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Operational Insights Into Mosquito Control Disaster Response in Coastal North Carolina: Experiences With the Federal Emergency Management Agency After Hurricane Florence

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Abstract

Preparation for post-hurricane mosquito control is essential for an effective emergency response to protect public health and promote recovery efforts. Effective pre-hurricane planning includes laying the groundwork for a successful reimbursement application to the Federal Emergency Management Agency. The critical and overlapping need to sustain funding for mosquito control programs is highlighted here in the context of both normal and emergency responses. Community support is an integral component of an effective integrated pest management program and is established over time with appropriate communication and engagement. Experienced mosquito control operators who are familiar with treatment areas are an essential component of successful operations. Here, practical advice is provided to plan, prepare, and implement a successful ground- and aerial-based mosquito control response.

Introduction

It is essential to have multiagency (e.g., local, state, regional, federal) communication channels defined for public health mosquito control response post-disaster (Goddard & Varnado, 2020). The Centers for Disease Control and Prevention (CDC) and U.S. Environmental Protection Agency (U.S. EPA) recommend that mosquito surveillance and control continue after natural disasters, such as hurricanes (Connelly et al., 2020). Successful post-disaster responses that address mosquitoes via ground and/or aerial insecticide treatments (Boze et al., 2020) involve collaboration among the Federal Emergency Management Agency (FEMA), contractors conducting ground and/or aerial treatments, and local or state programs. The *Public Assistance Program and Policy Guide*

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from FEMA (2020) dictates that mosquito control costs are paid in advance by the requesting local government.

If appropriate, FEMA reimburses 75% of mosquito control response costs, then state and/or local governments work together to determine the funding for the remaining 25% of the costs. FEMA sends funds to the state, which then administers funds to local programs (McAllister & Madson, 2020). Mosquito abatement can be eligible for reimbursement through FEMA (2020) if specific scenarios exist: 1) arbovirus transmission (i.e., disease-causing mosquitoes following disaster; potential for human exposure); 2) impact on emergency workers (e.g., mosquitoes hampering response and recovery efforts); or 3) secondary infections due to increased mosquito exposure.

Practical advice discussed here is provided to assist in planning, preparing, and implementing a successful post-disaster ground- and aerial-based mosquito control response. This guidance includes mosquito control needs assessment, agency roles, mosquito surveillance, several components of mosquito control, communications, reporting, and costs.

Mosquito Control Needs Assessment

Transmission risk of zoonotic arbovirus (e.g., Eastern equine encephalitis virus [EEEV], St. Louis encephalitis virus, West Nile virus [WNV]) is reduced immediately following a hurricane as high wind and rain events disrupt mosquito and reservoir host (e.g., bird) populations (Boze et al., 2020; Nasci & Moore, 1998). In disaster areas with power outages, however, residents are often forced to open windows to improve indoor air circulation and thus human–mosquito exposure likely increases over extended time periods. Surveillance is required to determine the risk of exposure to mosquitoes for residents and emergency workers.

Effective mosquito control is based on entomologic surveillance conducted by mosquito control programs (MCPs) as part of the emergency response (Boze et al., 2020; Brown, 1997; FEMA, 2020). If baseline mosquito surveillance/treatment data are lacking (i.e., 3 years of data per *Public Assistance Program and Policy Guide* requirements; www.ncagr.gov/SPCAP/pesticides/rksummary.htm), service records as well as physical, climatic, and phenological considerations can also be evaluated to determine mosquito control needs.

Factors to consider include timing of the disaster (i.e., early or late in the season) and amount of precipitation. If storm impact is early in the season, post-disaster mosquitoes might not be abundant or widespread because populations build throughout season. Additional informative variables include: 1) amount and type of flooding (e.g., saltwater versus freshwater, coastal versus inland); 2) extent and location of housing damage and power interruptions; 3) extent and duration of cleanup and recovery (e.g., debris contract status, roadway blockage, infrastructure issues leading to washed out roads); 4) resident requests when compared with background rates; and 5) rainfall and ambient temperatures.

North Carolina Hurricane Response: Agency Roles

To discuss agency roles, we provide a real-world example of a request for aerial insecticide application in Brunswick County, North Carolina (a coastal region in a southernmost county), after Hurricane Florence, which made landfall in New Hanover County, just north of Brunswick County on September 14, 2018. The emergency response period is the date of the request plus 45 days.

