

POPULATION OUTBREAKS OF MOSQUITOES AFTER HURRICANES MATTHEW AND IRMA AND THE CONTROL EFFORTS IN ST. JOHNS COUNTY, NORTHEASTERN FLORIDA

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ABSTRACT. Major flooding occurred throughout St. John's County, FL, from Hurricane Matthew on October 8, 2016, and Hurricane Irma on September 11, 2017. The flooding caused mosquito population outbreaks in the middle of October in 2016 and September in 2017. Due to the mosquito population outbreaks, Anastasia Mosquito Control District (AMCD) received >3,500 service requests countywide in October 2016 and ≥1,400 service requests in September 2017. During the response to the mosquito population outbreaks caused by the hurricanes, AMCD collaborated with the Emergency Operations Center, Department of Health of St. Johns County, and local media, including television stations, newspapers, and radio stations for public outreach. The AMCD also employed contractors for aerial adulticiding and used every possible resource to successfully control the outbreaks of mosquitoes using both ground and aerial applications.

KEY WORDS Adulticide, *Aedes atlanticus*, *Aedes taeniorhynchus*, *Culex nigripalpus*, larvicide, *Psorophora columbiae*

INTRODUCTION

At their peak Hurricane Matthew, October 2016, and Hurricane Irma, September 2017, were category 5 hurricanes; both hurricanes had impacts in St. Johns County, northeastern Florida. Hurricane Matthew was a category 2 hurricane as it passed the St. Johns County coastline. County rainfall totals during the hurricane event totaled 34.5 cm in the city of St. Augustine, 26.2 cm in St. Augustine South, and 22.4 cm at the Northeast Florida Regional Airport, St. Augustine. This rainfall coupled with substantial rainfall prior to the hurricane caused substantial freshwater flooding throughout the county.

Hurricane Irma made landfall in Marco Island in southwestern Florida and was a tropical storm when it passed west of St. Johns County, still causing significant impact to St. Johns County. The storm surge reported at Matanzas Inlet at the county's southeastern end was 1–1.3 m above ground level. Freshwater flooding was again an issue, with St. Augustine South reporting 25.9 cm of rain. Hurricane Irma was preceded by a very wet August and followed by an exceptionally large storm called a nor'easter, impacting the county September 30 and October 1, 2017, and caused extreme high tides. The total of these events—a wet August, Hurricane Irma, and the nor'easter—caused both fresh- and saltwater flooding throughout all of St. Johns County.

The Federal Emergency Management Agency (FEMA) issued a Disaster Declaration (DR-4283) for Hurricane Matthew, October 8, 2016, from October 3, 2016, to October 19, 2016; and a Disaster Declaration (DR-4337) for Hurricane Irma, on September 10, 2017, from September 4, 2017, to

October 18, 2017. The Florida Department of Health (DOH) in St. Johns County and Anastasia Mosquito Control District (AMCD) issued press releases and warned of the public health concern caused by the 2 hurricanes. These declarations allowed AMCD to use all methods necessary to control the mosquito outbreaks from these 2 weather events.

Both events caused large outbreaks of floodwater mosquitoes, *Aedes atlanticus* Dyar and Knab, *Psorophora columbiae* Dyar and Knab, *Culex nigripalpus* Theobald; and a super tide after Hurricane Irma caused an outbreak of salt-marsh mosquitoes, *Ae. taeniorhynchus* Wied. Therefore, AMCD received large volumes of service requests from the citizens of St. Johns County. This paper describes the AMCD response to the hurricanes, including enhanced public education and outreach, ground application of larvicides and adulticides, and using contractors to conduct emergency aerial spraying of adulticide in hot spots.

MATERIALS AND METHODS

St. Johns County is located in northeastern Florida and covers 1,650 km². It is bordered by the Atlantic Ocean on the east, with barrier islands between the ocean and the Intracoastal Waterway. The Intracoastal Waterway has 327 km² of salt marsh, much of it being under the protection of federal and state agencies as parks and preserves. The west side of St. Johns County is bordered by the St. Johns River, a wide slow-moving river affected by both floodwater and tides. Population of St. Johns County in July 2018 was 254,261, a 33.8% increase since April 2010. Population is concentrated on the coastline, the city of St. Augustine metro area, and the northwest portion of the county. The county's explosive

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population growth, with the influx of new residents and their housing, is changing the environment and adding to the demand for mosquito control service.

