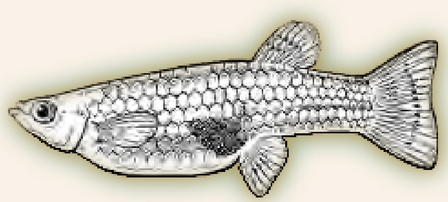
The New Orleans Experience: Using Gambusia to Control Mosquito Larvae in Abandoned Swimming Pools by Gerald Marten, Cynthia Harrison, Mieu Nguyen, Stephen Sackett, Gregory Thompson, Michael Carroll & Claudia Riegel

On August 29, 2005, Hurricane Katrina brought New Orleans a flood of unexpected and devastating consequences. Among them was the sudden creation of several thousand unattended swimming pools, littered with fallen trees, furniture, and other household goods and debris from the hurricane and receding flood waters. The mucky water in the pools provided ideal habitat for vectors of West Nile virus, eastern equine encephalitis, and St Louis encephalitis. During the months immediately following the hurricane, many of the pools were infested with large numbers of *Culiseta inornata*, *Culex quinquefasciatus*, and *Cx salinarius* larvae. There were few people in New Orleans at that time, but no one knew whether this unprecedented mosquito production would set in motion a serious disease outbreak when people returned. Many people would be living in trailers for extended periods, exposing them to mosquitoes.

The City of New Orleans Mosquito, Termite and Rodent Control Board (Mosquito Control) needed to take decisive action as quickly as possible, despite the fact that the city was in shock and preoccupied with an overwhelming roster of cleanup and reconstruction activities. Covering the pools was not a long-term solution because covers could collect rainwater that would continue to provide habitat. Covers could also be hazardous, particularly for children. Larviciding clearly had a role, but it was out of the question to rely entirely on larvicides because Mosquito Control lacked the staff to treat so many pools on a continuing basis.

Fish seemed most promising because a single treatment could provide long-lasting control. The effectiveness of fish was apparent in pools that already contained them from the Katrina flood, a natural stocking of approximately 750 pools with mosquito fish, mollies, killifish, and minnows. In January 2006, a decision was made to introduce fish to all unmaintained swimming pools. Thus began a program of emergency mosquito control for a city in disarray, a program that sometimes had to proceed under makeshift conditions and with less than adequate information, and which continued to be extremely challenging for several years.

Before Hurricane Katrina, Mosquito Control sometimes trapped local killifish or mollies for introduction to unmaintained swimming pools, but a larger fish supply was needed on a regular basis. After several months of searching, a catfish farm with large numbers of *Gambusia affinis* was found in Mississippi. Twenty thousand fish at a time were transferred by truck from the catfish farm to New Orleans for holding in two 18-foot-diameter, above-ground, aerated swimming pools. Fish introductions began in April 2006 and continued throughout the hot New Orleans summer.



Transporting fish from the holding tanks to swimming pools was an enormous job. Fortunately, the non-profit organization Operation Blessing provided out-of-town volunteers to assist Mosquito Control staff. Each morning an assembly line netted fish from the holding tanks, counted out approximately 50 fish by pouring them into a calibrated cylinder, poured those fish into a plastic bag, and put oxygen into the bags. The bags were transported to the pools in large coolers (without ice) in the back of pickup trucks that set out for the entire day. The crews worked with swimming pool address lists compiled from records of real estate listings and several thousand backyard inspections conducted during the previous months. Later, Mosquito Control staff used a Pictometry® aerial photo system and Google Map to survey every street by computer, viewing overhead photos to retrieve the addresses of houses with pools; see Figure 1. In the end, field teams inspected 4,651 pools to ascertain whether they needed fish.

Figure 1: Aerial photos showing the same swimming pools before Hurricane Katrina (top) and after Katrina (bottom). The clean swimming pools before Katrina are turquoise; the unmaintained swimming pools after Katrina are brown. Source: Pictometry.

One bag of fish was poured into each pool, and VectoLex® (*Bacillus sphaericus*) was applied to suppress mosquito production until the fish established a larger population. As the City was under a state of emergency due to public health threats, Mosquito Control crews had the authority to enter backyards even if no one was at the house. This was usually easy, but if the gates were locked, the policy was not to risk injury by climbing fences. Instead, a plastic bag containing fish, and arranged to open on impact, was lobbed over the fence and into the pool.

