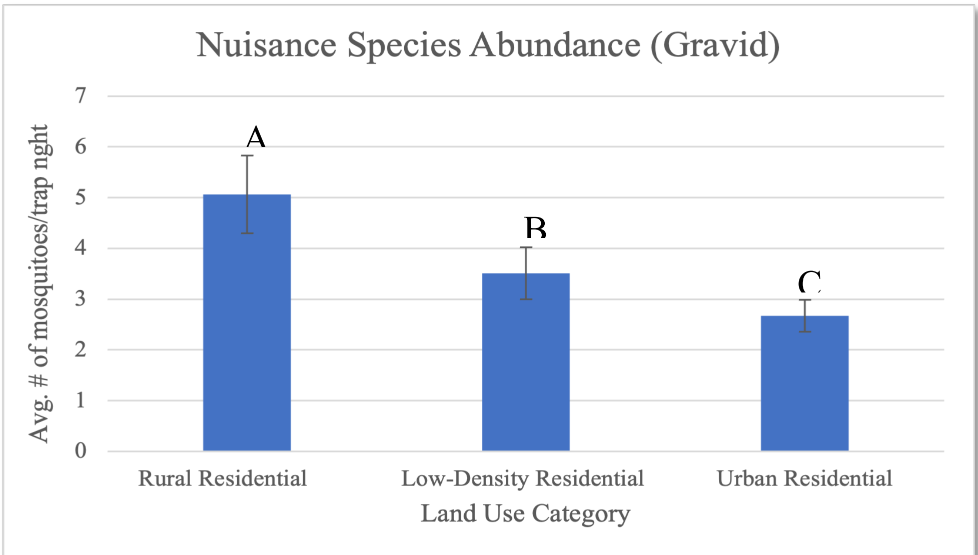

Figure 7. Mean abundance in nuisance mosquitoes captured per trap night across LUC in gravid traps

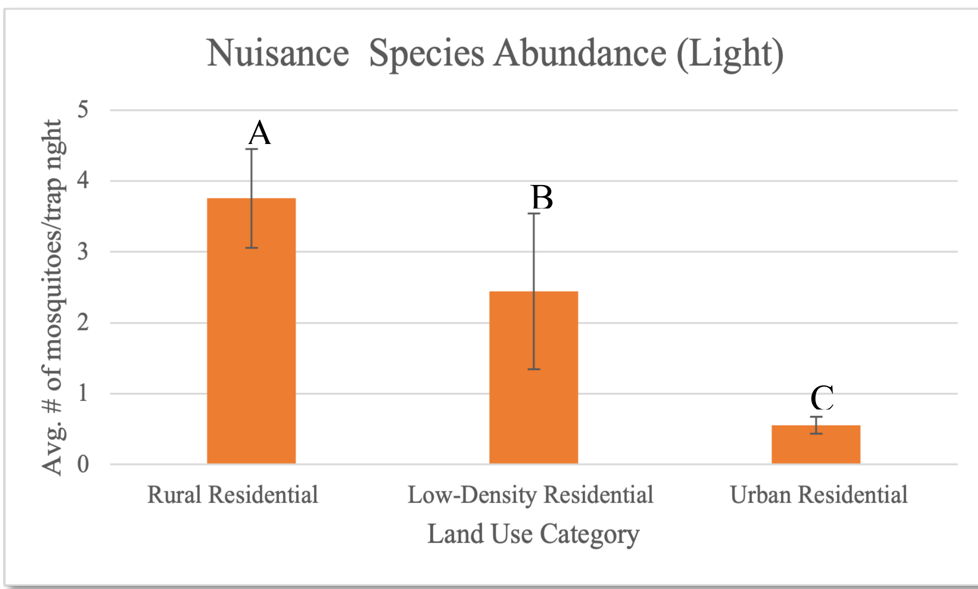

Figure 8. Mean abundance in nuisance mosquitoes captured per trap night across LUC in light traps

Artificial container breeding species mosquito abundance

In the conditional model, for artificial container breeding mosquitoes captured in gravid traps, there were significant differences between low-density and urban residential sites, and between urban and rural sites, but no significant difference between low-density and rural residential land use (Table 10). The highest mean number of artificial container breeding mosquitoes were captured in gravid traps at urban residential sites, and the lowest number of artificial container breeding species captured in gravid traps were collected at rural residential sites and low-density residential sites (Figure 9). In both the binomial and conditional models, mean abundance of artificial container breeding mosquitoes captured in light traps was not significantly different between residential land use categories (Table 10) (Fig. 10).

Table 10. Hurdle Model Comparison of Weekly Trap Night Artificial Container Breeding Mosquito Abundance in Gravid and Light Traps Across Residential Land Use Category. Asterisk indicates significance at p<.05.

Trap	Effect	Estimate	SE	Z	P
Gravid	Zero-Inflated Model				
	Intercept	-3.957	1.178	-3.359	0.00078*
	Land Use Category (Rural/Low Density)	0.585	0.349	1.676	0.094
	Land Use Category (Urban/Low Density)	0.907	0.364	2.489	0.013*
	Property	-0.007	0.017	-0.414	0.679
	Week	0.144	0.055	2.603	0.0092*
	Temperature	0.200	0.062	3.238	0.0012*
	Precipitation	-1.071	0.450	-2.377	0.0174*
	Conditional Model				
	Intercept	0.9548	0.1909	5.0021	5.67E-07*
	Land Use Category (Rural/Low Density)	-0.0383	0.0662	-0.5785	0.563
	Land Use Category (Urban/Low Density)	0.5083	0.0574	8.8613	7.91E-19*
	Property	-0.0027	0.0027	-0.9653	0.334
	Week	0.0432	0.0083	5.2270	1.72E-07*
	Temperature	0.0379	0.0086	4.3819	1.18E-05*
	Precipitation	-0.6458	0.1075	-6.0071	1.89E-09*

Table 10. (CONT.)						
Light	Zero-Inflated Model					
		Intercept	-3.126	1.014	-3.083	0.0021*
		Land Use Category (Rural/Low Density)	0.136	0.308	0.443	0.658
		Land Use Category (Urban/Low Density)	-0.615	0.329	-1.870	0.062
		Property	0.020	0.015	1.366	0.172
		Week	0.053	0.046	1.148	0.251
		Temperature	0.097	0.050	1.945	0.052
		Precipitation	-0.586	0.465	-1.259	0.208
	Conditional Model					
		Intercept	-2.102	0.737	-2.852	0.0043*
		Land Use Category (Rural/Low Density)	-0.023	0.192	-0.118	0.906
		Land Use Category (Urban/Low Density)	-0.313	0.241	-1.297	0.195
		Property	0.001	0.010	0.095	0.924
		Week	0.022	0.030	0.734	0.463
		Temperature	0.124	0.032	3.932	8.44E-05*
		Precipitation	-0.633	0.469	-1.349	0.177

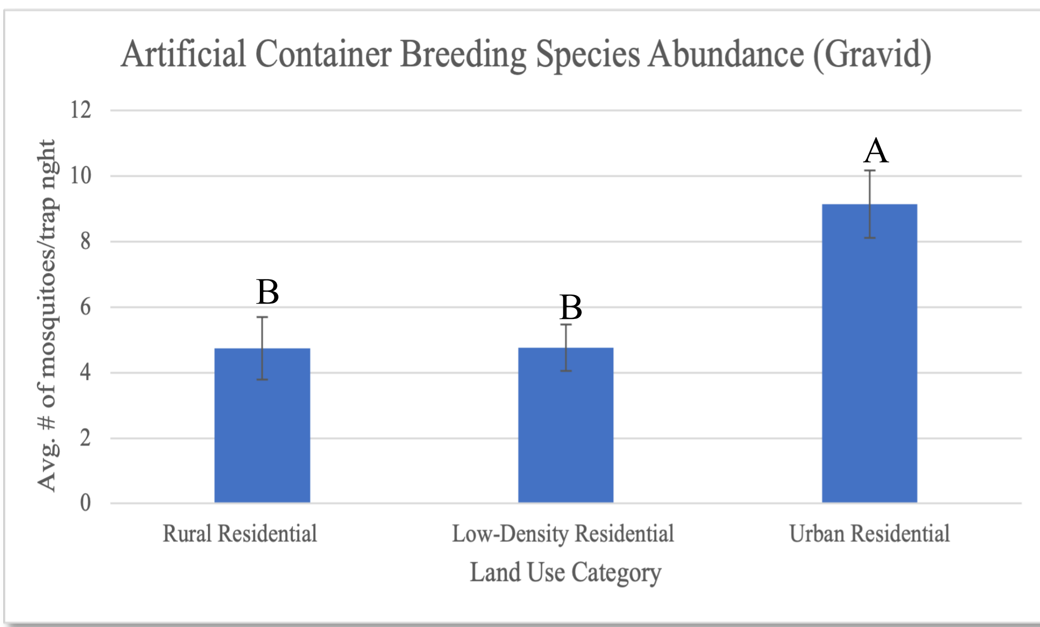

Figure 9. Mean abundance in ACB mosquitoes captured per trap night across LUC in gravid traps

