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Source: Florida Entomologist, 87(3) : 412-416

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/0015-4040(2004)087[0412:BWNVAO]2.0.CO;2

BATTLING WEST NILE VIRUS AND OTHER MOSQUITO-BORNE DISEASES: A TRIBUTE TO DR. MAURICE W. PROVOST

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This pioneer lecture honors the scientific career of Dr. Maurice W. Provost. Dr. Provost's distinguished career with the Florida State Board (later Division) of Health was devoted to freeing Floridians from the scourge of mosquitoes and sand flies, and preventing mosquito-borne diseases such as malaria and St. Louis encephalitis (SLE). The unprecedented invasion of West Nile virus (WNV) into North America in 1999 and its transcontinental spread from the Northeast over the past four years has added a new mosquito-borne disease to the Florida landscape. WNV is a close relative of SLE virus and has a similar maintenance and amplification cycle involving wild birds and *Culex* mosquitoes. SLE virus invaded Florida in 1959-63, just prior to when I joined Dr. Provost, then director of the Florida Medical Entomology Laboratory (FMEL) in Vero Beach. Now, 40 years later, history has been repeated, only this time the invader is an African virus. WNV moved southward into Florida in 2001 bringing human and equine illness and death to many wild birds. It is unfortunate that we no longer have the benefit of Dr. Provost's keen insight in planning our defense as we did when SLE invaded. However, he left us clear directions of how we should respond to this newest vector borne disease challenge.

Dr. Provost was unpretentious and so I will henceforth refer to him, simply as Maury. Despite his distinguished appearance and sophisticated tastes, Maury was at heart a naturalist who encouraged informality. He donned a coat and tie for the annual staff picture on the front steps of the FMEL (Fig. 1) and for the annual Christmas party (Fig. 2) but otherwise he dressed casually in loose, brightly colored shirts.

Fated with a strong genetic predisposition for coronary heart disease, Maury witnessed the untimely death from heart failure of his parents and all his brothers and sisters, except for one younger brother. He too experienced early symptoms of heart disease and as a biologist Maury understood inheritance and statistics. He realized his own longevity might be abbreviated despite his long daily walks, sensible life style, and

Fig. 1. Dr. Provost (front, center) with Senior Staff at the Florida Medical Entomology Laboratory in 1967.

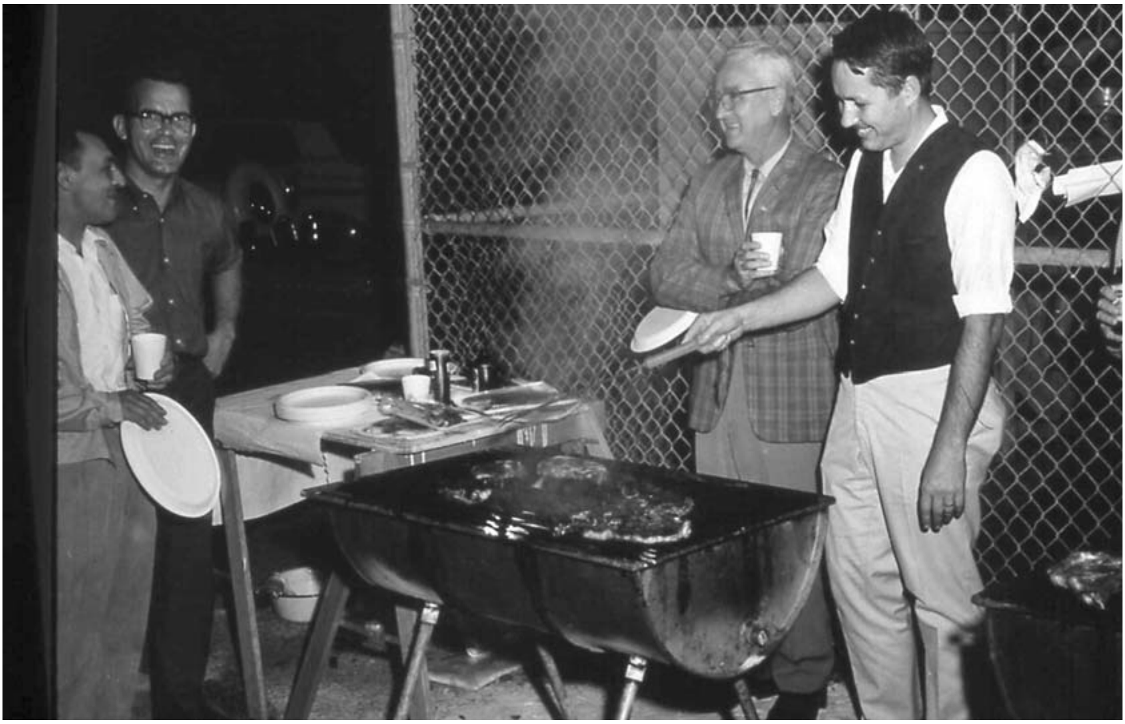

Fig. 2. Dr. Provost talking to the cook, Dr. Arden Lea, and hungry staff, Les Bourinot and Larry Webber, at the annual Florida Medical Entomology Laboratory Christmas Party in about 1962.

positive attitude. This gave focus and a quiet sense of urgency to his life. He was one of famous cardiologist Denton Cooley's early coronary bypass patients, and this hope-filled trip to Texas undoubtedly bought Maury some extra time. He used it unselfishly. Despite all that he contributed and left us there was still much more that he wanted to give to his profession and to the preservation of the wild side of Florida for which he cared so deeply. Those who knew him and worked with him realized that Maury represented someone special. This made his death at just 63 all the more tragic. Some reparation can be found in recalling some of the positive things that I personally learned from Maury, lessons that displayed the depth of his wisdom and demonstrate how slow we as a nation and public health community have been to take them to heart and turn them into positive action.