Fish were introduced to 1,278 unmaintained pools by September 2006. In October, field teams began returning to pools to check on the fish where they had already been introduced. Assessments were based on seeing fish or their characteristic ripples. As winter set in, some of the inspections revealed no fish, which could have been due to inactivity with pool temperatures as low as 11 °C. Various fish traps and nets were used to check the pools for fish, but we never found a completely reliable assessment method for the winter. The following spring, quality control tests were run with each inspection crew to assess the presence or absence of fish in pools that were independently known to contain fish or not. They confirmed visual assessment to be completely reliable outside the winter season.

By September 2007, the inspections extended to 600 pools that received fish the previous year, and 86% of those pools contained fish. *Gambusia* were reintroduced to pools where they had not survived, and they were introduced to hundreds of additional pools that were newly identified as abandoned. A few pools did not receive fish in order to monitor adult mosquito populations in the surrounding area.

How effective were the fish at preventing mosquito production? Very effective, but not a hundred percent. During 5,883 pool inspections in 2006-2008, mosquito larvae were observed in 2.2% of the pools that contained fish, compared to 36% of the pools without fish. *Culex quinquefasciatus* and *Anopheles (An crucians* and *An quadrimaculatus)* were most common. *Cx quinquefasciatus* larvae were seen throughout

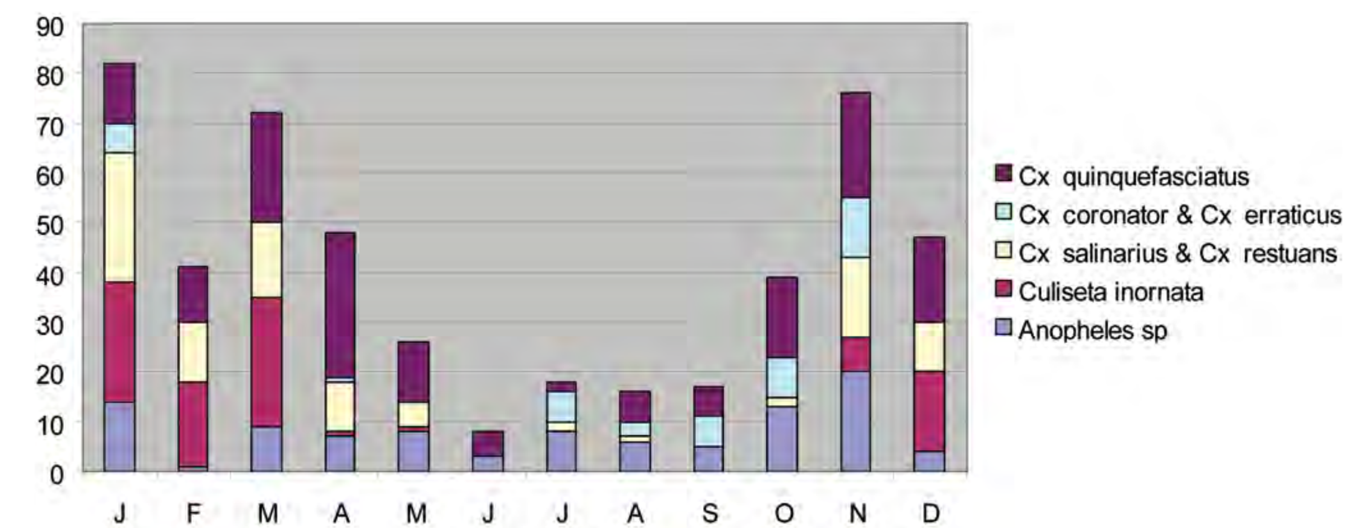


Figure 2: Seasonal frequency graph, showing the relative number of unmaintained swimming pools (without fish) in which various species of mosquito larvae were found each month, 2006 through 2008.

the year in pools without fish. They were sometimes very numerous, though less common during the summer; see Figure 2. *Anopheles* larvae were also observed throughout the year, but their numbers were seldom large. *Culiseta inornata* could be very numerous during November to March, *Cx salinarius* during November to May, and *Cx coronator* during July to November.

Most larvae in pools with fish were *Anopheles*, sometimes present even when fish were abundant. *Cx quinquefasciatus* were observed only where fish numbers were low. Other mosquito species were almost never seen in pools with fish.

