ABSTRACT

Title of Thesis:	SOCIOECOLOGICAL PREDICTORS OF COMMUNITY-LED MOSQUITO CONTROL SUCCESS
	Aubrey Tingler, Master's of Science, 2023
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The worldwide spread of the Asian Tiger Mosquito (ATM), *Aedes albopictus,* demands effective and sustainable urban mosquito management, due to their disease vector capacity and potential for causing high nuisance levels. Agency-led mosquito management is often ineffective at controlling ATM or unwanted by residents. In 2016 and 2017, citizens of University Park, Maryland, USA led a town-wide campaign to encourage residents to purchase Gravid *Aedes* Traps (GATs), a lethal oviposition trap successful at capturing *Aedes* mosquitoes. This campaign resulted in significant reductions of adult female ATM in areas with >80% GAT coverage among yards. The goal of this study was to test the continued effectiveness of University Park's citizen-led program and explore social and environmental predictors of household GAT deployment in 2021. We conducted adult trapping at 18 sites in University Park to test if current levels of GAT deployment still predicted reductions in area-wide adult female ATM, distributed an online questionnaire to gather data for testing relationships of demographic, environmental, knowledge, and attitude predictors with household GAT deployment, and conducted environmental yard

surveys to assess relationships of GAT deployment with container habitat and mosquito container infestation. We found that only 24.9% (130/523) of University Park households deployed GATs in 2021, which is substantially lower than the 46.0% (439/954) of households that deployed GATs in 2017. GAT coverage in 2021 did not exceed 50% (3/6) in any adult-trapping area, well below the 80% threshold thought needed to reduce area wide adult *Aedes*. Nevertheless, we found a significant negative relationship between household GAT deployment and adult female ATM, indicating that GATs are still effective at controlling *Aedes* at lower coverages. Households that deployed GATs had lower numbers of total, but not infested, water-filled containers, suggesting GAT deployment was often a part of a household's overall effort to reduce mosquitoes alongside source reduction, but that source reduction and GATs may not limit mosquito infestation at the yard scale. Households with middle incomes, further from town greenspace were less likely to deploy GATs along with respondents who spent less time outdoors, were less favorable toward University Park's GAT Program, and could not name ATM as University Park's most common human-biting mosquito. Respondent familiarity of ATM was lower in renters than homeowners, and respondent favorability towards University Park's GAT program was lower in households with children, and with respondents that do fewer yard activities and who had resided for less time in the town. The results of this study show that a citizen-led mosquito-control program using a passive lethal oviposition trap is still effective, four years after its inception, and that there were specific social and environmental predictors of household participation. In this thesis, I will discuss these results and their implications for bottom-up, citizen-led, control of ATM and other *Aedes* in other residential communities and demonstrate a framework for understanding drivers of participation and success in community-led environmental management.

SOCIOECOLOGICAL PREDICTORS OF COMMUNITY-LED MOSQUITO CONTROL SUCCESS

by

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Thesis submitted to the Faculty of the Graduate School of the
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Dedication

To my younger self, who didn't always believe she could do hard things and to my family and friends who always believed she could.

Acknowledgements

I would like to thank my advisor, Dr. Paul Leisnham for putting up with me being simultaneously headstrong and not always believing in myself. Thank you for letting me make as many of my own decisions as possible, while also being firm when I was wrong and guiding me when I had no idea what I was doing. I would like to thank Mary Fritzell and Naryan Spaur for their invaluable assistance in the field, and Mary again for her assistance on data management that was especially tedious. I would like to take a moment to acknowledge that starting graduate school as part of the "covid cohort" made it extremely hard, and I would like to thank the people who helped me push through that hard, including: my supportive and loving partner, Shon; my sister, Ana; my brother, Eli; my parents; my incredible circle of friends who I feel so lucky to have found over the years; the wonderful folks that make the "Dear Grad Student" podcast, and my cat Puck who never failed to provide cuddles and entertainment when I was feeling down.

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statistical significance between treatment levels when there is more than two ($p < 0.05$).

Figure 8. Mean (±1 SE) mosquito species knowledge score by respondent home ownership status (A), and GATP attitude score by household children (B), respondent numbers of yard activities (C), and respondent years in UP (D). Respondents were considered to have mosquito species knowledge if they could name *Ae. albopictus* as the most common pest mosquito in their area. Respondents received a GATP attitude score from 2-10 points that was the sum of two scores from 1-5 points on their perceived effectiveness and favorability of UP's GATP, with 1 point corresponding to lowest effectiveness and favorability and 5 points corresponding highest effectiveness and favorability.

Chapter 1: Introduction

The Public Health Threat of Mosquitoes

Worldwide, mosquitoes are responsible for nearly seven-hundred million human disease cases annually, one million of which result in death (Mack, 2016; *Mosquito-Borne Diseases | World Mosquito Program*, n.d.; World Health Organization, 2014). Currently, the majority of this disease burden falls in the globe's tropical and subtropical regions. With current climate trends pushing warmth poleward and to higher altitudes, and with increasing urbanization, mosquito-borne diseases historically restricted to tropical areas are becoming a growing threat in temperate areas (Arias-Castro et al., 2020; Rochlin et al., 2013; World Health Organization, 2014).

Mosquito-borne diseases that infect humans include malaria, dengue, various forms of encephalitis, yellow fever, West Nile virus (WNV), chikungunya virus, and Zika virus (CDC, 2020; *Mosquito-Borne Diseases | NIOSH | CDC*, 2020). More than 400,000 deaths annually are caused by malaria alone, mostly in children under 5 years (World Health Organization, 2020). While *Anopheles* and *Culex* mosquitoes are the primary vectors of malaria and WNV, respectively, *Aedes* species vector dengue, yellow fever, chikungunya, Zika, as well as other pathogens (World Health Organization, 2020).

A variety of arboviruses are transmitted by mosquitoes, primarily those from the *Aedes* and *Culex* genera. Dengue is the most predominant vector-borne arbovirus in the world, affecting 3.6 million people. Four distinct serotypes of the dengue virus exist which cause dengue disease (Cattarino et al., 2020). Ongoing epidemics throughout the tropics result in hundreds of millions of cases per year (Cattarino et al., 2020). Like many arboviruses, dengue does not have well-developed medical treatments or vaccines to prevent it (Leta et al., 2018). Vaccines are available for yellow fever, but this hemorrhagic fever is potentially lethal and still regularly causes outbreaks among unvaccinated populations (Dahmana & Mediannikov, 2020). This pathogen has a cyclical emergence, with outbreaks approximately 7–10 years apart and the highest recorded fatality rate of 33.6%. During the last major outbreak in 2016, forty-seven countries declared yellow fever epidemics (Dahmana & Mediannikov, 2020). WNV is contracted from mosquitoes that feed on infected birds and is spread primarily by *Culex* species. It is widespread due to its obligate amplification through avian reservoirs but has a comparatively lower human cost. The vast majority of WNV cases are subclinical or asymptomatic, but less than 1% of cases can become neuroinvasive (*Clinical Evaluation & Disease | West Nile Virus | CDC*, 2023; World Health Organization, 2020).

In recent years, *Aedes*-transmitted chikungunya and Zika viruses have caused an increasing number of outbreaks around the world, particularly in urban areas, raising concerns that these pathogens are emerging threats in an increasingly urbanized world (Bisanzio, Blitvich & Brault, 2018; Stoddard et al., 2009). chikungunya virus is typically flu-like with characteristic joint pain, which can become chronic and debilitating in some cases, with 1.4% to 90% of cases entering the chronic stage, and potentially adding a burden to healthcare systems in the several countries where outbreaks have been reported (WHO, 2022; Rahman et al., 2018).

Ongoing epidemics of Zika virus persist in several countries in Latin America and the Pacific. Outside of the current COVID-19 pandemic, Zika is considered one of the most serious disease threats to public health, as it shows the potential to spread widely and rapidly in densely populated urban areas (Brady & Hay, 2019; Dahmana & Mediannikov, 2020). Zika, like dengue, WNV, yellow fever, and Japanese encephalitis is a flavivirus in the family *Flaviviridae*. Zika was first discovered in 1947 in non-human primates but did not emerge as a major public health threat until outbreaks began in the Pacific in 2007. Analyses conducted at that time expected Zika to spread to Asia but discovered an indigenous variant of the pathogen had been circulating inconspicuously, likely for decades (Brady & Hay, 2019; Musso et al., 2019). Zika typically causes mild illness, with flu-like symptoms including fever, arthralgia, myalgia, and sometimes rash and conjunctivitis (Giron et al, 2019; Musso et al., 2019). However, the newer strains of Zika associated with outbreaks in the Americas that occurred throughout the 2010's cause more severe complications including Guillain-Barre syndrome and microcephaly. Pregnant women infected with Zika are expected to have a 5 - 14% risk of congenital Zika syndrome and a 4 - 6% risk of microcephaly for the fetus, both of which can result in an increased risk of neonatal mortality. Zika has already spread in a pandemic pattern across Asia, the Americas, the Caribbean, and Africa and has the potential to expand its range as *Aedes* mosquitoes continue to invade territory (Giron et al., 2019; Musso et al., 2019; Pomar et al., 2018).

While much of the world's mosquito-borne disease burden currently falls on tropical and subtropical regions, Zika and chikungunya outbreaks have been documented in temperate urban areas in southern Europe and the United States and have the potential to spread even more widely (Brady & Hay, 2019; Giron et al., 2019; Grard et al., 2014). Within the last decade, urban dengue transmission has increased in Asia and found a foothold in Mediterranean Europe (Cattarino et al., 2020; Schaffner & Mathis, 2014). Without preemptive plans for vector control, the potential for increased human suffering and healthcare system strain could greatly increase, as the range and impacts of mosquito species expand into temperate regions. The relationships between humidity, temperature, and vector biology are highly complex, making the future challenges of mosquito-borne disease ominously uncertain (Houé et al., 2019; Kraemer et al., 2019).

Aedes *Mosquitoes in Urban Environments*

Like other mosquitoes, the *Aedes* require a bloodmeal before a female can develop eggs, which she will then lay in water where they can develop and grow, a process known as oviposition (Day, 2016). In their native habitat, *Aedes* mosquitoes favor small natural containers, such as tree holes, to oviposit. After eggs are deposited, they grow into larva, pupae, and then adults, typically within two weeks (US EPA, 2013). However, with increasing urbanization, *Aedes* have adapted to utilizing structural (e.g., in-ground drains) and cryptic (e.g., flowerpots and litter) containers that occur in the built environment (Abílio et al., 2018; Bartlett-Healy et al., 2012; Bodner et al., 2016; Floore, 2006; Little et al., 2017).

The urban environment provides a habitat matrix where socioeconomic factors can influence the physical and built environment (LaDeau et al., 2015). Urban habitats generally provide ample breeding containers for *Aedes*, but habitat is not evenly distributed across the urban gradient, and can vary with the socioeconomic status as well and physical and climatic shifts in the urban environment (Evans et al., 2019; Li et al., 2014; Little et al., 2017; Shragai & Harrington, 2018). These mediating factors in the urban environment vary at relatively small scales, such as among neighborhoods or even city blocks, necessitating small-scale management by individual residents or communities (Evans et al., 2019; Fonseca et al., 2013; LaDeau et al., 2015; Little et al., 2017).

Aedes adeptly exploits urban habitat and poses a nuisance and an emerging and potentially severe threat for Zika proliferation, and possibly other pathogens (Brady & Hay, 2019; Faraji et al., 2014; Giron et al., 2019; Grard et al., 2014; Worobey et al., 2013). While tropical and subtropical cities have combatted this threat for decades, temperate cities are now beginning to face increasing mosquito pressure with few effective control programs in place (Leta et al., 2018; Petersen et al., 2016).

ATM Invasion in the United States

The Asian tiger mosquito (ATM), *Aedes albopictus* (Skuse), has emerged as one of the most important invasive mosquito species over the last 40 years. Native to Southeast Asia, ATM has invaded non-native territory faster than any other animal in the last two decades and is now found in 85 countries (Barlett-Healy et al., 2012; Benedict et al., 2007; Laporta et al., 2023). ATM invaded the United States in the mid-1980s. This species is an aggressive daytime biter of several host taxa but has been shown to favor human bloodmeals in urban areas (CDC, 2020; Faraji et al., 2014; Goodman et al., 2018), causing acute nuisance impacts for residents in infested neighborhoods (Worobey et al., 2013; Beyer et al., 2019; Biehler et al., 2019). ATM biting has been shown to dramatically impact people's decision to spend time outdoors and their overall wellbeing (Bodner et al., 2016). Worobey et al. found that in areas of New Jersey, USA, where ATM infestation occurs with little abatement, children play less outdoors, which may contribute to childhood obesity (2013). Reduced time outdoors can contribute to a host of negative impacts, ranging from increased risk of chronic disease to less affinity for environmental concerns (Beyer et al., 2019; Hoover, 2021).

ATM can vector at least 22 arboviruses, including chikungunya, Zika, and WNV (Leta et al., 2018; Moore, 1997; Sardelis et al., 2002) and its threat to drive disease outbreaks are expected to worsen, particularly due to increasing urbanization and temperatures and moisture because of climate change (Farajollahi & Nelder, 2009; Rochlin et al., 2013; Wilke et al., 2019). Although this transmission has so far been from *Aedes aegypti*, Texas and Florida have both documented vector transmission of dengue fever and Zika virus, and Florida has documented transmission of chikungunya (Leta et al., 2018). West Nile Virus outbreaks occur regularly throughout the United States, with 731 cases and 66 deaths occurring in 2020 (CDC, 2020). While these arboviral diseases have yet to proliferate widely throughout the country, they are of significant public health concern due to their predicted increase in spread and currently limited options for medical treatments or vaccines against them (Leta et al., 2018; Rochlin et al., 2013; Wilke et al., 2019).