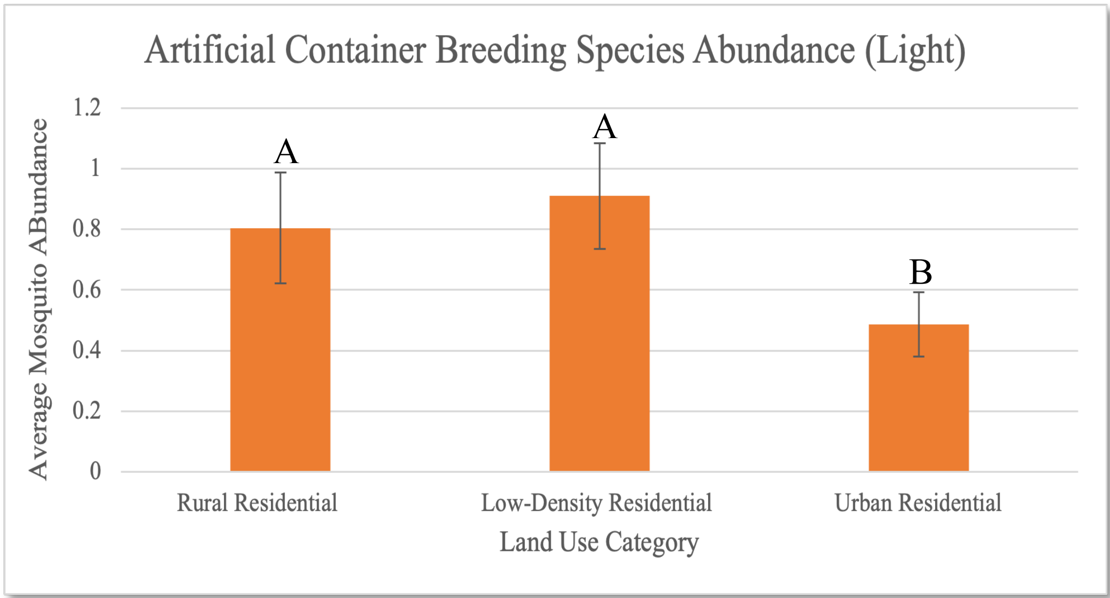

Figure 10. Mean abundance in ACB mosquitoes captured per trap night across LUC in light traps

Artificial Container Survey

Across the 30 residential properties, 212 containers were identified as potential larval habitat. The average number of observations was 7.07 ± 0.950 containers per property, the maximum number of containers observed on a single residential property site was 22 and the minimum was zero. The most common type of container observed were planters, comprising 12.34% of observations (n = 26), followed by tarps (9.43%, n = 20) (Table 11). Of the 212 containers observed, 14.14% (n = 30) were positive for mosquito larvae (Table 12). The HI results show that the highest proportion of households with positive containers were in the low-density residential LUC, and lowest in the rural LUC. The BI results shows that the highest proportion of the number of positive containers found on properties was at sites in the low-density LUC, and the lowest in the rural LUC as well (Table 13). Based on a Kendall's correlation test, there was no significant correlation (Figure 11) between the number of containers observed on a residential property and resident mosquito knowledge, as measured through a Knowledge, Attitudes and Practice survey.

Table 11. Types of Containers and Number of Observations During Container Surveys at Residential Field Sites

Type of Container	Number of Observations
Planter or base of planter	26
Tarp or plastic sheeting	20
Implement in use (actively used for work)	19
Bucket (2-3 gallon)	18
Bucket Lid	17
Ornamental Fountain	17
Discarded implement (was useful for work)	16
Tire	14
Decorative items (e.g., fire pits, tree stands, accessories)	12
Pail (5 gallon)	9
Animal drinking dish	7
Toy/Sports Equipment	7
Discarded containers (e.g., bottles)	6
Watering can	5
Garbage can	4
Discarded kitchen utensils	3
Drum	3
Plastic pool	2
Boat	1
Discarded appliances (e.g., washing machine)	1
Other	1
Structural (e.g., pipes, hollows in cement fence)	1
Tree hole or other plant cavity	1

Table 12. Number of Containers and Larvae-Positive Containers Observed During Container Surveys at Residential Field Sites and Resident Knowledge Score and Category

LUC	Site	Number of Containers	Number of Positive Containers	Proportion of Positive Containers	Resident Knowledge Score	Resident Knowledge Category
Low-Density	LD1	9	2	22.0%	-2	Low
Low-Density	LD2	3	1	33.0%	8	Low
Low-Density	LD3	22	2	9.0%	15	High
Low-Density	LD4	14	7	50.0%	-	-
Low-Density	LD5	2	0	0.0%	10	Mid
Low-Density	LD6	11	0	0.0%	-14	Low
Low-Density	LD7	4	1	25.0%	-	-
Low-Density	LD8	1	0	0.0%	-	-
Low-Density	LD9	10	2	20.0%	8	Low
Low-Density	LD10	4	1	25.0%	-	-
Rural	R1	4	0	0.0%	-	-
Rural	R2	8	0	0.0%	16	High
Rural	R3	0	0	0.0%	10	Mid
Rural	R4	14	0	0.0%	10	Mid
Rural	R5	8	2	25.0%	16	High
Rural	R6	8	0	0.0%	14	High
Rural	R7	7	0	0.0%	16	High
Rural	R8	16	2	12.5%	-	-
Rural	R9	5	0	0.0%	4	Low
Rural	R10	2	0	0.0%	8	Low
Urban	U1	5	0	0.0%	14	High
Urban	U2	15	6	40.0%	14	High
Urban	U3	11	0	0.0%	14	High
Urban	U4	3	0	0.0%	12	Mid
Urban	U5	8	2	25.0%	12	Mid
Urban	U6	2	0	0.0%	-	-
Urban	U7	3	0	0.0%	4	Low
Urban	U8	3	0	0.0%	10	Mid
Urban	U9	4	2	50.0%	2	Low
Urban	U10	6	0	0.0%	10	Mid
TOTAL	-	212	30	14.15%	-	-

Table 13. House and Breteau Indices for Juvenile Mosquito-Positive Containers Across LUC

Residential Land Use Category	House Index (HI)	Breteau Index (BI)
Rural	0.20	0.40
Low-Density	0.70	1.60
Urban	0.30	1.00
All sites	0.40	1.00

