A COMPARISON STUDY OF GRAVID AND UNDER HOUSE CO2 MOSQUITO TRAPS IN HARRIS COUNTY, TEXAS

A Thesis

by

STEPHANIE LYN WHITE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2008

Major Subject: Veterinary Public Health

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Approved by:

Chair of Committee,	Michael P. Ward
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ABSTRACT

A Comparison Study of Gravid and Under House CO2 Mosquito

Traps in Harris County, Texas. (May 2008)

Stephanie Lyn White, B.S.; B.S., Texas A&M University

Chair of Advisory Committee: Dr. Michael P. Ward

Harris County Mosquito Control Division (HCMCD) is responsible for surveillance of mosquito species that are vectors of St. Louis Encephalitis (SLE) virus and West Nile Virus (WNV) within Harris County, Texas, including the Houston metroplex. The metroplex area has some unique attributes and a vast variety of environmental habitats that are attractive to vectors of arboviruses and for the transmission of arboviruses to the human population. Data describing the efficacy of Gravid (GV) and Underhouse (UH) CO2 traps were analyzed to determine if there is a significant difference between these two trap types with respect to the number of mosquitoes and the variety of mosquito species caught. This study was conducted during the off-peak HCMCD trapping season, to gain information in preparation for a year-round trapping program utilizing Underhouse CO2 traps for WNV and SLE virus surveillance.

Adjusting for the week of collection, results suggest that Gravid traps caught significantly ($P = 0.009$) more mosquitoes (mean = 23.134 per trap) in the study area than Underhouse traps (mean = 3.616 per trap), and that Underhouse Traps caught a larger variety of mosquito species (n = 13) than Gravid Traps (n = 11), out of 15 total different species caught. Gravid and Underhouse traps caught 9 out of 15 of the same mosquito species during the study period. *Culex quinquefasciatus* mosquito catches in Gravid traps and temperature were strongly correlated (Spearman's Correlation Coefficient = 0.707, P = 0.005).

Geographic Information System spatial analysis indicated clustering of *Culex quinquefasciatus* mosquito catches in both Gravid traps, week 9 and 21 (Moran's I = 0.69, P = 0.040 and 0.74, P = 0.021, respectfully) and Underhouse traps, week 13 and 19 (Moran's I = 0.92, P = 0.002, and 0.89, P = 0.011, respectfully).

It is recommended that Harris County Mosquito Control Division continue to utilize gravid traps as a primary method of surveillance. Gravid traps (16,194) caught 85% more mosquitoes than Underhouse traps (2,531) over the fourteen week study period. Their overall success far outweighs the additional materials or labor required for their use in a successful surveillance program.

DEDICATION

I dedicate this project to my husband, Mike and my family for all their love, and unwavering support and patience. Without their help, I would not have been able to dedicate myself to my schoolwork and forgo concern of who was tending the home fires while I was away. Special thanks goes to my husband for working extra jobs, helping me juggle my military commitments and never making me feel less for not contributing equally to our household. I promise the hard work and wait will be worth it in the long run.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Ward, and my committee members, Dr. Budke, Dr. Cyr, and Dr Bueno, Jr., for their guidance and support throughout the course of this research.

Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience. I also want to extend my gratitude to the Harris County Mosquito Control Division, which provided the trapping equipment, labor, and expertise to help make this project a success.

Finally, I owe great thanks to Dr Jimmy Olson who sparked my interest in Medical Entomology and opened a whole new world to me.

NOMENCLATURE

Aeab	*Aedes albopictus*
Aeae	*Aedes aegypti*
ANOVA	Analysis of Variance
ArcGIS	Arc Geographic Information System
CDC	Centers for Disease Control and Prevention
Cxqf	*Culex quinquefasciatus*
Cxrs	*Culex restuans*
DNA	Deoxyribonucleic Acid
GIS	Geographic Information System
GLM	General Linear Model
GPS	Global Positioning System
GV	Gravid Trap
HCMCD	Harris County Mosquito Control Division
IDW	Inverse Density Weighted
MCD	Mosquito Control Division
PCR	Polymerase Chain Reaction
SLE	St. Louis Encephalitis
SPSS	Statistical Package for the Social Sciences
UH	Underhouse Trap
WNV	West Nile Virus

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1. INTRODUCTION: ST. LOUIS ENCEPHALITIS AND WEST NILE VIRUS - HISTORICALLY SIGNIFICANT ARBOVIRUSES

1.1 Public Health Impact of Arboviruses

Arbovirus is a descriptive term for a virus that is transmitted to humans or animals via a blood-feeding arthropod, such as a mosquito or tick (CDC 2005b, Eidson et al. 2001a). Past and present arboviruses of public health concern in the United States include Yellow Fever, Dengue, Eastern/Western/Venezuelan Equine Encephalitis, St. Louis Encephalitis, Rift Valley Fever, and West Nile Virus (Calisher 1994, Gubler 2001, 2002, Kuno and Chang 2005). Gubler (2001, 2002) reports that there are 534 viruses registered with the International Catalogue of Arboviruses. Of these, 134 have been shown to cause disease in humans. Arboviruses are found in eight taxonomic families. The three families containing the viruses of greatest public health concern are *Bunyaviridae, Flaviviridae,* and *Togaviridae* (see Table 1). Most arboviruses identified to date are not native to the United States, but are instead found in tropical regions. However, several changes in environment and human demographics have exposed people to a greater chance of exposure to the host or reservoirs of these viruses (Morse 1995).

This thesis follows the style of Vector-Borne and Zoonotic Diseases.

Table 1. Common Arboviruses of Public Health Concern.

Family/Virus	Vector	Vertebrate Host	Geographic Distribution
Bunyaviridae			
Rift Valley Fever	Mosquito	Unknown	Africa, Middle East, Asia
Sandfly Fever	Sandfly	Unknown	Europe, Africa, Asia
Flaviviridae			
Dengue Type 1-4	Mosquito	Human, primate	Worldwide in tropics
Yellow Fever	Mosquito	Human, primate	Africa, South America
Japanese Encephalitis	Mosquito	Bird, pig	Asia, Pacific
St. Louis Encephalitis	Mosquito	Bird	Americas
West Nile	Mosquito	Bird	Africa, Asia, Europe, US
Togaviridae			
Eastern Equine Encephalitis	Mosquito	Bird	Americas
Western Equine Encephalitis	Mosquito	Bird, rabbit	Americas
Venezuelan Equine Encephalitis	Mosquito	Rodent	Americas

Several changes have occurred in the last thirty years that contribute to exposure to reservoirs and arthropods carrying arboviruses. These changes include: ecological changes (for example, deforestation/reforestation), human demographics (including urbanization), international travel, trade, and deficits in the public health system (Calisher 1994, Gubler 2001, 2002, Kuno and Chang 2005, Morse 1995). Ecological changes and human demographics often go hand-in-hand as man's population continues to increase, causing habitation or destruction of ecological systems where reservoirs and arthropods are present. One example that includes both phenomena is deforestation or clearing for housing. This action disturbs the existing ecological system and places humans in closer contact to both mammals and arthropods native to that system. In addition, arthropods are exposed to a new potential blood meal source – humans or increased vertebrate populations, which were not there previously. The opposite involves reforestation efforts in which the newly reconstructed areas support new mammal and arthropod populations (for example, deer and ticks), which are now in close proximity to humans and present additional blood meal sources (Gubler 1996, 2001, 2002, Kuno and Chang 2005, Morse 1995). A second change that has increased potential exposure to arboviruses is international travel and trade. Today, international travel is available to a greater proportion of the population. The United States also has a liberal immigration policy that allows for people from all over the world to enter with few restrictions with respect to health (CFR 2007). Individuals can enter from areas where a foreign arbovirus is prevalent, thus allowing for a potential bridge for infection. People can now travel abroad to high risk areas, become infected and then return to the United States even before they become symptomatic and know they are sick (Gubler 1996, 2002, Morse 1995). International trade has grown exponentially over the last few decades, allowing goods from all over the world to be imported into the United States. An example is that of the important arbovirus vector *Aedes albopictus* (the Asian "tiger" mosquito) which is thought to have entered the United States via importation of used tires from northern Asia (Moore and Mitchell 1997, Sprenger and Wuithiranyagool 1986). The presence of *Aedes albopictus*, a known vector for Yellow Fever and Dengue in the United States was first reported in Harris County, Texas in 1985 (Sprenger and Wuithiranyagool 1986) and it has continued to flourish and spread mainly in the southeastern United States (CDC

2005a). A final contributing factor to an increased risk from arboviruses is a break down in the public health infrastructure itself (Gubler 2001, Morse 1995). Active surveillance programs are expensive, are logistically difficult to develop and operate, and require a large amount of labor. Compounding the problem is declining state, county, and city public health budgets and a public that is increasingly concerned with spraying and trapping operations in their local neighborhood.

There are several arboviruses that can impact public health. However, the arboviral encephalides are at the forefront of public health concerns. Specifically, in the United States these are St. Louis Encephalitis (SLE) virus and West Nile Encephalitis Virus (WNV). SLE virus and WNV are both arboviruses in the genus *Flavivirus* and family *Flaviviridae*. Infection can cause meningoencephalitis (inflammation of the brain and surrounding meningeal tissues) in more severe cases, and epidemics of disease can occur (Komar 2003, Reisen 2003). However, only a small proportion of human infections usually become symptomatic and progress to encephalitis (CDC 2005b, Reisen 2003). The majority of human infections are typically asymptomatic or mimic flu-like symptoms (fever, headache, myalgias, malaise, and occasionally prostration) (CDC 2005c) and resolve without further treatment. There are currently no human vaccines to prevent WNV or SLE encephalitides and because they are viral infections, common antibiotics are not effective in their treatment. Like other viral infections, their treatment consists of supportive therapy and treatment of symptoms rather than the underlying cause. Lack of effective vaccines or antiviral drugs dictates that preventive measures, such as surveillance, management of the environment and reducing the risk of exposure, are the primary means available to control many arboviruses and their vectors.

Figure 1 shows the typical transmission cycle of arboviruses. Wild birds serve as the reservoir for both WNV and SLE virus and are key to the transmission of these viruses, via mosquitoes, to humans. Birds cannot transmit these viruses directly to humans. Instead, they maintain the virus and mosquitoes are infected when they take a blood meal from an infectious bird. More than 300 species of birds in the United States have tested positive for WNV. The main difference between WNV and SLE virus, with respect to the impact on infected birds, is that WNV can cause morbidity and mortality in certain species (for example, blue jays and crows) whereas SLE does not. Birds are often used as sentinels to provide early warning of the presence of virus within an area; such monitoring of SLE virus and WNV activity is important in the latter phases of the transmission season.

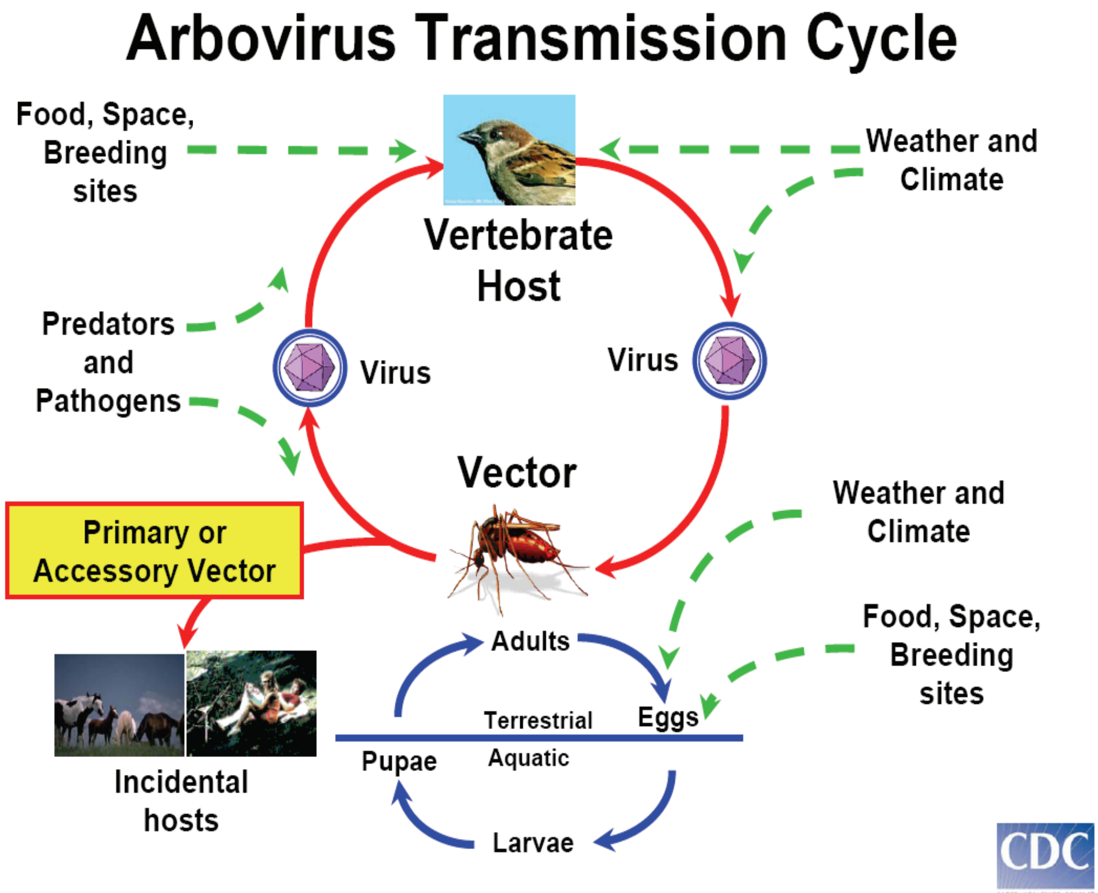

FIG. 1. Arbovirus Transmission Cycle. (CDC 2007).

1.2 Mosquito Species of Concern for Disease Transmission

According to CDC's West Nile website (2007c), there are currently 62 species of mosquitoes in the United States from which WNV has been isolated, or in which West Nile Virus RNA or West Nile Virus antigen was detected using various laboratory detection methods. The study area for this project was Harris County, Texas, and therefore the focus of this section is on the four mosquito species that the Harris County Mosquito Control Division (HCMCD) considers the vectors of greatest importance for transmission of SLE virus and WNV. There are over 3000 species of mosquitoes worldwide, but only 55 can be found in Harris County. The main vector of WNV/SLE virus in Harris County is *Culex quinquefasciatus* (the southern house mosquito). WNV has been isolated from several other species of mosquitoes identified in Harris County, including *Aedes aegypti* (the yellow fever mosquito) and *Culex restuans* (the white dotted mosquito). MCD also considers *Aedes albopictus* (the Asian tiger mosquito) an important transmitter of WNV to humans in the Harris County area, based on their historical collection and testing data.

There are a few concepts discussed below that should be explained beforehand to fully appreciate their meaning within the text. An amplifying vector is one that builds up the prevalence of an arbovirus in the avian hosts. Mosquitoes that are primarily avian feeders are considered amplifiers. They continually feed on infected birds and then on non-infected birds, transmitting the virus to the non-infected bird. A bridge vector is a vector that feeds on both birds and mammals and therefore can transmit the virus from infected birds to other mammals, such as humans and horses. *Culex quinquefasciatus* is both an avian and mammalian feeder that seeks its hosts primarily in the nighttime hours. It has a short flying range, probably < 1 mile from larval breeding sites. This species prefers to lay its eggs in standing water containing organic material, such as found in rainwater buckets, cesspools, and ditches. Storm sewers are also a common resting and breeding place in urban and suburban environments. *Culex quinquefasciatus* is approximately ½mm to 1mm in size, dirty brown in color with pale abdominal bands that narrow laterally. In warmer areas, this species tends to be active throughout the year, although with somewhat reduced populations during cooler months. *Culex quinquefasciatus* has been identified in laboratory testing as a very efficient vector for WNV with extremely efficient enzootic (or amplifying) vector potential and an efficient bridge vector potential, largely due to its avian and mammalian feeding tendencies. *Culex quinquefasciatus* also has been associated with transmission of SLE virus (Goddard et al. 2002, Komar 2003, Sardelis et al. 2001, Turell et al. 2005).

Culex restuans is another nighttime bird feeder, which occasionally feeds on humans. This species is a cooler weather mosquito, often seen in late fall and early spring in Texas. Their egg laying preference is also in stagnant pools of ground water (clear or containing organic matter) and this species often prefers artificial containers with standing water, such as old tires. *Culex restuans* is small, with a golden brown coloration, two pale spots on either side of its mesonotum and pale non-narrowing abdominal bands. *Culex restuans* has been identified with naturally occurring WNV infection. Laboratory testing has shown *Culex restuans* to have extremely efficient vector competence with very efficient enzootic vector potential and an efficient bridge vector potential (Sardelis et al, 2001, Turell et al. 2005).

Aedes albopictus and *Aedes aegypti* seek water-filled containers (such as tires, children's swimming pools, or buckets) to lay their eggs. Eggs are laid singly, along the sides of the containers just at the water level or on the surface. Both of these species are daytime feeders, preferring early morning to late afternoon, feed on humans, and have a very short flight range of usually less than half a mile. In addition, *Aedes albopictus* feeds on dogs, rabbits, humans, other mammals, and birds, which make it a good vector species for virus transmission. These are ornate mosquito species, each having silver-white and black patterns and stripes. *Aedes aegypti* has a silver-white "lyre shaped" marking on the mesonotum accompanied by distinct banding on the tarsi. In contrast, *Aedes albopictus* has a silver-white stripe on the dorsal surface, which extends across its head and thorax, or mesonotum, and has distinct leg banding of the tarsi. *Aedes albopictus* has had a role in transmission of Dengue and *Aedes aegypti* has been involved in both Dengue and Yellow Fever transmission (Shroyer 1986). Both *Aedes albopictus* and *Aedes aegypti* have demonstrated the ability to serve as extremely efficient vectors for WNV in the laboratory (Sardelis et al. 2002, Tiawsirisup et al. 2005, Turell et al. 2001a, Turell et al. 2005). In addition, because *Aedes albopictus* is largely an opportunistic feeder, it has been identified as having extremely efficient potential as a bridge vector, with inefficient potential as an enzootic vector (Komar 2003, Sardelis et al. 2002, Tiawsirisup et al. 2004, Turell et al. 2001a, Turell et al. 2005). *Aedes aegypti* mainly feeds on mammals and thus shows no potential as an enzootic vector and inefficient bridge vector potential (Turell et al. 2001a, Turell et al. 2001b, Turell et al. 2005). See Table 2 for a list of mosquito characteristics.

Table 2. Mosquito Characteristics.

Species	Host Preference	Activity Time	Flight Range	Vector Competence for WNV	Potential to serve as: Enzootic Vector	Bridge Vector
C. quinquefasciatus	Birds	Night	1 mile	+++	++++	++
C. restuans	Birds	Night	1 mile	++++	+++++	++
A. aegypti	Mammals	Day	< .5 mile	+++	0	+
A. albopictus	Opportunistic	Day	< .5 mile	++++	+	++++

Table taken in part from Turell, 2005. Efficiency indicated by 0, incompetent, +, inefficient, ++, efficient, +++, very efficient, ++++/+++++ extremely efficient.

