Wing Beats

of the Florida Mosquito Control Association

Vol 26, No 4

An Official Publication of the AMCA THE AMERICAN MOSQUITO CONTROL ASSOCIATION

Winter 2015

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About the Cover: The Chatham County Mosquito Control's sentinel chicken program was established in the early 1980s to monitor eastern equine encephalitis activity and to test for other mosquito-borne viruses. Sentinels are deployed once a week. Individual birds are deployed overnight in a cage elevated several feet into the lower tree canopy. *Photo by **David Oien**, Entomology Technician, Chatham County Mosquito Control, Savannah, GA.*

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Wing Beats is published quarterly by the Florida Mosquito Control Association. This magazine is intended to keep all interested parties informed on matters as they relate to mosquito control.

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Correspondence: Address all correspondence regarding *Wing Beats* to the Editor-in-Chief, Stephen Sickerman, 200 Derby Woods Drive, Lynn Haven, FL 32444-3318. Readers are invited to submit articles related to mosquito and biting fly biology and control. There is no charge if your article is printed, and authors will receive a PDF of their published article. Authors, photographers and artists are invited to submit high quality original artwork in electronic format for possible use in the magazine or on the cover; $100 will be paid for each cover photo. Businesses are invited to place advertisements through the Director of Advertising.

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Hail from the Editor-in-Chief *by Stephen Sickerman*

No doubt even the most casual reader will notice after a 2 year hiatus, the American Mosquito Control Association logo has returned to the cover of *Wing Beats* magazine – and once again the AMCA contact information appears on our Table of Contents page.

We are pleased to report that an agreement between AMCA and the Florida Mosquito Control Association was reached this Fall, and a Memo of Understanding involving *Wing Beats* was approved by both associations – thanks to the good-faith efforts of AMCA Presidents Steve Mulligan and Kenneth Linthicum and the AMCA Board of Directors, and FMCA Presidents Neil Wilkinson and Sue Bartlett and the FMCA Board of Directors.

Speaking of the AMCA, the 2016 Annual Meeting will be held in Savannah, Georgia, and this issue includes no less than four manuscripts from the Peach State: *A Brief History of Mosquito-Borne Disease in Georgia* by Mark Blackmore; *The Need for Better Multi-Agency Cooperation is Now* by Rosmarie Kelly, Robert Seamans, Joey Bland and Chris Rustin; *Special Projects: You Don't Have to be Big to be Special* by Rosmarie Kelly, Fred Koehle, Randy Wishard and Chris Rustin; and *Chatham County Mosquito Control Update* by Robert Moulis, Laura Peaty, La Drann Goodwin, Jeffrey Heusel and Henry Lewandowski, Jr.

In early 2015, Steve Mulligan, then the AMCA Immediate Past President, was approached by the *Wing Beats* Editorial Desk to request an article for the 100th anniversary of organized mosquito control in the State of California.

Some months later, a much anticipated manuscript was received from Dr Joseph Wakoli Wekesa: "*A Century of Mosquito Control in California: 1915 - 2015.*" The author prefaced his submitted paper with this introduction:

"At the 2015 spring meeting of the Mosquito and Vector Control Association of California (MVCAC) in Modesto, California, our representative to the AMCA Elizabeth Cline asked for a volunteer to write an article marking the 100 year anniversary of mosquito control in California.

"The article, she said would be published in the AMCA's Wing Beats magazine. I mistakenly volunteered to write this article because I did not understand the depth of the record until I settled into the project. There were copious documents and records of work from mosquito control people in California since the pioneer efforts of 1903 in San Rafael. A century of professional mosquito control is extensive, but for a person like myself, born and raised abroad, it was daunting. Nevertheless, this experience has been incredibly rewarding.

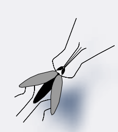
"I was able to delve into details of mosquito control in California for the past 100 years far beyond what I would have ever imagined. I have gained a great background in understanding the scientific, social, and sometimes political underpinnings of events past that shaped mosquito control in the state and beyond. Now, I appreciate even more the many personalities who toiled to make California a safe place for its residents and visitors, alike.

I hope my 25 years of residence in California has given me some legitimate clout to effectively discuss some of the major events, developments, and personalities that shaped the course of mosquito control in California over the past 100 years. I would like to present this history in four parts: the nascent period of mosquito control (1903-1940), the glory years (1940-1970), the greening of mosquito control products (1970--2000), and current and future challenges for mosquito control in California (2000 - present)."

Dr Wekesa's manuscript spans a century and we are pleased to present his historical account in its entirety.

We are also pleased to announce that Barbara Bayer, Entomologist at the Manatee County Mosquito Control District, has joined the *Wing Beats* Editorial Desk as our new Circulation Editor. Welcome aboard, Barbie!

We at the *Wing Beats* Editorial Desk are always looking for original articles, photographic essays, and operational notes to grace our pages and inform our readers. We understand the need - or desire - to publish in a refereed journal, and encourage you to submit your paper to JAMCA, the Journal of the American Mosquito Control Association – or to other professional vector or entomological association publications, including those of your local mosquito control associations. However, if you want to see your article presented in a full-color trade publication, then please consider contributing to *Wing Beats.* We're the official publication of not one, but two mosquito control associations – and we'd like to share what you've learned about mosquitoes and mosquito control.



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13th Arbovirus Surveillance and Mosquito Control Workshop

The 13th Arbovirus Surveillance and Mosquito Control Workshop will be held at Anastasia Mosquito Control District, March 29-31, 2016. The Workshop will be held at their new facility, located at 120 EOC Drive, St Augustine, FL 32092. For more information, please visit the AMCD website at www.amcdsjc.org or contact Director Rudy Xue via e-mail at xueamcd@gmail.com.

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A Brief History of Mosquito-Borne Disease in Georgia

by Mark Blackmore

Mosquito-borne diseases in the United States have varied historically with regard to their occurrence, prevalence, geographic distribution, and societal impact. Two in particular, malaria and yellow fever, were once common and widespread in the US, especially in the southeastern states. Agricultural development and settlement patterns were major determinants in the introduction and establishment of endemic malaria. Yellow fever outbreaks were episodic and related to urban sanitary practices and international trade. Both diseases profoundly affected health and economic development in the South throughout the 19th century and became important factors affecting both sides in the Civil War. The history of malaria and yellow fever in the state of Georgia illustrates how environmental changes and human activities can have epidemiological consequences and may provide insights into the potential for future outbreaks of these and other mosquito-borne diseases.

Anthropological and archeological data provide no indication of mosquito-borne diseases among the indigenous people of North America prior to contact with Europeans and Africans beginning in the fifteenth century. Early records of Spanish and English explorers describe the continent as an idyllic place free of the bad air and miasmas that afflicted many parts of the Old World. Arguably, some of this may have been hyperbole intended to lure further investment in trade and settlement of the new land, but contradictory evidence is lacking to dispute such claims.

Neither malaria nor yellow fever was present in North America prior to European and African colonization, but both were well established by the time Georgia was chartered. Malaria had been repeatedly introduced from endemic regions of Europe and Africa beginning with early Spanish explorers and the establishment of the "Columbian Exchange." *Plasmodium vivax* arrived in Virginia with English immigrants from malarious areas in England and *P falciparum* was introduced from West Africa via the slave trade. Native mosquito species, particularly *Anopheles quadrimaculatus* (*sensu lato*), proved to be competent vectors of the parasites, when they fed on immigrants who were infective hosts.

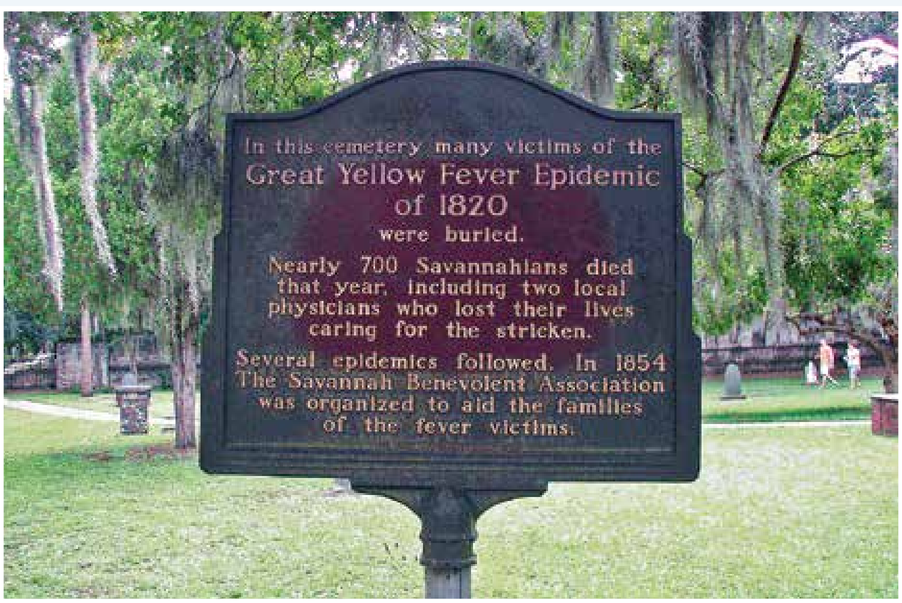

Figure 1: Marker at Colonial Park Cemetery in Savannah, GA marking the Great Yellow Fever Epidemic of 1820; courtesy of http://lat34north.com.

Georgia was the last of the 13 British colonies established along the Eastern seaboard, and differed from other colonies in ways that affected the eventual emergence of malaria and yellow fever. For one thing, Georgia was definitely a *southern* colony. Its northern border was set roughly at the 35th parallel, which meant that the more severe form of malaria, *P falciparum*, would be able to overwinter in many parts of Georgia. Relatively mild winters, particularly in the coastal plain, allowed vector populations to overwinter, and even feed year-round.

Rather than being primarily a commercial enterprise, the royal charter given to James Oglethorpe and his Board of Trustees in 1732 was intended to be a social experiment aimed at creating an outlet for England's suffering poor. The charter also expressly prohibited slavery. However, the envisioned charitable colony was never realized, and the colony failed to become self-sustaining or prosper, like neighboring colonies in the Carolinas and Virginia. Despite insistent demands by the colonists, and by planters from South Carolina, Oglethorpe and the Trustees steadfastly maintained the ban on slavery in Georgia, even though it impeded agricultural development. The end of the "Trustee Georgia" era, and removal of the legal prohibitions on slavery in 1751 drastically changed this pattern.

Rice plantations were established along the coast, initially using slaves from plantations in the Carolinas. This, plus the importation of over 18,000

West Africans over the next decade, introduced malaria to Georgia where it became, and remained, endemic for the next 150 years. The cultivation of rice on the Sea Islands of Georgia used techniques developed along the Windward Coast of Africa, principally Sierra Leone, Angola and the Gambia, from which slaves were captured. Conditions on these plantations were brutal, particularly during the summer months. Large numbers of laborers toiled on coastal plantations, with little protection from mosquitoes and other biting flies. Clear cutting in the flood plain, ditching and impoundment of fresh water for rice production, created ideal habitats for *Anopheles* mosquitoes; the workers supplied plasmodia.

Plantation owners and their families removed to summer quarters inland, to escape the malarial threat. Overseers, who regarded the rice fields as full of pestilence, spent as little time as possible on the islands. This, and the system of task labor used on the rice plantations, meant that there was less supervision of the rice slaves than occurred on other plantations, such as cotton and tobacco. As a result, slaves on coastal rice plantations developed a unique culture called “Gullah,” that blended the languages, cuisine and crafts of their homelands in Africa and preserved their native heritage to a far greater extent than elsewhere. Even after Emancipation, these coastal populations remained isolated due to the continuing perception that these regions were hotbeds of disease. Today, the “Geechee” culture lives on in Georgia among the descendants of these rice workers.

Although rice remained an important crop in Georgia until the 1860s, malaria made new in-roads into the interior of the state with the ascendancy of cotton production. Oglethorpe’s alliances with the Creek Indians limited colonial settlement away from coastal and riverine areas during the Trustee Georgia era. Even during the late Colonial and early post-revolutionary war era, expansion inland was limited, and most farmsteads were small and scattered. The forced removal of the Creek Indians, and later the Cherokees, from western lands in Georgia, opened the way for more white settlers to emigrate from the coast. Eli Whitney’s cotton gin rapidly accelerated the westward movement, as short-staple, green-seed cotton became a major crop. Large inland cotton plantations soon became a dominant factor in Georgia’s state economy. Clear-cutting of pine forests, to make way for cotton fields, once again increased *An quadrimaculatus* habitat, and greatly extended the geographic range of malaria in Georgia in the mid-1800s.

Malaria was regarded as a frontier disease in America during the nineteenth century, which would have described most of rural Georgia and the antebellum South at that time. The use of quinine as a preventative and treatment for malarial fevers began in the 1830s and revolutionized treatment of the disease, although it did not eliminate it. In fact, the presence of endemic malaria in in the South became a key factor in the American Civil War (1861-1865).

