West Nile virus in Maricopa County, Arizona: Investigating human, vector, and environmental interactions

by

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ABSTRACT

Despite the arid climate of Maricopa County, Arizona, vector-borne diseases have presented significant health challenges to the residents and public health professionals of Maricopa County in the past, and will continue to do so in the foreseeable future. Currently, West Nile virus is the only mosquitoes-transmitted disease actively, and natively, transmitted throughout the state of Arizona. In an effort to gain a more complete understanding of the transmission dynamics of West Nile virus this thesis examines human, vector, and environment interactions as they exist within Maricopa County. Through ethnographic and geographic information systems research methods this thesis identifies 1) the individual factors that influence residents' knowledge and behaviors regarding mosquitoes, 2) the individual and regional factors that influence residents' knowledge of mosquito ecology and the spatial distribution of local mosquito populations, and 3) the environmental, demographic, and socioeconomic factors that influence mosquito abundance within Maricopa County. By identifying the factors that influence human-vector and vector-environment interactions, the results of this thesis may influence current and future educational and mosquito control efforts throughout Maricopa County.

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CHAPTER 1

OUTLINE OF THESIS CHAPTERS

Despite the region's arid climate, the state of Arizona has historically been and currently is home to vector-borne disease. While threats like malaria have long been eradicated, recently emerging diseases like West Nile virus represent significant health challenges to the residents and public health professionals of Maricopa County and the state of Arizona in general. Like all vector-borne diseases, West Nile virus arises out of complex interactions among pathogenic agents, mosquito vectors, and human hosts. Facilitating the interactions among these actors, however, is a broadly defined environment, which in this study represents the social and ecological characteristics of a specific area of study. In an effort to contribute to a more complete understanding of West Nile virus as it exists within Maricopa County, Arizona, this thesis, organized into six chapters including this introduction, investigates numerous factors that influence interactions among humans and mosquito vectors as well as mosquito vectors and the environment.

Because vector-borne disease constitutes a relatively small and under-represented portion of research within the field of sustainability science, the second chapter of this thesis explores the similarities and the differences between the fields of sustainability and public health, the primary discipline for vector-borne disease research. The review continues to identify key principles of sustainability science that may benefit practitioners within the field of epidemiology, and vice versa, and concludes with a brief discussion of the value of addressing health challenges from a sustainability perspective.

In an effort to address the human- mosquito vector interactions within Maricopa County, Chapter 3 examines specific factors that influence individuals' knowledge of mosquito ecology as well as whether or not individuals perform recommended behaviors in response to local mosquito vectors. Because there is no specific medical treatment of vaccine available, human behavior has been identified as the most effective form of prevention with regard to mosquitoes and infection with West Nile virus. If local public health professionals are going to address misconceptions and emphasize behaviors that reduce one's risk to infection, a comprehensive understanding of the factors that influence individuals' knowledge, perceptions, and behaviors is necessary. The results presented in Chapter 3, therefore, may inform future educational and outreach efforts conducted within Maricopa County.

Among the behaviors recommended by public health agencies that reduce one's risk to infection, individuals are advised to avoid locations where mosquitoes are known to be numerous. If residents are to follow such preventive measures, knowledge of the distribution of local mosquito populations within Maricopa County is essential. Chapter 4 of this thesis describes the design, implementation, and results of a novel assessment tool related to individuals' knowledge of the spatial distribution of local mosquito populations. Similar to Chapter 3, the results presented in Chapter 4 will assist local public health professionals address potential misconceptions regarding the distribution of mosquito populations within Maricopa County.

While Chapters 3 and 4 both investigate human-mosquito vector interactions with regard to West Nile virus, Chapter 5 examines the mosquito vector-environment component of vector-borne disease. Building on a growing body of research, the study presented in Chapter 5 utilizes remote sensing and geographic information systems techniques to identify the ecological, demographic, socioeconomic, and treatment factors that impact mosquito abundance and mosquito presence within Maricopa County. While exploratory in nature, the results presented in this study will assist local mosquito control experts target limited financial and human resources associated with the surveillance and treatment of mosquito populations within Maricopa County.

In general terms, Chapter 6 briefly discusses the broader implications of this thesis. Additionally, Chapter 6 identifies potential future steps as they relate to this thesis and vector-borne disease in Maricopa County.

Apart from Chapters 1 and 6, each of the chapters presented in this thesis has been prepared for submission to diverse academic journals. Chapter 2 has been written to be submitted as a Perspectives piece for the Journal of Global Health, operated by the undergraduate and graduate students of Columbia University. Chapter 3 has been prepared for submission to EcoHealth. Chapter 4 has been prepared for submission to the Southwestern Geographer, which is the appropriate regional division of the Association of American Geographers. Finally, Chapter 5 has been prepared for submission to the Journal of the American Mosquito Control Association. In order to ensure that each study may stand on its own there is a certain degree of content redundancy within each chapter, for which the author apologizes.

CHAPTER 2

EXPLORING THE INTERSECTIONS OF SUSTAINABILITY SCIENCE AND PUBLIC HEALTH

INTRODUCTION

While sustainability science has only recently emerged over the past few decades as a vibrant field scholarship and practice (Clark, 2007; Clark & Dickson, 2003), sustainability as a concept is certainly not as young. In fact, challenges that we would describe as sustainability problems today, including resource extraction and consumption, equitable distribution of economic development, and environmental degradation have remained constant concerns for both past and present civilizations (Du Pisani, 2006). Since the United Nation's Commission on Environment and Development of 1987 (World Commission on Environment and Development [WCED], 1987), also known as the Brundtland Report's *Our Common Future,* sustainability as both a concept and a field have become pervasive throughout all aspects of life, including the media, our market, political agendas, and our educational institutions. Within these various domains and sectors, however, sustainability has taken on numerous conceptual definitions and operationalizations. For example, Singer and Caldas de Castro (2007) define what is considered to be sustainable as "capable of being maintained at a certain role or level" (Singer & Caldas de Castro, 2007, p. 16038). Other practitioners approach sustainability from a "maintenance" perspective and employ related synonyms such as "persistence," "continuation," "stability," and "resilience" when defining sustainability (Gruen et al., 2008). An obvious challenge related to operationalizing sustainability from this perspective is identifying what is to be maintained and what characteristics or processes ensure their maintenance or persistence. A more recent definition of sustainability is articulated by Kates (2011) and echoes the Brundtland Report (WCED, 1987): “meeting the needs of present and future generations while substantially reducing poverty and conserving the planet’s life support systems” (Kates, 2011, p. 19449). Here, a challenge surrounding operationalization includes identifying or developing indicators or metrics capable of reflecting multidimensionality and interlinkages among the broad “pillars” of sustainability—society, economy, and environment (Moldan & Dahl, 2007, p. 12).

While it is clear that defining and measuring sustainability will mean different things for different people of different sectors in different places across different timeframes (Kajikawa, 2008, p. 219; Solow, 1991), significant contributions often come from such fields as resource economics, conservation biology, and the social sciences in general; rare, however, do practitioners approach sustainability from a medical or health sciences perspective (Bettencourt & Kaur, 2011). While contributions from the fields of health and medicine are essential to achieving sustainability, as described in the WCED and the United Nation’s Millennium Development Goals, a recent review by Bettencourt et al. (2010), however, demonstrate that such fields constitute a relatively small, underrepresented portion of the research conducted within the field of sustainability (Bettencourt & Kaur, 2011; UN, 2012; Wilcox & Colwell, 2005; WCED, 1987, p. 109). There are, however, not only commonalities between the field of sustainability and health-related fields, but also opportunities for these seemingly disconnected fields to benefit from the other. In this short review, I first highlight the characteristics shared between sustainability science and epidemiology, one of the primary disciplines of public health and the health-related sciences. In particular, I highlight how both fields may be best described as use-inspired, basic sciences and how both fields experience difficulties related to solution development and implementation, particularly through the utilization of participatory methods. I follow with a brief discussion of the potential to expand and enhance epidemiology through the incorporation of specific, key principles from sustainability science. In the final section of this paper, I conclude by discussing the potential importance that health-focused research may represent if we are to achieve a sustainability transition.

SIMILARITIES OF SUSTAINABILITY SCIENCE AND EPIDEMIOLOGY

Elements of both sustainability science and epidemiology attempt to bridge the tension between basic and applied science (Lang et al., 2012; Wiek, Withycombe, & Redman, 2011). According to the classic dichotomy, there is a clear distinction between research that is conducted with the singular purpose of better understanding phenomena and research that is performed with the intent to develop applied uses (Tushman & O'Reilly, 2007). To a certain extent, this dichotomy may still be seen in both fields. Yet sustainability science and epidemiology are both more powerful when the quest for fundamental understanding and the quest for applied use complement one another (Channell, 1999). Fields that bring together both basic and applied science can be located in what has been described as Pasteur's Quadrant and contributes to the generation of use-inspired, basic knowledge (Lang et al., 2012; van der Leeuw, Wiek, Harlow, & Buizer, 2012; Wiek et al., 2011).

In its descriptive-analytical, or basic mode, sustainability science attempts to develop more complete, systemic fundamental understandings of problems as they exist within coupled social-ecological systems (Gibson, 2006; Leischow et al., 2008; McMichael, Butler, & Folke, 2003; van der Leeuw et al., 2012; Wiek et al., 2011). Such sustainability problems that demand attention today include climate change, desertification, deforestation, loss of biodiversity, water scarcity, globalization, poverty, urbanization, and pandemics (Kates & Parris, 2003; Lang et al., 2012; van der Leeuw et al., 2012). According to Kates and Parris (2003; pp.8062; 8067), in order to address such challenges, a greater understanding of the long-term implications that result from these and other sustainability challenges with regard to human-environment interactions is required. As a basic science of public health, one of the primary roles of practitioners within the field of epidemiology is to describe the distribution of disease and health outcomes. Additionally, practitioners of the field also attempt to identify the causes of disease in order to explain its observed distribution. In epidemiology, significant health challenges include the emergence and reemergence of vector-borne diseases, including malaria and dengue; access to clean water and sanitation; the rapid transmission of infectious diseases such as HIV/AIDS; the expansion of the obesity epidemic; and widespread rise of chronic diseases (WCED, 1987). For both fields, the assumption that an improved, more complete understanding of the specific problem is needed if we are to appropriately address the problem underlies the descriptive-analytical modes of research (Wiek, Ness, Schweizer-Ries, Brand, & Farioli, 2012). While the quest for improved understanding, or put another way, the quest for more comprehensive problem identification and description, is necessary within both sustainability science and epidemiology, the results of this basic research are enriched by solution-oriented approaches that attempt to significantly impact society.

As use-inspired science, both sustainability science and epidemiology attempt to translate fundamental understandings in the form of practical solutions. Such solutions, however, must be credible, relevant, and salient to diverse stakeholders (Cash et al., 2003). In order to create such knowledge products, both fields attempt to implement collaborative, participatory research methods (Israel, Eng, Schulz, & Parker, 2005). Through such methodological frameworks as participatory action research (PAR) and community-based participatory research (CBPR) practitioners of sustainability and epidemiology attempt to democratize the entire research process, from problem identification to data collection and analysis to intervention implementation, in an attempt to equally distribute decision-making power between experts and citizens (Gibson, 2006; Green & Mercer, 2001; Leung, Yen, & Minkler, 2004). While many of today's complex sustainability and health challenges may be profitably studied and addressed through more comprehensive and participatory approaches, in many cases, solution implementations and interventions have failed because participation was conceived as a panacea (Gürtler, Kitron, Cecere, Segura, & Cohen, 2007; Minkler, Glover Blackwell, Thompson, & Tamir, 2003; Morgan, 2001). There is no doubt that stakeholder engagement, mobilization, and participation are both alluring and promising; researchers and practitioners of sustainability science and epidemiology, however, have identified challenges that make participatory research both vexing and elusive (Morgan, 2001).

At times, researchers and practitioners within the field of epidemiology have been accused of losing touch with the public, whose health members of the field have been charged to protect and maintain (Cargo & Mercer, 2008; Leung et al., 2004; Wing, 1998). Prior to the 1970s and 1980s, control of the *Aedes aegypti*, the principal vector of dengue, was conducted through vertically-organized, government-directed programs that implemented broad application of larvicides and adulticides. In a comprehensive review of control efforts conducted during the 1970s and 1980s in the absence of the large amounts of financial resources and physical capital required of these programs, Gubler et al. (1996) describe how numerous interventions in Central and South America as well as the Caribbean attempted to implement community-based, bottom-up control programs. Many community-based interventions proved ineffective in controlling mosquito populations and preventing dengue transmission to humans according to Gubler et al. (1996) because such interventions often neglected to define the roles and responsibilities of community members, and did not promote a sense of community ownership throughout the program. Similarly, Gürtler et al. (2007) describe how unsupervised, intermittent community mobilization and participation proved incapable of controlling vector populations and interrupting human transmission of Chagas disease in Argentina (Gürtler et al., 2007). From the sustainability science literature, Lang et al. (2012) identify numerous limitations related to participatory research, including the identification of appropriate stakeholders, unbalanced problem ownership, unequal agency or capacity to direct the intervention, and discontinuous participation, either among unmotivated or too numerous stakeholders. While the researchers and practitioners who attempt to translate fundamental understandings into socially-robust, solution-oriented knowledge from many fields of interest struggle with these very challenges as they relate to participatory research (Gibbons, 1999), if sustainability science and public health sciences like epidemiology are to develop and implement salient interventions in response to wicked problems, the lessons learned from Gubler et al. (1996) and Lang et al. (2012) must be implemented and evaluated in future sustainability and public health initiatives.

To this point, the shared characteristics of both sustainability science and epidemiology have been described in a very limited manner. While I have highlighted both fields' attempts to bridge the traditionally dichotomous ontologies of science, basic, descriptive-analytical science and applied, solution-oriented, problem-solving science, as well as their share limitations related to participatory research methods in this section, to be sure, sustainability science and epidemiology enjoy numerous additional commonalities. For example, researchers and practitioners of both fields share an appreciation for complexity and scale with regard to the urgent problems that they address. The purpose of the following section, however, is to explore the specific opportunity spaces within epidemiology where key principles of sustainability science, such as a more comprehensive appreciation of complexity, may prove insightful.

DOMAIN 1: APPRECIATION OF COMPLEXITY

The first opportunity space where key principles of sustainability science may benefit the work of researchers and practitioners in the field of epidemiology addresses specific limitations regarding current orientations towards complexity and interdisciplinary research within the field of epidemiology. As described above, the health challenges of today, and those that will continue to manifest themselves in the future, exhibit wicked complexity and will require multiple, diverse perspectives and input to be completely addressed (Spangenberg, 2011; Wiek et al., 2012; Wiek et al., 2011). While it is clear that epidemiology is an interdisciplinary field that draws expertise, theory, and methods from diverse academic disciplines, the field of epidemiology and its practitioners have been criticized as incapable of addressing the true complexity of current and future health challenges due to the compartmentalization of research pathways with regard to the investigation of disease (Leischow et al., 2008; Leung et al., 2004; Shy, 1997). Using a common heuristic known as the epidemiologic triangle, the compartmentalization and prioritization of research pathways will be illustrated with regard to the investigation of the vector-borne disease malaria.

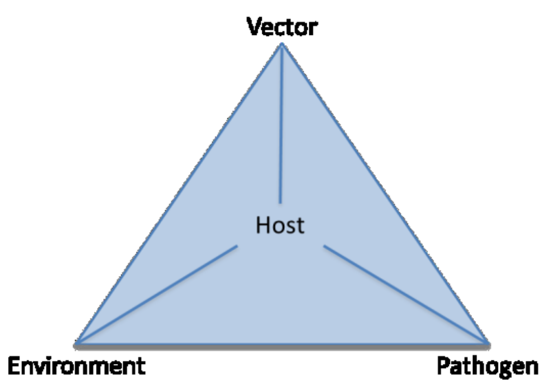


Figure 2.1. The epidemiologic triangle. (Adapted from Cohen, 2000)

In this context, the epidemiologic triangle (refer to Figure 2.1) consists of four elements: the pathogen (the specific Plasmodium parasite capable of infecting hosts and causing disease), the vector (a mosquito capable of becoming infected with and transmitting the malaria pathogen), the host (a human individual infected with the malaria parasite through the bite of the mosquito), and the environment (typically defined as the study area of interest in which malaria is actively transmitted). From this heuristic, the complex interactions among and within all four elements contribute to the specific distribution of malaria. Epidemiologists from specific research pathways, however, will often address one or a limited number of these elements as they attempt to reduce adverse health outcomes related to malaria. In an example that may be described as social epidemiology, Toé et al., (2009) attempt to identify the social, psychological, and cultural factors that influence adoption of insecticide treated bed nets within a malaria endemic region of Burkina Faso. Toé et al., (2009) explain that perceptions regarding the severity of malaria, the usefulness of bed nets, and the cultural practices associated with household sleeping arrangements all contributed to limited adoption and proper use of insecticide treated bed nets. Recommendations, therefore, all address social and cultural knowledge and behaviors regarding perceptions of malaria and utility of bed nets. In an example of environmental epidemiology, Ageep et al. (2009) attempt to identify the environmental factors, and in particular the landscape characteristics, associated with the larvae abundance of one mosquito vector within a malaria endemic area of the Sudan. Using remote sensing and geographic information systems, Ageep et al. (2009) concluded that larvae abundance was heterogeneous with regard to proximity to riparian areas and dominant vegetation. According to Ageep et al. (2009), knowledge of environmental and landscape factors that impact mosquito, in particular larvae, abundance will guide future control efforts within the region. In a final example of compartmentalized research pathways within the field of epidemiology, Corby-Harris et al. (2010) utilized molecular and genetic techniques to manipulate physiological functions within the malaria mosquito vector during parasite development. These genetic manipulations result in almost a complete reduction in the number of parasites developing within an infected mosquito as well as a reduction in mosquito lifespan (Corby-Harris et al., 2010).

In order to address the challenge of malaria, each of the above mentioned studies address a specific and separate element of the epidemiologic triangle. As described by Morse (2004), however, the (re)emergence and persistence of infectious diseases such as malaria result from the complex interactions related to microbial adaptation, ecological change, human behavior, and technological innovation. From the examples described here, it is clear that the tendency to compartmentalize research and implementation does not support an integrated approach needed to address the true complexity of malaria. Systems thinking, a key principle of sustainability (Boone, 2010; Gibson, 2006) science, however, may prove useful to the field of epidemiology and relieve some of the tensions associated with disparate research streams.

Within sustainability science, systems thinking attempts to address challenges as they exist within complex, nested social-ecological systems (Jerneck et al., 2011; van der Leeuw et al., 2012). Within social-ecological systems, processes interact across domains (society, environment, economy), across space (from local to global), and across time (from short- to long-term) (Rapport, 2007; Wiek et al., 2011). In developing a comprehensive understanding of processes as they exist within social-ecological systems, researchers and practitioners must also appreciate feedback loops and the cascading intended and unintended effects related to the problem as well as intervention strategies. As it has been widely practiced, modern epidemiology too often engages in compartmentalized, and in particular, biomedical, research (Shy, 1997). However, in order to improve the public's health, it will be necessary to gain a greater understanding of the complex and adaptive social-ecological systems involved in both causing and solving public health problems (Leischow et al., 2008). To this end, epidemiologists and public health professionals will not be able to meaningfully address specific health challenges, such as malaria, if they do not meaningfully reach across research pathways in order to integrate environmental factors, demographics, human behavior, and knowledge of the specific pathogen (Wilcox & Colwell, 2005). While each of the three studies described above attempt to address the challenges associated with malaria from diverse theoretical and methodological perspectives, opportunities for interdisciplinary research inspired by a systems thinking approach are abundant. Although there is no universal operational method that may guide epidemiologists and researchers in implementing systems thinking, through the development and appreciation of complex social-ecological systems, sustainability science provides a conceptual framework to not only bridge potentially compartmentalized, distinct research pathways within epidemiology, but also generate more comprehensive understandings of specific health challenges (Leischow et al., 2008; Leischow & Milstein, 2006).

DOMAIN 2: FUTURE-ORIENTATION AND THE (RE)EMERGENCE OF DISEASE

While epidemiology is predominantly concerned with describing and understanding the distribution and determinants of disease, it is essential that researchers and practitioners contribute to proactive or preventive measures prior to the emergence of disease in addition to reactive research and interventions that commence after disease is reported in or endemic to a specific location. One of the most significant challenges facing epidemiologists and public health professionals, however, is predicting how specific disease outcomes will manifest in the future with regard to changes in both the underlying processes that contribute to disease as well as specific intervention strategies (McMichael, 2006). The (re)emergence of infectious diseases the world over provides a telling example for increased anticipatory, or future-oriented, capacity within the field of epidemiology.

By the middle of the twentieth century, epidemiologists as well as medical and public health professionals believed that infectious disease such as influenza, small pox, measles, malaria, dengue, polio, and tuberculosis had "yielded up their secrets;" "the war on infectious disease had been won," according to the US Surgeon General (Cohen, 2000; Morens, Folkers, & Fauci, 2004). Contributing to such optimism: the establishment of germ theory and the identification of specific microbial pathogens capable of producing disease (Morens et al., 2004), the development of antibiotics, immunizations, and vaccines (Cohen, 2000), and the broad application of insecticides (Gubler & Clark, 1996). As a result, research and the necessary resources related to the surveillance, prevention, or control of infectious disease were de-emphasized and reduced (Cohen, 2000). The epidemics surrounding HIV/AIDS, hantavirus pulmonary syndrome, Ebola, West Nile virus, and dengue during the latter half of the twentieth and early years of the twenty-first centuries, however, would only reinforce the fact that despite previous successes related to eradication, infectious diseases will continue to emerge or reemerge, with potentially dramatic impacts on human health (Morens et al., 2004; Morse, 2004).

While the breakdown in public health services and epidemiologic research that would result the (re)emergence of infectious diseases across the globe may be attributed to numerous factors (Cohen, 2000; Morens et al., 2004; Morse, 2004), rarely mentioned is the field's inability to envision disease potentially decades into the future. As a future-oriented science, there is a marked dedication to anticipatory thinking and the field requires researchers and practitioners to not only anticipate but also prevent the unintended consequences of current actions in the future (Boone, 2010; Kates, 2011; Leischow et al., 2008; Solow, 1991; Wiek et al., 2011). While significant work has resulted from epidemiologists' initiatives to improve modeling techniques related to infectious disease, such efforts are often directed towards short-term predictions for the near future (McMichael, 2006; Wing, 1994). While the methods used to create, analyze, and evaluate future scenarios of disease from sustainability science will not replace the current efforts of epidemiologists and public health professionals to predict the drivers of disease and their outcomes in the future, because of the inherent concern for future generations, sustainability science will facilitate extending timeframes for prediction and motivate continued prioritization of surveillance, control, and prevention measures, particularly related to infectious disease.

DOMAIN 3: APPRECIATION OF CONTEXT

A final opportunity space in which sustainability science may benefit the field of epidemiology attempts to address the tension between generalizable, universal, explanations of disease and contextual explanations of disease (Wing, 1994). In an effort to produce knowledge that is generalizable, or applicable, to broad audiences, modern researchers and practitioners within the field of epidemiology focus primarily on the individual-level behaviors or risk factors associated with a particular disease outcome (McMichael et al., 2003). By focusing on individual-level, or proximate, causes of disease, the field of epidemiology is capable of recommending and implementing seemingly "ready-made" intervention materials that address the specific individual-level behaviors and risk factors that have been shown to contribute to a particular disease outcome (McMichael et al., 2003; McMichael et al., 1999; Wing, 1994). The power of modern epidemiology, therefore, is its ability to identify individual-level factors that contribute to a specific disease outcome that should hold true in all where ever a disease is present (Little, 1998). For example, in a recent study, Sutcliffe et al. (2011) examined individual-level risk factors related to malaria infection in Zambia and found that among other factors, younger age, using an open water source, and not sleeping under and insecticide-treated bed net were all associated with malaria infection. If studies continue to demonstrate similar results regarding individual-level factors and malaria infection, epidemiologists and public health professionals may feel more confident in directly addressing individuals that fit specific demographics or practice particular behaviors.

While increased confidence in and generalizability of individual-level risk factor-disease outcome relationships are invaluable to the field of epidemiology, and public health in general, absent from modern epidemiologic analyses and related interventions, however, is the recognition that 'context' may also contribute to disease. In this sense, 'context' is not defined in relation to specific (arbitrary) study areas identified by researchers from which individuals may be (randomly) selected and aggregated based on behaviors, risk factors, and disease outcomes. Rather, a sustainability science framework defines 'context' as the large-scale social, cultural, political, economic, and environmental processes that operate across both space and time (McMichael et al., 1999). According to the "risk factor" epidemiology described above, broad, multi-scalar processes such as economic development, social class, and land use/land cover transformations are recognized as confounding factors; factors that must be controlled for through research and analytic design methods (McMichael et al., 2003; Wing, 1994). As demonstrated by Graves et al. (2009), in addition to individual-level factors such as the number of long-lasting insecticide treated nets within household, environmental factors, including altitude and rainfall, contribute to disease infection status as well.

While it is the individual that exhibits a risk factor or becomes ill, it is impossible to divorce individuals from their social-ecological contexts (Morse, 2004; Wing, 1994). While incorporating contextual influences in the examination of the distribution and determinants of disease, as opposed to controlling for such factors, may limit the broader impacts of specific research, an epidemiology informed by sustainability science attempts to address place-based health challenges with place-based, contextual solutions. Moreover, an epidemiology that incorporates the contextual nature of disease may also explain disease as it is local experienced by answering such questions as ‘why are some individuals are exposed but not others,’ ‘what environmental changes explain current patterns of exposure and disease,’ or ‘how have long-term changes in broad population structure and economic development influenced disease transmission.’ According to the WHO, human health is more than simply the presence or absence of disease (Sartorius, 2006; World Health Organization [WHO], 2005). Similarly, human health is more than individual-level behaviors and risk factors. Rather, human health is also contextually embedded within and impacted by our social-ecological systems. Therefore, if researchers and practitioners within the field of epidemiology are to recognize the role that one’s social, economic, political, and environmental context plays in both causing and preventing or reducing disease, sustainability science may facilitate the generation of such contextual understandings of the distribution and determinants of disease (McMichael et al., 1999; Wilcox & Colwell, 2005).

