Mosquito Control in North Carolina: Funding Issues and Emergency Management

by
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Abstract

Natural disasters such as hurricanes may cause increases in mosquito abundance and, consequently, arbovirus transmission risk. In 2011, flooding from Hurricane Irene in eastern North Carolina (NC) resulted in increased mosquito populations that hindered recovery efforts. Budget shortfalls in NC have reduced the functionality of long-term mosquito surveillance and control programs; hence, many counties rely on the Federal Emergency Management Agency for post-disaster mosquito control. This pilot study examines mosquito abundance pre- and post-aerial insecticide spraying at eight study sites in Washington and Tyrrell Counties in rural eastern NC after Hurricane Irene. Traps in spray zones show decreases in mosquito abundance following aerial pesticide application compared to control traps, although no significant differences ($p > 0.05$) were observed. Implications of reactive rather than proactive mosquito control responses are discussed. The absence of state mosquito control funding left some emergency managers (EMs) with the added burden of mosquito control, including coordination, implementation, and reimbursement for control activities. In the second part of the study, surveys were sent to emergency managers in 100 counties in NC to gain a better understanding of the responsibilities EMs face with regard to mosquito control in post-disaster situations. . Results indicate mosquito problems impacted the eastern counties of NC more than the rest of the state, likely due to

additional burdens of salt marsh mosquitoes in eastern NC. Additionally, while EMs in eastern NC are confident that local mosquito control programs are capable of handling future disasters, they are concerned for the future of mosquito control in NC.

Mosquito Control in North Carolina: Funding Issues and Emergency Management

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LIST OF ABBREVIATIONS

AMCA	American Mosquito Control Association
ASTHO	Association of State and Territorial Health Officials
BC	Biological control
CALV	California serogroup viruses
CDC	Centers for Disease Control
DENR	Department of the Environment and Natural Resources
DVBD	Division of Vector-borne Diseases
DDT	Dichlorodiphenyltrichloroethane
ECU	East Carolina University
EEEV	Eastern equine encephalitis virus
EPA	Environmental Protection Agency
ENC	Eastern North Carolina
FEMA	Federal Emergency Management Association
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
IGRs	Insect growth regulators
IPM	Integrated pest management
IVM	Integrated vector management
LACV	La Crosse virus
MCP	Mosquito control program
NC	North Carolina
NCDC	National Climatic Data Center
NOI	Notice of Intention

NPDES	National Pollutant Discharge Elimination System
PHPMS	Public Health Pest Management Section
PGP	Pesticide General Permit
SIT	Sterile insect technique
SLEV	St. Louis encephalitis virus
ULV	Ultra-low volume
US	United States
WHO	World Health Organization
WNV	West Nile virus

Chapter I – Introduction and Purpose of the Study

Vector-borne disease is a global issue that must be managed at the local level (Lambrechts et al. 2009). Over one-fourth of the nearly 60 million worldwide deaths that occur annually are attributed to infectious diseases (Morens, Folkers, & Fauci, 2004; Mandell, Bennett, & Dolin, 2010; World Health Organization [WHO]; 2011). Approximately 60% of all known human pathogens and 75% of emerging or reemerging infectious pathogens are zoonotic, many of which are transferred from animal to human through hematophagous arthropods (Gubler, 1998; Higgs & Beaty, 2005; Jones et. al, 2008; Herring, 2010). Pathogens that cause many emerging and reemerging infectious diseases, such as dengue, chikungunya and West Nile encephalitis are transmitted by mosquitoes (Mandell, Bennett, & Dolin, 2010) and account for over 20% of all emerging infectious diseases (Jones et. al, 2008). Comprehensive investment (e.g. financial, staffing, etc.) in public health research is central to controlling many infectious threats (Mandell, Bennett, & Dolin, 2010).

Mosquitoes are responsible for more human suffering worldwide than any other organism (American Mosquito Control Association [AMCA], 2011). In the US, mosquito control programs (MCPs) control nuisance mosquitoes and mosquitoes that transmit pathogens. However, numerous counties either do not have MCPs or have faced budget cuts that have drastically reduced resources (Herring, 2010; Del Rosario et al. 2014). Numerous studies suggest mosquito-borne disease surveillance and MCPs are essential to protect public health and prevent disease outbreaks (LaBeaud and Aksoy, 2010; Herring, 2010; Kelly, 2011; Tomerini, Dale, & Sipe, 2011).

The budgets for many MCPs have been significantly reduced, causing many programs to either operate at less effective levels or be eliminated altogether (Herring, 2010). Because of this, county emergency managers in many areas have the added responsibility of mosquito control following disasters, such as hurricanes or floods. Many emergency managers do not have mosquito control experience; therefore, confronting mosquito populations following natural disasters presents a new challenge to already burdensome recovery efforts. Accordingly, the objectives of this study were to:

1. Explore how recent policy and funding changes in North Carolina (NC) impact mosquito control in post-disaster situations.
    a. Determine the extent to which state-level budget cuts affect mosquito control for NC counties following a natural disaster.
    b. Discuss the added burden of relying of post-disaster Federal Emergency Management Association (FEMA) assistance for local MCPs.
    c. Use a case-study in two rural eastern NC counties to show the extent to which aerial insecticide spraying was effective at controlling mosquito populations.
2. Determine the role county-level NC emergency managers play in routine and post-disaster vector control.
    a. Describe the role of emergency managers in mosquito control.
    b. Examine the views and expertise of emergency managers related to mosquito control.

Chapter II – Literature Review

Mosquito Biology

There are > 3,400 species of mosquitoes (Diptera: Culicidae) worldwide (Clements, 2000; Eldridge, 2005; Service, 2008). Mosquitoes oviposit in standing water and are found on every continent except Antarctica (Eldridge, 2005). The life cycle of a mosquito includes four stages: egg, larva (four larval instars), pupa, and adult (Clements, 2000; Eldridge, 2005). Eggs can be laid individually or in rafts in standing water, depending upon the genus (Clements, 2000; Eldridge, 2005) and typically hatch within four days. Other species, including many floodwater and container-ovipositing mosquitoes (temporary water), lay their eggs on moist surfaces above the water line (Clements, 2000; Eldridge, 2005). These eggs may remain dormant for months, until the area is inundated with water; therefore, eggs may accumulate in an area, allowing broods of mosquitoes to simultaneously emerge following flooding (Clements, 2000; Eldridge, 2005; Service, 2008).

Mosquitoes undergo complete metamorphosis, i.e. juvenile species undergo changes from larvae to pupae to adult in which the adult is anatomically different from the larvae and pupae (Clements, 2000). Mosquito larvae live exclusively in water, using a siphon or abdominal plates to breathe air above the surface (Clements, 2000; Eldridge, 2005; Service, 2008). Mosquitoes remain in the larval stage from three days to four weeks, depending on species and environmental conditions. Upon completion of the fourth instar, the mosquito molts into a pupa (Clements, 2000; Service, 2008). Pupae remain in water, breathing through two respiratory trumpets (Clements, 2000; Service, 2008). Pupae transform into adults after ≥ two days, with males usually emerging prior to females (Clements, 2000; Eldridge, 2005). Male mosquitoes can be distinguished from their female counterparts by their longer, hairier maxillary palps (Eldridge, 2005; Service, 2008). Males are also usually slightly smaller than the females (Eldridge, 2005). Adult mosquitoes live on land and can fly (Clements, 2000; Service, 2008). Some mosquito species remain in the same area their entire lives, whereas others may travel over 100 km away from their birthplace (Service, 2008).

Both male and female mosquitoes have a proboscis, which is used to pierce and suck fluids for nutrition (Clements, 2000). Males feed almost exclusively on plant nectar, whereas females feed on both nectar and vertebrate blood (Clements, 2000; Eldridge, 2005). While the sugar from nectar provides nutrients for mosquito survival, most female mosquito species must take a bloodmeal, which provides proteins to develop eggs (Clements, 2000; Service, 2008). Thus, females seek a bloodmeal shortly after mating with a male mosquito and may lay her eggs within a few days of the bloodmeal, depending on environmental conditions. Most adult mosquitoes may survive up to a month, though some may survive several months, depending on physiology (e.g. ability to overwinter) and/or environmental conditions (Service, 2008).

The Burden of Mosquitoes and Mosquito-borne Diseases

Because female mosquitoes require blood for egg development, mosquitoes serve as hosts to a wide variety of vertebrate pathogens (Clements, 2000). From the 17th to early 20th century, vector-borne diseases accounted for more human disease and death than all other causes combined (Gubler, 1998). Despite this, mosquitoes were not implicated in the transmission of pathogens until the 19th century (Clements, 2000). Since this time, mosquitoes have been associated with hundreds of pathogens affecting human health (Clements, 2000). Mosquito-borne diseases are responsible for 1-2 million deaths worldwide every year (Gubler, 1998; WHO, 2003; Association of State and Territorial Health Officials [ASTHO], 2008; AMCA, 2011). Mosquitoes transmit nematodes that can cause filariasis, a disease found almost exclusively in tropical regions, malaria parasites, bacteria, and arboviruses (Clements, 2000; Eldridge, 2005; Service, 2008). The pathogens transmitted by mosquitoes that are of primary concern in the US consist of a diverse group of RNA viruses referred to as arboviruses (Oxford & Oberg, 1985).

Arboviruses are maintained in epidemiologic cycles between hematophagous arthropods (primarily mosquitoes and ticks) and vertebrate hosts (Oxford & Oberg, 1985; Edman, 2004; Higgs & Beaty, 2005; Service, 2008). Arboviruses of interest to public health are included in the following families: Togaviridae, Flaviviridae, Bunyaviridae, Reoviridae, and Rhabdoviridae (Oxford & Oberg, 1985; Edman, 2004). Of the > 500 known arboviruses (Higgs & Beaty, 2005), ≈ 150 can be transmitted to humans by mosquitoes (Clements, 2000; Service, 2008). In many cases, humans are considered tangential or “dead-end” hosts, whereas other vertebrates, such as birds and rodents, may amplify viruses, depending on the epidemiological cycle of each virus (Morens, Folkers, & Fauci, 2004; Higgs & Beaty, 2005). Humans are typically not amplification hosts, though there are exceptions (i.e. dengue and chikungunya viruses) (Higgs & Beaty, 2005). Arboviruses can manifest themselves in humans in a wide variety of ways. The majority of victims may have a subclinical infection, in which the person is asymptomatic (e.g. West Nile virus). Common clinical indicators can include encephalitis, febrile conditions, and hemorrhaging; these symptoms can range from very mild to fatal (Oxford & Oberg, 1985; Edman, 2004).

An estimate of the public health burden of arboviruses is difficult to pinpoint, primarily due to lack of surveillance, misdiagnosis, and underreporting of illnesses. Despite these challenges, MCPs have had an enormous impact on controlling the transmission of mosquito-borne pathogens (Hill et al., 2005). Mosquito control programs typically use area-wide abatement strategies that encompass numerous approaches including surveillance, application of chemical insecticides, source reduction, biological control, and other technologies to combat mosquitoes (Rose, 2001; Eldridge, 2005; Kline, 2006; Kramer, Styer, & Ebel, 2008; Del Rosario et al., 2014). Integrated vector management (IVM) or integrated pest management (IPM) involves the use of multiple control practices that help to maintain mosquito abundance and potential pathogen transmission at a level acceptable to the public (Ginsberg, 2001; Rose, 2001; Centers for Disease Control [CDC], 2013). The most effective IPM practices are dynamic and dependent on vector-pathogen relationships along with geographic, social, and economic factors at the local level (Ginsberg, 2001; CDC, 2013). Models show that an effective IPM strategy utilizing more than one control method may have a synergistic effect in controlling mosquitoes and hindering transmission cycles (Ginsberg, 2001). Mosquito control programs are often funded through state and local government taxes and programs (Rose, 2001; Eldridge, 2005) and can be facilitated by other government agencies such as public works, agricultural extension services, and local public health programs (Del Rosario et al., 2014).

Surveillance and monitoring programs are essential to mosquito control (Rose, 2001; CDC, 2013). An effective surveillance program includes monitoring mosquito habitats, documenting mosquito abundance throughout the year, testing mosquito pools for pathogens, and monitoring other factors (e.g. weather patterns) that influence both abundance and transmission of pathogens (CDC, 2013). Mosquito control programs can utilize numerous tools to monitor mosquito and pathogen dynamics, such as sentinel chicken flocks for monitoring arbovirus (e.g. West Nile virus) antibodies, indicating pathogen transmission is occurring in nature (Rose, 2001). Additionally, many surveillance programs use geographic information systems, topographic mapping, mosquito trapping, landing and biting counts, seasonal weather data, and citizen complaints about mosquito abundance (Rose, 2001). Surveillance and monitoring are paramount to determine the effectiveness of any control efforts performed by MCPs (CDC, 2013).

The application of chemical pesticides is the most common approach for controlling mosquitoes (Eldridge, 2005; Kline, 2006). Larvicides are applied to standing water and kill mosquito larvae prior to adult emergence (Day, 2001). Adulticides are applied in aerosol form to kill adult mosquito populations. Adulticides applied via aircraft or truck-mounted equipment are applied using ultra-low volume (ULV; ≤ 10 mL) droplets (Eldridge, 2005; CDC, 2013). Public concern over the use of pesticides has been well documented, given the potential effects some pesticides have on fish, non-target insects, and humans (Rose, 2001). Pesticides used in mosquito control are applied by licensed (public health pesticide license) and trained employees who must follow federal laws governing their use (Rose, 2001; Environmental Protection Agency [EPA], 2012). This method reduces harmful effects to humans and other non-target species (Rose, 2001). Non-target species and humans are usually not affected due to low application rates (between 28-85 grams per acre), the ULV technique, public notification of spraying, and spraying at dawn and dusk, when humans are usually inside (Rose, 2001).

Organochlorides, such as DDT (dichlorodiphenyltrichloroethane), became a popular insecticide targeting mosquitoes following World War II; however, these were phased out due to numerous factors including insect resistance, financial costs, and political pressure due to environmental risks (Eldridge, 2005; Service, 2008). Organochlorides were replaced with other insecticides including organophosphates, carbamates, and synthetic pyrethroids; however, many of these also have similar problems, particularly environmental concerns and insect resistance

(Rose, 2001; Eldridge, 2005; Service, 2008). Because of this, other technologies should be used in an IPM system (Rose, 2001).

