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INTEGRATING VECTOR AND NUISANCE MOSQUITO CONTROL FOR SEVERE WEATHER RESPONSE

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ABSTRACT. Ideally, all mosquito control programs would have public health–driven and nuisance population–focused components in their mosquito control plan. However, due to resource limitations many mosquito control programs focus attention on one specific component of integrated mosquito control, i.e., adulticiding only. Programs run by public health departments with limited resources are frequently heavily focused on vector control, targeting a few mosquito species that are locally medically relevant in human and animal disease cycles. Focusing their mosquito management on these specific vector species can result in inefficiencies after hurricanes and severe flooding events that create a need for nuisance mosquito control. Floodwater nuisance species that emerge are not routinely a public health threat, but hinder operations related to response efforts and can negatively affect the lives of people in areas recovering from these disaster events. Staff, training, equipment, and facilities, when aimed at public health vector control, may not have the experience, knowledge, or tools to effectively respond to postdisaster, floodwater mosquito populations. As such, all mosquito management programs should have plans in place to handle not only known vectors of public health concern in response to mosquito-borne disease, but also to manage floodwater mosquito populations after natural disasters to safeguard public health and facilitate recovery operations. The current paper discusses the severe weather events in South Texas in 2018 and the resulting integrated nuisance floodwater mosquito control guidance developed by the Texas Department of State Health Services.

KEY WORDS Floodwater mosquito control, hurricane, integrated mosquito management, nuisance mosquito control, vector-borne disease control

INTRODUCTION

After severe weather events, like the flood in the Rio Grande Valley (RGV) in 2018, effective plans for integrated mosquito management (IMM) are necessary. The frequency of global weather-related disasters has increased and will continue to rise based on climatological data (Anyamba et al. 2014). Hurricanes and increased flooding will result in the continued occurrence of massive hatch-offs of floodwater mosquitoes (Harris et al. 2014). These floodwater mosquitoes, mostly from the genera *Aedes* and *Psorophora*, have drastically different oviposition, feeding, and host-seeking behaviors than their disease-carrying counter parts. Large emergences of these aggressive, often day-biting, mosquitoes hinder recovery operations for those attempting to restore necessary utilities and infrastructure in disaster zones.

Along with hindering the recovery efforts of people restoring and rebuilding, floodwater mosquito emergence significantly affects the quality of life of people unsettled by hurricanes and flooding. Residents who are displaced, or residing in damaged homes, frequently do not have the necessary barriers to keep mosquitoes out of their residences. Water-damaged buildings are frequently left with doors and windows open, with damaged screens and roofs, leaving little protection for affected residents.

Public perception of mosquito control does not always align with a program's management plan. Often the perceived risk of a disease threat may be low even though a majority of people in an area describe prevention and control efforts as extremely necessary due to the abundance of mosquitoes (Leslie et al. 2017). At odds with this perception, many public health–focused programs frequently perform limited spraying and control efforts and only target specific vector species in response to virus detection. Most residents have little knowledge of mosquitoes or their biology; they are unaware that there are different species and genera, with ranging life cycles, hosts, breeding, and feeding behaviors. Focusing solely on local disease-carrying species (vector species) utilizes the biology of only those few mosquitoes, leading to control plans and implementation that the public can have a difficult time understanding. In one study, >90% of the people surveyed perceived mosquito control as necessary; however, this perception was due to the nuisance of mosquito bites rather than the disease-causing potential of the mosquito (Kumar and Gururaj 2005). Consequently, a program could be regarded as ineffective, even if virus-carrying mosquitoes have been reduced in the area. Decreased public approval can compound limited resources, and a lack of confidence can lead to an absence of funding for these programs as evidenced by significant reductions in the mosquito surveillance and control budgets of health departments in a 2012 survey (NACCHO 2018). Augmenting public health–driven programs with nuisance control strategies can increase public approval and support of such programs.