Limitations of Traditional Mosquito Control on ATM

Traditional mosquito control methods in the United States and many areas worldwide typically rely on the application of affordable chemical insecticides by agency personal but these methods are largely ineffective against ATM due to their daytime activity patterns and preference for small, cryptic breeding containers (Floore, 2006; Leisnham & Juliano, 2011). In the United States, mosquito control agencies are typically funded at the local level, meaning they are small and may lack the funding, personnel, or authority to access containers on private lands, including yards in residential areas (Floore, 2006; Petersen et al., 2016). Reaching productive sites in residential areas requires repeated, relatively high intensity applications of adulticides or larvicides by truck or airplane mounted sprayers (Floore, 2006; Fonseca et al., 2013). Areawide applications of pesticides has been met with increasing fears of adverse human health effects, especially among elderly and children, and dangers toward non-target insects, such as honeybees and ladybugs (Biehler et al., 2019; Floore, 2006; Logomasini, 2004; Moyes et al., 2017).

Given the limitations of chemical approaches to control ATM, management of the species has often focused on preventing mosquito biting using and the removal of breeding containers or 'source reduction' is often focused on reducing nuisance-biting, while vector control may be an additional benefit if the community supports the program through tax dollars (Petersen et al., 2016). However, many municipalities cannot afford pesticide applications and decades of applying chemical control worldwide has resulted in mosquitoes developing a resistance to various chemical substances (Arias-Castro et al., 2020).

The container breeding behavior of ATM necessitates community involvement from residents themselves to achieve effective and sustained control of this invasive pest and potentially dangerous disease vector (Abramides et al., 2011; Benedict et al., 2007; Chandel et al., 2016; Chen et al., 2020; Moore, 1997). However, because urban residential areas are partitioned into many small, private parcels of land, effective control of ATM requires high levels of participation, which may be difficult for many communities to achieve (Fonseca et al., 2013; Johnson et al., 2018). Therefore, there is a need to understand what drives participation in community-led mosquito control programs, so that they can be implemented and maintained with the maximum participation possible.

Lethal Oviposition Traps

Lethal ovitraps represent a relatively novel approach for areawide control of urban *Aedes* and can supplement source reduction for biting prevention. Over the past 20 years, they have been used throughout the world in mass control strategies to explore their mosquito abundance and vector control effectiveness. Several types of lethal ovitraps, all of which mimic a water-filled container that would be ideal for *Aedes* oviposition, are available (Johnson et al., 2017). Here, we focus primarily on the larger, more modern lethal ovitraps: the autocidal gravid ovitrap (AGO) and the gravid *Aedes* trap (GAT). These two traps are similar in their design. The AGO was designed by the United States CDC and the GAT was designed by the German company Biogents. In both traps, there is a black bucket base filled with water with some grass or hay added as an attractant. This bucket is then connected to an upper chamber with a sticky killing agent and there is mesh over the water to prevent any deposited eggs from emerging. The GAT has a clear chamber that is larger than the sticky chamber of the AGO and uses only a small sticky card versus an entire sticky chamber (Figure 1) (Barrera et al., 2014; Johnson et al., 2017).

Figure 1. Front and sidecut view of a Gravid *Aedes* Trap (Biogents, 2021).

Lethal ovitrapping efforts have showed varying degrees of success in Puerto Rico, Brazil, Australia, and other nations that suffer significant mosquito-borne disease burdens (Johnson et al., 2017). In 2014, Barrera et al. found that placing 3 AGOs per household in 81% of the households in their study area led to mosquito density being 88% higher in the reference area than in the AGO treatment area. In 2017, Barrera et al. was able to show that this decrease in biting adult female abundance also led to a decrease in viral circulation during the chikungunya epidemic in Puerto Rico (Barrera et al., 2017). In 2018, Barrera et al. showed a similar reduction in biting adults during the Puerto Rico Zika endemic. While these studies were done with a focus on *Aedes aegypti*, a 2017 study in Florida compared the effectiveness of the AGO, GAT, and the CDC gravid trap (CDC-GT) for *Aedes* surveillance. The GAT outperformed the AGO in the collection of ATM, indicating it may be the superior passive trap for ATM suppression (Cilek et al., 2017). While this trapping was led by researchers and agencies, gravid ovitraps are passive, inexpensive, and relatively easy to deploy, making them a potentially effective control strategy when deployed by residents, if proper source reduction practices are also followed to ensure trap efficacy (Johnson et al., 2017).

Lethal ovitrap deployment has been recommended as a preemptive measure for controlling abundance of ATM (Johnson et al., 2017). However, successful use of lethal ovitraps traps requires a baseline of approximately 80% trap coverage in a community to have a meaningful reduction in biting adult abundance, thus lethal ovitrap success is limited by community participation. Successful use of lethal ovitraps has generally been defined by the traps significantly reduced *Aedes* abundances, and in some cases, reducing disease transmission (Johnson et al., 2017). Still, integrated control programs that incorporate both lethal ovitrapping and source reduction campaigns have been shown to be more effective than chemical control methods against arboviruses that tend to spread rapidly in urban environments, such as dengue and chikungunya (Barrera et al., 2017; Johnson et al., 2017; Mackay et al., 2013). However, no studies have shown lethal ovitrap effectiveness below a coverage threshold of 80% (Barrera et al., 2014, 2017; Johnson et al., 2017; Sharp et al., 2019).

Community-Led Mosquito Management Practices

A growing body of literature indicates that community-led mosquito control is among the most effective at combatting ATM proliferation and associated nuisance and arboviral disease risk (Abramides et al., 2013; Fonseca et al., 2013; Johnson et al., 2017; B. J. Johnson et al., 2018). Community-based work in Catalonia, Spain that involved residents and the city government found that multiple intervention strategies that included source reduction by residents were more effective at reducing relative egg abundance of ATM than traditional control methods (Abramides et al., 2011). Most of the community-led control efforts in the United States have relied on providing education to residents through various means with mixed results (Bodner et al., 2016; Dowling et al., 2013; Fonseca et al., 2013).

For example, Bodner et al. found that residents who received literature on mosquito infestations and management showed decreased concerns for mosquito infestation in their community compared to control households (2016). However, Fonseca et al. found substantial reductions in urban ATM populations after education was provided to both school aged-children and adults, via in-person and print outreach. Still, substantial reductions in populations were not achieved in suburban sites where ATM seems somewhat harder to control (2013). A shift to a multiple intervention strategy that educates residents about source reduction but also involves them in lethal ovitrapping is a potentially viable way to achieve sustainable ATM control (Johnson et al., 2017). Johnson et al. 2018 was the first study to show that citizen-led use of GATs can effectively reduce ATM abundance, finding that blocks with 80% GAT coverage or greater saw approximately a 66% reduction in ATM abundance. However, little is known about the longterm efficacy and sustainability of such interventions at the community-level because few have been tried, and even fewer have had any follow-up more than two years after implementation.

Socioecological Factors Predicting Citizen-Led Environmental Management

At its core, any community-led intervention or control for invasive ATM is an attempt to respond to an environmental disturbance. Therefore, we explored the existing literature on community response to urban environmental disturbance and environmental stewardship participation to contextualize how community members may respond to the threat of ATM and subsequent efforts to control them. This positions the work presented here not just in an integrated pest management context, but in a broader context of understanding and assessing community-led environmental management practices.

Time spent outdoors and connection to nature are known to facilitate environmental stewardship in children (Andrejewski et al., 2011). Similar and significant relationships between enjoyment of time spent outdoors and interest in environmental stewardship exist for adults (Hunter, 2011b; Ryan et al., 2001; Thapa, 2010). Outdoor recreation has been linked to environmental stewardship participation (Thapa, 2010), indicating that a personal relationship with the outdoors may be a significant factor in community-led environmental management and potentially mosquito management specifically. Additionally, the citizen science and environmental stewardship literature is clear that motivations affect volunteer behaviors and that motivations vary between demographic groups (Ryan et al., 2001;

Thapa, 2010; West et al., 2021). Therefore, understanding the motivations and differences between groups in any community-led effort is important to its characterization and analysis.

Community-Led GAT Program in University Park, Maryland

A lethal ovitrapping program was established in University Park, Maryland (UP) in 2017 using the Biogents Gravid *Aedes* Trap (GAT). The GAT Program (GATP) built on an existing mosquito management program that included extensive resident education about source reduction, yard inspections, and adult surveillance by interns paid for by the town. This program relied on communication through "block captains", residents who volunteered to assist in neighbor-to-neighbor education and GAT implementation (Johnson et al., 2018; E. Wells, personal interview, March 31, 2021).

In 2016, the residents of University Park reached out to a team of scientists at Rutgers University who study mosquito control. The residents were interested in what additional actions they could take to help control the mosquito populations in their town. At this time, the town already had a robust source reduction campaign since 2012 (E. Wells, personal interview, March 31, 2021). Through conversations with these scientists, the residents developed a passive trapping program using the GAT. The initial program required a resident "buy-in" of residents purchasing their own trap through the town at a reduced price. Education about trap purchasing, setup, continuing source reduction, and ATM ecology was made available on a website created and maintained by volunteers (Johnson et al. 2018; Wells, personal interview, March 31, 2021).

The GAT is a passive trap used to lure egg-laying *Aedes* female mosquitoes into the trap, which is equipped with a killing agent or sticky card, which causes the mosquitoes to become trapped and die. Thus, females do not deposit their eggs, or adults that emerge from eggs are trapped, removing the next generation of mosquitoes from the population. Passive traps do not require the use of lures or electricity, making GATs relatively inexpensive (compared to active traps or industrial insecticides) and easy to maintain (Biogents, 2020) (Figure 1).

When the GATP fully launched in 2017, residents were given the option to buy their traps at cost to participate; the original study on the efficacy of this program attributes resident “buy-in” (residents choosing to participate and purchasing their own trap) to the program's success and sustainability (Johnson et al. 2018). However, after the initial study to prove trap efficacy (Johnson et al. 2018), no subsequent follow up to confirm continued efficacy and sustainability was conducted. Currently, levels of participation in the GATP vary, and plenty of residents take other mosquito prevention measures, such as source reduction, but do not deploy a GAT (E. Wells, personal interview, March 31, 2021).

Because University Park had high levels of resident engagement in source reduction from previous mosquito control efforts since 2012, the town was more likely to have trapping success, due to better elimination of cryptic containers that may attract ATM more than the GATs (Johnson et al., 2017; B. J. Johnson et al., 2018). While the program showed promising and measurable success in the beginning, no follow-up has been done to determine if University Park still achieves statistically significant levels of ATM suppression in high coverage blocks and positive resident perceptions of the program's efficacy and success (Johnson et al., 2018). While the literature on integrated mosquito management (IMM) is rife with recommendations based on short term studies, follow-up on previously implemented programs more than two years later is nearly nonexistent.

Thesis Goal and Objectives

The overall goal of this thesis was to test the continued effectiveness of University Park's citizen-led GAT program and explore social and environmental predictors of household GAT deployment in 2021. To address this goal, I had two main objectives:

1. Test the relationship between household GAT coverage and adult female abundance in 2021, four years after the program started, and
2. Test relationships between resident demographic, environmental, knowledge, attitude, and practices on household GAT deployment

The results of this study will advance our specific understanding of social and environmental variables that sustain or erode the effectiveness of a citizen-led mosquito management effort, but also provide valuable broader insights in how communities view and manage their environment. This information will help inform mosquito and environmental management programs in the future.

Chapter 2: Methods

Study Area & Period

University Park (UP) is a town in Prince George's County, Maryland, USA consisting of ~923 single-family households across 55 blocks and a population of ~2,641 (U.S. Census, 2020; Data USA, 2020) (Fig. 2). It has a median income of ~$140,000, which is just over 2 times the median income of the United States ($67,521) (U.S. Census, 2020). Its racial makeup consists of 62.5% white, 13.6% Hispanic, 10.8% Black, 8.1% Asian, and 4.8% multiracial (U.S. Census, 2020; Data USA, 2020).

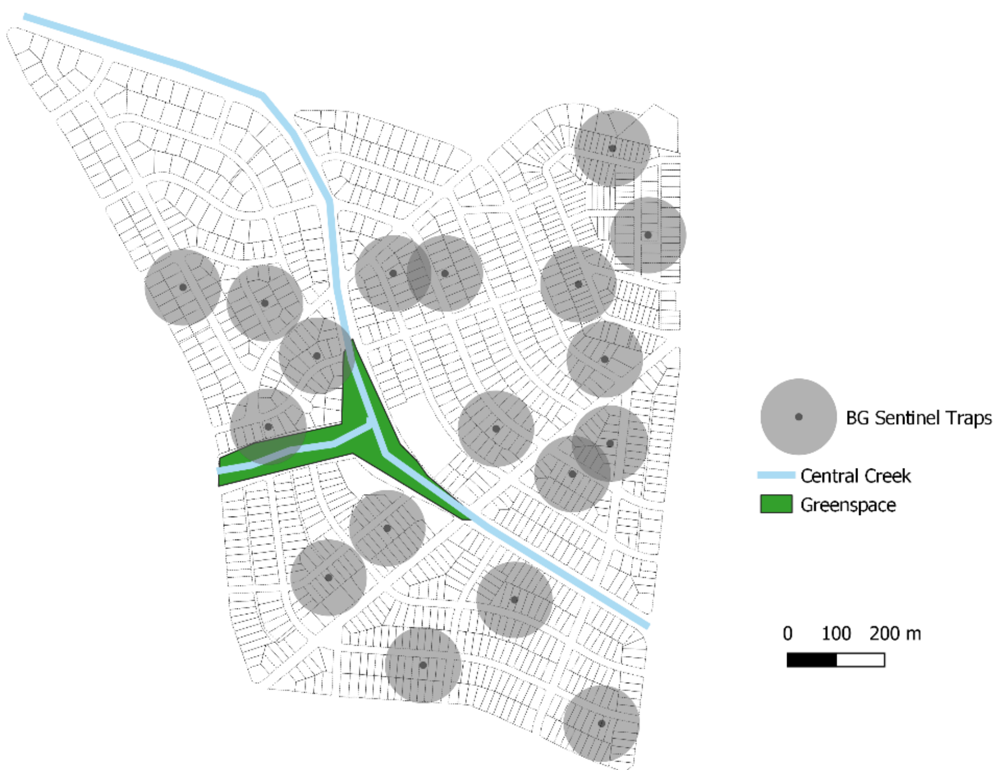

Figure 2. Map of University Park including BG Sentinel trapping sites, 75m trap buffers, town green space, and the central creek.