The mosquito goes through four stages in its life cycle: egg, larva, pupa, and adult (Figure 2). Each of these stages can be easily recognized by its unique appearance. *Culex* species lay eggs that clump together in groups of approximately 200 eggs called "rafts." Rafts float on the surface of the water. *Aedes* species lay their eggs singly in damp soil or surfaces that that are flood prone. In the study area, the complete cycle for the four mosquitoes described above takes on average approximately one to four weeks, based on various environmental conditions (HCMCD 2007). All mosquitoes require water to complete their life cycle, regardless of where they initially lay their eggs. Eggs are laid on the surface of water or in damp soil that will be flooded with water. Females can lay between 50 and 500 eggs at a time. Eggs develop over a two to six day period, after which they hatch and larvae emerge. Larvae live in water and go through four molts or instar stages, in which they shed their exoskeleton as they feed and outgrow it. The larval period can take four to ten days, and the fourth molt results in the pupa. Pupae continue to live in the water where the eggs were originally laid. They lay just beneath the surface of the water with two breathing tubes, called trumpets, connected to the surface so they can breathe. Although pupae do not feed, they are still very active. If danger approaches, they “tumble” to the bottom of the water until it is safe to return to the surface. This is a development stage, in which the mosquito is developing inside much like that of a butterfly in its cocoon. After approximately one to three days, the adult mosquito swallows air, increasing in size and splitting open the pupa so it can emerge. A newly emerged adult has wet wings and cannot fly immediately, so it rests on the surface of the water for a few minutes. The adult mosquito then flies away to nearby vegetation and rests while allowing the exoskeleton to dry and harden. The overall time to complete a life cycle largely depends on the individual characteristics of the mosquito species and environmental conditions such as rainfall and temperature. The life span of a female mosquito can last from just a few weeks to several months, while the male mosquito only survives a few weeks. Most female mosquitoes require a blood meal before their eggs can develop and be laid; therefore, the female mosquito is the “biter” of the two genders, while males feed on plant nectar for their subsistence. Knowledge of the mosquito life cycle is important in surveillance and control programs and will be discussed in a later section.

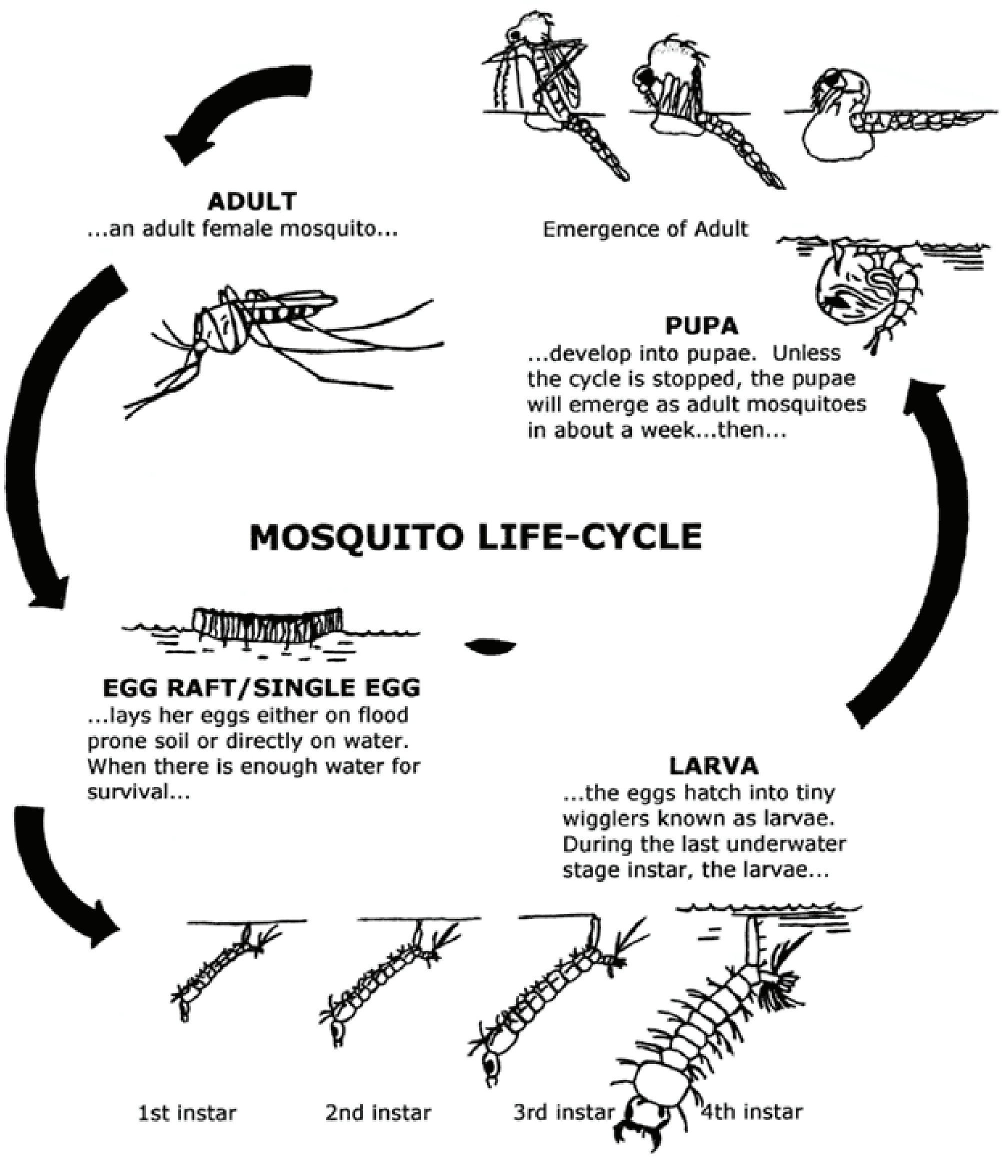

FIG. 2. Mosquito Life Cycle. (HCMCD 2007).

1.3 The Introduction of St. Louis Encephalitis Virus and West Nile Virus to the United States and Texas

In the 1800's, little was known about the exact role arthropods played in the transmission of diseases. It was only during the summer of 1900 when the Yellow Fever Commission was formed and sent to Columbia Barracks Hospital, just outside of Havana, Cuba, to study Yellow Fever that a definitive link was made between mosquitoes and disease transmission. The work of Walter Reed, James Carroll, Aristides Agramonte, and Jesse W. Lazear, all members of the U. S. Army Hospital Corps, laid the foundation for arbovirus research and future disease transmission discovery (Agramonte 2001). In the early 1990's, the school of thought largely still supported the "infectious disease" theory of direct contact transmission when confronted with outbreaks of disease. It was the infectious disease theory that initially presented itself when an outbreak of more than 1300 cases of encephalitis occurred in St. Louis City and the surrounding area of St. Louis County, Missouri, in late summer to early fall of 1933 (Lumsden 1958, Reisen 2003). The Surgeon General of the Public Health Service appointed epidemiologist Dr L. L. Lumsden to help investigate the encephalitis outbreak in St. Louis. Dr. Lumsden considered both insect transmission of the disease and the traditional contagious disease theory. After a careful and thorough investigation of the outbreak area and patients, Dr Lumsden concluded that the evidence supported the theory that the epidemic was a result of an organism, virus, or toxin transmitted to people by infected mosquitoes. He also named *Culex pipiens* and *Culex quinquefasciatus* as the possible vector species, based on the large mosquito populations in the vicinity of the outbreak (Lumsden 1958). The virus was later isolated and named St. Louis Encephalitis (Reisen 2003). St. Louis Encephalitis has continued to plague the United States: the largest numbers of cases have occurred in Texas (1954, 1956, 1964, and 1966), Missouri (1933 and 1937), Illinois (1975), Ohio (1975), Mississippi (1975), and Florida (1977 and 1990) (Luby et al. 1969, Reisen 2003). A transmission cycle involving peridomestic wild birds as reservoir hosts, and *Culex* species as a vector, was identified by an investigative team in the early 1940's (Luby et al. 1969, Reisen 2003). St. Louis Encephalitis virus was first isolated in 1955 from a naturally infected wild bird involved in an outbreak of SLE in Calvert City, Kentucky (Ranzenhofer et al. 1957). In subsequent years, it was noted that periods with above normal temperatures and below normal rainfall provided the ideal environmental combination for a SLE virus outbreak (Reisen 2003). The first description of St. Louis Encephalitis in Texas is in connection with an outbreak of encephalitis during the late summer of 1954 in Hidalgo County, in the lower Rio Grande Valley (Chin et al. 1957). In April 1954, the Governor of Texas declared Hidalgo County in a state of emergency and requested emergency mosquito control efforts to combat an overwhelming explosion in mosquito numbers. Above average rainfall in late spring led to pooling water and increased mosquito breeding areas causing an increase of mosquito population (Beadle et al. 1957). Control measures, such as larvicides for water treatment, adulticidal space spraying, and residual premise spraying, were employed from April 22 to May 8, 1954; by early May, adult mosquito populations were reported to be under control (Beadle et al. 1957). However, in late summer an increased number of cases with fever of an unknown origin were reported by physicians. This was the beginning of an encephalitis epidemic that lasted six weeks (Chin et al. 1957). Subsequent epidemiologic investigation revealed 373 cases of encephalitis, of which 10 (2.7%) died. Autopsies were performed on three victims and approximately 2000 mosquitoes were collected, using mosquito light traps, biting collections, and hand trapping mosquitoes in shelters, for further analysis. St. Louis Encephalitis virus was isolated from tissue samples of one victim and two pools of *Culex quinquefasciatus* mosquitoes (Beadle et al. 1957, Chin et al. 1957, Kunin and Chin 1957, Sullivan et al. 1957), confirming the first SLE outbreak in Texas. In 1957, a subsequent outbreak (114 cases) occurred in Cameron County, Texas (Luby et al. 1969).

In 1964, SLE appeared in Houston, Texas, for the first time (Luby et al. 1969). The epidemic lasted for fifteen weeks (late June through the beginning of October). There were 243 confirmed or presumptive cases and 19 (7.8%) deaths reported (Beadle 1966, Bell et al. 1981, Luby et al. 1969). The City of Houston did not have a surveillance program in place and no resources dedicated to combat the outbreak. Instead, help was obtained from fire department, Coast Guard, and local pest control company personnel to apply larvicides and adulticides to the environment. The CDC initiated a wild bird collection and testing protocol that yielded SLE virus from four bird specimens: blue jay, domestic goose, mockingbird, and pigeon (Beadle 1966, Bell et al. 1981). Mosquito collection and testing was also performed and yielded twenty-two SLE virus positive pools of *Culex quinquefasciatus* (Beadle 1966). At the conclusion of the epidemic, the City of Houston recognized the necessity of an active surveillance program for SLE virus to help prevent another such epidemic, or at least to have the means to combat it in the future (Bell et al. 1981). The Harris County Mosquito Control District was formed in November 1964 to establish a mosquito surveillance program and monitoring of the wild bird population for SLE virus activity (Bell et al. 1981). Subsequent SLE virus outbreaks have occurred in Texas: Hale County (1964, 1965, 1966), Dallas (1966, 1995), Corpus Christi (1966), and Houston (1975, 1980, 1986, 1990) (Beadle 1966, Bell et al. 1981, CDC 1986, 1990, Chandler et al. 2001, Luby et al. 1969, Rios et al. 2006, Wasay et al. 2000).

West Nile Virus was first isolated from the blood of a febrile woman in the West Nile district of Uganda in December 1937 during an epidemiological investigation for yellow fever virus (Smithburn et al. 1940). Further laboratory investigation revealed a new neurotropic virus, similar to St. Louis encephalitis virus and Japanese B encephalitis virus, with a stronger immunological relationship to the latter (Smithburn et al. 1940). West Nile Virus was implicated in outbreaks across Europe and the Mediterranean Basin in the subsequent years: South Africa (1974, 1983, 1984), India (1980, 1981), Ukraine (1985), Israel (1951,1952, 1957, 1962, 1998, 1999, 2000), France (1962, 1963, 1964, 1965, 2000, 2004), Algeria (1994), Morocco (1996, 2003), Romania (1996), Tunisia (1997), Italy (1998), and Russia (1999, 2000, 2001) (Gerhardt 2006, Hayes 2001, Komar 2003, Murgue et al. 2001, Zeller and Schuffenecker 2004).

West Nile Virus first appeared in the United States in New York City in August 1999. An infectious disease specialist contacted the New York City Department of Health to report two cases of human encephalitis in northern Queens. Six more cases were identified from patients admitted to Flushing Hospital between August 18, 1999 and September 2, 1999 (Asnis et al. 2000, Lanciottie et al. 1999, Nash et al. 2001). A concurrent investigation was underway due to the death of several exotic birds at the Bronx Zoo and a high mortality among crows in the same vicinity (Asnis et al. 2000, CDC 1999a, Lanciottie et al. 1999, Nash et al. 2001). Serology from the human cases at Flushing Hospital were tested September 3, 1999 at the CDC and indicated the encephalitis was the result of the St. Louis Encephalitis virus (Asnis et al. 2000, Nash et al. 2001). Avian specimens tested on September 10, 1999 at the U. S. Department of Agriculture National Veterinary Services Laboratory in Ames Iowa, reported negative for all "common avian pathogens and equine encephalitis viruses." These samples were then sent to the CDC for additional testing and identification using polymerase chain reaction (PCR) and DNA sequencing (CDC 1999a). Additional testing at the CDC, on September 23, 1999, revealed West Nile-like genomic sequences for both bird and human cases from the New York outbreaks. Genomic analysis (University of California, Irvine) also confirmed WNV virus in human samples from the New York outbreak and WNV ELISA results were stronger than SLE ELISA results. By late September 1999, both the human and avian outbreaks were confirmed as West Nile Virus, the first occurrence recognized in the Western Hemisphere (Asnis et al. 2000, CDC 1999a, Nash et al. 2001). Mosquito abatement was instituted in the early weeks of the outbreak, even when the initial diagnosis was SLE. Subsequent testing of mosquitoes, following the WNV diagnosis, revealed positive pools of *Culex pipiens, Culex restuans*, and *Culex salinarius* mosquitoes from New York and New Jersey collections and one positive *Aedes vexans* pool from Greenwich, Connecticut (Asnis et al. 2000, CDC 1999a, Nasci et al. 2001, Nash et al. 2001). At the conclusion of the 1999 epidemic in New York, there were 61 confirmed WNV human cases with 7 deaths (12%) (Asnis et al. 2000). There were 41 avian tissue samples (CDC 1999b) and 15 pools of mosquitoes (Nasci et al. 2001) positive for WNV. The WNV strain that caused this outbreak most closely resembled virus isolates from a goose in Israel in 1998. That epidemic, unlike previous Mediterranean outbreaks, involved a strain of WNV that was more pathogenic in birds than previously observed (Asnis et al. 2000, Gerhardt 2006, Lanciottie et al. 1999).

In 2000, human infections were reported in Connecticut, New Jersey, and New York and either avian, animal or mosquito infections were reported in Connecticut, Delaware, District of Columbia, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, Vermont, and Virginia (CDC 2007b). In 2001, WNV advanced from the eastern seaboard states into the south, Florida to Louisiana, and the central states Kentucky, Ohio, and Tennessee, to Iowa, Missouri, and Arkansas. WNV data reported for 1999 to 2007 are shown in Appendix A.

West Nile Virus first appeared in both Texas and Harris County, Texas, in June 2002. Two dead blue jays, collected on June 10, 2002, tested positive for WNV (Lillibridge et al. 2004, Parsons 2003). WNV was detected in a pool of *Culex quinquefasciatus* on June 11, 2002 (Texas Department of State Health Services 2007). Overall, there were 136 positive mosquito pools in 2002, 135 consisting of *Culex quinquefasciatus* and one consisting of *Aedes albopictus*; no positive mosquito pools were identified after November 1, 2002, despite trapping efforts through March 2003 (Lillibridge et al. 2004, Parsons 2003, Texas Department of State Health Services 2007).

By the end of 2002, 105 human cases of WNV were reported, 307 dead birds tested positive for WNV, and 8 human SLE cases were reported (Lillibridge et al. 2004, Parsons 2003, Texas Department of State Health Services 2007). In 2003, the beginning of the transmission season was noted by a WNV positive mourning dove, collected on April 29, a blue jay on May 13, and a pool of *Culex quinquefasciatus* on May 20. St. Louis Encephalitis virus was first detected in a pool of *Culex quinquefasciatus* on June 24, 2003, indicating that the two viruses could co-exist in the same environment at the same time (Lillibridge et al. 2004, Texas Department of State Health Services 2007). West Nile Virus continues to circulate in Harris County.

1.4 Effectiveness of Different Mosquito Traps for Surveillance

Mosquito surveillance has two main objectives: 1) to identify larval habitats and 2) to monitor adult activity. The former objective can allow future adult populations to be predicted and reduced (Moore et al. 1993). For monitoring adult mosquito activity, several issues should be considered, including: 1) species of interest, 2) goal of collection (virus isolation versus population estimation), 3) level of virus activity in the area, and 4) weather and environmental conditions. There is a substantial amount of research regarding how and to what mosquitoes are attracted. This behavior can be manipulated to help in surveillance and abatement programs. The two main components involved are olfactory senses and visual perceptions of the mosquito. Understanding how a mosquito sees its environment and what visually attracts it to a trap has been explored and provides good insight for trap construction and placement (Allan 1994, Bidlingmayer 1994, Fay 1968, Foster and Hancock 1994). Olfaction also plays a role in mosquito behavior and attraction and has been studied in depth (Foster and Hancock 1994, Kline 1994a, 1994b, Roitburg et al. 1994, Sutcliffe 1994). By exploiting normal mosquito behavior, mosquito traps are manufactured to maximize numbers caught. The New Jersey Light trap, a large (and cumbersome) semi-permanent based trap, utilizing an electrical source for both a light bulb and fan and a lethal gas-filled kill jar for collection, filled with lethal gas, was the first mosquito trap that did not require human operation and was constructed by T. D. Mulhern in 1932 (Mulhern 1942, 1953). The CDC Miniature Light Trap was developed by W.D. Sudia and R. W. Chamberlain in 1960 to provide a portable version of the New Jersey Light Trap. This trap design incorporated a collapsible catch net, detachable lid, durable light bulb with low amperage, and several power options (CDC 2007a, Sudia and Chamberlain 1962). Between 1966 and 1969, several studies were undertaken to examine the use of CO2 in conjunction with the CDC Miniature Light Trap, both with and without a light source (Carestia and Savage 1967, Morris and DeFoliart 1969, Newhouse et al. 1966). Results showed that CO2 increased the catches up to 4-fold and increased the variety of species trapped by as much as 25%. Many experiments have subsequently been performed to test a variety of gravid/oviposition traps using different attractants (Addison et al. 1979, Burkett et al. 2004, Dennet et al. 2004, Du and Millar 1999, Emord and Morris 1982, Hazard et al. 1967, Isoe et al. 1995, Jackson et al. 2005, Lampman and Novak 1996, Leiser and Beier 1982, Meyer 1991, Millar et al. 1992, Reisen et al. 1999, Reisen et al. 2002, Reiter et al. 1991, Ritchie 1984, Slaff et al. 1983, Stryker and Young 1970).