The severe weather event in the RGV between June 18 and June 22, 2018, resulted in substantial property and infrastructure damage. The affected municipalities submitted multiple State of Texas Assistance Requests (STARs; DSHS Response and Recovery Unit 2019) for resources to assist in control of the large populations of nuisance mosquitoes that were being reported to the local health departments. Because most programs in the RGV are singularly focused on controlling vector species, the information and data necessary to demonstrate the need for resources from the state were not available. Here we discuss how the Great June Flood event of 2018 in South Texas (NOAA 2018) demonstrates the importance of integrated mosquito management as a comprehensive strategy for mosquito control.

INTEGRATED MOSQUITO MANAGEMENT—A COMPREHENSIVE STRATEGY

Ideally, all IMM programs should have a nuisance and public health component; however, not all do. Mosquito control operations that are under the direction of public health programs (PHPs) generally focus exclusively on local mosquito species that transmit disease-causing agents as mandated through their governing bodies. Texas law states that mosquitoes and their breeding sites are a public health nuisance but leaves responsibility of control to local authorities and property owners (ASTHO 2018). Texas Health and Safety Code, chapters 341 and 344, states that all activities regulated by legislation are the responsibility of local officials (Westlaw 2019), and many are housed within the local public health departments. These laws are implemented by a county judge and the commissioner's courts and mandate PHPs to focus on the reduction of local vector populations, such as *Culex quinquefasciatus* (Say), *Cx. nigripalpus* (Theobald), *Aedes aegypti* (Linnaeus), and *Ae. albopictus* (Skuse), to prevent the transmission of arboviruses. For example, in Harris County, mosquito control services are mandated to: "Provide surveillance, education and control of mosquito-borne disease in compliance with state licensure requirements and regulations regarding pesticide/herbicide application." As such the Harris County Public Health Mosquito and Vector Control Division is tasked with controlling mosquito-borne disease, limiting operations to respond to evidence of pathogen presence, not mosquito population growths (HCPH 2017). Often PHPs focused on vector-borne disease control are ill-equipped to handle large-scale nuisance mosquito hatch-offs. As such, staff hours, equipment, training, and facilities are mostly geared to control a small subset of mosquito species and they do not have the resources in place to respond to a large emergence of nonvector mosquito species.

Historically, when West Nile virus (WNV) was introduced into New York in 1999 (Nash et al. 2001) mosquito control programs that existed were not focused on the control of *Culex* species. Before the introduction of WNV, *Culex* species were considered a pest species by most mosquito control programs (Crans et al. 1996). The mosquito control programs in the New York area that existed prior to WNV introduction were mainly in coastal areas and targeted salt-marsh mosquito control. Existing programs focused on aggressive biting species of *Aedes* and other floodwater mosquitoes that affected quality of life, such as *Ae. sollicitans* (Walker), *Ae. taeniorhynchus* (Wiedmann), *Psorophora columbiae* (Dyar and Knab), *Ps. cyanescens* (Coquillett), and *Ps. ferox* (von Humboldt). Even though *Culex* mosquitoes were the primary vectors of St. Louis encephalitis virus and other encephalitic arboviruses, the frequency of transmission was low enough that mosquito control programs had not focused extensively on their control (Roehrig 2013, Hadler et al. 2014). Lack of information on the *Culex* vectors, especially their distribution, behavior, and feeding preferences along with birds being the reservoir host, contributed to the introduction of WNV in New York City (Nash et al. 2001) and allowed it to spread throughout the USA. Programs were unable to effectively respond and limit the spread of WNV due to a lack of surveillance, trapping methods, and knowledge of these mosquitoes. Because of the rapid spread of WNV, federal funds were allocated to develop vector control programs in parts of the USA where these programs had not existed (Roehrig 2013, Hadler et al. 2014).