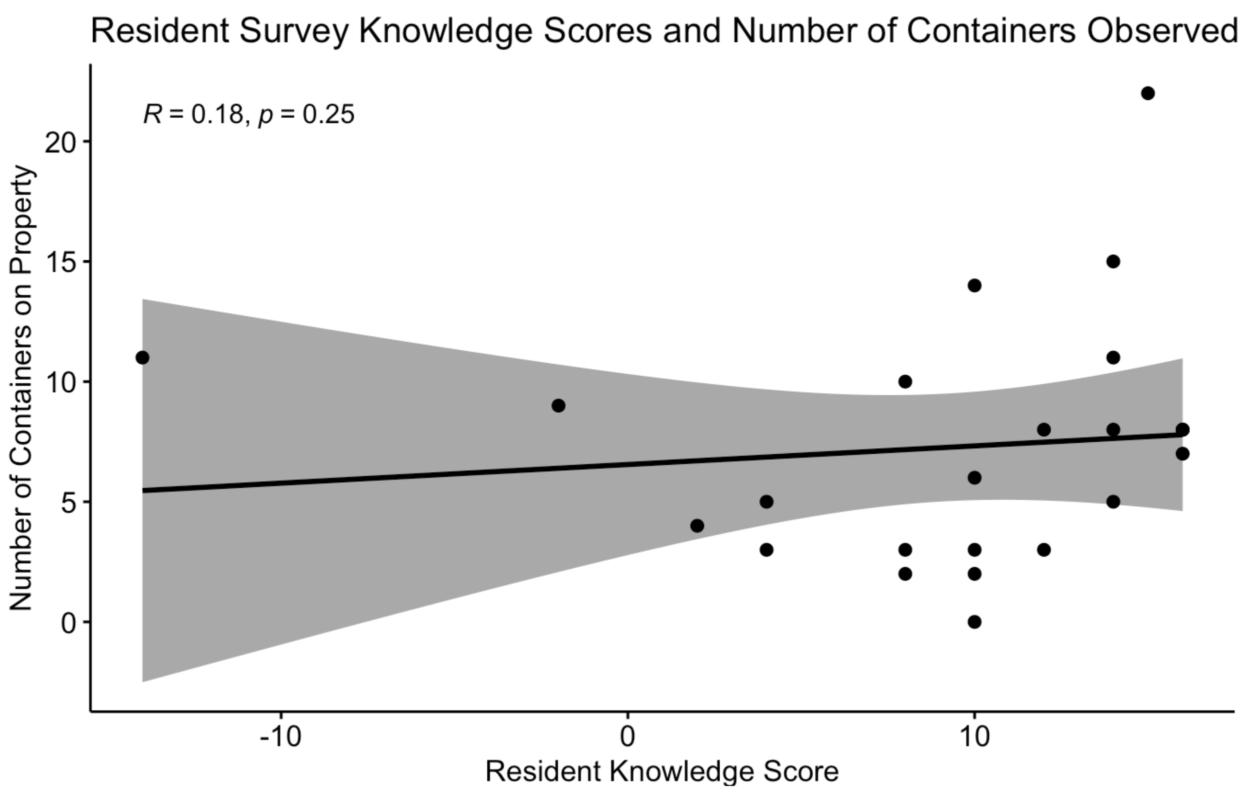

Figure 11. Scatter plot of resident mosquito knowledge scores measured through KAP survey, and the number of potential artificial breeding containers observed at resident property, with Kendall's Tau correlation. Shading indicates 95% confidence interval.

Discussion

Our study found that residential land use category has a significant effect on several variables relating to mosquito species distributions including mosquito abundance, species diversity, vector species abundance, nuisance species abundance and artificial container breeding species abundance. In particular, sites in rural and low-density land use categories had more mosquitoes overall, more nuisance species mosquitoes, and a higher species diversity of mosquitoes collected. Sites in the urban residential land use category had more vector and artificial container breeding species and lower species diversity compared to other less urban LUC. Additionally, the container assessment across LUCs revealed lower HI and BI on rural properties compared to more urban properties. These results are consistent with results from other mosquito studies which show similar patterns of vector concentration and lower species diversity in urban landscapes (Zettle et al. 2022, de Valdez 2017, Chavez 2011). This study contributes to the body of literature by showing that the effect of an urban to rural gradient on mosquito distributions is present even in smaller US cities with less urban sprawl than where much of prior work has taken place (e.g., Chicago, Baltimore, Washington D.C., San Antonio) and that lower mosquito species diversity is observed compared to rural sites in this smaller urban setting. Additionally, this study adds to the growing body of interdisciplinary approaches to mosquito research, by integrating a larval mosquito habitat survey with social science in the form of survey data to test the relationship of resident knowledge with number of containers at each collection site.

The highest mosquito abundance was observed in forested sites compared to residential sites, and within residential land use categories, rural sites had the highest mosquito abundance. This association of more mosquitoes in less developed areas is consistent with known mosquito ecology. Mosquito species such as *Ae. vexans, Ae triseriatus, Ps. ferox*, *Och. canadensis* and *Cq. peturbans* oviposit in floodplains, or areas with high likelihood of flooding, which provide temporary fresh water sources (Aziz and Hayes 1987; Horsfall et al 1973). Mosquito species with this oviposition preference tend to hatch and develop in large numbers compared to mosquito species that lay eggs in smaller water sources (Horsfall et al 1975). In addition, since oviposition occurs in dry areas, before flooding occurs, these eggs are especially resilient to desiccation and may remain dormant in the environment until flooding aids in embryonic development (Curtisi 1985). Adult female floodplain mosquitoes are also multivoltine, or able to reproduce more than one generation of offspring per year (Lundström et al. 2013, Östman et al 2015). Due to these traits, floodplain mosquito species, especially *Ae. vexans* and *Och. canadensis* are considered nuisance pests for both humans and livestock and are also aggressive human biting mosquitoes (Schäfer et al. 2008). Indeed, the highest number of nuisance species mosquitoes on residential sites in this study were also observed at sites in the rural land use category. Rural residential sites also had the highest Shannon's diversity and evenness indices compared to low-density and urban LUC. This is consistent with prior literature that attributes lower species diversity in more urbanized areas to the decreased variety in aquatic and semi-aquatic habitat available for oviposition and development in landscapes that are less human dominated (LaDeau et al. 2013, Little et al. 2017).

While the smallest number of mosquitoes found on residential sites were in the urban land use category, urban sites had the most West Nile Virus and Eastern Equine Encephalitis Virus vectors, the most artificial container species and the lowest Shannon's diversity and evenness indices. This likely due to biological and ecological mechanisms described in previous studies. Human dominated and urbanized landscapes are more associated with the presence of artificial containers which some disease vector species prefer for oviposition. These mosquito species, notably *Cx. pipiens, Cx. restuans, Och. japonicus* in the US Northeast, hatch in smaller broods compared to floodplain mosquitoes, but have evolved to occupy the aquatic and semi-aquatic niche environments provided by urbanized landscapes, such as in stormwater basins, gutter drains, and items on resident properties such as tires or buckets (LaDeau et al. 2013, Little et al. 2017, Marini et al. 2020). The results of our study show that observation of the number of artificial containers on resident properties did not vary by LUC, but the proportion of containers found positive for juvenile mosquito presence were higher on urban and low-density residential sites than rural sites.

To begin to unravel mechanisms that may explain differences in mosquito abundance across LUC, including those related to human knowledge, attitudes, and behaviors surrounding mosquitoes, a KAP survey was distributed to residents at each of the 30 mosquito collection sites. Knowledge scores quantified knowledge of mosquito ecology and mosquito control practices and did not significantly vary among LUC, and resident knowledge scores were not significantly correlated with the number of containers found on resident properties. Additionally, attitudes toward mosquito practices tended to be positive, indicating that people believe these control and protective methods work to reduce mosquito encounters or mosquito abundance. However, when asked how often they engaged in these methods, resident participants reported low engagement in control and protective behaviors. This indicates that metrics beyond level of knowledge and perception of effectiveness are important to understanding and predicting participant behaviors that influence risk of mosquito exposure, including metrics from both quantitative and qualitative approaches. For example, while our sample size was too low to detect relationships, we included survey questions on attitudes, subjective norms and perceived behavioral control to try to further explain reported engagement in mosquito control behaviors. Other US studies have employed a similar quantitative social science approach and found that socioeconomic status is related to mosquito and mosquito control knowledge (Dowling et al. 2013, Parker 2019, Tuiten et al. 2009). In addition, perceptions of high mosquito activity have been positively associated with reported engagement in preventative mosquito measures among participants in upstate New York (Tuiten et al. 2009) and mosquito knowledge was associated with reported engagement in source reduction behaviors among residents of the Baltimore-Washington metropolitan area (Dowling et al 2013). Fewer studies have used a qualitative approach, which allows for a richer understanding of human experiences compared to quantitative social science. One of these studies, conducted in a suburban city in southeast India, showed that while there were no differences in mosquito abundance metrics across sites of different LUC, there were differences among participant perception of mosquitoes, and these differences were largely explained by differences in individuals' engagement with outdoor space, and their hazard vulnerability (Evans et al. 2022).

As evidenced by Evans et al. 2022, reported human experiences with and perceptions of mosquito presence, abundance and risk of disease transmission may not match entomological data collection, pointing to a potential mismatch in engagement with mosquito control behaviors. For example, in our study, vector mosquito abundance was highest at urban sites, which had the lowest total mosquito abundance. If human experiences with high mosquito abundance, such as those in recreational forested areas, drive their motivation to control mosquitoes, then they may be less motivated to control mosquitoes or use protective measures when they experience them in lower numbers, such as on their own property or within their residential neighborhood. This could lead to engagement in mosquito control and protection behaviors when mosquitoes are a nuisance, but not when people are at a higher risk of exposure to vector species.

It is important to note several limitations within our methodological approach. First, carbon dioxide was not included in the deployment of light traps. This likely contributed to the differences in mosquito abundance patterns observed in the light versus gravid traps, particularly in the urban environments where light pollution may have been competing with the light traps. This is illustrated by the mosquito abundance results, which show that light traps collected significantly less mosquitoes than gravid traps at all sites, except recreational forests, and the pattern is most pronounced in the urban sites, supporting the light pollution hypothesis. Prior research shows that light pollution may compete with light trap attractiveness (Justice and Justice 2016) and that light pollution may increase photoperiod which has implications for mosquitoes such as nutrient accumulation and diapause initiation in adult *Cx pipiens* (Wolkhoff 2023)*,* and the nighttime biting activity of *Ae. aegypti* (Wolkhoff 2023,). Additionally, unpublished data shows that light traps baited with carbon dioxide in 2022 collected more mosquitoes in Bangor than observed in our non-baited study (Unpublished data, 2022). Lastly, a main objective of this study was to collect ecological and social variables at the same sites to make direct conclusions about resident behaviors, container presence, and mosquito distributions. A well-known problem in social-ecological research is that the sample size requirements vary widely for social and environmental data (Cumming 2006). While this study was adequately powered to make inferences about mosquito abundance, the social science sample size was insufficient to generalize to the broader population. This issue of scale is a common one in SES studies which rely on time and resource consuming data collection. Future SES studies of entomological pests and vectors might employ survey data collection from a larger sample size and limit entomological data collection as resources allow.