Born to French Canadian emigrants, Maury grew up hiking the mountains and wading the clear, cold streams of rural New England. Early in life, he developed the deep love of nature that so permeated his interests and values as an adult. His quiet, often stoic approach to controversial environmental issues belied the visceral feelings that were his constant motivator. He was a devoted environmentalist before the term was coined and popularized. Maury was a pragmatist who knew that marching and flag waving were not the best way to recruit those who harbored less passionate feelings toward mother nature than he did—and there were many who didn't during the "drain and develop era" following WW II. Maury, the consummate gentleman, found such displays of activism to be way outside of his comfort zone.

Maury had a special fondness for waterfowl and wetlands, and all their various inhabitants, except perhaps their mosquitoes, sand flies, and black flies. He must have donated considerable blood to these vexers of nature on those summer sojourns through the humid boreal terrain of New England. However, they did not stimulate an early calling to medical entomology. That was something Maury happened into without the medical entomology background and training one might expect. Although initially a student of vertebrate ecology, he ended up becoming a leader and innovative force in the early development of mosquito research and control efforts in Florida. World War II, malaria and chance all played a role in taking him in this fortunate direction. Perhaps it was this unique background that allowed him to step back and take a fresh and broader view of mosquito biology and control possibilities.

Maury's education included undergraduate studies at St. Anselm College in New Hampshire and graduate work at the University of California, Berkeley, and Iowa State University, plus considerable practical experience. The nesting ecology of waterfowl associated with Iowa's many cattail-ringed potholes was the topic of Maury's Ph.D. dissertation. This came after many summers of fish and waterfowl surveys for the New Hampshire Dept. of Fish and Game while a student at Saint Anselm College and following graduation. He talked fondly about the year he spent in graduate school at U.C. Berkeley before returning to New Hampshire to complete his Master's in Vertebrate Zoology on his native turf. He then began doctoral training at Iowa State in 1940 but was interrupted by service to his country (1942-45) with the U.S. Public Health Service assigned to the 'Malaria Control in War Areas' program in Florida. This assignment provided Maury with his first public health challenge, controlling malaria vectors. Paris Green and swamp drainage were the methods of choice, and seeing the environmental affects of both convinced Maury that there must be better ways to do battle with mosquitoes. When the war ended he stayed on for a year as State Entomologist before returning to Iowa to finish his doctoral studies. These Florida experiences and connections led Maury to return to accept a position in the Bureau of Entomology of the Florida State Board of Health, heading up research on mosquito biology and control.

Malaria was no longer a significant problem in Florida, but land and economic development along the coastline, while expanding, were being inhibited by the hordes of mosquitoes that laid claim to Florida's pristine salt marshes and mangrove swamps. This seemed like an almost insurmountable task and tested the strength of Maury's vision and leadership. Salt marsh mosquitoes were thought to disperse great distances, but no one knew how far they moved from their estuarine sources and, therefore, how far control efforts needed to be extended to protect the growing populace. Living in old lighthouse quarters on the tip of Sanibel Island (no bridge in those days), Maury and his small team of thick-skinned scientists, including Jim Haeger and Bill Bidlingmayer and their devoted wives, began to study the migratory behavior of *Aedes taeniorhynchus*. This was indeed a challenge and one that continued to occupy the rest of Maury's scientific career. Maury encountered a Danish scientist, Erik Nielsen, who was studying migration of the common salt marsh butterfly in Florida, and this interaction stimulated and broadened Maury's thinking about mosquito migration and dispersal. It led to a brief but productive research collaboration between the two. Maury realized that addressing the flood-water mosquito problems associate with Florida's many salt marshes, pastures, glades, and irrigated citrus would require a major research commitment, and so he launched plans for the creation of a research laboratory in Vero Beach. Mosquitoes were so thick it was easy to generate local support for any control effort, and Maury had the backing of his politically astute Bureau Chief, John Mulrennan Sr.