Similarly, after Zika virus spread rapidly in the Americas many mosquito control programs were unprepared to handle control of *Ae. aegypti* and *Ae. albopictus*, which were considered nuisance mosquitoes in most of Texas at the time (Yakob and Walker 2016). The 1st reports of local Zika mosquito transmission in Texas occurred in November of 2016 in Brownsville, TX, on the Texas–Mexico border (Hall et al. 2017). Prior to Zika, the majority of mosquito control entities in Texas used either Centers for Disease Control and Prevention (CDC) light traps or gravid traps and were focused on WNV surveillance. For comparison, there were no BG-Sentinel traps (Biogents, Regensburg, Germany) submitted to the DSHS State Arbovirus Laboratory from 2013 to 2015. In 2016, there were <1,000 BG-Sentinel trap submissions while in 2017 there were almost 8,000 BG-Sentinel trap submissions to DSHS. Programs requested and received additional resources to expand their surveillance capacity, vector control standard operating procedures, and knowledge of the Zika vectors were better able to identify how and when to control these vectors and reduce Zika transmission in subsequent years.

This expanded integrated vector management capacity allowed programs to monitor for multiple vector-borne diseases. However, it did not enhance

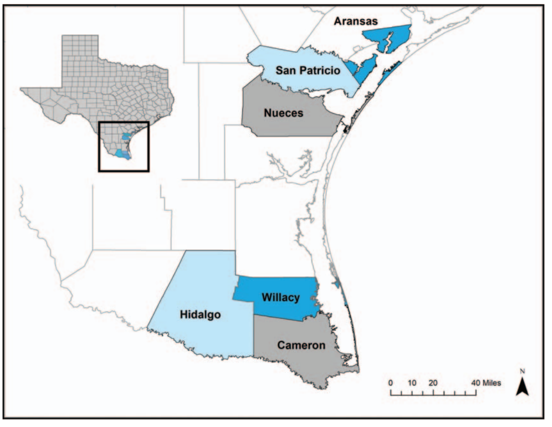

Fig. 1. State disaster-declared counties following the Great June Flood of 2018.

their ability to monitor and respond to nuisance floodwater mosquitoes resulting from severe weather incidents. Programs legally tasked and developed solely for vector-borne disease control lacked necessary surveillance data on floodwater, nuisance species due to variations in the traps used for disease-carrying mosquitoes and their nuisance counterparts. Gravid traps are commonly used to collect *Culex* mosquitoes looking to oviposit their eggs in stagnant, nutrient-rich water (Li et al. 2016, Popko and Walton 2016). The BG-Sentinel traps use a lure that attracts *Ae. aegypti* and *Ae. albopictus* (Meeraus et al. 2008). The CDC light traps attract a far greater variety of mosquito species, and effectively capture the populations of floodwater mosquitoes (Silver 2008). Trap placement also varies with type of trap used and target species collection; hence, traps being set for disease surveillance typically are placed in locations that provide harborage for local vector species. Without training, equipment, and set thresholds for nuisance mosquito species, these programs have difficulty requesting resources and demonstrating a significant increase in these populations that would warrant state-allocated resources.

SOUTH TEXAS GREAT FLOOD EVENT JUNE 2018

In Texas, during the Great June Flood, programs in affected areas were requesting resources from the state. Aransas, Cameron, and Hidalgo counties were undergoing recovery efforts due to the storm (Fig. 1). The Texas State Vector Control Response Operating Guidelines (DSHS Response and Recovery Unit 2015), which included disaster events, required historical and current mosquito population data to demonstrate need for state resources to be allocated. Because many of these entities were focused on vector species surveillance, municipalities encountered difficulties in responding to nuisance mosquitoes post–natural disaster and when requesting resources to manage these floodwater populations. For example, prior to the severe flooding the City of Brownsville Health Department, in Cameron County, was relying almost exclusively on BG-Sentinel traps for mosquito surveillance due to the threat of *Aedes*-borne virus transmission. From April to July 2018 in Cameron County, the majority of traps submitted to the state laboratory were from the City of Brownsville Health Department, totaling 525 traps, with 523 being BG-Sentinel traps and 2 gravid traps (Table 1).