Mosquito trapping in St. Johns County is primarily done using 2 trap types: Centers for Disease Control and Prevention (CDC) light traps (John W. Hock, Gainesville, FL), baited with octenol lure strips (BioSensory, Inc. Putnam, CT); and BG-Sentinel (BGS) traps baited with BG-lure (BioGents, Regensburg, Germany). In 2016 and 2017, AMCD placed 32 CDC light traps at 32 locations throughout the county. The CDC light traps were placed in the field on a weekly basis on Monday afternoon and collected Tuesday morning, staying in the field for an average of 20 h. Traps were set and records were kept for the CDC light traps in 2016 from May 12, 2016, to November 8, 2016, and in 2017 from April 4, 2017, to November 28, 2017. In 2016 AMCD placed 8 BGS traps and in 2017 AMCD placed 12 BGS traps in downtown St. Augustine, North Anastasia Island, and St. Augustine South. Traps were placed in the field on a weekly basis on Tuesday afternoon and collected Wednesday morning, staying in the field for an average of 20 h. Traps were set and records were kept for the BGS traps in 2016 from February 23, 2016, to December 13, 2016, and in 2017 from January 3, 2017, to December 20, 2017.

Service requests are collected by various methods, including phone calls to the AMCD office, reported on the AMCD website, and reported using the AMCD service request phone application. All methods of reporting service requests geo-locate the service request address and report the service request to the mosquito control technician (MCT). Data pertaining to the service requests are recorded, including MCT assigned to a request, zone affected, work performed, service request location, and time from submission to close.

Prior to, during, and after Hurricane Matthew and Hurricane Irma, AMCD collaborated with St. Johns County Health Department to provide enhanced public education and provide outreach about prevention and control of mosquitoes. This outreach was accomplished using local television and radio stations, local newspapers, social media, and the AMCD website, as well as distribution of pamphlets at events, door-to-door outreach, and the posting of notices at public locations. In 2016, AMCD received extensive media attention with Hurricane Matthew and the posthurricane aerial spray application as well the attention from the Zika virus and a local resurgence of *Aedes aegypti* (L.); this resulted in 111 media segments. Social media activity also increased, with 900 followers of the District's Facebook page before Hurricane Irma, to >17,000 followers after the storm.

The AMCD used a variety of pesticides to treat larval, pupal, and adult mosquito populations in 2016 and 2017. During the typical mosquito seasons, AMCD normally treats with larvicides, including liquid, granular, and solid *Bti* (AI: *Bacillus thur-*

ingiensis var. *israelensis* de Barjac), with the most commonly used being liquid *Bti* (Aquabac® XT; Becker Microbial Products Inc., Parkland, FL). The AMCD also used granular and solid insect growth regulators Altosid® (Wellmark International, Schaumburg, IL [AI: methoprene]); solid pellets, Natular DT® (Clarke Mosquito Control Products, Roselle, IL [AI: spinosad]); and a liquid surfactant, Coco Bear™ (Clarke Mosquito Control Products [AI: mineral oil]). For adult mosquito control, AMCD mainly used Aqualuer® 20-20 (Value Garden Supply, St. Joseph, MO [AI: 20.6% permethrin]) applied by truck as an ultra-low volume (ULV) aerosol spray. In resistance areas, AMCD used Mosquitomist™ Two (Clarke Mosquito Control Products [AI: chlorpyrifos]) applied by truck as a ULV aerosol spray. For small area treatment, AMCD used Duet® (Clarke Mosquito Control Products [AI: prallethrin and sumithrin]) applied as a thermal application. Also, AMCD conducted barrier treatments using TalStar® P (FMC Corporation, Philadelphia, PA [AI: bifenthrin]). In response to the 2 hurricanes as an emergency application, AMCD used aerial contractors to conduct aerial adulticiding with Dibrom® (AMVAC Chemical Corporation, Newport Beach, CA [AI: naled]).

All data reporting numbers of mosquitoes caught by CDC light traps, BGS traps, and the amounts of insecticides used are recorded in and reported from the District's GeoMosquito database (www.amcdsjc.org).