In 2007, we initiated a research program to help guide the operational program. It was encouraging that so many pools had fish after the introductions in 2006, but we needed to understand why fish were missing from 14% of those pools. We wanted to know:

- Did the fish fail to take hold in some of the pools to which they were introduced? Was this still a problem for introductions underway?

- Did fish take hold after introduction, but drop out of the pools later? Were they continuing to disappear from pools in which they were established?

- Was there still a fish survival problem in the pools?

- How were ecological conditions in the pools affecting larval abundance, fish abundance, and the effectiveness of fish for larval control?

We monitored a selection of pools for an extended period after introducing fish. We also conducted experiments to address specific concerns. For example, it was not unusual to see empty bleach bottles because people had dumped bleach in a dirty pool to "clean it up." However, bleach could wipe out the fish and other aquatic predators, converting a pool into prime mosquito habitat if left unmaintained. To gain perspective, we poured four

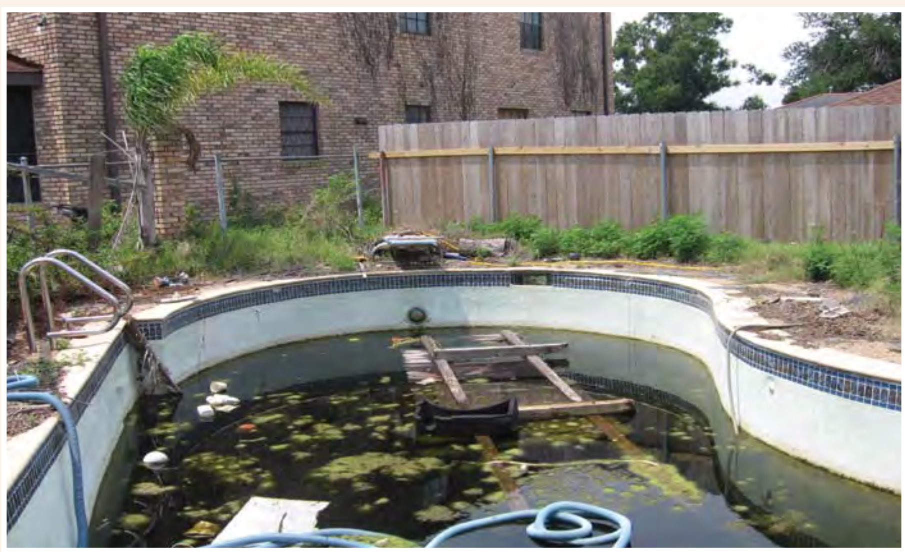


Figure 3: A pool treated experimentally with bleach to see its impact on the fish population. Fish normally thrived in this pool. Dumping four gallons of bleach led to high fish mortality, but the fish population recovered within a month.

gallons of bleach into each of three pools with thriving *Gambusia* populations, creating a chlorine concentration of 0.1-0.5 ppm. Massive fish deaths followed. No fish were observed in any of the pools the next day, but every pool had a thriving population within a month, despite the fact no fish were reintroduced to those pools; see Figure 3.

We observed a disturbing number of partially drained pools with only one or two feet of water at the bottom, no fish, and numerous mosquito larvae. The owners had drained the pools, killing all the fish and leaving the pools to collect rainwater after that. If the pool contained much trash, the organic pollution could be particularly severe in shallow water, creating ideal habitat for *Cx quinquefasciatus*. Because well-intentioned but counterproductive homeowner interventions were a problem, a sign was left at every inspected swimming pool informing the owner that the pool was under Mosquito Control management, urging the owner not to add chemicals that could injure the fish, and requesting the owner to notify Mosquito Control if the pool was drained or filled in.

Figure 4: The turbid, foul-smelling water of the "severe organic pollution" ecotype provided particularly favorable habitat for *Cx quinquefasciatus* larvae. *Gambusia* tolerated low oxygen in this ecotype but suffered if ammonia was high. Mieu Nguyen is inspecting the pool.

Figure 5: This above-ground swimming pool displays the turbid water characteristic of the "severe organic pollution" ecotype.