Although not necessarily holding for all geographical regions, general conclusions can be drawn from these studies. CDC light traps, without the use of a light source but baited with CO2, operate very well for *Culex quinquefasciatus*; light traps provide a poor representation of mosquito species that are not positively phototactic. *Aedes albopictus* and *Aedes aegypti* mosquitoes are attracted to battery-powered traps utilizing contrasting white and black color schemes and patterns. CDC gravid traps are efficient at collecting gravid *Culex* mosquitoes; *Culex quinquefasciatus* are attracted to alfalfa hay-infused gravid traps while *Aedes aegypti* are not, and *Culex restuans* shows greater preference for straw-infused solutions than manure infusions in gravid traps. The overall conclusion regarding trapping methods is that no one trap will provide a representative sampling of all species in a given area. Trap types and trapping methods are a trial and error process that must take into account mosquito species, geographic location, time of year, and trapping purpose (viral testing versus population sampling) to find what works best in a particular surveillance program.

1.5 Other Methods of Surveillance

Adult mosquito surveillance is not the only method used to predict or monitor both mosquito and disease presence in an environment. There are two other methods used in surveillance or sentinel programs for mosquito and disease control. The first method is larval surveillance, which includes mapping larval habitats and collection and identification of larvae (Moore et al. 1993). Larval sampling can identify locations at which to focus control measures and can provide estimates of adult emergence populations when larval control is not feasible (CDC 2003). A second method used to indicate the presence of WNV virus is dead bird surveillance. The presence of dead birds can be used as an early warning system (Eidson et al. 2001, Komar et al. 2003, Mostashari et al. 2003). In June of 1999, a large number of dead and dying crows were noted in the New York area and the first human encephalitis case was diagnosed later that summer(August), in the same geographical area (Eidson et al. 2001). WNV in both the birds and human case was not confirmed until later in September by the CDC and further diagnostics showed the virus isolates from the bird were identical to those from the human encephalitis case (Asnis et al. 2000, Eidson et al. 2001, Nash et al. 2001). While not conclusive, it appears a sudden increase in bird mortality and the identification of WNV during routine dead bird monitoring can give an indication of WNV activity in an area (Eidson et al. 2001). There are several limitations to this method of surveillance, including dependence on public participation, ability of birds to migrate, and other causes of mass mortality in birds. All these factors can reduce the usefulness of bird surveillance for WNV activity, but they do not negate its overall advantages (Eidson et al. 2001, Komar et al. 2003, Mostashari et al. 2003).

1.6 Previous Studies in Harris County, Texas

Three studies conducted within the Harris County area of Texas have been published. These studies highlight the importance of WNV and SLE virus in the Harris County and Houston area and help provide a greater understanding of both diseases in a unique and diverse environment.

1.6.1 Demographic and Spatial Analysis of West Nile Virus and St. Louis Encephalitis in Houston, Texas

Rios et al. (2006) found that proximity to waste and the number of containers, within a one-block radius of a trap, had a significant effect on the presence of SLE virus positive mosquito pools. They also concluded that the number of containers was correlated to the mosquito population or density in the area. Overall, they concluded that both socioeconomic and environmental conditions play a role in arbovirus infection.

1.6.2 The 2002 Introduction of West Nile into Harris County, Texas, an Area Historically Endemic for St. Louis Encephalitis

Lillibridge et al. (2004) addressed the possibility of whether WNV could establish in an area already endemic for SLE virus and if so, would it eventually displace SLE virus from the area. These authors concluded that not only could WNV establish itself in a SLE virus endemic area, but that the two viruses could co-exist and both be active in the same area.

1.6.3 Year-round West Nile Activity, Gulf Coast Region, Texas, and Louisiana

A study by Tesh et al. (2004) concluded that WNV is active, all year round, in the Gulf Coast region (including Texas and Louisiana), and meaning that the virus is capable of overwintering in the Harris County area, where the study was carried out. The study examined WNV isolations from both dead birds and mosquito pools from January

2003 to March 2004, with winter months identified as November through March. Eight dead birds tested positive during the November 2003 – March 2004 period, while only two mosquito pools were positive during the same period. However, no birds or mosquitoes tested positive from January – March 2003.

1.7 Description of the Study Area

An area of approximately 96.53 square miles (250.01 square km) in the middle of Harris County is the focus for this study. This area is bounded by Interstate Loop 610 and transected by Interstates 45 and 10, and U.S. Highway 59. This area contains several different environments, including man-made drainage bayous, industrial warehousing, some dense vegetation, and both lower and upper socioeconomic neighborhoods (Hunt and Hacker 1984). A unique aspect is that housing is built using a pier and beam foundation design. According to Dallas-based Granite Foundation Repair, Inc. (Granite Foundation Repair 2007), a pier and beam foundation consists of:

> a raised wooden sub-floor containing wooden cross members known as beams was supported every 6-10 feet by either a wooden post or a concrete pier. Typically, the posts and piers were buried 1-4 feet into the ground. Sometimes the wooden posts rested on a concrete slab that was placed on the surface of the ground. Typically, the perimeter of the house was supported by a continuous concrete beam.

This raised foundation creates a dark, damp, and cool crawl space beneath the houses, which HCMCD personnel have previously demonstrated provides an ideal resting location for mosquitoes during all seasons in this study area. From 1999 to 2002, the MCD utilized gravid traps baited with CO2 (not hay infused water) in the crawl space below pier and beam houses, referred to as Underhouse (UH) traps, in their SLE surveillance program. This trapping method was utilized during the winter trapping period, November through February of each year. For the 2006 – 2007 trapping season, the MCD personnel incorporated UH trapping into their WNV surveillance program for the winter trapping months. In previous seasons, only Gravid (GV) and Storm Sewer (SS) traps had been utilized in the SLE and WNV surveillance program and both had proven very effective indicators of mosquito activity and density. Gravid traps utilize water infused with an attractant, such as hay, sod, or manure. They are used to attract blood-fed female mosquitoes seeking an oviposition site. SS traps are modified-CDC light traps that also incorporate dry ice as an attractant for mosquitoes seeking a blood meal. MCD personnel have identified the storm sewer system as an ideal resting and breeding area for mosquitoes in the Harris County area. MCD decided that they would trap Underhouse traps continuously during the 2006-2007 trapping season in order to address questions regarding presence of WNV/SLE virus in the underhouse environment during peak transmission season. MCD also decided to perform a pilot study leading up to the peak season in order to ascertain if the continued trapping would be both cost-effective and productive for their surveillance program. This study served as the pilot study for the continued year-round underhouse surveillance and future WNV/SLE virus studies in the Houston area pursued by MCD personnel.

1.8 Study Objectives

The two questions addressed in this study are:

1) Is there a difference between the overall numbers of mosquitoes trapped in GV versus UH traps, and,
2) Is there a difference in the species composition trapped in GV versus UH traps?

The answer to these two questions will assist the HCMCD in developing the most representative, cost-effective SLE virus and WNV surveillance program in the future.

2. A COMPARISON OF GRAVID AND UNDER HOUSE TRAPS FOR MONITORING MOSQUITOES OF PUBLIC HEALTH IMPORTANCE

2.1 Introduction

The Harris County Mosquito Control District (HCMCD) has divided the inner loop area of the Houston metroplex into 39 separate "areas" for mosquito trapping and surveillance purposes (Figure 3, areas 1-4). The inner loop area contains a wide variety of man-made and natural environmental conditions that call for unique surveillance methods. It is also densely populated, with a wide spectrum of social classes and living conditions, thus serving as an important surveillance area for the MCD's program. Although areas 1-4 are designated as such for trapping routes, they also provide somewhat of a visual representation of the natural differences in environmental conditions that can be found in the Houston metroplex. For example, the upper northeast quadrant (area 1) is largely composed of older industrial businesses, lower income housing, and larger areas of unmanaged vegetation. The lower southwest quadrant (area 3) contains a large amount of higher income housing areas with lawns and gardens and probably fewer potential breeding sites for mosquitoes. However, this area also contains a few pier and beam houses in the middle of the more upscale neighborhoods that are of interest for mosquito surveillance. Therefore, the inner loop area represents an urban environment that poses several issues for mosquito surveillance. The study of the effectiveness of mosquito trapping methods within this environment is relevant to urban environments throughout the southern United States. The aim of this study was to determine if different numbers of mosquitoes are trapped in GV versus UH traps, and if there a difference exists in the species composition trapped in GV versus UH traps.

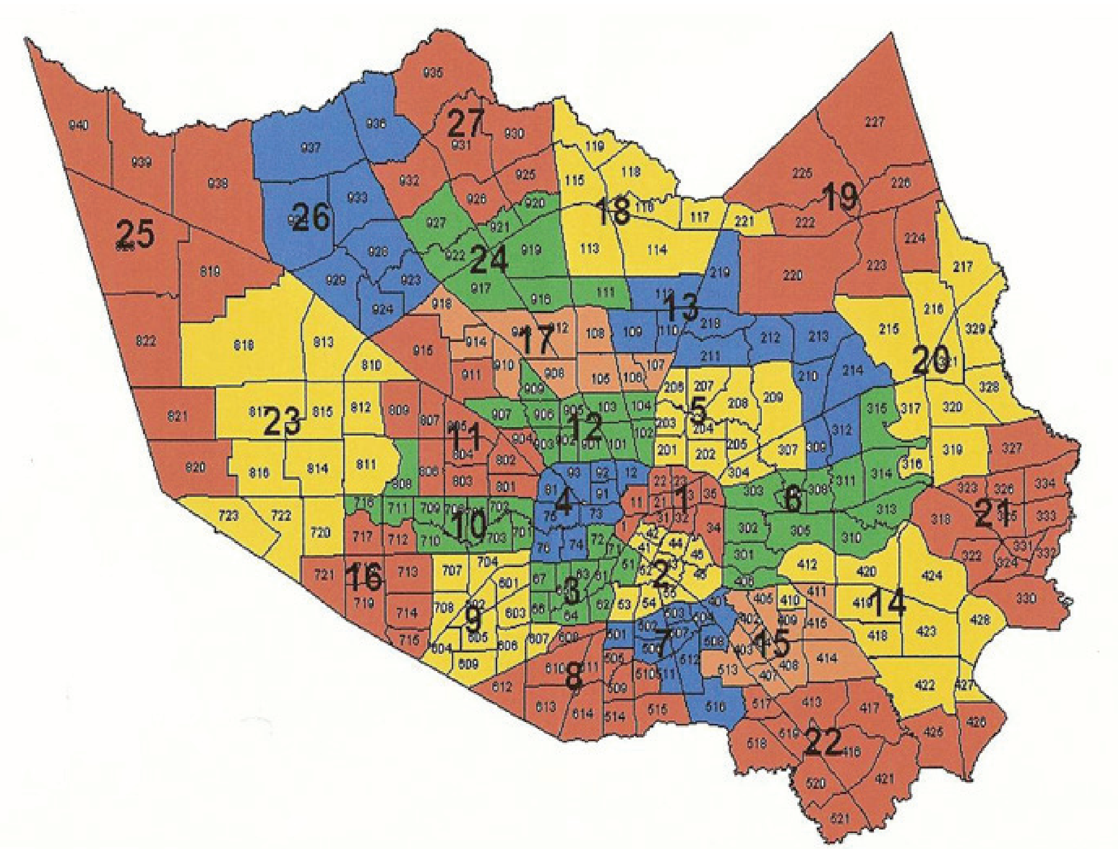

FIG. 3. Map of Mosquito Trapping Areas in Harris County, Texas.

2.2 Methods

2.2.1 Data Collection

Ten locations were identified inside the Interstate Loop 610 area for co-placement of one GV trap and one UH trap. Trap locations were based on historic positive WNV and SLE virus test data, to facilitate achieving sufficiently large trap numbers for the project.

Traps were placed and retrieved on a weekly basis for fourteen weeks, beginning March 1, 2007 and ending May 31, 2007 (weeks 9 - 22). Twenty trap collections were made each week, ten GV and ten UH, for the fourteen-week period. Figure 4 provides a visual representation of the trap locations of the inner-loop area in Houston, Texas. The stars mark the area in which the traps were placed but do not represent the physical location within an area.

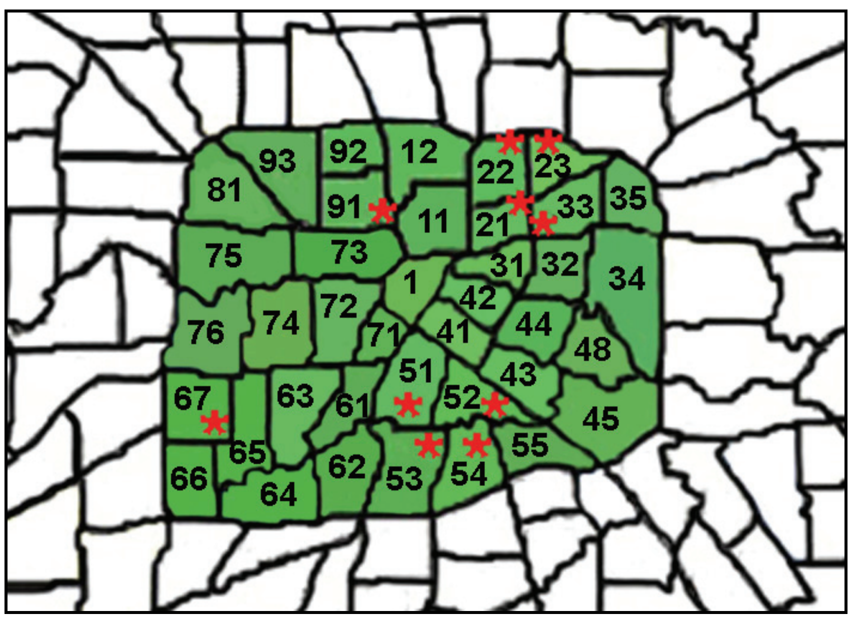

FIG. 4. Locations Used to Assess the Effectiveness of Gravid Versus Underhouse Traps for Catching Mosquitoes in a Surveillance Program for SLE Virus and WNV in the Inner Loop Area of Houston, Texas (Latitude 95.37°W, Longitude 29.75°N).

Gravid traps were placed in a lightly vegetated area where MCD personnel believe mosquitoes are likely to seek an egg-laying environment, while UH traps were placed under pier and beam houses, at least an arm's length from the outer edge of the house. All trap placements were subject to change or special requests from the property owner. Traps were placed in the afternoon hours between 12-noon and 3:00 pm, Monday through Wednesday and then retrieved the following morning between 6:00 am and 11:00 am, Tuesday through Thursday. A re-trap was attempted during the same trap week if any trap failed to collect any mosquitoes or was otherwise disrupted in the environment. In addition, Global Positioning System (GPS) coordinates were obtained for traps to use within Geographic Information System (GIS) software for spatial analysis of data (Section 3). The above guidelines are in accordance with current MCD surveillance protocol and thus did not place any additional requirements on the MCD personnel. Gravid traps utilized a fermented hay-infusion solution as the attractant while UH traps utilized the same trap design with CO2 as the attractant, but without a light source.

UH mosquito collections were counted, pooled, and tested by MCD personnel, in accordance with current MCD surveillance protocol. The remaining ten GV trap collections were placed in a -70°F freezer and the researcher traveled to MCD on a weekly basis to count and identify all mosquitoes trapped. The GV trap collections were separated and labeled by species, trap location, and week trapped and stored at Texas A&M University College of Veterinary Medicine and Biomedical Sciences (Department of Veterinary Pathobiology). No diagnostic testing for WNV or SLE virus was conducted on GV Trap collections. An effective cold chain was maintained while processing GV Trap collections to enable the MCD or the researcher the option of diagnostic testing in the future.

2.2.2 Data Analysis

Data was collected for GV traps and UH traps on a weekly basis and entered into a spreadsheet (Excel 2003, Microsoft® Corporation, Redmond, WA). For each collection, trap type (GV or UH), trap location (1–10) and week of collection (9–22) was recorded.

The primary outcome of interest for this project (mosquito counts per trap collection) is continuous data. Potential explanatory variables of mosquito counts considered in this study were trap type (GV or UH), collection week (9–22), and mosquito species (4 species expected to be trapped and of public health interest: *Culex quinquefasciatus*, *Aedes albopictus*, *Aedes aegypti*, and *Culex restuans*).

Descriptive statistics, including mean, median, and confidence intervals, were estimated for the counts of mosquitoes by trap type, week, and species. The data were analyzed (SPSS 15.0 for Windows. SPSS Inc., Chicago IL) utilizing a General Linear Model (GLM). A repeated-measures Analysis of Variance (ANOVA) model was fit to mosquito count data (dependent variable) to examine the effect of the 3 explanatory (independent) variables of interest: trap type, species and time. The primary comparisons of interest were: 1) whether there is a difference in mean trap numbers between GV and

UH traps, controlling for week and species, and 2) if there is a difference in mean trap numbers by species, controlling for trap type and week.

The repeated measures design allows for detection of differences in the outcome of interest (mosquito counts per trap) with respect to different levels of independent variables (such as GV versus UH trap type), whilst assessing the likelihood that differences detected might be caused by chance (random error). Experimental studies must always contend with background "noise" caused by uncontrollable differences between the conditions or treatments. A repeated measures design allows the "noise" to be minimized while allowing the effect of the experimental treatment to be identified. The advantages of GLM repeated measures ANOVA include reduction in random error, greater power to detect treatment effects, and more efficient because of a smaller required sample size. Treatment effect is shown by the within-subject variance, which is composed of 1) the effect of the experimental manipulation or treatment and 2) individual subject differences. Any variation, not explained by the experimental treatment, is considered due to random factors outside of our control and can be called "error." An F-ratio is used to compare the amount of the variation due to the experimental treatment and the amount of variation due to random factors; a large F value (P-value < 0.05) indicates that the observed results are unlikely to be due to chance, but rather the experimental treatment had some effect beyond any random error.

For the purposes of data analysis, trap counts was the dependent variable, trap week was entered as the Within-Subject Factor with fourteen levels representing the fourteen collection weeks, and trap type (two levels) was entered as the Between-Subject

Factor. GLM Repeated-Measures ANOVA was performed for each of the 4 species of interest individually. For both of the *Aedes* species data sets, a square root transformation (SPSS 15.0 for Windows. SPSS Inc., Chicago IL) was needed because of non-normality and low counts.

2.3 Results

A total of 280 trap collections were made from the 10 study sites during the 14-week study period. During this period, the following species of mosquito were trapped: *Culex quinquefasciatus, Culex restuans, Aedes aegypti, Aedes albopictus, Aedes vexans, Aedes triseriatus, Anopheles crucians, Coquillettidia perturbans, Culex erraticus, Culex salinarius, Culex tarsalis, Culiseta inornata, Psorophora ferox, Psorophora horrida,* and *Psorophora longipalpus*. Table 3 shows the number of each species (male and female) caught during the study period by trap type.