Due to these affected programs requesting resources from DSHS to control floodwater mosquitoes and their lack of nuisance mosquito surveillance data, an independent contractor, Vector Disease Control International (VDCI), was asked to conduct assessments on mosquito abundance to determine if recovery efforts were being hindered by floodwater mosquitoes. This contract was executed, in part, because the mosquito population data provided to the DSHS Vector Control Task Force did not indicate that there were large floodwater mosquito populations or that these populations were hindering recovery efforts. Following the severe flooding event, mosquito surveillance was being conducted. However due to the reliance on BG-Sentinel and gravid traps, nuisance floodwater mosquitoes were not being properly sampled to demonstrate the effect on recovery efforts. The data collected by VDCI (exclusively utilizing CO_2-baited CDC light traps) demonstrated a large number of floodwater mosquitoes in comparison to the local mosquito control entity's traps (Table 1 and Fig. 2). Table 1 demonstrates the large variations in numbers and species collected. In counties where VDCI conducted assessments, light traps demonstrated dramatically more floodwater mosquitoes present in comparison with the number of mosquitoes captured by the locally set traps before and after the flood event for those entities that relied primarily on BG-Sentinel and gravid traps (Fig. 2A–D). The Aransas County Environmental Health Department trapping program yielded >5 times fewer mosquitoes collected (Table 1). The VDCI-set traps yielded more species diversity than local program traps set in Aransas or Hidalgo county programs, but not the City of Brownsville Health Department's program. The data from the 2 nights of contractor-set CDC light traps set by VDCI, compared with the state data from the local mosquito control entities within the 3 counties, were >10 times the number of mosquitoes collected in July, along with large variations in the number of species collected (Figs. 2 and 3).

The contractor also located larval habitats, conducted landing rate counts, and identified mosquito "hot spots" in the areas with ongoing recovery operations. Local data provided, when compared with the VDCI data, did not demonstrate effective surveillance for the nuisance floodwater species emergence after the Great June Flood. This lack of in-house resources by the local programs to conduct their own surveillance and assessments for the

Table 1. Species totals as provided by collections from the programs within the affected counties and Vector Disease Control International (VDCI) collections post–flood event, April 4, 2018 to July 31, 2018.[1]

	Cameron County		Hidalgo County		Aransas County		
Species	VDCI (n = 24)	Cameron Co. (n = 525)	VDCI (n = 20)	Hidalgo Co. (n = 96)	VDCI (n = 20)	Aransas Co. (n = 39)	Total (by species)
Aedes aegypti	362	2,304	216	392	25	29	3,328
Ae. albopictus	27	244	10	33	30	38	382
Ae. bimaculatus	85	18	1	1	12	—[2]	117
Ae. infirmatus	5	—	—	—	—	—	5
Ae. mitchellae	—	—	—	—	1	—	1
Ae. scapularis	—	10	—	—	—	—	10
Ae. sollicitans	669	516	958	26	7,819	376	10,364
Ae. taeniorhynchus	672	1,170	110	13	7,546	723	10,234
Ae. thelcter	97	1,187	140	132	10	2	1,568
Ae. triseriatus	—	3	4	—	1	1	9
Ae. trivittatus	9	1	32	—	—	—	42
Ae. vexans	852	1,015	363	133	59	1	2,423
Aedes spp.	—	153	—	2	—	—	155
Anopheles albimanus	25	7	—	—	—	—	32
An. crucians	8	26	2	1	11	—	48
An. pseudopunctipennis	2	174	5	6	—	—	187
An. punctipennis	—	5	—	—	—	—	5
An. quadrimaculatus	24	536	—	5	—	—	565
Anopheles spp.	—	107	—	—	—	—	107
Coquillettidia perturbans	—	1	—	—	6	—	7
Culex coronator	1,712	270	805	69	—	1	2,857
Cx. erraticus	686	—	565	—	13	—	1,264
Cx. interrogator	—	50	3	32	—	—	85
Cx. nigripalpus	3,350	868	791	13	10	—	5,032
Cx. quinquefasciatus	2	9,683	14	277	12	58	10,046
Cx. restuans	—	—	1	—	1	—	2
Cx. salinarius	8	636	—	2	—	2	648
Cx. tarsalis	3	24	—	—	—		27
Culex spp.	—	1,441	—	95	—	1	1,537
Culex (*Melanoconion*) spp.	—	272	—	252	—	—	524
Culicidae species (female)	—	10,187	—	1,650	—	500	12,337
Culicidae species (male)	—	3,653	—	703	—	50	4,406
Deinocerites mathesoni	—	1	—	—	—	—	1
Mansonia titillans	—	2	—	—	13	7	22
Psorophora ciliata	288	4	32	3	497	3	827
Ps. columbiae	41,033	188	16,983	133	4,761	14	63,112
Ps. cyanescens	3,072	940	98	35	5,229	221	9,595
Ps. ferox	2	—	—	—	—	—	2
Ps. horrida	732	—	—	—	—	—	732
Ps. howardii	—	1	—	2	—	—	3
Ps. longipalpus	4	1	—	—	—	—	5
Psorophora sp.	—	1	—	—	—	—	1
Uranotaenia lowii	6	—	—	—	—	—	6
Wyeomyia smithii	—	—	1	—	—	—	1
Total (by collector)	53,735	35,699	21,134	4,010	26,056	2,027	142,661