Recent technologies include insect growth regulators (IGRs) and biological control methods (BC). Insect growth regulators work by disrupting the development process of the immature mosquito (Batra et al., 2005). Insect growth regulators work by either interfering with larval growth by mimicking hormones responsible for insect growth or by disrupting the molting process, resulting in the death of the mosquito (Batra et al., 2005; Service, 2008). Biological control methods use living organisms or products of living organisms to control mosquitoes (Eldridge, 2005; Service, 2008). The two primary examples of successful BC include using natural predators and microbial toxins. The most successful and popular predators are the mosquitofish (*Gambusia affinis* Baird and Girard; *Gambusia holbrooki* Girard), which are natural predators of immature mosquitoes (Rose, 2001; Eldridge, 2005; Service, 2008). Other predators include dragonfly nymphs and larval *Toxorhynchites* mosquitoes (adults do not blood feed) (Rose, 2001; Eldridge, 2005). Bacteria such as *Bacillus thuringiensis* Berliner and *Bacillus sphaericus* can be used to kill mosquito larvae (Federici, 2003; Eldridge, 2005; Service, 2008). These technologies have advantages such as specific targeting of mosquitoes and other nuisance fly species and being more environmentally friendly; however, these technologies are dependent on mosquito density, are difficult to mass produce, and can be costly (Eldridge, 2005).

Source reduction is another tool in controlling mosquitoes. Source reduction is the management, reduction, or elimination of standing or stagnant water (Rose, 2001; Eldridge, 2005; Service, 2008; CDC, 2013). In the past, source reduction included the draining of wetland areas which provided habitat for mosquitoes (Rose, 2001; Eldridge, 2005; Service, 2008). As the importance of wetlands was discovered, wetlands were no longer drained; instead, the timing of flooding in wetlands was controlled to help maintain a more natural system, while limiting the conditions needed for mosquitoes to proliferate (Eldridge, 2005). Source reduction also includes smaller scale operations, including public education that advocates eliminating standing water around residences, e.g. bird baths, flower pots, and tires (Knudsen & Sloof, 1992; Gubler, 1998; Rose, 2001; Norris, 2004; Service, 2008; CDC, 2013).

Emerging technologies have focused largely on molecular approaches to control mosquitoes. These include genetically modified mosquitoes that prevent or suppress pathogen transmission, kill the mosquito upon eclosion, and/or interfere with reproduction. One such technology, the sterile insect technique (SIT), involves the release of large quantities of laboratory-reared sterile male mosquitoes to mate with wild females (Alphey et al., 2010). Over time, and with enough males released, the reproduction of mosquitoes is diminished to the point of suppression and even elimination of the target mosquito species (Service, 2008; Alphey et al., 2010). Though these technologies have not become widely used or accepted in field applications, they hold promise as an environmentally friendly approach to be used in conjunction with other technologies (Eldridge, 2005; Alphey et al., 2010).

Impact of MCPs on Mosquito-borne Diseases

Established MCPs should employ control measures based on spatiotemporal tracking of mosquito populations and should replace non-surveillance-based programs (Lambrechts et al., 2009). The goal of MCPs is to reduce mosquito populations implicated in the transmission of pathogens and subdue nuisance mosquitoes (Del Rosario et al., 2014). The primary tool with which MCPs achieve this goal is with mosquito-based surveillance (CDC, 2013). This includes collecting data on mosquito abundance and pathogen infection rates, identifying areas that are at risk for human-mosquito contact and potential infection, determining appropriate action based on surveillance data, and monitoring the effectiveness of control strategies (CDC, 2013). With proper action, MCPs can greatly reduce the risk of mosquito-borne disease epidemics by limiting the potential for vector-human interaction or reducing the number of pathogen-infected vectors (Ginsberg, 2001). Source reduction and larviciding in the early spring when mosquito populations are less widespread significantly reduces adult mosquito abundance later in the year, thus reducing the risk of mosquito-borne disease transmission (ASTHO, 2008; CDC, 2013). Mosquito control must be focused on eliminating larval and adult populations to eliminate or interrupt potential disease transmission (ASTHO, 2008).

One of the earliest studies examining the impacts of mosquito control on transmission of mosquito-borne pathogens occurred in Dallas, Texas. Hopkins et al. (1975) examined the efficacy of ULV aerial spraying of malathion to reduce the transmission of St. Louis encephalitis virus (SLEV). Excessive rains and flooding in April 1966 resulted in conditions conducive to mosquito oviposition and rapid population growth. From July to September of the same year, 172 human cases of confirmed or presumed SLEV were recorded in Dallas County. During the epidemic, the incidence rate in humans was 15.2 cases/100,000 people with a mortality rate of 1.5/100,000 people (Hopkins et al., 1975). The infection rate in mosquitoes prior to aerial spraying was 1 infected/167 mosquitoes. Aerial spraying was conducted for eight days (Luby, Sulkin, & Sanford, 1969). Potential vector species (e.g. *Culex quinquefasciatus*) were effectively eliminated from the area for up to 10 days after aerial spraying concluded (Luby, Sulkin, & Sanford, 1969). Subsequent tests of *Cx. quinquefasciatus* populations showed the infection rate dropped to 1 infected/57,199 mosquitoes (Hopkins et al., 1975) and incidence of human cases also declined drastically, indicating that aerial spraying may have disrupted the transmission of SLEV (Luby, Sulkin, & Sanford, 1969; Hopkins et al., 1975).

Tedesco, Ruiz, & Lafferty (2010) explored the impact different policies and mosquito control strategies had on MCPs following an outbreak of West Nile virus (WNV) in the Chicago area in 2002. In this case, it is likely that local politics and lack of funding for mosquito control influenced the severity of WNV outbreak in four mosquito control districts (Tedesco, Ruiz, & Lafferty, 2010). Districts that used reactive methods including larviciding and adulticiding based on occurrence of WNV-infected mosquitoes experienced higher occurrences of human WNV infections than those using proactive surveillance and control (Tedesco, Ruiz, & Lafferty, 2010). The same study showed that the district with the lowest income was not adequately prepared to respond to the outbreak due to economic constraints. Local politics and citizen attitudes played a critical role in controlling the outbreak. For instance, the district with the highest income had many citizens who shared concerns over the use of adulticide spraying and its potential effects on the public and environment (Tedesco, Ruiz, & Lafferty, 2010). This public pressure to restrict preventative larvicide and adulticide measures limited the ability of the high income district to control mosquitoes, thereby curtailing the ability to control the outbreak, despite having adequate resources. Finally, the two MCPs experiencing larger outbreaks did not use preventative measures to combat the presence of adult mosquitoes, such as educating the public, increased larviciding, surveillance, arbovirus testing, and early spraying. The Chicago districts that experienced the fewest cases had extensive education and public information systems, significant larviciding measures, surveillance that focused on vector species rather than nuisance species, enhanced rapid WNV testing equipment, and conducted early adulticide spraying to reduce the number of adult mosquitoes (Tedesco, Ruiz, & Lafferty, 2010). This implies that counties or districts with actively involved MCPs may help mitigate outbreaks of WNV.

The reemergence of dengue in Central and South America in the 1980s can be attributed, in part, to a failure of continued proactive responses (Gubler, 2002). The primary vector of dengue virus, *Aedes aegypti*, was nearly eradicated in an effort to stop yellow fever through a program by the Pan American Health Organization (Gubler, 2002). After a successful start to the program, resulting in decreases in yellow fever and dengue outbreaks, the program was discontinued in 1970 (Gubler, 2002). After the elimination of the program, the distribution of dengue was more widespread in the Americas than it was prior to the program (Gubler, 2002; Mandell, Bennett, & Dolin, 2010). Malaria is another vector-borne disease that reemerged in areas without high incidence rates due to flawed vector control policies (Gubler, 2002). Malaria was eliminated from many areas of the world such as Europe, the United States (US), and parts of Asia and the Caribbean in the 1950s and 1960s. However, the disease reemerged in many low incidence areas such as South America and Asia, likely due to a lack of continued vector control (Gubler, 2002; Morens, Folkers, & Fauci, 2006; Mandell, Bennett, and Dolin, 2010).

Currently, WNV is an example of an emerging infectious disease that has caused a public health crisis in the US and many other regions of the world (Gubler, 2007; Kramer, Styer, & Ebel, 2008; CDC, 2013). West Nile Virus was first discovered in Uganda in 1937 and has been implicated in numerous epidemics ranging from Africa, the Middle East, Europe, and Asia (Kramer, Styer, & Ebel, 2008). The first case of domestically-acquired WNV in the US occurred in 1999 and rapidly expanded throughout most of the western hemisphere, ranging from central Canada to southern Argentina (Gubler, 2007; Kramer, Styer, & Ebel, 2008; CDC, 2013). It is now considered enzootic in the contiguous US. It is the most widely distributed arbovirus in the world (Kramer, Styer, & Ebel, 2008) and most frequently reported arbovirus in the US (CDC, 2013). WNV can be found in at least 30 North American mosquito species, though not all have been implicated in transmission to humans (Morens, Folkers, & Fauci, 2004). More than 150 species of birds have been found infected with WNV, providing ample sources to amplify and spread the pathogen, with migratory birds posing the danger of spreading the disease to new locations (Morens, Folkers, & Fauci, 2004). While annual numbers of cases in the US since 1999 are variable, WNV human cases are commonly found in in the central plains (CDC, 2013). Unfortunately, surveillance efforts have not allowed experts to predict when and where epidemic transmission will occur (Gubler, 2007).

The most recent outbreak of WNV occurred in 2012 in northeast Texas, i.e. 1,868 cases, with 844 positive for neuroinvasive WNV and 89 total deaths (Murray et al., 2013). Texas had experienced 2,202 cases in total from 2002-2011 (Murray et al., 2013). Murray et al. (2013) estimated that the outbreak cost $47.6 million in acute medical care and lost wages; however, long-term effects and additional mosquito control costs were not taken into account. Chung et al. (2013) added that aerial spraying in Dallas County alone cost over $1.7 million. Additional costs will likely to continue to mount when taking into account future productivity lost, long-term disability, and premature deaths (Murray et al., 2013). Murray et al. (2013) mentioned the need for surveillance and control to prevent future outbreaks.

Vector-borne disease epidemics most likely occur in areas that are unprepared or ill-equipped to handle the challenges these outbreaks present, whereas areas with effective surveillance methods are better prepared to prevent epidemics (Luby, Sulkin, & Sanford, 1969). Gubler (1998) contends that lack of financial support for vector control, loss of infrastructure for preventative public health action, and reliance on reactive measures such as insecticides are the primary reasons vector-borne diseases have reemerged throughout the world.

Mosquito Control Funding

Mosquito control programs are an integral component of environmental and public health programs on local, state, federal, and international levels. In relation to their costs, MCPs are often underestimated in terms of their importance to public health (Tomerini, 2005). Yet, these programs often experience funding cuts due to their inability to generate revenue (Herring, 2010). Many regions that do not have MCPs due to lack of funding rely on community efforts to control oviposition sources. Many MCPs only control nuisance mosquitoes, particularly in areas that experience sporadic outbreaks of vector-borne diseases (Ginsberg, 2001). Mosquito control personnel respond to citizen complaints, conduct public education, mosquito and mosquito-borne disease surveillance, and mosquito control (Vasquez-Prokopec et al., 2010; Herring, 2010). Surveillance is the first line of defense in detecting and responding to mosquito-borne disease outbreaks (Vasquez-Prokopec et al., 2010).

The success of MCPs is often measured by decreased mosquito-borne disease and mosquito abundance (Herring, 2010). However, when MCPs are successful, the public often becomes complacent and underestimates the importance of these programs (LaBeaud and Aksoy, 2010). Prior to the introduction of WNV into the US, many MCPs had limited resources, which may have contributed to the delay in recognizing and responding to the disease (Vasquez-Prokopec et al, 2010). The arrival and rapid spread of WNV through the US in the last decade led to the creation of many new arbovirus surveillance programs (Kelly, 2011) and a major boost in funding to combat the disease (Vasquez-Prokopec et. al, 2010; Herring, 2010). The interest in WNV has begun to wane; hence, vector control programs are again experiencing a decline in funding (Herring, 2010). Cutbacks in funding have resulted in many local programs being understaffed and state-level disease surveillance is lacking in many areas (Herring, 2010). The importance of MCPs and proper funding for surveillance and operations has been noted for decades. In the years following two SLEV outbreaks in the mid-1960s, Dallas and Houston (Texas) spent approximately $100,000 and $500,000 per year in their MCPs, respectively (Luby, Sulkin, & Sanford, 1969). Effective surveillance allows programs to determine the extent of an emergency and coordinate proper response measures in a timely manner (ASTHO, 2008).

Budget shortfalls in recent years have resulted in reduced functionality of many state and community-level vector surveillance and control programs. In 2011, the Centers for Disease Control and Prevention, Division of Vector-borne Diseases (CDC-DVBD) experienced a nearly $27 million decrease in budget (i.e. budget reduction of 70%) (Vasquez-Prokopec et al., 2010; Couzin-Frankel, 2010; LaBeaud & Aksoy, 2010). The primary functions of the DVBD are research and monitoring of vector-borne diseases at the national level as well as preventing the introduction and spread of potential pathogens into the country. Many states also depend on funding from the DVBD, as almost half of the federal program's budget provides assistance to state epidemiology programs (Couzin-Frankel, 2010; LaBeaud & Aksoy, 2010). Without the necessary funding, the DVBD would only be able to respond to disease outbreaks, rather than surveillance and control methods to prevent them (Vasquez-Prokopec et al., 2010; Couzin-Frankel, 2010). Due to public pressure, much of this funding has since been restored, saving the jobs of approximately 24 CDC employees and more than 100 state employees (Couzin-Frankel, 2010).

Vasquez-Prokopec et al. (2010) concludes that the cost of surveillance to prevent and monitor mosquito-borne disease outbreaks is cheaper than the costs associated with responding to an outbreak. In addition, removal of surveillance makes the US more vulnerable to emerging diseases such as a resurgence in malaria or the introduction of other mosquito-borne diseases such as Rift Valley fever or chikungunya viruses (Vasquez-Prokopec et al., 2010). Nevertheless, local MCPs continue to face drastic cuts (Labeaud & Aksoy, 2010).

Mosquito Control and Emergencies

Factors that increase the risk of vector-borne disease transmission following disasters and emergencies include higher populations of susceptible hosts, overwhelmed public health services, and disruptions in routine mosquito control operations (Watson, Gayer, & Connolly, 2007). Emergencies strain resources for local programs including equipment, staffing, and budgets (ASTHO, 2008). In some cases, the disaster is not to blame for the outbreak. Dengue outbreaks may occur due to higher availability of oviposition sources (e.g. artificial containers and debris), which can be neglected due to disruptions in water and waste disposal services (Watson, Gayer, & Connolly, 2007). State and local MCPs must rely on comprehensive and effective planning and emergency response, rather than help from federal sources in the immediate aftermath of an emergency (ASTHO, 2008). In order to do this, a well-established and organized MCP will greatly enhance recovery efforts rather than emergency response measures alone (ASTHO, 2008).