RESULTS

During the Hurricane Matthew event, trapping with CDC light traps showed comparatively low numbers for the mosquito season until the 2nd week after the hurricane passed (Fig. 1). Traps set from September 20, 2016, to October 25, 2016, 6 trap-weeks, the CDC light traps collected 17,297 mosquitoes, with 14,119 *Ae. atlanticus*, 773 *Anopheles crucians* Wiedemann, and 521 *Cx. nigripalpus*. The average trap count for this time period was 540 per trap (Table 1). The BGS traps showed higher than normal mosquito counts for the 3 wk after the hurricane event (Fig. 1). From September 20, 2016, to October 27, 2016, 5 trap-weeks, the BGS traps collected 431 mosquitoes, with the top species collected being 123 *Ae. albopictus* (Skuse), 84 *Ae. atlanticus*, and 71 *Ae. taeniorhynchus*. The average trap count for this time period was 77 per trap (Table 1). The Hurricane Irma event showed high trap counts before the hurricane, and continued high counts persisted well after the hurricane passed (Fig. 2). The CDC light traps set from August 22, 2017, to October 17, 2017 (9 trap-weeks), collected 31,548 mosquitoes, with 18,389 *Ae. atlanticus*, 4,491 *Cx. nigripalpus*, and 2,777 *An. crucians*. The average trap count for this time period was 986 per trap (Table 2). The BGS traps also showed high trap counts before the hurricane event, and these high

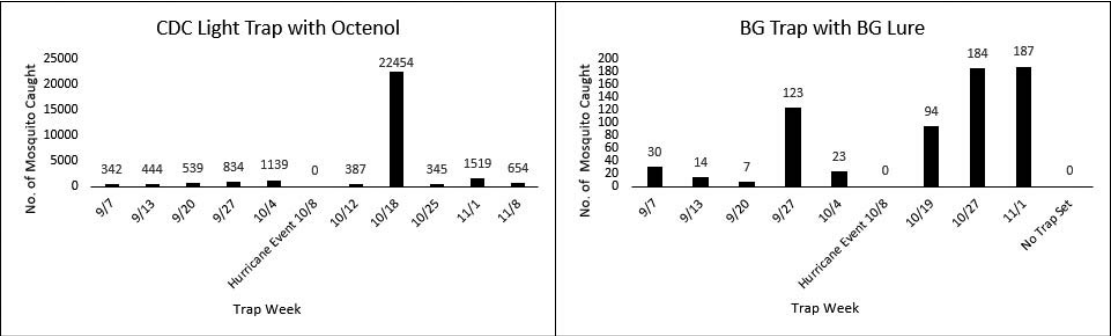


Fig. 1. Total numbers of adult mosquitoes caught by Centers for Disease Control and Prevention (CDC) light traps and BG-Sentinel traps, in St. Johns County, FL, before and after Hurricane Matthew, October 8, 2016.

counts persisted well after the hurricane passage (Fig. 2). From August 24, 2017, to October 11, 2017 (6 trap-weeks), BGS traps collected 7,783 mosquitoes, much higher amount than seen for the Hurricane Matthew event. The top species collected was 2,858 *Ae. taeniorhynchus*, followed by 1,440 *Cx. nigripalpus*, and 1,048 *Ae. atlanticus*. The average trap count for this time period was 648 per trap (Table 2). Both hurricane events produced large numbers of vector mosquitoes, such as *Ae. aegypti* (L.), *Ae. albopictus*, *An. quadrimaculatus* (Say), *Culiseta melanura* (Coquillett), *Cx. nigripalpus*, and *Cx. quinquefasciatus* Say.

The service requests reported before, during, and after the Hurricane Matthew event were: September 2016, 273 requests; October 2016 (event month), 3,569 requests; November 2016, 182 requests (Fig. 3A). The peak day of reported service requests was October 18, 2016, with 1,074 requests, 10 days after Hurricane Matthew passed (Fig. 3B). The service requests reported before, during, and after the

Hurricane Irma event were: August 2017, 361 requests; September 2017 (event month), 1,430 requests; October 2017, 1,239 requests; November 2017, 137 requests (Fig. 4A). The peak day of reported service requests was September 20, 2017, with 384 requests, 9 days after Hurricane Irma passed (Fig. 4B). Also, a 2nd peak event presented on October 9, 2017, with 335 requests (Fig. 4B). These events burdened AMCD with answering a total of 3,569 requests after Hurricane Matthew and 2,669 requests after Hurricane Irma.