Table 3. Total Species Collected by Trap Type, Inner-Loop Area, Houston, Texas, March – May 2007.

Species	Gravid Traps		Underhouse	
	Females Trapped	Males Trapped	Females Trapped	Males Trapped
Aedes aegypti	8	0	3	0
Aedes albopictus	57	16	12	9
Culex quinquefasciatus	15759	1840	2393	876
Culex restuans	196	3	9	0
Aedes triseriatus	1	0	0	0
Aedes vexans	2	0	26	1
Anopheles crucians	0	0	1	0
Coquillettidia perturbans	1	0	0	0
Culex erraticus	157	55	6	1
Culex salinarius	9	0	61	0
Culex tarsalis	1	0	1	0
Culiseta inornata	3	0	2	3
Psorophora ferox	0	0	15	0
Psorophora horrida	0	0	1	0
Psorophora longipalpus	0	0	1	0
Total by Sex	16194	1914	2531	890

2.3.1 Descriptive Statistics

Weekly total female mosquito counts and overall species counts (the four species of public health interest and all other species combined) for both Underhouse and Gravid traps are presented in Tables 4, 5, 6 and 7, respectively. The male mosquito counts are not included in these Tables because males do not take a blood meal and thus do not transmit WNV/SLE virus and are not of public health interest. A total of 18,725 female mosquitoes were caught during the study period. Overall, Underhouse traps caught 2,531 female mosquitoes (Table 4) and Gravid traps caught 16,194 female mosquitoes (Table 5) during the fourteen-week collection period. The highest numbers of female mosquitoes were caught during weeks 19 to 21. Underhouse traps caught thirteen different species, whereas Gravid traps caught eleven species out of the total of fifteen different species caught during the study period. Descriptive statistics are presented in Appendix B for each trap type and mosquito species and box plots are presented in Appendix C.

Table 4. Weekly Summary of Underhouse CDC Trap Collections, Inner-Loop Area, Houston, Texas, March – May 2007.

Week	No. of Traps	Total of Females	Mean Females per trap
9	10	40	4.00
10	10	94	9.40
11	10	81	8.10
12	10	63	6.30
13	10	56	5.60
14	10	136	13.6
15	10	142	14.2
16	10	191	19.1
17	10	84	8.4
18	10	82	8.2
19	10	426	42.6
20	10	421	42.1
21	10	579	57.9
22	10	136	13.6
Total	140	2531	----

Table 5. Species Composition of Underhouse CDC Trap Collections, Inner-Loop Area, Houston, Texas, March – May 2007.

Species	Total of Females	Mean Female Per Trap
Culex quinquefasciatus	2393	170.93
Culex restuans	9	0.64
Aedes aegypti	3	0.21
Aedes albopictus	12	0.86
All other species	114	10.29
Total	2531	----

Table 6. Weekly Summary of Gravid Trap Collections,
Inner-Loop Area, Houston, Texas, March – May 2007.

Week	No. of Traps	Total of Females	Mean Females per Trap
9	10	531	53.1
10	10	372	37.2
11	10	279	27.9
12	10	173	17.3
13	10	303	30.3
14	10	377	37.7
15	10	693	69.3
16	10	848	84.8
17	10	830	83.0
18	10	1249	124.9
19	10	3397	339.7
20	10	4689	468.9
21	10	1468	146.8
22	10	985	98.5
Total	140	16,194	----

Table 7. Species Composition from Gravid Trap Collections,
Inner-Loop Area, Houston, Texas, March – May 2007.

Species	Total of Females	Mean Female Per Trap
Culex quinquefasciatus	15759	1125.64
Culex restuans	196	14.00
Aedes aegypti	8	0.57
Aedes albopictus	57	4.07
All other species	174	12.43
Total	16,194	----

2.3.2 Trap Type

The ANOVA results for the Between-Subjects Factor (trap type) indicated a significant difference between trap types (F-statistic = 7.213, P = 0.009): mean GV catch was 23.134, compared to a mean catch in UH traps of 3.616. Significant differences in catches, by trap type were detected for *Culex quinquefasciatus* (F-statistic = 30.240, P < 0.001): mean GV catch was 112.564, versus a mean catch in UH traps of 17.093.

Differences were also detected for *Culex restuans* (F-statistic = 21.076, P < 0.001): mean GV catch was 1.4, compared to a mean catch of 0.064 in UH traps. A significant difference was found for *Aedes albopictus* between traps (F-statistic = 11.133, P = 0.004): mean GV catch of 0.407 versus a mean UH catch of 0.086; and no significant difference was found for *Aedes aegypti* between trap types (F-statistic = 0.875, P = 0.362): mean GV trap catch of 0.057 compared to a mean UH catch of 0.021. The differences in trap mean catch by mosquito species are presented in Appendix D.

Table 7 presents the confidence intervals for each trap and the four mosquito species considered of public health concern for WNV and SLE virus and then all others. If there is an overlap in the confidence intervals, for each trap and mosquito species, then the catches are not significantly different. However, no overlap indicates that the two traps are significantly different in their ability to catch the given mosquito species. Based on the confidence intervals presented in Table 7, catches from GV and UH traps were significantly different for all mosquito species except *Aedes aegypti*. This statistically verifies what the quantitative counts indicate, that the traps are significantly different with GV traps outperforming the UH traps, except in *Aedes aegypti* catches. While UH traps caught a larger variety of species, overall GV and UH traps were not significantly different for other species catches.

Table 8. Mosquito Catches and Confidence Intervals for Gravid and Underhouse Traps, Inner-Loop Area, Houston, TX, March – May 2007.

Mosquito Species	Gravid Traps Catches	Confidence Interval	Underhouse Traps Catches	Confidence Interval
Aedes aegypti	8	(0.0002, 0.104)	3	(0.00, 0.073)
Aedes albopictus	57	(0.205, 0.355)	12	(0.003, 0.152)
Culex quinquefasciatus	15759	(74.072, 151.056)	2393	(9.294, 24.892)
Culex restuans	196	(0.968, 1.832)	9	(0.00, 0.497)
Other species	174	(0.655, 1.831)	114	(0.012, 1.617)
Total	16,194	----	2,531	----

2.3.3 Weekly Catches

The results of the ANOVA, for Gravid traps and *Culex quinquefasciatus*, for the Within-Subjects Factor analysis indicated an overall significant difference between the fourteen trap weeks (F-statistic = 10.915, P < 0.001). Weekly trap catches increased as the study proceeded (Figure 5). Pairwise comparisons of weekly *Culex quinquefasciatus* catches in Gravid traps are shown in Appendix E. The Within-Subjects Factor for *Culex restuans* in Gravid traps also indicated an overall significant difference between the fourteen trap weeks (F-statistic = 5.233, P = 0.004). The mean distribution of *Culex restuans* catches, using Gravid traps, significantly decreased as the trapping season progressed (Figure 6). Pairwise comparisons of weekly *Culex restuans* catches in Gravid traps are shown in Appendix F. In addition, ANOVA results for Underhouse traps and *Culex quinquefasciatus*, for the Within-Subjects Factor did not indicate significant differences between the fourteen trap weeks (F-statistic = 2.546, P = 0.100). In general, weekly trap catches increased as the study proceeded (Figure 7).

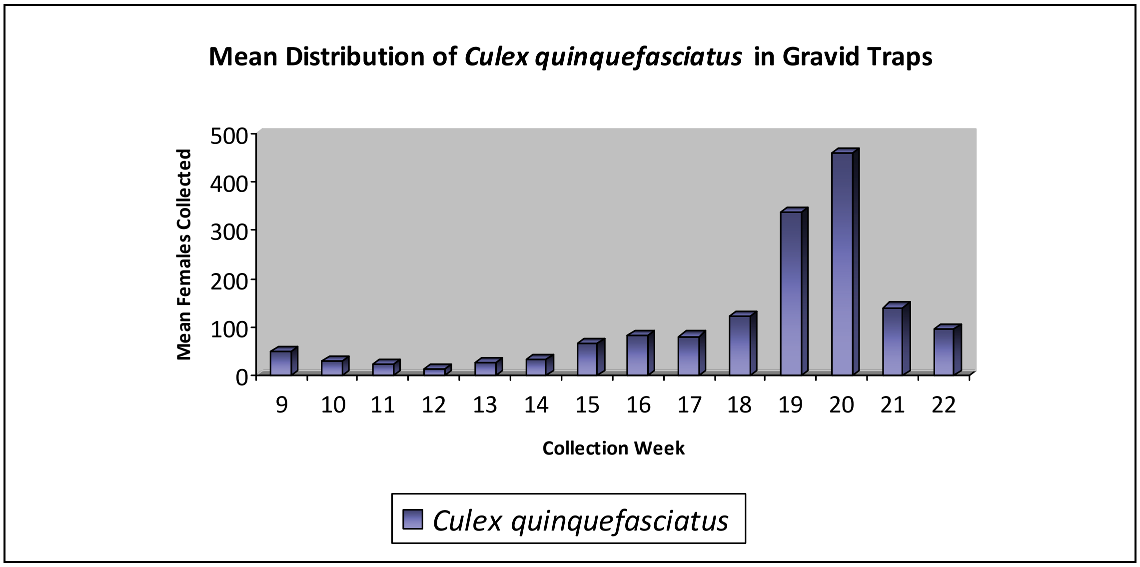

FIG. 5. Mean Distribution of *Culex quinquefasciatus* in Gravid Traps, Inner-Loop Area, Houston, Texas, March – May 2007.

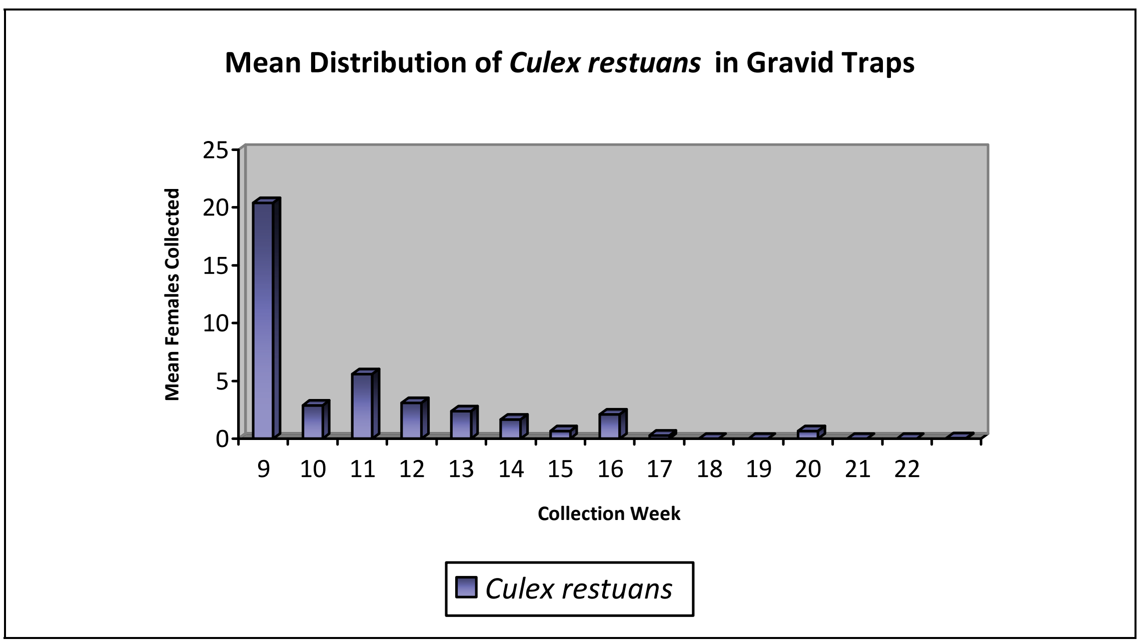

FIG. 6. Mean Distribution of *Culex restuans* in Gravid Traps, Inner-Loop Area, Houston, Texas, March – May 2007. No data (zero counts) collected for Weeks 17-18 and 20-21 for *Culex restuans* in Gravid traps, no pairwise analysis available.

For *Culex restuans* caught in Underhouse traps, overall no significant difference between the fourteen trap weeks (F-statistic = 0.917, P = 0.387) was found. Weekly catches of *Culex restuans*, using Underhouse traps, was sporadic, during the fourteen-week study period. *Culex restuans* were only trapped during three weeks of the period; weeks 10, 12 and 16 (Figure 8). An overall mosquito count, by trap type, for both *Culex* species is shown in Figures 9 and 10, respectively. The data was log- transformed because the count of these two species was non-normally distributed.

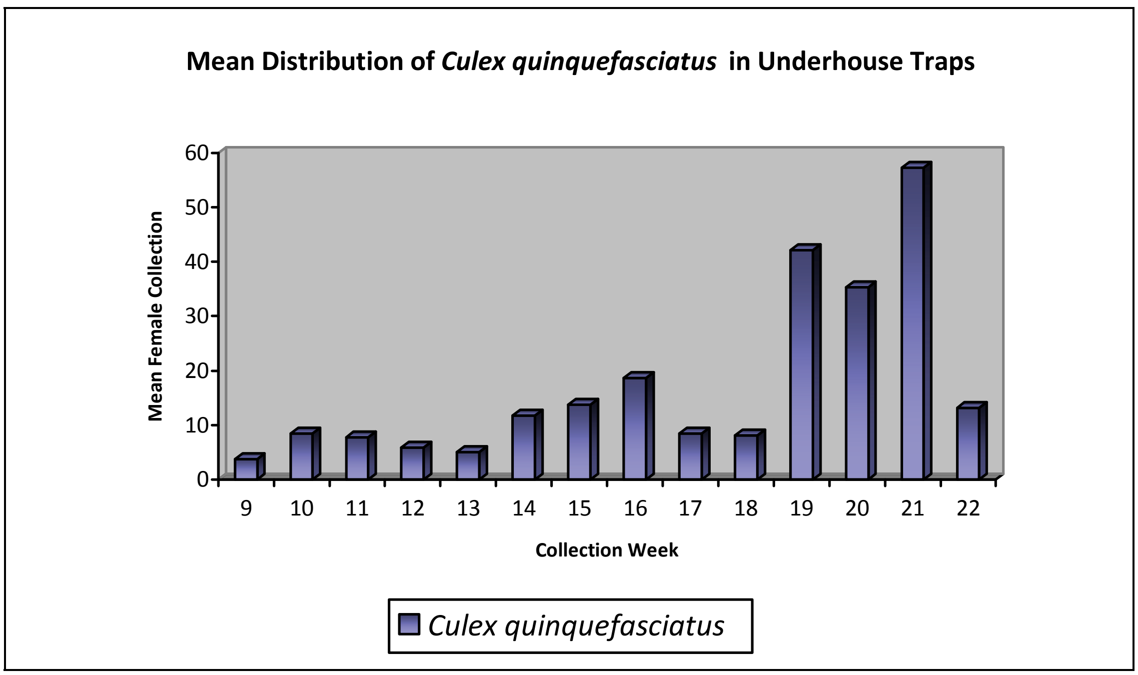

FIG. 7. Mean Distribution of *Culex quinquefasciatus* in Underhouse Traps, Inner-Loop Area, Houston, Texas, March – May 2007.

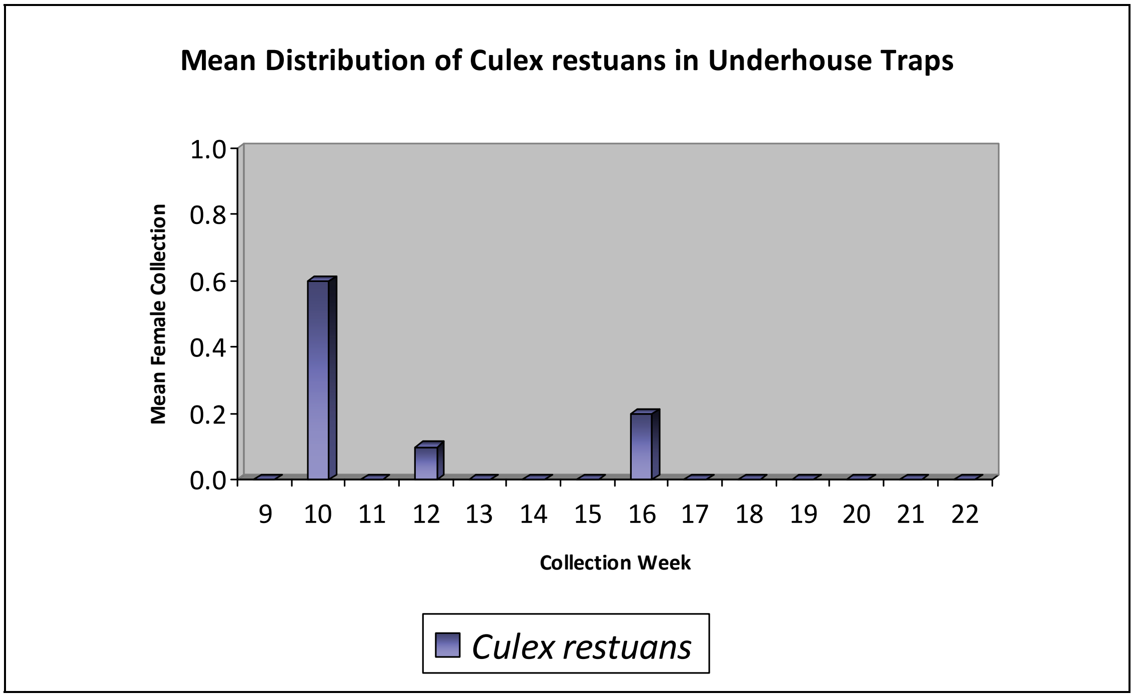

FIG. 8. Mean Distribution of *Culex restuans* in Underhouse Traps, Inner-Loop Area, Houston, Texas, March – May 2007. No data (zero counts) collected for Weeks 9, 11, 13-15, and 17-22 for *Culex restuans* in Underhouse traps, no pairwise analysis available.