Malaria - and the ability to treat malarial fevers - affected military planning and operations for both sides during the war. Troops enlisted from different geographic regions varied widely in terms of prior exposure to the disease and the two parasite species. *Plasmodium vivax* had largely disappeared in the North due to sanitary improvements and development that reduced *Anopheles* larval habitats. Because the 35th parallel, which forms the northern border of Georgia, also coincides with the northern limit of *P falciparum*, fewer soldiers had been exposed to this parasite. Federal armies were comprised largely of soldiers with little or no prior exposure to malaria, or at least not this serious variety of the disease. Northern generals were rightly concerned that their troops would be at a disadvantage when fighting in the Deep South. From 1861 to 1866 malaria was the second most commonly diagnosed ailment – diarrhea/dysentery was first – among Union troops, with over 1.3 million cases. Although soldiers native to the South were much more likely to have experienced malaria growing up, they also suffered deaths and incapacitation that affected the timing and outcome of battles.

A major difference between the two sides was the availability of effective medicine to treat acute infections. Because quinine had to be imported or prepared from imported cinchona bark, the Union naval blockade led to severe shortages among soldiers and civilians in the Confederate States. Realizing the importance of this, Confederate Surgeon General Samuel Preston Moore ordered systematic evaluation of indigenous plant products as potential quinine substitutes. Extracts of dogwood, tulip poplar and willow barks were among the botanical remedies tried. Even the most effective treatment, Georgia bark from the "fever tree" *Pinckneya pubens* proved inferior to cinchona (Hasegawa 2007). Morbidity and mortality among southern troops probably helped Sherman capture Atlanta, and the lack of quinine also led to suffering and lowered morale among the civilian population in the South.

In the latter half of the nineteenth century, malaria became a background disease in Georgia, affecting mostly lower income, rural populations. It seemed to occur in mysterious cycles in which low periods were followed by dramatic resurgences in cases. Chronic infections among the poor have been attributed as an underlying impediment to economic development in the post-war South. The discoveries of the parasites in 1880 by Laveran, and the role of *Anopheles* mosquitoes as vectors by Ross in 1897, inspired sanitation and drainage efforts which may have weakened the hold of malaria in Georgia. Migration from rural to urban centers, screening doors and windows

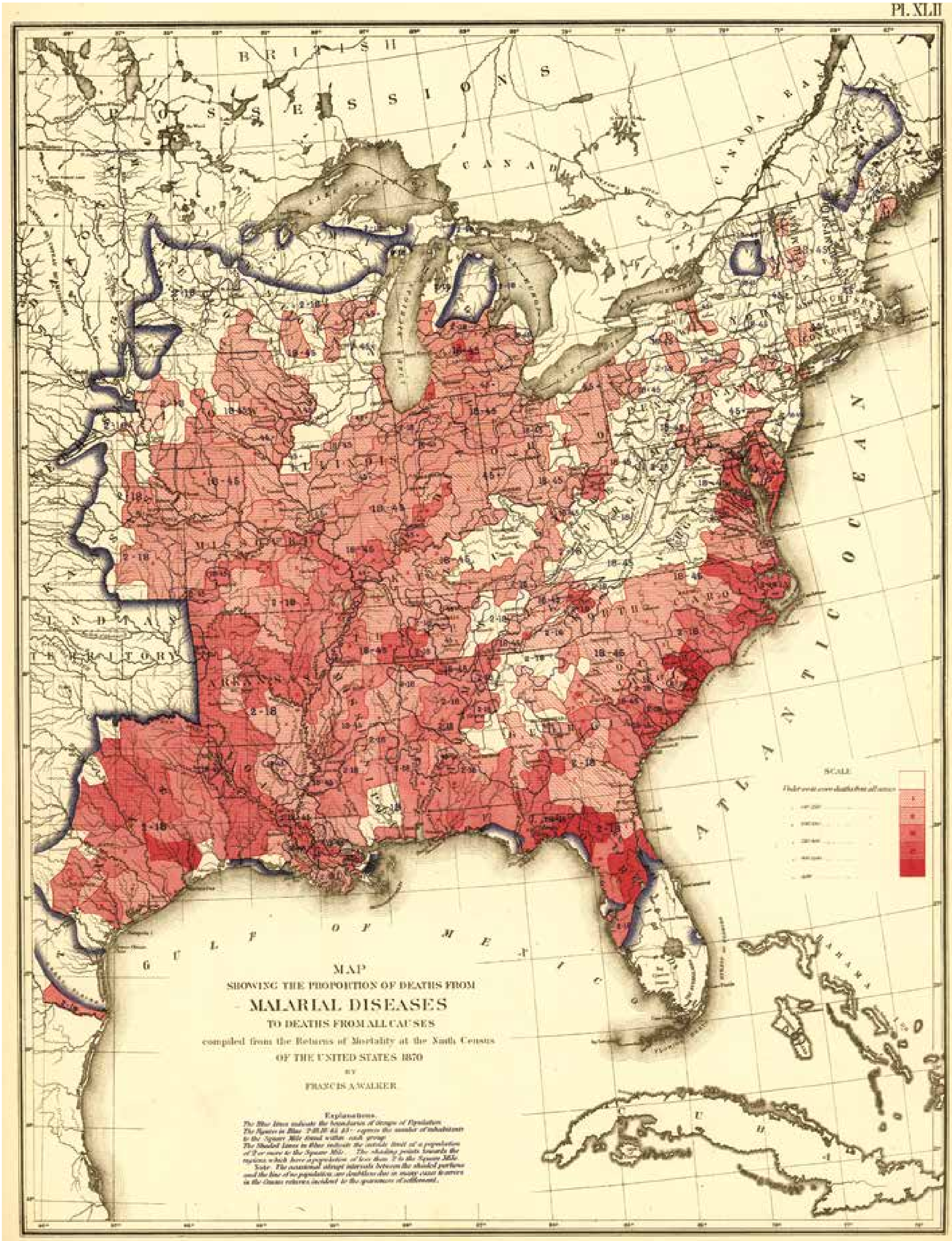

Figure 2: Malarial mortality map of the United States 1870 (US Census Office 9th census, 1870).

Figure 3: The South Atlantic Quarantine Wharf at Blackbeard Island, near Savannah, GA, where ships coming into the area to pick up lumber and timber were required to be inspected and disinfected for yellow fever (US Public Health Service 1896).

to exclude mosquitoes, and cultural shifts associated with rural electrification, mass media, and air conditioning have also been argued to be factors in breaking the transmission cycle. New therapeutic drugs and insecticides such as DDT probably put the final nails in the coffin of malaria in Georgia.

Yellow fever in Georgia provides a very different example of how a mysterious, and often deadly, disease can disrupt society, even when outbreaks are sporadic. The principal vector in America is an introduced container mosquito species, *Aedes aegypti*. Unlike *An quadrimaculatus*, *Ae aegypti* was not present in the New World before trans-Atlantic trade began. It was introduced through seaports and spread with immigrants as they moved inland. In North America there is no sylvatic primate cycle, so epidemics flare up suddenly when the virus is introduced by a viremic host, and then die out as the population either succumbs or develops immunity. Transmission is favored in densely populated urban centers frequented by infective visitors from epidemic or endemic locations. The cities of Savannah, Augusta and Brunswick were the only places in Georgia that fit this description during the first century of European/African settlement. Again, the institution of slavery and the ascendancy of cotton as a major crop played parts in the epidemics of yellow fever that struck Georgia in the nineteenth century.

Four major yellow fever epidemics occurred in Savannah between 1820 and 1876. The first of these, in 1820, killed 666 people out of a population of barely 7500 (about 9%). Outbreaks in 1854, 1858 and 1876 resulted in 1040, 114, and 896 deaths, respectively. The 1876 epidemic struck Darien, Brunswick and Augusta at the same time, and also spread inland to Macon and Atlanta as panicked Savannah residents fled on major rail lines, taking the virus with them. These outbreaks occurred before Koch and Pasteur proposed the germ theory of disease, so there was debate about whether the sickness derived from miasmas emanating from unhealthful environments or resulted from contagion introduced through trade with contaminated ships. US Army surgeon Major Ely McClellan headed an investigation into the simultaneous 1876 outbreaks in an attempt to answer the question. He concluded that yellow fever was most severe in ports, occurred shortly after ships arrived from Havana, Cuba and always started at the waterfront and radiated out from there. He suspected that ballast taken on in Cuba and offloaded in the port of arrival might have been the source. He noted that the inland cities to which the disease spread had much lower incidences of the fever, were all located on major rail lines and had received "refugees" from the coast. Based on his recommendations the US Marine Hospital Service established a quarantine station on Blackbeard Island that included a hospital as well as a cemetery and crematorium. The work of Carlos Finlay and the Reed Commission, demonstrating that *Ae aegypti* was the vector of yellow fever virus, helped stamp out transmission in ports like Havana, thus cutting off reintroduction of the virus in the US. The 1876 epidemic was the last in Georgia and the hospital at the quarantine station was never used. Today, Blackbeard Island is a national wildlife refuge and visitor center.

Today widespread mosquito-borne diseases are rare in Georgia. Epizootic transmission of arboviruses, such as eastern equine encephalitis, St Louis encephalitis and West Nile virus, occurs intermittently, but human deaths are rare. The establishment of *Ae albopictus* in the 1990s, and the

Figure 4: Melvin H Goodwin, assistant director (*left*), Emory University Field Station, established at Ichauway, GA in 1939 as a malaria research center; courtesy of Manuscript, Archives and Rare Book Library, Emory University.

emergence of WNV in Georgia in 2001, demonstrate that new vectors and pathogens can be introduced as easily today as they were 300 years ago. The factors that allowed *Ae aegypti*, yellow fever virus and malaria to become established in Georgia three centuries ago are relevant to diseases in the 21st century. Habitat disturbances can create opportunities for existing vectors to spread or come in contact with pathogens. Introduced pathogens can emerge when competent vectors are in place.

Speculation that climate change – and its resulting effects on temperature, precipitation and soils – may increase the likelihood of the emergence of such mosquito-borne diseases as dengue, chikungunya or malaria, should consider all aspects of disease ecology. The vectors of malaria are still present in Georgia, but the human population is now concentrated in urban centers, and their exposure to mosquitoes is greatly reduced by modern activities. Dengue and yellow fever viruses frequently come into Atlanta, but *Ae aegypti* has disappeared from most of the state, and the feeding preferences of *Ae albopictus* make it a poor alternative vector. During most of the period in which malaria and yellow fever afflicted Georgia, the concepts of germ theory, cell theory and ecology, that are taken for granted today, were completely unknown. Hopefully, the Civil War era description of Georgia as a "malarial pesthole" is a part of history that modern biology, medicine and mosquito control will keep from being repeated.

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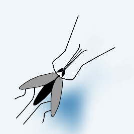

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The Need for Better Multi-Agency Cooperation is Now

by Rosmarie Kelly, Robert Seamans, Joey Bland and Chris Rustin

In 2011, the US Centers for Disease Control and Prevention (CDC) and the Pan American Health Organization (PAHO) jointly released a document entitled "Preparedness and Response for Chikungunya Virus: Introduction in the Americas" (PAHO 2011). In late 2013, chikungunya was found for the first time on islands in the Caribbean, where it has persisted and continued to spread.

Chikungunya fever is an emerging, mosquito-borne disease caused by the chikungunya virus (CHIKV). It is transmitted predominantly by *Aedes aegypti* and *Ae albopictus*, the same species involved in the transmission of dengue. Chikungunya is an RNA virus that belongs to the genus *Alphavirus* in the family Togaviridae. The name "chikungunya" derives from a word in Makonde, which roughly means "that which bends," describing the stooped appearance of persons suffering with the characteristic painful arthralgia.

Epidemics of fever, rash, and arthritis – resembling symptoms caused by CHIKV – were reported as early as the 1770s. However, the virus was not isolated from human serum and mosquitoes until an epidemic in Tanzania in 1952–1953. Subsequent outbreaks occurred in Africa and Asia, many of them affecting small or rural communities (CDC 2015).

In Asia in the 1960s, CHIKV strains were isolated during large urban outbreaks in Bangkok, Thailand. Large outbreaks also occurred in Calcutta and Vellore, India, during the 1960s and 1970s. Sporadic outbreaks continued to occur after the initial identification of CHIKV, but little activity was reported after the mid-1980s. In 2004, however, an outbreak originating on the coast of Kenya subsequently spread to Comoros, Réunion Island, and several other Indian Ocean islands in the following two years, resulting in an estimated 500,000 cases (Powers 2009).

The CHIKV epidemics have since crossed international borders and seas, and the virus has been introduced into at least 19 countries by travelers returning from affected areas. Because the virus had been introduced into geographic locations where the appropriate vectors are endemic, it was thought likely that the disease would likely establish itself in new areas of Europe and the Americas. In 2007, chikungunya transmission was reported for the first time in Europe, and in late 2013, CHIKV was found for the first time in the Americas, on islands in the Caribbean (Leparc-Goffart *et al* 2014). Since then, local transmission has been identified in 45 countries or territories throughout the Americas, with more than 1.7 million suspected cases reported to PAHO from affected areas (CDC 2015).

What about Georgia? There certainly is a risk of CHIKV introduction and subsequent spread; there is no immunity, and appropriate vectors and hosts exist here. McTighe and Vaidyanathan (2012) tested the vector competency of Virginia and Georgia strains of *Ae albopictus* for CHIKV and determined that they were all highly competent vectors of this virus. In their conclusions, the authors stated, "Only early and specific detection of human cases coordinated with vector control can reduce the risk of local transmission of CHIKV in the US."