In September 2016, the month prior to Hurricane Matthew, AMCD's MCTs made 165 applications of larviciding covering 401.2 ha. In October MCTs made 193 applications covering 734.3 ha, this amount being almost double the September area total; in November MCTs made 53 applications covering 122.8 ha. Treatments with adulticides were significantly increased both pre- and posthurricane months. Hectares treated in September, for all ground application of adulticides combined, covered 7,244

Table 1. Partial table of species and numbers of adult mosquitoes caught by Centers for Disease Control and Prevention (CDC) light traps and BG-Sentinel traps for the month before and the month of Hurricane Matthew, October 8, 2016.

Species	CDC light trap baited with octenol							BG-Sentinel trap baited with BG-lure						
	September		October					September		October				Total
	20	27	4	12	18	25	Total	20	27	4	19	27	Total	
<i>Aedes aegypti</i>	0	0	0	0	0	0	0	1	44	1	0	6	52	
<i>Ae. albopictus</i>	0	0	0	0	0	0	0	4	37	22	34	26	123	
<i>Ae. atlanticus</i>	57	5	67	7	13,862	121	14,119	0	0	0	24	60	84	
<i>Ae. infirmatus</i>	61	45	28	3	0	1	138	0	0	0	11	0	11	
<i>Ae. taeniorhynchus</i>	37	34	9	10	21	1	112	2	22	0	5	42	71	
<i>Anopheles crucians</i>	96	36	156	19	418	48	773	0	0	0	0	0	0	
<i>Culex erraticus</i>	1	6	66	96	93	3	265	0	0	0	0	0	0	
<i>Cx. nigripalpus</i>	26	144	227	59	20	45	521	0	0	0	11	0	11	
<i>Cx. quinquefasciatus</i>	0	0	0	0	0	0	0	0	20	0	0	27	47	
<i>Psorophora ciliata</i>	0	0	1	1	472	1	475	0	0	0	0	0	0	
<i>Ps. columbiae</i>	67	76	71	20	119	0	353	0	0	0	0	0	0	
<i>Ps. ferox</i>	0	0	1	0	355	0	356	0	0	0	5	23	28	
<i>Ps. howardii</i>	0	0	0	0	138	0	138	0	0	0	0	0	0	
<i>Uranotaenia sapphirina</i>	0	5	25	0	0	0	30	0	0	0	0	0	0	
Others	4	3	3	0	4	0	17	0	0	0	4	0	4	
Daily total	349	356	654	215	15,503	220	17,297	7	123	23	94	184	431	

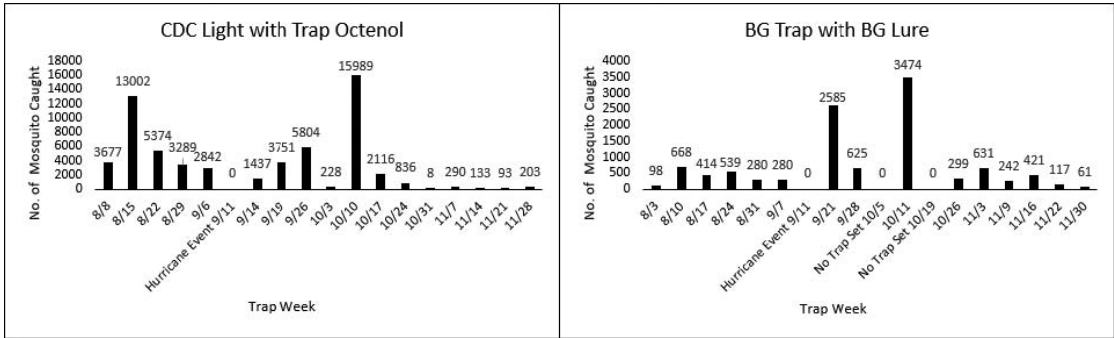


Fig. 2. Total numbers of adult mosquitoes caught by Centers for Disease Control and Prevention (CDC) light traps and BG-Sentinel traps in St. Johns County, FL, before and after Hurricane Irma, September 1, 2017.

ha. October applications were 46,695.1 ha treated using 166 truck applications; November was still busy with 11,264 ha treated using 51 truck applications (Table 3). The AMCD also used an aerial contractor who treated 23,845.7 ha on October 19 and 20,522.3 ha on October 20, bringing the total area treated with adulticides in October to a little over 91,054 ha.