Data collection consisted of three main components: 1. Household yard surveys of GATs, mosquito container habitats, and container mosquito infestation; 2. Area-wide adult female ATM sampling using professional BG-Sentinel traps; and 3. An online knowledge, attitudes, and practices (KAP) questionnaire that collected data on individual and household demographics, environment, knowledge, attitudes, and practices related to mosquitoes and their control. KAP questionnaires have been used regularly when exploring perceptions and behaviors on environmental issues and mosquitoes (e.g., Dowling et al., 2013; Bodner et al. 2016, Johnson et al., 2018).

Environmental Yard Surveys

Households were surveyed 3-5 days per week from June to September, encompassing the summer season of mosquito activity (e.g., Dowling et al, 2013, Freed et al., 2014). On each survey date, town blocks were randomly selected and all households on that block were visited by investigators. A household's yard was sampled when consent was granted by a resident adult (>18 years old). Blocks were revisited multiple times to survey households where residents were unavailable during prior visits. Over the summer period, a total of 873 (94.6%) households were visited and 38.7% (338) of these households were surveyed.

During each household survey, the entire yard was systematically searched for water-holding containers. We defined a water-holding container habitat as any container holding at least 3 mL of water and considered container habitat with larvae as a proxy of household mosquito infestation, consistent with past studies (Dowling et al; 2013; Bodner et al. 2016). Each mosquito container habitat was visually checked for larvae. Containers whose water could not be clearly assessed with a visual check had their entire contents homogenized and up to 1 L transferred to a white tray for a more thorough search. Some containers (e.g., in-ground drains) could not be sampled without structural modifications to the property; thus, were excluded from surveys, but these containers consisted less than 1% of total found containers.

For households that deployed a GAT, the yard survey also included an assessment of GAT deployment using an eight-point criteria based on the manufacturer's deployment instructions and guidelines provided to University Park residents during workshops in 2017 (Biogents, 2021; E. Wells, Personal Interview, March 31, 2021) (Appendix 1). Each household GAT received one point for each correct criterion, giving a household a GAT correctness score ranging from 1-8. GATs that received a score of 8 were considered fully correctly deployed. Only 44.7% (30/67) of the total households that deployed GATs had fully correct setup. However, 77.6% (52/67) of GATs received a correctness score of at least 6, indicating they are likely functioning well if not fully optimally. After all yard surveys were completed, Google Maps (Google, Seattle, USA) was used to measure the distances of each household to town greenspace and a central creek, since previous studies have indicated that urban mosquito abundance can vary with land cover, and the creek was an additional water source (Kiss et al., 2020; Zhao et al. 2019; Yang et al., 2019). We did not anticipate the running water of the creek to be mosquito habitat, but there were areas of stagnant pooling and trash that could act as potential water-holding containers (*personal observation*).

Adult Mosquito Sampling

Adult female ATM sampling was conducted in August and September when mosquito biting activity peaks in UP (Leisnham et al., *unpub. data*). A Biogents BG-Sentinel (BGS) trap (Biogents, Regensburg, Germany) was positioned at each of 18 sites located in resident yards across University Park, MD. The same sites were chosen as those in Johnson et al. 2018 to allow adult mosquito abundances to be directly compared between studies. We were unable to secure the exact yard for four of the 18 previous trapping sites of Johnson et al. 2018, in which case traps were located within two adjacent yards of the original sites. Each trap was positioned in a shaded area at least 2 m from any structures and powered by a 12-volt rechargeable battery. Consistent with Johnson et al. 2018, traps were baited with the propriety BG-Lure and without CO_2. We performed a total of eight 24-hour sampling events at all sites, avoiding days of expected heavy rain. All mosquitoes were identified to species and sexed whenever possible when processing the contents of the catch bag.

KAP Questionnaire

The KAP questionnaire was administered to all UP households (923) in August and September via a QR code and internet link on mailed. Semi-structured interviews of four University Park residents were conducted in March and April, 2021 to inform survey development by identifying critical themes identified by residents on mosquito-borne risks and control (Appendix 2) (Popping, 2015). The questionnaire was pretested to ensure the questions made sense to individuals within the target population. Written consent was requested from a household adult (>18 years old), and University of Maryland's Institutional Review Board (IRB#: 1712610-3) approval was obtained prior to questionnaire and interview administration.

Demographic information was collected on respondent age (18-35, 35-50, 50-65, >65), respondent gender (male, female, non-binary), household size (number of people), children (yes, no), number of outside pets, years residing in UP, home ownership (rent, own), household income (<$100,000, $100,000 - $200,000, >$200,000), and respondent education (bachelor's degree or less, graduate or professional degree). All demographic questions except the number of years residing in UP required respondents to select answers from a list. Some questions allowed for respondents to enter a non-listed answer in a text box. Data on gender, children, household income, and education were collected as continuous data or a larger number of categories but were collapsed into the categories described above to reflect natural breakpoints and give sufficient respondent numbers for statistical analyses. The questionnaire also collected data on household addresses to pair KAP questionnaire data with household yard survey data.

The next section of the questionnaire assessed relationships of households to their environment. Respondents were asked how much time they spent outdoors (<1 hour, 1-2 hours, 2-4 hours, 4-6 hours, 6-8 hours, >8 hours / week), what activities they do in their yard (play with or supervise children, landscaping, gardening, exercise, sitting in an outdoor space, home improvement, other), and what outdoor activities they do elsewhere (none, birding, hiking, hunting, fishing, kayaking/canoeing or other water sports, camping or backpacking, outdoor focused travel (such as visiting National Parks), other). Time spent outdoors was recoded as a continuous variable by assigning the midpoint of each category, rounded to the nearest whole number. For the final category of 8 hours or greater, it was assumed no residents spent more than 10 hours outside per week, based on results of interviews (Appendix 2). Numbers of yard activities and numbers of outdoor activities elsewhere selected were both summed. Because attitudes toward GATs in UP's GATP are expected to be shaped by neighborhood social interactions, we also asked respondents to report how frequently they interacted with their neighbors (daily, weekly, >weekly). Last, respondents were asked to indicate where they encountered the most mosquitoes in UP from a list of locations.

Respondent's mosquito knowledge was assessed based on answers to questions about: larval mosquito development (where mosquitoes develop and grow), species identification (most common biting mosquito species in UP), and identification of mosquito-borne disease (at least one disease they could be infected with from local mosquitoes). All questions required a custom text entry response and were hand-coded as correct or incorrect. Responses that indicated mosquitoes developed and grew in or near water, name *ATM* (by its species or common name) as the most common pest mosquito in the area, and that WNV or Eastern Equine Encephalitis were diseases that could be contracted from local mosquitoes were coded as correct. Correct answers scored 1 point and respondents were assigned an overall knowledge score from 0-3 points by summing all points.

Respondent attitudes were assessed across several aspects of mosquito-related risks and management. Respondents received a mosquito concern score from 2-10 points that was the sum of two scores from 1-5 on their concerns about mosquito nuisances and diseases, respectively. For each score, 1 point corresponded to least concern and 5 points to most concern. Respondents received a GATP attitude score from 2-10 points that was the sum of two scores from 1-5 points on their perceived effectiveness and favorability of UP's GATP, with 1 point corresponding to lowest effectiveness and favorability and 5 points corresponding highest effectiveness and favorability. The questionnaire defined effectiveness as the ability of the program to control mosquitoes and defined favorability as the efficiency, communication, and friendliness of the program personnel (i.e., block captains, city education interns). The last question focused on attitudes to mosquito management asked respondents to select reasons why it was important to control mosquitoes from a list, which was summed to give an index of mosquito control motivation.

Respondents were asked up to six questions related to their mosquito control practices. The first three questions focused on GAT deployment: GAT deployment in 2021 (yes, no), GAT deployment in previous seasons (yes, no), and which seasons (2016 (pilot program)-2020) a GAT was deployed if it was previously deployed. From these questions we categorized two types of household GAT dropout: households who purchased GATs in 2017 but did not deploy them in 2021 and households that reported deploying GATs in any year between 2016 and 2020 who did not deploy GATs in 2021. Likewise, we also categorized two types of household GAT adoption: those that had adopted GATs in any year since 2017, but did not deploy in 2021, and those that had not deployed them in 2017 but deployed them in 2021. Respondents were also asked three questions about other mosquito control practices: if they had ever used chemical pesticides (yes, no), if they had ever used BTI (yes, no, sometimes, I don't know), and if they remove artificial water-holding containers in their yards (yes, no, sometimes). Emptying water-holding containers, commonly called "source reduction", and the use of *Bacillus thuringiensis israelensis* (BTI) in habitats that cannot be easily emptied (e.g., rain barrels, ponds) are considered complimentary to GATs and required for the GATs to function optimally (Biogents, 2021; Johnson et al., 2017).

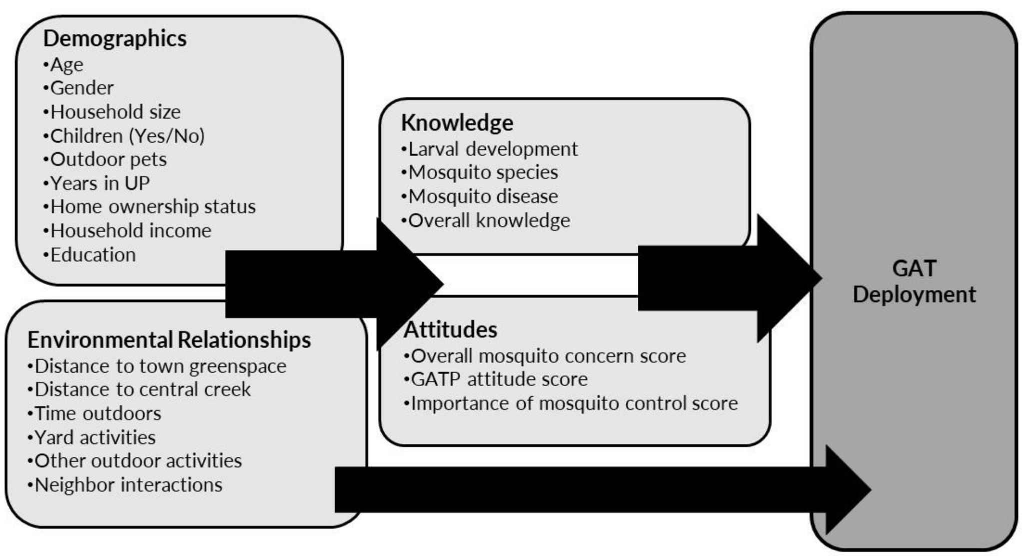

Figure 3. Predicted relationships of social and environmental variables with household GAT deployment.

Assessing GAT Coverage

Consistent with Johnson et al. 2018, we calculated the percentage of household yards with GATs within 75m of each BGS trap to test for the effect of GAT coverage on adult female host-seeking ATM abundance. Numerous studies have suggested that ATM have a typical dispersal range of only 10 m and rarely disperse further than 100 m in residential areas, making a 75 m radius around each trap a good buffer area for measuring local GAT impacts (Bellini et al., 2010; Marini et al., 2019; Vavassori et al., 2019). We determined if a particular household deployed GATs based on both the yard survey and KAP questionnaire data. A total of 70 households had their yards surveyed and responded to whether or not they deployed GATs in the KAP questionnaire, allowing us to assess the reliability of self-reported household GAT deployment. There was a highly significant positive association between self-reported and investigator-confirmed GAT deployment (Fisher Exact test: $p<0.0001$), with 75% (22/29) of households that self-reported deploying GATs having them confirmed by investigators and 97.6% (40/41) of households that self-reported not deploying GATs having them confirmed as not being in their yard.

For each adult trapping site, we defined spatially relevant GAT coverage as the total number of households deploying GATs divided by the total number of sampled households within its 75 m radius area (or "adult trapping area"). Sampling effort within each adult trapping area varied widely across the 18 total areas (range: 22.2-85.7% households sampled); thus, we weighted GAT coverage for sampling effort by multiplying the resulting GAT coverage by the proportion of visited households within the trapping area (Table 1).

Table 1. Number of total households, number of visited households, and GAT coverage in each 75 m adult mosquito trapping area.

Trapping Area Buffer	Total Households	Visited Households	Visited Households Deploying GATs	GAT Coverage	Weighted GAT Coverage
1	17	4	2	0.5	0.12
2	15	7	2	0.29	0.13
3	15	11	3	0.27	0.2
4	18	12	3	0.25	0.17
5	21	10	4	0.4	0.19
6	19	10	2	0.2	0.11
7	18	4	1	0.25	0.06
8	16	13	3	0.23	0.19
9	19	12	0	0	0
10	18	12	2	0.17	0.11
11	9	3	1	0.33	0.11
12	14	12	2	0.17	0.14
13	16	10	5	0.5	0.31
14	16	10	3	0.3	0.19
15	7	4	2	0.5	0.29
16	12	8	1	0.13	0.08
17	14	6	3	0.5	0.21
18	18	5	0	0	0

Data Analyses

Differences in adult female ATM abundance with weighted household GAT coverage and relationships between respondent demographics, environment, knowledge, attitudes, and practices and GAT deployment were analyzed using linear mixed effects models and generalized linear models, respectively, in R Studio using the stats and lem4 packages (Version 4.1.3; R Core Team, 2022; Douglas Bates, Martin Maechler, Ben Bolker, Steve Walker, 2015). For each analysis, the appropriate error structure was chosen. Adult female ATM abundance followed a Poisson distribution and the model testing for differences with weighted GAT coverage included female ATM abundance, if a trapping area bordered (intersecting or within 5 m) greenspace (yes/no), and if a trapping area bordered (intersecting or within 5 m) the town creek (yes/no) as fixed effects, and collection date and rainfall (yes/no) as random effects. Bordering greenspace or the creek was defined as the 75 m trap buffer coming within five meters of the edge of the town greenspace or central creek (Fig. 3.). Household GAT deployment, larval development knowledge, mosquito species knowledge, and mosquito disease knowledge followed binomial distributions. All other knowledge and attitude responses followed gaussian distributions.