CONCLUSIONS

To this point, I have described the shared commonalities between both sustainability science and public health, and in particular the field of epidemiology. Additionally, this review has provided specific examples that demonstrate how key principles of sustainability science may benefit the researchers and practitioners of the field of epidemiology. While recent reviews have identified specific limitations associated with the field of sustainability science (Lang et al., 2012), such recommendations are methodological in nature. For example, as described earlier in this review, sustainability scientists and scholars often encounter methodological challenges associated with participatory, collaborative research methods. Additionally, Lang et al. (2012) explain that researchers and practitioners of sustainability science often encounter challenges associated with the translation of actionable knowledge into political processes and legal resolutions (Lang et al., 2012, p. 38). Moreover, tracking societal impacts as they relate to and address sustainability science's core research agenda remains elusive at best (Lang et al., 2012, p. 39). While the field of sustainability science will certainly benefit from advances that address the methodological challenges described above, it is my opinion that if we are to achieve a sustainability transition, the field must expand its current conceptualization regarding sustainability outputs to incorporate human health.

In the face of numerous challenges that exhibit complexity that is beyond our current level of understanding (van der Leeuw et al., 2012), operate across both spatial (from local to global) and temporal (impacts will be experienced both immediately and into the future) scales, and require multiple perspectives and diverse knowledge-types to address, it is widely recognized that there is an urgent need for a sustainability transition (McMichael, 2006; McMichael, Smith, & Corvalan, 2000). However, how we "solve" sustainability problems and how society will achieve a sustainability transition is still very opaque (Jerneck et al., 2011; van der Leeuw et al., 2012). Because answering the question "what is to be sustained" is context-based, there are multiple routes by which individuals, neighborhoods, communities, and countries may achieve a sustainability transition (Du Pisani, 2006; Kajikawa, 2008; Kates, Parris, & Leiserowitz, 2005; Rapport, 2007; van der Leeuw et al., 2012). Among the diverse, competing worldviews, values, and priorities that must be negotiated, many researchers and practitioners view the economy, individual and collective livelihoods, environmental resources, cities, infrastructure, and social relations as the measureable outputs of a sustainability transition (Bloom, 2007; McMichael, 2006; McMichael et al., 2003). In aggregation, these outputs constitute a "triple-bottom line" of a sustainability transition. From a public health and epidemiology perspective, however, equitable and properly functioning social-ecological systems are the foundations upon which long-term human health is based (McMichael, 2006; McMichael et al., 2003).

Within the arena of sustainability, I believe that maintaining and improving individual and population health is a primary motivation for economic, social, human, and environmental development (McMichael, 2006). Human health is essential to productivity and innovation and it enables society to survive shocks and stresses that occur over the short- and the long-term, from local to global scales (Bloom, 2007; Wilcox & Colwell, 2005; Woodward et al., 2000). Until recently, however, researchers and practitioners of both sustainability science and public health have largely ignored the health implications of maintaining our coupled social-ecological systems as well as the significance of reconceptualizing sustainability science in light of human health (McMichael, 2006). It is true, the forces that oppose a sustainability transition, whether from indifference, incomprehension, or self-interest, are diverse and powerful

(McMichael et al., 2003, p. 1920). Given the amount of human and financial resources dedicated to addressing urgent health challenges across the globe, I believe that human health may serve as a common denominator within the arena of sustainability science. While it is clear that the fields of public health and epidemiology are likely to benefit from key principles of sustainability science, I believe that the field of sustainability has much to gain if society identifies the level of health attained by the world's population as a fundamental criterion of how well we succeeded at achieving a sustainability transition (McMichael et al., 2000).

CHAPTER 3

EXPLORING THE FACTORS THAT INFLUENCE INDIVIDUALS' KNOWLEDGE AND BEHAVIORS REGARDING MOSQUITO VECTORS OF MARICOPA COUNTY

INTRODUCTION

In the United States, following decades of sustained and successful prevention and control efforts, largely made possible through the development of antibiotics, immunizations, and vaccines, as well as widespread applications of insecticides, many medical and public health professionals concluded that "the war against infectious diseases [had] been won" (Morens, Folkers, & Fauci, 2004). However, infectious diseases, and in particular vector-borne diseases, do not abide by arbitrary political boundaries, and the recent emergence of West Nile virus and dengue in the United States demonstrates the fact that vector-borne disease remains an important global health challenge (Cohen, 2000). In an increasingly interconnected world, while international travel facilitates the mobility of the human population, it also contributes to the geographic expansion of both pathogens and vectors (Butterworth, Kolivras, Grossman, & Redican, 2010). While it will probably never be definitively proven, leading researchers and epidemiologists believe that infected individuals traveling between the Middle East, and in particular Israel, and the United States, introduced the West Nile virus to the New York City area in 1999 (Gubler, 2002b). Similarly increased economic development, precipitated by international trade and global commerce, complicate the distribution of vector-borne disease. While today the pathogen that causes dengue and the mosquito vector that transmits the pathogen enjoy a nearly global distribution, in the 1970s, epidemic dengue fever and dengue hemorrhagic fever were localized to Southeast Asia (Gubler, 2002a). With the expansion of shipping lines between Southeast Asia and North America, it is believed that stored water on ships, often unintentionally transported among goods such as tires, for example, provide sufficient breeding sources for mosquitoes to survive the trip (Gubler, 2002a).

In addition to the increased mobility of people and goods, numerous additional factors have contributed to the emergence and reemergence of vector-borne diseases. While broad biogeophysical changes, particularly changes in climate as well as land use and land cover transformations, changes in human behaviors and demographics, and microbial adaptation have contributed to the expansion of hantavirus pulmonary syndrome, HIV/AIDS, and tuberculosis, respectively, the general breakdown in public health and control measures is perhaps one of the most important factors that have contributed to the emergence of infectious diseases in the United States (Morse, 2004). In general, the belief that “modern medicine would prevail” (Cohen, 2000, p. 762) led to the de-emphasis of research related to the prevention and treatment of infectious and vector-borne diseases and previously effective control measures were allowed to lapse (Morse, 2004). In an effort to address the challenges presented by vector-borne disease in the United States, and assist local control and prevention efforts, this study examines how residents of Maricopa County, Arizona conceptualize risk to West Nile virus.

The emergence and persistence of West Nile virus within the state of Arizona and Maricopa County results from local interactions among the pathogenic agent that causes disease, the mosquito vector capable of transmitting disease, the host, in this case infected humans, and the environment. Researchers and practitioners within the field of public health, however, have often been accused of prioritizing the role of the individual with regard to mosquito-borne disease (Wing, 1994; Wing, 1998). At least with regard to West Nile virus, a focus on the human host, or individual, is understandable for two primary reasons: (1) neither a human vaccine nor specific medical treatments are available; and (2) limited financial and human resources are available to conduct broad applications of insecticides throughout the county. Due to these limitations, in order to prevent West Nile virus transmission, individuals are recommended to regularly perform specific personal protective behaviors (PPBs). Public health professionals are interested, therefore, in identifying specific individual-level factors, such as age or gender, that influence whether or not an individual will perform the recommended PPBs (Gibney et al., 2012). Such information may be incorporated in tailored educational and promotional materials and may improve the effectiveness of public health efforts designed to reduce risk to West Nile virus. Through the use of the Health Belief Model (HBM), one of the objectives of this study is to elucidate potential relationships among social, environmental, and demographic factors and individuals' knowledge, perceptions, and behaviors related to West Nile virus. In addition to individual-level factors, broad, larger-scale environmental factors have been shown to influence individuals' knowledge and behaviors (Ruiz, Tedesco, McTighe, Austin, & Kitron, 2004). By investigating the potential associations between both individual-level and environmental factors and individuals' knowledge of and engagement in PPBs to reduce one's risk to West Nile virus infection this study addresses theoretical and methodological deficiencies within the current body of vector-borne disease literature. The results of this study will contribute to the growing discussion of vector-borne disease, and in particular West Nile virus, within urban settings and will ultimately guide future prevention and control efforts within Maricopa County.

Theoretical framework: the Health Belief Model and mosquito-borne disease

In order to reduce West Nile virus transmission, public health and medical professionals recommend specific PPBs including: appropriately applying bug spray or repellent; avoiding being outside after sunset and before dawn when mosquitoes are known to be most active; wearing long sleeved shirts, jackets, and pants when outside during peak mosquito biting times; draining or removing water where it collects or pools surrounding domiciles or places of work; and repairing screens on windows and doors (Gibney et al., 2012). In order to communicate PPBs effectively to susceptible human populations it is important to first understand how various individual, household, and neighborhood factors impact an individuals' decision-making processes with regard to PPBs. In order to more explicitly elucidate the factors that influence risk-reducing behaviors in Maricopa County and the metropolitan Phoenix area, this study operationalizes components of the HBM with the goal of informing future educational and outreach efforts.

The HBM was developed in the 1950s by a team of social psychologists working for the U.S. Public Health Service and is now one of the most commonly used theories in health education and health promotion (Hayden, 2009). At the time of the model's formulation, researchers and public health professionals attempted to address low participation among the general public in free preventive and disease detection programs (Sharma & Romas, 2008). In particular, the relative failures associated with the Public Health Service's medical screenings and chest examinations for tuberculosis provided the impetus to more rigorously examine the factors that determined health behaviors. Underlying the HBM is the idea that the engagement in or adoption of health behaviors is mediated by individuals' beliefs or perceptions regarding a specific disease, or disease outcome, as well as the risk reducing strategies available to the individual (Hayden, 2009). In particular, according to the HBM, an individual will perform a recommended PPB if the individual recognizes the existence of a potentially serious disease or health condition, perceives that he or she is susceptible to the disease or condition, and believes the benefits from following a particular health behavior outweigh the barriers that hinder its performance (Rosenstock et al., 1998). In its original conceptualization, the HBM consisted of four constructs: the individual's perceived severity of a specific disease or condition, the individual's perceived susceptibility to a specific disease or condition, the perceived benefits of recommended behaviors, and the perceived barriers that prevent an individual's performance of recommended behaviors (Abraham & Sheeran, 2005). Over the last several decades, however, the HBM has evolved to incorporate additional, potentially more subjective, constructs that are believed to influence an individual's decision-making process regarding the practice or adoption of health behaviors: self-efficacy, cues to action, and modifying factors (Rosenstock et al., 1998).

While the HBM has become one of the most commonly utilized health behavior frameworks, there are several conceptual and operational deficiencies associated with the model. Conceptually, definitions for HBM constructs, especially regarding cues to action, modifying variables, self-efficacy, and perceived barriers, have not been standardized across studies (Rosenstock et al., 1998). This translates into difficulties associated with attempting to meaningfully and reliably operationalize the model's constructs and results in a lack of operationalization consistency. Moreover, these conceptual and operational deficiencies limit the potential extension of findings across behaviors and across studies (Abraham & Sheeran, 2005). Finally, there is a disconnect between examining modifiable, and perhaps subjective, perceptions and beliefs surrounding a disease outcome or health condition and achieving long-term, lasting behavioral change. The HBM, however, has been characterized as being capable of comprehensively examining the many factors that influence human behavior as well as informing effective educational and public health efforts. In the absence of prior research, the researchers of this study decided to operationalize the HBM in order to examine the psychological, cognitive, social, and ecological factors that influenced health behaviors within Maricopa County and the metropolitan Phoenix area, the hotbed of disease and control activities in Arizona.

Description and control of West Nile virus in Maricopa County

Located at the center of the state, and the northern reaches of the Sonoran Desert, Maricopa County is home to more than half of Arizona's population. Since the middle of the twentieth century, Maricopa County, and in particular the metropolitan Phoenix area, has experienced substantial demographic increases, and as of 2012, nearly four million individuals live within the county. Perhaps as an indirect or unintended result of this rapid urbanization and development, mosquito populations and mosquito-borne disease have flourished within the county. There are approximately nine mosquito species routinely found throughout Maricopa County, and while many are considered "nuisance" mosquitoes incapable of transmitting disease, there are several species capable of transmitting such diseases as dengue fever, yellow fever, and West Nile virus (Smith, 2009). In Maricopa County, the *Culex* species of mosquito, and in particular, *Culex tarsalis* and *Culex quinquefasciatus*, are the primary vectors of West Nile virus to humans (Townsend, 2012). *Culex* species are particularly suited to the urbanized, developed context of Maricopa County, and they have been described by researchers and public health professionals as 'urban-adapted,' or 'peri-domestic' due to their affinity for and proclivity of breeding in and around homes (Tuiten, Koenraadt, McComas, & Harrington, 2009; Venkatesan, Westbrook, Hauer, & Rasgon, 2007). Female *Culex* mosquitoes also preferentially deposit eggs where water pools or collects around residences. Because of the large, susceptible urban population living in close proximity to competent mosquito vectors capable of transmitting WNv, Maricopa County is the sight of the majority of West Nile virus within the state.

After emerging in the New York City area in 1999, West Nile virus was capable of traversing the rest of the contiguous United States in a matter of years. In 2003, the first human cases of West Nile virus were reported in Arizona, and since its arrival, the disease has permanently established itself within Maricopa County and is expected to persist within the county indefinitely in the future. While the state of Arizona averages between 70 and 110 reported cases of WNv annually, two significant outbreaks have occurred within the state, both primarily affecting residents of Maricopa County (Maricopa County Department of Public Health [MCDPH], 2011). In 2004, 391 individuals were reported to the Arizona Department of Health Services (ADHS) with confirmed West Nile virus infections, of which, 355 individuals were infected in Maricopa County. In 2010, 115 residents of Maricopa County were infected with West Nile virus, of 167 cases statewide. Despite the substantial difference in terms of reported cases of West Nile virus, both outbreaks were nearly identical in terms of deaths attributed to the disease: 16 deaths due to West Nile virus were reported in 2004; 15 deaths in 2010.

In response to the prevalence of adverse health outcomes related to West Nile virus, Maricopa County enlists numerous agencies in the control of mosquito populations and public health promotion. In particular, the Maricopa County Vector Control Division (MCVC), the Maricopa County Department of Public Health (MCDPH), and the ADHS all collaborate to address mosquito-borne disease as it exists within Maricopa County. In the face of limited financial and human resources, however, all three organizations have diminished capacities for conducting research and implementing promotional efforts within the county in response to West Nile virus. In an effort to assist the control and promotional efforts within Maricopa County, this study elicited residents' knowledge, perceptions, and behaviors surrounding mosquito populations and West Nile virus through the use of a self-administered questionnaire.

METHODS

Questionnaire development

In order to develop an appropriate instrument capable of operationalizing the HBM with regard to the specific health behaviors recommended to reduce one's risk to mosquito-borne disease, this study followed the recommended procedures described by Champion (1984). In order to build upon the research already conducted surrounding health behaviors and mosquito-borne disease, a review of recent studies was undertaken. During this review, validated questions and scales were identified to be potentially incorporated in the present study. Because many of the studies reviewed were conducted in diverse, temperate locations throughout the United States and Canada, and not in arid locations similar to Arizona, the elements identified in the literature review process were submitted to local content and research experts.

The initial draft of the instrument was submitted to public health and mosquito control experts with the Arizona Department of Health Services (ADHS) and the Maricopa County Vector Control Division (MCVC), both located in Maricopa County. Experts from ADHS provided input regarding the specific personal protective behaviors recommended in Arizona as well as barriers that are believed to likely impact residents' behaviors. While the public health professionals from ADHS have never conducted a study similar to the one completed here, the anecdotal evidence that they have collected through years of educational and promotional events represented a significant contribution to the instrument design process. Additionally, insights offered by experts from the MCVC proved invaluable in the development of questions that assessed individuals' knowledge of mosquito-borne disease in the metropolitan Phoenix area as well as individual/household-organization interactions and responsibilities regarding local mosquito control efforts. Finally, multiple drafts of the instrument were submitted to academicians with extensive training and knowledge of ethnography, medical anthropology, geography, and sustainability science. While not necessarily content experts, these methods experts provided numerous recommendations with the intent to improve participant comprehension and reliability during the data collection phase.

Following the iterative review processes with content and methods experts, a limited pre-test was conducted with 30 residents of the metropolitan Phoenix area. Participants were recruited in public parks and shopping centers during week days and week-ends such that an equal number of men and women participated. Because of the large Hispanic and Latino population in the metropolitan Phoenix area, equal numbers of Hispanic and non-Hispanic individuals were recruited to participate in the pre-test. During the pre-test phase, respondents were asked to participate in an informal cognitive interview while completing the survey instrument. For each question, the respondent would verbally explain his or her cognitive processes utilized in formulating a response. This is essential for eliciting reliable responses for behaviors that are not necessarily common-place, such as the behaviors recommended by public health professionals to reduce one's risk to mosquito-borne disease. In their verbal explanations, respondents were asked to identify any words or question structures that were confusing, unnatural, or unintuitive. Additionally, respondents were asked to suggest revisions or alternatives for such troublesome aspects of the instrument. Because multiple question formats were included in the draft instrument, respondents were asked to assess differing question formats. Finally, respondents described in detail how they arrived at specific responses. For example, based on the descriptions elicited during cognitive interviews, a specific time frame dating to the most recent summer was used for all questions (because data collection began in September 2012, this was only a few months prior). For longer time frames, such as for the previous year, respondents explained difficulties associated with reporting the frequency with which they performed personal protective behaviors. It was also valuable to discuss the tendency for individuals to alter their response patterns based on knowledge they inferred from previous questions as well as how they believed they "should" respond. Following extensive reflection on the cognitive interviews conducted during the pre-test phase, appropriate revisions were incorporated into the final instrument.

The final instrument implemented in this study incorporates components that are reflective of each of the constructs of the HBM. The structure and order of specific items and constructs within the survey instrument itself was particularly important and the insights provided by Dillman, Smyth, and Christian's (2009) *Internet, Mail, and Mixed-Mode Surveys: The Tailored Design Method,* Bernard's (2011) *Research Methods in Anthropology*, and Babbie's (2010) *The Practice of Social Research* proved invaluable. In the following sections, brief descriptions for each construct of the HBM will be provided.

Behaviors

As described above, public health professionals recommend five behaviors to prevent mosquito bites and infection of mosquito-borne disease. The behaviors specifically examined in this study include: wearing bug spray (mosquito repellent); wearing long sleeve shirts and long pants when outside; staying inside between dusk (sunset) and dawn (sunrise); removing or draining standing water from places or objects around one's home; and repairing holes in windows or door screens. In the questionnaire, each behavior was appended to a common prompt ("When thinking about this past summer how often did you…") and respondents selected among "Always," "Often," "Half of the time," "Some of the time," and "Never." These response options have been implemented by Ivan (2006) and Yerby (2007). Responses were coded numerically from 1 (Never) to 5 (Always) and responses were summed and averaged for each respondent.

Perceived susceptibility

Following other studies that implement the HBM with regard to mosquito-borne disease, the construct of perceived susceptibility was conceptually defined as an individual's belief that he or she may be bitten by mosquitoes and may acquire a disease after being bitten by mosquitoes (Hayden, 2009). In this sense, the two-fold nature of this construct was operationalized by eliciting how concerned individuals were of being both bitten by mosquitoes and becoming sick if they were indeed bitten by mosquitoes. Making this distinction was recommended by content experts as much of their educational materials stress that likelihood of being bitten by a mosquito and the likelihood of contracting an infection after a mosquito bite while different are both important. Respondents were to select their level of concern among ‘very,’ ‘somewhat,’ ‘a little,’ and ‘not at all.’

Perceived seriousness

This construct was conceptually defined as an individual’s perceptions surrounding the extent of medically related harm that may result from an infection of West Nile virus (Abraham & Sheeran, 2005). Using a single question, as has been done reliably in other studies, respondents were asked to report the perceived likelihood that he or she would need to seek medical attention if bitten by a mosquito. Respondents’ level of perceived likelihood was reported as ‘very,’ ‘somewhat,’ a little,’ and ‘not at all’ following the model of Yerby (2007) and Eichler (2011).

Perceived benefits

The construct of perceived benefits was conceptually defined as an individual’s perceptions regarding whether or not specific personal protective behaviors would prevent mosquito bites. While some studies operationalize the construct in terms of preventing an infection of West Nile virus, the recommended personal protective behaviors are more correctly specified to prevent mosquito bites, and therefore indirectly prevent an infection. This conceptual definition follows suit to that utilized by Butterworth et al. (2010). It is also similar to studies that define the concept in terms of effectiveness, such as Champion (1984). A single prompt was given: “I can prevent getting bitten by mosquitoes by…” to which each of the five recommended personal protective behaviors were appended. Respondents were then asked to identify the level of agreement or disagreement (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree) with each statement.

Perceived barriers

This construct was conceptually defined as the individual's beliefs concerning the factors that prevent him or her from performing recommended health behaviors. If respondents did not 'Always' perform the recommended personal protective behavior, as elicited in specific behavior frequency questions, they were asked to identify the reason or reasons that prevented them from performing the health behavior. The potential barriers that were included in this instrument were identified in the literature as well as during cognitive interviews of the pre-test phase (Loeb et al., 2005; Zielinski-Gutierrez & Hayden, 2006). In an effort to elicit honest responses, this construct included an "other" category in which respondents could write-in the barriers that prevented them from performing specific personal preventive behaviors.

Perceived self-efficacy and responsibility

Regarding individuals' perceived responsibility, a six-item scale was created that elicited respondents' levels of agreement with specific statements. Statements included in this scale focused on respondents' willingness to participate individually and in collaboration with other individuals, households, and organizations in the control of local mosquito populations. Additionally, perceived self-efficacy is operationalized to reflect individuals' beliefs surrounding responsibility of mosquito control efforts within Maricopa County.

Cues to action and modifying variables

Cues to actions and modifying variables were defined in this study as any factors, both internal and external to the individual, which may influence a person's motivation to adopt a new behavior (Hayden, 2009). In practice this construct is broad and usually cannot be neatly reduced to a single item or a single value. There are, however, specific items within the construct that are of particular importance to the study. For example, individuals' knowledge is perhaps the most significant factor identified as a cue to action in this study. While many studies assess individuals' awareness of mosquito-borne disease transmitted within the study area, as this instrument does, for numerous practical reasons few move beyond such limited assessments of knowledge. This study, therefore, also examines individuals' knowledge of mosquito ecology, including development and breeding requirements. Additionally, this study assumes that awareness of control efforts undertaken by the Maricopa County Vector Control Division is also an essential part of individuals' knowledge of mosquito-borne disease in Maricopa County. The five knowledge questions within the questionnaire were evaluated by the researcher in a binary manner; that is, responses were either correct or incorrect. Responses for each question were then totaled.

Demographic information has been identified in numerous studies as modifying variables. In this study, demographic information including age, gender, race and ethnicity, income, educational attainment, amount of time spent outside after sunset but before sunrise, and length of residence were all recorded in the questionnaire. Additionally, access to a pool, which includes shared pools within apartment complexes or private pools, but not public pools and neighborhood flood irrigation were included in the questionnaire.

Implementation and data collection

In an effort to survey a representative sample of the metropolitan Phoenix area and Maricopa County in general, this study borrowed from the sampling framework developed by researchers at Arizona State University related to the Phoenix Area Social Survey (PASS). The PASS is part of a larger research collaborative known as the Central Arizona Phoenix Long-term Ecological Research (CAP-LTER) project and beginning in 2003 the PASS has linked social measurements to the ecological data collected by CAP-LTER researchers. In their most recent 2012 iteration, PASS researchers selected 40 neighborhoods throughout the metropolitan Phoenix area for implementation.

In an effort to not only achieve a balanced sample, but to also build upon the work completed by PASS researchers, this study identified neighborhoods based on PASS income stratification (low, middle, high) as well as dominant land cover characteristics (mesic, xeric, and oasic/mixed). Mesic neighborhoods are best characterized by water-intense landscaping, including lush lawns and fruit trees. Xeric land cover consists of drought-tolerant, and likely drip-irrigated landscaping, that complements loose gravel. Oasic/mixed neighborhoods, therefore, are best characterized by residences that may have small patches of turf grass surrounded by gravel, cactus, and other drought-tolerant species of vegetation. Of the 40 PASS neighborhoods studied in 2012, this study randomly selected nine neighborhoods, one from each income-land cover stratification, in which the survey would be administered (refer to Figure 3.1).

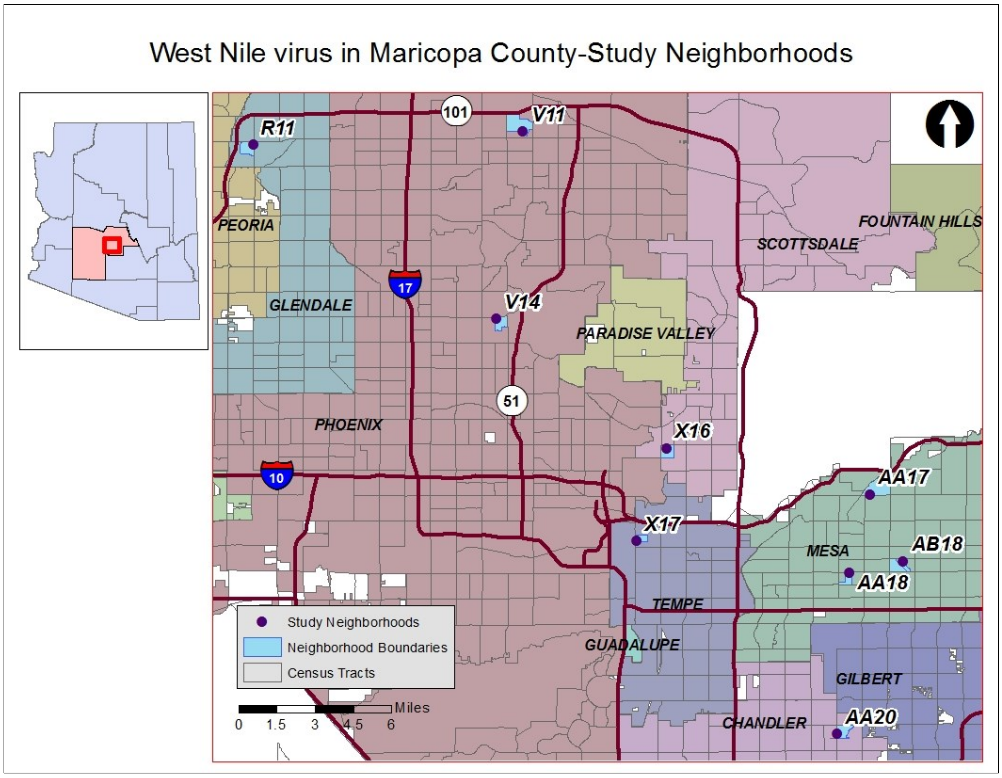


Figure 3.1. Geographic location of nine study neighborhoods throughout Maricopa County.