There was an above average amount of rain in both the pre- and post-Hurricane Irma months, with an average of 5.83 cm per month pre-Hurricane Irma and 7.37 cm post-Hurricane Irma (Weather Underground 2019).

In August, the month prior to Hurricane Irma, MCTs made 261 applications of larvicide covering 671 ha. In September, the Hurricane Irma event month, MCTs made 196 applications covering 596.5 ha, which was less larviciding than the previous month. In October, MCTs applied the highest quantity of larvicides for the event months, with 421 treatments covering 1,165.5 ha. In November, MCTs larvicided 114 times covering 465.2 ha. The treatment with adulticides in August, with all ground adulticide applications combined, was 32,313 ha using 104 truck applications. September's applications covered 30,646.8 ha using 103 truck applications; the amount of adulticide applications started to taper off in October with 14,104.5 ha covered using 46 truck applications. November showed a large reduction in applications with only 1,031.5 ha covered using 5 truck applications (Table 3). In 2017, the AMCD aerial contractor treated 32,470 ha on September 23, which brought the total acres treated with all adulticides for September to 67,163.6 ha, using both ground and aerial application methods.

DISCUSSION

After hurricanes, the District was inundated with a massive amount of service requests for about 10 days after the hurricane. The mosquito population outbreak was contained fairly quickly using both ground and aerial applications of adulticide. This pattern of events is typical in mosquito control operations after

hurricanes (Simpson 2006, Harris et al. 2014). The AMCD's MCTs performed 166 truck missions covering 43,796.7 ha and after a delay, AMCD's aerial contractor conducted 2 aerial missions covering 44,367.7 ha. Because the flooding in Florida was widespread, the aerial contractors were busy in other counties, forcing AMCD to wait for treatment. The AMCD contractor was still able to accomplish the aerial adulticide missions and used AMCD-owned Dibrom, kept on hand for emergencies. Larvicidal applications were elevated for the month of October but were near normal, pre- and post-hurricane event.

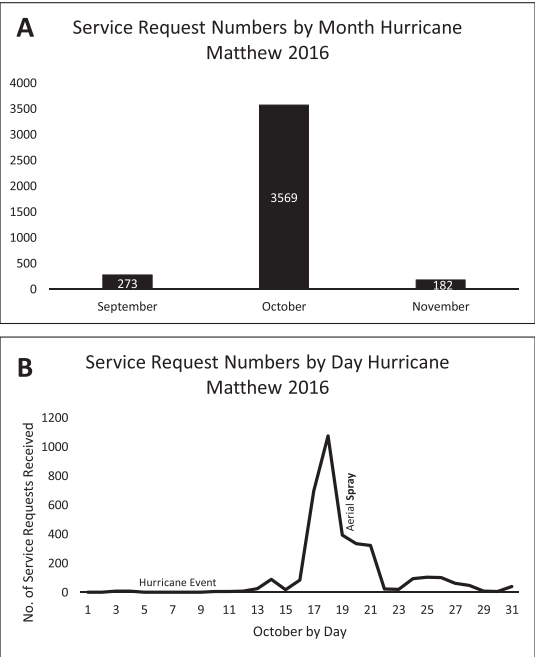


Fig. 3. Number of service requests from the month of and the month after Hurricane Matthew, October 2016. (A) Number of service requests for the months of September, October, and November in 2016. (B) Service request totals by day for the event month of October 2016.

Table 2. Species and numbers of adult mosquitoes caught by Centers for Disease Control and Prevention (CDC) light traps and BG-Sentinel traps for the month before and the month of Hurricane Irma, September 11, 2017.