Land was donated by Indian River County, and a special state appropriation funded construction of the initial facilities that opened in 1957 (Fig. 3). Maury knew it would take a long-term commitment and more resources and patience than he could expect from a non-research oriented health agency. Thus, he launched his strategy of applying for NIH grants to support basic research and collaboration with local mosquito control districts for the conduct of more short-term applied research. This strategy was highly successful, and research funding and staff grew rapidly. The lab had four Sections: Ethology, Ecology, and Physiology to conduct basic research, and a Control section to address operational issues of more immediate concern. When the Control section was surreptitiously removed to form a separate laboratory at Panama City in 1964, it disrupted Maury's master plan for a balance between basic and applied research. He quietly accepted the political reality and replaced the Control Section with a Biochemistry Section, an entomological field just coming into its own. He also consolidated the small chironomid midge substation at Winter Haven and used the associated positions and resources to develop a stronger salt marsh management effort within the Ecology section. The ecology research group, which included Maury and the mosquito control district directors in Indian River and Brevard counties, developed and fine-tuned salt marsh impoundments to prevent mosquito egg deposition. This control strategy effectively freed large areas of Florida's East Coast from the traditional hordes of salt marsh mosquitoes. Importantly to Maury, it did so without the extensive use of persistent insecticides.

Along with the expanding research capability at Vero Beach came the first major epidemic of St. Louis encephalitis (SLE) in Florida, near Tampa and St. Petersburg (1959-63). This provided the 3rd major mosquito research challenge in Maury's career, after malaria and salt marsh mosquito control. The SLE epidemic led to creation of the Encephalitis Research Laboratory in Tampa. Maury forged close ties with this new laboratory and enlarged the research focus in Vero Beach to include studies on birds and *Culex nigripalpus*. This mosquito was quickly shown to be the major vector transmitting SLE virus in Florida, both among birds and to dead-end human hosts.

I arrived at the FMEL during this period and began studying the blood-feeding behavior of Florida's mosquitoes. While waiting for the funds from Maury's new NIH grant, I became involved in several ongoing research projects and, despite my youth and naiveté about the subtropics, I quickly grew to appreciate how the Provost philosophy had permeated the way research was ap-

Fig. 3. The Florida Medical Entomology Laboratory at Vero Beach, Florida, as dedicated in 1957.

proached at the laboratory. When I interviewed with Maury, he explained that research ideas at the FMEL were usually generated from field observations, then brought into the laboratory for experimentation and clarification under controlled conditions, and finally taken back to the field and verified again whenever possible. He also explained that most U.S. university researchers did not have the benefit of Florida's long subtropical field season or the opportunity to engage in large, multi-year field studies utilizing the pooled talents of many different scientists all focusing on the same insect. Maury was a proponent of team research long before current biological complexity and rapid technological change forced this realization on the entire research community. He felt that the key to understanding the biology of insects was to be able to bridge field and laboratory based science, an approach that is now gaining many new proponents in medical entomology. For example, genetically modified mosquitoes can be created through novel technology but their population dynamics must be understood before they can be used for mosquito control.

I was personally involved in research at Vero Beach that exemplified Maury's approach. In his many field experiments on the movement of salt marsh mosquitoes, *Ae. taeniorhynychus*, Maury and colleagues observed that dense adult populations emerged synchronously in the salt marsh during the day and engaged in a mass exodus at first twilight. Much swarming and mating behavior preceded their departure, perhaps because they would never find each other again following distant migration. At the same time, Arden Lea and colleagues at the FMEL were engaged in laboratory experiments on the endocrine control of behavior, including mating. They noted that *Aedes aegypti* and other mosquitoes, including a colony of *Ae. taeniorhynchus*, would mate soon after emergence but successful sperm transfer did not take place unless females were 30-40 hr old. This raised doubts about whether the *Ae. taeniorhynchus* observed mating prior to their exodus from the marsh were actually being inseminated. A large field experiment with newly-emerged, dye-marked *Ae. taeniorhynchus* was subsequently conducted on an inland. Indeed, observations alone can sometimes be misleading, for no fertilized females <30 hrs old were recovered in the field.

The advent of West Nile virus (WNV) in the U.S. has revealed how little is still known about many of our most important vector species. The current epidemic also exposed a general deterioration of the public health infrastructure in most states. When WNV arrived, New York City no longer had a mosquito control program, anyone who could identify mosquitoes, or equipment for surveillance and operational mosquito control. An emergency response was mounted with the assistance of the Centers for Disease Control and Prevention (CDC), neighboring states, and private contractors. New York City was forced to use 30-year-old control technology that had not been properly evaluated for effectiveness in a disease control emergency. New, innovative technologies are needed for detecting pathogens, predicting risk, and controlling vectors. Until we better understand mosquito vectors and the cycles of diseases they transmit, we will continue to be vulnerable to natural, accidental, and intentionally caused epidemics. The ongoing WNV epidemic in the U.S., with over 4,000 cases and nearly 300 deaths in 2002, provides a strong argument for a dramatic increase in the kind of research advocated and conducted by Maury Provost.

The large body of research on salt marsh *Aedes* generated by Maury and the staff at the FMEL was published after his death in a monograph dedicated to him (Nayar 1985). Maury contributed a summary of the life history of *Cx. nigripalpis* in a monograph on St. Louis encephalitis published by the Florida State Board of Health (Provost 1969). Much has been added to our knowledge about mosquitoes since Maury's pioneering work, but he was responsible for providing the basis for conducting meaningful research on mosquito biology.

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