Univariate tests were used to screen demographics, environment, knowledge, and attitude variables as potential predictors of household GAT deployment, and demographic and environment variables as potential predictors of knowledge and attitudes using a stepwise approach (Fig. 2). Variables with a screening significance of $p \leq 0.2500$ were included in multivariate models with all two-way interactions. Final multivariate models were selected using backward stepwise selection. For each initial multivariate model, all two-way interactions were removed, and the model was checked for a loss of fit ($\Delta AIC > 2$), but none was detected. Least significant variables were then removed in sequential order until a loss of fit was detected. Multicollinearity was tested for all multivariable models using Variance Inflation Characteristics (VIF) from the R "car" package, with a VIF above 5 for variable indicating a problem, but no VIF above 3.5 was detected (John Fox and Sanford Weisberg, 2019). Because GAT effectiveness partly depends on source reduction (Biogents, 2021; Johnson et al., 2017), we tested if household GAT deployment and GAT correctness were related to numbers of water-holding and numbers of larva-positive containers, using a Poisson error distribution. All linear models used experimentwise $\alpha=0.05$.

Chapter 3: Results

GAT Coverage, Larval Habitat, and ATM Abundance

Only 24.9% (n = 130/523) of surveyed households deployed GATs representing a reduction from 46.0% (439/954) of households recorded to have purchased GATs in 2017 (Johnson et al. 2018). Household GAT coverage did not exceed 50% (3/6; range: 0% - 50%) in any area, well below the 80% threshold thought needed to reduce area wide adult *Aedes* (Johnson et al., 2017; Johnson et al., 2018). Nevertheless, there was a significant negative relationship between household GAT coverage and adult female ATM when weighting GAT coverage for sampling effort (coefficient (coef) = -1.6477; χ^2= 12.36; $p = 0.0004$, Fig. 4). Areas bordering town green space (coef = -0.5889; χ^2 = 23.99; $p < 0.0001$, Fig 5A) and areas bordering the central creek (coef = 0.5879; χ^2 = 24.26; $p < 0.0001$, Fig. 5B) had lower and higher adult female ATM abundances, respectively, indicating the importance of landscape on ATM abundances.

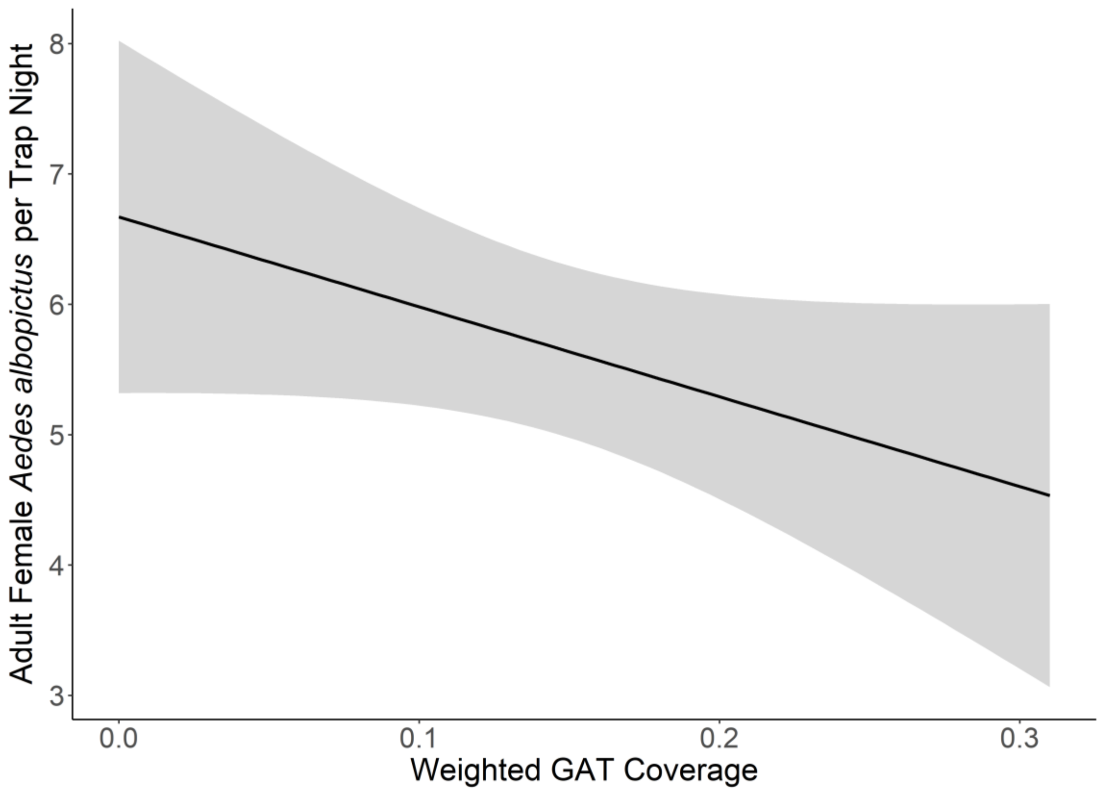

Figure 4. Mean (±1 SE) adult female *Aedes albopictus* per trap night by GAT coverage when weighted for sampling effort.

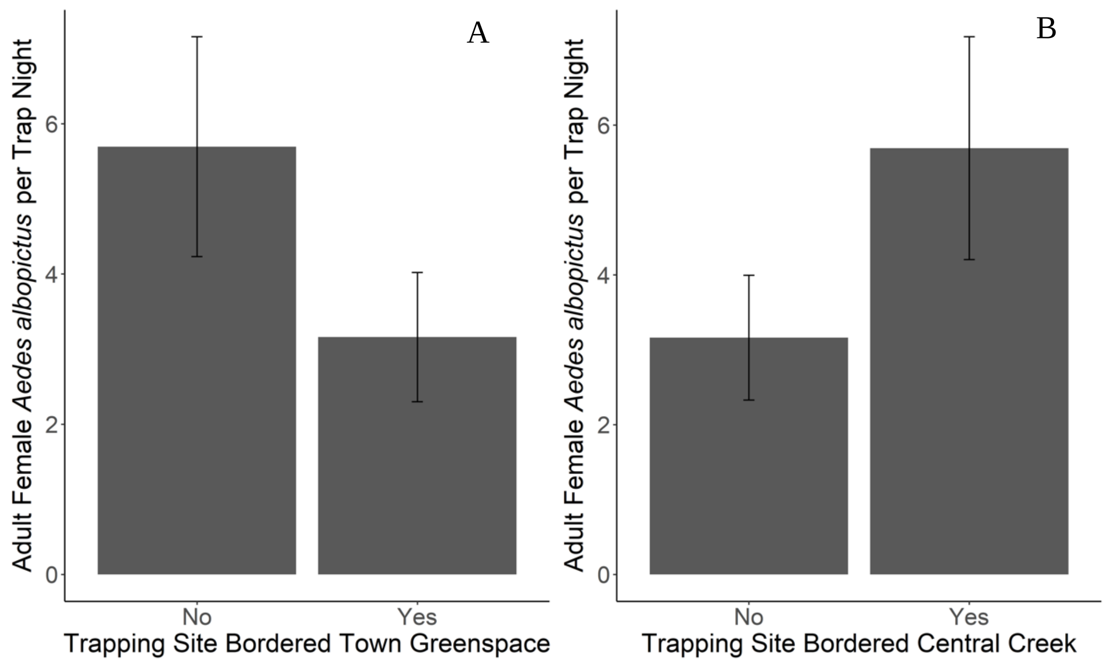

Figure 5. Mean (±1 SE) adult female *Aedes albopictus* per trap night by proximity to town greenspace (A) and the central creek (B).

There was an association of household GAT deployment with total numbers of water-holding containers (coef = - 0.2206; χ^2 = 5.12; p = 0.0237). Households that deployed GATs had 0.50 (+/-0.1890) fewer total water-holding containers than households that did not deploy GATs. There was no significant relationship of household GAT deployment with the numbers of larva-positive containers (coef = - 0.1737; χ^2 = 0.45617; p = 0.4994), nor was there a difference in numbers of total (coef = 0.02441; χ^2 = 1.6801; p = 0.1949) or larva-positive (coef = - 0.1237; χ^2 = 3.7546; p = 0.05266) containers between households with different GAT scores (score range: 1 – 8).

Of the 183 respondents in the KAP questionnaire, 62% (115/183) indicated that they deployed a GAT for at least one summer between the start of the pilot program in 2016 and the summer before this study in 2020. During this study, 38 of the 66 KAP survey respondents who indicated they deployed GATs purchased a GAT later than 2017 and still deployed it in 2021, making the GAT adoption rate from 2017 to 2021 57.5%. Most of this adoption occurred in 2018, when 33 respondents reported adopting new GATs, followed by 25 and 8 new GATs being adopted in 2019 and 2020, respectively. Of the 115 KAP respondents who indicated they deployed GATs at some point, 24.3% (28/115) did so for only a single summer. The majority, 26.08%, (30/115) did so for two summers and 23.4% did so for three summers (27/115). Only 8.6% (10/115) deployed their GAT for four summers and 17.4% (20/115) did so for all five summers leading up to our 2021 study. Of the 115 KAP respondents that reported previous GAT deployment at any time from 2016 - 2020, 53 stopped deploying GATs either in years prior to 2021 or in 2021, amounting to a 46.1% dropout rate. Although residents in the yard survey were not asked whether they deployed a GAT previously, University Park kept town records of everyone who purchased a GAT from 2016 – 2019, allowing us to determine that 30.5% (18/59) of GATs documented during the yard surveys were newly adopted since 2019. It should be noted that yard surveys and KAP surveys were conducted separately, and thus represent different datasets. However, when measuring overall GAT deployment, we combined the two data sources.

A total of 100 KAP questionnaire respondents provided a primary reason not to deploy GATs. The three most common reasons to not deploy a GAT were “I do not think it works” (32/100), "I do not want to maintain it" (25/100), and "I do not know what it is" (16/100).

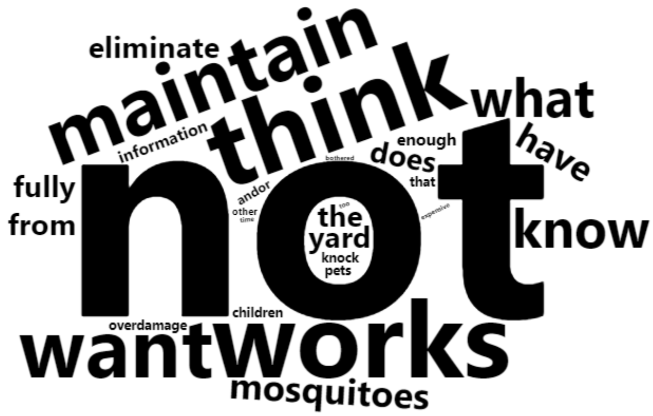

Figure 6. Reasons reported by residents for GAT dropout as a word cloud where larger words represent more frequent response occurrences.

KAP Predictors of GAT Deployment

Household GAT deployment varied with household income, time outdoors, larval development knowledge, mosquito species knowledge, mosquito disease knowledge, overall knowledge, and GATP attitude in univariate tests, although several other variables passed screening and were also included in multivariate models (Table 2). In the final multivariate model, household income (coefs: Up to \$100,000 = 1.3859, \$200,000 or greater = 1.4893; χ^2= 6.43036; p= 0.0402), household distance to green space (coef = -0.0031; χ^2= 4.39888; p< 0.03596), respondent time outdoors (coef = 0.2294; χ^2= 6.13857, p= 0.01323), respondent mosquito species knowledge (coef: correct knowledge = 1.6462; χ^2= 10.61350; p= 0.00112), and respondent GATP attitude (coef = 0.5453; χ^2= 22.19791; p<0.0001) significantly predicted household GAT deployment. Households with middle incomes and further from town greenspace, and respondents who spent less time outdoors, had no mosquito species knowledge, and had less favorable GATP attitudes were less likely to deploy GATs (Fig. 7).

Table 2. Linear model results testing resident demographics, environment, knowledge, and attitudes on household GAT deployment. Factors with p<0.2500 were included in multivariate models. Reference categories for categorical variables listed in parentheses after variable name.

*Larval knowledge was incorrect in only 16 respondents, resulting in overfit of the model for this variable, which was not included in final multivariate models.