Sustained MCPs increase efficiency in emergency response and save local emergency resources. Mosquito control programs can be sustained at a national average of $2.40 per person per year (ASTHO, 2008). This can be compared to a cost of $20.14 million dollars spent during a WNV outbreak from June 2002-February 2003 in Louisiana (Zohrabian et al., 2004). During this same outbreak in Louisiana, local MCPs in the state requested over $4.8 million in state reimbursements from the Louisiana Office or Emergency Preparedness and spent an estimated $8.3 million in mosquito control for the duration of the outbreak (Zohrabian et. al, 2004). Another study showing the impact of an emergency arboviral disease outbreak occurred in

Dallas, Texas July 1966 (Schwab, 1968). The outbreak in the aforementioned study, including 172 confirmed or presumptive cases and 20 deaths, cost an estimated $796,500. Of that, $348,500 was spent on vector control and other epidemic control activities (Schwab, 1968). Zohrabian et al. (2004) projected costs of the 1966 outbreak to be approximately $5.4 million (dollar value adjusted to equal currency in 2002).

Federal Emergency Management Policies for Mosquito Control

Federal efforts to mitigate damages from disasters have historically been focused on relief following a disaster rather than preventative measures prior to disasters (Birkland, 2006). While preventative measures have become more commonplace in recent years, it is still structured primarily as disaster response, in large part due to pressure to address problems considered more immediate when a disaster is not imminent or occurring (Birkland, 2006). The Federal Emergency Management Agency (FEMA) helps coordinate disaster preparation, assistance, and recovery for state and local jurisdictions that do not have the resources or have become overwhelmed following a disaster. Following a presidential disaster declaration, FEMA coordinates and implement financial and physical assistance to the affected locations (FEMA, 2012a). State and local jurisdictions can apply for reimbursement for emergency actions through FEMA (FEMA, 2012a).

Mosquito abundance can spike in the days following a flooding event due to increased incidence of standing water. Increases in mosquito occurrence and abundance may result in an increased risk of mosquito-borne disease if virus transmission was occurring prior to the disaster event (FEMA, 2012a). Emergency vector control is eligible for reimbursement from FEMA under the following conditions:

1. Evidence of higher levels of pathogen transmitting mosquitoes in the disaster area following the event or a significant number of pathogen-carrying mosquitoes in

the area due to the increase in event-related standing water; or evidence of the potential for pathogen transmission and human exposure to pathogen carrying mosquitoes based on the detection of arboviral diseases in sentinel organisms (poultry, wild birds, mosquito pools) in the impacted area: prior to the storm event, discovered during surveillance as part of mosquito abatement activities, or reported human cases in which transmission occurred prior to the storm event. Presence of known primary and secondary vector species in an affected area may presage future event-related disease transmission.

2. A determination that a significant increase in the mosquito population and/or the change of biting mosquito species poses a threat to emergency workers who are required to work out-of-doors; thereby significantly hampering response and recovery efforts. Such evidence may include an abnormal rise in landing rates or trap counts, significant changes in species composition or estimate of infection rates, when compared to pre-disaster surveillance results.
3. Verification from medical facilities within the affected area that an increase in the general public's exposure to mosquitoes has directly resulted in secondary infections, especially among those with weakened immune systems such as the elderly, the very young, or the sick. This may occur when increased numbers of residents in disaster areas with extended power outages are forced to open buildings for air circulation (FEMA, 2012a).

Vector control beyond the normal activities conducted by the county should be based on surveillance data provided to FEMA prior to the treatment. This includes surveillance data before and after insecticide treatment, arbovirus transmission activity (in mosquitoes, sentinel flocks, horses, or humans) and any additional information that would be helpful such as damage assessments, extent and type of flooding, and estimated length of recovery operations. FEMA also requires supporting evidence for which type of management method would be appropriate, i.e. aerial versus ground application; targeting adults and/or larvae (FEMA, 2012a).

Following a submitted request, the FEMA consults with the CDC and determines whether or not the added control measures are justified and eligible for funding. If they are considered justifiable, then FEMA may provide the appropriate level of assistance. This level of assistance includes only additional costs associated with mosquito control which is determined by comparing the disaster costs to the costs in the previous three years (FEMA, 2012a). Because of the requirements FEMA has placed on vector control reimbursement, it is paramount that local jurisdictions have up-to-date, precise records of previous mosquito surveillance and mosquito control expenditures. Areas with little or no funding for MCPs are likely not able to provide background data, thereby decreasing the likelihood of FEMA reimbursement. Therefore, proper record-keeping prior to a disaster is essential to any areas prone to flooding and mosquito proliferation.

Recent Funding and Policy Changes to MCPs in NC

In previous years, many NC counties depended on the Public Health Pest Management Section (PHPMS) of the Department of the Environment and Natural Resources (DENR) for assistance with post-hurricane responses dealing with mosquitoes. The PHPMS: 1) provided operational expertise, 2) dispensed state funds to local vector control agencies for mosquito control and sentinel flocks, and 3) provided post-disaster response to local communities (McKeithan, 2011). When a local MCP needed additional funding, PHPMS assisted programs when applying for FEMA assistance (McKeithan, 2011). Despite this managing role of the PHPMS, state budget cutbacks eliminated this agency in 2011 (Del Rosario et al., 2014). The 2011 session of the NC General Assembly repealed numerous statutes relating to vector control including statutes relating to funding, flood control measures, and control of outbreaks (NC General Assembly, 2011). All NC PHPMS positions, program funding and operations relating to the state control of mosquitoes ceased to exist; thus abolishing the primary source of funding for local level MCPs in NC. This has left many local MCPs without the necessary expertise and funds to continue, thereby forcing these programs to become more reactive than proactive (Del Rosario et al., 2014).

Additional legislation regulating the use of pesticides in mosquito control may add further financial strain to local MCPs. On October 31, 2011, programs and operators that use pesticides as a part of their MCP are required to obtain a Pesticide General Permit (PGP), as part of the National Pollutant Discharge Elimination System (NPDES) which is a part of the Clean Water Act of the EPA. This legislation was the result of a 2009 decision of the US Sixth Circuit Court of Appeals in the case *National Cotton Council et al. vs. EPA.* The decision expanded the definition of a point source pollution discharge, including any biological or chemical pesticide leaving a residue in water (EPA, 2012).

Any mosquito control pesticide spraying activity (such as adulticiding or larviciding) that can result in a point source discharge into US waters must now be covered by an NPDES permit in addition to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) certification requirement. This includes any spraying that may occur during emergency or disaster situations (EPA, 2012). While this action is intended to encourage the use of integrated pest management strategies and improve the quality of surface waters in the US, it also increases the time and financial burden put on local MCPs. Additional documentation required includes:

- Applicators must submit a Notice of Intention (NOI) prior to conducting any spraying operations; however the NOI may be completed 30 days after an event if there is a public health emergency.
- Applicators are also required to document what pesticide was used, what quantity, and which locations were sprayed during each event.
- Annual reports summarizing the pesticide use must also be submitted to the EPA.
- If any endangered species are present in the affected waters, additional consultation must be sought to ensure the endangered species will not be adversely affected (EPA, 2012).

NC and the Current State of MCPs

There are over 60 different mosquito species found in NC, some of which are pathogen vectors (Harrison, 2008). The most common pathogens found in NC include La Crosse virus (LACV), Eastern equine encephalitis virus (EEEV), and WNV; however, a few cases of SLEV and other California serogroup viruses (CALV) also occur (CDC, 2011). Human cases of mosquito-borne disease have been documented in 43 of 100 NC counties, 28 of which do not have MCPs (Del Rosario et al., 2014). Many employees in NC MCPs believe that continued cuts and the disbanding of PHPMS will continue to negatively affect their programs and may lead to an increase in mosquito-borne diseases in NC (Del Rosario et al., 2014).

Currently, MCPs protect approximately 48% of the NC population (McKeithan, 2011). Though there are a total of 86 MCPs in NC, they are dispersed among 39 of 100 counties in NC. The majority (83%) of MCPs are located in the coastal region of NC, compared to 12% and 2% for the Piedmont and Appalachian regions respectively (Del Rosario et al., 2014). Due to budget cuts and other financial burdens, many MCPs acknowledge operating under a smaller staff and with less ability to conduct surveillance and control activities that were once used by the MCP (Del Rosario et al., 2014). Most MCPs in NC (64%) are operating with fewer than 2 employees. Additionally, 55% of the MCPs in NC describe their current budget as barely functional (Del Rosario et al., 2014).

The disbanding of the NC PHPMS also eliminated statutes targeted at controlling mosquito-borne disease outbreaks following hurricanes and other disasters (Bjorneboe, 2012). Hence, following disasters, state and local EMs in addition to local level MCPs, public works, and public health programs, are responsible for mosquito control (Bjorneboe, 2012). There is no state support for coordinating responses to mosquitoes in disaster situations such as aerial spraying and filing paperwork for federal reimbursement (Bjorneboe, 2012). This leaves more of the burden on the county health director, EM, public health, and public works – all of which have additional responsibilities following disasters and may not be trained in effective vector control methods.

Hurricane Irene and its Effects on NC

In late August 2011, Hurricane Irene moved up the eastern coast of the US. Irene made landfall as a Category 1 hurricane at Cape Lookout, NC on August 27, 2011 (Figure 1), with sustained winds of over 85 mph and wind gusts over 115 mph. The effects of Hurricane Irene began for eastern NC well before landfall and lasted for weeks as widespread flooding, wind damage and power outages remained across the eastern part of the state for several days to weeks (Avila & Cangialosi, 2011). Rainfall totals for many coastal areas ranged between 17-38 centimeters. The hurricane also spawned tornadoes, the strongest of which occurred in Columbia, NC in Tyrrell County (Avila & Cangialosi, 2011).

In the weeks and months following the storm, many public and environmental health issues emerged. Among the most publicized and noticeable issues was the drastic increase in mosquito abundance throughout eastern NC counties. Flooded areas with standing water providing oviposition sites and temperatures that reached daily highs above 26°C following the hurricane facilitated a drastic rise in mosquito abundance. Species from genera *Culex*, *Aedes, Ochlerotatus*, and *Psorophora* are often the most prominent after flooding events (FEMA, 2012a). High mosquito populations may hinder post-hurricane recovery and reconstruction efforts by: 1) impeding emergency management and response services, 2) becoming a nuisance to the community in general, and 3) creating conditions conducive to the spread of arboviruses (Brown, 1997; FEMA, 2012a).

Following Hurricane Irene, 38 NC counties received disaster assistance (Figure 2). From 2011 through 2012, residents in NC received more than $160 million in disaster assistance from the state and federal levels (FEMA, 2012b). In addition to the costs associated with debris cleanup and removal, attention had to be paid to the mosquitoes which hindered recovery efforts and increased the risk for the transmission of mosquito-borne diseases. In many eastern NC counties, aerial adulticide spraying was conducted to help with nuisance mosquito control and reduce the risk of pathogen transmission.

Chapter III: Emergency Mosquito Control on a Selected Area in Eastern North Carolina after Hurricane Irene

**Note: This chapter is formatted as a complete manuscript and is in press with the peer-reviewed journal Environmental Health Insights*

Introduction

Vector-borne diseases are responsible for *ca.* 17% of all infectious diseases globally with over 1 billion people infected and 1 million deaths recorded annually (World Health Organization [WHO], 2014). The global issue of vector-borne disease must first be addressed at the local level (Lambrechts et al. 2009). Mosquitoes are the most common vector, having the ability to transmit > 100 pathogens, many of which can cause life-threatening symptoms such as encephalitis, meningitis, and hemorrhagic fever (Herrington, 2003; WHO, 2014). Investment (e.g. financial, staffing, etc.) in public health research and infrastructure is important for controlling threats such as vector-borne disease (Mandell, Bennett, & Dolin, 2010). In the United States (US), mosquito control programs (MCPs) protect public health by suppressing nuisance mosquitoes and those that transmit pathogens (LaBeaud and Aksoy, 2010; Herring, 2010; Kelly, 2011; Tomerini, Dale, & Sipe, 2011). However, some regions do not have MCPs and/or budget cuts have reduced resources so that programs may be ineffective (Herring, 2010; Del Rosario et al. 2014).

There are > 60 mosquito species found in North Carolina (NC) some of which carry pathogen vectors such as La Crosse virus (LACV), Eastern equine encephalitis virus (EEEV), and West Nile virus (WNV), among others (Harrison, 2008; CDC, 2014). There are 43 out of 100 NC counties that have reported human cases of mosquito-borne diseases, yet NC has lost state-level funding for vector control, causing many local MCPs to operate under a smaller staff with limited surveillance and control activities (Del Rosario et al. 2014). In 2011, numerous statutes relating to vector control were repealed including the Public Health Pest Management Section (PHPMS), which served as the primary state-level source of vector control expertise, funding, and response (McKeithan, 2011; Del Rosario et al. 2014). In 2014, the remainder of state-level vector control was also repealed (NC Office of State Budget Recommended Adjustments, 2014). Currently, there is no state-level support for mosquito control, creating an extra burden for local emergency managers, MCPs, public works, and public health programs, all of which may play a role in mosquito control (James Bjorneboe, personal communication).

Effective MCPs use surveillance-based targeted control as their primary tool to prevent epidemics by reducing mosquito populations implicated in pathogen transmission and suppressing nuisance mosquitoes (Ginsberg, 2001; Lambrechts et al. 2009; Herring, 2010; Mandell, Bennett, & Dolin, 2010; CDC, 2014; Del Rosario et. al. 2014). An effective MCP may: 1) monitor/reduce mosquito abundance, 2) monitor vertebrate and invertebrate infection rates, 3) identify and target high risk regions for control (areas with higher likelihood or mosquito-human interaction), and 4) monitor the efficacy of control measures (Ginsberg, 2001; CDC, 2014). Programs without arboviral surveillance data make decisions with limited knowledge (Ginsberg, 2001) and may experience delays in outbreak response (ASTHO, 2014).

Attempts to reduce the burden of vector borne diseases were successful during the 1940s through the 1970s, particularly with the use of pesticides and habitat management (WHO, 2014). However, success of these programs in controlling or eliminating mosquitoes and other vectors and the pathogens they transmit resulted in complacency in decision-makers and reductions in resources (WHO, 2014). Lack of financial support and infrastructure for preventative public health actions such as vector surveillance and control have encouraged reliance on reactive measures such as pesticides. This reactive stance is one of the primary reasons vector-borne diseases have reemerged throughout the world (Gubler, 1998; WHO, 2014). Mosquito control programs are an integral component of environmental and public health programs and their importance to public health is often underestimated (Tomerini, 2005; LaBeaud and Aksoy, 2010; Del Rosario et al. 2014). These MCPs often experience funding cuts due to their inability to generate revenue (Herring, 2010). The introduction and rapid spread of WNV through the US since 1999 resulted in the creation of many MCPs (Kelly, 2011) and a major boost in government funding to combat the disease (Vazquez-Prokopec et al., 2010; Herring, 2010). However, the interest in WNV has waned in recent years and MCPs budgets have declined (Herring, 2010; Del Rosario et al. 2014). A 2012 survey of local health departments in the US showed vector control was one of the top three environmental health services for which budget cuts negatively impacted services for the public (Li & Elligers, 2014). The same study estimated 12.7% of vector control programs have been reduced or discontinued in recent years. This despite the fact that sustained MCPs increase efficiency in emergency response and can be successful at a national average of $2.40 per person per year (ASTHO, 2014) as compared vector borne disease outbreak responses that typically cost millions of dollars (e.g. Gubler, 2002; Zohrabian et al, 2004; Chung et al, 2013) .