In 2014, the Georgia Department of Public Health created an in-house guidance document for managing travel-related cases of CHIKV in Georgia, with the goal of reducing the risk for local transmission. The document included a request to share information with local vector control agencies as appropriate, procedures on how to conduct surveillance to determine the presence of *Ae albopictus* and/or *Ae aegypti* populations, and control strategies for mosquito control as soon as possible.

Aedes aegypti was the focus of an eradication program that began in 1964. However, the arrival of *Ae albopictus* has been correlated with the decline in the widespread abundance and distribution of the *Ae aegypti*. There are a number of possible explanations for this competitive exclusion (Kaplan *et al* 2010), and the decline is likely due to a combination of: a) sterility of offspring from interspecific matings (Harper and Paulson 1994); b) reduced fitness of *Ae aegypti* from parasites brought in with *Ae albopictus* and; c) superiority of *Ae albopictus* in larval resource competition. Several authors reported the reduction of the yellow fever mosquito, beginning in 1989. By 1994, *Ae albopictus* was found in every county in Georgia. When systematic mosquito surveillance for WNV began in 2002, *Ae aegypti* was no longer found in most of Georgia. In 2005, two *Ae aegypti* were collected at one site in Columbus, GA. One specimen was collected from a gravid trap and the other from a light trap. In 2006, two *Ae aegypti* were found in Columbus and one in Chatham County. No other specimens were collected until 2011, when the apparent source of the Columbus *Ae aegypti* was found. The site looks no different than many other sites, but both *Ae aegypti* and *Ae albopictus* are consistently found there in high numbers.

On July 15, 2014 the State public health entomologist received a call from the Public Works Superintendent of Streets and Parks in a small Georgia town. A resident had been hospitalized with an unknown illness. Doctors suspected an arboviral disease. The resident had a high fever (105°), joint pain, nausea and vomiting, a low white blood cell count, and abnormal liver enzymes and platelet counts, symptoms consistent with CHIKV. The onset of illness had been July 4; there was no travel history. Two travel-associated CHIKV cases had previously been reported in this town – one in May and one in June – in residents who lived in the same general area, one within 0.25 mile of the unknown fever case. *Aedes albopictus*, a competent vector, was common in the town. The case symptoms were compatible with CHIKV. The timing worked. This illness could have been locally-acquired CHIKV.

Figure 1: One of many *Aedes albopictus* oviposition sites in Georgia cities.

Aside from the fact that chikungunya is potentially poised to be imported to new areas by infected travelers, why is this story of interest? First, there was a lag in notification about the potential CHIKV cases both to and from the state health department. The health department is often not notified about cases until well after the infected person could have been fed upon and infected local mosquitoes. Added to that, there was a HUGE lag time in testing for CHIKV, so even when a case is suspected, it can take months for the case to be confirmed. Of more import, the local mosquito control program was never notified of the travel-associated cases, so they were unaware of the potential problem. Because delays in testing and reporting increase the probability of local mosquitoes becoming infected, it is important for mosquito control to be involved as quickly as possible.

Florida is the only state in the US to have reported autochthonous cases of CHIKV. In 2014, the Florida Department of Health reported 12 cases of locally-acquired CHIK from four counties in South Florida, including 2 cases in Miami-Dade, 4 in Palm Beach, 4 in St Lucie, and 1 in Broward County. Surveillance related to local transmission of the virus was conducted in 50 to 100 meter clusters around a patient's residence and included enhanced syndromic surveillance and medical record review. Based on findings in 2015, none of the virus introductions appears to have resulted in ongoing transmission or spread of the virus.

Once notified of the unknown fever case, the Health District assigned an epidemiologist to facilitate testing, although it was eventually determined that the cause of the unknown fever was not CHIKV. The event proved to be a useful exercise for mosquito control officials, pointing out some very large gaps in Georgia's response to CHIKV. The local mosquito control program, a small complaint-driven operation located within the town's public works agency, reached out to build working relationships with other local mosquito control programs. After contacting the State public health entomologist, they did a walk-through of the site to evaluate the potential for the presence of *Aedes albopictus* and *Ae aegypti* in the area. They contacted their mosquito control products vendor and borrowed a second Ultra Low Volume (ULV) sprayer. They worked with a larger program to conduct surveillance at and around the site, using BG-Sentinel traps and focused their control efforts based on the location of the CHIKV cases and the data they collected. They discussed the possibility of testing mosquitoes for CHIKV if the resident was diagnosed with chikungunya. They looked into the possibility of buying or borrowing a thermal fogger. They also discussed the possibility of conducting aerial treatments if CHIKV was found to be transmitted locally.

Mosquito control officials maintained how information would be released to the public. There was no "media circus." They informed key officials – the city manager and the local hospital administrator – who then relayed the information to the local healthcare community. Overall, with the exception of the initial information sharing gaps, the response of the town to a possible locally-acquired CHIKV case was appropriate and timely, based on notification to mosquito control.

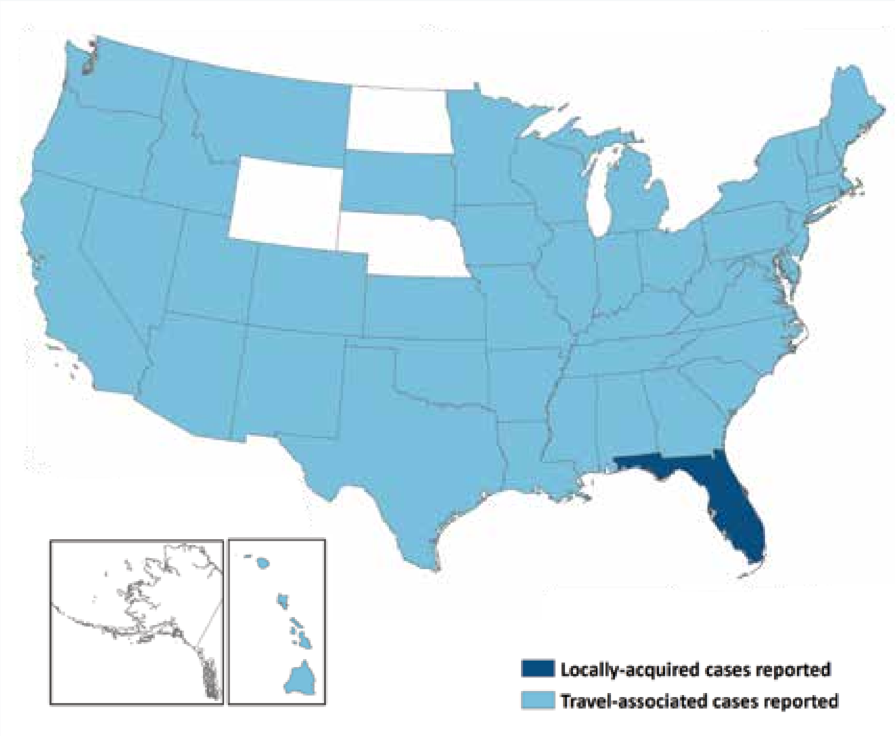

Figure 2: States reporting Chikungunya virus disease cases, US 2014.
Source: http://www.cdc.gov/chikungunya/pdfs/2014map-final.pdf

Communication within and between agencies is vital to the process of dealwith mosquito-related issues. In an emergency, it is important that someone at the Health District level have an understanding of mosquitoes and mosquito control-related issues.

Health departments and mosquito control programs are essential components of public health, each agency committed to protecting the health of Georgia's citizens. It is important that both maintain continuous working relationships at the local level to effectively deal with the threat from vector-borne disease.

ACKNOWLEDGMENTS

The authors would like to thank the Chatham County Mosquito Control Program and ADAPCO, Inc for all their assistance in dealing with this issue.

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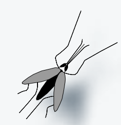

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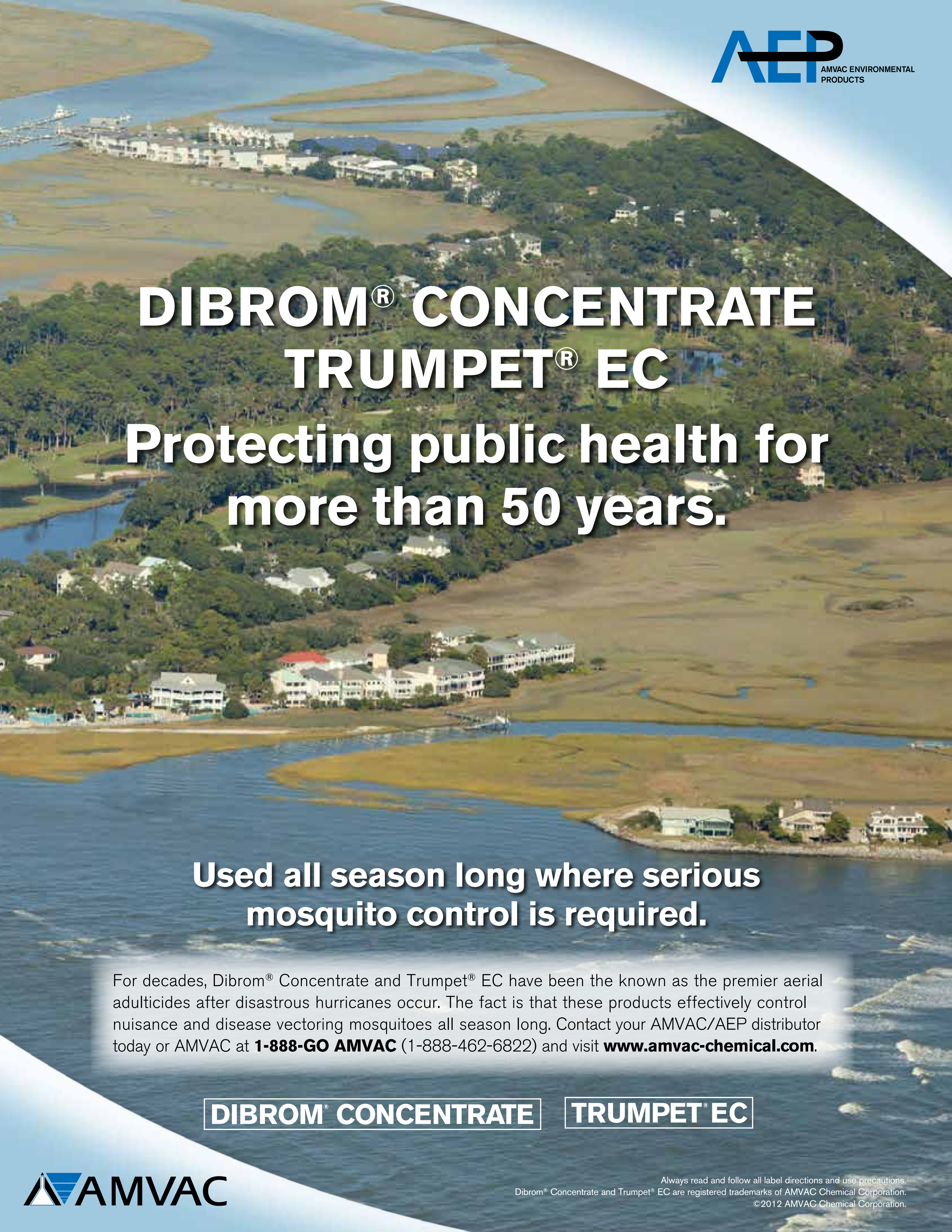
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Special Projects: You Don't Have to be Big to be Special

by Rosmarie Kelly, Fred Koehle, Randy Wishard and Chris Rustin

Richmond County is located in the Savannah River basin, on the border of Georgia and South Carolina, about 150 miles (240 km) east of Atlanta and 70 miles (110 km) west of Columbia. According to the US Census Bureau, the county has a total area of 329 square miles, 324 of which is land and 4.3 (1.3%) is water. Augusta is the principal city of the Augusta-Richmond County Metropolitan Statistical Area, which as of 2012 had an estimated population of 580,270, making it the third-largest city and the second-largest metro area in the state after Atlanta. Augusta is located about halfway up the Savannah River on the fall line, which creates a number of small falls on the river. The city marks the end of a navigable waterway for the river and the entry to the Georgia Piedmont area.

The Richmond County Mosquito Control (RCMC) program is part of the Health Department's Environmental Health Section. Special Projects was developed as a means of dealing with some specific issues causing mosquito problems in the county.

POOL REMEDIATION PROGRAM

The swimming pool remediation program was born out of necessity in May 2008, when RCMC first began receiving complaints of neglected pools throughout the county. This was taken seriously, as neglected pools are potential oviposition sites for mosquitoes that carry West Nile virus (AMCA 2009). Upon investigation RCMC found that the largest group of pools were from occupied homes. In response, the pool program was set up to give property owners a chance to fix or fill in the pool, but does impose penalties if no action is taken.

The program was developed using a system of checks and balances and was based on existing local ordinance, adopted on 1 July 1976. This ordinance, the Richmond County Environmental Health Mosquito and Rodent Control Health Ordinance HO 76-13, states that "no person, firm, corporation, municipality, institution, or public body shall cause, maintain, or permit any collection of standing or flowing water in which mosquitoes breed or are likely to breed." Local municipal judges were asked for their input as the program was developed. Their suggestions were incorporated into the final program.