Health Department

The county health director takes the lead in approving and initiating the local emergency mosquito control request response through FEMA. Local health departments can also verify that medical facilities have observed an increase in public and emergency worker mosquito exposure that could result in secondary infections (FEMA, 2020).

Emergency Management

Local emergency management helps determine the extent, location, and type of flooding, housing damage, power interruptions, and cleanup/recovery operations. An emergency request is submitted through incident management software (e.g., WebEOC; www.juvare.com/webeoc) and is processed by the state FEMA liaison (e.g., Public Health Preparedness and Response within the North Carolina Department of Health and Human Services).

Mosquito Control Program

Local MCPs determine: 1) abundance of mosquitoes capable of transmitting pathogens; 2) potential for human–mosquito exposure based on historical arbovirus activity in sentinel animals, humans, and mosquitoes; 3) if an increase in mosquito abundance poses a threat to emergency workers; and 4) type and duration of mosquito control required for threat reduction. It is crucial that county health directors have an open dialogue with MCPs within their jurisdictions.

Hurricane-Related Mosquito Surveillance: Operational Perspective

If a tropical storm or hurricane is anticipated, MCPs can pretreat known mosquito-productive areas using residual larvicides. MCPs should also ensure that surveillance equipment is operational and contingency plans are in place to access equipment after the storm.

Larval Surveillance

Larval surveillance is the primary method to determine the timing of post-storm emergence of adult mosquitoes. Larvae are difficult to find immediately after a flooding event because larval mosquito abundance can appear low due to the overwhelming water volume. The key is to have a few known larval production sites located at higher elevations in the landscape that are routinely monitored. If these sites are inaccessible due to flooding, larvae in pools adjacent to larger flooded areas can be monitored.

When predicting the timing of adult mosquito emergence, the number of larvae collected is not as important as developmental stage (e.g., early or late instars, pupae). Day 0 is when larvae (1st instar) hatch from eggs. After the larvae and pupae have developed and emerged as adults on approximately day 7, human landing counts are conducted. Approximately 7 days after 1st instar larvae observation, widespread emerging adult populations will be flying and should be addressed via truck-mounted ultra low volume (ULV) insecticide applications, aerial application, or both.

If left untreated, the egg deposition for propagation of future generations can be massive. A previous report in New Hanover County, North Carolina, after Hurricane Fran in 1996 showed that aerial larviciding was conducted 8 days post-hurricane, and aerial and ULV adulticiding occurred approximately 13–22 days post-hurricane (Brown, 1997). Recommendations, however, have been updated based on years of operational field experience and advise adulticiding as soon as 7 days after the 1st instar larvae observation (i.e., the first post-hurricane brood emergence).

Human Landing Counts

Human landing counts measure the number of mosquitoes landing on a human during a predetermined amount of time (Schmidt, 1989; Vigilant et al., 2020), beginning when the first mosquito lands on the person conducting the count. Landing counts should be conducted 5 ft into a tree line or in a shaded area if no trees are present. In some cases, such as aggressive day-biting salt marsh (e.g., *Aedes taeniorhynchus*) or open field (e.g., *Psorophora columbiae*) mosquitoes, counts can be obtained from mosquito numbers alighting on one's clothing in addition to skin. Landing counts are also useful to assess mosquito abundance pre- and post-treatment but are not recommended if there is evidence of arbovirus activity in the area.

Immediately after a hurricane, mosquito and bird populations are disrupted, which results in a resetting of the arbovirus clock. Hence infectious enzootic vector mosquitoes that are ≥14 days old, such as *Culiseta melanura*, and that can be involved in arbovirus (e.g., EEEV) transmission cycles, typically are not present until approximately 2 weeks after a hurricane (Brown & Hickman, 2005). In general, bridge vectors are not infectious for another 14–17 days (Brown & Hickman, 2005). If the hurricane response goes for longer than 30 days, depending on time of year and other factors, arbovirus risk should be considered. Once arbovirus activity is suspected in an area, landing counts are suspended.