Predictor	**Odds Ratio**	**95% CI**	χ^2	**df**	***p***
Demographics					
Age (18 - 35)			4.52	3	0.2104
35 - 50	2.8273	1.0163, 8.7872			
50 - 65	1.5833	0.5462, 5.0416			
65+	1.9904	0.7161, 6.1603			
Gender (Female)			0.04	1	0.8367
Male	0.9377	0.5063, 1.7261			
Household size	0.8704	0.6766, 1.1074	1.25	1	0.2618
Children (No)			2.02	1	0.1552
Yes	0.6274	0.3228, 1.1905			
Outdoor pets	1.1252	0.7784, 1.6191	0.4	1	0.5239
Years in UP	1.0015	0.9775, 1.0258	0.01	1	0.8964
Home ownership status (Own)			1.17	1	0.2779
Rent	0.4349	.06351, 1.8641			
Household Income (< $100,000)			6.44	2	0.0399
$100,000 - $200,000	0.5151	0.1466, 1.7070			
>$200,000	1.7046	0.6898, 4.4365			
Education (Bachelor's degree or less)			0.09	1	0.7531
Graduate/professional degree	1.13352	0.5241, 2.5432			
Environmental					
Distance to town greenspace	0.9985	0.9966, 1.0003	2.43	1	0.1186
Distance to central creek	0.9993	0.9974, 1.0012	0.39	1	0.5281
Time Outdoors	1.1425	1.0156, 1.2902	4.93	1	0.0263
Yard activities	1.1823	0.9946, 1.4150	3.6	1	0.0576
Other outdoor activities	1.1108	0.9576, 1.2893	1.93	1	0.1641
Neighbor interactions (Daily)			1.91	2	0.1673
Weekly	0.7327	0.3830, 1.3951			

Monthly or less	0.3376	0.0889, 1.0465			
Knowledge					
Larval development (No Knowledge)			15	1	0.028
Correct Knowledge	NA*	NA			
Mosquito species (No Knowledge)			27.21	1	0.0001
Correct Knowledge	6.0839	2.9824, 13.3474			
Mosquito disease (No Knowledge)			4.82	1	0.028
Correct Knowledge	2.0692	1.0801, 4.0932			
Overall knowledge			26.75	1	<0.0001
Attitude					
Mosquito concern	1.1003	0.1142, 0.8268	1.89	1	0.1681
GATP attitude	1.6822	1.4012, 2.0757	41.1	1	<0.0001
Mosquito control motivation	1.1975	0.9761, 1.483	2.98	1	0.0844

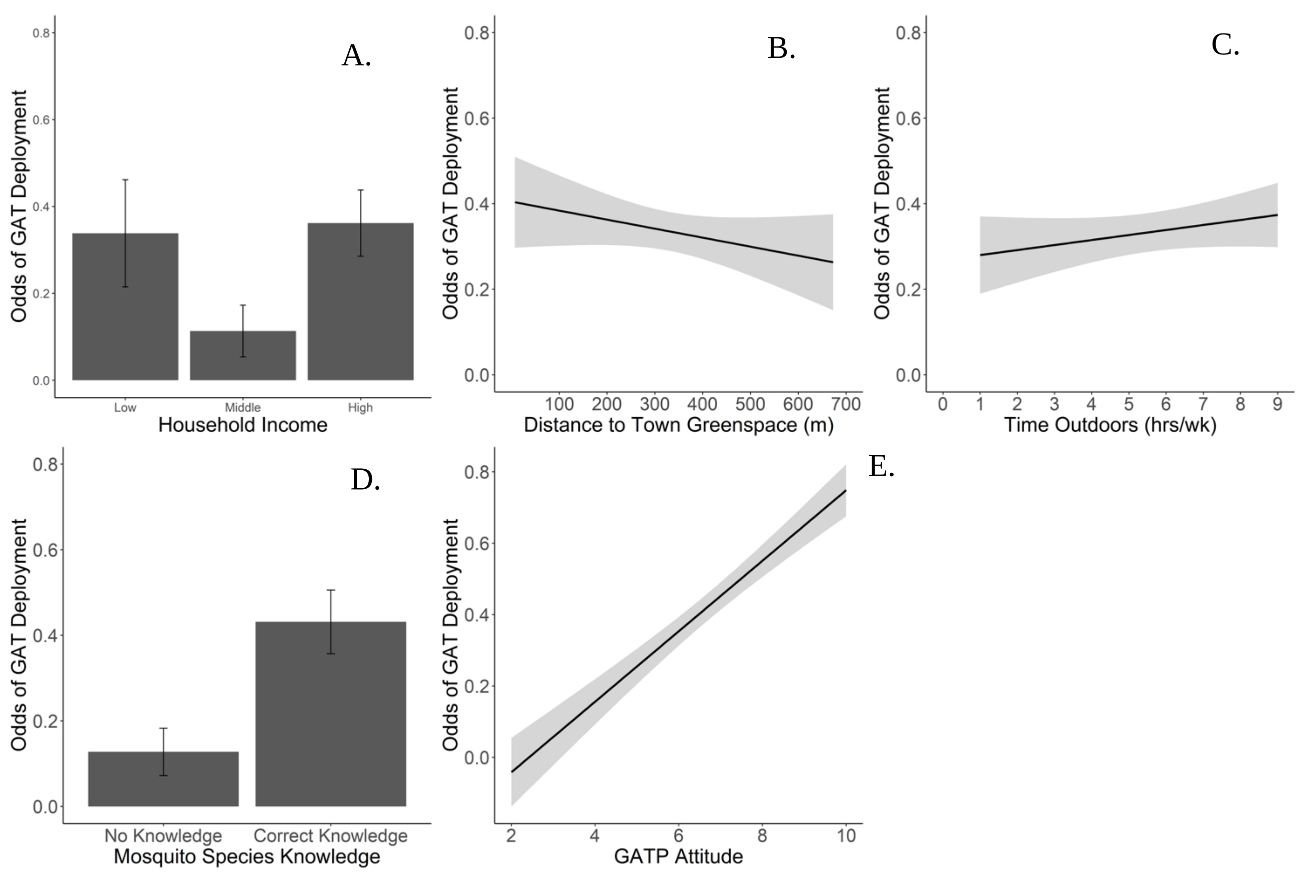

Figure 7. Mean (±1 SE) likelihood of household GAT deployment by annual household income (A), household distance to greenspace (B), respondent time outdoors (C), respondent mosquito species knowledge (D), and respondent GATP attitude (E). Low, middle, and high household incomes were <$100,000, $100,000-200,000, and >$200,000 per year, respectively. Respondents were considered to have mosquito species knowledge if they could name *ATM* as the most common pest mosquito in their area. Respondents received a GATP attitude score from 2-10 points that was the sum of two scores from 1-5 points on their perceived effectiveness and favorability of UP's GATP, with 1 point corresponding to lowest effectiveness and favorability and 5 points corresponding highest effectiveness and favorability. Different letters indicate statistical significance between treatment levels when there is more than two ($p < 0.05$).

Demographic and Environmental Predictors of Knowledge and Attitudes

Two knowledge and attitude variables that predicted household GAT were predicted by demographic and environmental variables: mosquito species knowledge and GATP attitude. Mosquito species knowledge varied only with home ownership status in univariate tests (Table 3), which also emerged as significant in multivariate models after other variables that passed screening were added (coef = -2.8245; χ^2= 7.65, p = 0.0057). Respondents who rented their home were less likely to name ATM as the most common pest mosquito in the area than renters (Fig. 8A). In univariate tests, GATP attitude varied among respondents from households with children, households with varying lengths of residence in UP, and the numbers of yard activities reported by the respondent (Table 4). These variables retained their significance in multivariate models after other variables that passed screening were added (Table 4), with respondents from households with children (coef = -0.84452; χ^2 = 5.1655, p = 0.0230; Fig. 8B) and that had lived in UP for fewer years (coef = 0.0366; χ^2= 8.2678 , p = 0.0040; Fig. 8C), did fewer yard activities (coef = 0.2430; χ^2 = 5.8998 , p = 0.0151; Fig. 8D) having less favorable GATP attitudes.

Table 3. Linear model results testing resident demographics and environment variables on respondent mosquito species knowledge. For this binomial regression model, estimate values are exponentiated coefficients to show odds ratios. Reference categories for categorical variables listed in parentheses after variable name.

Predictor	Mosquito species knowledge				
	Odds Ratio	**95% CI**	χ^2	**df**	***p***
Demographics					
Age (18 -35)			6.08	3	0.1076
35 - 50	2.475	0.9457, 6.7250			
50 - 65	2.2894	0.8628, 6.3007			
65+	3.3529	1.2724, 9.2204			
Gender (Female)			0.26	2	0.8774
Male	1.1557	0.6285, 2.1399			
Household size	0.8113	0.6374, 1.0283	2.98	1	0.0838
Children (No)			2.23	1	0.1347
Yes	0.6206	0.3315, 1.16024			
Outdoor pets	1.139	0.7893, 1.6877	0.47	1	0.4923
Years in UP	1.0222	0.9968, 1.0498	2.91	1	0.0876
Ownership status (Own)			10.9	1	0.0009
Rent	0.0665	1.3727, 2.5995			
Household Income (Up to $100,000)			2.5	2	0.2858
$100,000 - $200,000	1.0476	0.3502, 3.1311			
$200,000 or greater	1.8447	0.7202, 4.6778			

Education (Bachelor's degree or less)			0.3	1	0.5809
Graduate/professional degree	0.8	0.3493 , 1.7474			
Environmental					
Distance to town greenspace	0.9988	0.9970 , 1.0006	1.49	1	0.2221
Distance to central creek	0.9997	0.9979 , 1.0015	0.07	1	0.7795
Time Outdoors	1.0783	0.9578 , 1.2158	1.55	1	0.2122
Yard activities	1.1742	0.9912 , 1.3966	3.45	1	0.0631
Other outdoor activities	1	0.8625 , 1.1638	0	1	0.9993
Neighbor interactions (Daily)			0.64	2	0.4209
Weekly	0.8591	0.4357 , 1.6823			
Monthly or less	0.4791	0.1653 , 1.3801			

Table 4. Linear model results testing resident demographics and environment variables on GATP attitude. Estimate values are linear regression coefficients. Reference categories for categorical variables listed in parentheses after variable name.

Predictor	**GATP Attitude**				
	Estimate	**95% CI**	χ^2	**df**	p
Demographics					
Age (18 -35)			7.28	3	0.0633
35 - 50	0.6754	-0.4844 ,1.8354			
50 - 65	0.7458	-0.4333, 1.9249			
65+	1.4928	0.3429, 2.6427			
Gender (Female)			3.91	2	0.1413
Male	-0.5712	1.3023, 0.1597			

Household size	-0.2419	-0.5257, 0.04174	2.79	1	0.0946
Children (No)			4.64	1	0.0311
Yes	-0.8236	1.5726, 0.0746			
Outdoor pets	0.1379	-0.3019, 0.5777	0.37	1	0.5388
Years in UP	0.0424	0.0185, 0.0664	12.07	1	0.0005
Ownership status (Own)			0.78	1	0.3755
Rent	-0.6865	-2.2050, 0.8320			
Household Income (Up to $100,000)			1.95	2	0.377
$100,000 - $200,000	-0.6585	-1.9549, 0.6378			
$200,000 or greater	0.07128	-1.0115, 1.1540			
Education (Bachelor's degree or less)			0	1	0.9437
Graduate/professional degree	-0.0309	-0.8893, 0.8275			
Environmental					
Distance to town greenspace	0.0009	-0.0011, 0.0031	0.83	1	0.36
Distance to central creek	0.0004	-0.0017, 0.0026	0.14	1	0.7018
Time Outdoors	-0.0257	-0.1433, 0.0918	0.18	1	0.6675
Yard activities	0.379	0.1830, 0.5751	14.35	1	0.0001
Other outdoor activities	0.1255	-0.0534, 0.3044	1.88	1	0.1693
Neighbor interactions (Daily)			0.12	2	0.7321
Weekly	0.1157	0.4357, 1.6823			
Monthly or less	-1.125	0.1653, 1.3801			

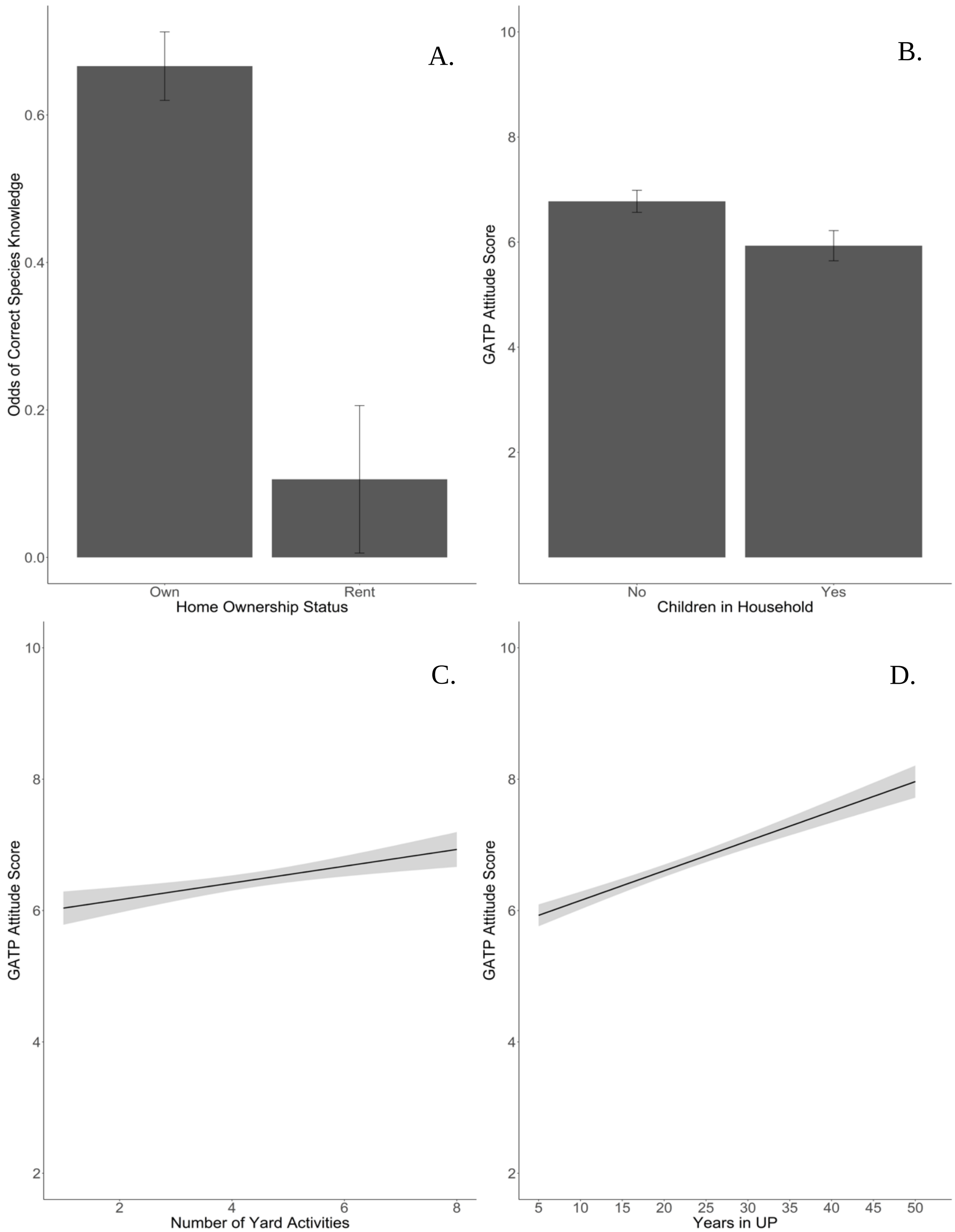

Figure 8. Mean (±1 SE) mosquito species knowledge score by respondent home ownership status (A), and GATP attitude score by household children (B), respondent numbers of yard activities (C), and respondent years in UP (D). Respondents were

considered to have mosquito species knowledge if they could name *Ae. albopictus* as the most common pest mosquito in their area. Respondents received a GATP attitude score from 2-10 points that was the sum of two scores from 1-5 points on their perceived effectiveness and favorability of UP's GATP, with 1 point corresponding to lowest effectiveness and favorability and 5 points corresponding highest effectiveness and favorability.