The following procedure is followed when answering mosquito complaints: 1) receive the complaint by phone or by observation; 2) log the complaint in the computer; and 3) print the Pool Remediation Program checklist.

The Special Projects Manager conducts an on-site inspection of the property and completes the Pool Mitigation Program checklist, which includes a list of mosquito habitats found on the property. If possible, the property owner is involved in the inspection. A copy of the inspection report and a letter of recommendations is sent to the property owner. The letter includes the specific code violations.

If the pool cannot be inspected, the Special Projects Manager sends a letter to the owner giving them 10 days to make an appointment to have the pool inspected. If the owner doesn't respond, a second letter is sent, setting a date and time about 15 days out. If the owner still doesn't show up for the appointment, the Marshal's office will be notified and a citation is issued.

Figure 1: Abandoned pools that require remediation are photographed to document code violations.

After the property is inspected, the owner is given 30 days to complete the the recommended improvements. In a case of dire hardship an extension can be given, not to exceed a total of 60 days. At 30 days, another inspection is conducted to see what progress has been made. If the problem has been eliminated, the property owner is sent a thank you letter and a copy of the inspection report. If the conditions aren't met, the property owner is sent notice that another inspection will be conducted in 15 days, and if the conditions again aren't met, the case is turned over to the Marshal's Office for Citation for violating the Health Ordinance.

Photographs are routinely taken at each visit, as the judges like to see what is described in the report. Photos are also important because the property owner always has a different version of the problem than mosquito control officials. Subsequently, if property owners are taken to court, the judge may reach his decision based on the photos, as well as on testimony.

Sentences can range to up to 30 days incarceration and/or $1,000 fine, since violations are a misdemeanor. Sometimes the judge may include up to 60 days probation and community service. The judge is also willing to work with the person just to get the problem solved. Most people will comply if treated fairly. However, it is important to schedule follow-up visits.

Figure 2: Mosquitofish decreased mosquito production in abandoned pools.

MOSQUITOFISH PROGRAM

There were some homes in foreclosure, making it impossible to locate the owner; if an out-of-town mortgage company owned the property, they usually just ignored the letters. The mosquitofish program is a new tool for RCMC, implemented as a means of reducing the cost of maintaining these pools. In 2014 about 30 mosquitofish were introduced into each of 4 selected pools in the county. The pools were rechecked after 2 weeks. In every case, the fish had survived and were reproducing, and preliminary surveillance data showed a decrease in numbers of mosquitoes being caught in traps set in the vicinity of the pools. The introduction of fish to these pools saved substantial time, chemicals and manpower that could be used for other purposes. If a technician is in the area he will stop and check on the condition of the fish. As of present, we have found no problems with the fish surviving.

RETENTION/DETENTION POND GOAT PROGRAM

Richmond County began acquiring goats in 2014 for a trial program to see if they were able to help with reducing vegetation in the county's 850 retention and detention ponds. A large part of the county is rural and there are numerous retention ponds because of new residential development. These ponds are fenced in, making it difficult for crews to get into the area to manage the vegetation, which provides

Date	4/17 2013	8/31 2014	9/31 2014	11/12 2014	2/10 2015	5/12 2015	5/27 2015	6/30 2015	7/31 2015	8/31 2015	9/30 2015	11/9 2015
Pools in Program	171	224	237	241	289	310	317	320	339	342	349	357
Pools Filled or Working	119	175	194	204	246	260	265	272	281	286	299	305
Pools Processing	43	32	28	21	27	33	35	29	34	34	30	32
Pools in Court	4	6	3	3	0	0	0	2	6	4	0	0
Constant Maintenance	5	6	0	0	0	0	0	0	0	0	0	0
Pools with Mosquito Fish	0	5	12	13	16	17	17	18	18	18	20	20

Table 1: Summary of Richmond County Mosquito Control's successful Pool Remediation Program.

Figure 3: Mosquitofish are transferred into an abandoned pool.

harborage for mosquitoes. Heavy vegetation also makes it difficult to see and treat the water.

The program began with 12 goats. They were put into retention pond areas and data recorded to determine how successful they were at keeping the vegetation trimmed back. The herd was increased to about 14 goats, which were rotated through 7 detention pond areas. The goats did extremely well and adapted to their new environment quickly. They were also well accepted by the neighborhood residents, and people began coming around to see what was going on. Kids especially liked the goats and soon everyone was watching out for them.

To ensure the safety of the goats, fence inspections for the ponds have had to be revised to insure that predators don't get inside the enclosure, as well making sure the goats could not get out. There has also been some discussion about getting a donkey as a "security guard" for the goats. Financially the goat program has been a success, as with all costs considered it has saved the county over $21,000 for one year, by replacing the human work crew required to maintain the 7 detention pond areas in the trial program.

Richmond County Mosquito Control is a small county-based program serving a substantial metropolitan area. In 2015, RCMC responded to 2659 individual complaints. In 2014, they responded to 2122 complaints. The average for the 3 years prior to 2014 was 975 complaints each year. RCMC has worked to make itself visible and responsive to the residents and their mosquito control issues. In order to make the best use of their resources, it has been important to "work smart." This is the motivation behind the Special Projects program.

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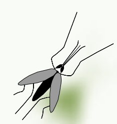

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Figure 4: Goats are used to manage vegetation around retention ponds.

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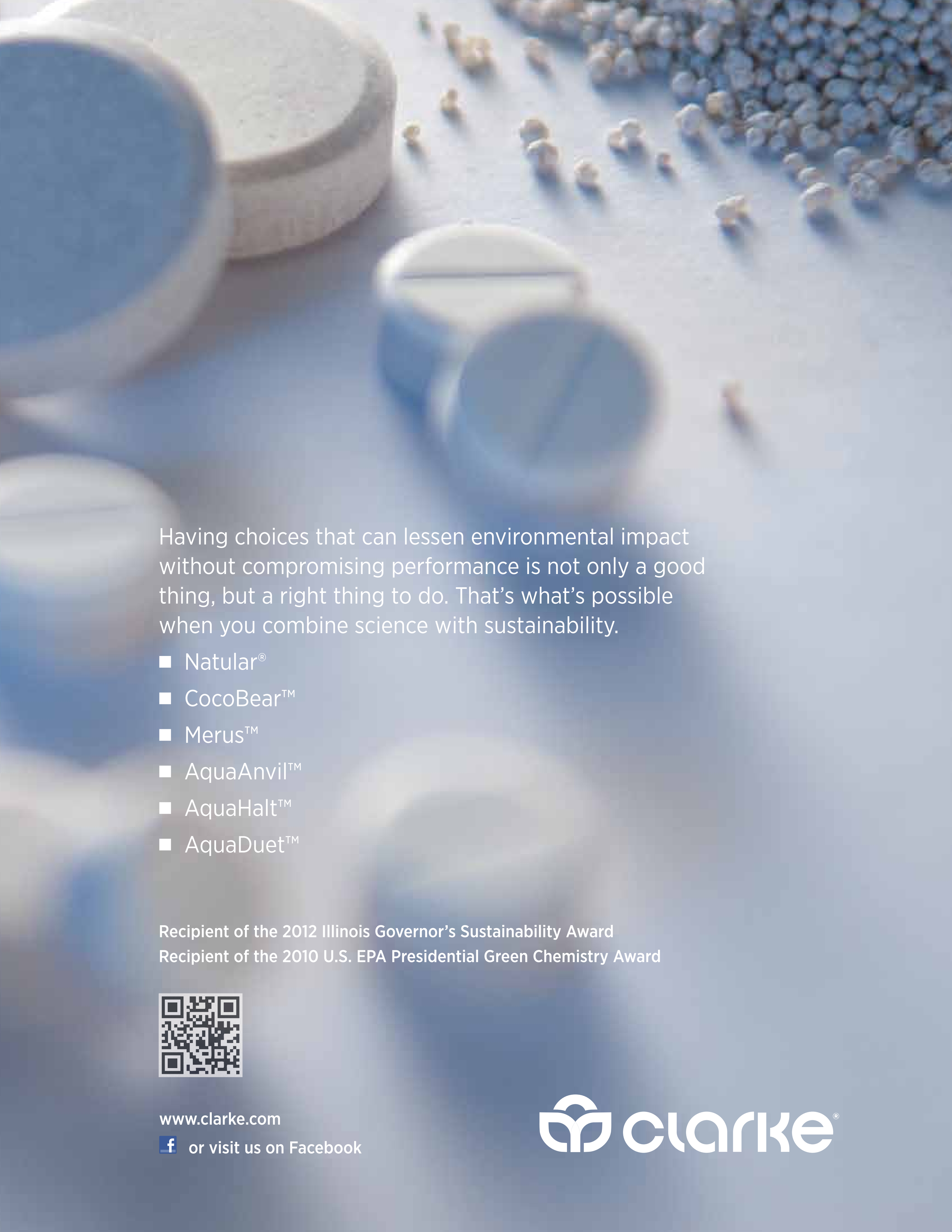
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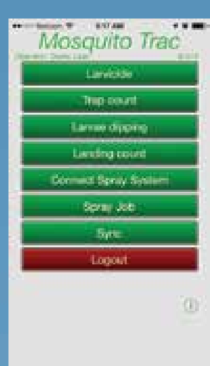

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Chatham County Mosquito Control Update

by Robert A Moulis, Laura FAW Peaty, La Drann Goodwin, Jeffrey L Heusel and Henry B Lewandowski, Jr

There are a few important changes that have taken place over the last several years since our last overview of Chatham County Mosquito Control (CCMC) in *Wing Beats* magazine (Lewandowski and Moulis 2008*a*). Modifications to our program are nothing new, as several changes were made from 2001 through 2004 in response to the introduction of West Nile virus (WNv) in our area (Lewandowski and Moulis 2008*b*). However, these more recent changes have less to do with local WNv activity, and are more related to the general overall operations of our program.

Our administration changed, as our long-time Director, Dr Henry B Lewandowski, retired at the end of 2014, and Jeff Heusel was promoted from Assistant Director to Director. Our new Assistant Director, Dr Tom Kollars, worked extensively on malaria overseas, and has much experience with ticks and tick-borne diseases. He began in June 2015 and has quickly settled into his new position.

Another administrative change that has evolved over the last three years is in the way CCMC contacts citizens who have requested advanced notification of mosquito adulticide applications in their immediate neighborhoods or even broader areas of the county. These individuals may have allergies to the products we use, maintain organic gardens, manage honeybee colonies, or have other interests that warrant advance notice of mosquito control efforts. In past years, such concerned citizens were simply called on an individual basis by telephone. However, as the county's population grew, so did our courtesy call list, and informing individuals of pending adulticide missions required an increasing amount of time. An automated call system was first used in 2014. This system worked well, as individuals were grouped into treatment zones, and pre-recorded calls or text messages were created for each day of the week. Most importantly, this system documented the name and time of each contact. A new automated system was installed in the summer of 2015 that geocodes individuals into the system based on their address, and allows residents to sign up for the service on-line. We look forward to achieving the full potential this system has to offer!

Other recent changes at CCMC are more technical in nature. For example, the 2008 article stated that there were 39 species of mosquitoes found in our county. Since then, 2 additional mosquito species have been recorded. *Culex coronator* was first discovered in the county in 2007 (Moulis *et al* 2008), and more recently, *Mansonia titillans* was collected in 2014 (Moulis *et al* 2015). Fortunately, the addition of

Figure 1: A BG-Sentinel trap.

Figure 2: Floating emergence trap used to collect *Mansonia titillans*.

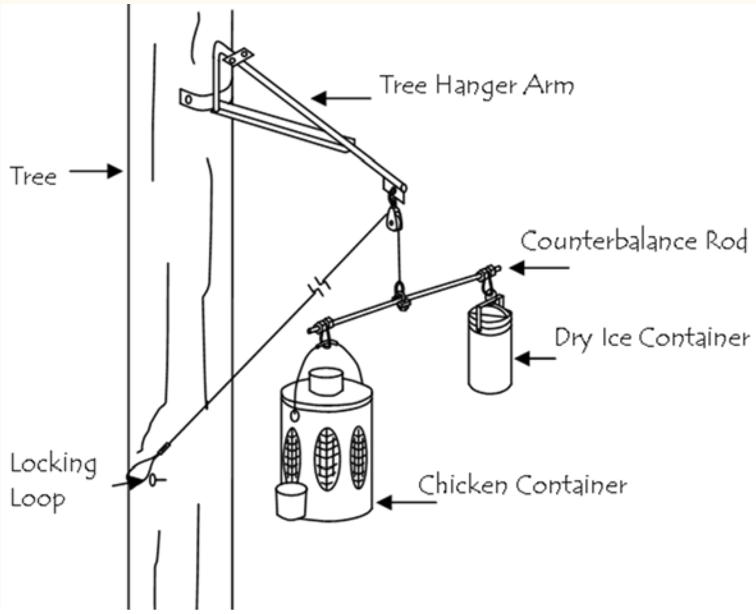

Figure 3: Chatham CMC sentinel chicken cages are deployed overnight into the tree canopy using a pulley system.

these mosquito species is not a current concern from either a nuisance or vector control perspective.