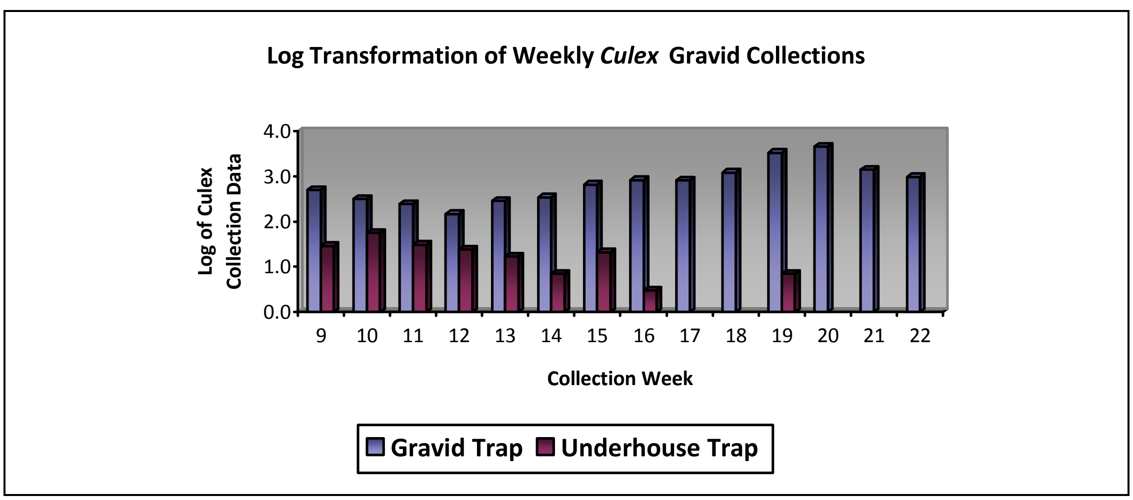

FIG. 9. Log Transformation of *Culex* Species in Gravid Traps, Inner-Loop Area, Houston, Texas, March – May 2007.

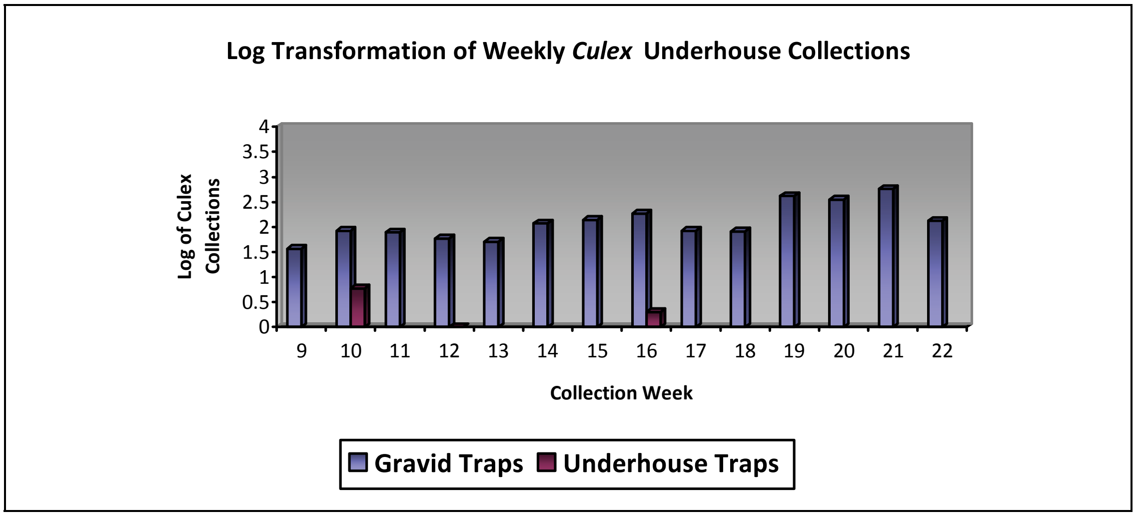

FIG. 10. Log Transformation of *Culex* species in Underhouse Traps, Inner-Loop Area, Houston, Texas, March – May 2007

Total counts for *Culex quinquefasciatus* and *Culex restuans* caught in Gravid traps, are shown in Tables 8 and 9 (both raw and log transformed totals). Gravid traps caught 80-times more *Culex quinquefasciatus* than *Culex restuans*, (approximately 3.7-times more, after data transformation). Underhouse traps caught approximately 265 times the number of *Culex quinquefasciatus* than *Culex restuans* (approximately 27-times more after data transformation). Overall, Gravid traps caught 15,759 *Culex* species mosquitoes during the fourteen-week period whereas Underhouse traps only caught 2,402 *Culex* species mosquitoes. Gravid traps collected 6.5-times more *Culex* mosquitoes than Underhouse trap.

Table 9. Total *Culex quinquefasciatus* Mosquitoes by Collection Week, Gravid Trap, Inner-Loop Area, Houston, Texas, March – May 2007.

Week	Total of Female Mosquitoes	Log (Total Females)
9	501	2.70
10	314	2.50
11	248	3.40
12	148	2.17
13	286	2.46
14	347	2.54
15	665	2.82
16	837	2.92
17	819	2.91
18	1241	3.09
19	3377	3.53
20	4588	3.66
21	1417	3.15
22	971	2.99
Total	15,759	----

Table 10. Total *Culex restuans* Mosquitoes by Collection Week, Gravid Trap, Inner-Loop Area, Houston, Texas, March – May 2007.

Week	Total of Female Mosquitoes	Log (Total Females)
9	29	1.46
10	56	1.75
11	31	1.49
12	24	1.38
13	17	1.23
14	7	0.85
15	21	1.32
16	3	0.48
17	0	NA
18	0	NA
19	7	.85
20	0	NA
21	0	NA
22	1	0.00
Total	196	----

Tables 10 and 11 show data for *Culex* species collected in Underhouse traps. Again, there was a large difference between the numbers of mosquitoes caught in Gravid versus Underhouse traps.

As stated above, the Between-Subjects analysis results indicated there was no significant difference between trap counts for *Aedes aegypti*; therefore, no Within-Subjects analysis was performed. However, for *Aedes albopictus*, significant difference between catches by trap type was found. The Within-Subjects Factor analysis for *Aedes albopictus* in Gravid traps indicated an overall significant difference between the fourteen trap weeks (F-statistic = 4.287, P = 0.007). The mean distribution of *Aedes albopictus* catches, using Gravid traps, increased as the trapping season progressed (Figure 11). Pairwise comparisons of weekly *Aedes albopictus* Gravid trap catches are shown in Appendix G.

Table 11. Total *Culex quinquefasciatus* Mosquitoes by Collection Week, Underhouse Trap, Inner-Loop Area, Houston, Texas, March – May 2007.

Week	Total of Female Mosquitoes	Log (Total Females)
9	37	1.57
10	84	1.92
11	78	1.89
12	59	1.77
13	51	1.71
14	117	2.07
15	137	2.14
16	187	2.27
17	84	1.92
18	81	1.91
19	421	2.62
20	353	2.55
21	573	2.76
22	131	2.12
Total	2,393	----

Table 12. Total *Culex restuans* Mosquitoes by Collection Week, Underhouse Trap, Inner-Loop Area, Houston, Texas, March – May 2007.

Week	Total of Female Mosquitoes	Log (Total Females)
9	0	NA
10	6	0.78
11	0	NA
12	1	0.00
13	0	NA
14	0	NA
15	0	NA
16	2	0.30
17	0	NA
18	0	NA
19	0	NA
20	0	NA
21	0	NA
22	0	NA
Total	9	----

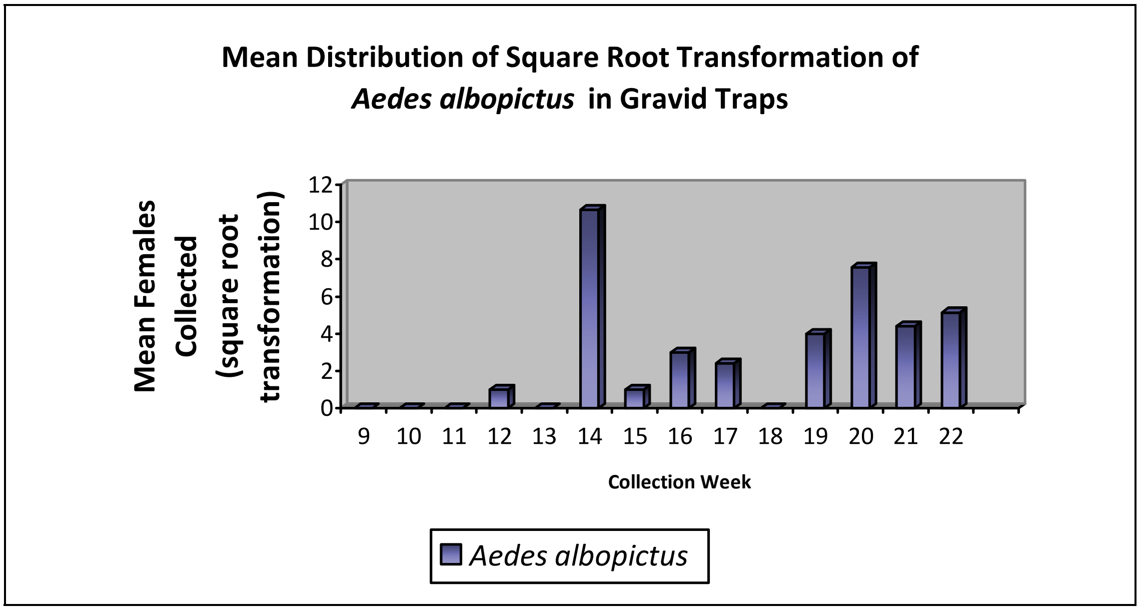

FIG. 11. Mean Distribution of the Square Root Transformation of *Aedes albopictus* in Gravid Traps, Inner-Loop Area, Houston, Texas, March – May 2007.

The results of the ANOVA, for Underhouse traps and *Aedes albopictus*, for the Within-Subjects Factor analysis did not indicate an overall significant difference between the fourteen trap weeks (F-statistic = 1.988, P = 0.105). The mean distribution of *Aedes albopictus* catches, using Underhouse traps, did however increase as the trapping season progressed (Figure 12).

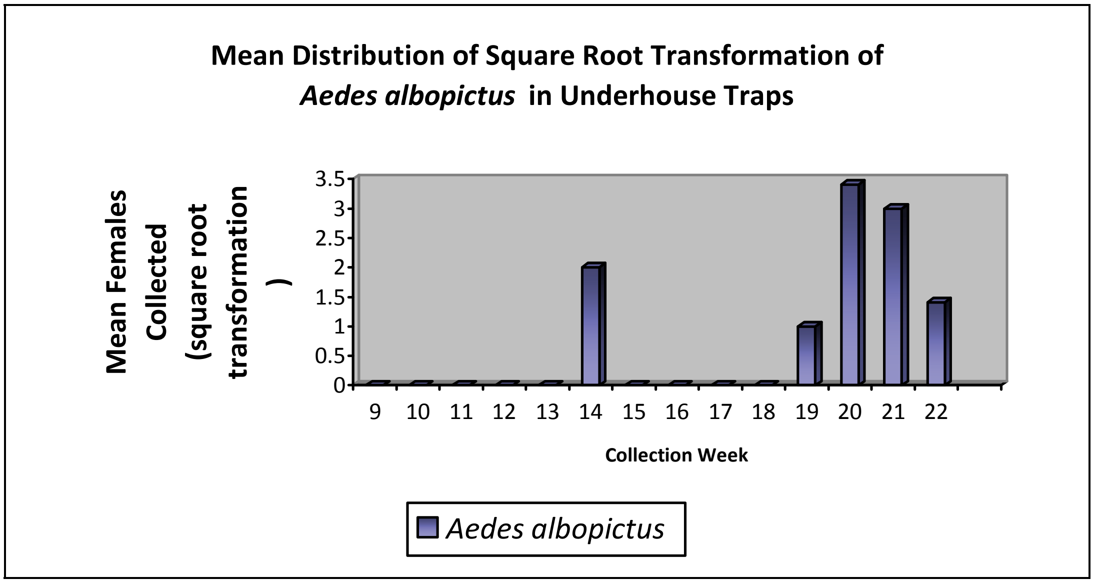

FIG. 12. Mean Distribution of the Square Root Transformation of *Aedes albopictus* in Gravid Traps, Inner-Loop Area, Houston, Texas, March – May 2007.

2.3.4 Associations between Trap Catches and Rainfall and Temperature

There was no monitoring of rainfall and temperature directly at each trap location. However, average temperature and rainfall totals were obtained (Figures 13 and 14) from a local weather station (Weather, 2007) in the inner-loop (Montrose) area (latitude 29.74°N, longitude -95.39°W). There were no weather stations located in close proximity to all site locations, thus the Montrose area was selected for its central proximity to the study area.

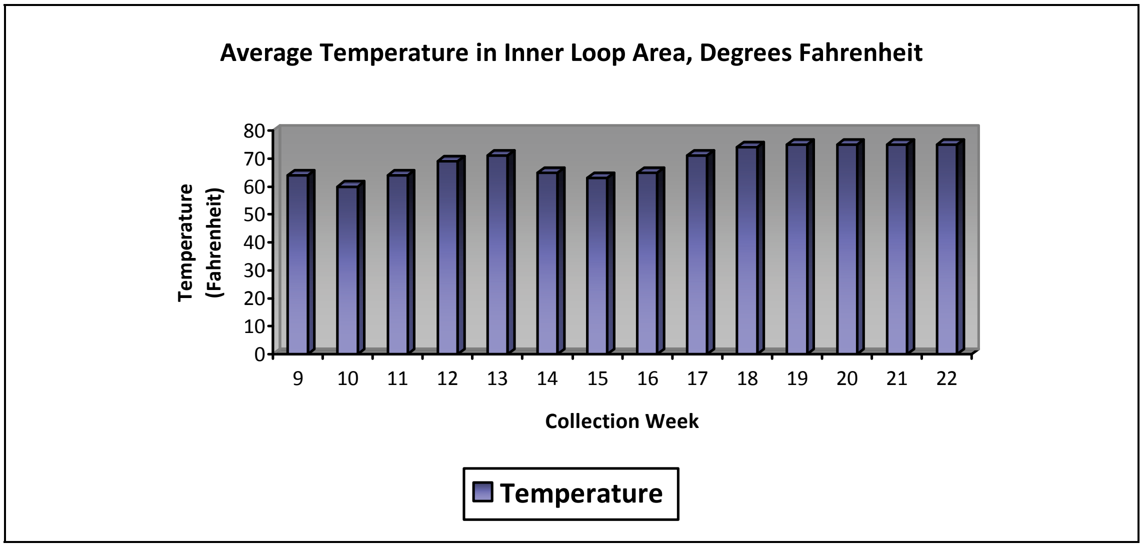

FIG. 13. Average Weekly Temperature (°F), Inner-Loop Area, Houston, Texas, March – May 2007. The weather station used (TX KTXHOUST78) was located in Montrose area (Latitude 29.74°N, Longitude -95.39°W).

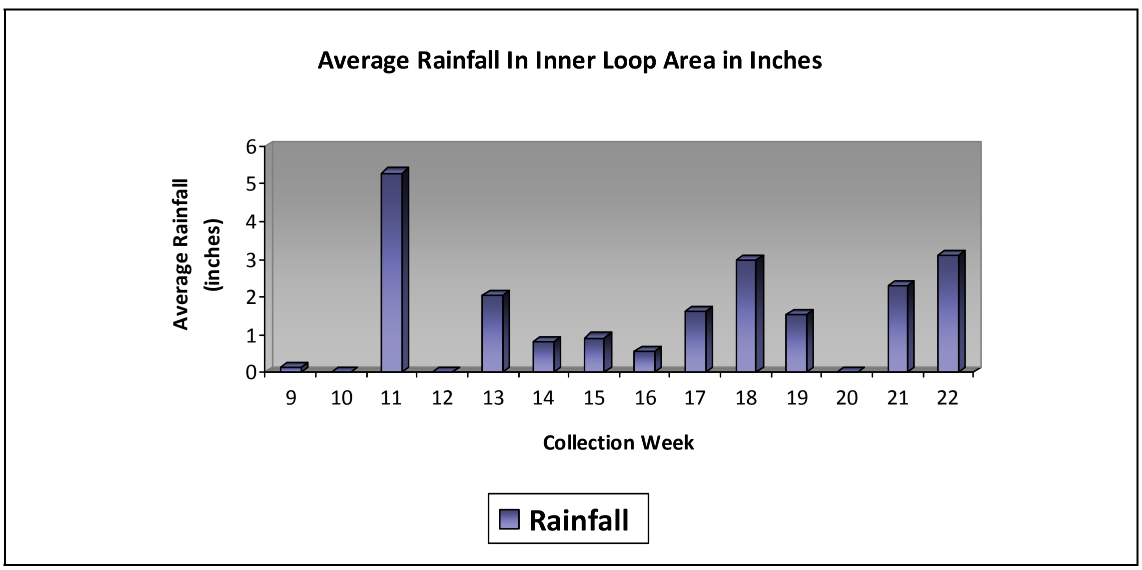

FIG. 14. Average Rainfall (Inches), Inner-Loop Area, Houston, Texas, March – May 2007. The weather station used (TX KTXHOUST78) was located in Montrose area (Latitude 29.74°N, Longitude -95.39°W).

Current mosquito surveillance knowledge correlates mosquito activity and density to seasonal temperature and rainfall averages. Table 12 presents *Culex quinquefasciatus* catches in Gravid traps and the average rainfall for each collection week, and the same data for Underhouse traps is presented in Table 13. Average weekly temperature and *Culex quinquefasciatus* catches in Gravid and Underhouse traps are presented in Tables 14 and 15. Finally, Table 16 presents Spearman's Correlation coefficient for *Culex quinquefasciatus* catches, from both Gravid and Underhouse traps, and average rainfall and temperature data.

Table 13. Weekly *Culex quinquefasciatus* Catches in Gravid Traps and Average Rainfall (Inches), Inner-Loop Area, Houston, Texas, March – May 2007.

Collection Week	*Culex quinquefasciatus* Weekly Catch (Gravid Trap)	Weekly Rainfall Average (inches)
9	501	0.14
10	314	0.00
11	248	5.29
12	148	0.00
13	286	2.06
14	347	0.82
15	665	0.93
16	837	0.58
17	819	1.62
18	1241	2.99
19	3377	1.55
20	4588	0.00
21	1417	2.29
22	971	3.12
Total	15,759	----

Table 14. Weekly *Culex quinquefasciatus* Catches in Underhouse Traps and Average Rainfall (Inches), Inner-Loop Area, Houston, Texas, March – May 2007.

Collection Week	*Culex quinquefasciatus* Weekly Catch (Underhouse Traps)	Weekly Rainfall Average (inches)
9	37	0.14
10	84	0.00
11	78	5.29
12	59	0.00
13	51	2.06
14	117	0.82
15	137	0.93
16	187	0.58
17	84	1.62
18	81	2.99
19	421	1.55
20	353	0.00
21	573	2.29
22	131	3.12
Total	2393	----

Table 15. Weekly *Culex quinquefasciatus* Catches in Gravid Traps and Average Temperature (°F), Inner-Loop Area, Houston, Texas March – May 2007.

Collection Week	*Culex quinquefasciatus* Weekly Catch (Gravid Trap)	Weekly Temperature Average (inches)
9	501	64
10	314	60
11	248	64
12	148	69
13	286	71
14	347	65
15	665	63
16	837	65
17	819	71
18	1241	74
19	3377	75
20	4588	75
21	1417	75
22	971	75
Total	15,759	----

Table 16. Weekly *Culex quinquefasciatus* Catches in Underhouse Traps and Average Temperature (°F), Inner-Loop Area, Houston, Texas, March – May 2007.