Chapter 4: Discussion

The invasive Asian Tiger Mosquito demands area-wide, community-involved control to reduce arboviral and nuisance risk (Abramides et al., 2013; Fonseca et al., 2013; Johnson et al., 2017; B. J. Johnson et al., 2018). Johnson et al. showed that citizen-led GAT deployment successfully lowered ATM abundance in 2018, but no study has tested the sustained success of a citizen-led program nor the socioecological predictors of lethal ovitrap deployment. Our analysis shows that higher GAT coverage negatively predicated ATM abundance, even below the previously documented 80% coverage threshold for GAT efficacy (Johnson et al., 2017). This thesis also identifies several clear predictors of GAT deployment and shows that landscape variables still predict ATM abundance, even when a citizen-led intervention strategy is in place. Overall, our results indicated sustained success of bottom-up, citizen-led mosquito control and the socioecological predictors of a key component of that success, GAT deployment.

GAT coverage in 2021 reflected a 57.5% adoption rate of household GATs from 2017 – 2021, although most of the adoption occurred in two years directly following the first full run of the GATP, 2018 and 2019. GAT adoption in the year immediately before this study, 2020, was likely lower due to the COVID-19 pandemic hampering the usual efforts of volunteers who run educational and logistical efforts in UP (E. Wells, Personal Interview, March 31, 2021). Nevertheless, the adoption rate shown in the years prior to 2020 indicates relatively healthy growth and interest in the GATP that could keep it viable for years to come.

GAT coverage negatively predicted ATM abundance in weighted coverage estimates. The highest GAT coverage measured in our weighted model was 29%, substantially lower than the 80% threshold that Johnson et al showed to be effective at reducing ATM abundance in their previous study in University Park. The reductions we measured in ATM abundance were lower than the reductions seen by Johnson et al., with Johnson et al. observing a 66% reduction in ATM abundance on blocks at or above the 80% coverage threshold while our model indicated only 28% reduction in ATM abundance from the lowest coverage (0%) to the highest coverage (29%) adult trapping areas. Our mean ATM per trap night was 12.6 (+/- 3.3) adult females and 23.3 (+/- 4.8) total adults across all traps, and did not exceed 30 for any individual trap. In Baltimore City, another ATM-infested community, 70.57 ATM (total adults) per trap night has been documented in some high infestation areas (Becker et al., 2014). Therefore, additional research may be needed to determine if GATs can be effective below the 80% coverage threshold even in areas of higher mosquito abundance than UP. In the Worobey et al. study finding that ATM infestation can impact children playing outdoors, the treated town had 6.86 average ATM per trap night versus 12.0 ATM per trap night in the treated town (2013). Since UP's average ATM per trap night falls above the average for the untreated town in Worobey et al (2013), there may still be some negative impacts on well-being, but areas with higher GAT coverage may experience some benefit over areas with low to no GAT coverage.

GAT deployers had significantly fewer water-holding containers on their property than non-deployers, but there was no significant difference in numbers of larva-positive containers. This may indicate that GAT deployers are aware of the need to empty containers but either do not do so regularly enough to prevent larval growth or are not aware of all possible containers that could harbor mosquito larva. This gap in applying knowledge from education (which has occurred for over a decade in University Park) would be consistent with previous studies showing that intervention with education materials did not consistently improve source reduction practices (Bodner et al., 2016). However, other studies (e.g, Fonseca et al., 2013; Bartlett-Healy, et al., 2011) have shown that education does increase sources reduction. For GATs to function optimally, UP needs to explore ways in which this gap in applying knowledge about mosquito ecology to sources reduction practices could be closed. More educational focus on the timeline of the ATM lifecycle could potentially address these issues since basic mosquito knowledge in UP is already high (average knowledge score of 2.19/3) from past education efforts.

ATM abundance was also negatively predicted by proximity to greenspace and positively predicted by proximity to the central creek in UP. This is especially interesting because households further from greenspace were less likely to deploy GATs, even though being further away from greenspace predicted higher numbers of biting ATM. It is possible that residents perceived greenspace as a potential source of ATM habitat, resulting in higher rates of GAT deployment. However, this perception would be contrary to our finding that proximity to greenspace predicted lower ATM abundance in UP. While general vegetation cover can be an important predictor of ATM abundance, well-managed greenspace is unlikely to be a source of container habitats, as containers that may hold water such as trash, flowerpots, or old tires are unlikely to be present, and the greenspace in UP was well-maintained (Little et al., 2017; Yang et al., 2019; *personal observation*). However, past studies have shown that residents may associate mosquitoes with vegetation, even when their primary source is yard habitats or abandoned lots (Biehler et al., 2019; Little et al., 2017). While the creek itself does not provide breeding habitat for container breeding ATM, it may contain trash that acts as breeding containers or provide a cool resting place for adult ATM during peak summer, contributing to its positive association with ATM abundance.

The likelihood of GAT deployment was negatively predicted by several key socioecological variables. Households with middle incomes, households further from greenspace, and respondents who spent less time outdoors were all more likely to deploy GATs. Two knowledge and attitude variables also predicted GAT deployment: respondents who could not name ATM and respondents who had less positive GATP attitude were less likely to deploy GATs. Correctly naming ATM was positively predicted by home ownership and GATP attitude was positively predicted by a respondent's number of yard activities and the number of years the respondent had lived in UP. Having children in a household negatively predicted GATP attitude. Our findings on proximity to greenspace, time spent outdoors, mosquito species knowledge, and GATP attitude mirrored known relationships previously explored in the mosquito and environmental management literature. Our findings on income were inconsistent with some similar studies on mosquito control (e.g. Dowling et al., 2013; Juarez et al., 2021).

First and foremost, it should be noted that University Park has a median income more than double that of the Unity States overall and little income disparity within the town (U.S. Census, 2020). Still, the nonlinear trend our model predicted for income is worth examining further and noting for potential implementation of future programs. Households in UP's middle income bracket ($100,000 - $200,000) being less likely to deploy GATs could be due to these households being primarily busy, working families in the child-rearing life stage. Therefore, it is possible that neighborhoods that are primarily families with two working adults may not be good candidates for community-led mosquito control or may require more targeted outreach efforts. Neighborhoods of more mixed income levels that include retirees and/or households with only one working adult may have more success. Dowling et al. and Juarez et al., both found more linear trends for income, even though this trend reversed direction between years in the Juarez study (2013; 2021). The Dowling study included populations with a more evenly distributed range of incomes than exists in University Park and the Juarez study only differentiated between low and middle income groups, with the middle income group only ranging up to $40,000 per year. Further research in other communities is needed to better understand motivating factors for this trend, particularly in communities with wider income ranges than are observed in UP.

Respondents that spend more time outdoors and lived closer to greenspace being more likely to deploy GATs is consistent with several studies that have shown that outdoor recreation and a personal relationship to the environment facilitate stewardship participation. Andrejewski et al. searched for a causal link between time spent outdoors, connection to nature, and environmental stewardship in children, and found that while stewardship is directly facilitated by time spent outdoors, connection with nature had a mediating effect that explained more of the variance in their model (2010). This can be similarly true for factors mediating environmental stewardship in adults (Hunter, 2011, Ryan, 2000; Thapa, 2013).

Hunter looked specifically at environmental stewardship interest after a disturbance, using tree loss from Emerald Ash Borer in Ann Arbor, Michigan as a case study system. In this study, some residents had experienced a noticeable change to their outdoor environment with street trees that had died off either directly in front of their property or nearby within their neighborhood (Hunter, 2011). Both level of enjoyment in outdoor activities and overall time spent outdoors contributed to a survey respondent's likelihood of believing that trees contributed to overall well-being. Those who had lost a tree directly were most likely to be interested in a community tree-planting effort (Hunter, 2011). This type of visible environmental disturbance can also be experienced by those who have resided in a neighborhood long enough to remember their experience of the outdoors before and after the invasion of ATM, which could motivate participation in a control program (Biehler, et al., 2019).

Time outdoors increasing GAT deployment likelihood could indicate that people who spent more time outside may have a greater desire to improve their experience of the outdoors by reducing mosquito populations. Alternatively, those who spend more time outside might be more easily reached by educational efforts, since UP uses methods such as outdoor signage and sending volunteers door to door in addition to the information provided in the town newsletter and on the town website (E. Wells, personal interview, March 31, 2021). Households that already spend more time outside may find it easier to deploy and maintain a GAT than households who do not spend much time outdoors. Households closer to greenspace were also more likely to deploy a GAT. This may indicate that households think they have more mosquitoes because they are closer to town greenspace or that households with more access to greenspace and nature may be more interested in improving the outdoor environment within their neighborhoods. This would be consistent with previous studies on relationships with the natural environment and how those relationships facilitate participation in environmental programs (Hunter, 2011; Schwass et al., 2021).

Knowledge has consistently been shown to play a role in success of resident-led mosquito management. Dowling et al. (2013) showed increased source reduction among residents who understood larval mosquito development and Fonseca et al. (2013) found decreases in urban ATM abundance after education through print outreach and school programs. However, Bodner et al. (2016) found that intervention with print education materials led to intervention households showing less mosquito-borne disease concern than control households, indicating that knowledge may not consistently translate into action. Correct mosquito species knowledge increased likelihood of GAT deployment, which shows the importance of educating residents about what a community-led intervention is trying to achieve and how it works. GATP attitude essentially measured how well residents believe the GATPs worked to control mosquitoes. Since GATP attitude significantly predicted GAT deployment and deployment was associated with reduced ATM abundances, believing the GATP worked well resulted in it actually working better. Ensuring belief in the efficacy of an intervention to boost participation is a tactic that could be broadly applied to various community-led mosquito control programs and other types of community-led environmental management.

Correct species knowledge was positively predicted by whether or not residents owned their homes. According to our survey data, renters had only lived in UP an average of two years. Therefore, it is possible that people who have lived in UP longer have been exposed to previous education efforts within UP, whereas renters who have only been there a year or two may not have been successfully reached. It is worth noting that UP had a robust source reduction campaign that included education efforts prior to the adoption of GATs, which may impact this trend in this particular study. GATP Attitude was positively predicted by number of yard activities and years in UP and negatively predicted by whether or not a household had children. It is possible that longer term residents and those who participate in yard activities are more likely to think the program works and is well-run because they have had more contact with UP's door to door outreach efforts.

Households with children may be more likely to desire a method of mosquito control they view as more reliable, such as allowing the county to spray the neighborhood or hiring their own private company to spray their yard, to reduce their children's exposure to mosquito bites (S. Keveney, personal interview, April 21, 2021). People with children may also have a harder time deploying GATs due to having less free time or struggling to keep their children from dismantling the trap, which was cited by four KAP survey respondents as a reason not to deploy a

GAT. Targeting households with children with additional education to inform them of how and why the GATP works well for ATM control may help to close this gap and increase their participation.

Understanding the socioecological variables of GAT deployment primarily serves to inform targeted outreach of how gaps in participation can be reduced to improve overall GATP efficacy and potentially inform where to begin and concentrate outreach efforts when starting similar citizen-led mosquito control programs. Renters, households in the middle-income bracket, people with children, people who spend more time indoors, and people who live further from greenspace could all potentially benefit from additional outreach efforts to improve University Park's GATP. While some of these groups could likely be targeted through a wider variety of educational materials emphasizing the need for robust community-participation, renters may prove especially hard to reach. Since renters live in the community for a shorter period of time and may not be as aware of townwide initiatives as homeowners, passing information to renters through landlords may help to increase their knowledge and participation. Due to the number of factors we found to predict GAT deployment, community-led programs could take a multifaceted approach to outreach efforts or choose to target a specific group to close a particular participation gap.

Even below an 80% threshold of GAT coverage, GATs may reduce ATM abundance, providing some protection against mosquito nuisance and mosquito-borne diseases even when higher rates of participation cannot be achieved (Barrera et al., 2014, 2017; Johnson et al., 2018; Juarez et al., 2021). Since this study did not specifically examine reduction in nuisance levels or disease risk, further research is needed to measure if reductions in nuisance and disease are significant when adult ATM is only reduced by ~28% or less. This study is the first to show evidence of GAT efficacy at substantially lower coverage rates than previously shown to be effective (Johnson et al., 2018) and builds on a body of literature that provides a multifaceted foundation for understanding the characteristics of households that participate community-led mosquito control. Finally, we believe that the KAP analysis framework coupled with on the ground sampling of intervention efficacy used here can be applied to other community-led environmental interventions to better understand motivations for and barriers to participation and to measure how participation is impacting the desired outcome.