Surveillance remains an essential part of our program. Approximately 50 traps are routinely deployed each week. These include 29 CDC light traps used primarily for our assessments of nuisance mosquito species and eastern equine encephalitis (EEE) vectors, and 26 gravid traps which capture relatively large numbers of *Cx quinquefasciatus*, our primary WNV vector. Combined, these two trap types provide adequate information for us to react quickly to sudden spikes in nuisance or vector numbers for most local mosquito species, as well as supplying us with ample mosquitoes for virus detection. Since 2001, over 40,000 mosquito samples from 29 species have been analyzed for virus. Virus isolates are identified by reverse transcriptase polymerase chain reaction conducted by the Southeastern Cooperative Wildlife Disease Study, and has revealed EEE in 2 species of mosquitoes, *Culiseta melanura* and *Cx erraticus*, and WNV in 4 species, *Aedes albopictus*, *Ae taeniorhynchus*, *Cx nigripalpus* and *Cx quinquefasciatus*. This process has also identified a substantial number of WNV positive pools from samples of *Culex* specimens too degraded for accurate identification to species.

In early 2014 we began experimenting with BG-Sentinel traps to enhance our ability to monitor our *Ae albopictus* populations. These traps have been shown to be very effective in collecting *Ae albopictus* adults, which would be our most likely vector of chikungunya, should this virus appear locally. A

Figure 4: Exit trap for sentinel chicken cage.

Figure 5: Bottle bioassays are used to test for pesticide resistance.

Figure 6: Chatham CMC's three MD 500 model helicopters.

limited number of field trials with emergence traps was also initiated late in 2014, in attempts to collect *Ma titillans*; see Figure 2.

Although sentinel programs are commonly used by mosquito control districts throughout Florida, the CCMC program is unique for Georgia. Our sentinel chicken program was established in the early 1980s to monitor EEE activity and test for other mosquito-borne viruses. Individual birds are deployed overnight in a cage elevated by a pulley system several feet into the lower tree canopy; see Figure 3. Sentinel chickens are stationed 12 feet from the ground to simulate roosting birds. The hanger has a counterbalanced rod supporting the sentinel cage at one end and a container of dry ice at the other. The hanger prevents arboreal predators from gaining access to, or injuring, the caged animal. Sentinels are deployed only once a week. While this method of surveillance prevents 24 hour/7 day a week surveillance, it does reduce the labor required to maintain chickens, virtually eliminates predation, and pinpoints the onset of any virus activity to a specific date. Since our 2008 report, we have incorporated an "exit" trap into our sentinel chicken cage, which

Figure 7: Chatham CMC's helicopters are involved with marine rescue, fire suppression and local police agencies.

Figure 8: Juniper Archer Field PC.

allows us to collect mosquitoes that are attracted to the sentinels, and then submit these mosquitoes for virus testing; see Figure 4. Adding exit traps to our sentinel program works well in our region, where *Cs melanura*, the primary vector of EEE, is not commonly collected in large numbers, and therefore is not readily available for virus testing.

CCMC staff began conducting bottle bioassay testing (CDC 2010) on local mosquito species on a regular basis in 2014; see Figure 5. We are most interested in early detection of pesticide resistance in *Cx quinquefasciatus*, although *Ae albopictus*, *Ae taeniorhynchus*, *Ae vexans* and *Cx restuans* have

Figure 9: Methoprene (*left*) and *Bacillus sphaericus* water-soluble packets.

also been tested. Prior to 2014, occasional testing for pesticide resistance had been conducted, primarily by the US Centers for Disease Control and Prevention (CDC) on *Cx quinquefasciatus* at our request. CDC's tests results showed that local populations of *Cx quinquefasciatus* had developed reduced susceptibility to most mosquito adulticides, although no resistance issues were found with the naled formulation, Trumpet® (Lew-andowski and Moulis 2008*b*).

We hired a third aviation mechanic and an aircraft maintenance supervisor for our Aerial Division. We trained our airplane pilot to operate helicopters, as we no longer use a fixed-wing aircraft for adulticide missions. All aerial treatments for adult mosquito control are now conducted using MD 500 model helicopters; see Figure 6.

Aerial treatment blocks have been established with a size and shape that allow the application of a 30 gallon payload of Trumpet in approximately an hour. A typical aerial adulticide mission encompasses an area of 10,000-14,000 acres that is treated with 2 helicopters working in tandem. In addition to mosquito control work, our aircraft are heavily involved in other public service endeavors that include short-haul marine rescue, fire suppression, Project Lifesaver, assisting other county departments, and working with local police agencies within Chatham County; see Figure 7.

Ultra Low Volume (ULV) trucks are used sparingly for adult mosquito control, and are used mostly for control of nuisance mosquitoes during special outdoor events. These applications are generally limited to just a few

Figure 10: Chatham CMC's rotary ditching equipment (*left*) and amphibious excavator.

Figure 11: The Maintenance Services Division fabricates rearing cages.

city blocks in size. All ground-based ULV treatments are tracked using a Juniper Systems Archer Field PC hand held device loaded with Sentinel™ GIS software; see Figure 8. Staff members continue to treat catch basins throughout urban Savannah and the Thunderbolt area of the county each month. We use a 30-day larvicide formulated as a water-soluble packet (WSP), alternating each year or treatment cycle between methoprene or *Bacillus sphaericus*; see Figure 9. Catch basins in the adjacent, more suburban areas are treated with an extended formulation of methoprene (Altosid® XR ingots) in late spring.

The Facility Maintenance Division includes our Source Reduction and Maintenance Service sections. The Source Reduction team's primary function continues to be ditching and water management operations in dredge material containment areas along the Savannah River. A change in the way ditches are constructed took place by 2010, when CCMC replaced rotary ditching equipment with amphibious excavators; see Figure 10. These newer machines have long-reach booms (50-55 feet) and give staff the ability to make much wider and deeper ditches (20 feet wide by 8 feet deep). As a result, the spacing between ditches increased from 100 to 500 feet. Additionally, the Maintenance Services Division maintains CCMC's buildings and grounds, keeps surveillance trails open and accessible, and formulates "altosand" used in our aerial larviciding program. Maintenance Services also fabricates unique equipment used in a number of operational functions, particularly for mosquito surveillance. Equipment such as portable and semi-permanent stands for mosquito traps, shelters for BG-Sentinel traps, sentinel chicken cages, and mosquito rearing cages are among the many items fabricated in-house; see Figure 11.

Changes, modifications, and adaptations in mosquito control are associated with physical changes in the environment, shifts in mosquito populations, emerging mosquito borne diseases, acquisition of new equipment, or any type of operational challenge. Only time will tell how our program will continue to evolve as we step into the future.

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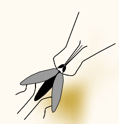

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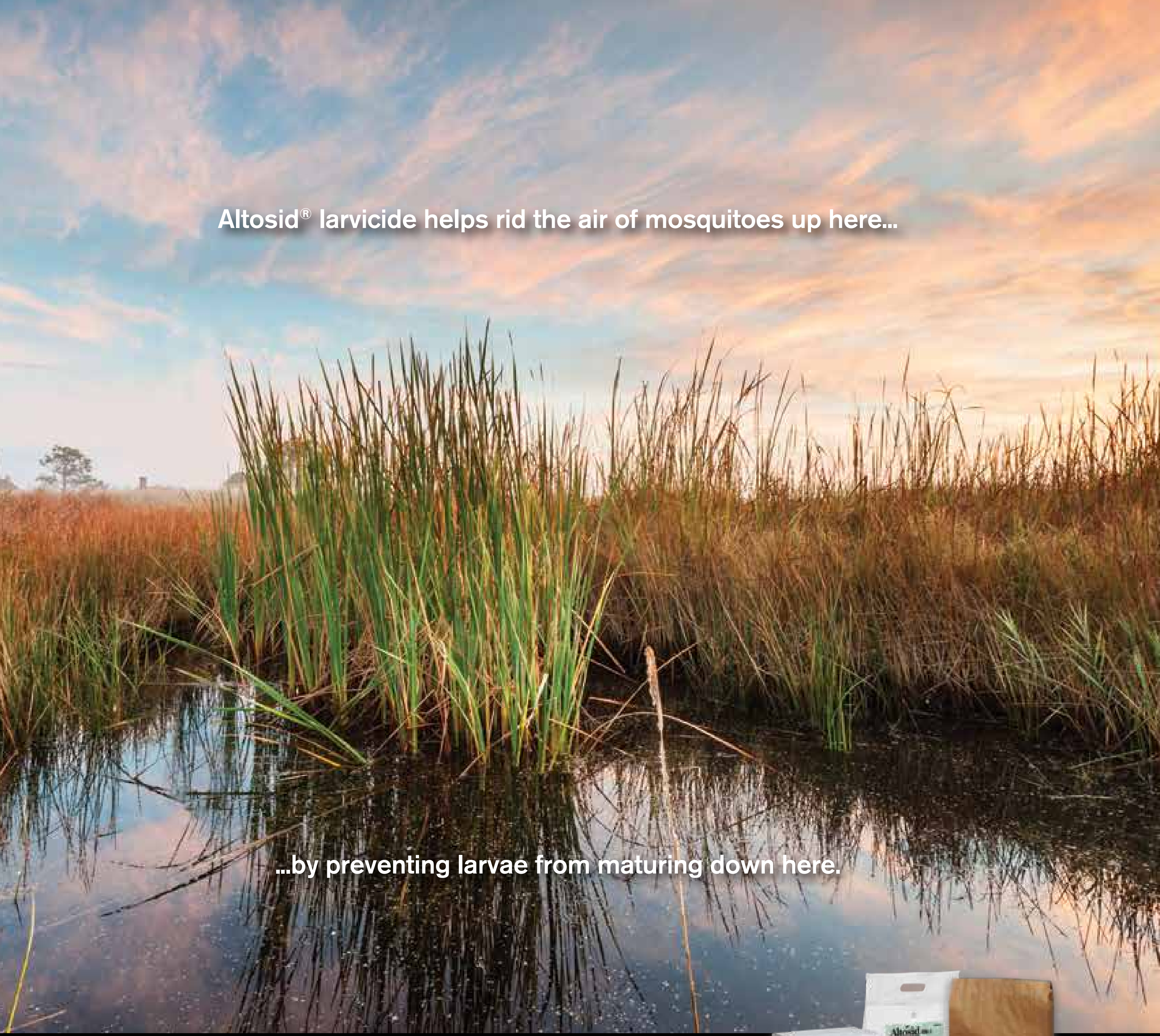

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A Century of Mosquito Control in California: 1915 - 2015

by Joseph Wakoli Wekesa

Figure 1: Oiling of mosquito larval habitat, *circa* 1906; courtesy of Alameda Mosquito Abatement District.

THE NASCENT PERIOD OF MOSQUITO CONTROL: 1904 - 1940

It was no accident that the first "service request" for relief from mosquito bites in 1904 by the Chair of the San Rafael Improvement Association was delivered to Professor Charles W Woodworth of University of California at Berkeley (UC Berkeley). The previous year Woodworth surveyed mosquitoes in the San Rafael salt marsh with his entomology class, which attracted the attention of local residents. The pioneering and successful work of John B Smith in New Jersey the previous year was the basis of recommendations by Woodworth to the San Rafael Improvement Association. On his suggestion the Association hired an inspector who "oiled" nearby salt marshes, greatly reducing mosquitoes. This success persuaded residents of Burlingame to form a similar improvement association and asked Woodworth for help. Woodworth's choice for the job was Henry Josef Quayle, a recent employee of the UC Berkeley Entomology Department. Quayle identified that unlike nearby San Rafael, where the nuisance pest was *Aedes dorsalis*, the problem in Burlingame was caused by *Ae dorsalis* and *Ae squamiger*. Digging dikes and building levees to control water and using oil was successful in 1905 Burlingame. Quayle, with the students enrolled in his class on "pest and nuisance mosquitoes," performed the necessary task of surveillance and control. The benefits were immediate and inspired several nearby communities (Quayle 1906), especially San Mateo, to pass the first anti-mosquito city ordinance that imposed fines and jail time for property owners that disobeyed.

After the April 18, 1906 Great San Francisco Earthquake, a 35 year old Amadeo Petro Giannini, who had started his Bank of Italy – which later became the Bank of America – in San Francisco just 2 years earlier, was devastated as the earthquake and resulting fires threatened his bank. He borrowed a wagon, collected his gold, currency, and records and took them to his home in nearby Marin (Evans *et al* 2004; PBS 2014). Despite the collapse of the local economy, the San Rafael and Burlingame Improvement Association, along with the great entrepreneurship ability of Giannini, helped resurrect real estate values in the city and the bay area. One of his collaborators, Harry Scott, a real estate developer in

Figure 2: Diking of salt marshes in San Mateo, Alameda, and Marin Counties, CA, *circa* 1906-1910; courtesy of Alameda Mosquito Abatement District.

Hillsborough, developed a formidable coalition with Quayle's replacement, a medical entomologist, Dr William B Herms, who arrived in 1908 and initiated efforts on a statewide mosquito abatement bill, which was eventually signed into law by Governor Hiram Johnson on May 29, 1915 (Patterson 2009). On November 6, 1915, the Marin Mosquito Abatement District (MAD) was the first District organized under this law, and a month later Three-Cities MAD, encompassing San Mateo, Burlingame and Hillsborough, was formed. Soon after, nearby Pulgas MAD was formed to protect southern San Mateo County. Thirty-eight years later, in 1953, the latter two districts combined to form the San Mateo County MAD.