Collection Week	*Culex quinquefasciatus* Weekly Catch (Underhouse Traps)	Weekly Temperature Average (oF)
9	37	64
10	84	60
11	78	64
12	59	69
13	51	71
14	117	65
15	137	63
16	187	65
17	84	71
18	81	74
19	421	75
20	353	75
21	573	75
22	131	75
Total	2393	----

Table 17. Spearman's Correlation Coefficient for *Culex quinquefasciatus* Mosquitoes, in Both Gravid and Underhouse Traps, and Average Weekly Rainfall and Temperatures.

Correlation	Coefficient	P- Value
Gravid Traps		
Culex quinquefasciatus in Gravid Traps Rainfall	0.117	0.690
Culex quinquefasciatus in Gravid Traps Temperature	0.707	0.005
Underhouse Traps		
Culex quinquefasciatus in Underhouse Traps Rainfall	0.009	0.976
Culex quinquefasciatus in Underhouse Traps Temperature	0.465	0.094

Spearman's Correlation Coefficient analysis indicates there is a strong correlation between *Culex quinquefasciatus* catches in Gravid traps and temperature (P = 0.005), meaning as the temperature increased so did the *Culex quinquefasciatus* catches, in Gravid traps. There is also a moderate of correlation (0.47) between temperature and Underhouse catches, although not significant (P = 0.094). There was no statistical correlation between rainfall and mosquito catches in either trap, for this data set.

2.4 Discussion

Based on the GLM Repeated Measure Analysis of Variance, there was a very clear Week effect on trap catches demonstrated by the data collected. There was also a definite difference between the mean number of mosquitoes trapped in Gravid versus Underhouse traps, with Gravid traps substantially out-performing the Underhouse traps. Because each week also represents a seasonal change in environmental conditions, the week effect can be interpreted as the effect of an increase in temperature or rainfall as spring progresses toward summer, the historical peak period for WNV/SLE virus activity in the Houston area. However, statistically only temperature was correlated with increasing trap catches for *Culex quinquefasciatus* in Gravid traps. There was no significant correlation between Underhouse traps and temperature; and there was no indication of a correlation between either type of trap and catches of *Culex quinquefasciatus* mosquitoes and rainfall. Therefore, while current knowledge suggests mosquito density is associated with both rainfall and temperature, this study failed to identify an association except for temperature and *Culex quinquefasciatus* catches in

Gravid traps. The short duration of the study could be one explanation for failure to detect associations across both types of traps and variables, as well as this season's particular weather trends.

Culex restuans is a cooler weather species and thus it was expected that abundance would be higher during the earlier trapping period and then decrease as the season progressed. *Culex quinquefasciatus*, although present in the study area year round, showed the inverse relationship to *Culex restuans* during the study period. Trap counts steadily increased as the collection weeks progressed. The weekly variations in counts of this species could reflect the variation in temperature and rainfall for the periods prior to the collection week. For example, there was an increase in rainfall during week 18; although the trap catches of *Culex quinquefasciatus* were average during week 18 (124.10 per trap), there was a substantial increase in the mean number of *Culex quinquefasciatus* that were caught during weeks 19-21 (141.70 to 458.80 per trap). The two *Aedes* species were trapped in such low numbers that it is impossible to make inferences regarding the temporal pattern of their abundance from the data. Neither trap type studied addresses the unique trap preferences of these species. Therefore, their numbers can be considered neither an indication of true population numbers in surveillance terms, nor an indication of trap effectiveness.

Trap locations were kept constant from week to week, during the study period, thus the only variable that changed was the progression in time, or seasonality. Thus, changes in trap numbers over time provides a strong indication that environmental conditions are important factors in determining the numbers of mosquitoes caught, a phenomenon already recognized within mosquito surveillance programs. However, there were significant differences between the two trap types studied, regardless of changing environmental conditions during the study period. The two factors that probably influence trap catches are the type of environment in which each trap is placed and the type of attractant used in each trap type. Because both of these factors occurred together in the study, it is impossible to conclude which factor might have been responsible for the difference in trap catches. The difference could be based simply on natural mosquito behavior: a larger population of gravid females seeking a suitable area for laying eggs versus blood-seeking mosquitoes seeking a host. There was also no method in this study of monitoring the effectiveness of the different attractants used in the traps and their strength and longevity during the daily trapping period or as seasonal environmental changes occurred. Therefore, although a strong week effect was identified in this study, the cause of this effect cannot conclusively be determined. However, it can be concluded that the number of mosquitoes increased during the study period and that Gravid traps caught many more mosquitoes than Underhouse traps, regardless of when traps were operated. If the aim of the surveillance program is simply to maximize the total number of mosquitoes caught, then the use of Gravid traps is recommended.

Overall, 15 different species were caught by the two traps in this study. Thirteen different species were caught by Underhouse traps, whereas Gravid traps caught 11 different species. Therefore, for this study period, the conclusion is that Underhouse traps caught a greater variety of mosquito species than Gravid traps, although the quantity of some species caught (one only) needs to be considered. The study period was limited in length and trapping was only carried out during one year. The difference observed might not hold true in future study periods. The importance of the different species collected in each trap is best judged by surveillance personnel regarding trap preferences or locations for future collections.

Overall conclusions are that Gravid traps clearly out performed Underhouse traps in quantity of mosquitoes collected. No significant inference could be made regarding the variety of species caught in Underhouse traps versus Gravid traps. There was a week effect demonstrated across the fourteen-week study period, however, the exact reason for that effect is undeterminable from this study. It could be based on trap design, environmental conditions, or trap placement.

3. GEOGRAPHIC INFORMATION SYSTEM – INVERSE DISTANCE WEIGHTED AND MORAN'S I INDEX CORRELATION ANALYSIS OF TRAP AND MOSQUITO DATA

3.1 Introduction

A Geographic Information System (GIS) is a software system for input, storage, processing, and retrieval of spatial data. The spatial component allows collected data to be presented in graphic map form. The spatial data gives information about a particular location or shape of a geographic feature using either vector data or raster data. In addition to shape and location of a feature, GIS allows a database-like table to be associated with the feature. This table contains "attributes" that provide additional information or records for each location.

Public health professionals utilize GIS for multiple reasons, including planning and policy development, research and preventive measures implementation. The different layers added to a map contain information such as vegetation, rainfall, soil composition, animal population/density, roadways, buildings or census population information. Data that is aggregated over space and time can be utilized to study "patterns," such as disease outbreaks or animal populations or distributions.

One of the most important uses in Public Health is the ability to predict unknown behavior or occurrence based on current known data. Preventive medicine is a key component in the public health arena. The ability to predict an outbreak, before it occurs, and thus be able to take measures to reduce or negate the impact, is immeasurable.

Researchers can use GIS to create “models” of future disease patterns and use that knowledge to prepare for and respond to those future occurrences. One example of this approach is shown by Tachiiti et al. (2006) and their use of GIS to perform a risk assessment of the potential impact West Nile Virus introduction on British Columbia. Using a *Culex tarsalis* model and environmental and social factor models, they were able to identify areas of greatest risk potential. This assessment demonstrated a need for increased bird and mosquito surveillance and the development of an early warning system for disease outbreaks. Ruiz et al. (2007) used GIS to compare WNV illness and urban landscapes in Chicago and Detroit. They developed a model for urban classes that was used to indicate the relationship between the age of housing, concomitant social and natural features and land use and the risk of WNV transmission. In addition to the risk assessment, their research provided information regarding field sites for avian and mosquito surveillance. Ruiz et al. concluded that the associations they used may be generalized and thus have implications for modeling other cities, with similar urban landscapes in the future. Both of these studies highlight the importance of a GIS program in Public Health disease prediction and prevention.

Another method of predicting outbreaks is based on the association between clusters of vectors or disease in animals and the subsequent increased risk of disease in the human population. While a cluster of dead birds or WNV positive mosquitoes does not directly indicate a human outbreak will occur, it does indicate an area or group at a higher risk than an area showing no disease clustering of vectors or early warning sentinels. This spatial clustering allows public health officials to recognize the increased risk and respond appropriately, whether it is increased surveillance or area spraying for WNV monitoring. It also allows Public Health agencies to be more prepared for a possible human outbreak.

3.2 Methods

Global Positioning System (GPS) coordinates were obtained, using a handheld GPS unit (Garmin eTrex Legend®), for each trap site. Coordinates were not specific to either trap but rather the physical property location. Site 23 was relocated during week eleven because of the death of the property owner. The trap was moved to the adjacent property, however new GPS coordinates were not obtained since the traps were relocated less than 50 feet from the original location and the properties shared comparable environmental conditions. In addition, a check of the latitude and longitude based on the street address revealed the same GPS coordinates as the original location (http://terraserver.microsoft.com, last accessed March 15, 2007). The following were imported into ArcMap Harris County shape (.shp) file and major roads shape file (Geographic Coordinate System: North American Datum 1983, Projected Coordinate System: North American Datum 1983 State Plane Texas South Central Federal Information Processing Standard (FIPS) 4204 Feet, Projection: Lambert Conformal Conic) and Houston-Galveston Area Council Land Cover Classification grid, hgaclc_u15 layer (.lyr) file (Spatial Reference: World Geodetic Datum 1984 Universal Transverse Mercator Zone 15 North). The Harris County shape file was used as the base layer map and all other layers were added in association with it. The land cover classification map and Houston-Galveston land area map are provided in Appendix H for background information about the area only; no vegetation surveys were conducted for this study. It also includes an overview map with both trap locations and the weather station location. All mosquito data, including GPS coordinates, was entered into multiple spreadsheets (Excel 2003. Microsoft® Corporation, Redmond, WA) and saved as either comma (.csv) or text delimited files (.txt) and imported into ArcMap (ArcGIS Desktop 9.2, ESRI® Incorporated, Redlands, CA) as tables. The X, Y coordinate information was added, along with assignment of the Coordinate System: Geographic Coordinate System-North America 1983 Datum. The files were then exported as shape files and added to the base layer map. The data included catch counts, over the fourteen-week study period, for the four main species and for all other species combined, for each trap type.

Two methods of analysis were used to interpret the data. The first method, Spatial Analyst (spatial interpolation) used to estimate values (mosquito counts for this study) at unsampled sites within a certain area covered by existing (sampled) observations. The type of spatial interpolation used was Inverse Distance Weighted Interpolation (IDW), which assigns values to locations based on the neighboring measured values. This method provides a visual depiction of the independent variable dispersal. The second analysis used was Moran's I, a spatial autocorrelation (spatial statistic) method. It measures spatial autocorrelation (feature similarity) based on both feature location and feature values, together. It evaluates whether a pattern is dispersed, clustered, or random. Both methods were conducted using the weekly *Culex* *quinquefasciatus* catches since they comprised approximately 97% of catches from both traps collectively. IDW analysis provides a visual output map of the weekly mosquito catches, while Moran's I indicates if spatial clustering occurred across the study period.

3.2.1 Inverse Distance Weighted Analysis

IDW analysis was performed on weekly *Culex quinquefasciatus* catches in both GV and UH traps. A separate IDW analysis was performed for each trap week and each trap for 28 individual map layers. The original raster resolution (cell size) has a ratio of 1:1 and provided an overall view of Harris County, and a less detailed view of the inner-loop or study area. The display was zoomed in until the inner-loop filled the display area and provided a larger view of the study area. The resulting resolution is a 1:.746 ratio, indicating each raster cell represent a much smaller land area than the original 1:1 ratio. The smaller cell size allows for higher resolution and higher feature spatial accuracy. The environment in Spatial Analyst was set with "no analysis mask," the same coordinate system as input, extent was set to "same as display," and cell size was set to "maximum of inputs." For the IDW analysis, the input points was set as the trap set (GV or UH), the z value field was the weekly *Culex quinquefasciatus* catches and the power was "2" (the default value that produces smoother surfaces). The search radius was set as "variable" so that the number of input points used in the calculations is set instead of needing a "fixed" amount of points inside a search radius. The number of points was set as "10," for the number of trap sites or data points available. The output cell size, decimal degrees, was accepted as "0.000798598," which was determined by the display and extent set earlier. Finally, the raster output was saved, making it a permanent layer in the working directory, in the ESRI GRID format. Once weekly data was processed, the layers properties was opened for each raster output and the color ramp was set, the classification was set at "9 equal intervals" and the range labels were changed to the nearest whole number. These steps were performed for all 28 IDW raster outputs. Finally, the view was changed from "data" to "layout," and a map was created using the cartography options (including North arrow, legend) and the maps were exported as jpeg image files and are displayed in Appendices I and J, for Gravid and Underhouse traps respectively.

3.2.2 Moran's I Spatial Correlation

The second analysis performed on weekly *Culex quinquefasciatus* catches, from each trap, was Spatial Autocorrelation (spatial statistics) using Moran's I. A separate text delimited file was created and imported into ArcMap, once again adding X, Y coordinates, assigning a geographic coordinate system, and exporting the file as a map layer, for each weekly catch and each trap. Moran's I, found in ArcMap Spatial Statistics (Analyzing Patterns), was selected and the input feature class set to the weekly *Culex quinquefasciatus* catch. The conceptualization of spatial relationships was set to "inverse distance squared," which allows for the impact of one feature on another to decrease more sharply over distance than the inverse distance, but either would have been acceptable for this analysis. The distance method was set as "Euclidean distance" which provides for straight line "as the crow flies" distance between two points.

Standardization was set at “none,” the threshold distance to “0” and no weights matrix was identified. Output for Moran’s I included an optional graphic display, Moran’s I Index, a z score, and the likelihood if the data was dispersed, clustered, or randomly distributed. An expected index and variance were also included in the output, but were reported or used in this paper. The results for Moran’s I are presented in a table in the results section and the corresponding P values have also been included. The z score and P value indicate statistical significance, while Moran’s I near +1.0 indicates clustering, a value near -1.0 indicates dispersal and close to 0 indicates random chance.

3.3 Results

The maps presented in Appendices I and J show the IDW visual trend of species collections as the trapping season progressed. While there is not a consistent trend across all the trap locations, some trends are easily seen through the study period. The first trend is, with few exceptions, that more *Culex quinquefasciatus* mosquitoes were caught in the northeast quadrant of the inner-loop area (Sites 21, 22, 23 and 33) consistently through the fourteen-week period. The major roadway, I-45, that runs north to southeast and transects the loop area, is the center of a second trend. On average, mosquito catches tended to be higher on the east side of I-45. This is also consistent with the environmental conditions of the city on either side of I-45. The west side has been developed more, and has a higher socio-economic population versus the east side of I-45 which has a large industrial and lower socio-economic population. Underhouse trap analysis followed somewhat of the same trends, although not as pronounced. While differences could be seen regarding the I-45 break, they were much more sporadic in Underhouse traps than in Gravid traps. Areas 51 and 52, near the center of the loop area, had consistently higher counts more often than they did in Gravid traps, although Underhouse traps generally collected far fewer mosquitoes. In the northeast quadrant, Area 23 also consistently had higher counts than sites 21, 22, and 33, unlike in Gravid traps where all four showed high counts consistently. While no strong inferences can be drawn from the IDW analysis, it does provide a visual mapping of the weekly catches.

Moran's I, however, does put a quantitative meaning to the catch numbers. Moran's I Index, z score, and P values for Gravid and Underhouse Traps are presented in Tables 17 and 18, respectfully. The null hypothesis regarding spatial clustering is that there is no clustering. The z score and associated P value ($P < 0.05$) indicate if Moran's I is significant. Based on the data for Gravid traps, Moran's I indicates clustering for weeks 9 and 21, with scores of 0.69 and 0.74 respectively. Likewise, the P value for those weeks indicates significance, with values of 0.040 and 0.021 respectively. Weeks 12, 13, 15, 16, 17 and 22 all indicate dispersal of catches with Moran's I values of -0.30, -0.43, -0.28, -0.01, -0.09 and –0.28, respectively. The P values support that analysis with values ranging from 0.368 to 0.944. The IDW maps for weeks 9 and 21 indicate much higher catches in the northeast quadrant, with consistently lower catches across the remaining traps. The Moran's I indications of dispersal can also be seen in the IDW maps for the corresponding weeks, when the trap catches seem varied across the study area.

Table 18. Moran's I Autocorrelation Index for *Culex quinquefasciatus* Mosquitoes Caught in Gravid traps, Inner-Loop Area, Houston, TX, March – May 2007.

Collection Week	*Culex quinquefasciatus* Total Weekly Catch	Moran's I Index	Z-Score	P Value
9	501	0.69	2.05	0.040
10	314	0.62	1.89	0.059
11	248	0.14	0.65	0.516
12	148	-0.30	-0.54	0.589
13	286	-0.43	-0.90	0.368
14	347	0.33	1.30	0.194
15	665	-0.28	-0.48	0.631
16	837	-0.01	0.27	0.787
17	819	-0.09	0.07	0.944
18	1241	0.30	1.33	0.184
19	3377	0.004	0.33	0.741
20	4588	0.02	0.34	0.734
21	1417	0.74	2.30	0.021
22	971	-0.28	-0.42	0.674

Significant Moran's I Autocorrelation Indexes, week 9 & 21, are in bold.

The Underhouse traps do not show the same patterns. Only three weeks show an indication of spatial clustering, week 13, 17 and 19, P = 0.002, 0.044 and 0.011, respectfully. The IDW for week 13 gives some indication of clustering in the northeast quadrant, but week 19 has high trap counts on either side of I-45 and the clustering is not as easily visualized. The IDW for Week 17 consistently had lower counts for all traps west of I-45, while only one site east of I-45 indicated significant catches. Of the remaining eleven collection weeks, eight indicate dispersal with negative Moran's I values and P values ranging from 0.0602 to 0.826. Underhouse traps do not show any consistency regarding clustering across the fourteen week study period.

Table 19. Moran's I Autocorrelation Index for *Culex quinquefasciatus* Mosquitoes Caught in Underhouse Traps, Inner-Loop Area, Houston, TX, March – May 2007.

Collection Week	*Culex quinquefasciatus* Total Weekly Catch	Moran's I Index	Z-Score	P Value
9	37	-0.04	0.23	0.818
10	84	0.11	0.89	0.912
11	78	-0.67	-1.88	0.060
12	59	0.18	0.73	0.465
13	51	0.92	3.07	0.002
14	117	0.28	1.01	0.312
15	137	-0.24	-0.34	0.734
16	187	-0.33	-0.64	0.522
17	84	-0.58	-2.01	0.044
18	81	-0.20	-0.22	0.826
19	421	0.89	2.54	0.011
20	353	-0.41	-0.83	0.407
21	573	0.04	0.53	0.596
22	131	-0.58	-1.20	0.230

Significant Moran's I Autocorrelation Indexes, week 13 & 19, are in bold.

3.4 Discussion

The higher concentration of catch numbers in the northeast quadrant of the study area (areas 21, 22, 23 and 33) corresponds with the environmental conditions suggesting there are areas suitable for increased mosquito populations. This area also contains housing that lack many fundamental prevention measures, such as window and door screens, or that lack central air conditioning or no air conditioning at all, leaving the inhabitants more susceptible to exposure to infected mosquitoes.