The research program included systematic data collection with regard to physical conditions, water quality, trash (eg, wood, furniture, and other household goods), leaves and branches, aquatic vegetation, aquatic insect predators, mosquito larvae, and fish at several hundred swimming pools. A temperature range of 11-35 °C, a pH range of 6-9, and a salinity range of 0.1-10 ppt observed in the various pools over the course of a year were comfortably within the published tolerances for *Gambusia*. We suspected that high concentrations of nitrite, which is toxic to aquatic animals, could be a problem, but the fish appeared to be unaffected at the highest nitrite concentration observed (2 ppm). Toxic chlorine concentrations were observed on a few occasions.

The data revealed four main swimming pool ecotypes. Some pools fell clearly within a single ecotype, while others displayed the characteristics of more than one. (Swimming pool photos were taken by Cynthia Harrison.)

1. Severe organic pollution; see Figures 4 and 5. Turbid and foul-smelling water, associated with fallen tree branches, trash, and other rotting materials, provided particularly favorable habitat for *Cx quinquefasciatus* larvae when there were no fish in a pool. This ecotype was particularly common during the first year after Katrina, with the pollution declining gradually after that, so it was much less noticeable by the third year. Fish generally provided effective mosquito control in this ecotype, except when organic loading was extreme. We were particularly concerned about the low oxygen concentrations and high levels of ammonia that could accompany organic pollution. It turned out that oxygen was not a problem. *Gambusia* thrived in many pools with no measurable oxygen. However, high ammonia concentrations of 10-40 ppm, though rare in occurrence, were distinctly associated with smaller fish populations.

Figure 6: The "ecologically productive without pollution" ecotype supported large populations of aquatic insects and provided favorable habitat for *Anopheles* larvae, which avoided fish predation by clinging to floating pine needles, floating sticks, or grass around the edge of a pool.

2. Ecologically productive without pollution; see Figure 6. This ecotype lacked the putrid conditions and numerous *Cx quinquefasciatus larvae* so characteristic of organically polluted pools. These pools were somewhat saline, suggesting that they had been flooded with brackish water from Lake Pontchartrain. Aquatic insects such as water boatmen, dragonfly nymphs, and water striders were often abundant, along with *Anopheles* and *Cx salinarius* larvae. Conditions favorable for one seemed favorable for all. *Gambusia* did well in this ecotype and eliminated *Culex* larvae, but *Anopheles* larvae frequently coexisted in small numbers with the fish, apparently because the larvae could avoid fish predation by clinging to floating pine needles, small floating sticks, or grass around the edge of a pool.

Figure 7: The "oak leaves" ecotype provided favorable habitat for *Culex* and *Anopheles* larvae, but supported relatively few fish. A Mosquito Control sign with information for homeowners is in the background.

3. Oak leaves; see Figure 7. Pools with a large number of oak leaves, and distinctively brown water from tannins in the leaves, provided favorable habitat for *Culex* and *Anopheles* larvae and water boatmen. *Gambusia* survived in this ecotype, but their populations were generally low. Mosquito larvae were sometimes observed when fish were in a pool.

4. Floating algal mats; see Figure 8. Dense mats of filamentous algae were most prominent in the summer, sometimes almost completely covering a pool. The clear water, shaded by the mats, supported few mosquito larvae even in the absence of fish. Backswimmers and diving beetles were often common if fish were not present. Fish thrived in this ecotype, and mosquito larvae were virtually absent if fish were present.

Why were fish missing from 14% of the pools to which they were introduced in 2006? Some of the introductions during 2006 simply failed to take hold in the first place. Dumping bleach was counterproductive, and draining pools could wipe out the fish, but this was not happening on a scale to explain so many pools without fish. While some pools were probably too polluted in 2006 for fish to survive, we concluded that the main problem was trauma during transport from holding tank to pool. The pace was intense, and the fish sometimes appeared in poor condition (swimming at a slant and moving erratically) when poured from the plastic bag into a pool, particularly if it was hot and they had been in the bag for the entire day. The success rate of *Gambusia* introductions during 2006 improved with experience. While 84% percent of the pools to which fish were introduced during the first two months of the program still had fish when next inspected, this measure of success increased month by month to 95% for pools receiving introductions late in the year. By 2007-2008 the pollution had declined significantly, and the smaller number of introductions at that time allowed more careful attention to the fish, including rapid transport to pools. Every monitored *Gambusia* introduction during 2007-2008 led to a thriving population within a month – an introduction success rate of 100% – and the population in every pool lasted for as long as the pool contained water.

Figure 8: The "floating algal mats" ecotype supported few mosquito larvae. Fish thrived when introduced to this ecotype.