Vector-borne disease epidemics are most likely to occur in regions unprepared to handle the challenges these outbreaks present, whereas areas with effective surveillance methods are more likely to prevent epidemics (Luby, Sulkin, & Sanford, 1969). Factors that increase the risk of vector-borne pathogen transmission following natural disasters include susceptible hosts, overwhelmed public health services, and disruptions in routine mosquito control operations (Watson, Gayer, & Connolly, 2007). Emergencies strain resources (e.g. equipment and staffing) and MCPs rely on effective planning and emergency response rather than help from federal sources (ASTHO, 2014). An established and organized MCP greatly enhances recovery efforts rather than relying on emergency response measures (ASTHO, 2014). However, when additional resources or funding is needed, the Federal Emergency Management Agency (FEMA) helps coordinate disaster preparation, assistance, and recovery for state and local jurisdictions that do not have the resources or have become overwhelmed following a disaster. State and local jurisdictions may apply for reimbursement of emergency actions through FEMA (FEMA, 2012a). Eligibility for FEMA reimbursement includes providing evidence that mosquito abundance, particularly those mosquitoes known to be pathogen vectors or nuisance biters, is markedly higher following the disaster than in the months and years prior (FEMA, 2014a). This typically requires surveillance data from multiple years – something localities without MCPs may not have. Additionally, FEMA requires data on prior pesticide use for comparison purposes following a disaster (FEMA, 2014a).

In August 2011, Hurricane Irene moved up the eastern coast of the US and made landfall as a Category 1 hurricane at Cape Lookout, NC (Figure 1, Appendix A). The hurricane caused widespread flooding, wind damage, power outages and affected eastern NC for weeks (Avila & Cangialosi, 2014). From 2011 through 2012, residents from 38 NC counties received more than $160 million in disaster assistance from the state and federal levels (Figure 2, Appendix A) (FEMA, 2012b). After Hurricane Irene, mosquito abundance increased throughout eastern NC counties as standing water provided oviposition sites and temperatures reached daily highs above 26°C. Abundant mosquito populations may hinder post-hurricane recovery and reconstruction efforts by impeding emergency management and response services, becoming a nuisance to the community, and creating conditions conducive to the spread of arboviruses (Brown, 1997; FEMA, 2014a). In many eastern NC counties, aerial pesticide spraying was conducted to suppress adult mosquitoes, hence reducing public health risks. Consequently, the current study investigates the consequences of reactive rather than proactive mosquito control using case studies of two counties in rural eastern NC following Hurricane Irene.

Materials and Methods

Study sites

Study sites in Washington and Tyrrell Counties (Table 1, Figure 3, Appendix A) in eastern NC were utilized for this study. Both counties are bordered to the north by the Albemarle Sound. The areas/populations of Washington and Tyrell Counties are respectively 901 km^2/13,228 people and 1,007 km^2/4,407 people. Both counties have Tier-1 status, i.e. poorest in the state (CDC, 2014). In Washington and Tyrrell Counties, 23% and 29% of people respectively live below the federal poverty line, compared to the state average of 16% (US Census Bureau, 2011). Washington and Tyrrell counties were significantly impacted by Hurricane Irene with precipitation totaling 35.5 and 21.5 cm, respectively (National Climatic Data Center [NCDC], 2012). Tornadoes occurred in the town of Creswell in Washington County (Bennett, 2014) and city of Columbia in Tyrrell County (Avila & Cangialosi, 2014). Both counties requested and received individual and public assistance funds from FEMA.

Mosquito Surveillance

Centers for Disease Control and Prevention light traps were baited with *ca*. 1 kg of dry ice. Traps were set at eight sites in Washington County (N = 4 sites) and Tyrrell County (N = 4 sites) where adult mosquitoes were prevalent (Table 1). Each trap was set for an approximate 12 hour period from 1900 h – 0700 h. Pre-spray surveillance was conducted for two nights (i.e. October 9-10, 2011). Data on temperature and precipitation was obtained from NCDC for weather stations nearest each trap site (NCDC, 2012). Weather data was collected: Washington

County: Plymouth 5 E weather station, Roper, NC; Tyrrell County: Columbia Ag Gum Neck weather station, Columbia, NC. Overnight low temperatures for the first night of trapping (October 9) were 14°C for Washington and Tyrrell Counties. Traps were set at all four sites in both counties (N = 8 sites total) the first pre-spray night; however, traps were set at only four sites in Washington County the second pre-spray night. This was due to travel expenses and safety concerns from high densities of mosquitoes (i.e. landing counts of *ca.* 50 mosquitoes/minute). The low temperature for the second night (October 10) of pre-spray trapping (Washington County only) was 18°C and 0.025 cm of precipitation was recorded (NCDC, 2012). Aerial spraying (Donald's Flying Service, Pantego, NC) of Trumpet EC pesticide (78% naled [active ingredient], 22% petroleum distillate and emulsifier) occurred overnight on October 15 for all sites in Washington County and all but the Alligator (T-1) and Gum Neck (T-3) sites in Tyrrell County. The T-1 and T-3 sites were used as controls. Traps were set at all eight sites in both counties two days post-spray (October 17). The overnight low temperature for post-spray trapping was 13°C for both counties and no precipitation was detected (NCDC, 2012). Mosquitoes were collected and identified to species using a standard key (Slaff, Apperson, & Rogers, 1989).

Calculations

The percent change in total mosquito population at each trap site was calculated to evaluate the effectiveness of aerial spraying for adult mosquito knockdown. Because two nights of surveillance were conducted in Washington County but not Tyrell County, the two pre-spray nights were averaged and used to calculate percent change.

$$\text{Percent Change} = \frac{\text{Post-Spray Mosquito Abundance} - \text{Pre-Spray Mosquito Abundance}}{\text{Pre-Spray Mosquito Abundance}} \times 100$$

Statistical analysis was conducted using the Statistical Package for the Social Sciences (SPSS, version 20.0) (2011, IBM Corp, Armonk, NY). Sites were grouped based on treatment (received aerial spray) or control (did not receive aerial spray). Due to the small sample size, an Independent Samples Mann-Whitney U test was used to determine significant differences ($p < 0.05$) between treatment and control sites.

Results

Mosquito Collections

A total of 23,069 mosquitoes representing 23 species were collected during pre- and post-spray surveillance in Washington and Tyrrell Counties. There were 9,668 mosquitoes collected over three nights in Washington County (n = 8,753, two nights pre-spray; n = 915, one night post-spray). In Washington County, *Psorophora columbiae* (n = 4,910) was the most abundant species, followed by *Aedes vexans* (n = 2,141) and *Culex salinarius* (n = 858). A total of 13,401 mosquitoes were collected over two nights in Tyrrell County (n = 6,729, one night pre-spray, n = 6,672, one night post-spray). In Tyrrell County, *Culex salinarius* (n = 6,197) was the most abundant species collected, followed by *Culex pipiens* (n = 4,123) and *Culiseta melanura* (n = 690) (Table 2-3, Appendix A).

Efficacy of Emergency Control Measures

Aerial pesticide spraying resulted in decreased mosquito abundance for most study sites. Four sites (Washington County: C-1, C-2, C-3; Tyrrell County: T-4) showed > 50% reduction in mosquito abundance. Two sites (Tyrrell County: T-1, T-2) showed an increase in mosquito abundance following aerial spraying. The T-1 site was a control site (no aerial spraying); however, T-2 received aerial spraying (Table 4-5, Appendix A).

Statistical Analysis

The means of percent change in pre- and post-spray trap counts are (% change ± standard deviation): treatment -52.93 ± 45.40 (median = -73.88); control 3.55 ± 23.58 (median = 3.55). No significant differences ($p = 0.286$) were found in mosquito abundance between treatment and control groups.

Discussion

Hurricane Irene affected eastern NC for months following the initial flooding event in August 2011. In the current study, Washington and Tyrrell Counties were eligible for federal emergency vector control reimbursement due to potential pathogen vectors affecting emergency response efforts. Mosquitoes require approximately seven days to complete a gonotrophic cycle following flooding events including hurricanes (FEMA, 2012a). However, aerial spraying was conducted in these counties almost two months after Hurricane Irene due in large part to funding insecurity and a lack of local funding, as both counties are among the poorest in the state. No clinical arbovirus cases were observed in humans following the hurricane; however, it is difficult to track asymptomatic cases. Potential vectors were abundant and emergency workers were likely exposed to mosquito bites while repairing damaged homes, etc.

After aerial spraying was conducted in Tyrrell and Washington Counties, mosquito populations dropped substantially (20 to nearly 100%) at most study sites. Despite this, a few sites experienced only minor reductions in abundance following spraying. These differences could be due to variation in topography hindering spray operations and/or variation in timing of eclosion of mosquitoes between sites as we did not monitor immature mosquitoes or adult mosquito age at trap sites. Trap sites not receiving aerial spraying continued to experience substantial mosquito populations. The results indicate that aerial spraying can be an effective method of emergency mosquito control once adult populations have reached large numbers, even months after a flooding event, though recovery and emergency efforts would have likely benefited from control of adult mosquitoes much earlier.

The elimination of state funds supporting local MCPs in NC has burdened resource poor counties unable to conduct routine surveillance and control. In the current study, financial insecurity in Washington and Tyrrell Counties hindered recovery efforts following Hurricane Irene due to insufficient planning and resources for mosquito control. Many local mosquito and vector control programs are facing similar issues (Herring, 2010) and it is important to continue to track the status of local MCPs. Washington and Tyrrell Counties are currently reliant on reactive measures, despite the known benefits of proactive surveillance and targeted control. There are no comprehensive studies that examine the extent to which counties with limited financial resources function without mosquito control. The current study was limited to two counties requesting assistance following Hurricane Irene; however, looking at other counties with different socioeconomic and geographic characteristics would provide a more thorough analysis for future study.

Chapter IV: The Emergency Management Perspective

**Note: This chapter is formatted as a complete manuscript and will be submitted to a peer-reviewed journal.*

Introduction

Mosquito control programs (MCPs) control nuisance mosquitoes and those that transmit pathogens to protect public health and prevent disease (LaBeaud and Aksoy, 2010; Herring, 2010; Kelly, 2011; Tomerini, Dale, & Sipe, 2011). Effective MCPs use surveillance-based targeted control as their primary tool to prevent epidemics by reducing potential vector populations (Ginsberg, 2001; Lambrechts et al. 2009; Herring, 2010; Mandell, Bennett, & Dolin, 2010; CDC, 2014; Del Rosario et. al., 2014). MCP managers without access to mosquito and pathogen surveillance data make decisions with limited knowledge (Ginsberg, 2001) resulting in delays in outbreak response (ASTHO, 2014). Some regions do not have MCPs and/or budget cuts have reduced resources so that programs are ineffective (Herring, 2010; Del Rosario et al. 2014).

Human cases of mosquito-borne diseases have been reported in 43/100 North Carolina (NC) counties. Despite this, NC has experienced drastic cuts to state-level funding for vector control, particularly at the state level. In 2011 numerous statutes relating to vector control were repealed including the PHPMS, which served as the primary state-level source of vector control expertise, funding, and response (McKeithan, 2011; Del Rosario et al. 2014). In 2014, the remainder of state-level vector control was also repealed (NC Office of State Budget Recommended Adjustments, 2014). Currently, there is no state-level support for mosquito control, creating an extra burden for local emergency managers (EMs), existing MCPs, public works, and public health programs, all of which may be involved in mosquito control (James Bjorneboe, personal communication).

Hurricane Irene made landfall as a Category 1 hurricane at Cape Lookout, NC in late August, 2011 (Figure 1), causing widespread flooding, wind damage, and disrupting routine services (i.e. electricity, trash collection, etc.) in eastern NC for weeks (Avila & Cangialosi, 2014). More than $160 million in disaster assistance from the state and federal levels were distributed to 38 NC counties, all in the east (FEMA, 2012b). Standing water and warm temperatures following the hurricane increased mosquito abundance throughout eastern NC. High populations of mosquitoes impede post-hurricane recovery by disrupting emergency response efforts, becoming a nuisance through persistent biting, and creating conditions that may lead to the spread of arboviruses (more opportunities to mosquito-human interactions) (Brown, 1997; Watson, Gayer, & Connolly, 2007; FEMA, 2014a).

An established and organized MCP greatly enhances recovery efforts rather than relying on emergency response measures (ASTHO, 2014). However, when additional resources or funding is needed, FEMA helps coordinate disaster preparation, assistance, and recovery for state and local jurisdictions that do not have the resources or have become overwhelmed following a disaster. State and local jurisdictions are eligible to apply for reimbursement for emergency actions through FEMA (FEMA, 2012a). However, FEMA requires multiple years of surveillance data and evidence of prior use of pesticides to be eligible for reimbursement (FEMA, 2012a), something localities without MCPs may not have.

Because of this budget cuts and/or reduced functionality of MCPs, county EMs are being asked to take on a greater role in local mosquito control. Little is known about the experience NC EMs have with mosquito control. Accordingly, the objective of this study is to determine the role

NC county EMs play in routine and post-disaster mosquito control and to examine knowledge and perceptions EMs have about their county's MCP.

Materials and Methods

Study area

North Carolina is located along the mid-eastern coast of the US and covers approximately 125,921 km^2. It has a population of approximately 9,752,073; making it the 28th largest state and 10th most populous state in the US (US Census Bureau, 2011). North Carolina's geography consists of a 41-county coastal plain to the eastern part of the state, the 33-county piedmont region, located in the central part of the state, and the 26-county mountain region in the west.

Survey design and implementation

A 34 question survey (Appendix B) was emailed to EMs from each NC county (n=100) in order to solicit as many responses as possible, given the small population of NC EMs (Survey Monkey Inc.; Palo Alto, California). Follow up telephone calls were conducted beginning one week after the survey was distributed for those EMs who did not yet complete the survey. Every county was called at least twice, unless they had already completed the survey or declined to participate. Prior to distribution, the survey was granted full exemption by the ECU Institutional Review Board (IRB no. UMCIRB 12-001645).