Species	CDC light trap baited with octenol										BG-Sentinel trap baited with BG-lure									
	August			September			October				August			September			October			
	22	29		6	14	19	26	3	10	17	Total	24	31	7	21	28	11			Total
<i>Aedes aegypti</i>	0	0	0	0	0	0	0	0	0	0	0	97	29	29	170	34	42			401
<i>Ae. albopictus</i>	7	5	2	749	489	1	2,404	0	0	1	17	69	8	8	68	28	11			192
<i>Ae. atlanticus</i>	920	721				2,005		30	10,055	1,016	18,389	0	0	0	1,080	4	0			1,084
<i>Ae. infirmatus</i>	1,078	425	246	72	83	20	1	1	40	7	1,972	214	70	70	0	0	108			462
<i>Ae. sollicitans</i>	2	0	0	0	0	0	2	1	15	0	20	15	0	0	8	4	586			613
<i>Ae. taeniorhynchus</i>	13	4	0	0	0	7	3	1	138	23	190	5	5	5	1,009	77	1,757			2,858
<i>Anopheles crucians</i>	453	414	183	182	182	185	365	39	625	331	2,777	0	17	17	0	11	0			45
<i>An. quadrimaculatus</i>	6	22	1	5	7	37	2	2	12	0	92	0	0	0	0	0	0			0
<i>Coquillettidia perturbans</i>	4	2	9	0	0	0	9	0	0	0	24	0	0	0	0	0	0			0
<i>Culex erraticus</i>	15	39	142	47	92	77	44	44	130	34	620	0	0	0	0	0	0			0
<i>Cx. nigripalpus</i>	1,342	470	103	67	130	130	1,685	41	500	153	4,491	49	4	4	12	351	900			1,440
<i>Cx. quinquefasciatus</i>	36	0	0	16	6	6	0	0	12	15	85	41	140	20	118	113	65			498
<i>Psorophora ciliata</i>	1	1	1	1	1	0	3	0	132	0	139	0	0	0	0	0	0			0
<i>Ps. columbiae</i>	141	23	597	102	102	227	6	11	1,056	54	2,217	0	0	0	0	0	0			0
<i>Ps. ferox</i>	3	0	0	0	0	108	53	1	79	0	244	36	5	5	96	0	5			147
<i>Ps. howardii</i>	11	16	1	1	159	3	0	0	2	0	193	10	1	2	24	0	0			36
<i>Uranotaenia lowii</i>	0	6	2	4	4	0	37	0	0	2	51	0	0	0	0	0	0			0
Others	1	2	2	2	4	14	1	2	0	1	27	4	1	1	1	0	0			7
Daily total	4,033	2,150	2,038	991	3,024	4,705	173	1,637	12,797	1,637	31,548	539	280	280	2,585	623	3,474			7,783

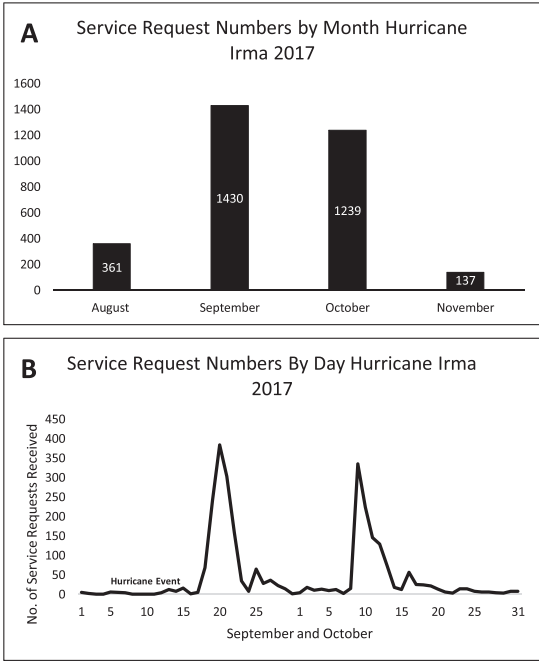


Fig. 4. Number of service requests from the month prior, the month of, and 2 months after Hurricane Irma, September 2017. (A) Number of service requests for the months of September, October, and November in 2017. (B) Service request totals by day for the event month of September and the month of October 2017.