The target population for the study included residents of Maricopa County who were 18 years old or older. For each neighborhood the target number of surveys was 25, constituting a sample population of 225 individuals. The researcher and six undergraduate students comprised the research team that would administer the survey. Training was administered to all assistants by the researcher and included, among the protocols described below, individual certification for human subjects research and project certification through the Institutional Review Board (IRB) of Arizona State University (ASU) as well as the research office of the Arizona Department of Health Services.

The research team administered the survey instrument through door-to-door recruitment. For each neighborhood, members of the research team identified a starting point and approached every third residence for recruitment. Upon contacting residents, members of the research team recruited eligible residents for participation. Informed consent, which described the nature of the project, the role of the participant, and the potential benefits and the consequences of participation, was provided to all participants. In particular, participants' voluntary and anonymous participation was emphasized. Additionally, contact information for the researcher, the IRB of ASU, and the research office of ADHS was provided to all participants.

Surveys were conducted in-person and were self-administered, meaning the participant, and not a member of the research team, selected response options to complete the survey. When the survey could not be completed in the presence of a member of the research team, a copy of the survey was left with the participant and an appointment was scheduled for the member of the research team to retrieve the completed survey.

Recruitment was conducted between the hours 3:00 and 7:00 PM during the week, and between 11:00 AM and 7:00 PM on weekends. For each recruitment attempt (this study considers knocking on the door as a recruitment attempt) there were several potential results. During the calculation of the project's response rate, members of the research team reported failing to contact the potential respondent, contacting the respondent but unsuccessfully recruiting the respondent to complete the survey, and contacting the respondent and successfully recruiting the respondent to complete the survey. From the American Association of Public Opinion Research (AAPOR), a response rate of 37.7% was calculated using the following formula:

RR = (CP) / [(CP) + (R + NC + O)]

RR = (212) / [(212) + (58 + 256 + 36) = 0.3772

CP = the number of completed and partially completed survey

R = the number of in-person refusals (i.e. a member of the research team was able to contact the resident but was unable to successfully recruit the resident to complete the survey)

NC = the number of non-contacted residences (In this study, a non-contact result was designated when a member of the research team approached the residence, knocked or rang the doorbell, but was unable to speak with the resident. In other response rate calculations, the number of unoccupied residences and the number of residences whose occupancy status is questioned or unknown are separated into individual variables. In this study, because it is difficult to accurately determine that a residence is vacant or unoccupied, these cases were reported as non-contacts.)

O = recruitment results classified as “other” (in this study, a designation as ‘other’ signifies that a member of the research team was able to contact and successfully recruit the resident to complete the survey, but for various reasons, was unable to make contact with the resident in order to collect the completed survey)

All completed and partially completed surveys were recorded in digital form through the use of Survey Monkey and prepared for analysis using the Statistical Package for Social Sciences (SPSS, Inc., Chicago, IL).

Data analysis

All data were analyzed using SPSS 19 software. Because the dependent variables of interest were recorded and prepared as different data types, i.e. continuous and dichotomous, both multiple linear regression and binary logistic regression were performed in order to identify statistically significant independent predictors, or explanatory, variables. While multiple linear regression allows multiple continuous or dichotomous variables to be applied in the statistical analysis, the technique requires that the dependent variables whose variance is being explained be continuously recorded. Therefore, only the dependent variables reflecting respondents' knowledge of mosquito-borne disease and respondents' performance of recommended personal protective behaviors were analyzed using multiple linear regression. Binary logistic regression is commonly employed by researchers investigating health related and behavioral outcomes as it is a technique that can be used to generate odds ratios (Adams, LoBianco, Wilcox, & Hadler, 2003; Aquino, Fyfe, MacDougall, & Remple, 2004; Elliott, Loeb, Harrington, & Eyles, 2008; Han et al., 1999). Briefly, odds ratios represent the "changes in odds of being in one of the categories of outcome when the value of a predictor variable increases by one unit" (Tabachnick & Fidell, 2007, p. 461). Put another way, odds ratios express the relationship among categorical variables (Bernard, 2011, p. 506) and reflects the likelihood that individuals exhibiting a specific outcome for a dependent variable also exhibit specific outcomes for independent predictor variables. While the technique allows researchers to explain the variance observed in dependent variables by independent, predictor variables, similar to multiple linear regression, in this case, the dependent variable of interest must be dichotomously recorded, as opposed to continuously recorded variables used in multiple linear regression. In this study, dependent variables of interest examined through binary logistic regression include: “Always or Often performing at least one personal protective behavior,” “Always or Often performing at least two personal protective behaviors,” as well as “Always and Often” performing each specific personal protective behavior individually.

RESULTS

Demographics

Table 3.1.
Respondent demographic information.

	Frequency (%)
Gender and Age Figures (n=206)	
Female	112 (52.8)
Male	94 (44.3)
Median Age (Range) (*n*=205)	42.85 (18-87)
Race and Ethnicity (n=188)	
African American/ Black	6 (2.8)
American Indian/ Native Alaskan	3 (1.4)
Asian/ Asian American	8 (3.8)
Caucasian/ White	158 (74.5)
Native Hawaiian/Pacific Islander	2 (0.9)
Other	17 (8.0)
Hispanic/ Latino (*n*=205)	43 (20.3)

Table 3.1. *(continued)*

Educational Attainment (n=208)	
Elementary school (grades K-8)	5 (2.4)
High school (or GED equivalent)	32 (15.1)
Technical school or post-high school vocational school	13 (6.1)
Some college or university (you did not receive a Bachelor's degree)	62 (29.2)
College or university (you received a Bachelor's degree)	50 (23.6)
Post-graduate or professional degree (master's degree; Ph.D., J.D., MBA, etc.)	29 (13.7)
Decline to answer	17 (8.0)
≤ HS (Completed 12 years of less of school; includes ED equivalent)	37 (17.5)
> HS (Completed 13 or more years of school)	154 (72.6)
≥ College Degree (Completed 16 or more years of school)	79 (37.3)
Reported Income (n=202)	
< $20,000	15 (7.1)
≥ $ 20,000 but < $27,500	13 (6.1)
≥ $27,500 but < $35,000	8 (3.8)
≥ $35,000 but < $42,500	14 (6.6)
≥ $42,500 but < $50,000	10 (4.7)
≥ $50,000 but < $60,000	16 (7.5)
≥ $60,000 but < $70,000	21 (9.9)
≥ $70,000 but < $80,000	16 (7.5)
≥ $80,000 but < $100,000	16 (7.5)
≥ $100,000 but < $125,000	15 (7.1)
≥ $125,000	16 (7.5)
Decline to answer	42 (19.8)

Knowledge

Of 211 respondents who completed the question, 82 (38.7%) reported that they were aware of diseases were that were spread by mosquitoes within Maricopa County and correctly identified West Nile virus. 103 (48.8%) respondents did not believe that there were mosquito-borne diseases currently transmitted in Maricopa County and 26 (12.3%) respondents were unsure or undecided whether or not mosquito-borne disease existed in Maricopa County. Four individuals incorrectly identified malaria, and two incorrectly identified dengue as being transmitted within Maricopa County. Of those who correctly identified West Nile virus as a mosquito-borne disease currently transmitted in Maricopa County, nearly all respondents (80; 37.7%) correctly identified West Nile virus as potentially fatal. When asked to name the agency primarily responsible with the surveillance and control of mosquito populations within Maricopa County, only 5 individuals (2.4%; n=209) correctly identified the Maricopa County Vector Control Division. The majority of respondents, therefore, either did not believe that there any organization or entity was responsible for mosquito control (123; 57.7%) or were unaware that mosquito control efforts were being conducted within the county (83; 38.8%).

This study expanded on typical assessments of knowledge as described above to assess individuals' knowledge of local mosquito ecology. For example, when asked to identify the length of time required for mosquitoes to develop from egg to adult 15.1% (32 of 211) provided a response within the appropriate range seven and twelve days. Fully 70% of respondents (149 of 211) correctly identified breeding habitats for mosquitoes.

Behaviors

Table 3.2.
Respondent performance of personal protective behaviors (% of all respondents).

	Never	Some of the time	Half of the time	Often	Always
Wear bugspray (mosquito repellent)	122 (57.5)	48 (22.6)	11 (5.2)	13 (6.1)	16 (7.5)
Wear long clothing	107 (50.5)	64 (30.2)	15 (7.1)	17 (8.0)	5 (2.4)
Stay inside during peak mosquito times	64 (30.2)	59 (27.8)	21 (9.9)	39 (18.4)	26 (12.3)
Remove or drain standing or pooled water	65 (30.7)	31 (14.6)	10 (4.7)	28 (13.2)	75 (35.4)
Repair window and door screens	112 (52.8)	19 (9.0)	8 (3.8)	7 (3.3)	61 (28.8)

Table 3.3.
Number of respondents who 'Always' or 'Often' perform PPBs (% of all respondents).

	Frequency
Always' or 'Often' performing 0 PPBs	62 (29.2)
Always' or 'Often' performing 1 PPB	58 (27.4)
Always' or 'Often' performing 2 PPBs	56 (26.4)
Always' or 'Often' performing 3 PPBs	24 (11.3)
Always' or 'Often' performing 4+ PPBs	11 (5.2)

The number of individuals who 'Always' or 'Often' perform a specific personal protective behavior can be calculated from the table above. 149 (70.3%) respondents 'Always' or 'Often' performing at least one personal protective behavior, and 91 respondents (42.9%) reported 'Always' or 'Often' performing at least two personal protective behaviors.

Perceived susceptibility and seriousness

Table 3.4.
Respondents' perceived susceptibility and seriousness of West Nile virus (% of all respondents).

	Not at all	A little	Somewhat	Very
Concern for being bitten by mosquitoes	71 (33.5)	68 (32.1)	35 (16.5)	34 (16.0)
Concern for becoming sick if bitten by mosquitoes	104 (49.1)	58 (27.4)	30 (14.2)	18 (8.5)
Likelihood of seeking medical attention if bitten by mosquitoes	159 (75.0)	27 (12.7)	13 (6.1)	10 (4.7)

As mentioned above, this study operationalized the perceived susceptibility construct in two parts: concern for being bitten by mosquitoes, and concern for becoming ill following a mosquito bite. Approximately one-third of all participants did not express any concern for being bitten by mosquitoes, while nearly one-half of all respondents did not express any concern for becoming ill if bitten by mosquitoes. In an alternative structure reflecting perceived susceptibility, residents were asked to assess their neighborhood in terms of mosquito abundance and biting frequency. Individuals were prompted to characterize their neighborhood as "high" if they see mosquitoes outside almost every day and almost always are bitten by mosquitoes when they are outside. Individuals of a "medium" neighborhood see mosquitoes on most days and are bitten only once or a few times a week. Finally, residents of a "low" neighborhood see very few mosquitoes when they are outside around their home and almost never are bitten. 92 (43.4%) of all respondents identified their neighborhood as "low", while 40 (18.9%) respondents classified their neighborhood as "high" in terms of mosquito abundance and biting activity.

Perceived benefits

Table 3.5.
Respondents' perceived benefits of PPBs (% of all respondents).

	Strongly Disagree	Disagree	Neither Agree/ Disagree	Agree	Strongly Agree
Wear bug spray	10 (4.7)	18 (8.5)	38 (17.9)	83 (39.2)	53 (25.0)
Wear long clothing	11 (5.2)	26 (12.3)	35 (16.5)	90 (42.5)	41 (19.3)
Stay inside during peak mosquito times	11 (5.2)	11 (5.2)	24 (11.3)	99 (46.7)	56 (26.4)
Remove or drain standing or pooled water	8 (3.8)	8 (3.8)	16 (7.5)	66 (31.1)	106 (50.0)
Repair window and door screens	7 (3.3)	8 (3.8)	28 (13.2)	88 (41.5)	72 (34.0)

Operationalized in terms of effectiveness, the perceived benefits construct asked respondents to identify the extent to which they agreed or disagreed with the ability of each specific personal protective behavior would prevent getting bitten by mosquitoes. At least 61% of respondents either agreed or strongly agreed that each personal protective behavior is capable of preventing getting bitten by mosquitoes; fully 81% of respondents agree or strongly agreed that removing or draining standing or pooled water would prevent getting bitten by mosquitoes.

Perceived barriers

Nine barriers, identified in the literature, through conversations with local mosquito control and public health experts, and cognitive interviews during the pre-test phase, were included in the survey. 56 (26.4%) respondents identified that they did not 'Always' wear bug spray (mosquito repellent) because they considered it to be too greasy or messy. The amount of time that respondents perceive bug spray to work or function properly was also noted as a barrier and 35 (16.5%) respondents explained that bug spray was not “long lasting.” The third most frequent barrier to wearing bug spray as identified by respondents surrounded health concerns: 31 (14.6%) of respondents did not ‘Always’ wear bug spray because it irritates their skin or produces rashes. Finally, 21 (9.9%) individuals explained that they forgot to either purchase or apply bug spray.

Of the three barriers provided in the questionnaire, 166 (78.3%) respondents explained that wearing long clothing, including long sleeve shirts and long pants, when outside during peak mosquito biting times (after sunset and before sunrise) was uncomfortable due to summer temperatures. Of the 26 respondents who provided their own response, 15 similarly explained that summer temperatures are “too hot” to wear long clothing.

When asked why individuals did not ‘Always’ stay indoors between sunset and sunrise, respondents cited that they enjoy leisure activities, such as gardening, relaxing, or walking pets, (111, 52.4%) and they tend to socialize, through picnics, barbeques, reunions, etc., (92 (43.4) during this time.

The most common barrier that prevents individuals from ‘Always’ removing or draining standing or pooled water from around their homes as identified by the respondents reflects the presence of standing or pooled water: 71 (33.5%) respondents stated that water does not pool or collect around their home. The utility of removing standing water was also identified as a barrier to respondents: 23 (10.8%) explained that they did not ‘Always’ remove standing water because it will just pool or collect in the future.

Of the barriers provided in the survey, cost was most frequently identified by respondents: 26 (12.3%) explained that repairing window or door screens is too expensive. The next most numerous barrier that prevents respondents from 'Always' repairing window and screen doors focused on utility as well: 20 (9.4%) of respondents believe that mosquitoes can get through window and door screens, and therefore repairing them is not useful. Of the 72 responses that participants provided, 49 (23.1% of all respondents) explained that there was no need for repairs.

Perceived self-efficacy and responsibility

Table 3.6.
Respondents' perceived self-efficacy and responsibility regarding mosquito control (% of all respondents).

	Strongly Disagree	Disagree	Neither Agree/ Disagree	Agree	Strongly Agree
Only public health organizations should be responsible for controlling mosquito populations	41 (19.3)	71 (33.5)	56 (26.4)	32 (15.1)	7 (3.3)
I would allow members of the health department to install and monitor a mosquito trap around my home	12 (5.7)	14 (6.6)	48 (22.6)	79 (37.3)	51 (24.1)
It is not my responsibility to control mosquito populations	30 (14.2)	75 (35.4)	60 (28.3)	29 (13.7)	8 (3.8)
There is no use worrying about West Nile virus; I can't do anything about it anyway	43 (20.3)	80 (20.3)	63 (29.7)	13 (6.1)	3 (1.4)
Individuals, families, and neighborhoods must work together to control mosquitoes in Maricopa County	7 (3.3)	6 (2.8)	33 (15.6)	100 (47.2)	58 (27.4)
I would participate in neighborhood programs designed to control and reduce mosquito populations	12 (5.7)	16 (7.5)	56 (26.4)	84 (39.6)	36 (17.0)

112 (52.8%) respondents disagreed or strongly disagreed that only public health organizations should be responsible for controlling mosquitoes and 158 (74.6%) respondents agreed or strongly agreed that controlling mosquitoes in Maricopa County

will require collaborative efforts among individuals, families, and neighborhoods. 37 (17.5%) respondents agreed or strongly agreed that it is not the responsibility of individuals to control mosquito populations, and 16 (7.5%) respondents agreed or strongly agreed that there is no need to worry about West Nile virus infections because they are powerless against the disease.

Cues to action and modifying variables

Regarding information seeking behavior, 127 (59.9%) respondents stated that they would seek information regarding mosquitoes, mosquito-borne disease, and West Nile virus via the internet. The television (69 respondents; 32.5%), medical doctors (60 respondents; 28.3%), and public health organizations (53; 25.0) were also largely identified by respondents as sources of information regarding mosquito-borne disease in Maricopa County. Respondents identified printed materials, including brochures, least frequently (6 respondents; 2.8%).

Of the 212 respondents who participated in the survey, while none had previously been infected with West Nile virus, five respondents knew family members, friends, or acquaintances who had been previously infected. Additionally, two individuals knew someone who had been previously infected with dengue fever, another mosquito-borne disease.

Multiple linear regression

Prior to multiple linear regression, explanatory, predictor variables were analyzed through bivariate regression techniques. Factors with significance values ≤ 0.1 were then selected for multivariate regression analysis. Perceived benefits (perceived effectiveness);

perceived self-efficacy and willingness to participate; race (evaluated as either "White/Caucasian" and "Other"); ethnicity; educational attainment (evaluated as "completed 12 years of school or less, including GED equivalency" or "completed 13 or more years of school); amount of time spent outside; whether or not the individual is outside five or more times per week during sunset and sunrise; the number of years the individual has resided in Maricopa County, and whether or not the individual has resided in Maricopa County eight or more years were all found to be associated with individuals' knowledge of mosquito-borne disease and West Nile virus in Maricopa County at *p*-value ≤ 0.1. After multiple linear regression, perceived self-efficacy and willingness to participate, race (evaluated as either "White/Caucasian" or "Other"), ethnicity, and whether or not the individual is outside five or more times per week during sunset and sunrise were found to remain significant. These four variables were found to explain 25% (F (8, 147) = 7.451, p <0.005). Ethnicity was found to have the largest impact on respondents' knowledge of mosquito-borne disease in Maricopa County (standardized beta coefficient = -0.27, p = 0.002), followed by time spent outside (-0.213; p = 0.003), perceived self-efficacy and willingness to participate (0.179; p = 0.018), and race (0.162; p = 0.045).

With regard to individuals' behavior of all recommended PPBs, perceived susceptibility, perceived severity, perceived self-efficacy and willingness to participate, race, educational attainment, and length of residence in Maricopa County were found to be significant at the *p*-value ≤ 0.1 level after bivariate analysis. After multiple linear regression only perceived susceptibility and race remained significant at $p \leq 0.05$. The model was found to predict 11.8% of individuals' behaviors of PPBs (F (6, 165) = 4.812, p <0.005). Perceived susceptibility was found to have a slightly larger impact (standardized beta coefficient = 0.208, p = 0.02) than race (standardized beta coefficient = 0.158, p = 0.033).

Binary logistic regression

Table 3.7.
Binary logistic regression analysis for respondents who 'Always' or 'Often' wear bug spray (mosquito repellent).

	Univariate analysis			Multivariate analysis		
Predictors	β	OR* (95% CI†)	p value	β	OR* (95% CI†)	p value
MosqNeighRec‡	1.157	3.18 (1.176-8.600)	0.023	1.668	5.302 (1.641-17.134)	0.005
Gender	-0.73	0.482 (0.208-1.116)	0.089			
Residence 8 Years	-0.873	0.418 (0.185-0.946)	0.036			
Landcover§	1.956	0.141 (0.040-0.505)	0.003	-2.071	0.126 (0.032-0.495)	0.003

* Odds Ratio

† Confidence Interval, at 95% level. Calculated by multiplying 1.96 by standard error

‡ Comparison between "Low" and "High" subjective, individual assessments of mosquito abundance

§ Bivariate analysis (β; OR* (95% CI†); p value): Mesic-Oasic/Mixed: -1.956; 0.141 (0-1; 0.040-0.505); 0.003; Mesic-Xeric: -0.863; 0.422 (0-2; 0.170-1.048); 0.063; Multivariate analysis (β; OR* (95% CI†); p value): Mesic-Oasic/Mixed: -2.071; 0.126 (0.032-0.495); 0.003

Table 3.8.
Binary logistic regression analysis for respondents who 'Always' or 'Often' wear long clothing.

	Univariate analysis			Multivariate analysis		
Predictors	β	OR* (95% CI†)	p value	β	OR* (95% CI†)	p value
Severity‡	2.688	14.7 (3.62-59.332)	<0.005	3.491	32.83 (1.598-674.537)	0.024
AvgSusc	0.897	2.453 (1.509-3.990)	<0.005			
PoolRec	-0.863	0.422 (0.149-1.193)	0.104			
Icnome50000	-0.947	0.388 (0.146-1.029)	0.057			
PASSINCOMErec§	-0.998	0.369 (0.110-1.239)	0.107			
Education2Rec	-1.786	0.168 (0.065-0.435)	<0.005	-1.625	0.197 (0.056-0.686)	0.011

* Odds Ratio

† Confidence Interval, at 95% level. Calculated by multiplying 1.96 by standard error

‡ Comparison of "Not at all likely" and "Very likely" in response to likelihood of requiring medical attention after a mosquito bite

§ Comparison of "Low" and "Medium" PASS income classes

Table 3.9.
Binary logistic regression analysis for respondents who 'Always' or 'Often' stay inside during peak mosquito biting times.

	Univariate analysis			Multivariate analysis		
Predictors	β	OR* (95% CI†)	p value	β	OR* (95% CI†)	p value
MOSQNEIGHrec‡	1.358	3.889 (1.754-8.623)	0.001			
Severity§	0.953	2.595 (1.116-6.033)	0.027			
AvgSusc	0.758	2.134 (1.516-3.005)	<0.005			
AvgSelfEff	0.672	1.958	0.007			
Total Knowledge	0.227	1.255 (0.996-1.582)	0.055			
NumYearsResid	0.027	1.027 (1.008-1.047)	0.006			
TIMEOUTSIDE	-0.342	0.71 (0.614-0.821)	<0.005	-0.239	0.788 (0.651-0.952)	0.014
Icnome50000	-0.651	0.522 (0.260-1.045)	0.066			
Education2Rec	-0.909	0.403 (0.193-0.842)	0.016			
TimeOutside5Rec	-1.582	0.205 (0.101-0.418)	<0.005			

* Odds Ratio

† Confidence Interval, at 95% level. Calculated by multiplying 1.96 by standard error

‡ Comparison between "Low" and "High" subjective, individual assessments of mosquito abundance

§ Comparisons in response to the perceived likelihood of requiring medical attention after a mosquito bite (β; OR* (95% CI†); p value): "Not at all" and "A little": 0.953; 2.595 (1.116-6.033); 0.027; "Not at all" and "Somewhat": 1.331; 3.784 (1.197-11.962); 0.023; "Not at all" and "Very": 2.024; 7.568 (1.863-30.744); 0.005

Table 3.10.
Binary logistic regression analysis for respondents who 'Always' or 'Often' remove or drain standing water around the home.

	Univariate analysis			Multivariate analysis		
Predictors	β	OR* (95% CI†)	p value	β	OR* (95% CI†)	p value
RACE_WHITE_ALL_OTHERS	1.513	4.54 (1.929-10.684)	0.001			
MOSQNEIGHrec‡	1.405	4.077 (1.784-9.317)	0.001	1.765	5.842 (1.544-22.098)	0.009
RESIDENCE8YEARS	1.059	2.882 (1.480-5.613)	0.002			
AvgSelfEff	0.993	2.698 (1.661-4.384)	<0.005	0.793	2.211 (1.128-4.333)	0.021
PASSINCOMErec§	0.799	2.222 (1.122-4.401)	0.022			
LandcoverRec¥	0.767	2.152 (1.093-4.238)	0.027			
PoolRec	0.6	1.822 (1.038-3.200)	0.037			
AvgSusc	0.427	1.533 (1.120-2.098)	0.008			
Total Knowledge	0.37	1.448 (1.158-1.811)	0.001			
NumYearsResid	0.03	1.03 (1.010-1.050)	0.002			
AGE	0.015	1.015 (0.998-1.032)	0.079			

* Odds Ratio

† Confidence Interval, at 95% level. Calculated by multiplying 1.96 by standard error

‡ Comparison between "Low" and "High" subjective, individual assessments of mosquito abundance

§ Comparison of "Low" and "Medium" PASS income classes

¥ Comparison between Mesic and Oasic/Mixed land cover classifications

Table 3.11.
Binary logistic regression analysis for respondents who 'Always' or 'Often' repair window and door screens.

	Univariate analysis			Multivariate analysis		
Predictors	β	OR* (95% CI†)	p value	β	OR* (95% CI†)	p value
AvgSelfEff	0.668	1.951 (1.194-3.189)	0.008	0.683	1.98 (1.171-3.348)	0.011
Total Knowledge	0.22	1.246 (0.990-1.567)	0.061			

* Odds Ratio

† Confidence Interval, at 95% level. Calculated by multiplying 1.96 by standard error

Table 3.12.
Binary logistic regression analysis for respondents who 'Always' or 'Often' perform one or more PPBs.

	Univariate analysis			Multivariate analysis		
Predictors	β	OR* (95% CI†)	p value	β	OR* (95% CI†)	p value
Severity‡	1.792	6 (0.760-47.381)	0.089			
MOSQNEIGHrec	1.569	4.8 (1.568-14.690)	0.006			
RACE_WHITE_ALL_OTHERS	1.409	4.091 (1.883-8.887)	<0.005			
AvgSelfEff	0.977	2.656 (1.563-4.514)	<0.005	1.04	2.829 (1.209-6.620)	0.017
AvgSusc	0.629	1.876 (1.277-2.755)	0.001			
AvgEff	0.452	1.571 (1.083-2.279)	0.017			
Total Knowledge	0.299	1.348 (1.055-1.723)	0.017			
NumYearsResid	0.019	1.019 (0.998-1.040)	0.08			
TIMEOUTSIDE	-0.112	0.894 (0.806-0.992)	0.035			
TimeOutside5Rec	-0.596	0.551 (0.278-1.093)	0.088			
LATHISPrec	-0.754	0.471 (0.233-0.949)	0.035			
LandcoverRec§	-1.143	0.319 (0.154-0.661)	0.002	-1.608	0.2 (0.049-0.812)	0.024

* Odds Ratio

† Confidence Interval, at 95% level. Calculated by multiplying 1.96 by standard error

‡ Comparison between "Not at all" and "Somewhat" regarding the likelihood of requiring medical attention after a mosquito bite

§ Comparison between Mesic and Oasic/Mixed land cover classifications

Table 3.13.
Binary logistic regression analysis for respondents who 'Always' or 'Often' perform two or more PPBs.