Returning to 1908, Herms, who is credited with the successes of mosquito control in California, was recruited by Woodworth to replace Quayle, who had departed three years earlier. What he lacked in experience, Herms compensated for with grit and passion. Although he and some of his colleagues in Ohio and at Harvard considered this job "a mistake and dead end," Herms proved his worth at UC Berkeley. He arrived when efforts to control mosquitoes at San Rafael and Burlingame had lost support and funding after the Great Earthquake. Although his primary interest was in malaria, and not the pestiferous salt marsh mosquitoes that were plaguing the improvement associations of the two cities, opportunity knocked in the fall of 1909. A "service request" for help with an outbreak of malaria that was ravaging Placer County arrived from Fredrick E Morgan of Penryn, California. Morgan and a local fruit grower, Harry E Butler, requested help to control the malaria mosquitoes that "had laid to waste a burgeoning English style society" (Patterson 2009). The work in Penryn marked the first anti-*Anopheles* mosquito campaign in the country, aptly described by Butler, who was the President of Penryn Malaria Extermination Committee in 1910 (Gray 1912).

The successful actions taken by Herms in 1910 provided the trajectory for mosquito control in California for the next 100 years. His three beliefs have characterized mosquito campaigns in California. First, mosquito control needed to focus primarily on controlling mosquito vectors and only secondarily to control nuisance mosquitoes. Second, decisions guiding mosquito control required extensive research and must be grounded in scientific facts. Finally, he believed that mosquito control could succeed only by educating the public and persuading them to support controlling mosquitoes (Gray and Fountaine 1957).

Dr Herms great success in Placer County was achieved in part by collaborating with the State Board of Health – today's California Department of Public Health – under the leadership of Secretary of Health Dr William Snow. Snow made Herms a deputy Health Officer in 1909 to help him control malaria in California. This project was partially funded by Butler in Penryn and was conducted from 1909 through 1911; by 1912 malaria was controlled. Wealthy individuals and community trustees in the towns of Oroville in Butte County and Bakersfield in Kern County donated funds for similar campaigns in 1910. Despite endearing himself to several politicians and wealthy landowners in the Central Valley, Herms and Assemblyman John Guill of Butte County unsuccessfully attempted in 1911 to have anti-malaria legislation passed.

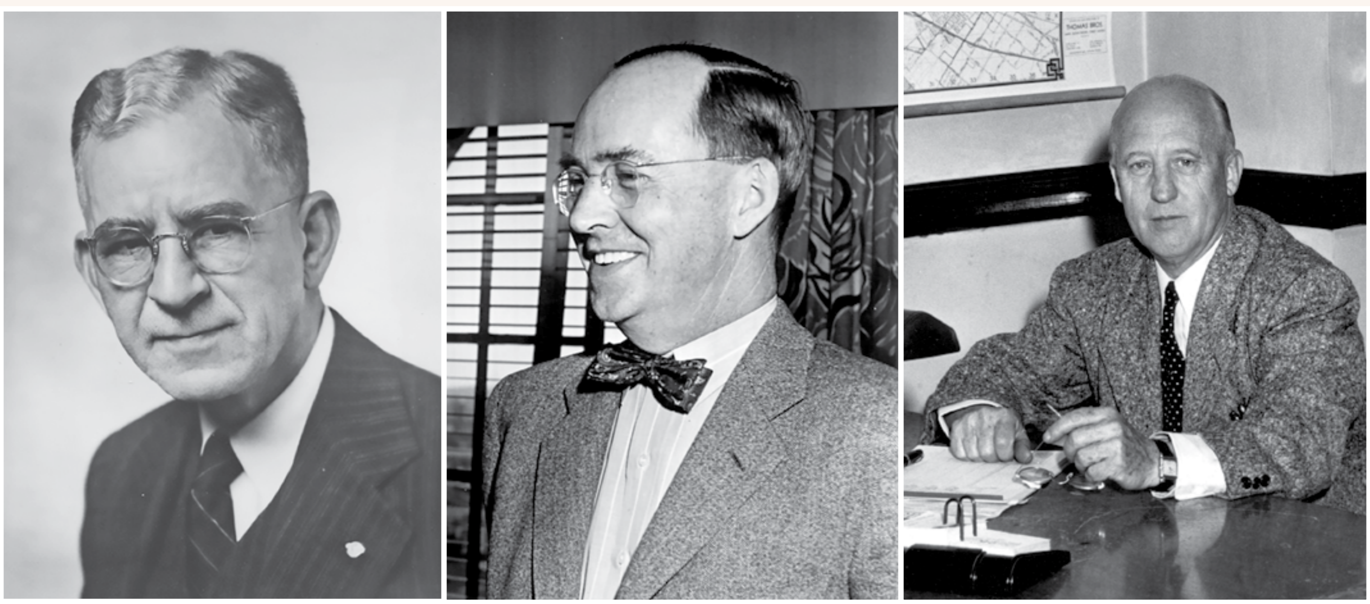

Figure 3: *Left to right*: Dr William B Herms, Professor of Entomology, Dept of Entomology and Parasitology, UC Berkeley; Dr Stanley B Freeborn, Professor of Entomology, Chancellor of UC Davis; Harold F Gray, District Manager, Alameda County MAD. Photos courtesy of RM Bohart Museum of Entomology, UC Davis; University Archives, Photography Collections, Department of Special Collections, General Library, UC Davis; and Alameda County MAD, respectively.

The year before, Harold F Gray, a civil engineer from a nearby water company joined Herms to conduct malaria surveys at the Los Molinos Land Company in Tehama County. The success of the anti-malaria campaign there was well received. In 1912, Tehama County passed the first anti-mosquito ordinance with orders to arrest, impose fines and imprison landowners who allowed mosquitoes to proliferate on their property. Attempts to have the Tehama County ordinance catalyze a statewide anti-mosquito law in 1913 also failed. Herms finally succeeded when he teamed up with real estate developer Scott,4 to finally get the Mosquito Abatement Law passed on May 29, 1915. The progress against malaria thereafter proceeded quickly, and by 1921 malaria was no longer an endemic mosquito-borne disease in California (Hughes 1993).

In 1909, Herms travelled up and down the state on a demonstration train informing the public about agricultural topics in collaboration between University of California and the Southern Pacific Railroad. Herms was to make this and many other road trips across the state conducting surveys of California's mosquito fauna. In 1916, the State Board of Health under the new Secretary, Dr Wilbur A Sawyer, allocated funds to conduct a comprehensive survey of the endemicity of malaria in California, determine the distribution of mosquitoes, especially *Anopheles* species, and use the results of this survey to formulate a robust strategy for mosquito control. Herms, assisted by Gray and a recent hire, Dr Stanley B Freeborn, conducted the survey from the spring of 1916 through summer of 1917. Gray, who later became District Manager of Alameda County MAD, and Freeborn, who rose to great distinction as a scientist and the first Chancellor of the University of California at Davis, started their work with Herms. Dr Karl F Meyer, the new Director of the George William Hooper Foundation for Medical Research in San Francisco, part of University of California, helped rally support for Herms (Hughes 1993). By the end of 1916, Kern County organized Dr Morris MAD, the first Central Valley MAD. The Oroville and Pulgas MADs also were formed. In 1917, Herms and Freeborn volunteered for military service in World War I, providing malaria control to military installations across the country and abroad.

In 1919 after the war, armed with additional experience, Herms and Freeborn resumed the mosquito survey abandoned 2 years earlier. The results helped lower malaria incidence and provided further scientific basis for mosquito control in California. When Woodworth announced his retirement as the head of the reorganized Division of Entomology and Parasitology in 1919, Herms was the natural replacement. Gray was appointed District Health Officer with the State Board of Health, and became responsible for malaria control and management of water facilities in northern Sacramento Valley. He identified an outbreak of malaria in the City of Anderson, which had been made worse when a nearby irrigation project was completed. The cap of a ten-cent ($0.10) per parcel assessment approved in the 1915 Mosquito Abatement Law proved too small to provide effective malaria control. In July of 1919, the State legislature appropriated $10,000 for the State Board of Health to launch the Anderson MAD in Shasta County. Freeborn took charge of the Anderson project after Gray had abruptly been dismissed from his job at the State Board of Health. Freeborn conducted malaria surveillance and created the infrastructure for the District. During these investigations, Freeborn determined that 60 to 100 percent of the local population was suffering from malaria. The funding accelerated Anderson's malaria eradication campaign, such that by the close of 1920 there were no new cases of malaria in the area (Mulla 1994). In 1921 the Anderson MAD made the first attempt at biological control of mosquitoes by using the mosquitofish, *Gambusia affinis* (Stockwell 1996). By 1923 fifteen communities had formed MADs under the 1915 law and 10 of them were in the Central Valley.

In March 1920, Herms organized a two-day meeting at Berkeley to discuss the future of mosquito control in California. Similar meetings continued for the next decade before the California Mosquito Control Association (CMCA) was launched in March of 1930. The attendees were from the University of California, State Board of Health and the Abatement Districts. Nobel M Stover and Harold Gray were named the CMCA's first president and secretary, respectively. Stover was district manager of several MADs, including Marin MAD, Three-Cities MAD, and Contra Costa MAD; and Gray was manager of nearby Alameda County MAD. The statewide mosquito surveys were completed in 1922, with Freeborn cataloguing all 650 samples of mosquitoes that had been collected from every county of the state. He used these data to complete his doctorate in 1924 and listed 36 species of mosquitoes, described their habit and distribution, and provided identification keys in the first edition of *The Mosquitoes of California* in 1926 (Freeborn 1926).

In 1930, a mysterious illness sickened thousands of horses and mules, killing more than 6,000 horses in the San Joaquin Valley. In 1931 Meyer, by then a leading authority in pathology and bacteriology, isolated western equine encephalomyelitis virus (WEE) from a horse's brain. The isolation of WEE required fresh brain tissue from a horse with neurological symptoms. High stakes intrigue was involved in retrieving a horse's brain from a farm in Merced. Meyer and his veterinarian colleague, Dr CM Haring of University of California at Davis (formerly University of California Experimental Station), in the dark of night "knocked the horse down," cut off its head and raced down the road. They left $50 under a shoe on the back porch of the house,

Figure 4: Dr Karl F Meyer, Professor of Pathology and Bacteriology, Director, George William Hooper Foundation of Medical Research, UC San Francisco, *circa* 1925; courtesy of Wikipedia.

apparently reaching an understanding earlier in the day with the farmer's wife (Hughes 1993). For the next seven years in the US, outbreaks of two additional unknown viruses caused morbidity and mortality in humans and horses. This kept mosquito control work quite interesting across the state and the country. Saint Louis encephalitis (SLE) in the mid-west and eastern equine encephalitis (EEE) in the eastern United States were discovered during this period, creating new challenges for mosquito control just as the malaria menace was declining in California.

In California the period between 1904 and 1940 is characterized by a very small group of scientists at the University of California, who worked closely with State Board of Health, local communities, and an informed state legislature to define the principal species of mosquitoes that were transmitting diseases and creating a biting nuisance. In addition, the scientists and other contributors developed the base of knowledge about local mosquitoes, understanding their biology and recommending the best physical, biological, and chemical methods to control them. Finally, the legislature passed laws grounded in scientific research that implemented mosquito control in the state.

This period could also be considered rudimentary by today's standards, as far as the array of measures available for mosquito control. Besides relying too heavily on building dikes, levees, and draining swamps and standing water, the conditions for mosquito production were made worse by the increase of irrigation-based agriculture. The arsenal for mosquito control then consisted largely of shovels, pick axes and slashers, and fuel oil and Paris green for larvicides.

THE GLORY YEARS OF MOSQUITO CONTROL: 1940-1970

The progress of mosquito control in California for the next 30 years stood on the shoulders of some young entomologists from Professor Herms' lab at UC Berkeley in the mid to late 1930s, and several other notable folks. The students, ably dubbed the "fantastic seven" were "*Cal's*" standout basketball players – Richard F Peters, George N Bohart, Thomas HG Aitken, Paul DeBach, William C Reeves, Robert Usinger and George Ferguson. In 1939, Peters was hired by Chester Gillespie, Chief of the Bureau of Sanitary Engineering, State Board of Health, the first non-engineer professional in the bureau, with specific assignment to assist the 19 mosquito abatement districts with his expertise in mosquito control. Peters helped standardize surveillance and operational efforts, advised the district managers, reviewed protocols, and collected mosquitoes all over the state for testing. Samples brought back to UC Berkeley were processed by Aitken and Reeves (Hughes 1993). In 1941, Peters was appointed head of the State Board of Health's federally funded anti-mosquito defense program to protect military personnel against mosquitoes and mosquito-borne diseases in World War II.