The mosquito classification system (vector versus nuisance versus artificial container breeding mosquitoes) employed for this study allowed us to identify general patterns of mosquito distribution as a non-expert audience might best understand. While this general classification does not distinguish between enzootic, bridge or primary vectors within the WNV, JCV, or EEEV systems, allowing nuances of these vector distribution to be lost, it also allowed us to consider mosquito distribution generally, as it best relates to human experiences. In conclusion, this study adds to the current state of knowledge on mosquito abundance and species distributions across residential and recreational land use. We employed a social-ecological data collection approach, expanding known patterns of mosquito abundance across rural to urban gradients to a smaller US city than typically studied. This study underlines the importance of integrating data types across disciplines to understand how interactions between people and their environment affect mosquito distributions and motivates further social-ecological mosquito studies with more power to detect these complex relationships.

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CHAPTER 3

KNOWLEDGE, ATTITUDES AND PRACTICE (KAP) MOSQUITO SURVEY RESULTS AMONG BANGOR, MAINE RESIDENTS

ABSTRACT

Understanding factors that determine behavioral engagement related to mosquito control and personal protection is important for community health and recreation related to mosquitoes. The Theory of Planned Behavior (TPB) provides a framework to understand human behaviors using beliefs, attitudes, perceived behavioral control, subjective norms, and behavioral intention to predict behavioral engagement. One method that operationalizes the TPB is a Knowledge, Attitudes, and Practices (KAP) survey. These surveys use three constructs from the TPB (knowledge, attitudes, and behavioral engagement) to determine how individual's knowledge and perceptions shape their behavioral engagement. KAP surveys are useful in public health interventions during disease outbreaks and have been implemented in many communities affected by mosquito-borne disease (MBD). These studies are often conducted as a rapid response to ongoing MBD transmission to inform control strategies and community education. Hence, KAP studies are more common in international countries compared to the United States. In this study, a KAP survey was conducted among 30 residents in Bangor, Maine along a rural-urban gradient, in conjunction with a larval habitat survey on each resident property. The survey response rate was 77% (n = 23). Participant knowledge was not correlated with the number of containers observed on their property. Participants reported that they perceived mosquitoes as a nuisance, but not as a risk for MBD in Bangor. Attitudes and subjective norms were significantly associated with behavioral engagement. This study provides a theory based KAP mosquito survey for future investigation of mosquito control and personal protective behaviors in the Northeast United States.

Introduction

Across the globe, mosquitoes are a nuisance pest and pose a risk for arbovirus transmission among their vertebrate hosts during mosquito bloodmeals necessary for the mosquito life cycle. Humans are among these vertebrate hosts on which mosquitoes feed, and are exposed to mosquitoes, their potential bites and associated pathogens in almost any outdoor environment. The presence and distribution of mosquitoes in a given environment, and therefore the risk of human exposure to mosquitoes, is determined by habitat availability, which is associated with environmental factors such as land use type and climactic variables such as temperature and precipitation (Norris 2004, Kilpatrick 2011, Reiter 2001, Chandrasegaran et al. 2020). However, human exposure to mosquitoes, particularly on their own properties, is also subject to the effect of human behaviors, both in the context of habitat modification through larval habitat source reduction and personal protective behaviors. Human behaviors could affect human exposure to mosquitoes through two main pathways. First, some behaviors might influence mosquito abundance. These are property management practices that include removal of standing water that may serve as mosquito breeding habitat, the use of chemical treatments in water sources, or the application of chemical sprays on vegetation (CDC 2020). Second, other behaviors might reduce the risk of mosquito bites. These are personal protective behaviors that include the application of mosquito repellent, wearing long sleeved shirt or pants, or avoiding the outdoors altogether (CDC 2022). Understanding what factors affect engagement in these behaviors is important for informing what people consider when it comes to engaging, or not engaging, in mosquito control or personal protective mosquito behaviors.

The Theory of Planned Behavior (TPB) is a framework from the field of social psychology developed by Icek Azjen that can be used to predict human behaviors in a specific time and place. The TPB assumes that behaviors are intentional, and that decision-making is guided by cognitive self-regulation, a process through which thoughts and beliefs guide behavioral decisions (Azjen 1991). Behavioral intent is also central to the TPB. Behavioral intent indicates the level of motivation one has to engage in a behavior based on beliefs and attitudes, and behavioral intent immediately predicts behavior (Hamilton et al., 2020). The TBP is comprised of eight main constructs (Figure 1), and the predictive relationships between each construct have been supported through studies of health behaviors such as supplement use (Conner et al. 2001), sun protection (White et al. 2008), blood donation (Godin et al. 2007), and quitting smoking (Moan and Rise, 2005). The TPB distinguishes between three types of beliefs, behavioral beliefs, normative beliefs and control beliefs. These beliefs are the product of our personal experiences and our individual and social backgrounds. Behavioral beliefs describe beliefs about the outcome of a given behavior. Normative beliefs refer to perceived behavioral expectations from important individuals in one's life including friends, spouses, and children. Control beliefs refer to factors that may facilitate or act as a barrier to performing a behavior. Attitudes are a positive or negative evaluation of an action based on personal beliefs. In the TPB, attitude toward the behavior describes the positive or negative value of the outcome of a behavior. Subjective norms refer to perceived social pressure to engage in a behavior not. Perceived behavioral control refers to one's perceived ability to perform a behavior. Attitude towards the behavior, subjective norms, and perceived behavioral control all influence behavioral intention, which ultimately determines behavioral engagement, and can be used as a proxy for behavior, in some cases (Azjen 2020)

The Theory of Planned Behavior is used to understand what knowledge and perceptions drive decision-making about behavioral engagement. In the context of public health and mosquito-borne disease, the TPB can be applied to understand what constructs drive health behaviors that can prevent exposure to mosquitoes. For example, preventative behaviors can reduce the incidence of Dengue hemorrhagic fever, a mosquito-borne disease. A study investigating preventative Dengue behaviors found that knowledge of and attitude toward of Dengue preventative behaviors correlated to engagement in those behaviors (Prabaningrum et al. 2020). Often in areas endemic to mosquito-borne diseases, a tool based on the TBP called a Knowledge, Attitudes and Practices (KAP) survey is used to efficiently assess predictors of mosquito health behaviors. KAP surveys operationalize just three of the TPB constructs- knowledge in the form of beliefs, attitudes, and practices in the form of behaviors. KAP surveys are often specific to one mosquito-borne disease and administered to at-risk communities to guide informed intervention (Nguyen et al. 2019, Selvarajoo et al. 2020, Paz et al. 2015, Elson et al. 2020).

In particular, studies that use KAP surveys tend to be conducted at the municipal level in areas with recurring MBD outbreaks, which typically occur in countries in the tropics region. For example, dengue fever and chikungunya fever are transmitted by the *Aedes aegypti* mosquito, and many KAP studies have addressed communities at risk for *Aedes*-borne MBD. A review of KAP studies in Malaysia reported results from 48 KAP studies, majority focused on dengue virus, in the country and found that lower knowledge was associated with poor prevention practices, with lower knowledge associated with sociodemographic factors such as health beliefs and poor living conditions. However, high knowledge and positive attitudes did not always have a positive associated with good prevention practices (Subramaniam 2021). In the Democratic Republic of the Congo, which has experienced four chikungunya outbreaks in the last twenty years, reported poor knowledge and poor implementation of window screen installation in the home, both which were associated with education and income (Mbanzulu 2022). In a study of malaria-endemic and non-endemic regions of Botswana, residents of both reported high knowledge of adult mosquitoes, but low knowledge of juvenile mosquitoes, with no difference due to socio-economic factors (Buxton 2020).