	Univariate analysis			Multivariate analysis		
Predictors	β	OR* (95% CI†)	p value	β	OR* (95% CI†)	p value
Severity‡	1.295	3.651 (0.910-14.650)	0.068			
MOSQNEIGHrec§	1.045	2.843 (1.320-6.125)	0.008			
RACE_WHITE_ALL_OTHERS	0.956	2.602 (1.140-5.939)	0.023			
RESIDENCE8YEARS	0.762	2.143 (1.104-4.160)	0.024			
AvgSelfEff	0.711	2.036 (1.283-3.231)	0.003			
LandcoverRec¥	0.673	1.961 (1.004-3.831)	0.049			
AvgSusc	0.52	1.683 (1.228-2.306)	0.001			
Total Knowledge	0.23	1.259 (1.012-1.565)	0.039			
NumYearsResid	0.032	1.033 (1.014-1.053)	0.001			
AGE	0.015	1.015 (0.998-1.032)	0.085			
Education2Rec	-0.724	0.485 (0.234-1.006)	0.052			

* Odds Ratio

† Confidence Interval, at 95% level. Calculated by multiplying 1.96 by standard error

‡ Comparison of "Not at all" and "Very" regarding the likelihood of requiring medical attention after a mosquito bite

§ Comparison between "Low" and "High" subjective, individual assessments of mosquito abundance

¥ Comparison between Mesic and Xeric land cover classifications

Seven outcomes were modeled with univariate and multivariate binary logistic regression. While no factors, environmental, social, demographic, or cognitive/perceptual (i.e. HBM constructs) were found to predict the behavioral outcomes examined in this study, at least one factor was found to predict each of the five personal protective behaviors recommended by public health organizations. For example, individuals' subjective assessment of mosquito abundance in their neighborhoods, evaluated as high, medium, or low, was found to partially explain always or often wearing bug spray. With regard to wearing bug spray, individuals who perceive their neighborhood to have numerous mosquito populations and frequent biting (evaluated as "high") are more than five times as likely to wear bug spray compared to those individuals who assess their neighborhood to be “low” in terms of mosquito abundance and biting activity. A similar result is found for draining or removing standing water. Land cover characteristics were also found to predict whether or not an individual always or often wore mosquito repellent, and the mesic (lush vegetation) - oasic/mixed (lush vegetation usually surrounded by xeriscaped gravel) comparison was found to predict behavior. In particular, individuals whose neighborhood is characterized by oasic/mixed land cover features were less likely to wear bug spray compared to individuals whose neighborhood may be predominantly characterized as mesic.

Despite numerous variables revealed through univariate logistic regression to predict always or often wearing long clothing, significant at $p \leq 0.1$, only two factors remained significant after multivariate binary logistic regression: perceived severity and educational attainment. Compared to individuals who are not at all concerned about requiring medical attention after a mosquito bite, individuals who are very concerned are more than 32 times more likely to always or often wear long clothing when outside between dusk and dawn. Education, however, is shown to have a different association with wearing long clothing: compared to individuals who have completed up to 12 years of school, individuals who have completed 13 or more years of school are five times less likely to wear long clothing. Only the time spent outdoors was found to predict whether or not individuals always or often stayed indoors between dusk and dawn, and intuitively there is a negative association.

In addition to individual’s assessment of neighborhood mosquito abundance, perceived self-efficacy and willingness to participate was found to predict individuals’ removal of standing water. As revealed through multivariate binary logistic regression, as individuals' perceived self-efficacy, willingness to participate in mosquito control measures, and sense of responsibility increase, specific to the scale operationalized in this study, individuals are twice as likely to drain or remove standing water. Perceived self-efficacy, willingness to participate and responsibility was also found to predict repairing window and door screens.

While numerous social, environmental, demographic, and individual/cognitive factors were found to predict whether or not individuals always or often performed at least one PPB and two or more PPBs through bivariate analysis, limited factors were retained in the multivariate model. Regarding always or often performing at least one PPB, perceived self-efficacy was found to be significantly associated. Neighborhood land cover classification, specifically the comparison between mesic and oasic/mixed land cover classes, was also retained in the model. No factors, however, were retained in the multivariate analysis with regard to always or often performing 2 or more PPBs.

DISCUSSION

While knowledge was found to be significant in nearly all univariate regression analyses, it was retained as a significant explanatory factor for any behavioral outcome of interest after multivariate analysis. Relative to other studies, respondents' knowledge of mosquito-borne disease and mosquito ecology in this study is low. In Canada, Elliott et al. (2008) found that 99% of all respondents (n = 1,650) were aware of West Nile virus. Aquino et al. (2004) and LaBeaud, Kile, Kippes, King, and Mandalakas (2007) report similarly high levels of awareness surrounding West Nile virus in British Columbia, Canada, and Cuyahoga County, Ohio, US, respectively. In two counties of southwestern Virginia, US, however, Butterworth et al. (2010) report levels of awareness similar to those of this study.

Unlike other studies that identify demographic factors such as age, income, education, and length of residence as predictors of knowledge and awareness of mosquito-borne disease (Bethel & Waterman, 2010; Butterworth et al., 2010; Tuiten et al., 2009), only ethnicity and race were retained as predictive variables of knowledge after multiple linear regression in this study. Specifically, ethnicity, classified as either non-Latino/non-Hispanic or Latino/Hispanic, exhibits a negative association regarding knowledge; race, classified as Caucasian/white or any other race, a positive association. That is, Latino/Hispanic respondents may be less aware of mosquito ecology and West Nile virus in Maricopa County than non-Latino/non-Hispanic respondents. Conversely, Caucasian/white respondents may be more aware of mosquito ecology and West Nile virus than respondents of other races. The fact that the questionnaire instrument of this study was administered only in English is likely to partially explain this finding. Because of the significant proportion of respondents in this study who identified themselves as Latino/Hispanic (20.3%, $n = 43$), it is important that future data collection materials are both culturally and linguistically appropriate. Not only is this likely to provide more reliable responses, but it is likely to more accurately assess respondents' knowledge and awareness of mosquito ecology and West Nile virus in Maricopa County. State and local public health organizations, specifically ADHS and MCDPH, are often cognizant of language barriers with regard to educational and promotional materials. In fact, from both organizations, all West Nile virus materials are available in both English and Spanish. Perhaps more importantly, however, these materials are available in print as well as online.

Public health and mosquito control professionals may address the relatively low knowledge and awareness of mosquito ecology and West Nile virus in Maricopa County via specific information seeking behaviors expressed by the respondents of this study. Several studies from the past decade demonstrate that respondents most frequently consult broadcast media, including television, radio, and newspapers, for information regarding West Nile virus (Aquino et al., 2004; Bethel & Waterman, 2010; LaBeaud et al., 2007; Tuiten et al., 2009). In this study, however, only one third of respondents identified the television as a primary source of information. While the employees of the ADHS and the MCDPH routinely produce press releases for radio spots and local television news programs, according to the responses of this study, it is clear that respondents obtain information from different, non-traditional modes. In particular, more than half of the respondents of this study, 59.9% (n = 212), stated that they would first consult the internet for information regarding West Nile virus. Many studies suggest that length of residence impacts information seeking behaviors and knowledge (Butterworth et al., 2010; Tuiten et al., 2009): that is, the more recently one has moved into the county, the more likely one is to turn to consult internet sources for information. In this study, almost 7% (n = 14) of respondents have lived in Maricopa County for one year or less; 30% of respondents have lived in Maricopa County for eight years or less. In other words, almost one third of the respondents of this study were not residents of Maricopa

County when West Nile virus was first identified. If respondent – public health organization interactions are going to occur more frequently via the internet, health professionals should prepare to take advantage of this alternative channel of communication. In particular, public health messages should be readily accessible to the public and highly specific to local contexts.

As is evident in the linear and logistic regression analyses of this study, individuals' knowledge and awareness of mosquito-borne disease is not enough (Tuiten et al., 2009) when it comes to reducing one's risk of exposure to mosquitoes via personal protective behavior. Several constructs of the HBM, however, are also incapable of explaining personal protective behavior in this study. While perceived susceptibility and to a certain extent perceived severity have been shown to be primary factors regarding whether or not an individual will engage in personal protective behaviors, in this study, perceived susceptibility was found to be predictive of only respondents' knowledge of mosquito-borne disease an perceived severity was found to be predictive of always or often wearing long clothing when outside between dusk and dawn. Indicative of the limited explanatory power of these constructs is the relatively low levels of perceived susceptibility and severity of respondents. In southwestern Virginia, Butterworth et al. (2010) found more than half of respondents to be somewhat to very concerned that they would contract a disease after being bitten by a mosquito. Elliott et al. (2008) report even higher figures: fully three-quarters of respondents stated that they were somewhat or very worried about becoming ill if bitten by a mosquito. While it is not clear whether such high levels of perceived susceptibility and severity are acceptable for the study areas of

Butterworth et al. (2010) and Elliott et al. (2008), it is clear that health messages that emphasize susceptibility to and severity of West Nile virus infection must be appropriate to contextual manifestations of disease. In Maricopa County, and the state of Arizona in general, the vast majority of individuals infected with West Nile virus will not even know they were infected; 20% of infected individuals will present mild symptoms. While one infected individual of 150 will develop severe symptoms, meningitis and encephalitis, and require hospital treatment, these are the cases reported to local and state health departments and the media. While the respondents of this study express low levels of perceived susceptibility and severity relative to other studies (Adams et al., 2003; LaBeaud et al., 2007), public health and mosquito control professionals should not resort to “scare tactics” and over-emphasize the detrimental effects of a West Nile virus infection. Rather, ADHS and MCDPH should continue to public weekly reports of West Nile virus cases in addition to annual summaries of caseloads and fatalities within the county.

While a majority of respondents believe that each recommended personal protective behavior is effective at preventing contact with mosquitoes and mosquito bites, it is clear that there exist significant barriers that need to be overcome to justify, and thereby increase, performance of PPBs. Relative to other studies, respondents of this study perform recommended PPBs with less frequency. For example, while 42.9% of respondents in this study always or often practiced at least two PPBs, 61% of respondents in Elliott et al. (2008) and 59% in Adams et al. (2003) report performing two or more PPBs. While removing or draining standing water is the most commonly practiced PPB among respondents of this study, similar to the results of Aquino et al. (2004), Bethel and Waterman (2010), and Tuiten et al. (2009) the belief that water does not pool or collect around respondents' homes is the most commonly identified barrier of this study. Given the minimal amount of water required of female *Culex* spp. mosquitoes for oviposition, public health messages should emphasize the ecological requirements of local mosquitoes in addition to effectiveness of removing or draining standing water (Zielinski-Gutierrez & Hayden, 2006).

Wearing bug spray (mosquito repellent) was one of the least practiced PPBs as reported by respondents in this study. Unlike other studies in which respondents cite concern for human and environmental health as the primary barrier to wearing mosquito repellent, in this study, respondents most commonly identified the "messy" or "greasy" nature of mosquito repellent as a significant barrier. In addition to emphasizing the effectiveness of mosquito repellent, as recommended by ADHS and the Centers for Disease Control and Prevention (CDC), health messages should highlight to more recent developments of mosquito repellents. While similarly effective compared to products that contain DEET, products that contain the active ingredient Picaridin are marketed as non-greasy alternatives. Such messages may convince respondents of this study to wear repellent while enjoying leisure activities or social events and may represent an appropriate alternative to long clothing, especially given the elevated temperatures of Maricopa County during the summer mosquito season.

In addition to specific individual and demographic factors, this study examined the impact of specific neighborhood-level environmental factors as they relate to individuals' knowledge and behaviors. Because respondents interact with and perform PPBs within household and neighborhood biophysical environments, it is important to investigate multi-scalar explanatory variables with the intent to contribute to more complete understandings of mosquito-borne disease (Han et al., 1999; Liu et al., 2009). In this study, while respondents' knowledge did not significantly differ among three land cover classes (mesic; oasic/mixed; xeric), wearing mosquito repellent was predicted by neighborhood land cover, particularly when comparing respondents of mesic and oasic/mixed land cover neighborhoods. Health messages, therefore, may be effective if they target the specific barriers associated with respondents of specific neighborhood land cover types. For instance, respondents of oasic/mixed land cover neighborhoods are less likely to wear mosquito repellent when compared to respondents of mesic neighborhoods. Health messages, therefore, should not only target individual-level characteristics of respondents, but also specific neighborhood-level characteristics such as land cover.

Respondents' perceived self-efficacy and responsibility was found to predict numerous behavioral outcomes of interest, including the most frequently performed individual PPB, removing or draining standing water around the home, always or often performing at least one PPB, and always or often repairing window and door screens. While respondents of this study expressed confidence in being able to correctly perform recommended PPBs, there is a strong willingness to participate in programs designed to control and reduce mosquito populations on the part of the respondents. This sentiment also extends to engaging with local mosquito agencies such as the MCVC during mosquito surveillance at respondents' residences. Regarding responsibility of mosquito control efforts, respondents of this survey strongly disagree that only public health organizations are responsible. In fact, the majority of respondents agree or strongly agree that collaborations among individuals, families, and neighborhoods are necessary. Not only does this respect the complexity of mosquito-borne disease and mosquito control efforts in Maricopa County, but respondents' perceived sense of responsibility may address the resource constraints of organizations including the ADHS and MCVC. For the respondents of this study, it is clear that health messages should attempt to build upon the perceived self-efficacy and responsibility expressed here.

Future research efforts conducted in Maricopa County should address certain limitations I encountered during this study. Firstly, participants who completed the questionnaire were not selected using probability sampling techniques. While lists of residence addresses were obtained for each study neighborhood from the Tax Assessor's Office courtesy the Maricopa County Association of Governments, after preliminary field verification, it became clear that the most recent records available at the time of the study were incomplete, sometimes by hundreds of residences. Because of the limited financial and human resources available for this study, as well as a relatively short timeline required by sponsor organizations, it was not possible to validate and update the residence address lists used in the study. As described in the methods section above, this study did not simply utilize purposive, or convenience, sampling techniques. The neighborhoods iwhere recruitment occurred were specifically selected by the researchers as indicative of income (low, medium, high) and landscape (xeric, oasic/mixed, mesic) strata, factors have been shown in other studies to influence human behavior as well as mosquito presence and abundance. With the intent of obtaining at least 20 completed questionnaires from each of the nine study neighborhoods, a starting residence and walking path were identified for each neighborhood, and members of the research team recruited participants at every third residence. Because the respondents who completed the questionnaire were not selected at random the results of this study cannot be generalized to the larger population of Maricopa County.

Limitations associated with respondent recruitment also likely limit the generalizability of results. In particular, while recruitment was conducted during the afternoons and evenings of week days and throughout weekends, it is possible that occupational or personal commitments may have limited respondents' participation resulting in a 'non-contact' during recruitment.

In an effort to determine the circumstances or factors that influenced individuals' decision to decline participation, members of the research team attempted to collect information after in-person refusals. A common reason identified by residents who refused to participate in the study related to being occupied at the time of recruitment and unable to find time in the near future to complete the questionnaire. While the in-person recruitment of eligible participants utilized in this study facilitated the collection of this information, as opposed to other recruitment techniques, members of the research team were unable to speak with 256 potential participants (classified as non-contacts), and therefore such information could not be recorded at a substantial number of residences.

Because the only method of data collection was through the use of a self-administered questionnaire, the results of this study are based on self-reported data from respondents. As such, if respondents attempted to answer specific questions in a manner they believed to be more favorable, especially to the researchers, social-desirability effects are likely to result. As an example of this phenomenon, in studies similar to this, social desirability often results in an inflation of the frequency of performing recommended personal protective behaviors; that is, individuals may report that they more frequently perform behaviors measured within the questionnaire than they actually do.

While the study explicitly asked respondents to reflect on personal protective behaviors performed between June and September 2012, which at the time of data collection (October-November 2012) ended only two months prior, this study is not exempt from recall bias.

Regarding the validity of the self-administered questionnaire implemented in this study, while the instrument consists of numerous items and scales developed and validated in previous research, more extensive administration of the instrument is required within Maricopa County.

Finally, as described above, due to financial constraints and a short timeline for project completion, the self-administered questionnaire was administered entirely in English. For many respondents, and for many residents of Maricopa County, English is potentially a second language, and therefore comprehension may be limited.

This study represents the first attempt at investigating the factors that influence individuals' performance of personal protective behaviors for mosquito-borne disease within Maricopa County, Arizona. While the data collected in this study establishes a baseline to build upon, the ability of local mosquito control and public health professionals to reduce residents' risk to mosquito-borne diseases such as WNv will benefit from repeated implementations of the study instrument. Future iterations should strive to secure funding that will support extensive sample frame verification within the specific neighborhoods examined here and also expand implementation throughout the metropolitan Phoenix area. For this, researchers may again build upon the methodologies designed by researchers of the Phoenix Area Social Survey, operated by researchers at Arizona State University. Additionally, researchers should expand the type of data collected at each residence.

Following the data collection methods of LaDeau, Leisnham, Biehler, and Bodner (2013), Tuiten et al. (2009), and Brown et al. (2008), researchers should attempt to conduct what have sometimes been referred to as entomological surveys surrounding participants' domiciles. Observational data recorded may include the number and function of containers immediately surrounding a residence, damage to window or door screens, the type of landscape characteristics present, and the type of irrigation utilized at the residence. All of this information may be used to verify the responses to the questionnaire implemented in this study, which may improve the overall quality of the data elicited. Samples of standing water may also be collected with the participants' permission and analyzed for egg, larvae, and pupae concentrations. Finally, similar to

Shaw, Robbins, and Jones (2010) and Robbins, Farnsworth, and Jones (2008), such contact between researchers and residents may identify individuals willing to assist the Maricopa County Vector Control division's mosquito collection efforts through the deployment of mosquito traps deployed at residences and monitored by volunteers. While such surveys will likely prove beneficial to researchers and professionals, they will likely result in significant increases regarding the financial and human capital required to support such field work and analyze such data.

CONCLUSIONS

Since its emergence in 2003 and 2004, West Nile virus has and will continue to represent a significant health challenge within Maricopa County. While West Nile virus is currently the only mosquito-borne disease natively transmitted within Maricopa County, and therefore the focus of the study described here, Maricopa County is home to many of the components required for native transmission of dengue and yellow fever. In light of these current and future health challenges, as well as the limited capacity of local public health and mosquito control experts to address such challenges, the results of this study have several methodological and practical implications related to the study of mosquito-borne disease, particularly within Maricopa County.

While the Health Belief Model is one of the most widely utilized theoretical frameworks within the broad field of public health, few studies explicitly draw on the HBM in the study of mosquito-borne disease. The instrument developed and implemented in this study, not only draws from this limited body of research, but further expands the HBM into a new, important research domain. In Maricopa County, there has been limited research that examines the numerous factors that influence individual behavior. In response to the 2010 Wet Nile virus outbreak in Maricopa County, a team of epidemiologists investigated modifiable risk factors for West Nile virus infection (Gibney et al., 2012). While the authors investigated the frequency that infected (cases) and non-infected (controls) individuals of Maricopa County performed personal protective behaviors, the purpose of the study was to compare behavioral and neighborhood exposures between cases and controls (Gibney et al., 2012). The constructs of the HBM, however, prove invaluable when the objective of public health professionals is to identify factors that may contribute to the prevention of infection.

Because there is no specific medical treatment or vaccine available for West Nile virus, PPBs have been identified as the most effective method of preventing exposure to mosquitoes and transmission of West Nile virus (Adams et al., 2003; Eisen et al., 2010; Gubler & Clark, 1996). If local and county public health organizations like ADHS and MCDPH are going to emphasize PPBs in Maricopa County, they require a comprehensive understanding of the numerous factors that influence individuals' decision-making processes related to performing recommended PPBs. Because mosquito-borne disease results from the dynamic interactions of the pathogenic agent, the mosquito vector, the human host, and the environment, this study identified cognitive, demographic, social, and environmental factors that influence or predict individuals' knowledge and perceptions of West Nile virus as it exists in Maricopa County as well as their practice of PPBs. In practice, statistical analyses revealed that each of the five PPBs recommended by the ADHS and MCDPH is associated with diverse individual- and neighborhood-level predictive variables. These results highlight the idea that promotional and educational efforts must be tailored not only to specific demographic or socioeconomic factors, but also neighborhood environmental characteristics as well. Such targeted messages, therefore, may sufficiently motivate individuals to more frequently practice recommended PPBs and therefore reduce their risk to infection with West Nile virus.

Mosquito-borne disease in Maricopa County is the result of the dynamic interactions of pathogens, vectors, and hosts across both space and time. In light of recent West Nile virus epidemics both in Arizona and in other parts of the US, if local public health professionals intend to disseminate relevant and effective health messages, continued implementation and evaluation of the instrument developed in this study must be undertaken. In order for public health campaigns to meet community members' needs, it is essential that public health professionals continue to examine how disease is understood and conceptualized by the residents of Maricopa County. This study provides a model for local public health professionals to conduct on-the-ground research in an efficient and cost-effective manner and the lessons learned from this study may prove useful to future health challenges within Maricopa County.

CHAPTER 4

AN ASSESSMENT OF RESPONDENTS' KNOWLEDGE OF THE SPATIAL DISTRIBUTION OF THE MOSQUITO POPULATIONS CAPABLE OF TRANSMITTING WEST NILE VIRUS IN MARICOPA COUNTY, ARIZONA

INTRODUCTION

If researchers and practitioners are to maintain and improve the public's health with regard to infectious disease, there is a need to investigate exposures to and outcomes of disease from a spatial perspective (Clarke, McLafferty, & Tempalski, 1996; Kistemann & Queste, 2004; Krieger, 2003; Ostfeld, Glass, & Keesing, 2005). Too often, however, the spatial extent of disease is characterized solely by the distribution of health outcomes; that is, researchers and practitioners identify the locations of individuals who are ill (Cromley & McLafferty, 2002). For diseases that are transmitted from person-to-person, such as the influenza virus, it is important to identify cases, or infected individuals, in order to provide treatment as well as prevent further spread of disease. However, the spatial extent of diseases with alternative transmission routes is more complex than simply identifying the distribution of human cases of illness (Mayer, 1996; Reisen, 2010). In addition to human hosts, or human cases, the geographic distribution of vector-borne diseases is also determined by the extent of the organisms capable of transmitting disease to humans (Kalluri, Gilruth, Rogers, & Szczur, 2007). For diseases that are transmitted by mosquitoes, such as West Nile virus (WNv), the distribution of the mosquito species capable of infecting humans and other mammals may not only benefit the work of public health professionals, but the public as well (Eisen & Eisen, 2008).

Despite diminishing financial resources, city, county, and state public health agencies continue to advance surveillance efforts, predominantly through the deployment and monitoring of traps, regarding local mosquito populations (Kitron, 1998; Shaw, Robbins, Jones III, 2011; Vazquez-Prokopec, Chaves, Ritchie, Davis, & Kitron, 2010). With such data, not only do experts increase their understanding of potentially heterogeneous distributions of local mosquito populations, but they may also target control efforts designed to eliminate mosquitoes and their breeding grounds (Kitron, 2000). Additionally, knowledge of the distribution of mosquito populations may guide educational and promotional efforts designed to reduce individuals' risk to infection (Eisen & Eisen, 2011). Because there is neither a human vaccine available, nor specific antiviral treatments available for individuals infected with WNv, it is of particular importance that individuals avoid areas where mosquitoes are known to breed or be active (Gubler, 2007; Kramer, Styer, & Ebel, 2008). Knowledge of the distribution of local mosquito populations is therefore essential if members of the public are to follow recommended preventive and protective measures themselves (Eisen & Eisen, 2011).

In a new assessment technique, this study examines individuals' knowledge of the spatial distribution of mosquito populations within Maricopa County, Arizona (USA). In particular, individuals were asked to identify on a map where they believed local mosquito populations to be most numerous. When compared with the actual distribution of mosquito populations, this study attempts to address whether or not specific individual-level demographic, behavioral, socioeconomic, and neighborhood characteristics explain individuals' perceptions of the spatial distribution of mosquito populations within the county. Additionally, this study attempts to determine whether or not common misconceptions, or incomplete understandings, of mosquito ecology, specifically mosquitoes' need for hydrologic resources for breeding and development and the benefit of vegetation with regard to mosquito development, influence or explain individuals' knowledge of spatial distribution of mosquitoes. Because there is a general need within the field of public health to gain a better understanding of individuals' perceptions, beliefs, and knowledge of vector-borne diseases, both aspects of this study may inform future control and outreach efforts within Maricopa County (Eisen & Eisen, 2011; Jacquez, 2000). In particular, identifying individual and neighborhood characteristics that influence individuals' knowledge of the spatial distribution of mosquitoes will facilitate the creation and dissemination of tailored, meaningful health messages. Additionally, examining the environmental cues that may mislead individuals will assist public health experts to confront potential misconceptions regarding the distribution of mosquitoes within the county.

METHODS

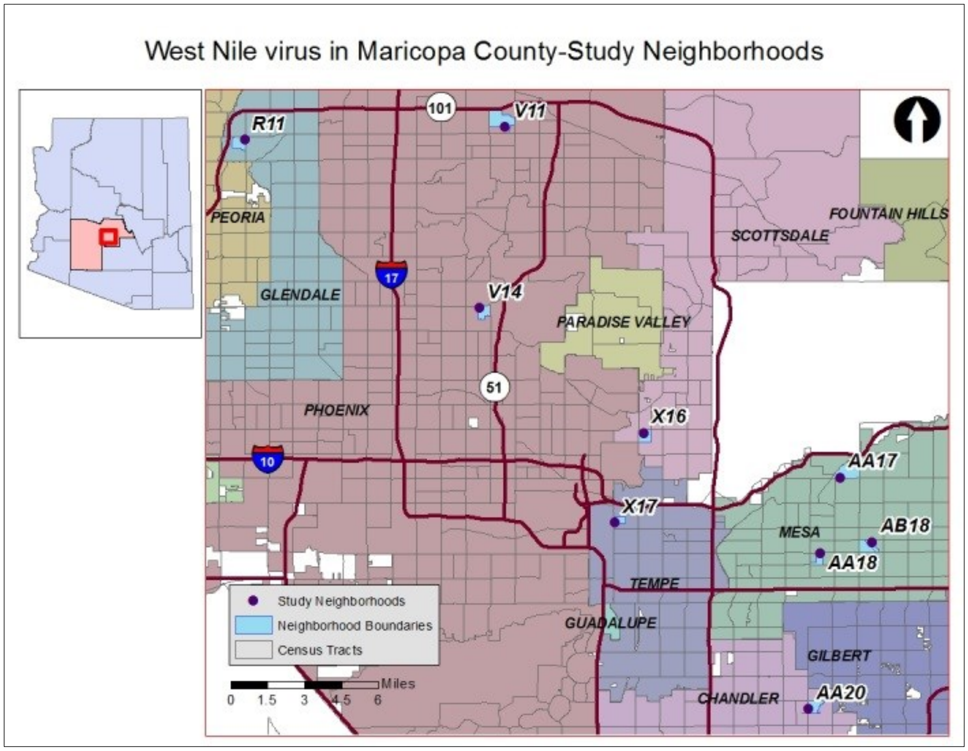


Figure 4.1. Geographic location of nine study neighborhoods throughout Maricopa County.