Fifty-one responses were gathered to form a convenience sample of available and willing participants in the study. Respondents were grouped based on the region (mountain, piedmont, coastal) of NC in which they were employed. The current study focuses on eastern NC counties (i.e. 41 coastal plain counties) as this region is most affected by flooding and hurricanes. Chi-square analyses were conducted using the Statistical Package for the Social Sciences (SPSS, version 20.0) (2011, IBM Corp, Armonk, NY). Significant results were reported at the $p < 0.05$

level (Table 5; Appendix C). To provide a more robust analysis, Likert scale variables were recoded within SPSS to “Agree”, “Disagree”, or “Neither Agree nor Disagree”. Specific themes that emerged from the survey include EM involvement in mosquito control, funding characteristics and assistance for local mosquito control, EM training in mosquito control, and EM views on mosquito control.

Results

Descriptive statistics

A total of 51 of the 100 local EMs responded to the survey (51% response rate) (Appendix C; Table 6). Nearly 40% of respondents (15/39) had > 10 years of EM experience, 26% had less than five years of experience (10/39), and 36% had between five and 10 years of experience (14/39). Males represented > 70% of respondents (28/38) and females represented < 30% (10/38). Only 5% of respondents (2/38) were under the age of 35, 50% (19/38) were 35-50 years old, and 45% (17/38) were > 50 years old. Most respondents described themselves as Caucasian, accounting for 94% of the sample (34/36). One person described themselves as both black/African-American and Asian or Pacific Islander, respectively. Most respondents worked in coastal counties in eastern NC (ENC) (24/51) compared to 19 in the piedmont counties and 8 in western counties.

Emergency manager involvement in vector control

About half of EMs in NC are involved in routine (pre-disaster) vector control activities (51%) (Figure 4, Appendix C). However, there is a noticeable increase in EM involvement in post-disaster vector control. Participation of ENC EMs in vector control increased from 33% in routine activities to > 70% following a disaster. Likewise, 37% of EMs participate in routine vector control compared to 62.9% following disasters. Many EMs stated that their involvement in vector control has remained the same over the last five years (Figure 5, Appendix C), though nearly half (46.5%) of ENC EMs reported their post-disaster roles in vector control have increased, roughly double the percentage from the other combined NC regions.

Funding characteristics and assistance for mosquito control

Though many EMs contend that local vector control funding has remained relatively constant over the past five years, half of EMs state that funding has decreased (45.8% of ENC and 51.9% of all other NC counties) (Figure 6, Appendix C). Both ENC (56.5%) and other NC regions (54.5%) report that they are heavily dependent on state-level funding, with a majority of counties relying on at least some level of state assistance. Only 18.2% of ENC EMs did not rely on either NCPHPMS or NCDENR for assistance, compared to 31.8% of the rest of NC (Figure 7; Appendix C).

Half (50%) of ENC EMs reported having more (p=0.033) state assistance for Hurricane Irene compared to prior hurricanes, whereas 59.3% of the rest of NC EMs did not require state assistance (Figure 8; Appendix C). This is likely due to the impact that Hurricane Irene had on ENC compared to the rest of NC. One-third (33.3%) of ENC EMs were asked to assist with mosquito control for Hurricane Irene compared to only 14.8% of the rest of NC; however, most EMs in ENC (54.2%) and the rest of NC (74.1%) did not notice a change in mosquito control duties post-hurricane (Figure 9, Appendix C). Nearly half of ENC EMs sought assistance from other counties or private companies following Hurricane Irene (Figure 10, Appendix C). Significantly (p=0.025) more ENC counties sought help from private companies compared to EMs in other parts of NC. Forty-five percent of ENC counties sought help from neighboring counties and 47.6% sought assistance from private companies. Fewer counties from the other NC regions sought any outside assistance (26.3% from other counties and 15% from private companies).

Emergency manager training in vector control

The majority of NC EMs receive little to no routine training in vector control (Figure 11, Appendix C). Nearly half (48.8%) (42.9% in ENC and 54.6% in the other NC counties) of NC EMs never received training in vector control and 30.2% received training every three years. One respondent (2.3%) received vector control training more than once per year. Co-workers (26.7%) and the internet (22.1%) were the most common sources county EMs used to gain information on vector control (Appendix B).

Emergency manager views on vector control

Significantly (*p*=0.011) more ENC EMs agree (34.1%) that citizen complaints about mosquitoes increased following Hurricane Irene compared to much fewer (9.8%) for other NC regions (Figure 12, Appendix C). Significantly (*p*=0.007) more ENC EMs (55%) believed more responsibilities have been placed on them than in the past compared to 10.5% of the other NC counties. Significantly (*p*=0.001) more ENC EMs (54.6%) compared to the rest of NC (20%) believe their vector control program can respond to a disaster equal to Hurricane Irene. More than 72% of all NC EMs (80% of ENC and 65% of the other NC counties) believe arboviral surveillance is an important tool to assess public health risks during disasters. Most ENC (68.2%) and other EMs in NC (65%) were concerned about the ability of their local MCP to respond to an arbovirus outbreak. Significantly more ENC EMs (85.7%) compared to other NC EMs (60%) are worried about the future of local MCPs (*p*=0.049). Over half (54.6%) of ENC EMs and 80% of other NC EMs believe state and local funding sources should be used to support mosquito control, compared to 18.2% and 5% that do not believe state and local funding should be used, respectively. Fifty percent of ENC EMs are in favor of a county or municipality tax that would fund long-term MCPs locally compared to 36.8% of other NC regions (Figure 12, Appendix C).

Discussion

Following the disbanding of PHPMS and the subsequent funding cuts to most NC MCPs, it was assumed that the burden of post-disaster mosquito control would fall on other governmental departments, particularly county EM divisions. Not surprisingly, EMs report having an increased role in post-disaster compared to routine mosquito control, though, this sentiment is not consistently applied across NC. Significantly more ENC EMs reported increased in citizen complaints about mosquitoes, illustrating the impact Hurricane Irene had on mosquito populations in many ENC counties. More ENC counties relied on help from other counties and private companies for mosquito control, though this may also be due to fewer mosquito and vector related issues further inland. Many EMs have little experience in mosquito control, although they are often asked to handle post-disaster mosquito control. Lack of knowledge about mosquito control operations may lead to an increased risk of arbovirus transmission following disasters. The current study shows that EMs recognize MCPs operate at a reduced functionality due to budget cuts. They also recognize the importance of state funding/support for local MCPs and worry about the ability of MCPs to prevent or respond to potential outbreaks of a mosquito-borne disease. These results are consistent with results found in a survey given to local NC MCPs who also worry about the future of mosquito control in NC (Del Rosario et al., 2014).

The survey administered here shows that EM roles are changing with regard to post-disaster mosquito control. County EMs will likely continue to play significant roles during future hurricane seasons. Most EMs lack the necessary training in mosquito control and instead rely on co-workers and the internet for training. Co-workers, especially ones who have experience in mosquito control, can be a valuable resource for EMs with little training. The internet can be reliable as well, particularly use of websites such as county/state/regional vector control sites, the CDC Division of Vector-borne Diseases (http://www.cdc.gov/ncezid/dvbd/), and national organizations such as the American Mosquito Control Association (www.mosquito.org). However, these resources cannot replace years of vector control training and experience.

Chapter V: Conclusion

Policy changes to state-level mosquito control in NC have increased the burden on local levels, particularly following a disaster. Budget cuts have attributed to breaks in communication and difficulties managing resource allocation between the local and federal levels. This burden has particularly affected counties without resources to conduct routine surveillance and control. Washington and Tyrrell Counties in rural ENC are prime examples that struggle to respond to mosquito control post-disaster. Pre-disaster preparation is paramount in mounting an effective response to post-disaster mosquito control. Preparation of aerial spraying contracts and plans to streamline the process to apply for federal funding will result in quicker response to mosquito-related issues.

Emergency manager roles have not changed throughout NC over the last five years; however, EMs in ENC counties are substantially involved in post-disaster mosquito control. As EMs have little training in mosquito control, many are worried about the ability of their local MCP to respond to an arbovirus outbreak. Given budget constraints and increased burdens associated with managing post-disaster mosquito control without a link to state assistance; it is increasingly likely that programs will be forced to rely on reactive rather than proactive mosquito management following hurricanes and flooding. The pressure on MCPs is immense post-disaster, as millions of dollars can be riding on reimbursement for emergency mosquito control. Future studies analyzing costs associated with emergency mosquito operations compared to fully functional MCP budgets would be of great benefit to improving mosquito control operations.

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Appendix A: Chapter III Tables and Figures

Table 1: Mosquito surveillance site locations

County	Site Location	Latitude/ Longitude		Trap
Washington	Pettigrew State Park	35 47’21.77”	-76 21’32.86”	C-1
	Cherry St. – Mary Church	35 50’38.47”	- 76 21’24.27”	C-2
	Summerby	35 56’26.51”	-76 32’28.51”	C-3
	Plymouth Airport	35 48’32.94”	-76 45’47.49”	C-4
Tyrrell	Alligator – Old 64	35 56’32.35”	-76 06’51.05”	T-1
	Oakwood Cemetery - Columbia	35 55’28.6”	-76 14’53.11”	T-2
	Gum Neck	35 43’33.07”	-76 06’59.58”	T-3
	Travis Road	35 54’13.30”	-76 18’36.55”	T-4

Table 2: Washington County mosquito surveillance results

	C-1 **Pettigrew State Park**			**C-2** **Cherry St. - Mary Church**			**C-3** **Summerby Old 32 on river,**			**C-4** **Airport**		
	Pre-Spray		**Post-Spray**	**Pre-Spray**		**Post-Spray**	**Pre-Spray**		**Post-Spray**	**Pre-Spray**		**Post-Spray**
	Night 1 Oct. 9-10	**Night 2 Oct. 10-11**	**Night 3 Oct. 17-18**	**Night 1 Oct. 9-10**	**Night 2 Oct. 10-11**	**Night 3 Oct. 17-18**	**Night 1 Oct. 9-10**	**Night 2 Oct. 10-11**	**Night 3 Oct. 17-18**	**Night 1 Oct. 9-10**	**Night 2 Oct. 10-11**	**Night 3 Oct. 17-18**
Aedes albopictus	0	0	0	0	0	0	1	1	0	0	0	0
Aedes atlanticus	8	51	4	0	81	1	1	3	0	1	11	22
Aedes canadensis	0	1	1	0	0	0	4	0	0	1	0	1
Aedes infirmatus	19	103	98	4	37	1	0	2	0	0	7	2
Aedes sollicitans	52	52	1	1	14	2	4	1	0	2	0	2
Aedes taeniorhynchus	5	4	3	0	5	1	3	0	0	6	0	2
Aedes triseriatus	0	0	0	0	0	0	0	0	0	0	0	0
Aedes vexans	323	440	72	420	726	133	2	9	1	1	0	14
Anopheles bradleyi/crucians	12	3	14	29	75	31	9	16	4	0	0	1
Anopheles punctipennis	0	0	0	0	0	0	0	1	1	0	0	0
Anopheles quadrimaculatus	1	2	1	4	16	2	1	5	0	0	0	0
Coquillettidia perturbans	0	0	0	0	1	0	0	0	0	0	0	0
Culiseta melanura	22	100	107	4	9	3	3	9	1	0	4	3
Culex erraticus	0	0	0	2	10	0	0	13	0	0	0	0
Culex pipiens complex	50	48	21	9	110	9	61	12	1	11	3	1
Culex restuans	1	20	1	20	2	4	1	41	0	0	0	0
Culex salinarius	13	129	188	105	300	63	6	34	1	2	5	12
Culex spp.	0	0	-	0	0	-	0	24	-	0	0	-
Culex territans	0	0	0	0	0	0	0	0	0	0	0	0
Psorophora ciliata	8	14	0	1	5	0	4	0	0	2	6	2
Psorophora columbiae	539	3035	4	534	536	33	71	28	0	48	65	17
Psorophora ferox	13	24	23	14	19	3	14	5	0	0	2	0
Psorophora howardi	1	0	0	0	1	0	0	0	0	0	0	0
Uranotaenia sapphirina	0	0	1	0	1	2	0	0	0	0	0	0
Total	**1067**	**4026**	**539**	**1147**	**1947**	**288**	**185**	**204**	**9**	**74**	**103**	**79**

Table 3: Tyrrell County Mosquito Surveillance Results

	T-1		**T-2**		**T-3**		**T-4**	
	Alligator Old 64		**Oakwood Cemetery in Columbia**		**Gum Neck Fire Dept.**		**Travis Rd.**	
	Pre-Spray	**Post-Spray**	**Pre-Spray**	**Post-Spray**	**Pre-Spray**	**Post-Spray**	**Pre-Spray**	**Post-Spray**
	Oct. 9-10	**Oct. 17-18**	**Oct. 9-10**	**Oct. 17-18**	**Oct. 9-10**	**Oct. 17-18**	**Oct. 9-10**	**Oct. 17-18**
Aedes albopictus	0	0	0	0	0	1	0	0
Aedes atlanticus	22	16	5	0	3	2	35	8
Aedes canadensis	1	0	0	2	2	0	2	15
Aedes infirmatus	0	6	4	10	2	1	155	18
Aedes sollicitans	4	26	1	1	48	42	0	2
Aedes taeniorhynchus	1	10	3	6	25	35	0	1
Aedes triseriatus	1	1	0	1	0	0	0	0
Aedes vexans	54	50	22	34	191	42	113	63
Anopheles bradleyi/crucians	38	235	27	45	29	6	25	3
Anopheles punctipennis	0	0	0	0	0	0	0	0
Anopheles quadrimaculatus	9	8	0	5	18	1	2	1
Coquillettidia perturbans	0	0	0	0	0	0	0	0
Culiseta melanura	105	109	34	60	203	137	13	29
Culex erraticus	34	19	7	1	18	4	0	0
Culex pipiens complex	3226	126	152	46	297	41	199	36
Culex restuans	14	3	0	1	10	8	44	2
Culex salinarius	545	4236	40	129	213	729	157	148
Culex territans	0	0	0	0	1	0	0	0
Psorophora ciliata	0	1	0	0	1	1	24	1
Psorophora columbiae	11	16	0	3	178	28	140	11
Psorophora ferox	1	16	3	2	2	0	208	8
Psorophora howardi	0	0	0	0	0	0	0	0
Uranotaenia sapphirina	0	10	7	13	0	0	0	1
Total	**4066**	**4888**	**305**	**359**	**1241**	**1078**	**1117**	**347**