In 1940, Meyer had recruited Dr William McDowell Hammon to the George William Hooper Foundation for Medical Research to study the role of mosquitoes in transmitting WEE and SLE viruses. Hammon started his job in the middle of an outbreak of WEE in the Yakima Valley of Washington State. In the summer of 1941, Reeves joined him to start a new project for his (Reeves) PhD dissertation, after his previous study was compromised. Hammon and Reeves resolved the mystery of human and equine encephalitis by identifying WEE and SLE in pools of *Culex tarsalis* collected while feeding on cows and horses, and demonstrated how they transmitted the disease to laboratory animals (Hammon 1941; Hammon & Reeves 1942). Subsequently Reeves further revealed that wild birds were a reservoir host for these viruses. In the following 15 months most of the University of California entomologists were in different parts of the world on military duty. Peters, Usinger, Bailey, Freeborn,


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Richard M Bohart, James Douglas and others served in the Malaria Control in War Areas divisions of the US Armed Forces. In 1942, the compound Gesarol was discovered and an active ingredient in it was described as dichlorodiphenyltrichloroethane (DDT). Further tests, conducted by the US Department of Agriculture (USDA) at its Orlando, Florida laboratory, confirmed its potency against larvae and adults of lice, mosquitoes and flies and it was incorporated into WWII disease control strategies (Knipling 1945). The discovery of DDT opened the door for using a new class of compounds as pesticides: chlorinated hydrocarbons. Their potency against mosquitoes, limitations, and methods of application required extensive research.

Herms and Gray published *Mosquito Control* in 1940 and revised it in 1944. They showed that human activities had driven most of the changes in mosquito control. Mosquitoes were still emanating from natural habitats, but new sources of mosquitoes had increased through agricultural activities and water impoundments in the state (Herms and Gray 1940; 1944). In the 1940s, rivers that used to flood were diked and dammed, and new irrigation systems were built to increase agricultural and urban development. Septic tanks, cesspools, and privies in urban areas were replaced with sewers, wastewater treatment plants, and industrial wastewater treatment ponds. Major new mosquito sources in the state were no longer natural, but man-made, created by humans.

The end of World War II brought concerns that returning servicemen would bring back malaria. The US Malaria Control in War Areas unit in California, headed by Peters, earlier received increased federal funding which set the stage for growth in mosquito research and control. The state legislature followed suit. In 1944 and 1945 the state solicited and received a detailed report from the State Department of Health, University of California, and mosquito abatement districts, that focused on disease transmitting mosquitoes in California. The report outlined immediate challenges and urged the state to shift from wartime concerns about malaria to the larger issue of controlling mosquito-borne diseases and nuisance mosquitoes (Reeves 1992).

The capacity for mosquito research in California was quite small at the end of World War II. In fact, the entire University of California research group was domiciled at the Hooper Foundation for Medical Research at UC San Francisco. The research staff who returned to the University of California after serving in WWII included Reeves, Bohart, Bailey, and Freeborn. Peters and few others returned to the State Department of Health. The report prepared by Meyer, Reeves and Frank Stead in 1945 for the legislature was ambitious, and laid the groundwork for expanding mosquito control in the state (Reeves 1992). By the 1960s California had rivaled New Jersey and Florida in mosquito research and control in the US. Resources available in California in 1945 consisted of 29 MADs that protected 1 million people within 4,645 square miles and with a budget of $369,000. The report projected that the cost of an effective mosquito-borne disease control program could reach $10 million. The legislature responded with an allocation of $400,000 to the State Department of Health for subvention to local MADs and $200,000 per year for research on the role of *Culex tarsalis* as

Figure 5: *Left* to *right*: Richard F Peters, Chief, Bureau of Vector Control, Division of Environmental Sanitation, Calif Dept of Public Health; Dr William C Reeves, Prof of Entomology and Arbovirology, Dean, School of Public Health, UC Berkeley; and Dr A Ralph Barr, Prof of Entomology, School of Public Health, UC Los Angeles. Photos courtesy of Calif Dept of Public Health; RM Bohart Museum of Entomology, UC Davis; and Society of Vector Ecology, respectively.

a vector of encephalitis (Reeves 1985). Three years later the number of MADs had increased to 42 and covered more than 15,000 square miles. By 1954, there were 53 MADs covering more than 30,000 square miles.

In 1947, the State Department of Health headed by Secretary of Health, Dr Wilton Halverston reorganized the oversight of mosquito control under the Bureau of Vector Control, Division of Environmental Sanitation (BVC). The subvention of funds to MADs created a role for the bureau to standardize surveillance, operations, and management of the MADs. The MADs were required to maintain records of mosquito abundance and pesticide use, add trained entomologists to their staffs, and establish standards for the qualifications of district managers. Peters was assigned sanitary inspection, and eventually was appointed to head the bureau's biological section. He spent most of his time on the road providing technical support to existing MADs and encouraging formation of new districts. The relationship between the bureau and MADs for the coming years was characterized by politics, personalities, and pesticides. After WWII the management of State Board of Health, Division of Environmental Sanitation was overseen by civil or sanitary engineers. The relationship between the bureau and the MADs became contentious as the MADs had to meet standards or lose subvention funds. In 1950, a handful of MAD managers organized a meeting in Kern County. Reeves, who was directing Hooper Foundation's encephalitis research program in Bakersfield (Kern County), was invited to the meeting. The managers chose Reeves to deliver their dissatisfaction to the Director of State Department of Health. Six months later, AH Dahl, the Chief of the Bureau of Vector Control had resigned, and Peters was appointed in his place. Peters managed the growth of mosquito control in the state as the Chief of the Bureau of Vector Control, later known as Bureau of Vector and Waste Management (BVWM) for the next 27 years (Hughes 1993).

After the 1949 CMCA annual meeting held in Berkeley, the Bureau took the lead in conducting operational research to explore new ways for mosquito control. Turlock MAD offered use of their space for research and Peters assigned Earl W Mortenson, a recent hire, to oversee the research. Thomas D Mulhern, the Executive Secretary of the American Mosquito Control Association (AMCA), moved from New Jersey to California to work with Mortenson at Turlock MAD. These actions transferred the AMCA central office and the national center for mosquito control interests to California and cemented the progress the state had made in mosquito world. Glen Collet, who later moved to Salt Lake MAD, served at Turlock MAD with Mulhern (Patterson 2009). In 1953, the research started at Turlock MAD relocated to new headquarters at the Fresno Field Research Laboratory (later to become University of California Mosquito Research Laboratory) under the California Department of Health, Bureau of Vector Control. The research lab had broad objectives in coordination with the University of California to oversee a centralized and integrated research effort on mosquito biology and control in California in support of local districts. In 1952, Dr RE Bellamy joined the Hooper Foundation encephalitis research station (later to become the Arbovirus Research Station) in Bakersfield (Kern County) as the field director from the US Communicable Disease Center (later to become Centers for Disease Control and Prevention) (CDC). A youthful Dr A Ralph Barr was recruited from Minnesota by Peters to head the BVC Fresno Research Laboratory, where he remained until it was absorbed into the University of California system in 1965.

In 1952, California experienced its largest epidemic of encephalitis (WEE and SLE) with 429 human cases, 51 deaths in 37 of 58 counties. There were similar numbers of encephalitis cases in horses. Also, there was an epidemic of malaria at Lake Vera, Nevada County, with 35 cases in the same year (Reeves 1985). The encephalitis outbreak provoked a huge backlash from the people and led to hearings by the legislature. The CDC was asked by the California legislature to review the BVC's response. The report given by the CDC praised the capability of the State Department of Health and its BVC, to the chagrin of public critics (Patterson 2009). At the time there was widespread development of resistance in a variety of mosquito species to DDT and related chlorinated hydrocarbons that extended to organophosphates. Research showed the genetic basis for resistance and recommended how it should be managed. In the midst of the panic about mosquito resistance to multiple compounds, a glimmer of hope appeared in 1954. A successful formulation of a broad spectrum repellent called DEET (N, N-diethyl-m-toluamide) was developed and released for use by the USDA. This gave the BVC high ground to advocate for research, and highlight the dangers of over-reliance on insecticides. The MADs suddenly became conscious of the need to return to source reduction programs, which had guided earlier mosquito control operations.

In 1952, Dr Mir S Mulla of the University of California at Riverside, working with Coachella Valley MAD on an eye gnat problem, developed a program to mitigate pesticide resistance that encompassed mosquito control. In 1960, Professor George P Georghiou joined Mulla at UC Riverside and together with other exceptional colleagues, conducted excellent research on the chemistry of insecticide and insecticide resistance. Their research revolutionized pesticide compounds and formulation while collaborating with the statewide MADs and the World Health Organization. The contribution of these individuals led to the development of new and innovative, environmentally-friendly compounds

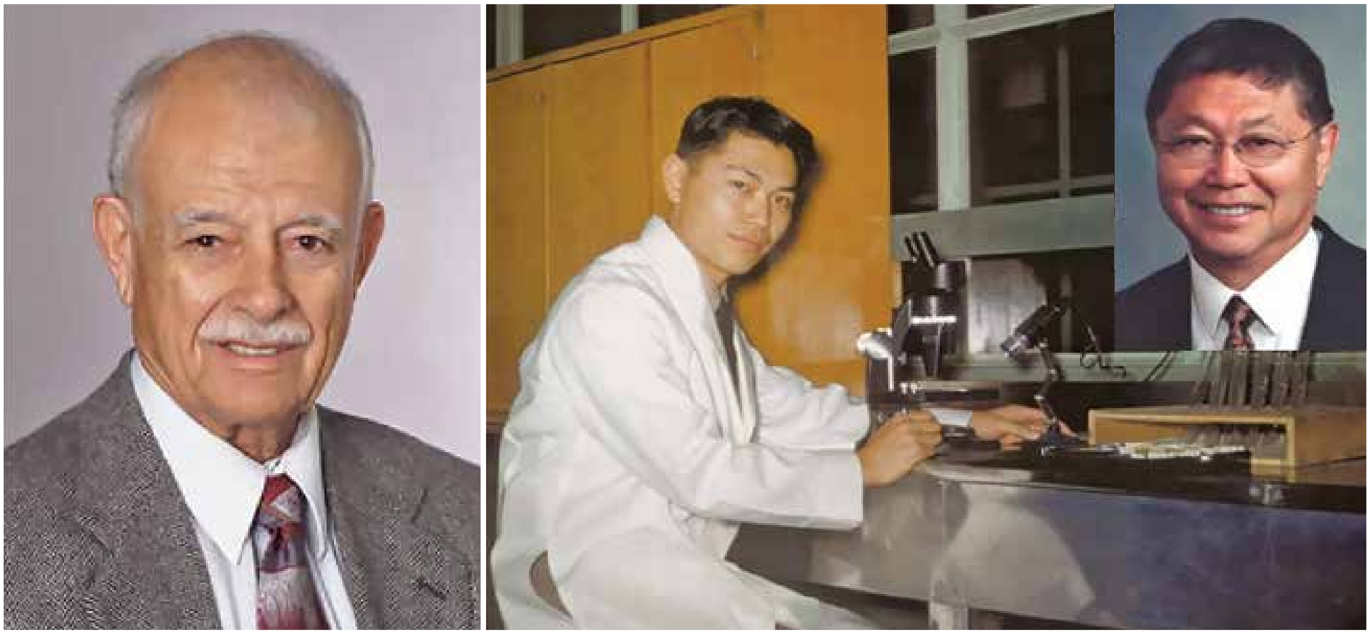

Figure 6: *Left to right*: Dr Mir S Mulla, Professor of Entomology, UC Riverside; courtesy of UCR Strategic Communicaton, UC Riverside; and Dr Robert K Washino, Professor of Public Health Entomology, Dept of Entomology and Nematology, UC Davis; serving in US Army Medical Service Corp, *circa* 1956-58; inset photo Associate Dean, College of Agriculture and Environmental Sciences, UC, Davis; courtesy of Entomology & Nematology News, UC Davis.

against mosquitoes for the next five decades (Hughes 1993). In 1961, Dr Harold Chapman of the USDA/Agriculture Research Service (ARS) was transferred to Fresno as USDA/ARS staff and joined the dynamic mosquito control group at the BVC Fresno Research Laboratory (later to become University of California Mosquito Research Laboratory) headed by Barr. Under Barr's direction and Chapman's supervision, William Willis assisted William R Kellen, Truman B Clark and James E Lindegren in isolating and identifying biological control properties from bacterial, fungal, protozoan, and viral pathogens of mosquitoes. Their work identified many biological control products that are currently being used in mosquito control, and developed many mosquito rearing techniques used in many rearing facilities around the world (Fukuda 2010; Tokuo Fukuda and Robert K Washino, *personal communication*).

From 1957 to 1965 the BVC Fresno Research Laboratory was producing detailed annual insecticide resistance maps for distribution to the MADs with a full spectrum of compounds recommended at beginning of the season. In February 1965 a joint report by the State Department of Health, the University of California, and the mosquito control agencies informed the legislature about the "proposed expanded research and extension programs for the control of mosquitoes affecting man and animals." The report supported expanding mosquito research and control to most parts of the state. To the surprise of many, on June 21, 1965, the state legislature abruptly passed a motion that as of July 1st, all the responsibility for research on mosquitoes and the budget for the Fresno Research Laboratory were transferred to the University of California. In less than two weeks, a budget of $141,000 and twelve professional staff at Fresno Research Laboratory and six others at the Arbovirus Research Station in Bakersfield and Davis were transferred to the University of California. Some of its programs, especially diagnosis and surveillance of diseases spread by mosquitoes, were reabsorbed into the State Department of Health. Professional research staff affected by this abrupt reallocation of resources included Barr, RK Washino, and CL Judson. Barr joined TF Work and JN Belkin on faculty at UC Los Angeles; Judson and Washino joined Bailey, Bohart, Fontaine, GAH McClelland and others at UC Davis. The remaining staff re-assigned within the BVC included MM Boreham, T Fukuda, PA Gillies, J Hitchock, RC Husbands, L Llewellyn, Mortenson, Mulhern, CM Myers, B Rosay, DJ Womeldorf, and several others. Prominent new members joining the research program for mosquito control in the University of California system during this time included Drs Charles Schaefer, Takeshi Muira, and Richard Garcia. Chapman, Clark and Fukuda later moved to the USDA/ARS lab in Louisiana, and CM Gjullin, Lewis, Lindegren, and Kellen remained with USDA/ARS unit in Fresno (Eldridge and Zavortink 1996; Tokuo Fukuda and Charles Myers, *personal communication*).