[1] n = number of traps set. Traps used: VDCI traps were 64 Centers for Disease Control and Prevention (CDC) light traps set over 2 nights, July 11 and 13, 2018, after the Great June Flood. Health department and mosquito control program traps were set between April 4, 2018, and July 31, 2018. Aransas County Environmental Health Department set 14 BG-Sentinel, 6 CDC light traps, and 19 gravid traps. The City of Brownsville Health Department and Cameron County Health Department set 523 BG-Sentinel and 2 gravid traps. Hidalgo County set 54 BG-Sentinel traps, 21 CDC light traps, and 21 gravid traps.

[2] A dash indicates zero specimens of that species collected by that agency.

nuisance floodwater species that emerged slowed the process for state assistance.

Staff and training also affect efficiency across program types. Since most of the programs affected by the Great June Flood focused on key vector species, their capacity and training to manage large mosquito populations was limited. Setting traps and identifying species varies depending upon the species of primary concern. Those who regularly identify a handful of vector species would be slow to learn and identify the increased diversity of nuisance mosquitoes a CDC light trap would collect. Identification of new species after a severe weather incident can be

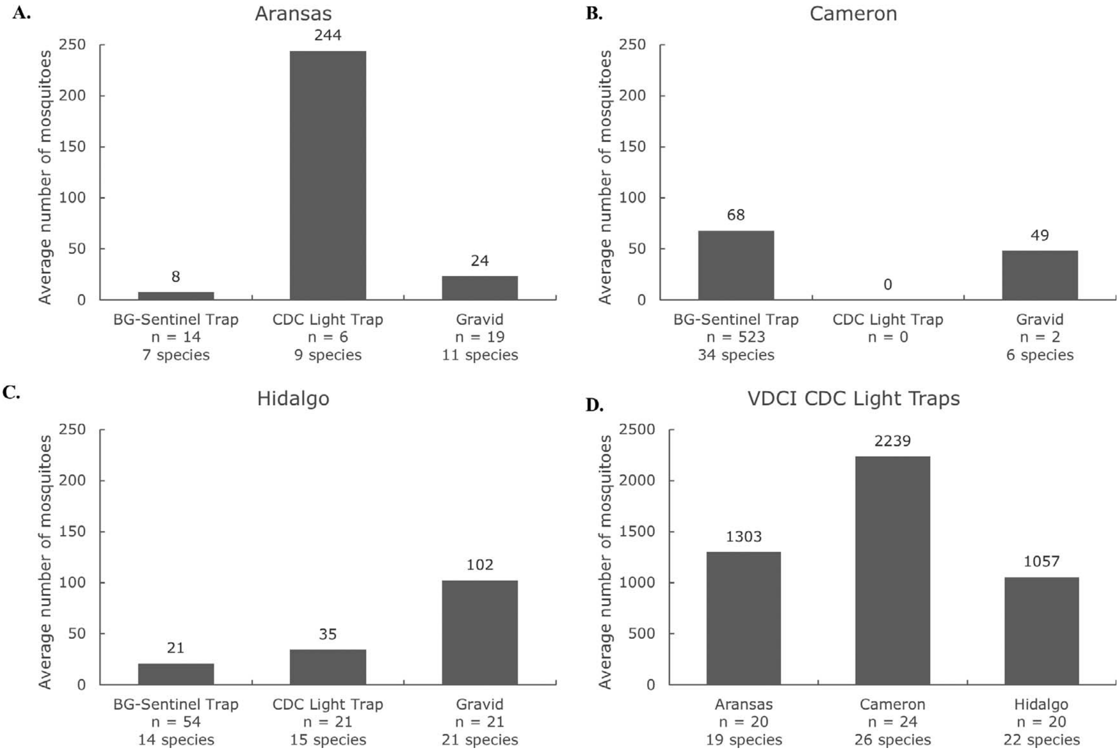

Fig. 2. Average number of mosquitoes collected by trap type and collector. (A) Total of 14 BG-Sentinel, 6 Centers for Disease Control and Prevention (CDC) light traps, and 19 gravid traps set out by the Aransas County Environmental Health Department, which collected 8, 244, and 24 mosquitoes on average per trap-night, respectively. (B) Total of 523 BG-Sentinel traps and 2 gravid traps set in Cameron County, which collected 68 and 49 mosquitoes on average per trap-night, respectively. (C) Total of 21 BG-Sentinel traps, 21 CDC light traps, and 21 gravid traps set out in Hidalgo County, which collected 21, 35, and 102 mosquitoes on average per trap-night, respectively. (D) Vector Disease Control International (VDCI) traps that were set in 3 counties to conduct postflood assessments on floodwater mosquito emergences. All traps were CDC light traps, set on July 11 and 13, 2018. Average mosquitoes collected per trap were 1,303 in Aransas, 2,239 in Cameron, and 1,057 in Hidalgo with 19, 26, and 22 species represented, respectively.