Table 4: Percent change in mosquito abundance at each study site

Site Name	Site Number	Pre-Spray	Post-Spray	Percent Change
Pettigrew State Park	C-1	4026	539	-86.61
Cherry St. - Mary Church	C-2	1947	288	-85.21
Summerby - Old 32 on River	C-3	204	9	-95.59
Airport	C-4	103	79	-23.30
Alligator - Old 64	T-1	4066	4888	20.22
Oakwood Cemetery - Columbia	T-2	305	359	17.70
Gum Neck Fire Dept.	T-3	1241	1078	-13.13
Travis Rd.	T-4	1117	347	-68.93

Figure 1: Path of Hurricane Irene: August 21-28, 2011 (Avila & Cangialosi, 2011)

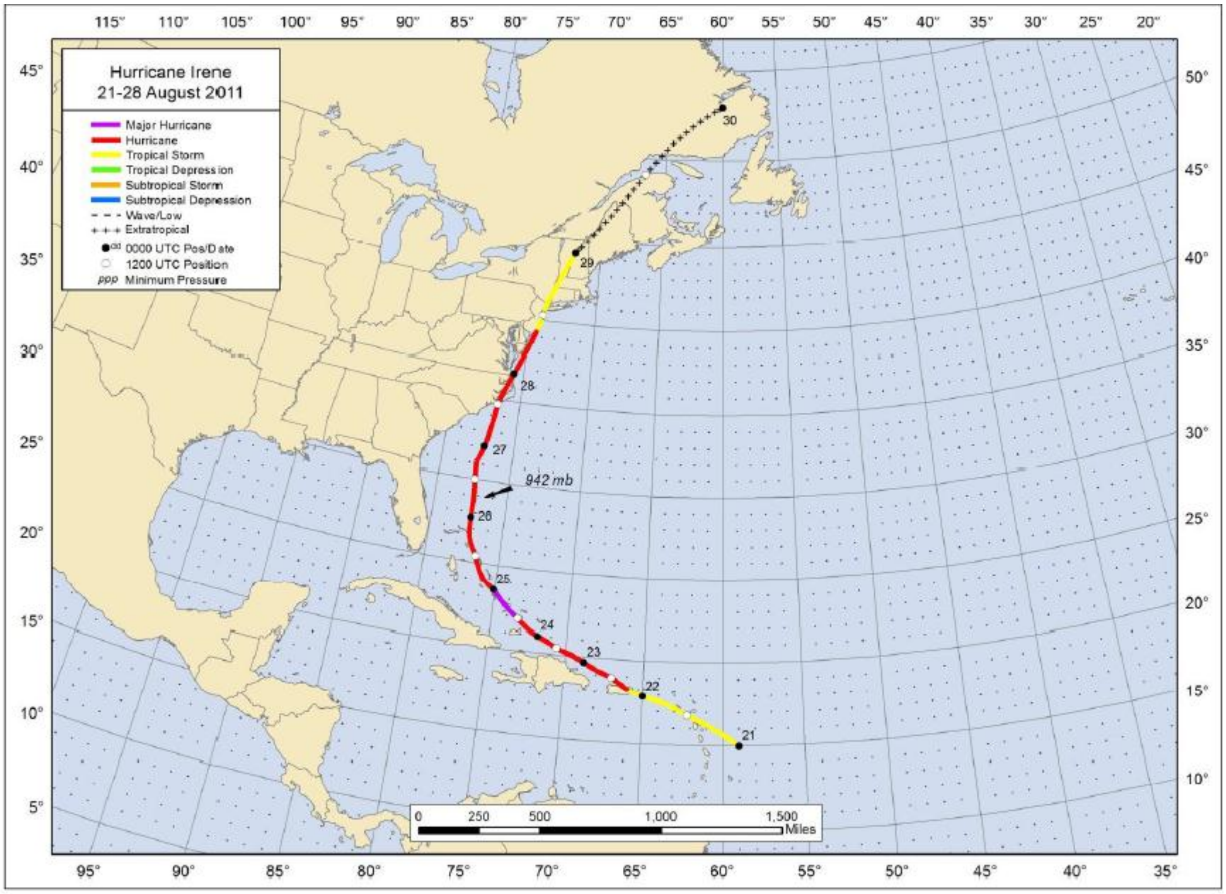


Figure 2: NC counties that applied for FEMA assistance

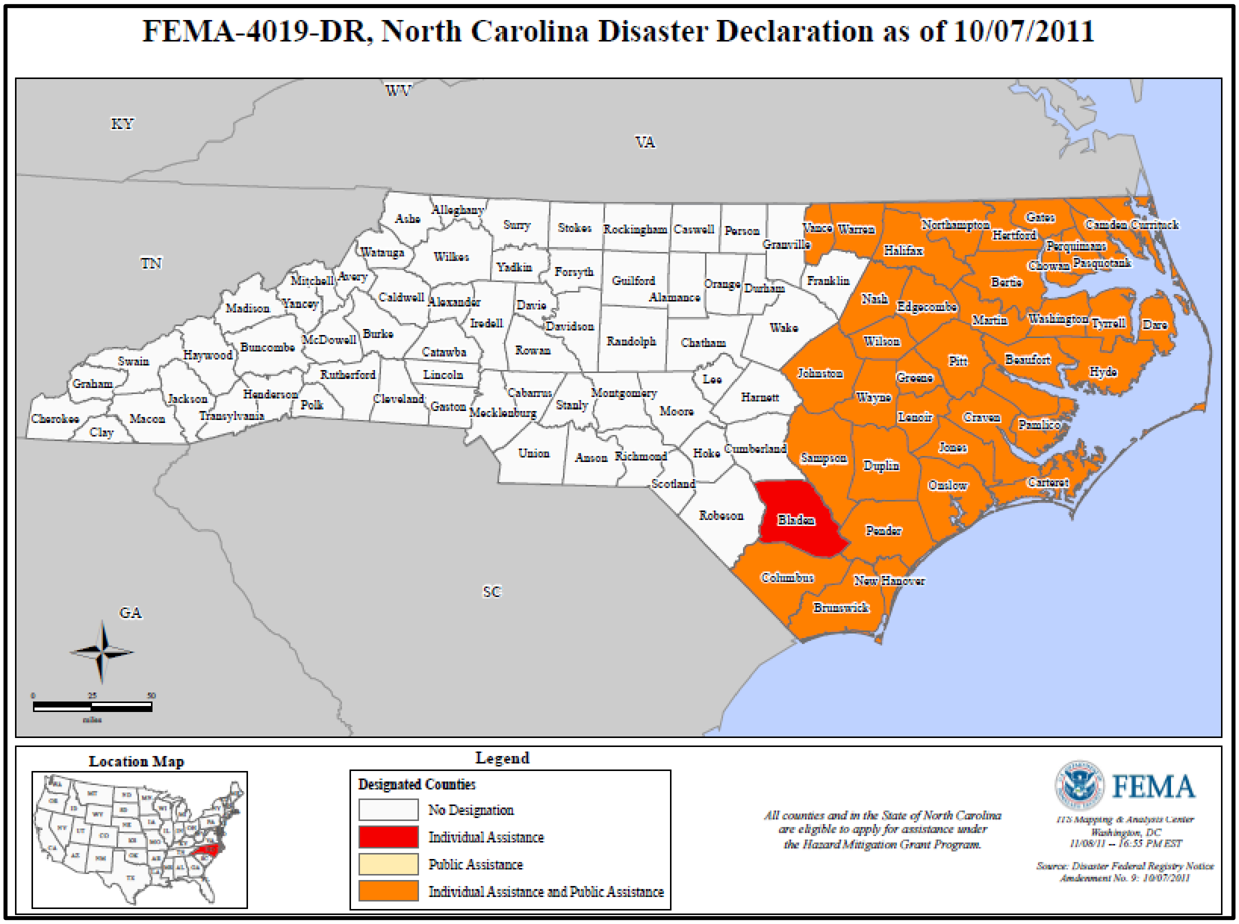
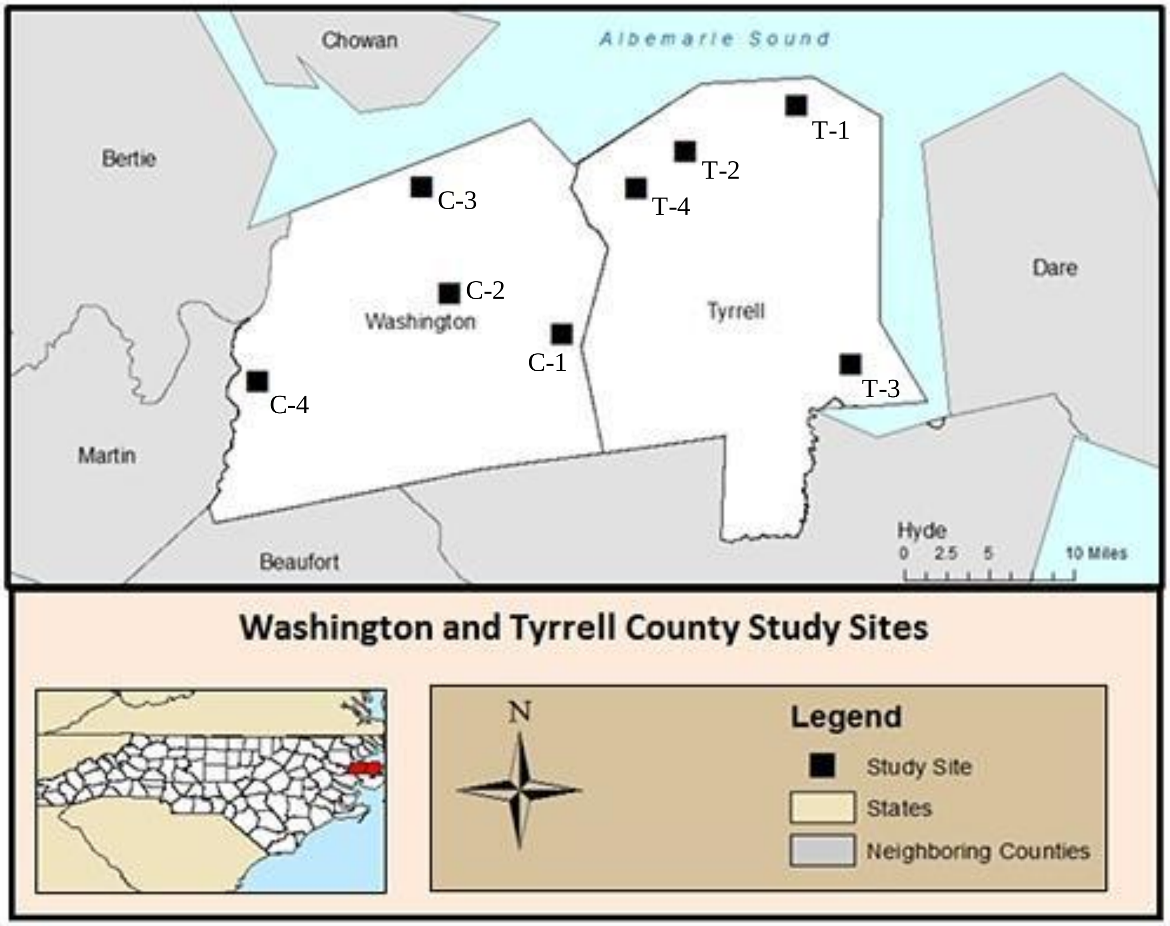


Figure 3: Map of Washington and Tyrrell County study sites



Appendix B: Survey Assessing North Carolina Emergency Manager Involvement in Vector Control

Post-Disaster Implications of Recent Policy Changes to North Carolina Mosquito Control Survey

As an emergency manager, my involvement in routine mosquito control is _______.	**East**	**Piedmont**	**West**	**NC Total**
Substantial	6	5	0	11
Occasional	2	3	2	7
Not very substantial	2	3	3	8
Not involved at all	14	8	3	25
As an emergency manager, my involvement in post-disaster mosquito control is ________.				
Substantial	11	4	0	15
Occasional	6	9	4	19
Not very substantial	4	3	3	10
Not involved at all	3	3	1	7
My involvement in routine mosquito control over the past 5 years has ________.				
Greatly increased	5	1	0	6
Somewhat increased	3	2	0	5
Remained the same	15	13	5	33
Somewhat decreased	0	0	1	1
Greatly decreased	0	2	0	2
My involvement in post-disaster mosquito control over the past 5 years has ________.				
Greatly increased	5	1	0	6
Somewhat increased	5	4	0	9
Remained the same	10	10	5	25
Somewhat decreased	1	0	1	2
Greatly decreased	1	1	0	2
Over the past 5 years funding has _________ at my local mosquito control program.				
Greatly increased	2	0	0	2
Somewhat increased	2	2	0	4
Remained relatively constant	9	9	2	20
Somewhat decreased	3	4	1	8
Greatly decreased	7	1	2	10
In the past, how much did your local mosquito control program depend on state-level assistance (funding, expertise, paperwork) following disasters, such as hurricanes?				