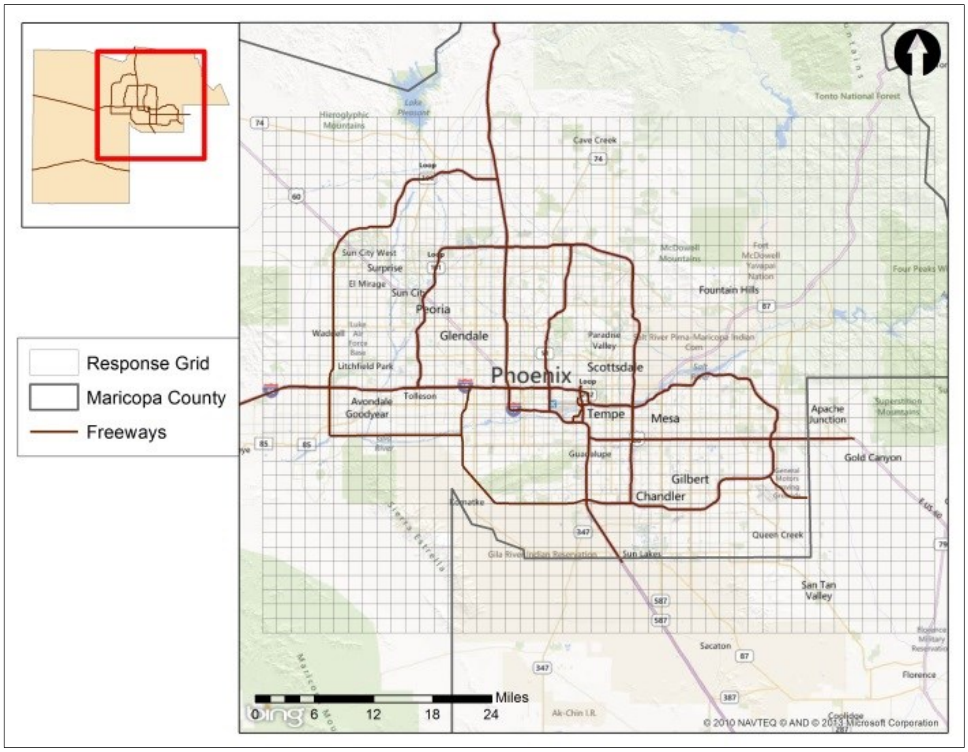


Figure 4.2. Response grid overlaid with basemap of Maricopa County utilized in the questionnaire mapping exercise.

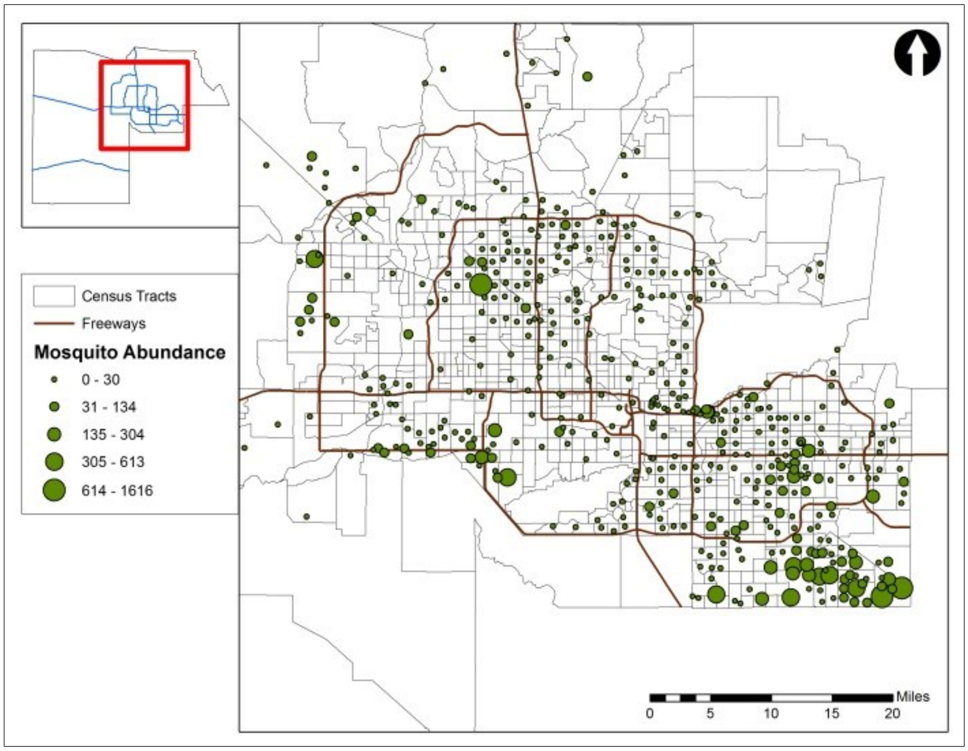


Figure 4.3. Summer (May-September) 2012 mosquito abundance, as recorded by 517 routinely monitored mosquito traps. Data provided courtesy the MCVC.

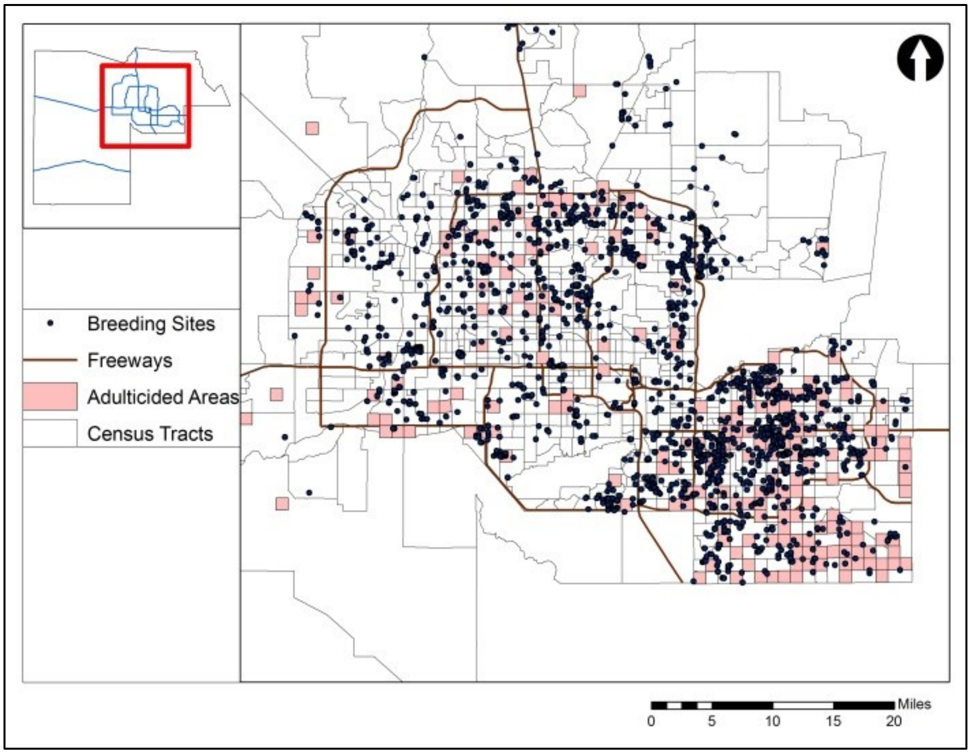


Figure 4.4. Locations of known mosquito breeding sites and adulticided (fogged) areas of Maricopa County. Data provided courtesy the MCVC.

Study sites and survey implementation

In order to elicit perceptions and beliefs regarding the spatial distribution of local mosquito populations, the researchers of this study implemented a self-administered questionnaire to 212 residents of Maricopa County. In an effort to elicit the diverse perspectives among the residents of Maricopa County, members of the research team administered the questionnaire to residents of nine study neighborhoods who were 18 years or older (refer to Figure 4.1). The research team administered the questionnaire through door-to-door recruitment and for each neighborhood members of the research team identified a starting point and approached every third residence for recruitment. Upon contacting residents, members of the research team recruited eligible residents for participation. Informed consent, which described the nature of the project, the role of the participant, and the potential benefits and the consequences of participation, was provided to all respondents. In particular, participants' voluntary and anonymous participation was emphasized. Additionally, contact information for the researcher, the IRB of Arizona State University, and the research office of the Arizona Department of Health Services (ADHS) was provided to all participants.

Participatory map item and processing

In order to assess respondents' knowledge of the spatial distribution of mosquitoes in Maricopa County, a new mapping item was developed for this project (refer to Figure 4.2). Respondents were provided a map of Maricopa County and asked to identify the three locations that they believed mosquito populations to be most numerous. In order to analyze the mapping responses, the authors utilized several techniques found in standard geographic information systems (GIS) packages. In an effort to generate a frequency map in which the number of responses, in this case dots, are tallied for a given areal unit, a rectangular grid was created and overlaid on each respondent's map prompt. Each quadrat cell represented 1.45 mi by 1.45 mi in area, which approximates the flight ranges of the local mosquitoes of the study area. The locations identified by each respondent were then located to the geographic centroid of the quadrat cell with which it intersected.

Mosquito trap data and outcome variables

Mosquito trap data was provided by the Maricopa County Vector Control (MCVC) for 2012. During that year, the MCVC deployed and analyzed more than 1,000 traps at least once. Approximately one-half of these traps, however, were deployed and collected a single time. This study examined only the 517 mosquito traps designated as 'routine,' as they are more frequently monitored and permanently located throughout the county (refer to Figure 4.3). Information is collected on a weekly basis and includes the number of mosquitoes collected, by gender as well as by species. Through the use of tools found in the ArcMap package (ESRI, Redlands, CA), mosquito traps were georeferenced and their figures visualized.

Because respondents were asked to think back on the previous summer, at the time of the study the end of the previous summer was only one month prior, mosquito trap data between the months of May and September were included in the analysis. While public health and mosquito control professionals monitor WNv and mosquito populations year-round, the majority of human cases of WNv and mosquitoes positive for WNv are reported and trapped during this summer period, respectively. Additionally, control measuring including larvicide and adulticide (fogging) applications occur most frequently during the summer months as well (refer to Figure 4.4). In order to account for the disparate number of collections for each mosquito trap (For example, the greatest number of collections between May and September for any single trap was 29; the fewest number of collections for the same period is zero), the sum total of female mosquitoes captured in each trap between the months of May and September was divided by the number of collections for each trap.

After the mosquito trap data collected by the MCVC were prepared for analysis, the local Getis Ord Gi* tool was utilized in order to identify statistically significant hot (clustering of high mosquito abundance) and cold (clustering of low mosquito abundance) spots throughout the county. This spatial statistical tool provided the visual output with which respondents' perceptions were compared. In a binary manner responses were assessed as to whether or not respondents correctly identified the areas of high mosquito abundance, as reported by the MCVC and identified through the Getis Ord Gi* tool.

Statistical analyses

Because the dependent variable of interest (whether or not respondents' perceptions regarding the spatial distribution of local mosquito populations in Maricopa County correctly identified specific areas of high mosquito abundance in Maricopa County), is evaluated in a binary manner, binary logistic regression was utilized. Univariate analyses were first conducted in order to identify specific demographic and socioeconomic variables that may predict respondents' spatial knowledge. Variables with significance values of ≤ 0.15 were then included in multivariate analyses. All statistical analyses were conducted using SPSS (SPSS, Inc., Chicago, IL). 145 respondents completed the mapping item.

RESULTS

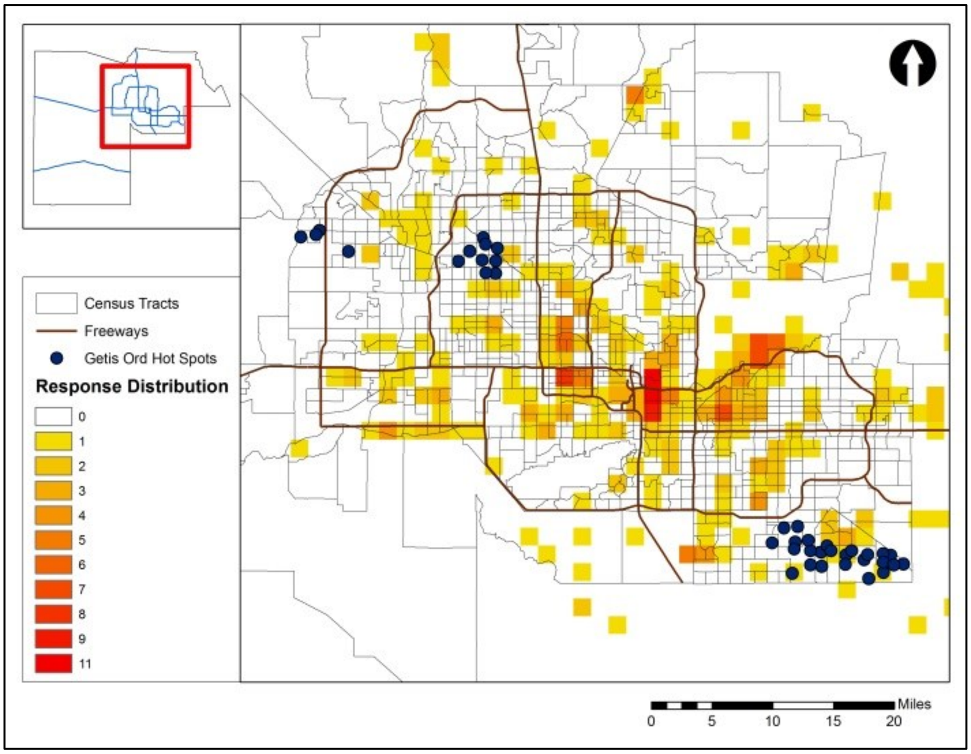


Figure 4.5. Participant response distribution and location of hot spots, as identified by the Getis Ord Gi* tool.

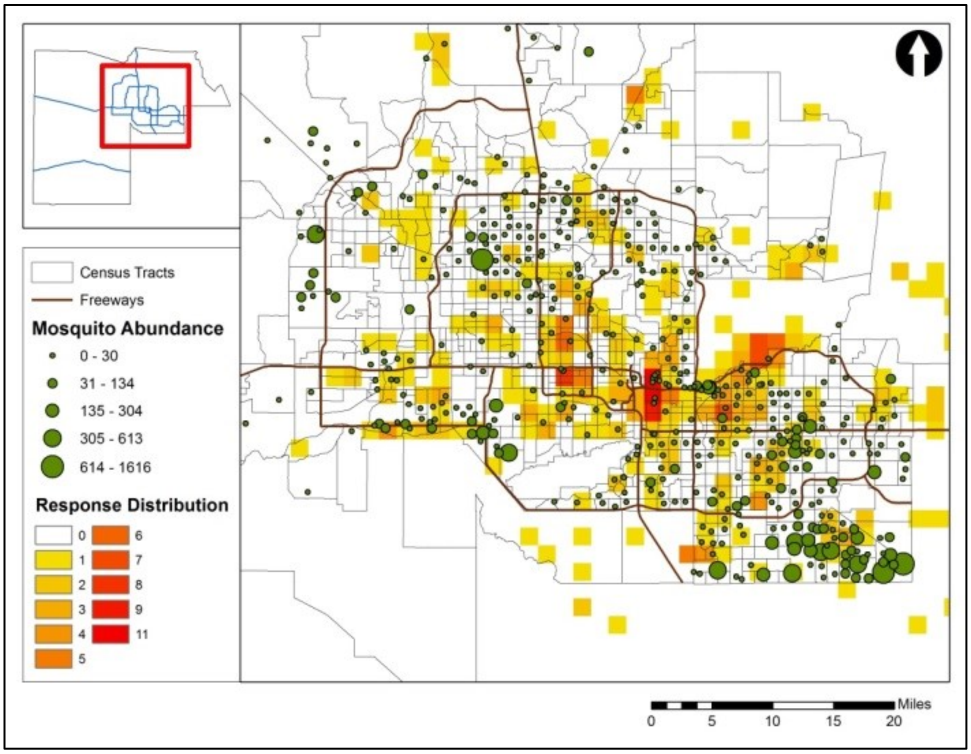


Figure 4.6. Participant response distribution and mosquito abundance values.

Table 4.1.
Respondent demographic information.

	Frequency (%)
Gender and Age Figures (n = 141)	
Female	76 (52.4)
Male	65 (44.8)
Mean Age (Range) (n = 141)	42.2 (18-87)
Race and Ethnicity (n=145)	
Caucasian/White	111 (76.6)
All other races	34 (23.4)
Hispanic/Latino (n=145)	21 (14.5)
Educational Attainment (n=143)	
Elementary school (grades K-8)	3 (2.1)
High school (or GED equivalent)	19 (13.1)
Technical school or post-high school vocational school	8 (5.5)
Some college or university (you did not receive a Bachelor's degree)	44 (30.3)
College or university (you received a Bachelor's degree)	38 (26.2)
Post-graduate or professional degree (master's degree; Ph.D., J.D., MBA, etc.)	22 (15.2)
Decline to answer	9 (6.2)
≤ HS (Completed 12 years or less of school; includes ED equivalent)	22 (15.2)
> HS (Completed 13 or more years of school)	112 (77.2)
≥ College Degree (Completed 16 or more years of school)	60 (42.0)
Reported Income (n = 138)	
< $20,000	14 (9.7)
≥ $ 20,000 but < $27,500	6 (4.1)
≥ $27,500 but < $35,000	4 (2.8)
≥ $35,000 but < $42,500	8 (5.5)
≥ $42,500 but < $50,000	7 (4.8)
≥ $50,000 but < $60,000	13 (9.0)
≥ $60,000 but < $70,000	14 (9.7)
≥ $70,000 but < $80,000	13 (9.0)
≥ $80,000 but < $100,000	11 (7.6)
≥ $100,000 but < $125,000	10 (6.9)
≥ $125,000	11 (7.6)
Decline to answer	27 (18.6)

Table 4.2.
Respondent identification frequencies (% of respondents per neighborhood).

Study neighborhood	AA17	AA18	AA20	AB18	R11	V11	V14	X16	X17	Total
No. of respondents	18 (100)	9 (100)	23 (100)	13 (100)	17 (100)	18 (100)	7 (100)	19 (100)	21 (100)	145 (100)
Getis Ord Gi* Hot Spot Identification	3 (16.7)	1 (11.1)	3 (13.0)	2 (15.4)	6 (35.3)	2 (11.1)	0 (0)	1 (5.3)	0 (0)	18 (12.4)

Table 4.3.
Univariate and multivariate model output, Getis Ord Gi Hot Spot identification: Socioeconomic, demographic, and neighborhood factors.*

	Univariate analysis			Multivariate analysis		
Predictors	β	OR* (95% CI†)	p value	β	OR* (95% CI†)	p value
Education2Rec	1.681	5.368 (0.686-42.042)	0.11			
Land cover Rec‡	1.356	3.882 (1.136-13.268)	0.031			
PASSINCOMErec§	1.247	3.478 (0.916-13.207)	0.067			
Income50000	1.205	3.336 (0.700-15.892)	0.13			

* Odds Ratio

† Confidence Interval, at 95% level. Calculated by multiplying 1.96 by standard error

‡ Comparison between Mesic and Xeric land cover characteristics

§ Comparison of "Low" and "High" PASS income classes

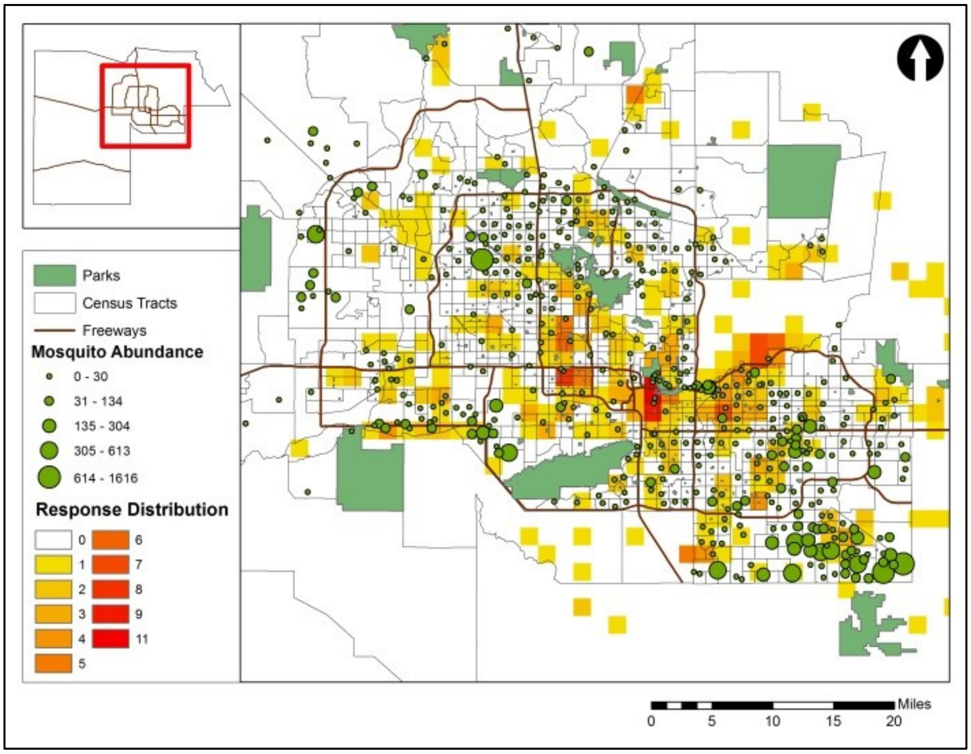


Figure 4.7. Participant response distribution, mosquito abundance values, and the distribution of public parks in Maricopa County.

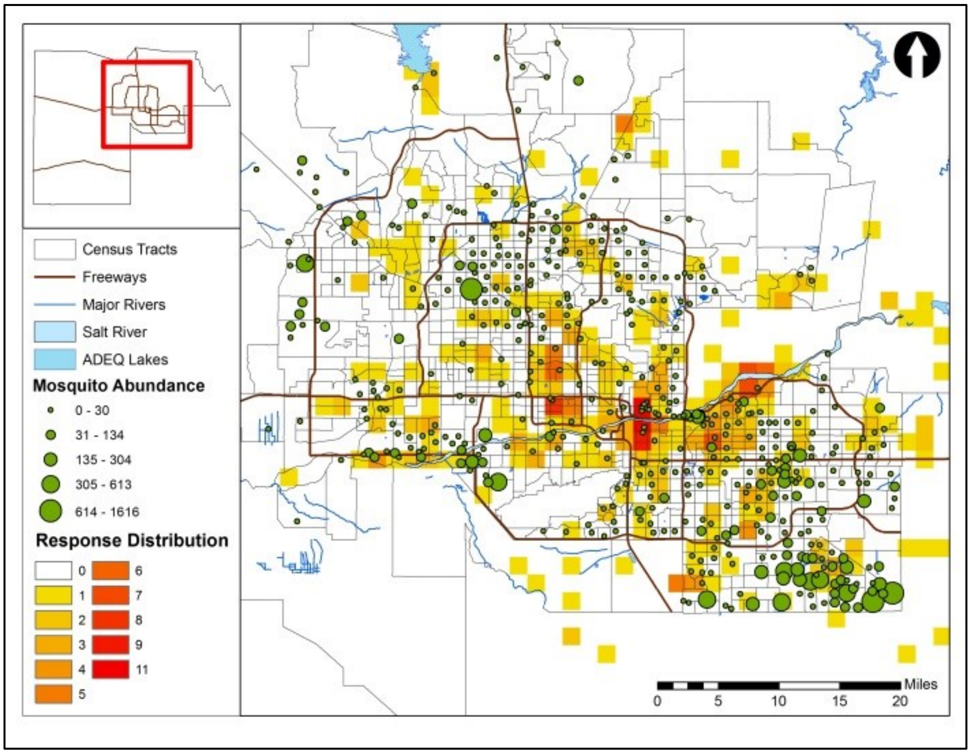


Figure 4.8: Participant response distribution, mosquito abundance values, major rivers, including the Salt River, and lakes, as identified by the Arizona Department of Environmental Quality, in Maricopa County.

145 individuals completed the mapping exercise in this study. More than half of all participants were female, and more than three-fourths identified themselves as Caucasian/White (refer to Table 4.1). 14.5% of participants (*n*=21) identified themselves as Hispanic or Latino. Just 2% of all respondents have not completed high school, or GED equivalent, and 42% of respondents have completed their Bachelor's degree or higher. While the educational attainment of respondents of this study is higher than the figures reported for all residents of Maricopa County, median income is between respondents and residents is similar.

The Getis Ord Gi* tool did not reveal any statistically significant cold spots (mosquito traps reporting significantly low mosquito abundance) within the county. The tool, however, revealed several statistically significant hot spots, or clusters, of mosquito traps with relatively high mosquito abundance (refer to Figures 4.5 and 4.6). These hot spots are located in the northwestern region of the metropolitan Phoenix area, particularly in the cities of Peoria and Glendale. Additionally, the GIS analysis identified hot spots in the eastern valley of Maricopa County, in Chandler and Queen Creek. 18 respondents (12.4%) correctly identified at least one of the three general clusters of statistically significant high mosquito abundance (refer to Table 4.2).

Four socioeconomic predictor variables were found to be significant to the $p \leq 0.15$ level (refer to Table 4.3): educational attainment (dichotomously categorized into individuals who have completed 12 or fewer years of education and individuals who have completed 13 or more years of education); neighborhood land cover characteristics, particularly individuals who live in neighborhoods characterized as mesic (lush, turf lawns and water-intensive vegetation such as fruit trees) and xeric (desert-like landscaping; gravel or stone replaces turf; drip irrigated and low water requirements); neighborhood income classifications, particularly low and high income neighborhoods; and income dichotomously categorized as < \$50,000 and ≥ \$50,000. When included in multivariate binary logistic regression, however, no socioeconomic predictor variables were significant at the $p < 0.05$ level, and therefore, none were retained.