taxing, with high trap counts and more diverse samples (Table 1).

Implementation of control efforts was also challenging as most programs in the RGV focused on *Culex* and container-breeding *Aedes* vector control. These vector populations oviposit, undergo their larval stages, and emerge in a consistent cycle. Treating for these populations tends to utilize highly focused larvicide and small-scale truck ultra-low volume (ULV) applications. The nuisance floodwater populations that emerged were not able to be controlled with the established larvicide protocols for local vector species due to cost and the large areas requiring treatment, so ground ULV applications were the only option. However, since most of the programs had incomplete mosquito abundance data, population increases and hot spot areas for floodwater mosquitoes were hard to identify, resulting in misaligned ULV missions using predetermined routes that did not cover the entire area affected. Without proper data to indicate which areas require treatment and when to treat them, the ULV applications were less likely to have the greatest effect against the floodwater mosquito being targeted. Thresholds for vector populations are also different from those for nuisance populations. In a public health–driven vector control program, thresholds typically relate to the presence of virus in tested mosquitoes or positive human cases (Jones et al. 2011, NYC DHMH 2017). For nuisance mosquitoes, thresholds are typically set based on trap or landing rate counts, at a determined point where it would be deemed uncomfortable for humans (MA SRMCB 1998, MDA 2019). This difference can lead to a vector IMM program lacking the knowledge of when peak emergence is truly occurring.

STATE OF TEXAS TECHNICAL GUIDANCE: MOSQUITO ABATEMENT POST–WEATHER INCIDENT

In response to Hurricane Harvey and the floods in the RGV, the DSHS Regional and Local Health and