Depended heavily on state-level funding	13	8	4	25
Depended somewhat on state-level funding	4	3	2	9
Depended very little on state-level funding	1	1	1	3
Did not use state-level funding	5	3	0	8
In the past, my local mosquito control program was given assistance from NCPHPM or NCDENR in filling out paperwork to receive federal and/or state funds following a disaster				
Yes, many times	5	3	1	9
Yes, occasionally	7	5	1	13
Yes, but rarely	6	3	2	11
Never	4	5	2	11
Following Hurricane Irene in 2011, my local mosquito control program was well-prepared to handle mosquito control responsibilities.				
Strongly Disagree	2	0	0	2
Disagree	4	2	0	6
My local vector control program was not affected by Hurricane Irene	4	9	2	15
Neither Agree nor Disagree	3	1	3	7
Agree	8	3	1	12
Strongly Agree	1	0	0	1
The assistance my local mosquito control program received from state-level organizations following Hurricane Irene was ______.				
Much Greater than before	2	0	0	2
Somewhat Greater than before	9	3	0	12
About the Same as before	4	2	3	9
Somewhat Less than before	0	0	0	0
Much Less than before	2	0	0	2
My local vector control program did not require assistance following Hurricane Irene	5	9	2	16
Following Hurricane Irene, more mosquito control responsibilities were placed on local mosquito control programs than before.				
Strongly Disagree	0	1	0	1
Disagree	2	0	0	2
Neither Agree nor Disagree	7	10	6	23
Agree	5	2	0	7
Strongly Agree	6	0	0	6
My local mosquito control program's resources were not sufficient to properly handle all mosquito control duties following Hurricane Irene.				
Strongly Disagree	0	0	0	0
Disagree	4	1	0	5

Neither Agree nor Disagree	7	4	2	13
Agree	4	2	1	7
Strongly Agree	4	1	0	5
My county did not have a mosquito problem following Hurricane Irene	3	7	2	12
My local mosquito control program sought help from other county departments or agencies in handling vector control following Hurricane Irene				
Yes	9	3	2	14
No	11	10	4	25
My local mosquito control program sought help from private companies in handling vector control following Hurricane Irene				
Yes	10	2	1	13
No	11	12	5	28
Emergency management agencies were asked to assist _____ in dealing with mosquito control following Hurricane Irene				
More than in the past	8	4	0	12
About the same	10	6	6	22
Less than in the past	3	3	0	6
Citizen complaints about nuisance mosquitoes increased after Hurricane Irene				
Strongly Disagree	0	1	0	1
Disagree	1	1	0	2
Neither Agree nor Disagree	6	9	5	20
Agree	8	2	1	11
Strongly Agree	6	1	0	7
My local mosquito control program currently has the resources and capabilities to respond to a natural disaster equal to Hurricane Irene.				
Strongly Disagree	5	0	0	5
Disagree	3	2	1	6
Neither Agree nor Disagree	2	9	4	15
Agree	11	3	1	15
Strongly Agree	1	0	0	1
Arboviral disease surveillance is an important tool when assessing public health risk.				
Strongly Disagree	0	0	0	0
Disagree	0	0	0	0
Neither Agree nor Disagree	4	4	3	11
Agree	10	5	4	19
Strongly Agree	6	4	0	10

I worry about my local mosquito control program's ability to respond to an outbreak of West Nile virus or some other arbovirus.				
Strongly Disagree	0	0	0	0
Disagree	6	2	1	9
Neither Agree nor Disagree	1	3	2	6
Agree	8	5	2	15
Strongly Agree	7	3	2	12
I worry about the future of mosquito control at the local level in the state of North Carolina.				
Strongly Disagree	0	0	0	0
Disagree	2	1	0	3
Neither Agree nor Disagree	1	4	3	8
Agree	10	4	2	16
Strongly Agree	8	4	2	14
State and local funding sources should not be used to support mosquito control programs in North Carolina.				
Strongly Disagree	6	7	0	13
Disagree	10	4	1	15
Neither Agree nor Disagree	3	2	4	9
Agree	1	2	2	5
Strongly Agree	6	7	0	13
I would support a county or municipality tax increase to pay for long-term mosquito surveillance and control.				
Strongly Disagree	0	0	0	0
Disagree	4	4	2	10
Neither Agree nor Disagree	8	3	2	13
Agree	6	7	3	16
Strongly Agree	1	1	0	2
The amount of training I have received in mosquito control could be described as _________.				
Very Extensive	0	0	0	0
Extensive	5	5	0	10
Not very extensive	3	2	0	5
Very little	7	3	4	14
None	6	5	3	14
I receive training and education on mosquito control such as conferences, presentations, or demonstrations _______.				
More than once per year	1	0	0	1
Yearly	4	4	0	8
At least Every 3 Years	4	2	0	6

Less than once every 3 years	3	3	1	7
Never	9	6	6	21
I receive information on mosquito control from (choose all that apply)				
Private Companies	8	6	0	14
Magazines, Journal Articles, Newspapers	5	4	2	11
The internet	9	9	1	19
Co-workers	12	9	2	23
Friends and Family	4	4	0	8
Conferences	5	5	1	11

Appendix C: Chapter IV Tables and Figures

Table 5: Chi-square analysis results

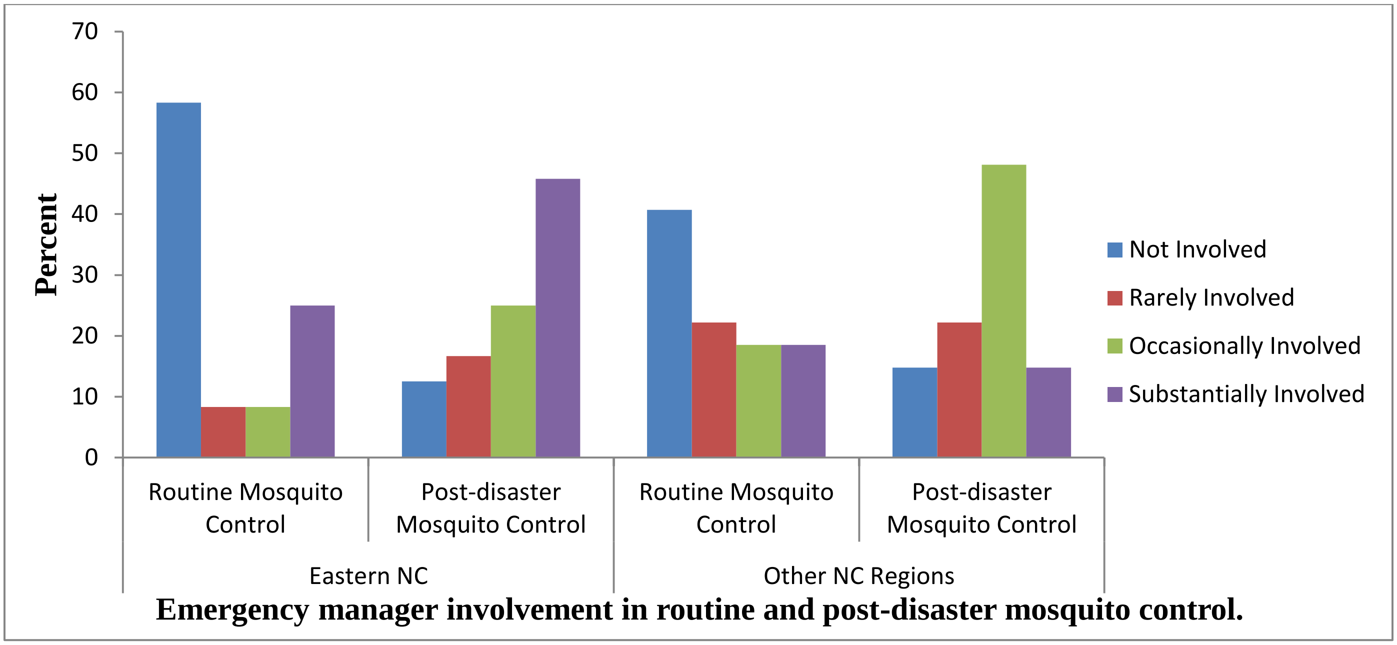
Variable	Chi-Square Value	df	*p*-value
EM involvement in routine mosquito control	0.076	1	0.782
EM involvement in post-disaster mosquito control	0.354	1	0.552
Change in EM routine mosquito control involvement – past 5 years	5.527	2	0.063
Change in EM post-disaster mosquito control involvement – past 5 years	3.771	2	0.152
Funding characteristics for local mosquito control – past 5 years	1.000	2	0.607
Funding dependence at the state level for local mosquito control	0.069	1	0.793
How often did local mosquito control receive assistance from PHPMS or NCDENR	0.091	1	0.763
State level assistance for Hurricane Irene compared to previous hurricanes	8.760	3	0.033*
Emergency manager assistance for Hurricane Irene compared to previous hurricanes	1.419	2	0.492
Did local mosquito control seek assistance from other counties after Hurricane Irene	1.478	1	0.224
Did local mosquito control seek assistance from private companies after Hurricane Irene	5.034	1	0.025*
Describe the level of training you have in mosquito control	0.043	2	0.979
How often do you receive training for mosquito control	0.594	2	0.743
My local MCP was well-prepared to handle mosquito control responsibilities after Hurricane Irene	7.313	3	0.063
More mosquito control responsibilities were placed on local MCPs than before Hurricane Irene	10.067	2	0.007**
My local MCPs resources were not sufficient to handle mosquito control duties following Hurricane Irene	6.129	3	0.106
Citizen complaints about mosquitoes increased after Hurricane Irene	9.070	2	0.011*
My local MCP has the resources and capabilities to respond to an natural disaster equal to Hurricane Irene	14.277	2	0.001***
Arboviral disease surveillance is an important tool when assessing public health risk	1.129	1	0.288
I worry about my local MCP's ability to respond to an arbovirus outbreak	3.914	2	0.141
I worry about the future of mosquito control at the local level in the state of North Carolina	6.013	2	0.049*
State/local funding sources should not be used to support mosquito control in NC	3.284	2	0.194
I would support a county/municipality tax increase to pay for mosquito control	1.771	2	0.412

* = significant at ***p***<0.05 ** = significant at ***p***<0.01 *** = significant at ***p***<0.001

Table 6: Descriptive statistics of respondents

Variables/Response Categories	**Percent**
Sex	--
Male	73.68
Female	26.32
Age	--
18-35	5.26
35-50	50.00
50+	44.74
Race	--
White/Caucasian	94.44
Black/African-American	2.78
American Indian/Alaskan Native	0
Asian or Pacific Islander	2.78
Other	0
Hispanic	0
Years of Experience	--
Less than 5 years	25.64
5-10 years	35.90
10+	38.46

Figure 4: Emergency manager involvement in routine and post-disaster mosquito control



Emergency manager involvement in routine and post-disaster mosquito control.

Figure 5: Change in emergency manager involvement in mosquito control - past 5 years