The year 2017 had unusual weather, and Hurricane Irma added to the distinctive weather that occurred in other Florida counties (Lucas et al. 2019) as well as St. Johns County. In 2017, the AMCD performed more ground ULV aerosol spray missions than ever in its history, covering 155,289.6 ha using 458 truck

applications. Mosquito populations were high both pre- and post-Hurricane Irma, with high trap counts mid-August and mid- to late September (post-Hurricane Irma), with a 2nd peak (post-Hurricane Irma) in the 2nd wk of October. Service requests were high in August, with an average of 12 per day. Both September and October had peak days at about 350 service requests and averages of 48 service requests per day in September and 41 service requests per day in October. Larvicide treatment was higher in the months of August (pre-Hurricane Irma) and October (post-Hurricane Irma), with 671 ha treated in August and 1,165.5 ha treated in October, as compared with the Hurricane Irma event month of September with 596.5 ha treated. Adulticide applications peaked in September, with 63,116.8 ha treated using ground ULV, thermal, and aerial methods. Once again, in 2017, our aerial contractor was delayed. This delay was caused by massive flooding throughout Florida, and the contractors were also still busy from flooding in Texas caused by Hurricane Harvey. After a delay of several days, the aerial contractor conducted the aerial adulticiding, assisting AMCD with control of the mosquito population outbreaks.

The AMCD aerial contractor used naled, which has been documented not to have a significant influence on humans in St. Johns County when used to adulticide by aerial application (Duprey et al. 2008).

The 2 hurricane events coupled with wet years and the Zika outbreaks in Florida (Grubaugh et al. 2017) increased public scrutiny of the District and taught AMCD some important lessons. The 3 most important lessons and supplemental changes that were made were:

1) The hurricane events resulted in a large volume of service request calls. The District received a lot of

Table 3. Mosquito adulticides used in the months of August, September, October, and November, for Hurricane Matthew, October 8, 2016, and Hurricane Irma, September 11, 2017.

Chemical used	Hurricane Matthew				Hurricane Irma			
	Times sprayed by truck	Times sprayed by backpack	Acres treated	Gallons used	Times sprayed by truck	Times sprayed by backpack	Acres treated	Gallons used
Aqualuer 20-20								
August	17	26	7,285	15	89	20	64,901	131
September	20	27	14,563	29	91	3	63,394	128
October	150	7	101,877	206	41	1	28,681	58
November	35	12	26,615	54	3	1	2,720	5
Duet								
August	0	62	2,498	16	23	91	3,697	45
September	0	50	507	3	33	88	3,233	40
October	0	77	7,102	46	31	63	2,099	26
November	0	22	585	4	13	40	1,162	14
Mosquitomist 2								
August	3	0	338	4	15	0	11,248	58
September	11	0	2,830	34	12	0	9,103	47
October	16	0	6,347	75	5	0	4,073	21
November	1	0	634	8	2	0	1,115	6

attention from the public voicing concerns, offering advice, and support. From this public input, the AMCD Board of Commissioners found the public wanted better notification of spray events and a smart phone-compatible service request program. The AMCD Board of Commissioners quickly authorized staff to contract for the development of a phone application. The phone application (app) would be capable of entering service requests, show the customer the status of their service requests, show pending fog missions, and the ability to send push notifications to AMCD app users. These notifications would contain important information, including upcoming major ground adulticiding or aerial spray mission, locations, and times, as well as public health notices. The app was approved in December 2017 and rolled out for public use in April 2018. The AMCD currently has more than 350 county residents using the phone application.

2) During the FEMA reimbursement process for Hurricane Matthew and Hurricane Irma, AMCD staff learned how important good data and a strong database are to be able to provide the required information. The amount of information is staggering and the person-hours needed to collect and collate the data are high. A small sample of the required data are: chemical data, 5–6 wk of trap data, contracts, request for proposals, insurance, invoices, copies of checks, maps, charts, vehicle and machine data, payroll records, DOH letter, and 3 years of baseline data for surveillance. The AMCD staff were able to collect and provide all the required data and received reimbursement after more than a year of waiting.

3) Due to delays with our aerial contractors after both Hurricane Matthew and Hurricane Irma and the sheer intensity of the work it took to try to control the outbreaks of mosquito populations with truck ULV, the Board decided that it was time to invest in a local aerial program and purchased a used Bell 206B helicopter that was surplus by Lee County Mosquito Control District in August 2018. The District also constructed a helicopter hangar as part of an ongoing building project and hired a full-time pilot in October 2018. With the county's population growth, the change in demographics to a more urban population, 2 years of unusual weather, and an increase in mosquito-borne disease, the District decided that changes to the AMCD program were necessary to continue to provide a high level of services demanded by the St. Johns County citizens. The District's current programs and capabilities will ensure improved service, technology, and perfor-

mance in emergencies and allow AMCD to be more proactive in the event of future large weather event.

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