Trapping Adult Mosquitoes

To quantify the effectiveness of an aerial insecticide application, pre- and post-treatment trapping within the treatment area is essential. CDC light traps baited with carbon dioxide (CO_2; i.e., dry ice) are set inside treatment areas. In Brunswick County, 8 CDC traps were used for pre- and post-aerial treatment analysis across 12 sites after Hurricane Florence. Traps were set in the evening, retrieved the following morning, and the collections stored in a laboratory freezer until mosquito enumeration and identification could be performed (Harrison et al., 2016). Additionally, post-treatment trapping should be completed the day after aerial adulticide treatments to minimize trapping of newly emerged mosquitoes,

which would be unaffected by treatment. If an MCP cannot conduct trapping per FEMA requirements, this activity can be built into a request for proposal (RFP) as a contracted service.

Mosquito Control Post-Disaster

Ground Response

Targeting adult mosquitoes using truck-mounted ULV insecticide applications after a disaster requires a plan of action. Fundamental considerations include knowing the specific mosquito species to be controlled and identifying and prioritizing treatment areas. There are >60 mosquito species in North Carolina (Harrison et al., 2016). An understanding of mosquito biology improves the targeting effort, increases subsequent control effectiveness, and protects public health. This understanding is the first step toward developing an emergency mosquito control strategy. Mosquito biology considerations related to ULV applications include mosquito activity, flight times, flight ranges, habitat, and seasonal distribution. In North Carolina, the state-level medical entomologist and/or the statewide network of members of the North Carolina Mosquito and Vector Control Association can assist with mosquito identification and control advice.

Locating and prioritizing treatment areas prior to mosquito control is essential (e.g., mosquito habitats within restricted areas such as no-fly zones or those for endangered wildlife), as well as evaluating mosquito production adjacent to restricted areas. Treatment zones of populated areas are delineated and mapped with knowledge of jurisdictional boundaries and available human population data. Roadways are used to plot treatment routes from one zone to another in a methodical manner. For dead-end roads, operators drive to the end of the road and apply the insecticide on their way out. Insecticide is applied via a truck-mounted ULV device while driving down all roads in treatment areas on the operational map.

Total treatment area can be calculated—via trial run vehicle odometer readings, onboard GPS, or other types of mapping tools—within zones to determine the number of roadway miles treated. Treatment zones are prioritized by mosquito production and resident service requests. Historical records can be reviewed and followed by ground truthing, which is the practice of identifying mosquito habitats and evaluating impact on residents. Other considerations include assessing available equipment, personnel, and insecticides. Prior planning, coordination, and sharing information and resources with other MCPs within the county and across jurisdictions improves the response by the MCPs.

A major factor restricting ground operations is the number of available truck-mounted ULV machines and trained operators. Locating and training ULV operators prior to an emergency is crucial. Each state-assisted MCP must have someone certified or licensed in public health pest control (www.ncagr.gov/SPCAP/pesticides/categexp.htm). Support personnel can work under licensed operators who are willing to accept responsibility for supervising additional personnel. Documentation of appropriate training with the specific insecticides, equipment, and treatment areas is essential.

Additionally, the time required for treatments should be calculated, including for emergency mosquito control, and plans should optimize spraying capacity. Use of ground-based equipment should be maximized at every opportunity during the response period. Most ground-based ULV machines are calibrated to operate at 10 mph and optimum times for applications are dusk and dawn for 3- to 4-hr periods per session. Each truck can cover 30–40 miles per application; times vary depending on weather conditions and route complexity.

To maximize the response, both crepuscular treatment windows should be utilized, and thus this approach might require two operators (one per shift). One ULV machine operated at dusk and dawn for 21 days at 10 mph can treat 1,680 miles with 168 personnel hr/machine (number of personnel hr × number of ULV machines = operational capacity). Pre-determined treatment routes facilitate ground applications by allowing adjacent routes to be treated the same evening without overlap. Controlling mosquitoes over large areas is most effective if applications are applied uniformly across treatment areas in time and space.

Some ULV formulated products are licensed for higher rates of application than others. In some cases, as allowable by pesticide label instructions, it might be possible to double the application speed by adjusting the ULV machine flow rate. Doubling the application speed proportionally increases the amount of insecticide applied, which can double the area that each machine is able to treat during an emergency response. Preparation is essential and it is important to make as many decisions as practically possible prior to an emergency (Connelly & Borchert, 2020; Vigilant et al., 2020).

Planning treatment routes are based on providing service to community and residents while incorporating mosquito hotspots identified from the monitoring phase of the disaster response. The goal of Brunswick County MCP is to minimize human–mosquito interactions for 21 days, which is the post-hurricane period when significant increases in mosquito abundance are expected to occur if not treated appropriately. Spot treatments at the neighborhood or residential scale can address individual resident complaints and enhance the control effort if used with an organized treatment strategy.