While less common, which is not surprising given the lower burden of mosquito-borne disease, KAP surveys have been conducted in a small number of studies in the United States. In 2009 Tuiten et al. published a study examining mosquito knowledge attitudes and practices of upstate New York residences found that knowledge was generally high among participants and was highest among high income residents. The study also found that perceptions of high mosquito activity were positively associated with reported engagement in preventative mosquito measures. In the Washington D.C. metropolitan area, KAP survey results also indicated that income is positively correlated to general mosquito knowledge, as well as negatively correlated with perceptions of disease risk (Dowling 2013). Similarly, in Champaign, IL KAP survey showed that high socioeconomic status, and age were positively correlated with mosquito knowledge and engagement in mosquito control behaviors, and participants with higher socioeconomic status were more likely to report a change in behaviors due to experiences with mosquitoes (Parker 2019). A KAP study in New Orleans also showed that overall mosquito knowledge was low, but that socioeconomic factors like home ownership and employment status were important predictors of higher mosquito knowledge. Collectively, these studies show that while certain factors, such as socioeconomic status, are more associated with mosquito control knowledge and engagement in the US, predicting how people make decisions regarding mosquito control behaviors needs further elucidation, particularly in more rural areas where these studies are less common. Additionally, if we can better understand these factors public health campaigns could become more targeted for specific populations and behaviors to help protect communities from the nuisance and disease risk posed by mosquitoes.

The purpose of this study was to design and implement a KAP survey grounded in the TPB theoretical framework to understand what factors were important in determining the mosquito control and personal protective behaviors of Bangor, Maine residents across an urban to rural gradient, accompanied with entomological mosquito assessments at each residence. This study is novel in its application of a KAP survey among residents of a small city in a dominantly rural region and adds to the growing body of literature of social-ecological approaches to couple human-natural systems.

Methods

Participant Recruitment

We conducted our study among residents in Bangor, Maine (44.80° N, 68.77° W), a US city of 34.26mi^2 and a population of 31,191 with a population density of 927 people per square mile according to 2021 US Census Bureau data. Study participants were recruited from randomly selected residential properties along an urban to rural gradient, with 10 sites from each of the following residential land use categories (LUC): urban residential, low-density residential, and rural residential. Residential land parcel data was acquired from the Bangor City Planning Office. Participants were recruited from the randomly selected residential properties by approaching property owners with a request to participate in the study. If property owners from the randomly selected list were not home, or otherwise unable to participate, we instead recruited a neighboring property within the same land use category. One resident aged 18 years or older per participant property was asked to complete the survey and if more than one member of the household was eligible, the individual with the closest birthdate was asked to complete the survey.

Survey Design

Using the Qualtrics platform (Qualtrics, Provo, UT) a Knowledge, Attitudes, and Practices (KAP) survey was designed to understand the relationship between participants' mosquito control and protection behaviors and their knowledge and attitudes about mosquitoes and mosquito related behaviors. KAP surveys are an instrument developed from the Theory of Planned Behavior to identify beliefs which determine behavioral choices. KAP surveys measure behavioral intention, which is the measure of how an individual is motivated to perform a behavior. KAP surveys are widely used in public health and coupled human-environment research to assess the knowledge that informs health behavior choices. They are commonly used to assess community knowledge, attitudes and practices surrounding mosquito-borne disease (Higuera-Mendieta et al., 2016; Tuiten et al., 2009). In the context of mosquitoes and mosquito borne disease, health behaviors that could reduce mosquito abundance include spraying properties with pesticides and emptying water containers that serve as mosquito breeding habitats. Other health behaviors can limit the exposure one has to mosquitoes without reducing abundance. These behaviors include using personal insect repellant spray, wearing long-sleeves and pants when recreating outdoors, and avoiding the outdoors altogether.

We designed a KAP survey instrument to understand factors that determine mosquito control behaviors including participant knowledge of mosquitoes, attitudes towards mosquito control behaviors, behavioral intentions, and sociodemographic questions. General right/wrong questions about seasonal activity, habitat, and mosquitoes as disease vectors were used to measure knowledge. Participant attitudes and practices surrounding mosquitoes were measured by asking questions about the importance of mosquito control/prevention, the severity of mosquito disease risk, and where responsibility for mosquito control lies. In addition to the three main constructs that are operationalized with KAP surveys (knowledge in the form of beliefs, attitudes, and practices in the form of behaviors) we also operationalized the constructs of subjective norms and perceived behavioral control, which have roots in the TPB. According to a systematic review of chikungunya KAP survey studies, the KAP survey has become disconnected in practice from its roots in the TPB; only 24% of studies in the review used formal change theory to guide data collection. The authors of the review emphasis the importance of incorporating the structural framework of theory in KAP surveys to fully investigate predictors of health behaviors related to chikungunya and other mosquito-borne diseases (Corrin et al. 2017).

A literature review of studies that operationalized the Theory of Planned Behavior was conducted to determine which constructs to include in the KAP survey instrument. Previous studies have reported explanations and predictors of behaviors such as physical activity, drug use, technology adoption, and recycling (Azjen 2020). In studies that use the TPB framework (Fig. 12), these predictors typically include the constructs behavioral beliefs, subjective beliefs, control beliefs, attitudes towards the behavior, subjective norms, perceived behavioral control, and behavioral intention. In typical KAP studies that address ongoing disease outbreaks, only knowledge attitude and practice constructs are investigated (e.g., Fig. 13). In our study, we included additional TPB constructs to strengthen our understanding of the factors that might predict engagement in mosquito control and protective behaviors (Fig. 14).

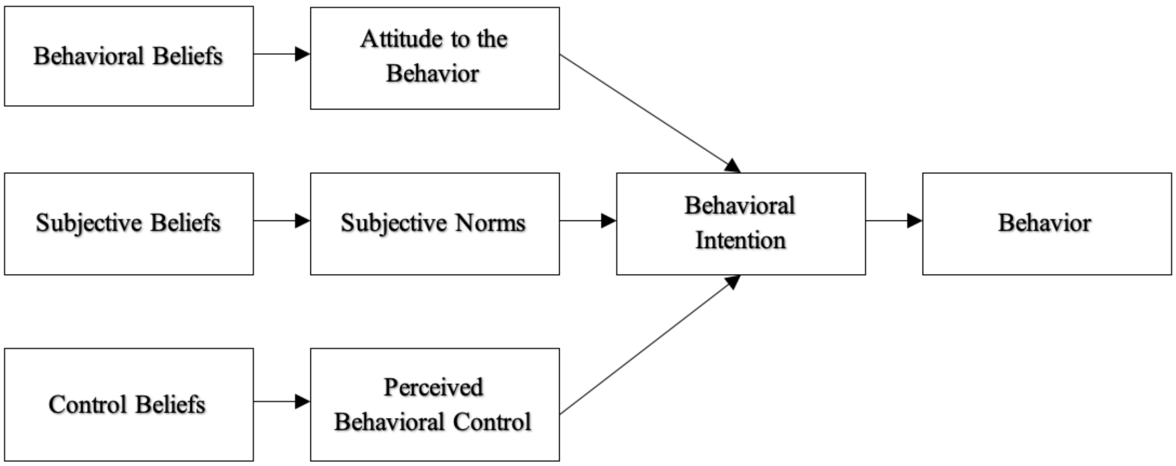

Figure 12. Constructs and relationships in the Theory of Planned Behavior model. Adapted from Azjen (1991).

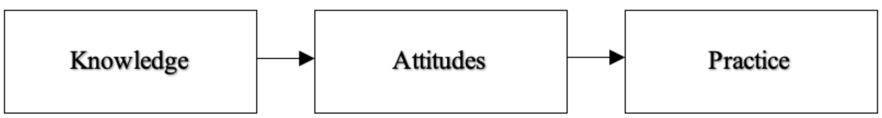

Figure 13. Constructs and relationships in the KAP survey model.

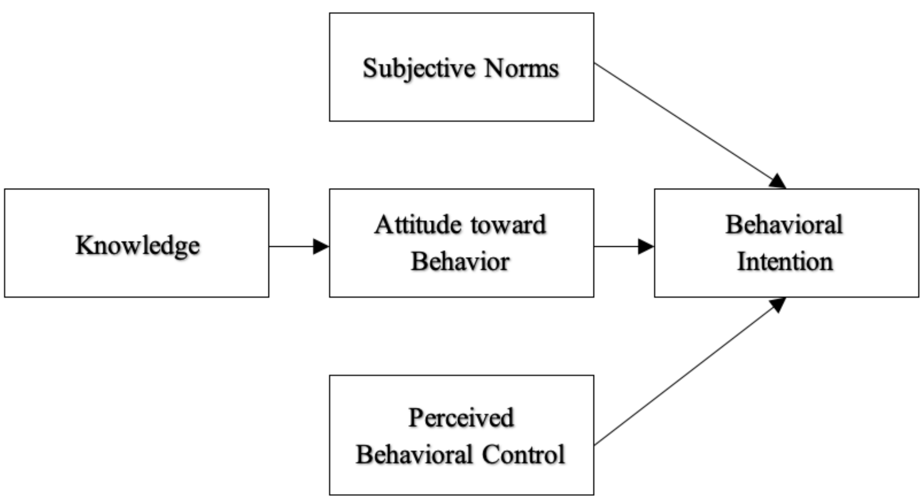

Figure 14. Constructs and relationships in the KAP survey model used in this study, including additional constructs from the full TPB model.