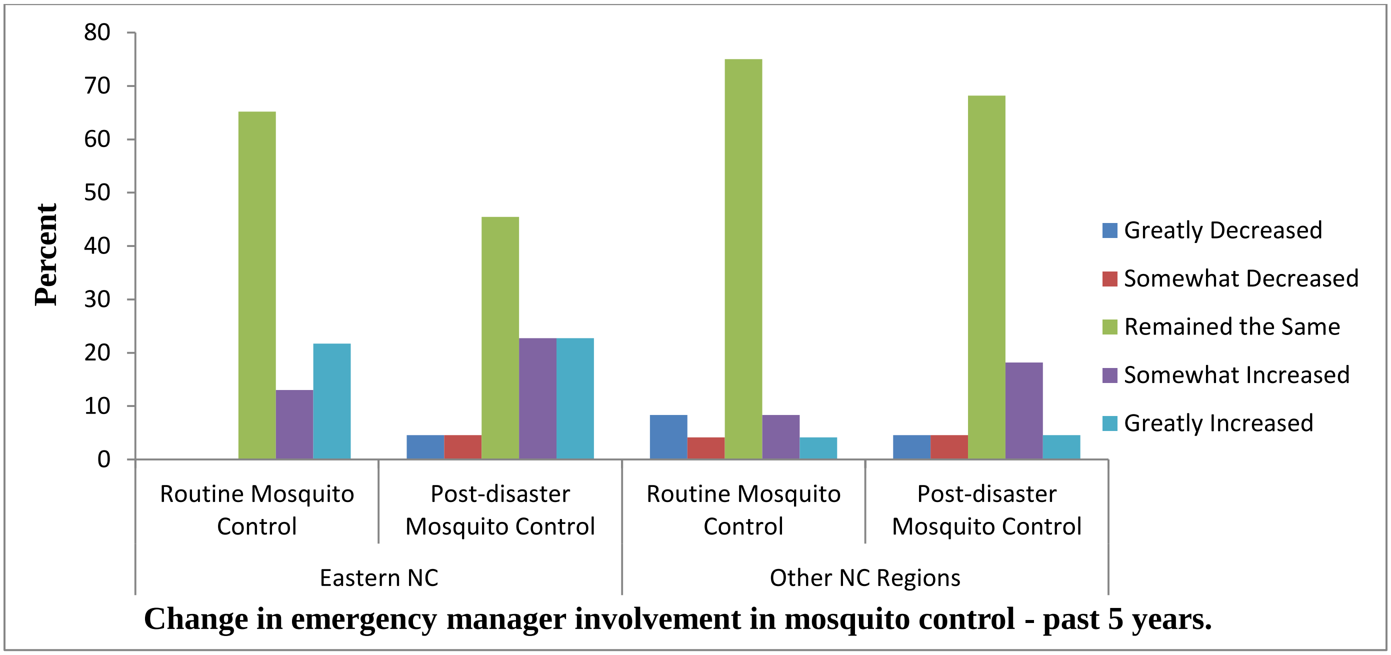


Figure 6: Funding characteristics for local mosquito control – past 5 years

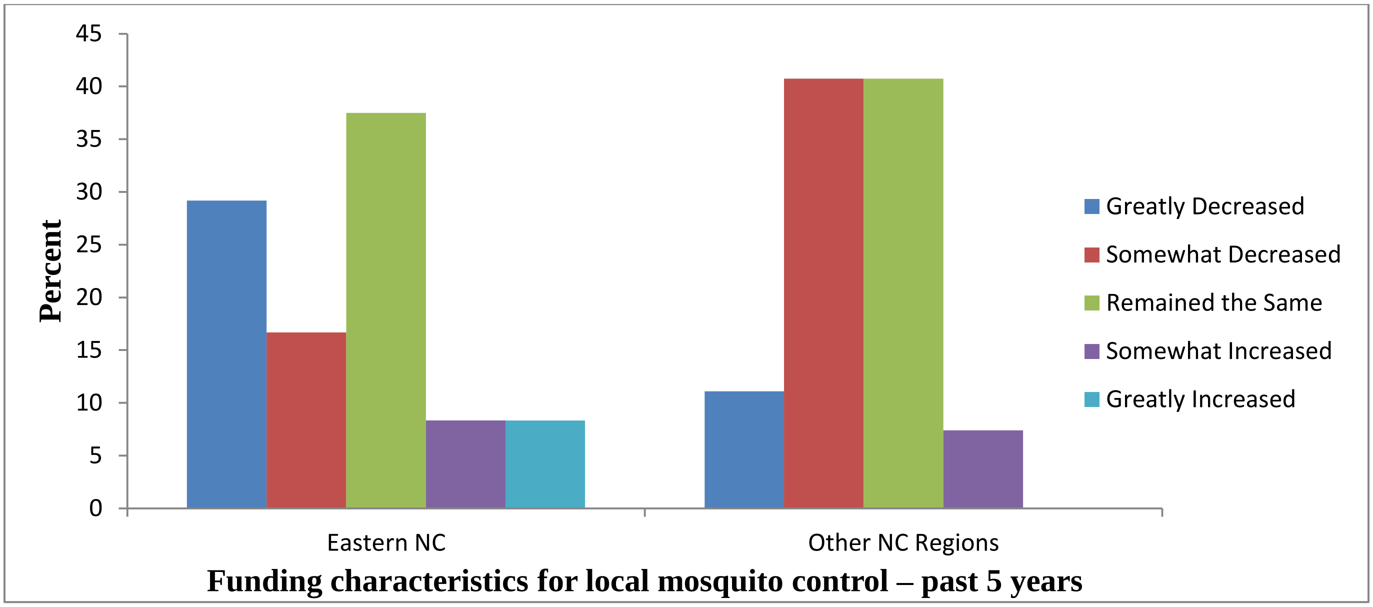


Figure 7: Funding dependence at the state level for local mosquito control

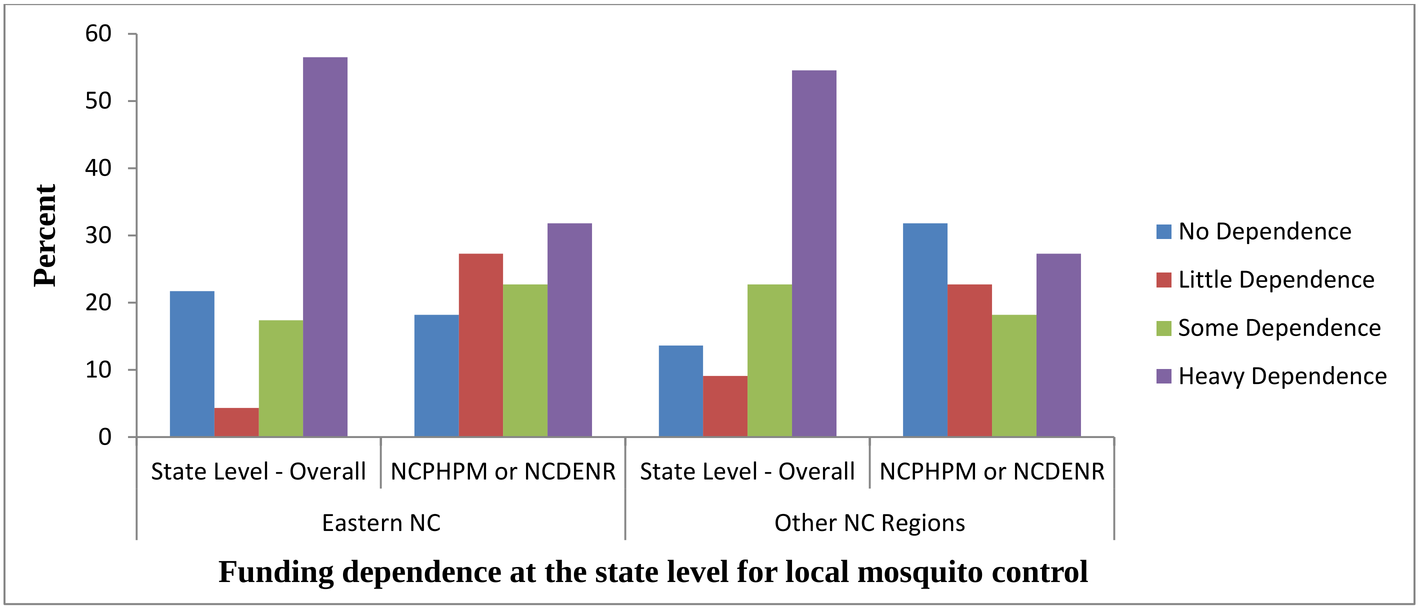


Figure 8: State level assistance for Hurricane Irene compared to previous hurricanes

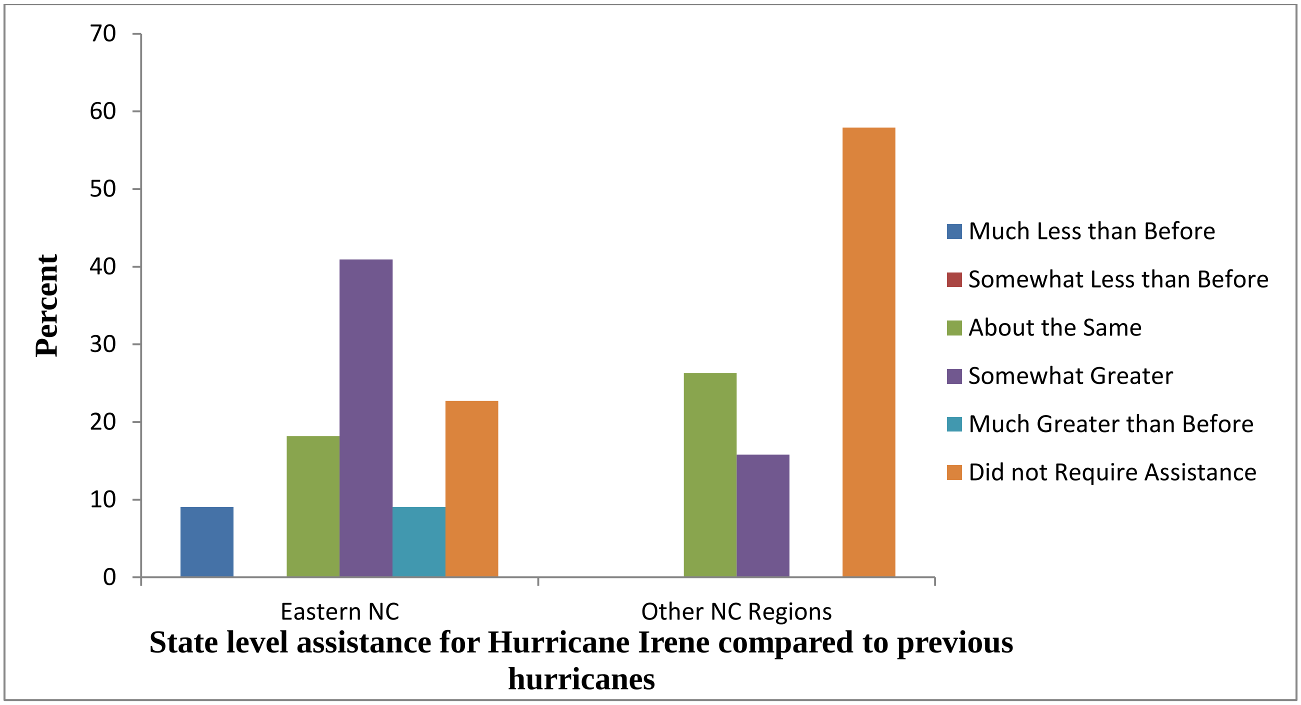


Figure 9: Emergency manager assistance for Hurricane Irene compared to previous hurricanes

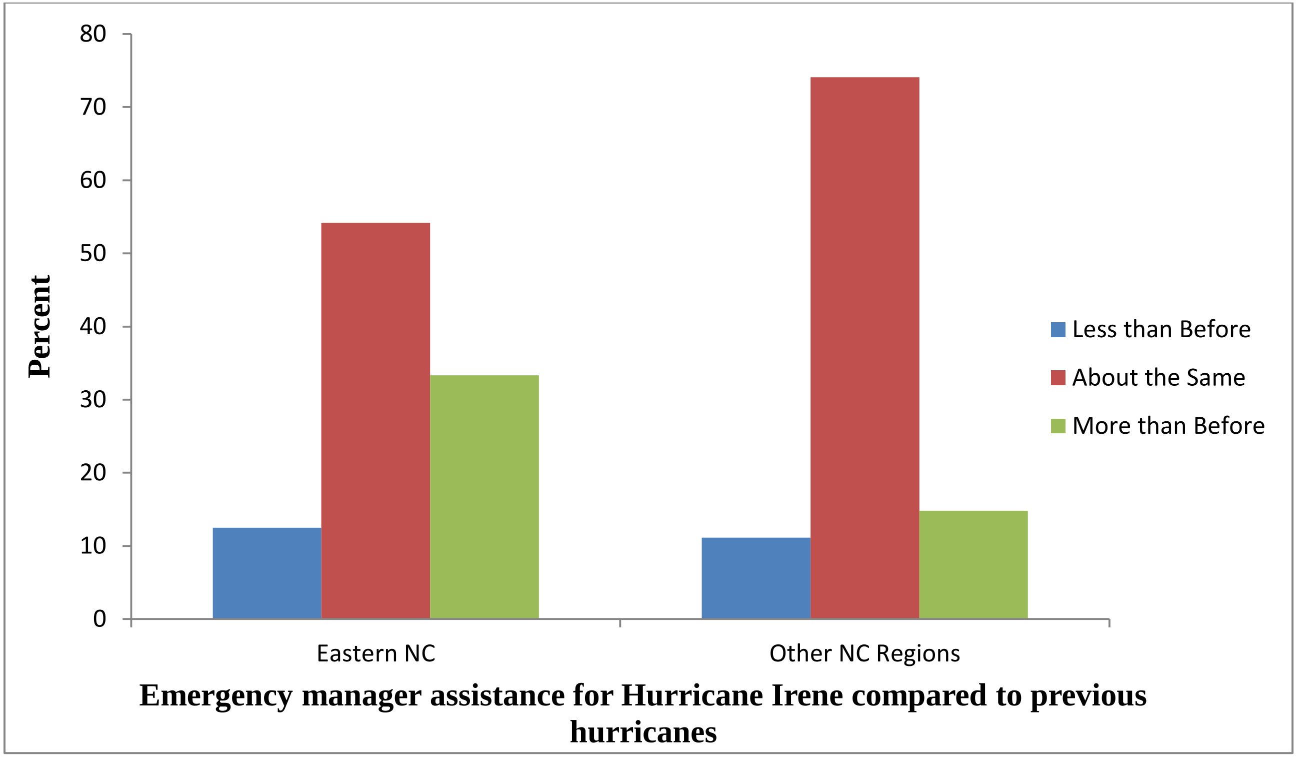


Figure 10: Assistance for mosquito control following Hurricane Irene

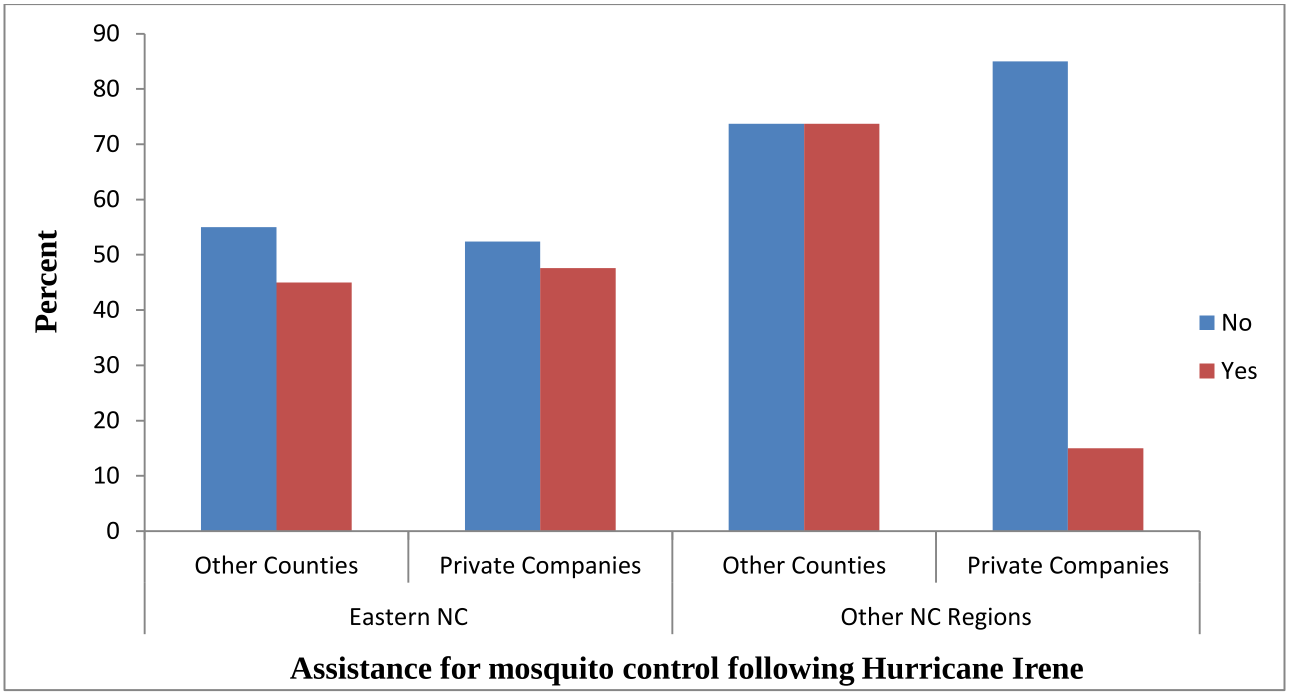


Figure 11: Emergency manager training in mosquito control

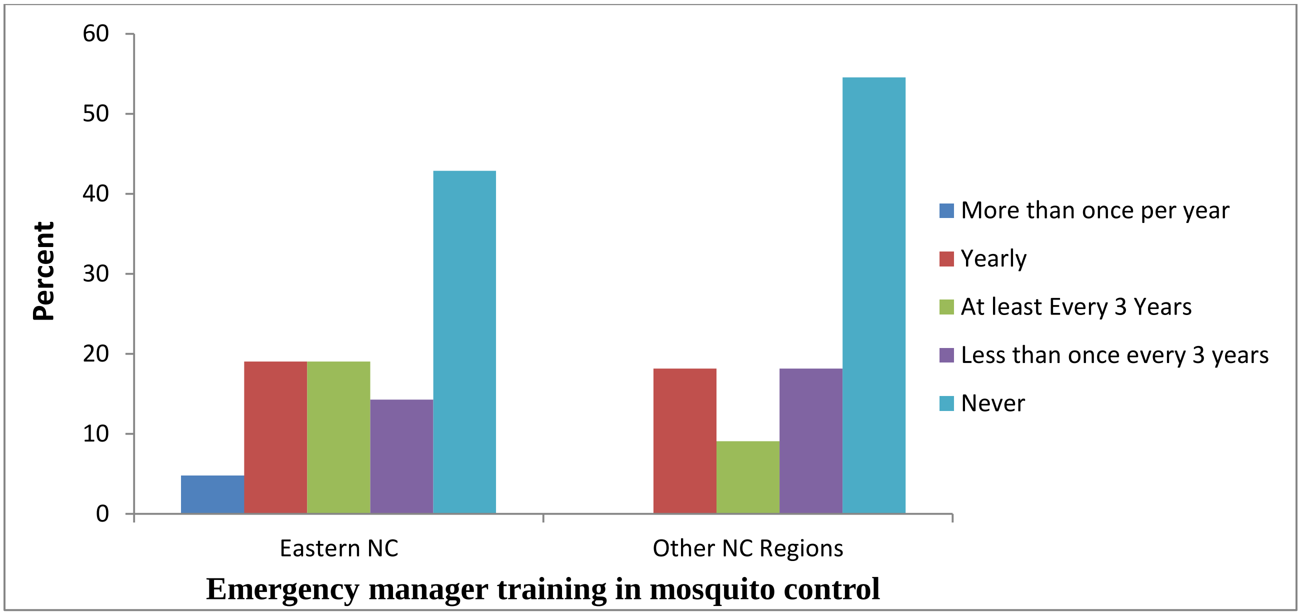


Figure 12: Emergency manager views on mosquito control