Spot treatments might be the only option available in sparsely populated treatment zone areas. If mosquitoes surrounding the treatment area are abundant, mosquitoes can disperse back into treated areas. If applications are well-timed, it is possible to treat only the perimeter of these areas. Timing of strategies depends on the number of ULV machines, total treatment area, and mosquito abundance within treatment zones. Abundant mosquito populations next to highly vegetated or sheltered areas with few roads could need treatment more frequently than other areas to address mosquito dispersion.

Anticipating the number of applications needed for each area is also important. In a populated area along a rural road, the primary source of mosquitoes usually is from the habitat located behind houses. During crepuscular periods, host-seeking mosquitoes move out of the tree line toward populated areas. Truck-mounted ULV machines can treat a 300-ft swath from the road. If the mosquito habitat behind houses is large (e.g., hundreds of acres), mosquitoes are expected to disperse back into sheltered areas within 1–2 days of the initial treatment.

Each area should be evaluated for surrounding habitat, wind direction, equipment accessibility, and surveillance history. Ground-based mosquito control during emergencies necessitates intensified mosquito control for 21 days post-adult emergence to minimize human exposure to mosquitoes. Handheld or ATV-mounted equipment can be used for treatments where access is limited. This approach requires frequent applications during the initial 21-day period post-hurricane.

Wind direction must also be considered when planning mosquito control. As an example, prevailing wind direction shown in Figure 1 restricts ULV application on the south side. In this case, trucks can be driven directly next to the tree line in backyards on the north side of the street for ULV application. Although this method will not result in the maximum 300-ft insecticide penetration into the woods, mosquitoes along the edge of the forested area can be treated. Homeowner permission is required, though, as trucks are driven in backyards and thus can damage the yard and septic systems, for example, without proper planning. Experienced operators who are familiar with treatment areas and potential hazards are a crucial component of success. Other adulticiding possibilities include mounting ULV machines on ATVs or using handheld ULV equipment for spot treatment.

Written records of treatments for vegetated or sheltered areas facilitate planning of an emergency response. Of note, areas historically requiring frequent applications likely include areas adjacent to salt marsh edges and communities next to woodland pool habitats. An insecticide worksheet (Table 1) enables FEMA reconciliation and meets North Carolina Department of Agriculture (NCDA) insecticide reporting criteria.

Aerial Response

In North Carolina, the state medical entomologist maintains aerial maps of treatment blocks reviewed in 2001 by the U.S. Fish and Wildlife Service (USFWS) for the Coastal Plain and other regions. Base map polygons can be used as starting points for health departments and should be verified or updated using data layers (e.g., structures) from the county tax office to provide an indication of population density. MCPs should maintain routine contact with USFWS to ensure aerial maps are updated periodically and communicated to the appropriate parties. Elected municipal leaders should be contacted to confirm support for mosquito control in respective jurisdictions within the county.

Multiple products are available for aerial control (www.epa.gov/mosquitocontrol/controlling-adult-mosquitoes). Factors to consider include rate per acre range, concentration of active ingredient, price of contracted airplane and insecticide formulated products, product efficacy, insecticide resistance status of mosquitoes to the active ingredient, and environmental restrictions (Table 2).

In North Carolina, licensed aerial mosquito contractors can be found via the North Carolina Department of Agriculture and Consumer Services (https://apps.ncagr.gov/AgRSysPortal/publiclicensesearch/index). When selecting a vendor for post-disaster control, it can be useful to consider several factors beyond cost and rate of application per acre:

1. formulated products and their efficacy, risk assessment, appropriateness for aerial application;

2. insecticide label requirements;
3. aerial applicator license and availability;
4. aircraft calibration and certification;
5. number of aircraft;
6. pilot certification in use of military-grade night vision goggles;
7. aircraft certification by Federal Aviation Administration for congested air space;
8. flight guidance systems that utilize offset technologies;
9. aircraft spray optimization guidance software;
10. aircraft real-time meteorological data at release height to optimize treatment;
11. conducts missions between dusk and 10:30 p.m. and coordinates missions through county MCP (per our experience, *Aedes* and *Psorophora* floodwater mosquitoes stop actively searching for a bloodmeal at approximately 10:30 p.m.);
12. provides maps of treatment applications;
13. uses nearest airport as base of operations;
14. on-site with material within 72 hr of contract activation;
15. provides MCP access to base of operations;
16. allows access to media (i.e., vendor has personnel capable of discussing operations with county leadership and the media);
17. services completed within 4 days as weather allows;
18. ability to conduct pre- and post-treatment trapping if needed; and
19. complies with federal, state, territorial, and/or local laws, ordinances, and regulations regarding vector control.