Statistical Analysis

The survey data was managed by and downloaded from the Qualtrics platform. Participant knowledge was measured through answers to the KAP survey knowledge questions. Answers were scored as +1 for correct answers, and -1 for incorrect answers. Knowledge question scores were aggregated into a single score (highest possible score = 28), and knowledge scores were further categorized in High, Mid, and Low levels of knowledge. Likert scale questions assessing attitudes and behaviors were collapsed from 7-point to 3-point using IBM SPSS Software (Version 27). Data were analyzed using R software version 4.2.1 (R Core Team 2022). To test the association between variables, a Fisher's exact test (stats package; R Core Team 2022) was computed due to small sample size.

Statement of Ethics

All study participants provided written and oral consent before conducting the survey described above. The survey design and distribution were approved to be compliant with the University of Maine Institutional Review Board for the Protection of Human Subjects under application No. 2021_07_0

Results

Of the 30 participants involved in the biophysical mosquito assessments, the response rate for the KAP survey was 76.67% (N = 23). Of these respondents, 81.3% were female, 64.5% were aged 60+, and 100% identified as white. (Table 14). Education level of at least a bachelor's degree was reported by 70.6% of participants, and 94.1% own their home. A majority of the respondents (66.7%) had no children in the home, and 53.3% of respondents identified as liberal, in terms of politics.

Table 14: Results from the Demographics Questions section of the KAP survey.

Demographics	
What is your sex assigned at birth?	**%**
Male	18.8% (3)
Female	81.3% (13)
What is your age (in years)?	**%**
18-40	0% (0)
41-60	35.5% (5)
60+	64.5% (5)
What is the highest level of school you have completed?	**%**
Middle school or lower	0% (0)
Some high school, no diploma	0% (0)
High school diploma or equivalent	5.9% (1)
Some college, no degree	17.6% (3)
Associate degree	5.9% (1)
Bachelor's degree	35.3% (6)
Master's degree	29.4% (5)
Professional degree	5.9% (1)
Doctorate degree	0% (0)
How many people live in your household? (18+)	**%**
1-2	81.3% (13)
3-4	18.7% (3)
5+	0% (0)
How many people live in your household? (Children)	**%**
0	66.7% (6)
1-2	11.1% (1)
3+	22.2% (2)
Are you Hispanic or Latino?	**%**
Yes	0% (0)
No	100% (16)
What race(s) do you consider yourself?	**%**
American Indian	0% (0)
Asian	0% (0)
Black or African American	0% (0)
White	100% (17)
Other	0% (0)
Do you rent or own this property?	**%**
Own	94.1% (16)
Rent	5.9% (1)
When it comes to politics, you generally consider yourself to be:	**%**
Liberal	53.3% (8)
Independent	13.3% (2)
Conservative	33.3% (5)

The mean participant knowledge score was 10.23, the maximum score was 16, and the minimum score was -2. Based on the sample, scores 14 and up were categorized as high, scores 9-13 were categorized as mid, and scores below 9 were considered low. Given a list, participants were most likely to know that mosquitoes can transmit Dengue Fever Virus (82.6% correct) and Malaria (78.3%), and least likely to know that mosquitoes can transmit Eastern Equine Encephalitis Virus (52.2% correct) and Jamestown Canyon Virus (0% correct). For mosquito suitable habitats, participants were most likely to identify storm catch basins (95.7% correct), and stagnant water (91.3% correct), and least likely to identify vernal pools (47.8% correct). Given a true/false prompt, 85.7% of participants correctly associated aquatic habitat with juvenile mosquitoes, while only 38.1% of respondents knew that some mosquito species do not bite humans (Table 15).

Table 15. Results from the Knowledge Question section of the KAP survey. Asterisks indicate the correct answer to the question.

KAP Survey Knowledge Questions Responses		
Which of the following diseases are transmitted by mosquitoes in Maine?	**% Correct (N)**	**%Incorrect (N)**
Babesiosis	95.7% (22)	4.3% (1)
COVID-19	100% (23)	0% (0)
Dengue Fever	82.6% (19)	17.4% (4)
Eastern Equine Encephalitis*	52.2% (12)	47.8% (11)
Influenza	91.3% (21)	8.7% (2)
Jamestown Canyon Virus*	0% (0)	100% (23)
Lyme disease	100% (23)	0% (0)
Malaria	78.3% (18)	21.7% (5)
West Nile fever*	60.9% (14)	39.1% (9)
Zika Virus	65.2% (15)	34.8% (8)
What time of day are mosquitoes most active in Maine?	**% Correct (N)**	**%Incorrect (N)**
Dawn*	8.7% (2)	91.3% (21)
Dusk*	95.7% (22)	4.3% (1)
Midday	91.3% (21)	8.7% (2)
Overnight	87% (20)	13% (3)
Which of the following are potential habitat for mosquitoes to lay eggs and grow?	**% Correct (N)**	**%Incorrect (N)**
Impervious surfaces	82.6% (19)	17.4% (4)
Lawns	91.3% (21)	8.7% (2)

Table 15. (CONT)		
Running water	73.9% (17)	26.1% (6)
Stagnant water*	91.3% (21)	8.7% (2)
Storm catch basins*	95.7% (22)	4.3% (1)
Stream beds*	56.5% (13)	43.5% (10)
Vernal pools*	47.8% (11)	52.2% (12)
Wetlands*	60.9% (14)	39.1% (9)
In which season are mosquitoes most abundant in Maine?	**% Correct (N)**	**%Incorrect (N)**
Fall	100% (23)	0% (0)
Spring	56.5% (13)	43.5% (10)
Summer*	65.2% (15)	34.8% (8)
Winter	65.2% (15)	34.8% (8)
In which season are the diagnosed cases of mosquito-borne disease highest in Maine?	**% Correct (N)**	**%Incorrect (N)**
Fall	100% (21)	0% (0)
Spring	71.4% (15)	28.6% (6)
Summer*	71.4% (15)	28.6% (6)
Winter	100% (21)	0% (0)
Adult mosquitoes live in aquatic habitats	**% Correct (N)**	**%Incorrect (N)**
TRUE	75% (15)	25% (5)
FALSE*	75% (15)	25% (5)
All mosquito species can transmit disease to humans	**% Correct (N)**	**%Incorrect (N)**
TRUE	50% (10)	50% (10)
FALSE*	50% (10)	50% (10)
All mosquito species will bite humans	**% Correct (N)**	**%Incorrect (N)**
TRUE	38.1% (8)	61.9% (13)
FALSE*	38.1% (8)	61.9% (13)
Juvenile mosquitoes live in aquatic habitats	**% Correct (N)**	**%Incorrect (N)**
TRUE*	85.7% (18)	14.3% (3)
FALSE	85.7% (18)	14.3% (3)

Respondents were most likely to report that they perceived wearing protective clothing (95.2%), treating clothing with insect repellent (90.5%) and screening windows/doors (90.5%) as effective practices for reducing mosquito bites. Using an electric racket and using citronella candles were most likely to be reported as ineffective for reducing mosquito bites (52.6% and 28.6%, respectively). For reducing mosquito abundance near their home, participants most commonly reported eliminating standing water container (90%) and keeping lids on water containers (90%) as effective and treating their property with pesticide spray to target juvenile mosquitoes as ineffective (23.1%). Most residents indicated that they did not think they were likely to contract an MBD in Maine (81%), but that they were likely to get mosquito bites in Maine (100%), and on their properties (90.5%). However, only half (52.4%) reported mosquitoes on their property as a nuisance (Table 16). More than half of participants (55%) reported that people who are important to them would not support spraying pesticides on their property to reduce mosquitoes. Additionally, 50% of participants reported that people who are important to them would not support them avoiding spending time outdoors to reduce mosquito encounters (Table 17).

Table 16: Results from the Attitudes Question section of the KAP survey.