In 1962, Rachel Carson's *Silent Spring* captured the attention of the nation, to the bewilderment of many mosquito control people. She awakened public consciousness about the danger of misusing pesticides. Mosquito control people in California, such as

Gray, Peters and Reeves, had been aware of resistance since the 1940s. In 1959, University of California agricultural entomologists Vern Stern, Ray Smith, Robert van den Bosch and Kenneth Hagen published a groundbreaking paper that advocated the concept of integrated control (Stern *et al* 1959). This paper formed the basis of integrated pest management (IPM) – later this term was adopted for mosquito control as integrated vector management – which formed part of the "green revolution" of the next several decades

THE GREENING OF MOSQUITO CONTROL PRODUCTS: 1970 - 2000

The realignment of mosquito surveillance and control research in California from the State Department of Health to the University of California shifted the interaction of these two state agencies. It expanded responsibilities of the local MADs and increased mosquito control activities within the state. California Department of Health funds and budgetary support from the University of California system major mosquito research programs expanded on the Berkeley, Davis, Los Angeles and Riverside campuses. By the 1970s no other university, and few major government agencies, had professional staffs and research facilities on vectors and vector-borne diseases and control equal to University of California. Its programs were fully supported by vector control and other programs of the State Department of Health, and by mosquito control agencies protecting most of the densely populated areas of the state. This growth was coordinated by the State Department of Health and by representatives at the California Mosquito and Vector Control Association (CMVCA) in Sacramento.

It became very obvious that a change in mosquito control was urgently required to diminish overreliance on pesticides, and accelerate research on alternative products against mosquitoes. Research on neglected pests and vectors was needed, as were alternative approaches to managing mosquitoes apart from using insecticides. Special attention was given to biological agents, physical alteration of agricultural environments, improved management of water or wastewater, and resolving issues raised by "environmentalists."

In 1970 President Richard Nixon signed the US National Environmental Policy Act into law, creating the US Environmental Protection Agency (EPA), and soon after California enacted similar legislation. Use of DDT was banned in the United States and around the world. The ban was extended to several other hydrocarbons including organophosphates in the coming years. On May 1, 1970 the world celebrated Earth Day. University of California professors, led by Barr, RH Dadd, Garcia, BA Fredrici, JL Hardy, EC Loomis, Mulla, EG Platzer, VH Resh, CH Schaefer, Washino and others, the entomological staff of local MADs, and the State Department of Health, accelerated research on biological and bio-rational mosquito control agents, physical alteration of agriculture, and managing excess water, with environmental quality as a goal. The quality of publications of the *Proceedings of the California Mosquito Control Association* greatly improved, and by 1973 they were being distributed worldwide. In 1975, the legislature appropriated $300,000 for research on mosquitoes and mosquito-borne diseases with the support of a *troika:* the California Department of Public Health, the University of California, and the CMVCA, which represented the MADs (Reeves 1985). These funds were to support operational research by the University of California, which would be applied to managing vectors and vector-borne diseases in California. Drs Carl Mitchell, Edmond Loomis, and Russell Fontaine administered the funds, and the awarding and policy committees of CMVCA represented the entire organization. In 1982 Dr Bruce F Eldridge was recruited by the UC Division of Agriculture and Natural Resources (Oakland, CA) and stationed at UC Davis, from the University of Oregon, to oversee this Mosquito Research Program.

In 1978, the third edition of *The Mosquitoes of California* was published by Bohart and Washino and it covered 47 species, compared with 36 species in the 1926 edition. Research into alternative products for mosquito control continued and was accelerated on the campuses of Berkeley, Davis, Los Angeles and Riverside. Notable researchers in bio-rational field were: EC Bay, rearing and instant availability of mosquitofish; Platzer, mermithid nematodes; JL Kerwin, (*Lagenidium giganteum*), Fredrici (*Coelomomyces*, and *Bacillus thuringiensis*), and Mulla (*B thurungiensis* and *B sphaericus*) (Reeves 1990; Kerwin *et al* 1994; Mulla 1994). The pinnacle of California's mosquito research, in terms of breath and scope, was captured in the 34 articles of the March 1980 issue of the University of California publication, *California Agriculture*, exclusively dedicated to mosquito research at all UC campuses, state and MADs (California Agriculture 1980).

Internationally, new mosquito control products were reaching the marketplace. In 1967, *B thuringiensis* var. *israelensis* was isolated and studied for its larvicidal properties; by 1982 it was commercially available for use. Per capita use of various formulations of pyrethrum and pyrethroid-based products increased. The juvenile hormone analog *s*-methoprene, first registered by EPA in 1975, was developed to control mosquito larvae, as was *Bacillus sphaericus*, which was registered in 1991. Different formulations of these products expanded their use into a variety of habitats. Biological agents such as mosquitofish were incorporated into integrated vector management programs. Many other products remained in the research and development stages, spinosad for example, finally became available in the first quarter of the 21st Century.

Different ways of extending the efficacy of existing compounds were researched and other products were evaluated and brought to market for specific applications (Mulla 1994; Mir S Mulla, *personal communication*).

Mosquito control research was consolidated at UC campuses in the 1990s because of budget cuts and the tremendous success of mosquito control itself, from the Berkeley and Los Angeles to the Davis and Riverside campuses. Legislators and the general public no longer felt vulnerable to emerging and re-emerging diseases. The University provided "golden handshakes" that incentivized some mosquito and vector control professors to take early retirement. In 1995, the arbovirus research field station in Bakersfield (Kern County), the Kearney Agricultural Research and Extension Center in Parlier (Fresno County), and the Vector and Vector-Borne Diseases group at UC Berkeley were all moved to UC Davis and integrated into the Center for Vector-Borne Diseases, within the Department of Entomology and Nematology. Drs Washino (Associate Dean, College of Agriculture and Environmental Sciences, UC Davis), Eldridge (Director of the System-wide UC Mosquito Research Program, Division of Agriculture and Natural Resources), and Michael P Parrella (Chair, Department of Entomology and Nematology, UC Davis) were key individuals who helped reorganize mosquito research at University of California in the wake of these budget cuts. Professional staff transferred in the consolidation included Laura M Kramer, William S Reisen, Robert Chiles, and Barbara Calhoun-Young. For the next several years UC Davis and UC Riverside recruited more staff into vectors and vector-borne disease programs, including Drs Anthony J Cornel, John D Edman, Sharon Lawler, Walter S Leal, Shirley Luckhart, Jocelyn Miller, Alexander Raikhel, Tom W Scott, William E Walton, and several others. In 1996 CMVCA changed its name to the Mosquito and Vector Control Association of California (MVCAC). The MADs across the state broadened capabilities in vector control and vector-borne disease research; several of the 64 districts developed varying degrees of expanded expertise. These resource shifts increased the number and quality of mosquito research, but the *troika* of the California State Department of Health, University of California, and the MADs helped keep California's place as a leader in innovation and protecting its residents from vectors and vector-borne diseases.

By the year 2000, the State was allocating more than $500,000 annually to support research on mosquitoes. There were also University departmental budgets of more than $600,000. These funds, along with grants and contracts from federal, private, and other sources, and the MADs' investment in their own research, added up to more than $4,000,000 in funds dedicated to controlling mosquitoes and the diseases they transmit (MVCAC 2000).

CURRENT & FUTURE CHALLENGES FOR MOSQUITO CONTROL IN CALIFORNIA: 2000 – 2015

As we celebrate 100 years of mosquito control in California, there are new challenges, but also new opportunities to safeguard our health. California may not have all the money it needs to support its research, but it has come a long way since 1915 when the Mosquito Abatement Law was first enacted. The law had minor revisions in 1926 and 1939; in 2003 it went through a comprehensive revision. The University of California has a large professional staff dedicated to research on mosquitoes. The strength of California mosquito control is its agility to change and address current problems. Over the years the California Department of Public Health went through several name changes, from California State Board of Health, California Department of Public Health, to California Department of Health Services, and finally back to California Department of Public Health. The Bureau of Vector Control switched to Bureau of Vector and Waste Management and after a series of name changes, finally settled on Vector-Borne Disease Section; Peters, the original Chief, was succeeded by Womeldorf, later replaced by its current Chief, Dr Vicki Kramer. The Vector Borne Disease Section continues its organized surveillance of vectors and vector-borne diseases. Its efforts are closely integrated with those of the local health departments and MADs.

Perhaps the greatest asset for mosquito control in California is the corporate membership of the MVCAC, which in 2015 stood at 64 agencies representing mosquito-related annual budgets from local taxation of $156,469,767, covering 77,273 square miles, and protecting about 40 million residents and visitors (MVCAC 2015). Many of the local agencies are involved in operational and disease surveillance research. In 2009, the state-funded mosquito research program, which provides resources for University of California mosquito research projects, was discontinued by the University of California. Efforts are underway to restart this research program.

The continuing challenges include development of mosquito resistance to the current insecticides. In general, the mosquito control industry currently uses the most environmentally friendly products compared to other applicators of pesticides in the state and country. Research into new compounds continues at the state's universities, state and federal agencies and private industry.

The greatest immediate challenge to mosquito control in California is emerging and re-emerging vectors and vector-borne diseases. West Nile virus (WNv) was introduced into California in 2003 and spread across the state rapidly. From 2004-2012, it settled into a four-year cyclical pattern, and human cases have steadily been prevalent from 2013 to 2015. The future behavior of WNv in California is not predictable. As quickly as WNv appeared on the scene, WEE and SLE virus disappeared, but after 13 years SLE has resurfaced (CVMVCD 2015).

In 2001, *Ae albopictus* was re-introduced in California through imported shipments of *Dracaena*, "lucky bamboo" (Linthicum *et al* 2003). Agencies in California deemed a flurry of quarantine and eradication activities successful, only to discover larger and established populations of *Ae albopictus* in 2011 in Los Angeles County (Fujioka *et al* 2012). These populations are now spreading to other cities and counties in southern and central California (Wekesa *et al* 2014). In 2013, the Central Valley counties of Madera and Fresno discovered populations of *Ae aegypti*. They can be found now in 10 more counties throughout the state: Alameda, Imperial, Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego, San Mateo, and Tulare. In 2014, *Ae notoscriptus*, a native of Australia was found in Los Angeles County, but has not received the same attention as its cousins, *Ae albopictus* and *Ae aegypti*. The entomologists at the University of California Mosquito Research Laboratory in Fresno and mosquito researchers at UC campuses in the 1950s-60s never imagined that any of these *Aedes* species would be found here, let alone overwinter and thrive in California. If the past giants of mosquito control in California were here today, some of their beliefs would have been turned upside down, but undoubtedly they would have been giddy at the prospect of new opportunities and challenges. As we celebrate 100 years of mosquito control in California we are proud to note that of more than 50 mosquito species recorded in California, 5 bear names of University of California faculty (Durso 1996):

William B Herms – *Anopheles hermsi*
Stanley B Freeborn – *An freeborni*
William C Reeves – *Culex reevesi*
Richard M Bohart – *Cx boharti*
Robert K Washino – *Aedes washinoi*

CONCLUSION

Mosquito and vector control agencies in California are looking to the future, understanding that the full impact of climate change may yet be unfelt. We are celebrating this 100-year anniversary in the midst of a severe drought while dealing with a multitude of emerging and re-emerging mosquito and mosquito-borne diseases. The collaboration between the California Department of Public Health, the University of California, and the health departments and MADs (represented by MVCAC) that has guided mosquito control in California over the past 100 years is ever more important to carrying the day. Each component of the *troika* must continue to fulfill its portion with dedication, passion, and ingenuity, so that California's rich legacy in mosquito control can continue.

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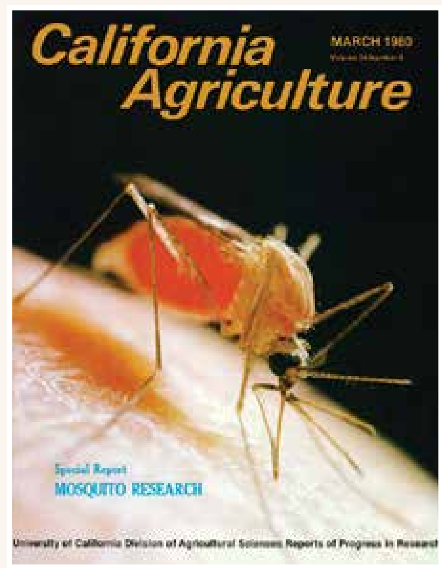

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