Appendices

Appendix 1: GAT Assessment Criteria Field Data Sheet

Address:
Date Visited/Revisited (add R for revisited):

GAT Deployment (all Y/N)

Criteria	**Yes/No**	**Comments**
GAT positioned in shady area		
Dunks used		
GAT upright		
Netting intact		
Pieces properly connected		
Sticky card/killing agent used		
Grass used as bait		
At least 2 GATs deployed		

Other GAT setup (describe):

GAT Questions for Resident:

1. Is your GAT deployed continuously (always out in the same spot) throughout the whole mosquito season (June - September)? **Yes/No Notes:**

2. How often do you check/perform maintenance on your GAT?

3. Do you use BTI or a mosquito dunk in the water?

4. Do you use a killing agent (such as canola oil or insecticide) on the clear chamber?

Appendix 2: Semi Structured Interview Questions

Area 1: Mosquito Ecology and Control Measures

1. Where do you encounter the most mosquitoes within University Park? (your property, parks, walking down the street etc.) and why do you think this is?
2. What do you do (if anything) to control mosquitoes on your property?
3. Have these actions made a difference in your experience of/encounters with mosquitoes

Area 2: Perceptions and Knowledge

4. What motivates you to control mosquitoes/why do you think mosquito control is important? OR (if they do not engage in mosquito control) What do you think most of your neighbors do to control mosquitoes?

5. Please describe the University Park mosquito control program…

6. How much time do you spend outside and what activities do you do outdoors?

Area 3: Socioeconomics and Demographics

7. Please describe yourself (age, occupation, hobbies) and your family (size, routines, habits, etc.)...

Bibliography

Abílio, A. P., Abudasse, G., Kampango, A., Candrinho, B., Sitoi, S., Luciano, J., Tembisse, D., Sibindy, S., de Almeida, A. P. G., Garcia, G. A., David, M. R., Maciel-de-Freitas, R., & Gudo, E. S. (2018). Distribution and breeding sites of Aedes aegypti and Aedes albopictus in 32 urban/peri-urban districts of Mozambique: Implication for assessing the risk of arbovirus outbreaks. *PLOS Neglected Tropical Diseases*, *12*(9), e0006692. https://doi.org/10.1371/journal.pntd.0006692

Abramides, G. C., Roiz, D., Guitart, R., Quintana, S., & Giménez, N. (2013). Control of the Asian tiger mosquito (Aedes albopictus) in a firmly established area in Spain: Risk factors and people’s involvement. *Transactions of The Royal Society of Tropical Medicine and Hygiene*, *107*(11), 706–714. https://doi.org/10.1093/trstmh/trt093

Abramides, G. C., Roiz, D., Guitart, R., Quintana, S., Guerrero, I., & Giménez, N. (2011). Effectiveness of a multiple intervention strategy for the control of the tiger mosquito (Aedes albopictus) in Spain. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *105*(5), 281–288. https://doi.org/10.1016/j.trstmh.2011.01.003

Andrejewski, R., Mowen, A. J., & Kerstetter, D. L. (2011). An Examination of Children’s Outdoor Time, Nature Connection, and Environmental Stewardship. *Proceedings of the Northeastern Recreation Research Symposium*, 5.

Angela-Logomasini-Pesticides-and-the-West-Nile-Virus-An-Examination-of-Environmentalist-Claims.pdf. (n.d.). Retrieved April 3, 2023, from https://cei.org/wp-content/uploads/2010/10/Angela-Logomasini-Pesticides-and-the-West-Nile-Virus-An-Examination-of-Environmentalist-Claims.pdf

Arias-Castro, J. H., Martinez-Romero, H. J., & Vasilieva, O. (2020). Biological and Chemical Control of Mosquito Population by Optimal Control Approach. *Games*, *11*(4), 62. https://doi.org/10.3390/g11040062

Barrera, R., Acevedo, V., Felix, G. E., Hemme, R. R., Vazquez, J., Munoz, J. L., & Amador, M. (2017). Impact of Autocidal Gravid Ovitraps on Chikungunya Virus Incidence in Aedes aegypti (Diptera: Culicidae) in Areas With and Without Traps. *Journal of Medical Entomology*, *54*(2), 387–395. https://doi.org/10.1093/jme/tjw187

Barrera, R., Amador, M., Acevedo, V., Hemme, R. R., & Félix, G. (2014). Sustained, Area-Wide Control of Aedes aegypti Using CDC Autocidal Gravid Ovitraps. *The American Journal of Tropical Medicine and Hygiene*, *91*(6), 1269–1276. https://doi.org/10.4269/ajtmh.14-0426

Bartlett-Healy, K., Hamilton, G., Healy, S., Crepeau, T., Unlu, I., Farajollahi, A., Fonseca, D., Gaugler, R., Clark, G. G., & Strickman, D. (2011). Source Reduction Behavior as an Independent Measurement of the Impact of a Public Health Education Campaign in an Integrated Vector Management Program for the Asian Tiger Mosquito. *International Journal of Environmental Research and Public Health*, *8*(5), Article 5. https://doi.org/10.3390/ijerph8051358

Bartlett-Healy, K., Unlu, I., Obenauer, P., Hughes, T., Healy, S., Crepeau, T., Farajollahi, A., Kesavaraju, B., Fonseca, D., Schoeler, G., Gaugler, R., & Strickman, D. (2012). Larval Mosquito Habitat Utilization and Community Dynamics of Aedes albopictus and Aedes japonicus (Diptera: Culicidae). *Journal of Medical Entomology*, *49*(4), 813–824. https://doi.org/10.1603/ME11031

Becker, B., Leisnham, P. T., & LaDeau, S. L. (2014). A Tale of Two City Blocks: Differences in Immature and Adult Mosquito Abundances between Socioeconomically Different Urban Blocks in Baltimore (Maryland, USA). *International Journal of Environmental Research and Public Health*, *11*(3), Article 3. https://doi.org/10.3390/ijerph110303256

Bellini, R., Albieri, A., Balestrino, F., Carrieri, M., Porretta, D., Urbanelli, S., Calvitti, M., Moretti, R., & Maini, S. (2010). Dispersal and Survival of Aedes albopictus (Diptera: Culicidae) Males in Italian Urban Areas and Significance for Sterile Insect Technique Application. *Journal of Medical Entomology*, *47*(6), 1082–1091. https://doi.org/10.1603/ME09154

Benedict, M. Q., Levine, R. S., Hawley, W. A., & Lounibos, L. P. (2007). Spread of The Tiger: Global Risk of Invasion by The Mosquito *Aedes albopictus*. *Vector-Borne and Zoonotic Diseases*, *7*(1), 76–85. https://doi.org/10.1089/vbz.2006.0562

Beyer, K. M. M., Szabo, A., Hoormann, K., & Stolley, M. (2018). Time spent outdoors, activity levels, and chronic disease among American adults. *Journal* *of Behavioral Medicine*, *41*(4), 494–503. https://doi.org/10.1007/s10865-018-9911-1

BG-GAT to stop the next generation of tiger mosquitoes. (n.d.). *Biogents USA*. Retrieved April 4, 2023, from https://us.biogents.com/bg-gat/

Biehler, D., Leisnham, P. T., LaDeau, S. L., & Bodner, D. (2019). Knowing nature and community through mosquitoes: Reframing pest management through lay vector ecologies. *Local Environment*, *24*(12), 1119–1135. https://doi.org/10.1080/13549839.2019.1681387

Bisanzio, D., Dzul-Manzanilla, F., Gomez-Dantés, H., Pavia-Ruz, N., Hladish, T. J., Lenhart, A., Palacio-Vargas, J., Roldan, J. F. G., Correa-Morales, F., Sánchez-Tejeda, G., Morales, P. K., Manrique-Saide, P., Longini, I. M., Halloran, M. E., & Vazquez-Prokopec, G. M. (2018). Spatio-temporal coherence of dengue, chikungunya and Zika outbreaks in Merida, Mexico. *PLOS Neglected Tropical Diseases*, *12*(3), e0006298. https://doi.org/10.1371/journal.pntd.0006298

Blitvich, B. J., & Brault, A. C. (2018). Chikungunya and Zika Viruses: Global Emerging Health Threats. *The American Journal of Tropical Medicine and Hygiene*, *99*(4), 1105–1106. https://doi.org/10.4269/ajtmh.18-0613

Bodner, D., LaDeau, S. L., Biehler, D., Kirchoff, N., & Leisnham, P. T. (2016). Effectiveness of Print Education at Reducing Urban Mosquito Infestation through Improved Resident-Based Management. *PLOS ONE*, *11*(5), e0155011. https://doi.org/10.1371/journal.pone.0155011

Brady, O. J., & Hay, S. I. (2019). The first local cases of Zika virus in Europe. *The Lancet*, *394*(10213), 1991–1992. https://doi.org/10.1016/S0140-6736(19)32790-4

Cattarino, L., Rodriguez-Barraquer, I., Imai, N., Cummings, D. A. T., & Ferguson, N. M. (2020). Mapping global variation in dengue transmission intensity. *Science Translational Medicine, 12*(528), eaax4144. https://doi.org/10.1126/scitranslmed.aax4144

CDC. (2020, March 11). *Potential Range of Aedes Mosquitoes in US | CDC*. Centers for Disease Control and Prevention. https://www.cdc.gov/mosquitoes/mosquito-control/professionals/range.html

Chandel, K., Suman, D. S., Wang, Y., Unlu, I., Williges, E., Williams, G. M., & Gaugler, R. (2016). Targeting a Hidden Enemy: Pyriproxyfen Autodissemination Strategy for the Control of the Container Mosquito Aedes albopictus in Cryptic Habitats. *PLOS Neglected Tropical Diseases, 10*(12), e0005235. https://doi.org/10.1371/journal.pntd.0005235

Chen, X., Wu, T., Liang, J., & Zhou, L. (2020). Urban mosquito management administration: Mosquito (Diptera: Culicidae) habitat surveillance and questionnaire survey in Wuhan, Central China. *PLOS ONE*, *15*(5), e0232286. https://doi.org/10.1371/journal.pone.0232286

Chikungunya fact sheet. (n.d.). Retrieved April 1, 2023, from https://www.who.int/news-room/fact-sheets/detail/chikungunya

Cilek, J. E., Knapp, J. A., & Richardson, A. G. (2017). Comparative Efficiency of Biogents Gravid Aedes Trap, Cdc Autocidal Gravid Ovitrap, and CDC Gravid

Trap in Northeastern Florida1. *Journal of the American Mosquito Control Association*, *33*(2), 103–107. https://doi.org/10.2987/16-6628.1

Clinical Evaluation & Disease | West Nile Virus | CDC. (2023, March 7). https://www.cdc.gov/westnile/healthcareproviders/healthCareProviders-ClinLabEval.html

Dahmana, H., & Mediannikov, O. (2020). Mosquito-Borne Diseases Emergence/Resurgence and How to Effectively Control It Biologically. *Pathogens*, *9*(4), 310. https://doi.org/10.3390/pathogens9040310

Day, J. F. (2016). Mosquito Oviposition Behavior and Vector Control. *Insects*, *7*(4), Article 4. https://doi.org/10.3390/insects7040065

Dowling, Z., Armbruster, P., LaDeau, S. L., DeCotiis, M., Mottley, J., & Leisnham, P. T. (2013). Linking Mosquito Infestation to Resident Socioeconomic Status, Knowledge, and Source Reduction Practices in Suburban Washington, DC. *EcoHealth*, *10*(1), 36–47. https://doi.org/10.1007/s10393-013-0818-6

Evans, M. V., Hintz, C. W., Jones, L., Shiau, J., Solano, N., Drake, J. M., & Murdock, C. C. (2019). Microclimate and Larval Habitat Density Predict Adult Aedes albopictus Abundance in Urban Areas. *The American Journal of Tropical Medicine and Hygiene*, *101*(2), 362–370. https://doi.org/10.4269/ajtmh.19-0220

Faraji, A., Egizi, A., Fonseca, D. M., Unlu, I., Crepeau, T., Healy, S. P., & Gaugler, R. (2014). Comparative Host Feeding Patterns of the Asian Tiger Mosquito, Aedes albopictus, in Urban and Suburban Northeastern USA and Implications for Disease Transmission. *PLoS Neglected Tropical Diseases*, *8*(8), e3037. https://doi.org/10.1371/journal.pntd.0003037

Farajollahi, A., & Nelder, M. P. (2009). Changes in <I>Aedes albopictus</I> (Diptera: Culicidae) Populations in New Jersey and Implications for Arbovirus Transmission. *Journal of Medical Entomology*, *46*(5), 1220–1224. https://doi.org/10.1603/033.046.0533

Floore, T. G. (2006). Mosquito Larval Control Practices: Past and Present. *Journal of the American Mosquito Control Association*, *22*(3), 527–533. https://doi.org/10.2987/8756-971X(2006)22[527:MLCPPA]2.0.CO;2

Fonseca, D. M., Unlu, I., Crepeau, T., Farajollahi, A., Healy, S. P., Bartlett-Healy, K., Strickman, D., Gaugler, R., Hamilton, G., Kline, D., & Clark, G. G. (2013). Area-wide management of *Aedes albopictus* . Part 2: Gauging the efficacy of traditional integrated pest control measures against urban container mosquitoes. *Pest Management Science*, *69*(12), 1351–1361. https://doi.org/10.1002/ps.3511

Giron, S., Franke, F., Decoppet, A., Cadiou, B., Travaglini, T., Thirion, L., Durand, G., Jeannin, C., L’Ambert, G., Grard, G., Noël, H., Fournet, N., Auzet-Caillaud, M., Zandotti, C., Aboukaïs, S., Chaud, P., Guedj, S., Hamouda, L., Naudot, X., … Leparc-Goffart, I. (2019). Vector-borne transmission of Zika virus in Europe, southern France, August 2019. *Eurosurveillance*, *24*(45). https://doi.org/10.2807/1560-7917.ES.2019.24.45.1900655

Goodman, H., Egizi, A., Fonseca, D. M., Leisnham, P. T., & LaDeau, S. L. (2018). Primary blood-hosts of mosquitoes are influenced by social and ecological conditions in a complex urban landscape. *Parasites & Vectors, 11*(1), 218. https://doi.org/10.1186/s13071-018-2779-7