The use of Inverse Distance Weighted interpolation provides a visual representation of the mosquito catches and a method of estimating the collections at other unsampled areas in the same vicinity. This information can be used to predict areas that are impacted by mosquitoes of public health concern without expending materials and resources to trap all possibly affected sites. In turn, that information can be utilized in the mosquito surveillance program for the areas in question. The IDW maps give a clear representation of the species and numbers caught by each of the different traps, GV and UH. They show that GV caught far more mosquitoes and they give indications in which areas they were caught. They also show a natural pattern, based on environmental conditions, between the collections from the four study quadrants (although it must be remembered that areas 1 and 2 contained more traps than areas 3 and 4). Overall, the results reinforce current knowledge of viable mosquito habitats and highlight the risk for those who reside in those areas. Moran’s I analysis gave meaning to the visual depiction of the IDW maps. It also clearly indicates where clustering occurred during the study period, much less often than was expected or even suggested by the raw catch data. One consideration for both analysis methods used is that this study only included 10 data points and they were not randomly assigned. While these results generate ideas regarding the patterns seen, any future study should attempt to include a minimum of 30 data points to draw inferences for the surrounding areas and future mosquito clustering and surveillance.

4. SUMMARY AND CONCLUSIONS

4.1 Summary

This study has provided answers to the two questions posed: 1) Is there a difference between the overall number of mosquitoes trapped in GV versus UH traps? and, 2) Is there a difference in the species composition trapped in GV versus UH traps? The answer to the first question is yes, Gravid traps caught an overwhelming larger quantity of mosquitoes during the fourteen-week study period. The answer to the second question is that Underhouse traps collected a larger variety of species during this study period, trapping thirteen of the total fifteen species collected overall, while the Gravid trap only collected eleven on the fifteen species (although, the number caught of each different species was not enough to be considered significant).

GLM repeated measures ANOVA indicates there is a week effect, meaning there is a significant difference in the mean mosquito collections between the different trap weeks. It also indicated there was a significant difference between the mean mosquito collections based on the two trap types higher mean catches for Gravid traps. Spearman's Correlation Coefficient also indicated there is a strong correlation between *Culex quinquefasciatus* mosquito catches and increasing temperatures. This observation is consistent with the mosquito lifecycle and density patterns already established.

The IDW and Moran's I analyses both provide information on the spatial distribution of the mosquito catches during the study period. Despite several weeks appearing to have clustering in the IDW output, Moran's I indicates only two weeks involved clustering for each trap, although they were not the same two weeks in either case. In addition, there were more weeks in which spatial distribution of catches was more dispersed than expected.

Although there was a trap and week effect on trapping counts, the reason for the differences in catches could not be identified in this study. There are at least three possible explanations: 1) trap attractant (CO2 versus hay infusion water); 2) trap placement (vegetated area versus underhouse area); and 3) environmental elements (temperature and rainfall). Without being able to control for each of these influences, this study could not identify the factors responsible for the week and trap effects. This study provides preliminary information, or reconfirmation of current surveillance knowledge, that should prove useful to MCD in the current and future surveillance applications and endeavors.

4.2 Conclusions

This study had several limitations that should be addressed in future studies. First, this study examined two different trap types, which inherently attract two different populations of mosquitoes, gravid, egg laying, and host seeking. Secondly, the nature of the traps or their intended target dictate they be placed in two different environments, in vegetated areas or underhouse areas. Finally, due to funding and equipment constraints, temperature and precipitation data was not recorded at the individual trap locations, but rather from a centrally located weather station.

Any future studies should focus on controlling the above factors in order to obtain more meaningful collection results. One type of trap should be chosen and placed in the different environments in order to test the traps' ability in that given environment or a four-trap study should be conducted in which one trap each would be placed in both environments. This might help answer the question of trap performance based on trap design/method or the environment in which the trap was placed. A full complement of thirty or more traps, of each design, should also be incorporated into any future studies to give more weight to the spatial analysis methods used to map and predict patterns and clustering.

Because current surveillance knowledge links mosquito density with environmental elements, the study should be correlated with corresponding temperature and precipitation measures for the trap location. This would provide a more precise manner to gauge the relationship between the mosquito collections and environmental conditions.

Lastly, this study did not include any testing for WNV or SLE virus on pooled samples. Without simultaneous testing of pools, the data collection has purely quantitative meaning, but no direct qualitative meaning regarding WNV or SLE virus presence or risk to the community.

In the end, this study succeeded in providing a snapshot of a period in time for this surveillance season and the results could be used to judge whether to pursue a more in-depth study at a future date. The data collected and the conclusions drawn can only be correlated to this specific trapping period and can only serve as predictive material for a period with the same or similar environmental conditions in the future. Different strategies for trapping and surveillance should be employed based on the season and environmental conditions. This study also provided information regarding species variety in the traps for this trapping period, which could prove useful in the future. Although this study by no means adequately represents mosquito trends in Harris County, it does provide useful information as a baseline for future surveillance seasons and studies.

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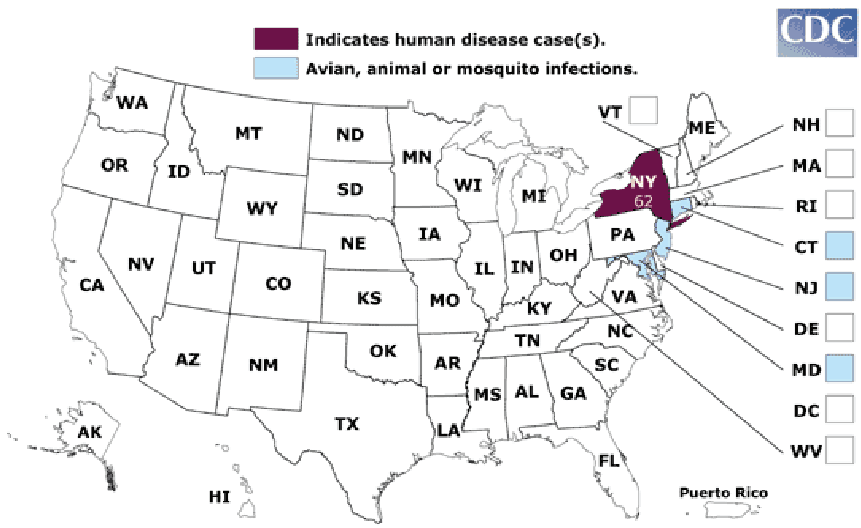
APPENDIX A

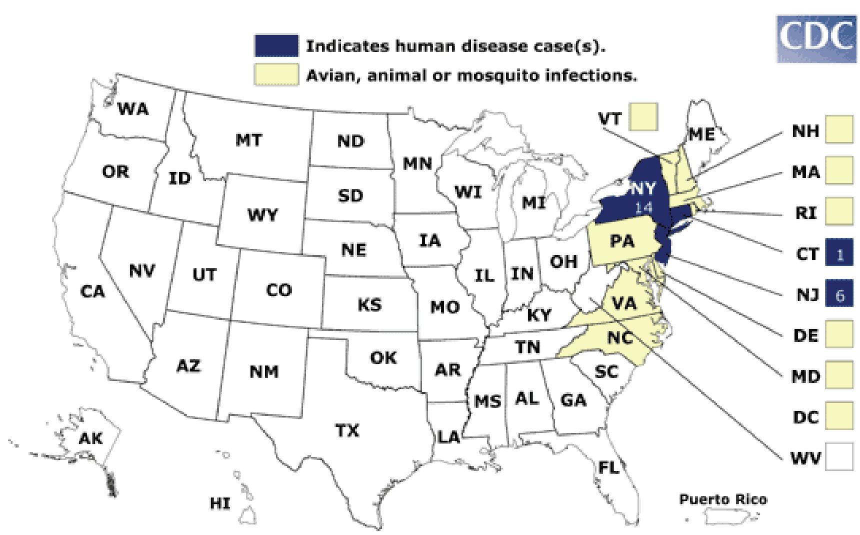
YEARLY WEST NILE VIRUS ACTIVITY IN THE UNITED STATES

All figures from Centers for Disease Control and Prevention www.cdc.gov

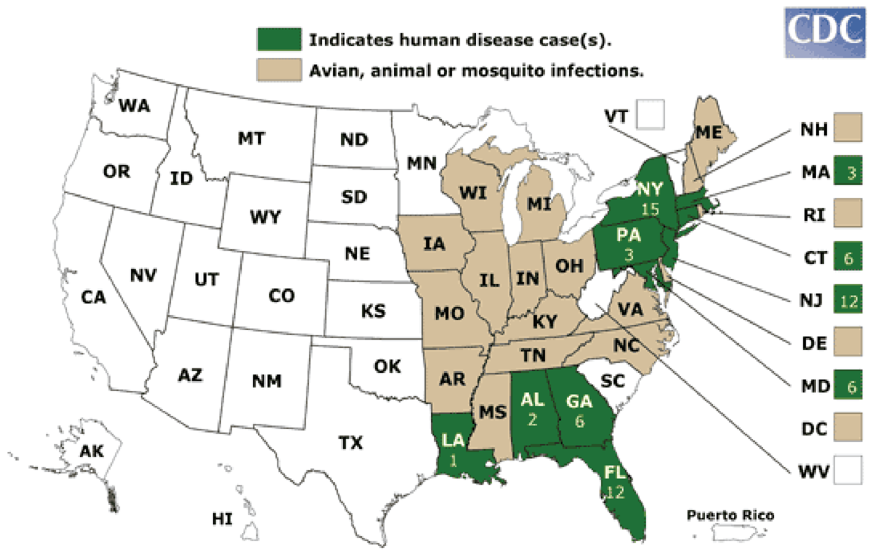
1999 West Nile Virus Activity in the United States



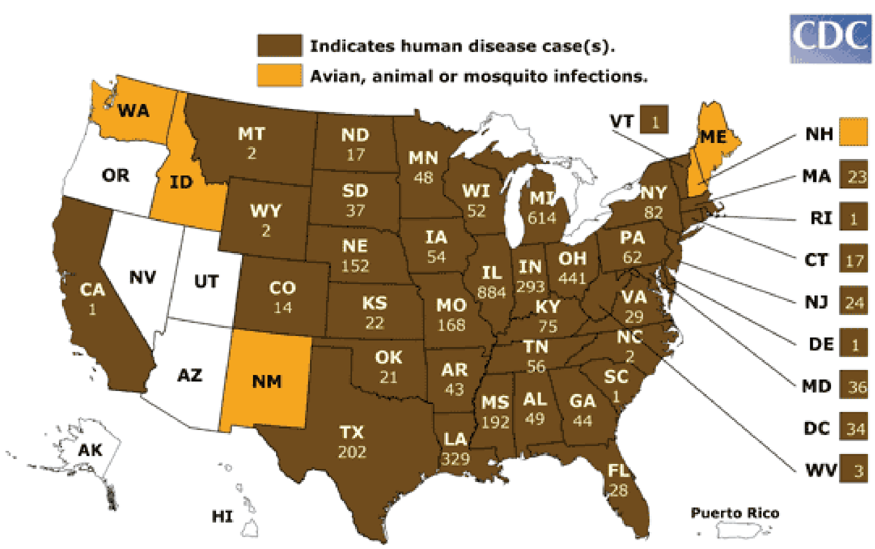
2000 West Nile Virus Activity in the United States



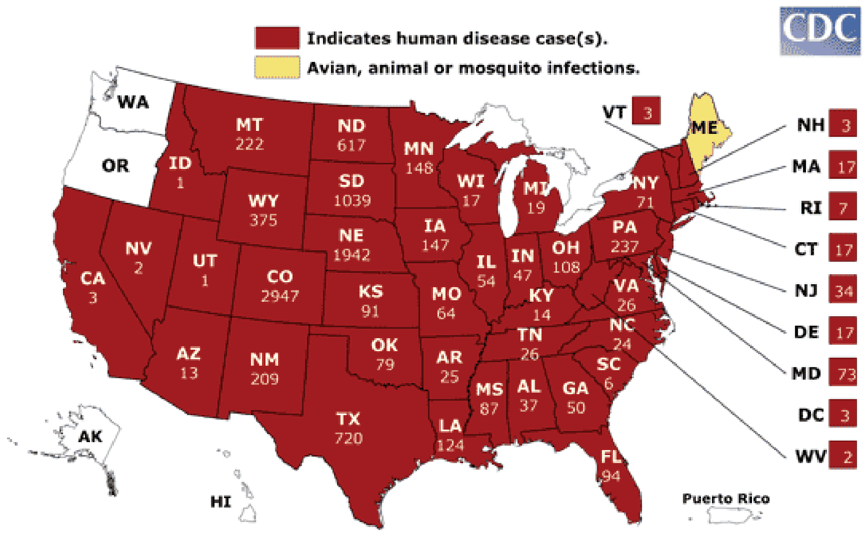
2001 West Nile Virus Activity in the United States



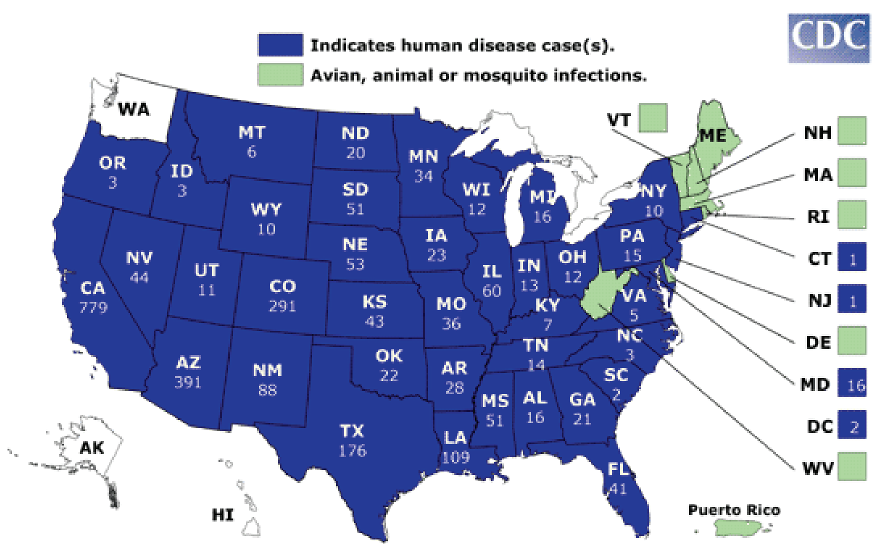
2002 West Nile Virus Activity in the United States



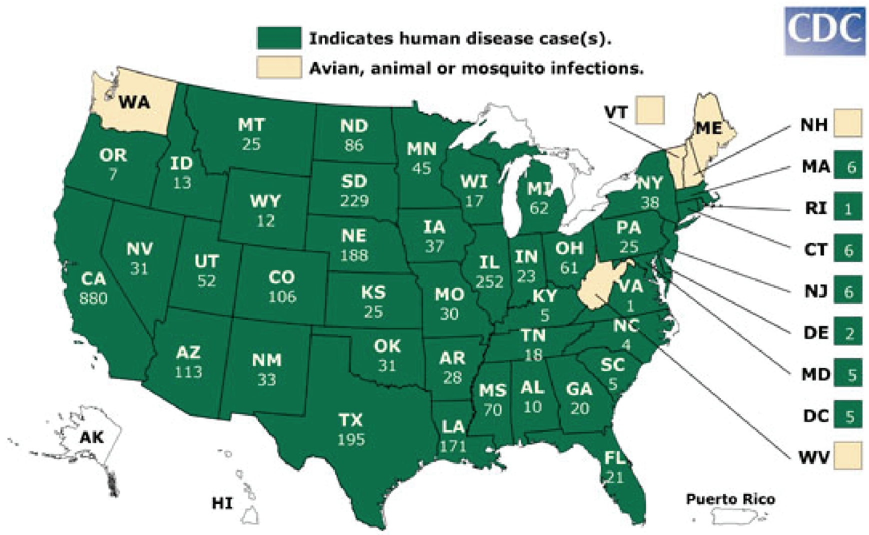
2003 West Nile Virus Activity in the United States



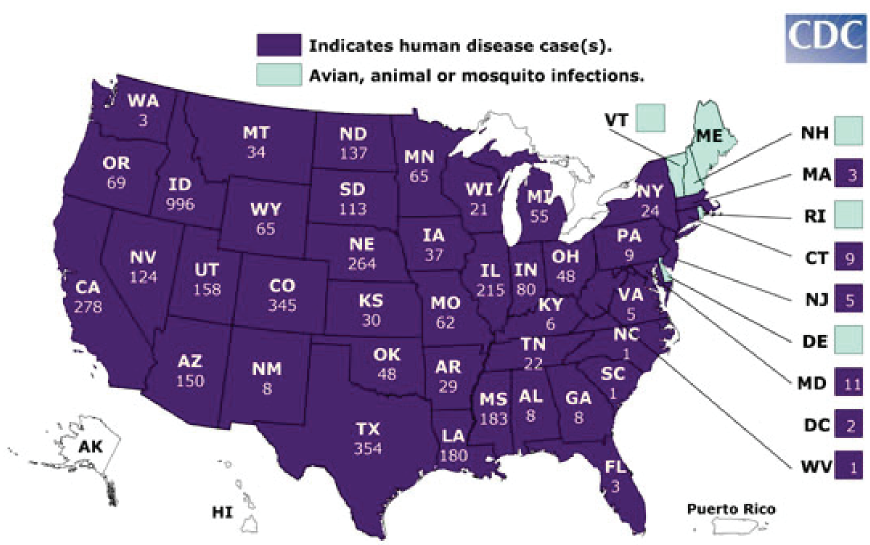
2004 West Nile Virus Activity in the United States



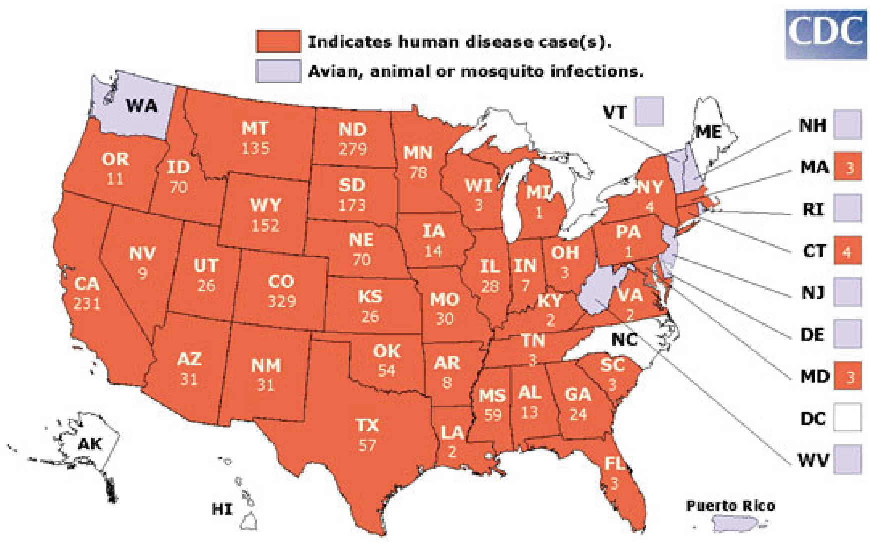
2005 West Nile Virus Activity in the United States