More information can be found in the Supplemental Appendix at www.neha.org/jeh/supplemental.

Insecticide labels specify ULV application of formulated products only when mosquitoes are actively flying and when winds are <10 mph, which typically is after dusk. This time frame mirrors routine ground-based efforts; hence, the community is accustomed to evening applications. This time frame for application also minimizes risk to bees that are not active during evening and follows U.S. EPA (2020) recommendations to minimize human exposure for up to 4 hr after application.

Application cost is important; however, a cornerstone of integrated pest management is to follow best management practices for insecticide application, especially post-disaster when reimbursement is requested but not guaranteed. Any RFP for aerial application contract work should include a request for information on these issues, hence allowing MCPs to rank vendors on ability in addition to cost. Then each vendor is scored and a contract is generated

for the selected vendor. In the Brunswick County example, contracts were reviewed by the county attorney, forwarded to the county manager, and then sent to the board of commissioners for final approval. Ultimately, the county finance office makes the initial payment up front with a purchase order. This process takes time; however, pre-planning can make the process go more smoothly.

Coordinating Ground and Aerial Applications

In some post-hurricane situations, aerial insecticide applications can be warranted. Coordinating ground and aerial insecticide applications adds another component to the emergency response. It is crucial that county MCPs coordinate with aerial applicators to maximize control without duplicating treatments (Vigilant et al., 2020). Furthermore, municipal and county MCPs should be informed about the scheduled times and locations for aerial applications. Before each flight, environmental conditions should be evaluated so that pilots can make informed decisions on treatments. Ground-based ULV equipment should be used in areas not scheduled for aerial treatment for approximately 3 days post-aerial application. Pre- and post-aerial application-treated areas should be evaluated using landing counts to assess control effectiveness.

Post-treatment surveillance focuses on identifying areas that ground-based equipment can address using spot treatments. It is possible that adult mosquitoes reenter the aerial treatment zone. In this case, ground ULV treatments are used along the edge of the aerial treatment zone to minimize mosquito dispersion at perimeters. If a county does not have an MCP that uses ground ULV equipment and residents are unfamiliar with routine mosquito control, aerial insecticide application can be problematic. Community support is an integral component of an effective integrated pest management program and should be built over time with appropriate communication, experience, and outreach.

Role of the U.S. Fish and Wildlife Service

When requesting federal funding for mosquito control, USFWS reviews endangered species in proposed treatment areas. Federally managed lands, military bases, state parks, and aquaculture farms are excluded from treatments. Untreated buffers should also be mapped around major bodies of water. Aerial polygons should be reviewed by USFWS pre-disaster, as post-disaster review could delay aerial response.

Public Relations and Communications

Regardless of whether a ground or aerial response—or both—is conducted, public communication is essential (Schoch-Spana et al., 2020). MCPs should maintain a list of do not spray locations, such as those necessitated by chemically sensitive people, beekeepers, call-before-spray residents, fish farms, organic farms, and any other concerned residents. Furthermore, public information officers should have relevant and up-to-date materials to share with media outlets. Information provided to the public about mosquito treatments typically includes what to do during treatments (e.g., stay indoors, shut windows and doors, turn off air conditioning) and points of contact (e.g., health department, county MCP, poison control).

Working With Beekeepers

The NCDA Pesticide Section uses DriftWatch, a voluntary specialty crop registry and mapping program that enables farmers, beekeepers, and pesticide applicators to collaborate (www.ncagr.gov/pollinators/driftwatch.htm). Beekeeper information can also be found through local cooperative extension offices. Personnel from the Brunswick County MCP communicate with the Brunswick County Bee Keepers Association in most years to address any concerns. After Hurricane Florence, Brunswick County mosquito control personnel contacted beekeepers using the CodeRED system (i.e., reverse 911, an emergency notification system used by police, fire, or government officials to notify the public in emergencies). Other local agencies to contact prior to aerial application include school and park recreation personnel, such as those in charge of scheduling and rescheduling after-school events and evening sports leagues. Parks should be closed early on the evening that their respective spray block is to be treated.