DISCUSSION

As seen in Table 4.2, the majority of participants did not correctly identify areas within Maricopa County with high mosquito abundance as reported by the MCVC. Similarly, awareness of the MCVC, the agency charged with controlling mosquito populations and the primary purveyor of information regarding the mosquito populations within Maricopa County, is minimal: when asked to identify the organization responsible for monitoring and controlling mosquitoes within the county, only 3 of 145 respondents correctly identified the MCVC.

Through personal conversations with employees of the MCVC, as well as demonstrations of the agency's publicly available online information and resources, it is clear that the MCVC is dedicated to assisting residents of Maricopa County control mosquitoes and reduce their risk to infection with mosquito-borne disease. In particular, the MCVC provides both a telephone hotline and an online submission form through which residents of Maricopa County may describe the location of a local mosquito breeding site, request larvivorous fish, or describe mosquito abundance and activity. Residents of the county may also find daily updates regarding fogging activities (truck-mounted application of adulticides) through the telephone hotline or online. Most important to improving individuals' knowledge of the spatial distribution of mosquito populations, the MCVC also displays the locations of all routinely monitored mosquito traps throughout the county in an interactive map format. As a first, and perhaps the most important, step, the MCVC should consider publishing the reported mosquito trap data to their interactive map tool, similar to the geospatial manipulations conducted for this study. There are several barriers that currently limit the MCVC's ability to publish such information, including the need to process and organize the large amount of data resulting from just one trap collection and the limited number of employees who manage the GIS resources of MCVC, but approximations of mosquito abundance may expand communication between the experts and the public regarding the heterogeneity of mosquito populations throughout the county (Johnson, 2008).

In an effort to target communication and outreach efforts this study analyzed demographic, behavioral, socioeconomic, and neighborhood characteristics as they related to respondents' knowledge of the spatial distribution of mosquitoes within Maricopa County. Through univariate and multivariate binary logistic regression analyses, this study investigated whether or not differences in respondents' age, length of residence time in the county, income, educational attainment, race, ethnicity, gender, self-reported time spent outdoors per week, and dominant neighborhood land cover characteristics influenced or explained their likelihood of correctly identifying hot spots of high mosquito abundance. From the results reported in Table 3, it is clear, however, that individual- and neighborhood-level factors are insufficient to explain respondents' knowledge of the spatial distribution of mosquitoes within Maricopa County. From implementations of the mapping exercise in previous studies, it is likely that the county map image itself, and potential misconceptions regarding mosquito ecology and distribution within Maricopa County, are likely to influence respondents' identification of areas of high mosquito abundance.

Because respondents were provided a physical image of Maricopa County in which to identify areas of high mosquito abundance, respondents were likely able to discern the locations of vegetated public parks as well as sources of water. When investigated further, 132 of 145 respondents (91%) identified at least one public park as a location of high mosquito abundance (refer to Figure 4.7). Vegetation has been identified in numerous studies as a critical factor related to mosquito abundance, especially because green vegetation mediates the temperature of microhabitats suitable for mosquito breeding and reproduction (Buckner, Blackmore, Golladay, & Covich, 2010; Deichmeister & Telang, 2010; Hay, Snow, & Rogers, 1998; Reisen, 2010). For example, in both the field and in the laboratory, excessive heat has been shown to adversely impact oviposition and egg development as well as adult biting activity (Miramontes, Lafferty, Lind, & Oberle, 2006; Pecoraro et al., 2007). So while respondents are correct to believe that green vegetation, for its temperature mediating properties, is likely to create habitats more suitable to mosquitoes, health messages should emphasize that the mosquito species responsible for transmitting WNv in Maricopa County, in particular, two *Culex* species of mosquito, are considered to be peri-domestic. That is, the local mosquitoes of Maricopa County not only prefer to breed in and around residences, but also prefer to take blood meals from humans as opposed to other mammals, such as birds, as well. So while respondents should remain cognizant that vegetated areas such as parks may provide suitable habitat for mosquitoes, vegetation surrounding homes and residences are likely to provide preferred habitats, in addition to increased access to human blood meals.

When asked where mosquitoes are likely to breed or lay eggs, 104 of 145 individuals (71.7% of respondents) identified standing water. It is clear, therefore, that, in general, the respondents of this study understand that all mosquitoes require an aquatic habitat during development. In this study, 101 of 145 respondents (69.7%) identified the large and potentially flowing sources of water throughout Maricopa County as areas of high mosquito abundance (refer to Figure 4.8). In particular, the cells intersecting with

Lake Pleasant in the northwest corner of the map image, as well as the Salt River, which cuts through the heart of Maricopa County and the metropolitan Phoenix area, were more frequently identified by respondents in the mapping exercise. The *Culex* species of mosquito are very unlikely to reproduce and development along the banks of open bodies of water, such as those of Lake Pleasant, and even the slow moving waterways and canals are unlikely to provide suitable habitats for oviposition and larval development for local mosquito populations (Townsend, 2012; Zou, Miller, & Schmidtmann, 2006). Again, due to the urban-adapted nature of the local mosquito populations of Maricopa County, ponded water from sprinklers or residential flood irrigation regimes, unmaintained swimming pools, or any container capable of holding water (including bird baths, flower pots, watering cans, children's inflatable swimming pools, tires, wheelbarrows, and other items of life) are the preferred site for oviposition and larval development. Health messages, therefore, should explain that the distribution of mosquito populations throughout Maricopa County is determined by residential, human-made sources of standing water, as opposed to large or flowing sources of surface water.

If local public health and mosquito control professionals are to implement this item in the future to inform health messages, several limitations must be addressed, first of which being the reliability of the item itself. During implementation of the question item, numerous respondents reported that they were unsure or simply guessing as they completed the item. It is therefore possible, if not probable, that respondents who correctly identified areas of high mosquito abundance were also unsure and guessed correctly. A simple improvement to the item would require respondents to provide a brief explanation justifying their responses. While a test-retest format was not possible in this study, to assess the reliability of the item, repeat assessment of the same respondents should be conducted within the same season or year.

In addition to the challenges associated with identifying and marking areas of high mosquito abundance within the county, the methodological techniques to analyze responses are also limited. In this study, it was not possible to digitize responses to the exact location specified by participants. Rather, participant responses were recorded to the centroid of the quadrat cell in which they were contained. As such, responses have been displaced by as much as one mile from where the respondent placed them within the county map item. To control for such error, researchers may decrease the quadrat cell size utilized in the grid. Reducing cell size, however, may increase the likelihood of user error when converting responses from the physical survey items to digital frequency maps. A digital, interactive mapping tool that allows respondents to enter responses directly into GIS software would dramatically reduce the limitations described here. While alternative methods of implementation should be investigated in future iterations of the item, trade-offs among financial expenses, item administration, and respondent convenience must be negotiated.

While the drawbacks associated with this study thus far surround the collection and presentation of respondents' perspectives, there are several limitations that influence the mosquito trap data used in this study as well. In particular, the distribution of the MCVC mosquito traps plays an important part in the visualization of the distribution of mosquito populations throughout the county. While the MCVC deploys and monitors more than 500 mosquito traps, they are not randomly located throughout the county. From personal conversations with MCVC employees, mosquito traps locations are based on a number of factors, but preference is given to residential areas. Additionally, the MCVC deploys routinely monitored traps at locations where mosquitoes are known to be numerous, as recorded in previous mosquito trap data, or where mosquitoes are known to breed, as recorded by previous treatment location data. Traps are also deployed where human cases of WNv have been reported per the Arizona Department of Health Services. Additionally, the MCVC deploys traps in neighborhoods whose residents produce numerous complaints, either via the telephone hotline or online form described above. Finally, traps are located such that employees may conveniently monitor and collect the contents of the trap. For all of these reasons, it is not possible for the MCVC to utilize a random sampling strategy with regard to mosquito trap location.

Because the mosquito traps deployed and monitored in Maricopa County are not randomly distributed, there are limitations associated with certain geospatial analytical techniques. When comparing respondent perceptions of the spatial distribution of mosquito populations, the data displayed in Figure 4.3 reflects mosquito population figures reported only at the traps themselves. Therefore, there are large portions of the study area in which there are no mosquito traps located. While the GIS technique known as interpolation is capable of estimating, in this study, mosquito abundance values at areas where no traps are located, because the MCVC traps are not randomly distributed throughout the county, assumptions of this technique are violated. Future studies that would benefit this research should attempt to model abundance based on environmental (such as surface temperature, humidity, and precipitation) and social (such as population density, for example) variables as they exist in Maricopa County. Such knowledge would likely benefit the spatial techniques utilized in this study that identify hot spots, or clusters of high mosquito abundance, as well as the comparisons between the actual distribution of mosquitoes throughout Maricopa County, as measured by the MCVC, and respondents' perceptions of the spatial distribution of mosquitoes.

CONCLUSIONS

Understanding the spatial extent, or the geographic distribution, of disease is essential not only for the control and prevention measures undertaken by public health and mosquito control experts, but also for the preventive measures taken by the public as well (Stoddard et al., 2009). If individuals are to reduce their risk to infection from mosquito-borne diseases such as West Nile virus, they must understand not only where human cases occur, but also the distribution of the mosquito populations capable of infecting them. To my knowledge, this study is the first to assess individuals' knowledge of the spatial distribution of local mosquito populations. Despite the numerous limitations, the item developed and implemented in this study is capable not only of elucidating individuals' knowledge and perceptions of the spatial distribution of mosquito populations throughout Maricopa County, but also facilitating the comparison between individuals' perceptions and the actual distribution of mosquito populations, as reported by county-wide mosquito surveillance efforts. Because this study presents the results of the first attempt at such an assessment, it is clear that this mapping exercise should be reiterated, not only within the nine neighborhoods of this study, but throughout the metropolitan Phoenix area and Maricopa County in general. Ultimately, the method of assessment described here may provide public health and mosquito control experts with new insights regarding how individuals perceive mosquito populations and guide future educational and promotional efforts designed to reduce individuals' exposure to or contact with mosquitoes capable of transmitting disease.

CHAPTER 5

ENVIRONMENTAL, DEMOGRAPHIC, SOCIOECONOMIC, AND TREATMENT PREDICTORS OF MOSQUITO ABUNDANCE AND PRESENCE IN MARICOPA COUNTY, USA—2012

INTRODUCTION

By the middle of the 20th century, following decades of sustained and successful prevention and control efforts, many medical and public health professionals in the United States concluded that "the war against infectious diseases [had] been won" (Morens, Folkers, & Fauci, 2004). As a result, the human and financial resources that had previously supported the surveillance and control efforts surrounding infectious disease were deprioritized (Cohen, 2000). For numerous reasons, however, including changes in demographics and human behavior, increased human mobility, economic globalization, environmental and land use changes, microbial adaptation, and a breakdown in public health measures in general, infectious disease, and in particular, mosquito-borne disease, will continue to represent a significant threat to human health in the United States (Cohen, 2000; Morens et al., 2004; Morse, 2004). With the recent emergence of West Nile virus (WNv) within the United States as evidence, it is clear that researchers and practitioners must continue to examine the factors that contribute to such diseases, including the mosquitoes that transmit them.

While WNv currently enjoys a global distribution, prior to 1999, the disease was not observed in the United States or the Americas in general (Artsob et al., 2009; Kramer, Styer, & Ebel, 2008). While the mechanisms are still not completely known, it is believed that infected individuals traveling between the Middle East, and in particular Israel, and the United States, introduced WNv to the New York City area (Gubler, 2002). In a matter of years, WNv expanded throughout the Americas, traversing the country and dispersing throughout Canada, Central and South America, and the Caribbean (O'Donnell & Travis, 2007; Petersen & Hayes, 2004). While the extensive expansion of WNv at the regional, national, and international scale has been made possible through human travel and bird migratory patterns, at the local scale, such as states, counties, and neighborhoods, the distribution of WNv is largely determined by mosquito populations (Gubler, 2007). The distribution and abundance of mosquitoes has been shown to be associated with numerous environmental, demographic, and socioeconomic factors. For example, temperature, precipitation, humidity, vegetation, and soil moisture have all been investigated in relation to mosquito presence and abundance (Cleckner, Allen, & Bellows, 2011; Deichmeister & Telang, 2010; Gong, DeGaetano, & Harrington, 2011; Liu & Weng, 2011; Pecoraro et al., 2007; Reisen, Fang, & Martinez, 2006). Because many mosquito species have become suitably adapted to the land use and land cover transformations associated with urbanization, researchers have also identified several demographic and socioeconomic factors associated with the distribution and abundance of mosquitoes as well, including population density, housing characteristics, and socioeconomic status (Eisen & Eisen, 2011; Harrigan et al., 2010; Rochlin, Turbow, Gomez, Ninivaggi, & Campbell, 2011; Ruiz, Tedesco, McTighe, Austin, & Kitron, 2004; Harrigan article).

Because of such diversity regarding the factors that contribute to the distribution and abundance of mosquito populations within a given area, the surveillance and control of mosquito populations is challenging (Reiter & LaPointe, 2007). While mosquito traps are capable of providing direct estimates of mosquito abundance and distribution, their methods of deployment and monitoring are limited in terms of accessibility and resources (Brown, Duik-Wasser, Andreadis, & Fish, 2008). Due to the relatively small amount of water required by females of many mosquito species during oviposition, the identification and treatment of breeding locations and larval habitats are both time and labor intensive for field workers and control organizations (Butterworth, Kolivras, Grossman, & Redican, 2010). In addition to being resource intensive, the application of chemical pesticides designed to eliminate adult mosquitoes encounters additional challenges. Not only do control organizations encounter significant pushback from the general public regarding the environmental and human health concerns related to adulticides, but control organizations themselves recognize the waning effectiveness of adulticides given increased levels of genetic resistance demonstrated in many mosquito species. In light of such challenges associated with surveillance and control efforts, and in the face of diminishing human and financial resources available for such activities, over the last few decades, public health and mosquito control experts have examined alternative techniques and methodologies to enhance surveillance and control efforts (Reynolds & Riley, 2002).

Remote sensing and geographic information systems (GIS) techniques have emerged as powerful, useful tools that may assist professionals in the control of mosquitoes and the management of disease (Kitron, 2000; Mushinzimana et al., 2006). While remote sensing techniques cannot replace the data provided by mosquito traps, data collected by remote sensing instruments aboard satellite systems, for example, can supplement and enhance on-the-ground, field efforts (Kitron, 1998; Ostfeld, Glass, & Keesing, 2005). In particular, environmental and land cover data such as vegetation and surface temperature collected via remote sensing instruments may assist professionals characterize the areas in which mosquitoes thrive when surveillance efforts including mosquito trap deployment are limited or not possible (for example, on private property) (Kalluri, Gilruth, Rodgers, & Szczur, 2007). Because mosquito-borne disease arises through direct interactions between mosquitoes and humans, publicly available demographic and socioeconomic data analyzed in a GIS may provide experts with a more complete understanding of mosquito abundance and distribution (Dale et al., 1998). This study, therefore, attempts to implement remote sensing and GIS techniques in an effort to examine the associations among environmental, treatment, demographic, and socioeconomic factors and mosquito abundance within Maricopa County, Arizona. Because the distribution of mosquito populations is often dynamic and heterogeneous throughout a given area this study also identifies the environmental, treatment, demographic, and socioeconomic factors that are associated with the presence and absence of various mosquito species, including species of the *Aedes, Anopheles, Culex, Culiseta,* and *Psorophora* genera.

For many reasons, including a climate conducive to rapid mosquito development, urban microhabitats suitable for mosquito reproduction and breeding, and access to a susceptible human host population, WNv is unlikely to be eradicated from Maricopa County (Gibney et al., 2012; Smith, Dushoff, & McKenzie, 2004). If local public health and mosquito control professionals are to reduce individuals' risk to WNv, however, they must be able to accurately describe, explain, and predict mosquito abundance and presence within the county. Practically speaking, the techniques utilized in this study represent cost-effective measures capable of guiding surveillance efforts in the field, such as mosquito trap deployment, as well as targeting control activities including the treatment of larval habitats and the application of adulticides. More importantly, however, the results of this research may highlight gaps in knowledge and understanding of local mosquito populations and precipitate future hypothesis-driven research capable of addressing the dynamic nature of mosquito-borne disease within Maricopa County.

METHODS

Study area

Covering more than 9,200 square miles, Maricopa County is located at the center of the state of Arizona and the northern extent of the Sonoran Desert. The county is also home to the metropolitan Phoenix area and boasts a population of more than four million residents. As an unintended result of the rapid urbanization and development the county has experienced over the last few decades, mosquito populations and mosquito-borne disease have flourished within the county.

Table 5.1.
Mosquito species typically captured by Maricopa County Vector Control (MCVC) trapping efforts and the diseases that may be transmitted by such species.

Mosquito vector genus and species	Diseases transmitted	Diseases currently present in Arizona
Culex *Culex quinquefasciatus* *Culex tarsalis*	Equine Encephalitis St. Louis Encephalitis West Nile virus†	West Nile virus
Aedes *Aedes aegypti* *Aedes vexans*	Dengue Fever Yellow Fever West Nile virus*†	West Nile virus*
Anopheles *Anopheles freeborni* *Anopheles gambiae* *Anopheles hermsi*	Malaria West Nile virus*†	West Nile virus*
Culiseta *Culiseta incidens*	St. Louis Encephalitis* Equine Encephalitis*† West Nile virus*†	West Nile virus*
Psorophora *Psorophora columbiae*	Venezuelan Encephalitis* West Nile virus*†	West Nile virus*

** Species exhibits limited ability to transmit disease*
† Currently present in Arizona

While more than 40 mosquito species are found throughout the state of Arizona, approximately nine species of mosquito are routinely captured by local mosquito control specialists in Maricopa County. While each species or mosquito trapped in Maricopa County may exhibit variations in terms of habitat preference, temporal development requirements, biting habits, and ability to transmit pathogenic agents, their lifecycles are nearly identical: each requires an aquatic period, which includes egg, larval, and pupal stages, followed by a terrestrial, adult period. Throughout the entirety of the mosquito's lifecycle, however, environmental, demographic, and socioeconomic factors have been shown to influence mosquito development, survival, and distribution (Brownstein et al., 2002). While a rich body of research surrounding vector-borne disease continues to materialize within the United States as well as globally, to date, no formal research efforts have been undertaken that investigate the factors that influence mosquito abundance and presence within Maricopa County. In the following sections the environmental, demographic, and socioeconomic factors investigated in this study are described in terms of their applicability in examining mosquito abundance and presence.

Environmental independent variables

Remotely sensed surface temperature

Temperature has been commonly identified in the literature as predictive of mosquito presence and abundance (Buckner, Blackmore, Golladay, & Covich, 2011; Cleckner et al., 2011; Deichmeister & Telang, 2010). Not only is temperature negatively associated with the number of days required for a mosquito to develop from egg to adult (Gong et al., 2011), but temperature also reduces the amount of time needed for mosquitoes to become infective (known as the extrinsic incubation period) (Reisen et al., 2006). Additionally, temperature is positively correlated with mosquito abundance and distribution (Lui & Weng, 2009; Pecoraro et al., 2007). While laboratory studies have demonstrated specific thresholds above which development and biting activity are severely limited, in Maricopa County, such thresholds are mediated by the presence of vegetation (Gleiser & Zalazar, 2010). In this study, we utilize MODIS 1-kilometer eight-day summary of surface temperature estimates for May 2012. While MODIS data has been successfully utilized by similar studies, the 1-km spatial resolution available for such data differs with the spatial resolution of additional remotely sensed data described below utilized in this study (Liu & Weng, 2011).

Remotely sensed vegetation and soil moisture indices

In addition to temperature, precipitation and humidity have also been shown to influence mosquito presence, abundance, and distribution (Cleckner et al., 2011; Kramer et al., 2008; Rahman, Kogan, Roytman, Goldberg, & Guo, 2011; Rochlin et al., 2011; Zou, Miller, & Schmidtmann, 2006). Because collecting such data may be time and resource intensive, let alone methodologically difficult, and because precipitation and humidity data made publicly available by the National Climatic Data Center of NOAA is collected only at a limited number of locations, typically airports, many scholars use remotely sensed vegetation and soil moisture indices as proxies (Kalluri et al., 2007). In several studies the presence of vegetation is known to provide carbohydrate resources for flight energy, enhance local bird abundance and therefore access to avian blood meals, and provide suitable habitats for mosquito survival in general (Brownstein et al., 2002; Liu & Weng, 2011). With regard to human behavior, human hosts are likely to enjoy or recreate in vegetated areas, especially during summer months, and therefore, vegetation provides access to human blood meals as well. Additionally, soil moisture is known to contribute to the distribution of larval habitats (Brown et al., 2008; Gong et al., 2011). For these reasons, vegetation and water content indices have been shown to be informative indicators of mosquito abundance. This study utilizes the normalized difference vegetation index (NDVI) derived from the Landsat 5 Thematic Mapper mission and calculated as:

$$\frac{Near\ Infrared\ Band - Red\ Band}{Near\ Infrared\ Band + Red\ Band} \quad \text{or} \quad \frac{Band\ 4 - Band\ 3}{Band\ 4 + Band\ 3}$$

to characterize local vegetation.

In order to estimate water content of vegetation and ground water, which might contribute to suitable mosquito breeding and larvae habitats, this study adopts the Disease/Water Stress Index (DWSI) developed by Penuelas, Pinol, Ogaya, and Filella (1997) and recently implemented by Brown et al. (2008). Derived from the Landsat 5 Thematic Mapper mission, the DWSI is calculated as follows:

$$\frac{Near\ Infrared\ Band - Green\ Band}{Short\text{-}Wave\ Infrared\ Band + Red\ Band} \quad \text{or} \quad \frac{Band\ 4 - Band\ 2}{Band\ 5 + Band\ 3}$$

As described in Brown et al. (2008), the bandwidth of the near-infrared band is 0.76-0.86 µm; the green band = 0.52-0.60 µm; short-wave infrared = 1.60-1.70 µm; and the red band = 0.63-0.69 µm.

Finally, this study utilizes three bands from the Tasseled Cap transformation, specifically brightness, greenness, and wetness, to characterize the presence of vegetation and soil moisture in addition to the NDVI and DWSI. As a commonly accepted method of spectral manipulation in the remote sensing community, Tasseled Cap transformations are used to transform the spectral data collected in the multiple bands of remotely sensed data to reflect brightness (TCB), greenness (TCG), and wetness (TCW) variability across a given study area (Crist & Kauth, 1986). As explained in Cleckner et al. (2011), the Tasseled Cap transformation provides useful indices for characterizing mosquito habitat suitability and mosquito abundance (Cleckner et al., 2011; Crist & Kauth, 1986; Lillesand, Kiefer, & Chipman, 2008, p. 535). As it is commonly applied, the brightness index represents a sum total of reflectance. In particular, the index represents soil background reflectance and is associated with partially covered or bare soils, typically with little vegetation present. In practice, greater values reported by the TCB index are associated with a lack of vegetation, and therefore, are likely to represent habitats ill-suited to mosquito populations. The greenness index reflects the presence and density of green vegetation, and is similar to the NDVI utilized in this study. The TCG index is correlated with canopy cover, leaf area index, and healthy biomass and therefore reflects habitats that may be suitable for mosquito behavior including reproducing, host seeking for blood meals, and resting. Finally, the wetness index reflects the moisture present in soils and vegetation, as well as water features in general. While three additional band transformations, typically referred to as fourth, fifth, and sixth, are derived from the Tasseled Cap transformation, in practice, the information provided in the brightness, greenness, and wetness bands provide the most useful information for analysis; the remaining three bands contain atmospheric and noise effects (Crist & Kauth, 1986).

Each of the above indices (NDVI, DWSI, and Tasseled Cap transformation) was derived from bands 1-5 and band 7 (recorded at 30-meter spatial resolution) from a 12 May 2011 image from the Landsat 5 Thematic Mapper (LS5 TM) mission. This data, therefore, reflects environmental data from one year prior to the time period during which mosquito trap data was collected. For a number of reasons, including the limitations associated with the Landsat 7 Enhanced Thematic Mapper-Plus mission and the decommissioning of the LS5 TM mission during the year 2012, the LS5 TM data analyzed in this study was considered appropriate. Moreover, other studies have successfully utilized remotely sensed data from years prior to mosquito trapping (Brown et al., 2008; Zou et al., 2006).

Irrigated land surfaces

Due to the region's arid climate, precipitation in Maricopa County is limited. Residential outdoor water use and agricultural flood irrigation practices, therefore, are primary processes that contribute to permanent and semi-permanent standing water throughout the study area. As demonstrated in several studies, the results of such practices represent a patchwork of suitable habitats in which mosquitoes may deposit eggs and where abundance levels may be high (Knudsen & Slooff, 1992; Miramontes, Lafferty, Lind, & Oberle, 2006; Reiter & LaPointe, 2007). This study, therefore, utilizes data collected by the Arizona Department of Health Services and the Arizona Department of Water Resources representing residential and agricultural flood irrigation regimes throughout Maricopa County to further identify areas likely to have high levels of mosquito abundance.

Demographic and socioeconomic independent variables

Population density

In Maricopa County, it is likely that urbanization has favorably impacted transmission of mosquito-transmitted diseases such as West Nile virus. In addition to providing habitats suitable for breeding and development, urbanization has facilitated human host-mosquito vector interactions (Gleiser & Zalazar, 2010; Knudsen & Slooff, 1992). Subsequently, according to employees of the MCVC, the local mosquito species capable of transmitting disease to humans, particularly of the *Culex* genus, are considered to be "urban-adapted," or "peri-domestic" (Robbins, Farnsworth, & Jones, 2008; Shaw, Robbins, & Jones, 2010). Because such mosquitoes prefer to live and breed around human domiciles as well as take blood meals from human hosts, human population density, or the number of people per unit area, likely influences mosquito abundance (Liu & Weng, 2009; Carnes & Ogneva-Himmelberger, 2011; Tuiten, Koenraadt, McComas, & Harrington, 2009; Venkatesan, Westbrook, Hauer, & Rasgon, 2007). To calculate human population density, five-year population estimates from the year 2011 American Community Survey at the Census Block level were utilized in this study.