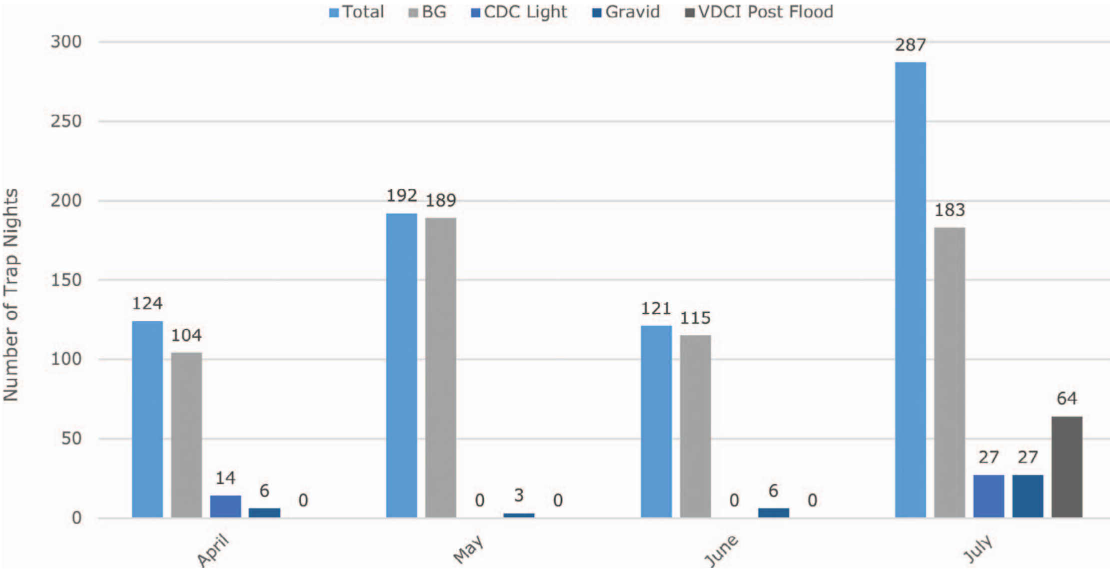

Fig. 3. Total number of trap types set and submitted to the Texas Department of State Health Services laboratory from Aransas, Cameron, and Hidalgo counties, before and after the Great June Flood of 2018 in the Rio Grande Valley.

Emergency Preparedness and Response Section developed new guidance for local jurisdictions (DSHS Response and Recovery Unit 2019). The technical document has several sections providing guidance for the process and requirements to request state-level assistance for mosquito abatement post–weather incident. It details when jurisdictions should request assistance. Such as when "an extraordinary or unusually large number of nuisance floodwater mosquitoes could impede response or recover operations even when evidence of vector-borne diseases is not present." It also provides critical information on the requirements of the local jurisdiction to request assistance—what supporting data they must provide in their STAR, including current surveillance and abatement capabilities and which chemical suppression measures (such as ground or aerial application, including labels for specific chemicals requested) are being used. The technical guidance explains the requirements and responsibilities of the local jurisdiction, state, and federal level for assistance. The document contains flowcharts for what documentation jurisdictions must provide and the process flow for STAR submission. On June 24, 2019, the RGV experienced another flood event, a year after the Great June Flood, referred to as the Great June Flood: The Sequel (NOAA 2019). Local municipalities again requested STARs to assist with the anticipated increase of floodwater mosquitoes. The DSHS Vector Control Task Force was able to utilize the new technical guidance to direct and help inform local jurisdictions on how to submit a request, and document the necessary items outlined in the guidance.

CONCLUSION

After severe weather incidents, jurisdictions that request assistance should have plans in place for operations to control nuisance mosquito populations postdisaster. Increased capability to respond to floodwater mosquito emergence requires additional training, surveillance, equipment, and planning to be effective. Time lost documenting the requests and resources without prior planning decreases efficiency in responding to floodwater mosquito emergence post–severe weather, for both the local jurisdiction and state and federal partners receiving requests for aid.

Vector control programs must become more IMM focused to be better prepared for both routine management strategies and emergency operations. Plans and strategies should already be in place to not only respond to evidence of mosquito-borne disease circulation, but also for mosquito emergences that affect response and recovery operations after natural disasters. Management of vector populations is important but augmenting these programs with strategies for nuisance abatement as well, increases the capacity of these jurisdictions to respond and manage nuisance populations post–severe weather events. Augmenting these programs toward a comprehensive mosquito management program improves quality of life while utilizing limited resources effectively and garnering additional public support.

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