Post-Hurricane Federal Emergency Management Agency Reporting

Information required by FEMA for mosquito control cost reimbursement is uploaded through a reporting portal. Typically, one agency handles the reporting for a local government. Information reported to FEMA might also be reported to the state later if the state is reimbursing the county on the 25% cost share. FEMA can request follow-up information for claimed expenditures.

After Hurricane Florence, Brunswick County received FEMA clarification requests in general, ground, and aerial categories (see Supplemental Appendix). FEMA equipment rates apply to applicant-owned equipment in good condition used for eligible work. Labor, materials, and equipment costs are approved separately. Mosquito control ULV machines are not listed in FEMA equipment documents. Machines, however, with similar specifications such as horsepower and size on the FEMA list can be used for comparison. MCPs should provide justification for the ULV machine engine selected (e.g., Clarke Grizzly ULV machine [18 HP (694 cc) engine] to demonstrate that it is comparable to an ATV [FEMA cost code 8085] with 18–20 HP (300 cc).

Costs of Post-Hurricane Mosquito Control

An important consideration to a post-hurricane response is the unbudgeted costs required to pay for the emergency mosquito control activities in advance; thus, pre-planning is essential. The post-treatment documentation required by FEMA is significant and can delay local reimbursement. Hence, understanding what is needed in advance and planning for these steps can prevent these delays. For example, North Carolina provided $4 million toward mosquito control after Hurricane Florence in 2018 for affected counties (North Carolina Office of the Governor, 2018). Brunswick County was allocated $199,913. Table 3 shows cost breakdowns for post-hurricane mosquito control.

Regardless of whether a ground-based, aerial-based, or mixed response is used, a county needs technical expertise, reserve funds, and equipment to be available to implement a disaster response. Not all counties have the funds or program experience to conduct an aerial response at the county level, which supports a strong argument for a post-disaster aerial

response at the state level. Because post-disaster mosquito response with documentation required by FEMA is a complex undertaking, pre-planning is crucial.

Comprehensive written response protocols should be developed at the state level so that local programs can make timely emergency response decisions. In North Carolina, a Mosquito Management Task Force has been created and tasked with developing written protocols. The task force comprises state-level personnel from Emergency Management, Division of Public Health, Department of Agriculture and Consumer Services, as well as advisors from federal agencies such as CDC, FEMA, and USFWS.

As of 2021, there is a renewable, 3-year, state-level contract that expires in 2024 (North Carolina Department of Public Safety, n.d.). This contract could be activated by counties or the state and would include contractor-performed mosquito control activities including trapping adult mosquitoes, surveying larvae, applying barrier treatment, and conducting ground and aerial larviciding/adulticiding. The contract could be used for activities ranging from small-scale arboviral transmission management to large-scale multicounty hurricane response. Disaster declarations would not be necessary for activation but would be required for most state and/or federal reimbursement of costs.

Discussion and Conclusion

In 2018, increasingly abundant mosquito populations post-Hurricane Florence hampered response and recovery efforts in Brunswick County. Flooding contributed to substantially increased mosquito abundance and increased the mosquito biting rates within the county. Ground and aerial insecticide applications, informed by weather and mosquito life history, occurred as quickly as possible to reduce the immediate threat to public health. Reimbursement from FEMA was successful.

As seen in other U.S. regions, widespread flooding and mosquito abundance post-hurricane can necessitate aerial treatment (Carlson et al., 2020; Vigilant et al., 2020). Additionally, it is vital to restore MCP services as soon as possible post-hurricane (Connelly et al., 2020, Vigilant et al., 2020). Property damage, road access, and other factors can impact MCPs and the ability of other agencies to resume work immediately (Caillouët & Robertson, 2020). These infrastructure issues must be addressed quickly to optimize the emergency response. Furthermore, it is important to protect emergency workers from mosquitoes, as these workers are essential for restoring electrical power and telephone operations, relocating residents from damaged homes, and assisting injured people (Ahmed & Memish, 2017).