Median family income and median household value

During the last decade, a limited, and divided, body of research has demonstrated that mosquito-transmitted disease may result from social and economic inequities. For example, both Dowling (2011) and Rios, Hacker, Hailey, and Parsons (2006) demonstrate that West Nile virus activity within both humans and mosquitoes tended to be associated with lower socioeconomic status of the local community. In an attempt to explain such conclusions, Harrigan et al. (2010) suggest that variations in property upkeep, microhabitat conditions conducive to viral amplifications in mosquitoes and human hosts, and human behaviors may differ by income or social status. Similarly, in a recent study, LaDeau et al. (2013) find that pupae density of *Aedes albopictus* was greater in lower income neighborhoods of Baltimore particularly due to the greater frequency of containers related to refuse and automobile tires. With regard to mosquito abundance, Unlu et al. (2011) represents the only study to examine and demonstrate the negative association between poverty and abundance. In an attempt to provide a more complete understanding of the social and economic factors potentially related to mosquito abundance, this study utilizes median family income and median household value as reported at the Census Tract level in Summary File 1 (SF1) of the 2010 Census. While population estimates are available at the Census Block Group and Census Block level, the Census Tract is the smallest areal unit for which household social and economic data has been prepared for Maricopa County. Additionally, 2010 is the most recent year such data is reported.

Mosquito treatment and control independent variables

Larviciding and adulticiding activity

Because mosquito abundance is impacted by local treatment and control efforts, this study included larviciding (the elimination of mosquito larvae, usually via point-based chemical application) and adulticiding (the elimination of adult mosquitoes via truck-mounted ultra-low volume pesticides applied typically to 1-square mile geographic areas) information with regard to mosquito abundance. In particular, employees of the Maricopa County Vector Control (MCVC) division treated more than 2,000 locations known to be breeding sites (refer to Figure 5.1) of local mosquito populations and completed more than 300 individual adulticide fogging events between May and September 2012 (refer to Figure 5.2).

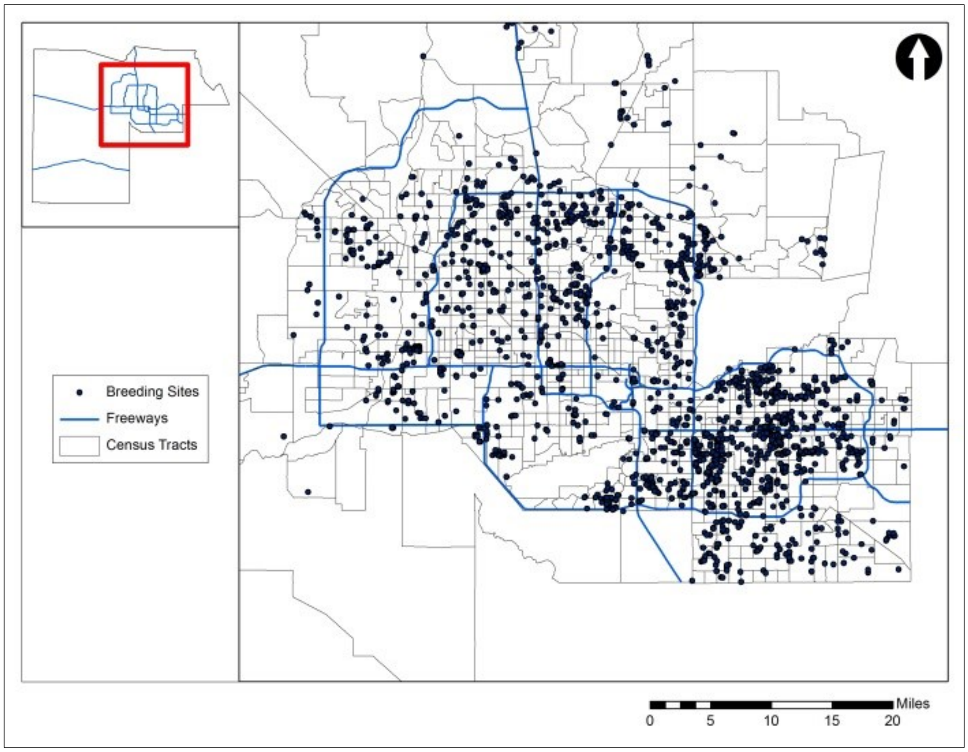


Figure 5.1. Locations of known mosquito breeding sites throughout Maricopa County. Data provided courtesy the MCVC.

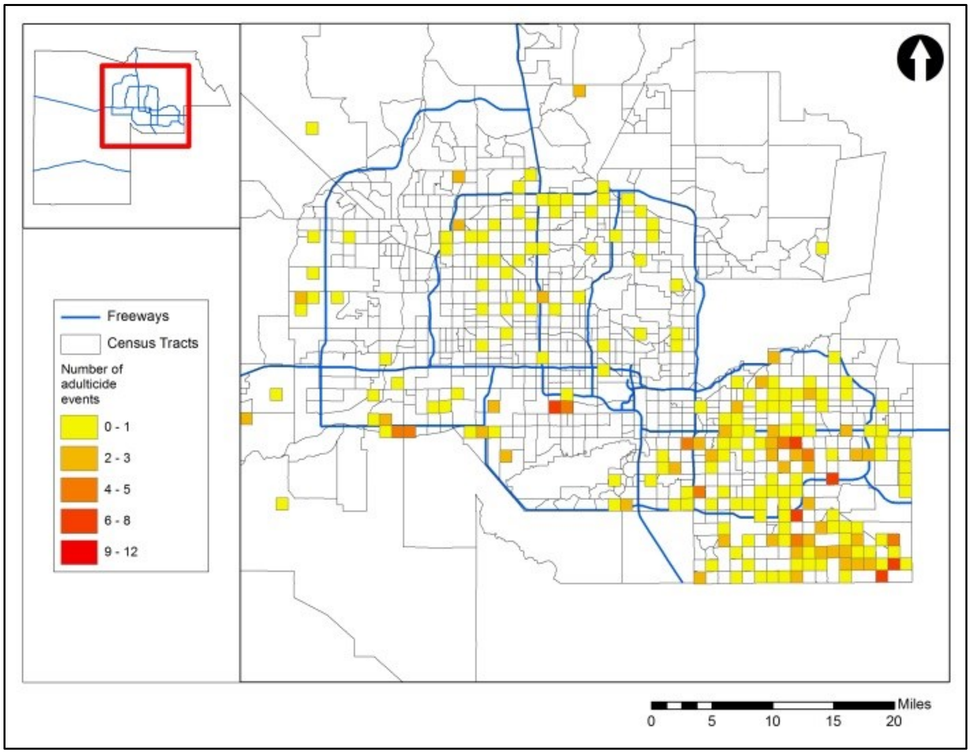


Figure 5.2. Locations of adulticided (fogged) areas throughout Maricopa County. Data provided courtesy the MCVC.

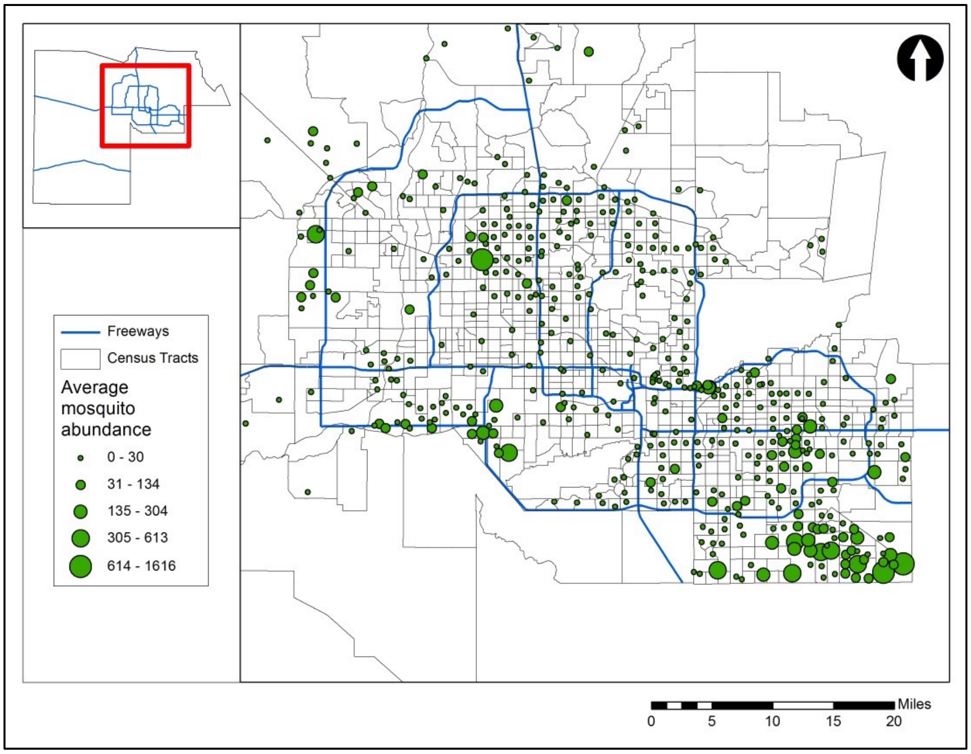
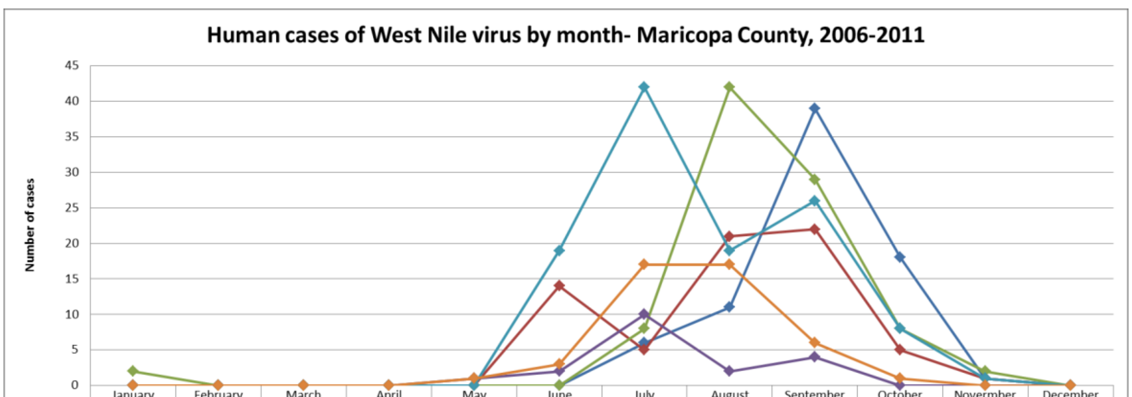


Figure 5.3. Average summer (May-September) mosquito abundance, as recorded through 517 routinely monitored mosquito traps. Data provided courtesy the MCVC.



	January	February	March	April	May	June	July	August	September	October	November	December
2006	0	0	0	0	0	0	6	11	39	18	1	0
2007	0	0	0	0	0	14	5	21	22	5	1	0
2008	2	0	0	0	0	0	8	42	29	8	2	0
2009	0	0	0	0	1	2	10	2	4	0	0	0
2010	0	0	0	0	0	19	42	19	26	8	1	0
2011	0	0	0	0	1	3	17	17	6	1	0	0

Figure 5.4. Human cases of West Nile virus within Maricopa County reported to the Arizona Department of Health Services (ADHS) and the Maricopa County Department of Public Health (MCDPH), 2006 – 2011. Data courtesy the MCDPH.

Mosquito trap data was provided by the MCVC and represents summer collection data for 517 routinely monitored mosquito traps (refer to Figure 5.3). Such traps are permanently located throughout the county and monitored on a weekly basis. Information recorded for each collection includes the number of mosquitoes collected by gender. Summer mosquito abundance, the outcome variable of interest, was calculated by normalizing the total number of female mosquitoes captured between May and September by the number of collection events for each trap. Summer mosquito abundance figures are appropriate for this study for numerous reasons: in conversations with MCVC employees, the summer months between May and September have typically exhibited the highest levels of mosquito activity; the monsoonal precipitation experienced in Maricopa County between May and September provide suitable habitats for breeding and mediate temperatures for development; and as reported by the Arizona Department of Health Services, cases of human West Nile virus activity typically emerge in late spring and peak between June and August (refer to Figure 5.4).

Geospatial analytical techniques

In order to investigate whether the specific environmental, demographic, socioeconomic, and treatment factors described above are associated with mosquito abundance as measured by local mosquito traps, this study implements a buffering technique utilized by numerous studies (Brown et al., 2008; Buckner et al., 2011; Gleiser & Zalazar, 2010; Reiter & LaPointe, 2007). Briefly, a 1-mile buffer zone, which approximates commonly observed mosquito flight distances which range from 0.25 miles to 2 miles, was created for each mosquito trap (Nasci & Miller, 1996; Rochlin et al., 2011). For each mosquito trap, therefore, relevant values for the above described environmental, demographic, socioeconomic, and treatment data could be calculated using ArcMap 10.1 (ESRI, Redlands, CA) as they exist within each buffer zone and examined in association with mosquito abundance. For variables including surface temperature, NDVI, DWSI, and the Tasseled Cap transformation indices, zonal statistics were utilized to calculate the mean value for each buffer. In order to calculate the amount of land surface that is irrigated within each buffer, a simple intersection was performed between mosquito trap buffers and relevant agricultural and residential irrigation regime data. To calculate the population density present in each mosquito trap buffer zone, the number of individuals was interpolated from Census Block data and divided by the area of the one-mile buffer zone. Using more simplistic, yet more appropriate, techniques, median family income and median household value was assigned to each trap by the Census Tract in which it was located. Additionally, the number of locations where mosquitoes are known to breed and which were treated was tabulated for each buffer zone. Finally, the number of adulticiding events that occurred at the site of the mosquito trap was recorded for each trap.

Statistical techniques

In order to identify the effect of each independent environmental, treatment, demographic, and socioeconomic factor as it relates to mosquito abundance univariate and multivariate linear regression techniques were utilized using SPSS 19 software (Chicago, IL). Factors with significance values less than or equal to 0.15 ($p \leq 0.15$) were identified in univariate analysis and included in multivariate regression analysis.

Because the dependent variable mosquito presence was measured dichotomously, either a particular mosquito species of a specific genus was present and reported for a given trap or was not, it was not possible to utilize standard linear regression. Therefore, in order to identify the effects of the various environmental, treatment, demographic, and socioeconomic factors included in this study with regard to mosquito presence binary logistic regression was utilized. Similar to above, factors with significant *p* values less than or equal to 0.150 were identified in univariate logistic regression for each of the five primary mosquito genera regularly trapped in Maricopa County. Such variables were then included in multivariate logistic regression analyses where those predictor factors where $p \leq 0.05$ were retained.

RESULTS

Table 5.2.

Correlation matrix of independent (predictor) and dependent (outcome) variables.

	Abundance	DWSI	NDVI	TCB	TCG	TCW	SurTemp	TimesFog	NumBreed	TotalPop	MedFamInc	MedHousVal	PerIrrLS	PopDen
Abundance	1													
DWSI	0.118**	1												
NDVI	0.246**	0.495**	1											
TCB	0.215**	0.352**	-0.132**	1										
TCG	0.259**	0.436**	0.979**	-0.211**	1									
TCW	-0.303**	-0.270**	0.118**	-0.812**	0.105*	1								
SurTemp	-0.083	-0.136**	-0.668**	0.293**	-0.692**	-0.290**	1							
TimesFog	0.434**	0.110*	0.233**	0.078	0.226**	-0.093*	-0.090*	1						
NumBreed	-0.013	-0.047	0.046	-0.371**	0.048	0.371**	-0.037	0.117**	1					
TotalPop	0.072	0.103*	0.036	0.014	0.064	-0.078	-0.047	-0.018	-0.034	1				
MedFamInc	0.085	0.368**	0.354**	0.067	0.370**	-0.077	-0.346**	0.061	0.067	0.083	1			
MedHousVal	0.011	0.270**	0.356**	-0.009	0.371**	-0.04	-0.331**	0.035	-0.016	0.029	0.806**	1		
PerIrrLS	0.263**	0.298**	0.405**	-0.041	0.387**	0.151**	-0.244**	0.236**	0.314**	0.111*	0.180**	-0.04	1	
PopDen	-0.339**	-0.077	-0.232**	-0.488**	-0.268**	0.665**	0.151**	-0.154**	0.370**	0.104*	-0.250**	-0.252**	0.091*	1

** Correlation is significant at the 0.05 level (2-tailed).*
*** Correlation is significant at the 0.01 level (2-tailed).*

Variable descriptions: Abundance = mosquito abundance; DWSI = Disease Water Stress Index; NDVI = Normalized Difference Vegetation Index; TCB = Tasseled Cap Brightness; TCG = Tasseled Cap Greenness; TCW = Tasseled Cap Wetness; SurTemp = Surface Temperature; TimesFog = number of adulticide events; NumBreed = number of treated breeding locations; TotalPop = total population; MedFamInc = median family income; MedHousVal = median house value; PerIrrLS = percent irrigated land surface; PopDen = interpolated population density.

Table 5.3.

Univariate and multivariate linear regression analysis for average mosquito abundance.

Predictors†	Univariate analysis					Multivariate analysis*				
	Coeff.	S.E.	Standardized β	t	p value	Coeff.	S.E.	Standardized β	t	p value
TimesFog	0.389	0.036	.434	10.946	.000	0.284	0.034	0.317	8.291	0
PerIrrLS	0.008	0.001	.263	6.178	.000	0.006	0.001	0.21	4.902	0
TCG	0.041	0.007	.259	6.092	.000					
NDVI	0.064	0.011	.246	5.762	.000					
TCB	0.017	0.003	.215	5.008	.000					
DWSI	6.233	2.31	.118	2.699	.007	-8.212	3.066	-0.156	-2.678	0.008
MedFamInc	4.9E-06	0	.085	1.923	.055					
TotalPop	5.6E-05	0	.072	1.640	.102					
SurTemp	-0.001	0.001	-.083	-1.901	.058					
TCW	-0.035	0.005	-.303	-7.208	.000	-0.033	0.012	-0.292	-2.787	0.006
PopDen	0	0	-.339	-8.186	.000					

**Constant: Coefficient = -9.365; S.E. = 14.838; t = -0.631; p value = 0.528*

†Predictor descriptions: TimesFog = number of adulticide events; PerIrrLS = percent irrigated land surface; TCG = Tasseled Cap Greenness index; NDVI = Normalized Difference Vegetation Index; DWSI = Disease Water Stress Index; MedFamInc = Median Family Income; TotalPop = Total Population; SurTemp = Surface Temperature; TCW = Tasseled Cap Wetness Index; PopDen = Interpolated Population Density

Table 5.4.

Univariate and multivariate binary logistic regression analysis for Aedes species presence. (Model outputs: $\chi 2$ (3, N = 517) = 16.144, $p = 0.001$; Cox and Snell R-square = 0.031; Nagelkerke R-square = 0.049).

	Univariate analysis						Multivariate analysis					
Predictor	β	S.E.	Wald	p value	OR* [Exp(B)]	95% C.I.†	β	S.E.	Wald	p value	OR* [Exp(B)]	95% C.I.†
NumBreed	0.029	0.012	5.704	0.017	1.029	1.005 - 1.054						
TCW	0.024	0.009	7.045	0.008	1.025	1.006 - 1.043						
TCB	-0.024	0.006	13.588	0	0.977	0.964 - 0.989	-0.03	0.012	5.957	0.015	0.971	0.948 - 0.994

Table 5.5.

Univariate and multivariate binary logistic regression analysis for Anopheles species presence. (Model outputs: χ^2 (3, N = 517) = 17.651, p = 0.001; Cox and Snell R-square = 0.034; Nagelkerke R-square = 0.069).

	Univariate analysis						Multivariate analysis					
Predictor	β	S.E.	Wald	p value	OR† [Exp(B)]	95% C.I.‡	β	S.E.	Wald	p value	OR† [Exp(B)]	95% C.I.‡
DWSI	-9.452	5.324	3.152	0.076	0	0.000 - 2.673	-13.653	5.864	5.421	0.02	0	0.000 - 0.115
PerIrrLS	-0.007	0.003	3.857	0.5	0.993	0.987 - 1.000						
TCW	-0.037	0.011	11.461	0.001	0.964	0.944 - 0.985	-0.043	0.012	13.035	0	0.958	0.936 - 0.981

Table 5.6.

Univariate and multivariate binary logistic regression analysis for Culex species presence. (Model outputs: $\chi 2$ (2, N = 517) = 12.492, $p = 0.002$; Cox and Snell R-square = 0.024; Nagelkerke R-square = 0.065).

	Univariate analysis						Multivariate analysis					
Predictor	β	S.E.	Wald	p value	OR† [Exp(B)]	95% C.I.‡	β	S.E.	Wald	p value	OR† [Exp(B)]	95% C.I.‡
Times Fog	0.833	0.4	4.335	0.037	2.3	1.050 - 5.039	0.813	0.407	3.994	0.046	2.254	1.016 - 5.002
NumBreed	0.048	0.026	3.411	0.065	1.049	0.997 - 1.104						

Table 5.7.

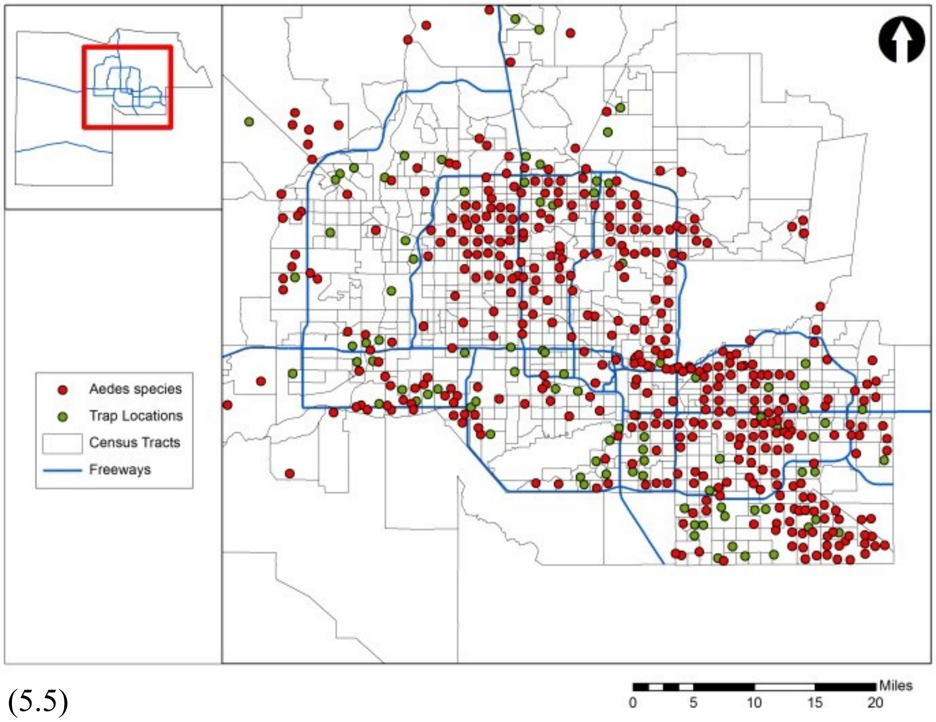
Univariate and multivariate binary logistic regression analysis for Culiseta species presence. (Model outputs: $\chi2$ (4, N = 517) = 14.160, p = 0.007; Cox and Snell R-square = 0.027; Nagelkerke R-square = 0.036).

	Univariate analysis						Multivariate analysis					
Predictor	β	S.E.	Wald	p value	OR† [Exp(B)]	95% C.I.‡	β	S.E.	Wald	p value	OR† [Exp(B)]	95% C.I.‡
Times Fog	0.141	0.071	4	0.045	1.151	1.003 - 1.322						
NDVI	0.037	0.019	3.866	0.049	1.037	1.000 - 1.076						
TCG	0.025	0.012	4.608	0.032	1.025	1.002 - 1.049						
TCW	-0.02	0.009	5.777	0.016	0.98	0.964 - 0.996	-0.021	0.009	5.94	0.015	0.979	0.963 - 1.269

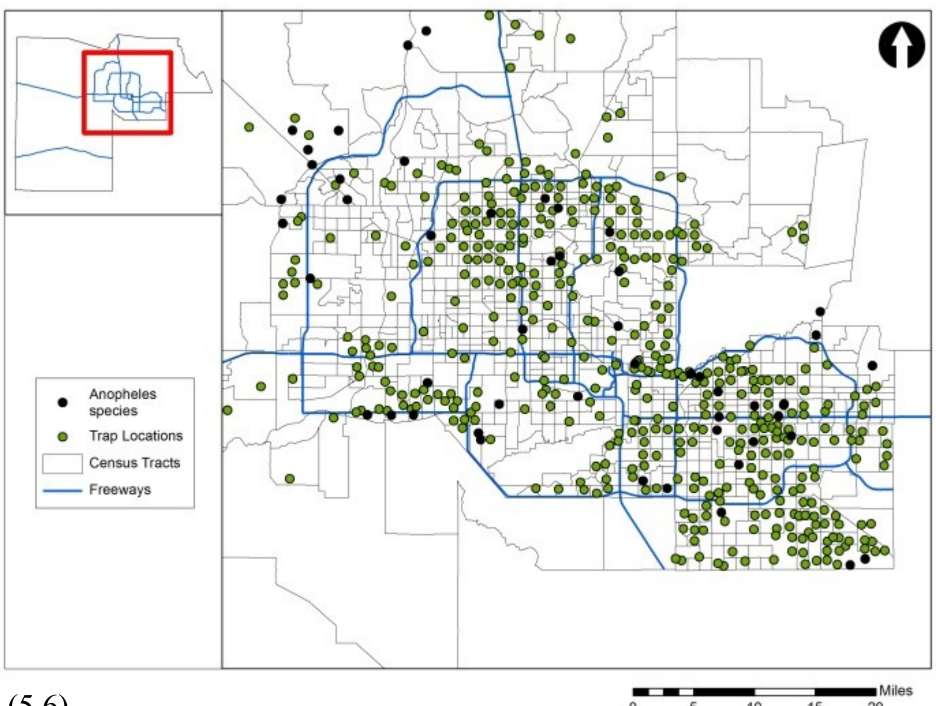
Table 5.8.

Univariate and multivariate binary logistic regression analysis for Psorophora species presence. (Model outputs: $\chi2$ (7, N = 517) = 50.510, p = 0.000; Cox and Snell R-square = 0.093; Nagelkerke R-square = 0.137).