KAP Survey Attitudes Questions Responses			
Please rank the effectiveness of the following practices for reducing mosquito bites.	**% Effective (N)**	**% Neutral (N)**	**%Ineffective (N)**
Avoiding mosquito habitat	80% (16)	10% (2)	10% (2)
Screening of doors/windows	90.5% (19)	0% (0)	9.5% (2)
Treating clothing with insect repellent	90.5% (19)	4.2% (1)	4.2% (1)
Using an electric racket or electric bug swatter	36.8% (7)	10.5% (2)	52.6% (10)
Using citronella candles	47.6% (10)	23.8% (5)	28.6% (6)
Using mosquito repellent coils/incense	57.9 % (11)	21.1% (4)	21.1% (4)
Using personal mosquito repellent	85% (17)	5% (1)	10% (2)
Wearing long pants outdoors	95.2% (20)	0% (0)	4.8% (1)
Wearing long sleeves outdoors	85.7% (18)	0% (0)	14.3% (3)
Wearing mosquito nets	90.5% (19)	4.8% (1)	4.8% (1)
Please rank the effectiveness of the following practices for reducing mosquito abundance near your home.	**% Effective (N)**	**% Neutral (N)**	**%Ineffective (N)**
Clearing rain gutters	73.7% (14)	10.5% (2)	15.8% (3)
Eliminating standing water containers	90% (18)	5% (1)	5% (1)
Keeping lids on water containers	90% (18)	0% (0)	10% (2)
Managing plants/landscapes	72.2% (13)	22.2% (4)	5.6% (1)
Treating property with pesticide spray to target adult mosquitoes	75% (12)	12.5% (2)	12.5% (2)
Treating property with pesticide spray to target juvenile mosquitoes	76.9% (10)	0% (0)	23.1% (3)
Treating water with mosquito chemical dunks	50% (5)	40% (4)	10% (1)

Table 16. (CONT.)			
Please rank the extent to which you agree or disagree with the following statements about mosquitoes in Maine.	**% Agree (N)**	**% Neutral (N)**	**% Disagree (N)**
I am likely to get a mosquito-borne disease in Maine	9.5% (2)	9.5% (2)	81% (17)
I am likely to get mosquito bites in areas of public recreation such as wooded trails	79.2% (19)	8.3% (2)	0% (0)
I am likely to get mosquito bites in Maine	100% (21)	0% (0)	0% (0)
I am likely to get mosquito bites on my property	90.5% (19)	4.8% (1)	4.8% (1)
Mosquitoes are a nuisance in areas of public recreation such as wooded trails	81% (17)	9.5% (2)	9.5% (2)
Mosquitoes are a nuisance in my neighborhood	47.6% (10)	23.8% (5)	28.6% (6)
Mosquitoes are a nuisance on my property	52.4% (11)	19% (4)	28.6% (6)

Table 17: Results from the Subjective Norms Question section of the KAP survey.

KAP Survey Subjective Norms Questions Responses			
Please rank the extent to which you agree or disagree with the following statements about how others feel about mosquitoes and mosquito control.	**% Agree**	**% Neutral**	**% Disagree**
People who are important to me would support avoiding spending time outdoors to reduce mosquito encounters	35% (7)	15% (3)	50% (10)
People who are important to me would support emptying water containers on my property to reduce mosquitoes	70% (14)	10% (2)	20% (4)
People who are important to me would support installing window screens to reduce mosquito encounters	95% (19)	0% (0)	5% (1)
People who are important to me would support spraying pesticide on my property to reduce mosquitoes	15% (3)	30% (6)	55% (11)
People who are important to me would support using personal insect repellent to reduce mosquito bites	95% (17)	5% (1)	10% (2)
People who are important to me would support wearing protective clothing while outdoors to reduce mosquito bites	75% (15)	20% (4)	5% (1)

For engagement in practices that reduce the number of mosquitoes on their property, 84.2% and 100% reported never treating their property with pesticide spray, or treating water with mosquito chemical dunks, respectively. The only mosquito reduction behaviors that respondents reported frequent engagement in were cleaning rain gutters and storm drains (31.6%) and removing standing water from containers on their property (21.1%). For participant engagement in practices that reduce mosquito encounters, 94.7% report sometimes wearing protective clothing, and 89.5% report sometimes using mosquito repellent, but 89.5% of respondents always use window screens. Additionally, 73.7% of respondents report sometimes avoiding spending time outdoors to avoid mosquito encounters (Table 18).

Table 18: Results from the Behaviors Questions section of the KAP survey.			
KAP Survey Behavior Questions Responses			
Please indicate how frequently you intend to perform the following behaviors to reduce the number of mosquitoes on your property.	**% Frequently**	**% Sometimes**	**% Never**
Clean rain gutters and storm drains	31.6% (6)	68.4% (13)	0% (0)
Remove standing water from containers on my property	21.1% (4)	63.2% (12)	15.8% (3)
Treat my property with pesticide spray	0% (0)	15.8% (3)	84.2% (16)
Treat water sources with mosquito chemical dunks	0% (0)	0% (0)	100% (19)
Please indicate how frequently you intend to perform the following behaviors to reduce mosquito encounters.	**% Always**	**% Sometimes**	**% Never**
Avoid spending time outdoors	0% (0)	73.7% (14)	26.3% (5)
Use personal mosquito repellent	10.5% (2)	89.5% (17)	0% (0)
Use window screens	89.5% (17)	10.5% (2)	0% (0)
Wear a mosquito net	0% (0)	52.6% (10)	47.4% (9)
Wear long sleeves or long pants	5.3% (1)	94.7% (18)	0% (0)

There were no significant relationships detected between attitudes or reported engagement in behaviors with land use category (Table 19, Table 20), and no relationship detected between participant knowledge and attitudes (Table 21). When we tested the relationships between constructs, we found two significant associations using Fisher's tests. One significant association was detected between respondent's reported subjective norms and engagement in treating their properties with pesticide spray ($p = 0.0196$) (Table 22). A second significant association was detected between respondent attitudes and engagement in the practice of wearing long pants while outdoors ($p = 0.0526$) (Table 23). There was no correlation between participant knowledge and the number of artificial containers suitable for larval habitat on their property.

Table 19: Participant Site Land Use Category and Attitudes Towards Mosquito-related Practices	
Statement	**Fisher's Test P-Value**
Please rank the effectiveness of the following practices for reducing mosquito bites.	
Avoiding mosquito habitat	0.8921
Screening of doors/windows	0.1619
Treating clothing with insect repellent	1
Using an electric racket or electric bug swatter	0.9293
Using citronella candles	0.2343

Table 19. (CONT.)	
Using mosquito repellent coils/incense	0.1803
Using personal mosquito repellent	0.5135
Wearing long pants outdoors	0.5714
Wearing long sleeves outdoors	1
Wearing mosquito nets	0.4857
Please rank the effectiveness of the following practices for reducing mosquito abundance near your home.	
Clearing rain gutters	0.5001
Eliminating standing water containers	0.4789
Keeping lids on water containers	0.1421
Managing plants/landscapes	0.5513
Treating property with pesticide spray to target adult mosquitoes	0.6667
Treating property with pesticide spray to target juvenile mosquitoes	0.2552
Treating water with mosquito chemical dunks	1
Please rank the extent to which you agree or disagree with the following statements about mosquitoes in Maine.	
I am likely to get a mosquito-borne disease in Maine	0.1248
I am likely to get mosquito bites in areas of public recreation such as wooded trails	1
I am likely to get mosquito bites in Maine	NA
I am likely to get mosquito bites on my property	0.3524
Mosquitoes are a nuisance in areas of public recreation such as wooded trails	0.3865
Mosquitoes are a nuisance in my neighborhood	0.5891
Mosquitoes are a nuisance on my property	0.8971

Table 20: Participant Land Use Category and Reported Engagement in Mosquito-related Practices

Statement	P-Value (Fisher's)
Please indicate how frequently you intend to perform the following behaviors to reduce the number of mosquitoes on your property.	
Clean rain gutters and storm drains	0.6821
Remove standing water from containers on my property	0.1087
Treat my property with pesticide spray	0.2776
Treat water sources with mosquito chemical dunks	NA
Please indicate how frequently you intend to perform the following behaviors to reduce mosquito encounters.	
Avoid spending time outdoors	1
Use personal mosquito repellent	0.6316
Use window screens	0.4211
Wear a mosquito net	1
Wear long sleeves or long pants	0.5263