Different areas can experience variability in hurricane damage; hence, arbovirus transmission risk assessments will differ (Caillouët & Robertson, 2020). Lack of pre-preparation due to underfunded MCPs or other reasons and/or uncertainty about FEMA reimbursement can delay mosquito control operations (Harris et al., 2014), which is a significant concern from both public health and emergency management perspectives (Connelly & Borchert, 2020). Personnel from MCPs should be trained and ready for the procedures necessary for a successful post-disaster mosquito control response in advance of a disaster.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

Ahmed QA, & Memish ZA (2017). The public health planners' perfect storm: Hurricane Matthew and Zika virus. Travel Medicine and Infectious Disease, 15, 63–66. 10.1016/j.tmaid.2016.12.004 [PubMed: 28017726]

Boze BGV, Markowski DM, Bennett D, & Williams MG (2020). Preparations and activities necessary for aerial mosquito control after hurricanes. Journal of the American Mosquito Control Association, 36(Suppl. 2), 90–97. 10.2987/19-6881.1 [PubMed: 33647138]

Brown JS (1997). Chronology of a mosquito control effort after Hurricane Fran. Journal of Environmental Health, 60(5), 8–13.

Brown J, & Hickman R (2005). Vector bearings: An operational timeline for initiating Eastern equine encephalitis bridge vector control. Wing Beats, 16(3), 7–8.

Caillouët KA, & Robertson SL (2020). Temporal and spatial impacts of hurricane damage on West Nile virus transmission and human risk. Journal of the American Mosquito Control Association, 36(Suppl. 2), 106–119. 10.2987/19-6887.1 [PubMed: 33647148]

Carlson DB, Richards DD, & Reilly JE (2020). Hurricane preparedness and response along Florida's central-east coast: Indian River Mosquito Control District's experiences over the years. Journal of the American Mosquito Control Association, 36(Suppl. 2), 5–10. 10.2987/19-6875S.1 [PubMed: 33647140]

Connelly CR, & Borchert J (2020). Mosquito control emergency preparedness and response to natural disasters. Journal of the American Mosquito Control Association, 36(Suppl. 2), 2–4. 10.2987/8756-971X-36.2S.2 [PubMed: 33575685]

Connelly CR, Gerding JA, Jennings SM, Ruiz A, Barrera R, Partridge S, & Beard CB (2020). Continuation of mosquito surveillance and control during public health emergencies and natural disasters. Morbidity and Mortality Weekly Report, 69(28), 938–940. 10.15585/mmwr.mm6928a6 [PubMed: 32673302]

Federal Emergency Management Agency. (2020). Public assistance program and policy guide: Version 4 (FP 104-009-2). https://www.fema.gov/sites/default/files/documents/fema_pappg-v4-updated-links_policy_6-1-2020.pdf

Goddard J, & Varnado WC (2020). Disaster vector control in Mississippi after Hurricane Katrina: Lessons learned. Journal of the American Mosquito Control Association, 36(Suppl. 2), 55–60. 10.2987/18-6870.1

Harris JW, Richards SL, & Anderson A (2014). Emergency mosquito control on a selected area in eastern North Carolina after Hurricane Irene. Environmental Health Insights, 8(Suppl. 2), 29–33. 10.4137/EHI.S16001 [PubMed: 25574141]

Harrison BA, Byrd BD, Sither CB, & Whitt PB (2016). The mosquitoes of the Mid-Atlantic region: An identification guide. Mosquito and Vector-borne Infectious Diseases Laboratory Publication 2016-1, Western Carolina University.

McAllister JC, & Madson SL (2020). Federal assistance for mosquito abatement postdisaster or during disease outbreaks. Journal of the American Mosquito Control Association, 36(Suppl. 2), 74–77. 10.2987/19-6895.1

Nasci RS, & Moore CG (1998). Vector-borne disease surveillance and natural disasters. Emerging Infectious Diseases, 4(2), 333–334. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2640131/pdh9621210.pdf [PubMed: 9621210]

North Carolina Department of Public Safety, (n.d.). Mosquito abatement contract, https://www.ncdps.gov/mosquito-abatement-contract

North Carolina Office of the Governor. (2018, September 26). Governor Cooper orders mosquito control for disaster counties. https://governor.nc.gov/news/governor-cooper-orders-mosquito-control-disaster-counties

Schmidt RF (1989). Landing rates and bite counts for nuisance evaluation. Proceedings of the New Jersey Mosquito Control Association, 76, 34–37. https://vectorbio.rutgers.edu/outreach/landing.htm

Schoch-Spana M, Watson C, Ravi S, Meyer D, Pechta LE, Rose DA, Lubell KM, Podgornik MN, & Sell TK (2020). Vector control in Zika-affected communities: Local views on community engagement and public health ethics during outbreaks. Preventive Medicine Reports, 18, Article 101059. 10.1016/j.pmedr.2020.101059 [PubMed: 32154093]