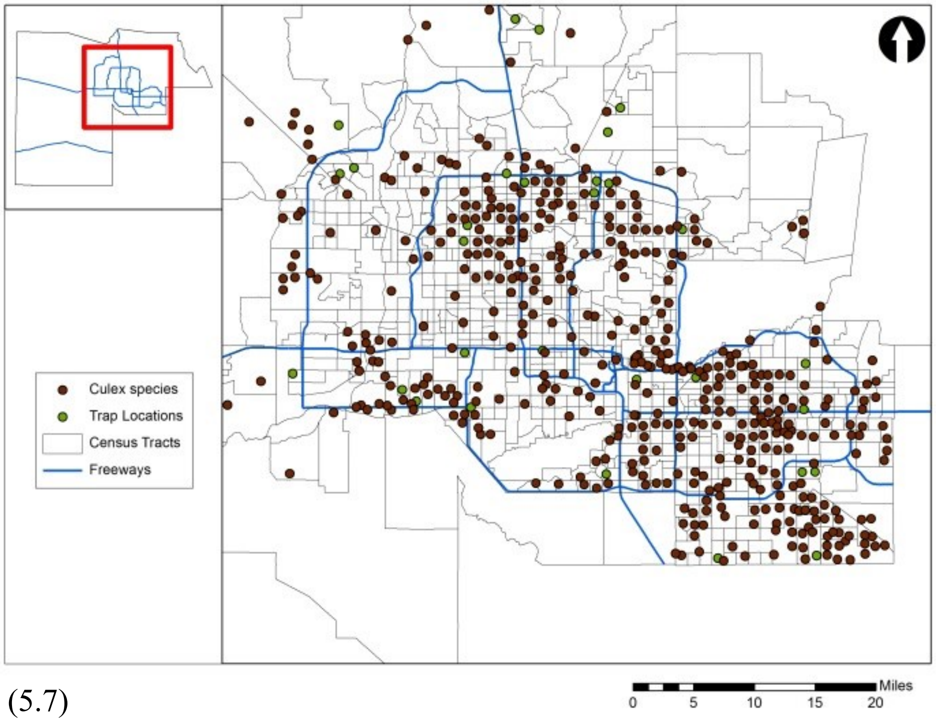
	Univariate analysis						Multivariate analysis					
Predictor	β	S.E.	Wald	p value	OR† [Exp(B)]	95% C.I.‡	β	S.E.	Wald	p value	OR† [Exp(B)]	95% C.I.‡
DWSI	8.817	4.083	4.662	0.031	6745.252	2.255 -						
Times Fog	0.338	0.117	8.368	0.004	1.402	1.115 - 1.762						
NDVI	0.06	0.023	7.162	0.007	1.062	1.016 - 1.110						
TCG	0.038	0.014	7.583	0.006	1.039	1.011 - 1.067						
NumBreed	0.029	0.011	7.148	0.008	1.029	1.008 - 1.051	0.042	0.014	9.119	0.003	1.042	1.015 - 1.071
PerIrrLS	0.01	0.002	17.608	0	1.01	1.005 - 1.015	0.008	0.003	7.396	0.007	1.008	1.002 - 1.013
TCW	-0.032	0.011	0.011	0.004	0.969	0.948 - 0.990	-0.058	0.014	17.229	0	0.944	0.919 - 0.970

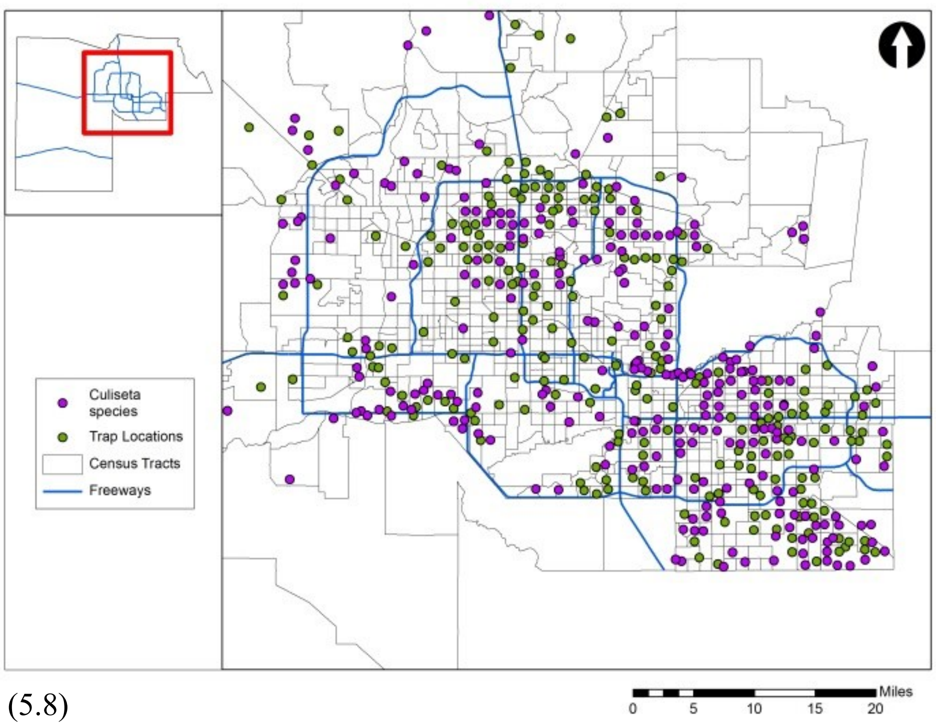

Aedes species
Trap Locations
Census Tracts
Freeways
Miles
0 5 10 15 20

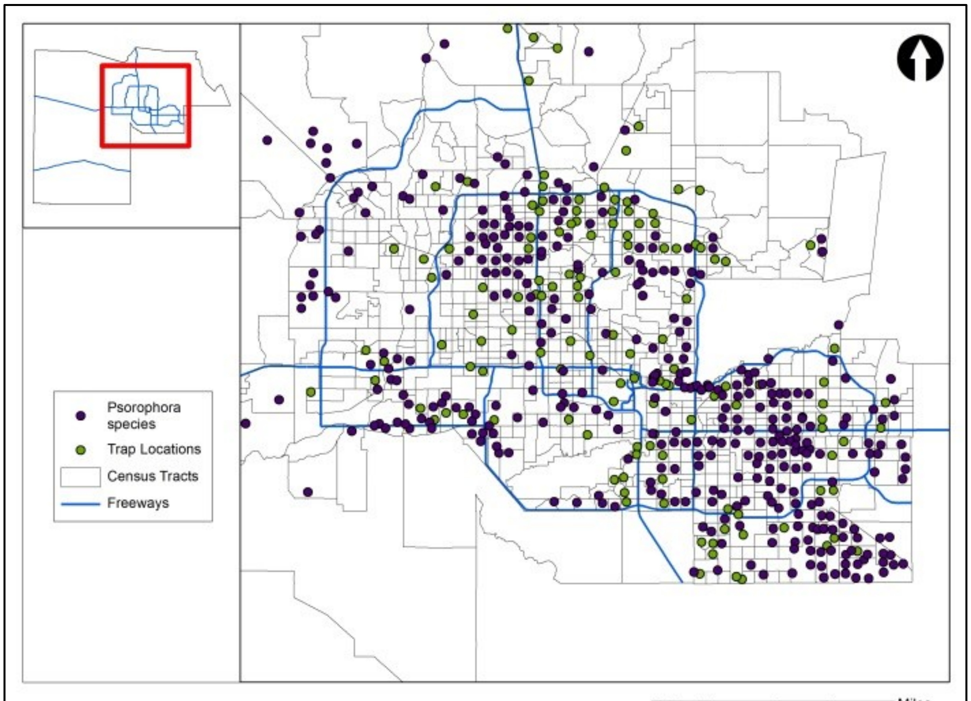
(5.5)


Anopheles species
Trap Locations
Census Tracts
Freeways
Miles
0 5 10 15 20

(5.6)


Culex species
Trap Locations
Census Tracts
Freeways
Miles
0
5
10
15
20
(5.7)


Culiseta species
Trap Locations
Census Tracts
Freeways
Miles
0
5
10
15
20
(5.8)



(5.9)

Figure 5.5-5.9. Mosquito species presence as recorded by species identification for each mosquito trap: (5.5) Aedes species; (5.6) Anopheles species; (5.7) Culex species; (5.8) Culiseta species; (5.9) Psorophora species.

As is evident in the correlation matrix of Table 5.2, mosquito abundance is correlated, both positively and negatively, with several dependent predictor variables examined in this study. In particular, a positive, medium correlation exists between mosquito abundance and the number of adulticide events (TimesFog, $r = 0.434$, n = 517, $p \leq 0.01$). Several positive, weak correlations with mosquito abundance are apparent as well, including: the percent of land surface surrounding mosquito trap buffers that is irrigated (PerIrrLS), the Tasseled Cap Greenness (TCG) index, the Normalized Difference Vegetation Index (NDVI), and the Tasseled Cap Brightness (TCB) index. Two negative correlations exist with mosquito abundance, population density ($r = -0.339$, n = 517) and the Tasseled Cap Wetness (TCW) index (r = -0.303, n = 517), and are statistically significant at the $p \leq 0.01$ level.

While nearly all predictor variables were identified through univariate linear regression analysis (Table 5.3) as potential factors capable of explaining the variation found in the dependent variable mosquito abundance, only four predictors were retained after multiple linear regression analysis. When entered simultaneously, the number of adulticide events, the percent of irrigated land surface, the Disease Water Stress Index, and the Tasseled Cap Wetness index were capable of explaining 33.4%, F (11, 501) = 24.383, $p < 0.01$, of the variance in mosquito abundance. Individually, the number of adulticide events (TimesFog) was positively associated with mosquito abundance and accounted for 8.9% (semi-partial correlation coefficient = 0.299). The amount of irrigated land surface within a 1-mile distance of mosquito traps was also found to positively affect mosquito abundance, although to a lesser extent compared to the number of adulticide events. Conversely, both the Tasseled Cap Wetness (TCW) index and the Disease Water Stress Index (DWSI) exhibit a negative association with mosquito abundance.

While five mosquito genera are regularly captured by the Maricopa County Vector Control division (MCVC), their presence, as reported for each mosquito trap, is diverse (Figure 5.5-5.9). For example, present in 486 of 517 mosquito traps (94.0%), members of the *Culex* genus are nearly ubiquitous throughout Maricopa County. Of the remaining four common genus of mosquito, the *Aedes* (415/517), the *Psorophora* (383/517), and the *Culiseta* (282/517) genera are each present at more than half of the mosquito traps deployed in Maricopa County. Most limited in terms of presence observed in mosquito traps is the *Anopheles* genus, found in just 54 mosquito traps.

In order to assess the potential impacts of the environmental, treatment, demographic, and socioeconomic variables included in this study on the likelihood that mosquito genera are present in Maricopa County, binary logistic regression was performed. Thirteen variables were included in univariate logistic regression analyses (Tables 5.4 – 5.8) for each of the five mosquito genera and factors with significance values of less than or equal to 0.150 ($p \leq 0.150$) were retained for multivariate logistic regression analyses. In general, several environmental variables (including the Tasseled Cap Wetness index) and treatment variables (including the number of adulticide events and the number of known breeding locations) were identified in both univariate and multivariate analyses to influence the presence of specific genera of mosquito. For example, not only was the Tasseled Cap Wetness index retained for the *Anopheles, Culiseta,* and *Psorophora* genera after multivariate logistic regression, but the TCW index also decreased the likelihood of the presence of these genera. Both treatment variables included in the study, the number of adulticide events and the number of treated breeding locations, were found to positively impact the likelihood of the *Culex* and *Psorophora* genera.

While for each mosquito genus at least one predictor variable was identified through multivariate logistic regression analysis to make a unique statistically significant contribution, all models explained relatively little variance regarding the likelihood of the presence of the specific mosquito genera. For example, while the multivariate logistic regression analysis was statistically significant, χ^2 (3, N = 517) = 16.144, p = 0.001, the model of *Aedes* species (Table 5.4) in Maricopa County was only capable of explaining between 3.1% (Cox and Snell R-square) and 4.9% (Nagelkerke R-square) of the genus's variance. Additionally, only the Tasseled Cap Brightness (TCB) index uniquely and statistically significantly contributed to the *Aedes* model: as TCB index remotely sensed values increased by one unit, *Aedes* species are 0.971 times less likely to be present.

While the *Anopheles* (Table 5.5)*, Culex* (Table 5.6)*,* and *Culiseta* (Table 5.7) models all performed similarly in terms of explanatory power, refer to Cox and Snell R-square and Nagelkerke R-square values, treatment variables statistically significantly contributed to the *Culex* genus, as opposed to environmental variables for the *Anopheles* and *Culiseta* models. Specifically, as the number of adulticide events increases by a single event the likelihood of *Culex* species presence increases more than two times. Conversely, with regard to A*nopheles* genus presence, as the DWSI increases, the likelihood of *Anopheles* species being present is reduced to nearly zero.

Regarding the *Psorophora* genus logistic regression model, three predictor variables reflecting both treatment and environmental domains were found to uniquely contribute to explaining the variance associated with the presence of the *Psorophora* species within Maricopa County (Table 5.8). The Tasseled Cap Wetness (TCW) index represents the relatively strongest, and negative, predictor where an increase in the TCW index results in a slightly reduced likelihood of presence. Conversely, and potentially counter-intuitively, as the number of known breeding locations treated with larvicides increases *Psorophora* species are slightly more likely to be present.

DISCUSSION

The techniques described here, as well as those described in similar studies, are capable of providing public health professionals and mosquito control experts with new insights regarding how environmental, treatment, demographic, and socioeconomic factors influence mosquito abundance and mosquito presence. In this study, the presence of water resources were identified through linear and logistic regression analyses as significant contributors to both mosquito abundance and mosquito presence, respectively. Because female mosquitoes require permanent or semi-permanent sources of water when depositing eggs, public health and mosquito control experts may expect that the presence of water features is positively associated with mosquito abundance and presence. It should be noted, however, that the semi-permanent flood waters that result from agricultural and residential irrigation regimes within Maricopa County and the permanent, relatively larger water features detected by the Landsat TM instrument and reflected by the TCW index influence mosquito abundance and presence in opposing manners.

In Maricopa County, irrigated agriculture continues to demand large amounts of water resources and contributes to the intermittent flooding of large areas in order to support the production of crops. While several studies have demonstrated the impacts of agriculture with regard to mosquito abundance and presence (Miramontes et al., 2006; Reiter & LaPointe, 2007; Rochlin et al., 2011), within the study area, water-intensive agricultural lands continue to be decommissioned in the face of water scarcity. With the population of Maricopa County expected to continue to grow, the irrigation regimes that maintain outdoor vegetation including lush grasses as well as shade and fruit trees within residential areas are likely to further contribute to suitable soil moisture content as well as intermittent aquatic habitats required for mosquito breeding. Mosquito control efforts should, therefore, continue to examine residential flood irrigation as a potential driver of mosquito abundance and seek to understand the local institutions that promote the use of such water regimes throughout the county.

While this study revealed a positive association between the irrigated land surface and mosquito abundance, for numerous reasons the TCW index exhibited an opposite influence on mosquito abundance. Regarding the derivation of the Tasseled Cap transformation, and the TCW index, similar to a principal components analysis, of the six band transformations useful information is contained only within the brightness, greenness, and wetness indices. However, relative to the TCB and TCG indices, the TCW index provides the least amount of new, and useful, information for scene interpretation. Therefore, through a phenomenon referred to as “leakage” (Crist & Cicone, 1984, p. 261), some of the information, or variation, contained in the TCW index may be attributable to the contained in the higher TCB and TCG indices. As seen in Table 5.4, the TCB index was found to decrease the likelihood of presence with regard to the *Aedes* species of mosquito. It is possible; therefore, that the negative association observed in the TCW index and mosquito abundance and presence may be at least partially attributed to the TCB index.

In another explanation, while the TCW index may be used to reflect the presence of “moist” or “wet” features, because the TCW index is derived from 30-meter resolution

Landsat Thematic Mapper data locations within the study area that exhibit high values likely are large water features such as ponds, lakes, large pools, rivers, or canals. However, because the mosquito species present in Maricopa County preferentially deposit eggs in storm basins, sewer heads, and unmaintained swimming pools, it is unlikely that large water features would represent breeding locations. Future iterations should derive the TCW index from data of varying spatial resolutions. For example, female mosquitoes require a relatively small amount of standing water to deposit eggs, and local mosquito control experts explain that bird baths, flower pots, automobile tires, and refuse may hold enough water to be suitable for larval development. Therefore, high spatial resolution data sources, such as the 2.40 meter resolution products of the QuickBird satellite, may prove useful to experts interested in investigating how the presence of relatively smaller moist, wet features influence mosquito abundance and presence.

As remote sensing and geographic information systems continue to gain traction with public health and mosquito control experts, several studies demonstrated the value of incorporating population-based data including demographic and socioeconomic information. While the work of Ruiz et al. (2004) demonstrates important associations between factors like age, income, race, and age of housing and incidence of West Nile virus in humans, at the present, few studies have investigated the direct influence of such factors on mosquito abundance and presence. As evidenced in the results section above, this study did not identify any statistically significant demographic or socioeconomic factors related to abundance or presence and from the correlation matrix (Table 5.2) it is clear that the associations between the total number of people present immediately surrounding each mosquito trap, as well as median family income and median house value and mosquito abundance are especially limited. According to Harrigan et al. (2010), the relationship between variables such as income and house value and mosquito abundance is likely mediated by the presence of suitable breeding habitats. For example, because residents of areas of lower income and lower house value may be less likely to eliminate breeding locations through regular upkeep and maintenance, standing water may be present in gutters, drains, ditches, and refuse, from which mosquito populations are likely to emerge (Dowling, 2011). New metrics, including the number of human-made containers used for yard work, refuse, and storage found around domiciles, should be collected at the household level in order to complement remotely sensed ecological data.

Of the results presented in this study, the positive relationship between treatment efforts such as the application of chemical pesticides and the treatment of known breeding sites and mosquito abundance and presence appears counter-intuitive. If control efforts are effective, experts can expect that increasing the number of adulticide events should reduce the mosquito population. In this study, however, not only did the number of adulticide events, recorded as TimesFog, have the greatest contribution to mosquito abundance (refer to Table 5.3), but it also positively increased the likelihood of the presence of *Culex* species, the only species capable of transmitting disease in Maricopa County, at mosquito traps. Through conversations with employees of the Maricopa County Vector Control division, it is obvious that control and treatment efforts are reactive to mosquito populations (Vazquez-Prokopec, Chaves, Ritchie, Davis, & Kitron, 2010). In the study area, chemical pesticides are not applied by employees of the Maricopa County Vector Control division unless county-specific thresholds regarding abundance of local mosquito populations and confirmed cases of human illness have been met. In light of the limited financial and human resources available to mosquito surveillance and control efforts within the area, while such reactive measures may be cost-effective, this study is interested in identifying the factors that influence or drive mosquito abundance and presence, as opposed to the interaction observed where mosquito populations motivate treatment and control efforts in Maricopa County. While local mosquito experts express a desire to reduce response time to mosquito populations, because the number of adulticide events and the number of treated breeding locations are unsuitable predictors of mosquito abundance and presence, they should not be included in future analyses.

This study is subject to a number of limitations, first of which regards the collection of mosquito population data via mosquito traps. While mosquito abundance is often recognized as an accurate indicator of threat to infection, how mosquito abundance was recorded in this study represents a significant limitation to the study (Hay, Snow, & Rogers, 1998; Johnson, 2008). Because there are multiple species of mosquito native to the study area, each with potentially different and dissimilar ecological and physiological requirements, mosquito abundance would ideally be recorded for each species. In this way, experts might then be able to identify factors that impact species that may have different priorities or require different management and control techniques (Eisen &

Eisen, 2008). For example, while samples of the *Aedes* genus were present at nearly three out of four mosquito traps deployed throughout Maricopa County, at the present, such widespread distribution reflects minimal risk in terms of diseases transmitted to humans. Moreover, *Aedes* species are known to be "day-biters;" that is, peak activity occurs during the day. In contrast, not only are members of the *Culex* genus responsible for transmitting West Nile virus, the only mosquito-borne disease currently present in Arizona to humans, but periods of biting activity occur between dusk and dawn. So if the surveillance and control of the diverse mosquito species found within the study area may require differing management strategies, local public health and mosquito control experts will be best served by data collected at the genus and species level for each mosquito trap.

In addition to measuring mosquito abundance in a general sense, as opposed to incorporating species specific figures, as a methodological exercise, future analyses should also incorporate numerous additional predictor variables. In response to the challenges associated with interpreting the Tasseled Cap Wetness index, the influence of precipitation with regard to mosquito abundance and presence should be investigated for Maricopa County. Because precipitation is scarce within the study area, the monsoonal summer events may be indicative of rapid mosquito population increases. Additionally, because Gibney et al. (2012) demonstrate a positive association between the number of storm heads, drainage ditches, and sewer grates immediately surrounding an individual's residence and West Nile virus infection, such information, collected by various state and county organizations, should be investigated in future analyses. Finally, and perhaps most importantly, the location of unmaintained, “green,” swimming pools throughout Maricopa County should be included in future analyses. Since the economic downturn of 2006, thousands of private, residential swimming pools located at foreclosed properties have fallen into disuse and have been improperly maintained. As an example, in 2010, more than 8,000 unmaintained swimming pools were reported to the Maricopa County Vector Control division that required treatment and monitoring. Because mosquitoes are likely to deposit eggs within such habitats, a positive association between the number of unmaintained swimming pools and mosquito abundance is to be expected.

CONCLUSIONS

Despite the region’s arid climate, mosquito-borne disease continues to not only represent significant challenges to residents of Maricopa County, but also to the experts charged with monitoring and controlling the mosquito populations responsible for human illness. Because mosquito populations may be influenced by numerous factors, this study investigated the potential associations between environmental, demographic, and socioeconomic factors and mosquito abundance and presence. While this study points to the influence of water resources with regard to local mosquito populations as well as the limits associated with treatment efforts within the county, the results presented here should also inform future research efforts. Methodologically, data products from alternative remote sensing platforms should be considered, particularly with regard to spatial resolution. Additionally, demographic and socioeconomic factors should continue to be examined with regard to mosquito abundance. As mosquito species continue to adapt to urban locations, how individuals interact with mosquitoes within cities and suburbs will only gain in importance (Allan et al., 2009). Future research efforts must build upon the remote sensing and geographic information systems techniques utilized in this study and continue to validate associations of factors as they impact abundance. The ultimate goal, therefore, is to develop the capacity to predict mosquito abundance based on environmental, demographic, and socioeconomic data for Maricopa County. With a more complete understanding of the factors that influence mosquito abundance, public health and mosquito control experts may be able to effectively target human and financial resources in control and outreach efforts.

CHAPTER 6

CONCLUSIONS, IMPLICATIONS, AND FUTURE STEPS

Through conversations with professionals of local organizations including the Maricopa County Department of Public Health (MCDPH), the Arizona Department of Health Services (ADHS), and the Maricopa County Vector Control division (MCVC), it is clear that West Nile virus is permanently established, or endemic, in Maricopa County and the state of Arizona. By investigating vector-borne disease, particularly West Nile virus, in relation to human-mosquito vector and mosquito vector-environment interactions, the studies presented in this thesis attempt to address numerous theoretical limitations that currently hinder efforts of the local public health and mosquito control experts of Maricopa County. Building on the limited understanding of how residents perceive West Nile virus, the results of Chapters 3 and 4 establish an initial baseline of information regarding respondents' knowledge of and behaviors in response to mosquitoes and mosquito-borne disease. Additionally, the results of Chapters 3 and 4 identify specific individual-level factors that influence respondents' knowledge and behaviors which may be incorporated in the future development and dissemination of educational materials within Maricopa County. Regarding the work of the MCVC, the results presented in Chapter 5 highlight distinct relationships among diverse explanatory variables and mosquito abundance that had not been investigated previously in Maricopa County. Such knowledge may not only guide the deployment of surveillance resources but also enrich public health messages describing local mosquito populations throughout the county.

While the results of this thesis enrich our understanding of local mosquito populations as well as human knowledge and behavior surrounding such vectors of disease, the data collection instruments and the research methods designed and utilized in this thesis address significant financial limitations facing local public health professionals of Maricopa County. As is the case in the rest of the state of Arizona, and the United States in general, resources that fund and support vector-borne disease surveillance and research are limited. To a certain extent, this may be justified based on prevalence of illness: relative to the thousands of cases of cardiovascular disease, cancer, and respiratory illness within Maricopa County, the 120 annual human cases of West Nile virus represent an infrequent and unlikely health threat. In the absence of a human vaccine or specific medical treatment, treatment of West Nile virus is best achieved via the prevention efforts of local public health organizations. While the research agenda presented in this thesis must be scaled up, especially with regard to the household survey, the collection and analysis of data was efficient in terms of human and financial resources. Therefore, as information brokers to the residents of Maricopa County, the professionals at MCDPH and ADHS may adopt, revise, and implement these methods and instruments in order to cost-effectively generate up-to-date knowledge.

While the results of this thesis enhance our understanding of mosquitoes and mosquito-borne disease in Maricopa County, it is clear that further research must be done in order to more completely explain mosquito abundance as well as human knowledge and behavior. Each of the studies presented in Chapter 3, 4, and 5 identify factors that only partially explain the dependent variables of interest. For example, the results of

Chapter 3 demonstrate that respondents' willingness to participate in mosquito control efforts within their neighborhoods is a significant predictor of performing specific personal protective behaviors. In order to further understand the factors that influence individuals' knowledge of mosquito ecology and mosquito-borne disease and engagement in personal protective behaviors, professionals must continue to revise and administer the self-administered questionnaire developed and implemented in this thesis. While the instrument was administered in nine neighborhoods throughout Maricopa County, in order to achieve generalizability, research efforts should target larger samples of respondents in a greater number of neighborhoods.

Likewise, the results of Chapter 5 demonstrate that the presence of irrigated land surfaces positively influences mosquito abundance and the likelihood of mosquito presence immediately surrounding surveillance traps. In an effort to better understand the diverse factors that influence local mosquito populations, professionals of the Maricopa County Vector Control division will also benefit from adjustments and further implementations of the remote sensing and geographic information system techniques. In particular, professionals of the MCVC should identify new metrics and adjust their data collection and recording procedures in future analyses.

In an effort to improve our understanding of mosquitoes and mosquito-borne disease within Maricopa County, it is this author's intent that the methods utilized and the results described in this thesis will facilitate collaborations among the local public health and mosquito control organizations present within the county (specifically the Arizona Department of Health Services, the Maricopa County Department of Public Health, and the Maricopa County Vector Control division). While each study presented in this thesis was developed with input from various local experts, it is clear that professionals from each of the three organizations described here may benefit from discussions that bring everyone to the table. As opposed to the division of prevention and control efforts that currently exists in Maricopa County (i.e. ADHS and MCDPH track human cases and promote health behaviors, while MCVC monitors mosquito populations), the research agenda presented in this thesis highlights the complementary nature of such efforts as professionals continue to address the challenges associated with West Nile virus and mosquito-borne disease in Maricopa County.

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