Table 21: Participant Knowledge and Attitudes Towards Mosquito-related Practices.	
Statement	**P-Value (Fisher's)**
Please rank the effectiveness of the following practices for reducing mosquito bites.	
Avoiding time outdoors/ mosquito habitat	1
Screening of doors/windows	0.5048
Treating clothing with insect repellent	0.3714
Using an electric racket or electric bug swatter	1
Using citronella candles	0.3628
Using mosquito repellent coils/incense	0.1079
Using personal mosquito repellent	0.4105
Wearing long pants outdoors	0.619
Wearing long sleeves outdoors	0.3474
Wearing mosquito nets	0.3714
Please rank the effectiveness of the following practices for reducing mosquito abundance near your home.	
Clearing rain gutters	0.9241
Eliminating standing water containers	0.2368
Keeping lids on water containers	0.4947
Managing plants/landscapes	1
Treating property with pesticide spray to target adult mosquitoes	0.4277
Treating property with pesticide spray to target juvenile mosquitoes	1
Treating water with mosquito chemical dunks	1
Please rank the extent to which you agree or disagree with the following statements about mosquitoes in Maine.	
I am likely to get a mosquito-borne disease in Maine	1
I am likely to get mosquito bites in areas of public recreation such as wooded trails	0.7333
I am likely to get mosquito bites in Maine	NA
I am likely to get mosquito bites on my property	1
Mosquitoes are a nuisance in areas of public recreation such as wooded trails	1
Mosquitoes are a nuisance in my neighborhood	0.2935
Mosquitoes are a nuisance on my property	0.2362

Table 22: Participant Subjective Norms Towards Mosquito-related Practices and Reported Engagement in Practices	
Practices	**P-Value (Fisher's)**
Practices for reducing mosquito bites	
Avoiding time outdoors/in mosquito habitat	1
Screening of doors/windows	1
Using personal mosquito repellent	1
Wearing protective clothing	1
Practices for reducing mosquito abundance	
Eliminating standing water containers	0.06455*
Treating property with pesticide spray	0.01961*

Table 23: Participant Attitudes Towards Mosquito-related Practices and Reported Engagement in Practices. Asterisk indicates significance at P< 0.1.

Practices	**P-Value (Fisher's)**
Practices for reducing mosquito bites	
Avoiding time outdoors/in mosquito habitat	1
Using personal mosquito repellent	1
Screening of doors/windows	1
Wearing long pants outdoors	0.05263*
Wearing long sleeves outdoors	0.1579
Wearing mosquito nets	1
Practices for reducing mosquito abundance	
Clearing rain gutters	0.4454
Eliminating standing water containers	1
Treating property with pesticide spray to target adult mosquitoes	1
Treating property with pesticide spray to target juvenile mosquitoes	1
Treating water with mosquito chemical dunks	NA

Discussion

The results of this study, while not generalizable to a greater population, still give important insight into the factors that shape mosquito control and personal protective behaviors in a group of Bangor, ME residents. The participants in our survey indicated higher knowledge of exotic MBDs of no concern in Maine (e.g., Zika Virus, Dengue) compared to local MBDs of public health considerations in this region (e.g., West Nile Virus, Eastern Equine Encephalitis Virus). Participants also reported a mismatch in their perception of control and protection practices' high efficacy with low control and protection practice engagement, especially when their perception of mosquitoes as a nuisance on their properties is considered. Additionally, one of our findings, the significant association between subjective norms and reported engagement for the mosquito control practice of spraying pesticides on their properties, is consistent with previous literature. Overall, this study provides a blueprint KAP survey instrument for further application in US MBD systems, with a novel incorporation of model constructs from Azjen's Theory of Planned

Behavior to further explore factors that impact engagement in mosquito control and personal protective behaviors.

The demographics reported by the 23 survey participants in this study were very uniform. This is not surprising, given the small sample size and the demographics of Bangor, ME, in addition to established demographic patterns in survey research. According to US census data, 89.1% of residents racially identify as white (US Census, 2021). To observe the limited racial diversity of Bangor, ME residents, we would have needed a much larger sample size to participate in our survey. Our proportion of female respondents was also higher than the general Bangor population. Previous survey research has shown that women are more likely to respond to a survey, and more likely to respond faster to online survey invitations compared to men, leading to gender disparities in survey respondents (Smith 2008, Becker 2022, Becker et al., 2019). The respondents in our survey were generally from high SES, with high education levels. This is also consistent with prior survey research which shows that people with high income and education levels are more likely to participate in online surveys (Roberts et al. 2020).

The generally high levels of knowledge reported by participants in our survey is consistent among mosquito related KAP survey research in the US. Research using KAP surveys in Washington D.C., Champaign IL, and San Antonio, TX have shown similarly overall high general knowledge about mosquitoes and mosquito habitat (Dowling et al 2013, Parker et al. 2019, Bohmann et al. 2022). In the studies conducted in Washington D.C. and Champaign, IL, higher knowledge was associated high socioeconomic status and higher education status. This association between socioeconomic status and knowledge is observed in many different research topics in the literature. For example, SES has been associated with knowledge of tick-borne illness risk (Cuadera 2023), cardiovascular disease risk (Potvin et al 2000), parenting skills (Rigas et al. 2003), H1N1 influenza prevention (Ho, 2012) and many other research areas. The low knowledge of commonly locally acquired MBD in our study was contrary to other mosquito related KAP studies in the US. High knowledge of WNV specifically has been documented in KAP studies in San Antonio and upstate New York (Bohmann 2022, Tuiten et al. 2009). This suggests that residents in far Northeastern US states like Maine may have less exposure to information on locally acquired MBD. Resident knowledge of MBD should continue to be studied in the context of applying information or media campaigns to promote high MBD literacy in this region.

The mismatch in the positive attitudes toward but low engagement reported in mosquito control and personal protective behaviors is a common theme in human dimensions of vector borne diseases research. In a study that used a KAP survey to address park visitor's tick bite prevention behaviors on Staten Island, New York City, NY participants reported that parks were the main location for tick exposure, but also report that they did not perceive themselves at risk of exposure and reported low engagement in prevention practices (Hassett et al. 2022). Additionally, in Connecticut, participant reported belief in the local presence of WNV did not predict engagement in prevention practices (CDC, 2003). This highlights the need to continue unraveling factors which may be important for predicting engagement in vector control and personal protective behaviors.

In our study, we detected a significant association between participant subjective norms and reported engagement in the use of pesticide spray, and between reported attitudes towards and engagement in wearing protective clothing. While our statistical tests were not powerful enough to draw conclusions about the directions of these associations, we can draw on inferences based on prior studies that use the KAP and TPB frameworks. Attitudes have consistently been found to be significant predictors of behavioral intention and engagement in the TPB since Azjen first published the framework in 1991 (Bosnjak et al. 2020). In a meta-analysis of 206 studies that used the TPB to explain factors in health behavior decision-making, attitudes were found to be the most important predictor of behavioral intention, and the second-most important predictor of behavioral engagement (McEachan et al. 2011). In a study examining engagement in organic food purchasing behavior, subjective norms were found to have a positive relationship with reported attitudes toward buying organic food, and a positive relationship with intention of engaging in organic food purchasing behavior (Al-Swidi et al. 2013). Additionally, using the TPB, subjective norms were found to be the most significant predictor of tourist decision making behavior in China (Quintal et al. 2010). In a meta-analysis of the role of subjective norms in predicting engagement in behavior using the TPB, Rivis and Sheeran (2003), subjective norms were concluded to an important predictor in the model. The meta-analysis also showed that younger samples and behaviors related to health risks were associated with stronger correlations between norms and behavioral intention.

In conclusion, while our KAP survey lacked the sample size to draw conclusions about relationships between constructs or to generalize to a larger population, important themes can still be drawn from the sample. Bangor, ME residents who participated in our survey had low knowledge of locally acquired MBD and were likely to report a mismatch in attitudes towards and engagement mosquito control and personal protective behaviors. This is valuable information for future mosquito research endeavors in this region that should recruit higher participation among a more diverse group and continue to explore the knowledge, attitudes and practices surrounding mosquito control and personal protective behaviors. Understanding factors that contribute to engagement in these behaviors among residents in the Northeast is important for protecting public health and designing informational campaigns as related to MBDs, especially as they continue to become more prevalent in this part of the US.

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BIOGRAPHY OF THE AUTHOR

Megan Schierer was born in Wheeling, Illinois on June 26th, 1994, and graduated from Freeport High School in May 2012. She attended the University of Illinois and received a B.S. in Integrative Biology in August 2017. During her time at the University of Illinois, she discovered her passion for disease ecology and medical entomology. Following those passions after graduation lead her to a research assistant position in the lab of Dr. Richard Ostfeld at The Cary Institute in Millbrook, NY. There, she continued to gain skills in the field and lab and was promoted to a project management position, examining microclimate effects on black-legged tick survival. Megan moved to Maine in June 2020, during the height of the COVID-19 pandemic, joining Dr. Allie Gardner and Dr. Sandra De Urioste-Stone on their interdisciplinary collaboration through the National Science Foundation National Research Traineeship "One Health for the Environment." After receiving her degree, Megan looks forward to continuing her studies with Allie and Sandra as a PhD student, continuing to explore arthropod vectors through an integrated social and ecological lens. Megan is a candidate for the Master of Science degree in Ecology and Environmental Sciences from the University of Maine in May 2023.