U.S. Environmental Protection Agency. (2020). Naled aerial mosquito control application parameters. https://www.epa.gov/sites/default/files/2020-09/documents/naled_amca_final_letter_9_4_2020_v2.pdf

Vigilant M, Battle-Freeman C, Braumuller KC, Riley R, & Fredregill CL (2020). Harris County Public Health Mosquito and Vector Control Division emergency response to Hurricane Harvey: Vector-borne disease surveillance and control. Journal of the American Mosquito Control Association, 36(Suppl. 2), 15–27. 10.2987/19-6890.1 [PubMed: 33647149]

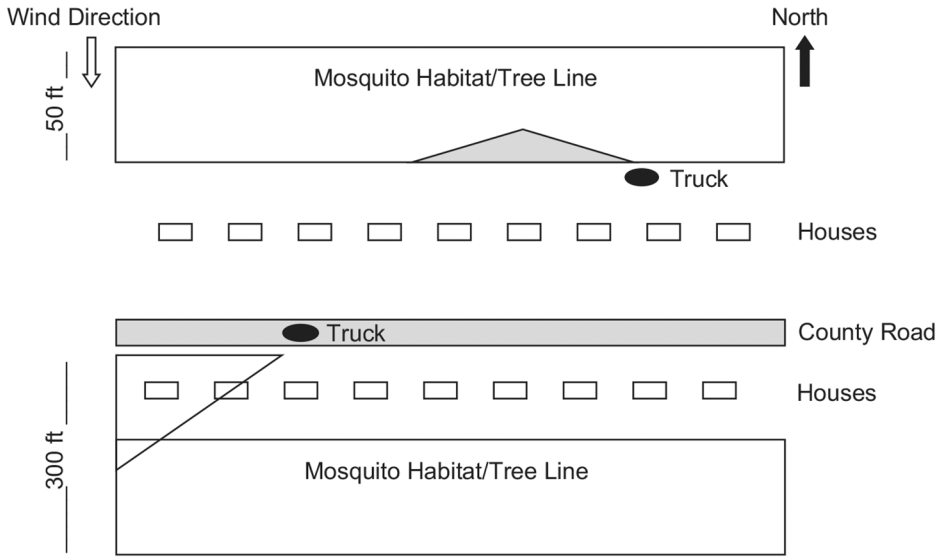

FIGURE 1. Truck-Mounted ULV Treatment of Populated Area in a Rural Setting
Note. The figure is not to scale. ULV = ultra low volume.

TABLE 1

Insecticide Tracking Worksheet

Date	Employee	Truck #	ULV #	Treatment Zone	Start Time	End Time	Total Hours	ULV Hours	Insecticide Used	Acres Treated	Miles Treated

Note. ULV = ultra low volume.

TABLE 2

Examples of Several Formulated Products Used in Aerial Insecticide Application in North Carolina

Product	Active Ingredient (%)	Active Ingredient/ Gallon (lb)	Droplet Size (μm)	ULV Rate (oz/acre)	Flight Height (ft)
Dibrom	Naled (87)	13.2	25–35	0.5–1.0	300
Trumpet EC	Naled (78)	10.8	25–35	0.6–1.2	300
Duet HD	Prallethrin (1)	1.027	25–35	0.33–0.99	300

Note. ULV = ultra low volume.

TABLE 3

Cost of Mosquito Control Response to Hurricane Florence Brunswick County, North Carolina

Aerial Response	Ground Response		
Cost of Aerial Application	**Normal Operation Cost/Week**	**Doubled Operation Cost/Week**	**Operation Cost for the 3-Week Response**
$686,473.87 (included $486,560.87 in federal reimbursement and $199,913.00 in state reimbursement)	$16,582.00 (included $7,861.76 in labor, $2,979.15 in equipment, and $5,741.10 in materials)	$33,164.02 (included $15,723.52 in labor, $5,958.30 in equipment, and $11,482.20 in materials)	$99,492.06 *

* Federal reimbursement provided for the increased cost that exceeded “normal” operations for the 3-week response period: $99,492.06 (emergency operations for 3 weeks): $16,582.00 × 3 weeks (normal operations for 3 weeks) = $49,746.00 in federal reimbursement.