Grard, G., Caron, M., Mombo, I. M., Nkoghe, D., Mboui Ondo, S., Jiolle, D., Fontenille, D., Paupy, C., & Leroy, E. M. (2014). Zika Virus in Gabon (Central Africa) – 2007: A New Threat from Aedes albopictus? *PLoS Neglected Tropical Diseases*, *8*(2), e2681. https://doi.org/10.1371/journal.pntd.0002681

Hoover, K. S. (2021). Children in nature: Exploring the relationship between childhood outdoor experience and environmental stewardship. *Environmental Education Research, 27*(6), 894–910. https://doi.org/10.1080/13504622.2020.1856790

Houé, V., Bonizzoni, M., & Failloux, A.-B. (2019). Endogenous non-retroviral elements in genomes of Aedes mosquitoes and vector competence. *Emerging Microbes & Infections*, *8*(1), 542–555. https://doi.org/10.1080/22221751.2019.1599302

Hunter, M. R. (2011a). Impact of ecological disturbance on awareness of urban nature and sense of environmental stewardship in residential neighborhoods. *Landscape and Urban Planning*, *101*(2), 131–138. https://doi.org/10.1016/j.landurbplan.2011.02.005

Hunter, M. R. (2011b). Impact of ecological disturbance on awareness of urban nature and sense of environmental stewardship in residential neighborhoods. *Landscape and Urban Planning*, *101*(2), 131–138. https://doi.org/10.1016/j.landurbplan.2011.02.005

Johnson, B. J., Brosch, D., Christiansen, A., Wells, E., Wells, M., Bhandoola, A. F., Milne, A., Garrison, S., & Fonseca, D. M. (2018). Neighbors help neighbors control urban mosquitoes. *Scientific Reports*, *8*(1), 15797. https://doi.org/10.1038/s41598-018-34161-9

Johnson, B., Ritchie, S., & Fonseca, D. (2017). The State of the Art of Lethal Oviposition Trap-Based Mass Interventions for Arboviral Control. *Insects*, *8*(1), 5. https://doi.org/10.3390/insects8010005

Juarez, J. G., Chaves, L. F., Garcia-Luna, S. M., Martin, E., Badillo-Vargas, I., Medeiros, M. C. I., & Hamer, G. L. (2021). Variable coverage in an Autocidal Gravid Ovitrap intervention impacts efficacy of Aedes aegypti control. *Journal of Applied Ecology*, *58*(10), 2075–2086. https://doi.org/10.1111/1365-2664.13951

Keveney, S. (2021, April 21). *Susanne Keveney Personal Interview* [Lonline].

Kiss, T., Leitol, C., Márovics, G., Zentai, T., Baczur, R., & Girán, J. (2020). The First Steps to Develop a Monitoring-Based Method to Support the Sustainable Mosquito Control in an Urban Environment in Hungary. *Sustainability*, *12*(12), 5013. https://doi.org/10.3390/su12125013

Kraemer, M. U. G., Reiner, R. C., Brady, O. J., Messina, J. P., Gilbert, M., Pigott, D. M., Yi, D., Johnson, K., Earl, L., Marczak, L. B., Shirude, S., Davis Weaver, N., Bisanzio, D., Perkins, T. A., Lai, S., Lu, X., Jones, P., Coelho, G. E., Carvalho, R. G., … Golding, N. (2019). Past and future spread of the arbovirus vectors Aedes aegypti and Aedes albopictus. *Nature Microbiology*, *4*(5), Article 5. https://doi.org/10.1038/s41564-019-0376-y

LaDeau, S. L., Allan, B. F., Leisnham, P. T., & Levy, M. Z. (2015). The ecological foundations of transmission potential and vector-borne disease in urban landscapes. *Functional Ecology*, *29*(7), 889–901. https://doi.org/10.1111/1365-2435.12487

Laporta, G. Z., Potter, A. M., Oliveira, J. F. A., Bourke, B. P., Pecor, D. B., & Linton, Y.-M. (2023). Global Distribution of Aedes aegypti and Aedes albopictus in a Climate Change Scenario of Regional Rivalry. *Insects*, *14*(1), Article 1. https://doi.org/10.3390/insects14010049

Leisnham, P. T., & Juliano, S. A. (2012). Impacts of Climate, Land Use, and Biological Invasion on the Ecology of Immature Aedes Mosquitoes: Implications for La Crosse Emergence. *EcoHealth*, *9*(2), 217–228. https://doi.org/10.1007/s10393-012-0773-7

Leta, S., Beyene, T. J., De Clercq, E. M., Amenu, K., Kraemer, M. U. G., & Revie, C. W. (2018). Global risk mapping for major diseases transmitted by Aedes aegypti and Aedes albopictus. *International Journal of Infectious Diseases*, *67*, 25–35. https://doi.org/10.1016/j.ijid.2017.11.026

Li, Y., Kamara, F., Zhou, G., Puthiyakunnon, S., Li, C., Liu, Y., Zhou, Y., Yao, L., Yan, G., & Chen, X.-G. (2014). Urbanization Increases Aedes albopictus Larval Habitats and Accelerates Mosquito Development and Survivorship. *PLoS Neglected Tropical Diseases*, *8*(11), e3301. https://doi.org/10.1371/journal.pntd.0003301

Little, E., Biehler, D., Leisnham, P. T., Jordan, R., Wilson, S., & LaDeau, S. L. (2017). Socio-Ecological Mechanisms Supporting High Densities of Aedes albopictus (Diptera: Culicidae) in Baltimore, MD. *Journal of Medical Entomology*, *54*(5), 1183–1192. https://doi.org/10.1093/jme/tjx103

Mackay, A. J., Amador, M., & Barrera, R. (2013). An improved autocidal gravid ovitrap for the control and surveillance of Aedes aegypti. *Parasites & Vectors*, *6*(1), 225. https://doi.org/10.1186/1756-3305-6-225

Marini, F., Caputo, B., Pombi, M., Travaglio, M., Montarsi, F., Drago, A., Rosà, R., Manica, M., & della Torre, A. (2019). Estimating Spatio-Temporal Dynamics of Aedes Albopictus Dispersal to Guide Control Interventions in Case of Exotic Arboviruses in Temperate Regions. *Scientific Reports*, *9*(1), 10281. https://doi.org/10.1038/s41598-019-46466-4

Moore, C. (1997). Aedes albopictus in the United States: Ten-Year Presence and Public Health Implications. *Emerging Infectious Diseases*, *3*(3), 329–334. https://doi.org/10.3201/eid0303.970309

Mosquito-borne diseases | World Mosquito Program. (n.d.). Retrieved November 10, 2021, from https://www.worldmosquitoprogram.org/en/learn/mosquito-borne-diseases

Moyes, C. L., Vontas, J., Martins, A. J., Ng, L. C., Koou, S. Y., Dusfour, I., Raghavendra, K., Pinto, J., Corbel, V., David, J.-P., & Weetman, D. (2017). Contemporary status of insecticide resistance in the major Aedes vectors of arboviruses infecting humans. *PLOS Neglected Tropical Diseases*, *11*(7), e0005625. https://doi.org/10.1371/journal.pntd.0005625

Musso, D., Ko, A. I., & Baud, D. (2019). Zika Virus Infection—After the Pandemic. *New England Journal of Medicine*, *381*(15), 1444–1457. https://doi.org/10.1056/NEJMra1808246

Petersen, L. R., Nasci, R. S., Beard, C. B., & Massung, R. F. (2016). EMERGING VECTOR-BORNE DISEASES IN THE UNITED STATES: WHAT IS NEXT, AND ARE WE PREPARED? In *Global Health Impacts of Vector-Borne Diseases: Workshop Summary*. National Academies Press (US). https://www.ncbi.nlm.nih.gov/books/NBK390433/

Popping, R. (2015). Analyzing Open-ended Questions by Means of Text Analysis Procedures. *Bulletin of Sociological Methodology/Bulletin de Méthodologie Sociologique*, *128*(1), 23–39. https://doi.org/10.1177/0759106315597389

Rahman, M. M., Sayed, S. J. B., Moniruzzaman, M., Kabir, A. K. M. H., Mallik, M. U., Hasan, M. R., Siddique, A. B., Hossain, M. A., Uddin, N., Hassan, M. M., & Chowdhury, F. R. (2018). Clinical and Laboratory Characteristics of an Acute Chikungunya Outbreak in Bangladesh in 2017. *The American Journal of Tropical Medicine and Hygiene*, *100*(2), 405–410. https://doi.org/10.4269/ajtmh.18-0636

Rochlin, I., Ninivaggi, D. V., Hutchinson, M. L., & Farajollahi, A. (2013). Climate Change and Range Expansion of the Asian Tiger Mosquito (Aedes albopictus) in Northeastern USA: Implications for Public Health Practitioners. *PLoS ONE*, *8*(4), e60874. https://doi.org/10.1371/journal.pone.0060874

Ryan, R. L., Kaplan, R., & Grese, R. E. (2001). Predicting Volunteer Commitment in Environmental Stewardship Programmes. *Journal of Environmental Planning* *and Management*, *44*(5), 629–648. https://doi.org/10.1080/09640560120079948

Sardelis, R., Turell, J., O'Guinn, L., Andre'Eno, G., & Roberts', R. (2002). *VECTOR COMPETENCE OF THREE NORTH AMERICAN STRAINS OF AEDES ALBOPICZUS FOR WEST NILE VIRUS'*. *18*(4), 6.

Schaffner, F., & Mathis, A. (2014). Dengue and dengue vectors in the WHO European region: Past, present, and scenarios for the future. *The Lancet Infectious Diseases*, *14*(12), 1271–1280. https://doi.org/10.1016/S1473-3099(14)70834-5

Schwass, N. R., Potter, S. E., O'Connell, T. S., & Potter, T. G. (2021). Outdoor journeys as a catalyst for enhanced place connectedness and environmental stewardship. *Journal of Outdoor and Environmental Education*, *24*(2), 215–231. https://doi.org/10.1007/s42322-021-00079-6

Sharp, T. M., Lorenzi, O., Torres-Velásquez, B., Acevedo, V., Pérez-Padilla, J., Rivera, A., Muñoz-Jordán, J., Margolis, H. S., Waterman, S. H., Biggerstaff, B. J., Paz-Bailey, G., & Barrera, R. (2019). Autocidal gravid ovitraps protect humans from chikungunya virus infection by reducing Aedes aegypti mosquito populations. *PLOS Neglected Tropical Diseases*, *13*(7), e0007538. https://doi.org/10.1371/journal.pntd.0007538

Shragai, T., & Harrington, L. C. (2019). *Aedes albopictus* (Diptera: Culicidae) on an Invasive Edge: Abundance, Spatial Distribution, and Habitat Usage of Larvae and Pupae Across Urban and Socioeconomic Environmental Gradients.

Journal of Medical Entomology, *56*(2), 472–482. https://doi.org/10.1093/jme/tjy209

Stoddard, S. T., Morrison, A. C., Vazquez-Prokopec, G. M., Soldan, V. P., Kochel, T. J., Kitron, U., Elder, J. P., & Scott, T. W. (2009). The Role of Human Movement in the Transmission of Vector-Borne Pathogens. *PLOS Neglected Tropical Diseases*, *3*(7), e481. https://doi.org/10.1371/journal.pntd.0000481

Thapa, B. (2010). The Mediation Effect of Outdoor Recreation Participation on Environmental Attitude-Behavior Correspondence. *The Journal of Environmental Education*, *41*(3), 133–150. https://doi.org/10.1080/00958960903439989

University Park, MD | Data USA. (n.d.). Retrieved November 10, 2021, from https://datausa.io/profile/geo/university-park-md/#demographics

U.S. Census (2020). *Census.gov*. Census.Gov. Retrieved April 22, 2023, from https://www.census.gov/en.html

US EPA, O. (2013, February 21). *Mosquito Life Cycle* [Overviews and Factsheets]. https://www.epa.gov/mosquitocontrol/mosquito-life-cycle

Vavassori, L., Saddler, A., & Müller, P. (2019). Active dispersal of Aedes albopictus: A mark-release-recapture study using self-marking units. *Parasites & Vectors*, *12*(1), 583. https://doi.org/10.1186/s13071-019-3837-5

Wells, E. (2021, March 31). *Ed Wells Interview* [Online].

West, S., Dyke, A., & Pateman, R. (2021). Variations in the Motivations of Environmental Citizen Scientists. *Citizen Science: Theory and Practice*, *6*(1), 14. https://doi.org/10.5334/cstp.370

Wilke, A. B. B., Vasquez, C., Medina, J., Carvajal, A., Petrie, W., & Beier, J. C. (2019). Community Composition and Year-round Abundance of Vector Species of Mosquitoes make Miami-Dade County, Florida a Receptive Gateway for Arbovirus entry to the United States. *Scientific Reports*, *9*(1), 8732. https://doi.org/10.1038/s41598-019-45337-2

World Health Organization. (2014). *A global biref on vector borne diseases* (pp. 1–56). http://apps.who.int/iris/bitstream/handle/10665/111008/WHO_DCO_WHD_2014.1_eng.pdf;jsessionid=B76895404967F20ACC7909E959DDEA40?sequence=1

World Health Organization. (2020). *Vector-borne diseases*. https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases

Worobey, J., Fonseca, D. M., Espinosa, C., Healy, S., & Gaugler, R. (2013). Child Outdoor Physical Activity is Reduced by Prevalence of the Asian Tiger Mosquito, *Aedes albopictus*. *Journal of the American Mosquito Control Association*, *29*(1), 78–80. https://doi.org/10.2987/12-6296R.1

Yang, L., Turo, K. J., Riley, C. B., Inocente, E. A., Tian, J., Hoekstra, N. C., Piermarini, P. M., & Gardiner, M. M. (2019). Can urban greening increase vector abundance in cities? The impact of mowing, local vegetation, and landscape composition on adult mosquito populations. *Urban Ecosystems*, *22*(5), 827–839. https://doi.org/10.1007/s11252-019-00857-7

Zhao, J., Tang, T., & Wang, X. (2020). Effects of landscape composition on mosquito population in urban green spaces. *Urban Forestry & Urban Greening*, *49*, 126626. https://doi.org/10.1016/j.ufug.2020.126626