Experience with the swimming pools taught us some lessons that could be of use to others for disaster readiness planning. For example, it is best to line up a reliable source of fish in advance. It took us several months to track down a supply for such large-scale use.

We also used larvicides, mainly VectoLex, to suppress mosquito production until the fish took over. VectoLex does not kill *Anopheles* larvae but is known for its effectiveness and residual capacity against *Culex*. We could count on a single VectoLex application to kill all the *Culex* and *Culiseta* larvae in a swimming pool within a day or two. However, the residual period in such deep water was limited because *Bacillus sphaericus* eventually sank to the bottom while the mosquito larvae fed mainly at the top. We found that VectoLex reliably killed all new larvae for only a few days after application, though complete kill extended for as much as 10 days in pools with heavy organic loading.

Locating swimming pools was a challenge when searching through a hundred thousand houses in a city devoid of residents over areas extending for miles. The Pictometry aerial photo system, Google Earth, and real estate listing records proved invaluable for tabulating the addresses of houses with pools. Up-to-date photos showed whether pools were maintained.

Cleaning trash out of pools was basic habitat management because organic detritus fueled the food web leading to mosquito larvae. Putrid conditions, which could last for more than a year if not corrected, were ideal for *Culex* larvae and stressful for fish. Trash of any kind provided refuge for *Anopheles* larvae to evade predators.

Healthy fish were a key to successful introduction. Careful handling, limiting the transport time from holding tanks to swimming pools to a few hours, and watching for signs of stress were important. At first, we transported the fish in a separate plastic bag for each pool, but later we stopped using the plastic bags, transporting all the fish for one trip together in a large cooler. It saved work, and the fish arrived in good condition.

Use of the media for clear communication with the public about what was happening and what was expected from the public helped pave the way for reconnaissance and fish-introduction teams. Wherever we introduced fish, we posted a sign with key information for homeowners. Access to properties was a concern when residents were not at home and gates were locked. The legal basis for access should be clear, and the public should be thoroughly informed about policies and procedures in this regard.

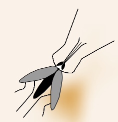
Systematic records were essential. They can be simple. At every visit we recorded the state of pool maintenance, whether fish were already in the pool, whether larvicide was applied to the pool at the time of the visit, whether fish were introduced, and whether there were mosquito larvae in the pool. If there were larvae, we took a standard number of dips and a sample for identification. The number of pools without fish after the introductions in 2006 caught us by surprise. Particularly at the beginning of a program, pools should be checked about a month after fish introduction to make sure they contain viable populations.

Non-profit organizations can offer exceptional flexibility for providing resources and other forms of assistance after a disaster. Volunteers were particularly important for an enterprise of this scale. Careful supervision and training of volunteers was essential because volunteer turnover was often high, most volunteers had no experience with this kind of work, and the calamitous conditions after Katrina hindered orderly operations. The general practice was to have a Mosquito Control staff person working directly alongside volunteers at all times.

Organizational self-sufficiency helped to get things done under chaotic conditions. Coordination with other agencies was necessary and beneficial, but it was not wise to be totally dependent. Although other City agencies had to focus on their own post-Katrina priorities, we were fortunate to receive valuable assistance from state and federal sources.

In conclusion, the fish introductions were well worth the effort. It was a strenuous couple of years, but ultimately satisfying for everyone involved. Using mosquito larvae in unmaintained swimming pools without fish as an indicator of adult mosquito populations, 53% percent of those pools contained larvae during March-August 2006, when fish were not yet established in many of the pools. This figure dropped to finding larvae in only 8% of pools without fish during the same months in 2007 and 6% in 2008, indicating a dramatic decrease in adult mosquito populations from 2006 to 2007-2008. There was a surge in West Nile virus after Hurricane Katrina, 12 cases in Orleans Parish in 2006 compared to the one or two cases during the two years preceding Katrina. West Nile virus dropped to two cases per year in 2007-2008 and no cases have been reported since then.

While many of the swimming pools that needed emergency fish introductions in 2006 are now maintained by their owners or have been filled in, fish still provide mosquito control in approximately 600 of those pools. Additional unmaintained pools have come into the system in recent years due to home mortgage foreclosures and other causes unrelated to Hurricane Katrina. Further details about this story and the research program can be found at www.gerrymarten.com/swimmingpoolsneworleans.html.



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