2006 West Nile Virus Activity in the United States



2007 West Nile Virus Activity in the United States, as of 18 Sep 07



APPENDIX B

DESCRIPTIVE STATISTICS BY TRAP TYPE AND MOSQUITO SPECIES

Gravid Traps and *Culex quinquefasciatus*

	N	Minimum	Maximum	Mean		Std.	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
WK9	10	1	135	50.10	15.577	49.258	2426.322
WK10	10	0	84	31.40	9.376	29.651	879.156
WK11	10	0	71	24.80	7.378	23.332	544.400
WK12	10	1	40	14.80	3.602	11.390	129.733
WK13	10	6	76	28.60	6.576	20.796	432.489
WK14	10	4	118	34.70	11.311	35.768	1279.344
WK15	10	5	219	66.50	20.462	64.707	4186.944
WK16	10	5	159	83.70	15.811	50.000	2500.011
WK17	10	2	226	81.90	24.888	78.703	6194.100
WK18	10	2	426	124.10	37.839	119.656	14317.66
WK19	10	69	1087	337.70	104.827	331.493	109887.8
WK20	10	56	817	458.80	88.029	278.372	77490.84
WK21	10	11	401	141.70	39.222	124.032	15384.01
WK22	10	11	178	97.10	18.082	57.179	3269.433
Valid N	10						

Gravid Traps and *Culex restuans*

	N	Minimum	Maximum	Mean		Std.	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
WK9	10	0	8	2.90	.983	3.107	9.656
WK10	10	0	19	5.60	1.968	6.222	38.711
WK11	10	0	10	3.10	1.120	3.542	12.544
WK12	10	0	6	2.40	.653	2.066	4.267
WK13	10	0	5	1.70	.517	1.636	2.678
WK14	10	0	3	.70	.335	1.059	1.122
WK15	10	0	8	2.10	.836	2.644	6.989
WK16	10	0	3	.30	.300	.949	.900
WK17	10	0	0	.00	.000	.000	.000
WK18	10	0	0	.00	.000	.000	.000
WK19	10	0	6	.70	.597	1.889	3.567
WK20	10	0	0	.00	.000	.000	.000
WK21	10	0	0	.00	.000	.000	.000
WK22	10	0	1	.10	.100	.316	.100
Valid N	10						

Gravid Traps and *Aedes aegypti*

	N	Minimum	Maximum	Mean		Std.	Variance
	Statistic	Statistic	Statistic	Statistic	Std.Error	Statistic	Statistic
WK9	10	0	0	.00	.000	.000	.000
WK10	10	0	0	.00	.000	.000	.000
WK11	10	0	0	.00	.000	.000	.000
WK12	10	0	0	.00	.000	.000	.000
WK13	10	0	0	.00	.000	.000	.000
WK14	10	0	2	.40	.221	.699	.489
WK15	10	0	0	.00	.000	.000	.000
WK16	10	0	1	.10	.100	.316	.100
WK17	10	0	0	.00	.000	.000	.000
WK18	10	0	0	.00	.000	.000	.000
WK19	10	0	0	.00	.000	.000	.000
WK20	10	0	1	.10	.100	.316	.100
WK21	10	0	1	.10	.100	.316	.100
WK22	10	0	1	.10	.100	.316	.100
Valid N	10						

Gravid Traps and *Aedes albopictus*

	N	Minimum	Maximum	Mean		Std.	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
WK9	10	0	0	.00	.000	.000	.000
WK10	10	0	0	.00	.000	.000	.000
WK11	10	0	0	.00	.000	.000	.000
WK12	10	0	1	.10	.100	.316	.100
WK13	10	0	0	.00	.000	.000	.000
WK14	10	0	5	1.80	.593	1.874	3.511
WK15	10	0	1	.10	.100	.316	.100
WK16	10	0	1	.30	.153	.483	.233
WK17	10	0	2	.30	.213	.675	.456
WK18	10	0	0	.00	.000	.000	.000
WK19	10	0	1	.40	.163	.516	.267
WK20	10	0	10	1.50	.969	3.064	9.389
WK21	10	0	2	.50	.224	.707	.500
WK22	10	0	3	.70	.335	1.059	1.122
Valid N	10						

Underhouse Traps and *Culex quinquefasciatus*

	N	Minimum	Maximum	Mean		Std.	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
WK9	10	0	17	3.70	1.693	5.355	28.678
WK10	10	0	54	8.40	5.201	16.447	270.489
WK11	10	0	42	7.80	4.171	13.189	173.956
WK12	10	0	16	5.90	1.997	6.315	39.878
WK13	10	0	19	5.10	1.841	5.820	33.878
WK14	10	1	34	11.70	3.780	11.954	142.900
WK15	10	1	48	13.70	5.321	16.826	283.122
WK16	10	1	83	18.70	8.580	27.134	736.233
WK17	10	0	56	8.40	5.330	16.854	284.044
WK18	10	0	25	8.10	2.888	9.134	83.433
WK19	10	1	108	42.10	13.774	43.557	1897.211
WK20	10	1	124	35.30	12.672	40.072	1605.789
WK21	10	0	315	57.30	30.514	96.494	9311.122
WK22	10	1	31	13.10	3.526	11.150	124.322
Valid N	10						

Underhouse Traps and *Culex restuans*

	N	Minimum	Maximum	Mean		Std.	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
WK9	10	0	0	.00	.000	.000	.000
WK10	10	0	6	.60	.600	1.897	3.600
WK11	10	0	0	.00	.000	.000	.000
WK12	10	0	1	.10	.100	.316	.100
WK13	10	0	0	.00	.000	.000	.000
WK14	10	0	0	.00	.000	.000	.000
WK15	10	0	0	.00	.000	.000	.000
WK16	10	0	2	.20	.200	.632	.400
WK17	10	0	0	.00	.000	.000	.000
WK18	10	0	0	.00	.000	.000	.000
WK19	10	0	0	.00	.000	.000	.000
WK20	10	0	0	.00	.000	.000	.000
WK21	10	0	0	.00	.000	.000	.000
WK22	10	0	0	.00	.000	.000	.000
Valid N	10						

Underhouse Traps and *Aedes aegypti*

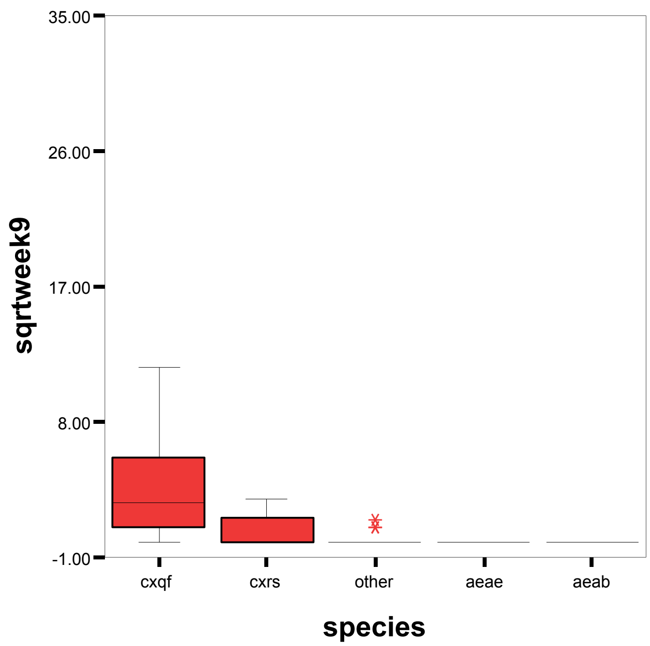
	N	Minimum	Maximum	Mean		Std.	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
WK9	10	0	0	.00	.000	.000	.000
WK10	10	0	0	.00	.000	.000	.000
WK11	10	0	0	.00	.000	.000	.000
WK12	10	0	0	.00	.000	.000	.000
WK13	10	0	0	.00	.000	.000	.000
WK14	10	0	2	.40	.221	.699	.489
WK15	10	0	0	.00	.000	.000	.000
WK16	10	0	1	.10	.100	.316	.100
WK17	10	0	0	.00	.000	.000	.000
WK18	10	0	0	.00	.000	.000	.000
WK19	10	0	0	.00	.000	.000	.000
WK20	10	0	1	.10	.100	.316	.100
WK21	10	0	1	.10	.100	.316	.100
WK22	10	0	1	.10	.100	.316	.100
Valid N	10						

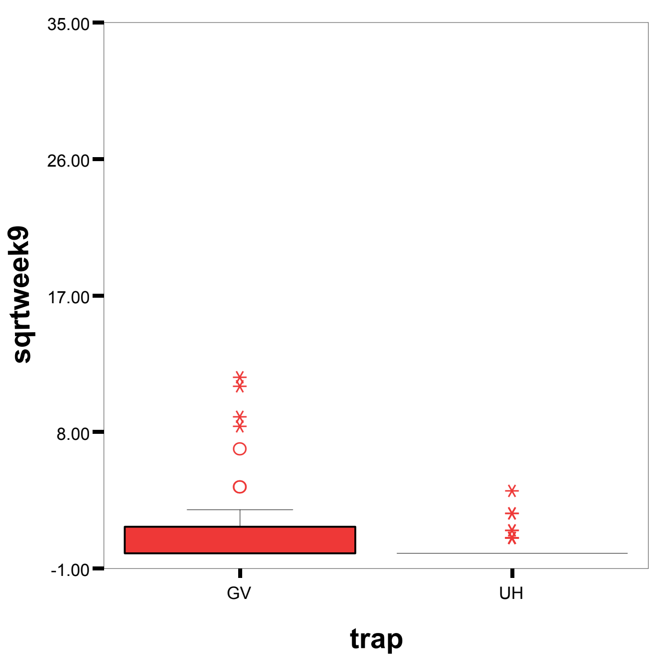
Underhouse Traps and *Aedes albopictus*

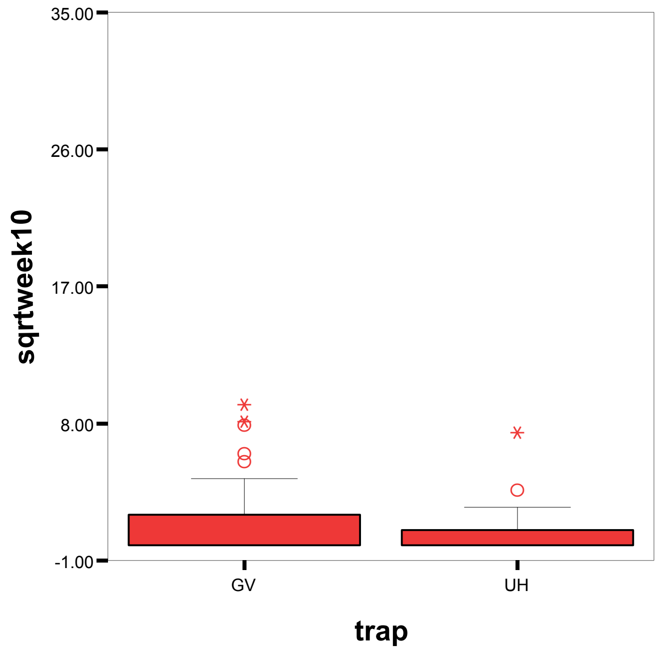
	N	Minimum	Maximum	Mean		Std.	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
WK9	10	0	0	.00	.000	.000	.000
WK10	10	0	0	.00	.000	.000	.000
WK11	10	0	0	.00	.000	.000	.000
WK12	10	0	0	.00	.000	.000	.000
WK13	10	0	0	.00	.000	.000	.000
WK14	10	0	1	.20	.133	.422	.178
WK15	10	0	0	.00	.000	.000	.000
WK16	10	0	0	.00	.000	.000	.000
WK17	10	0	0	.00	.000	.000	.000
WK18	10	0	0	.00	.000	.000	.000
WK19	10	0	1	.10	.100	.316	.100
WK20	10	0	2	.40	.221	.699	.489
WK21	10	0	1	.30	.153	.483	.233
WK22	10	0	2	.20	.200	.632	.400
Valid N	10						

APPENDIX C

BOX PLOTS OF TRAP CATCH MEAN DISTRIBUTION



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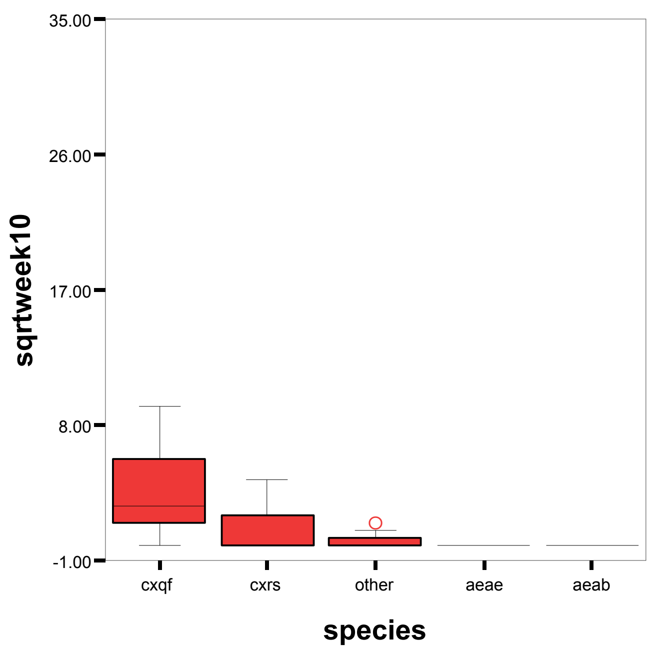
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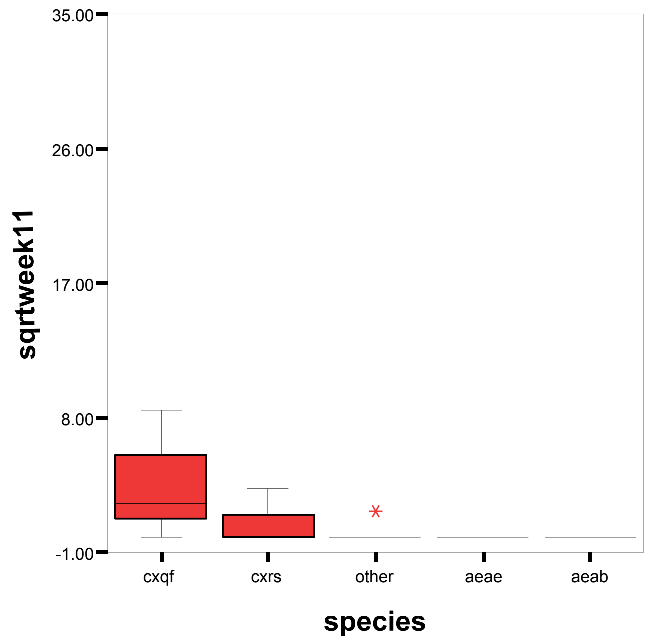
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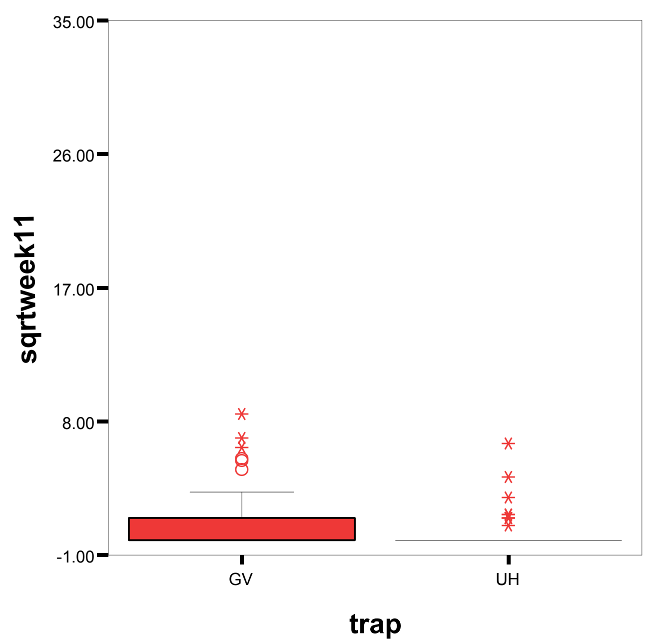
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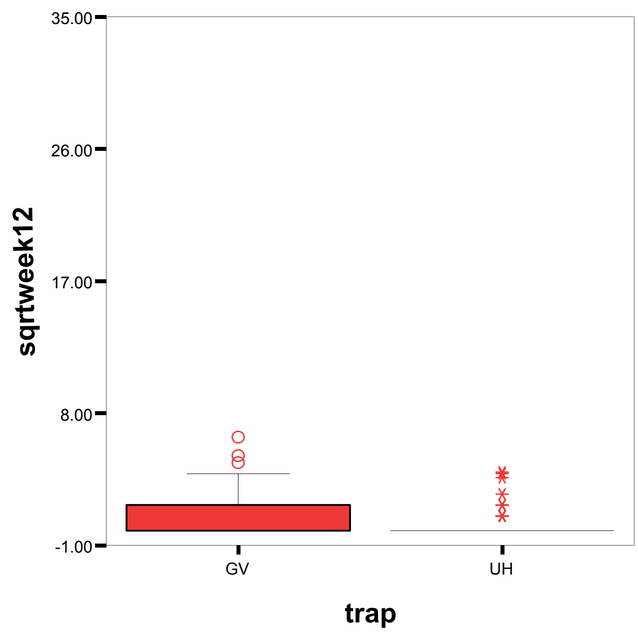
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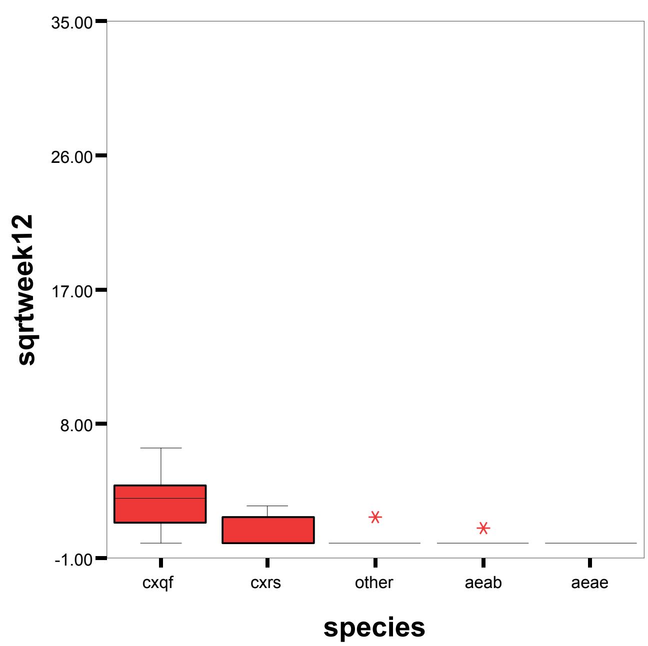
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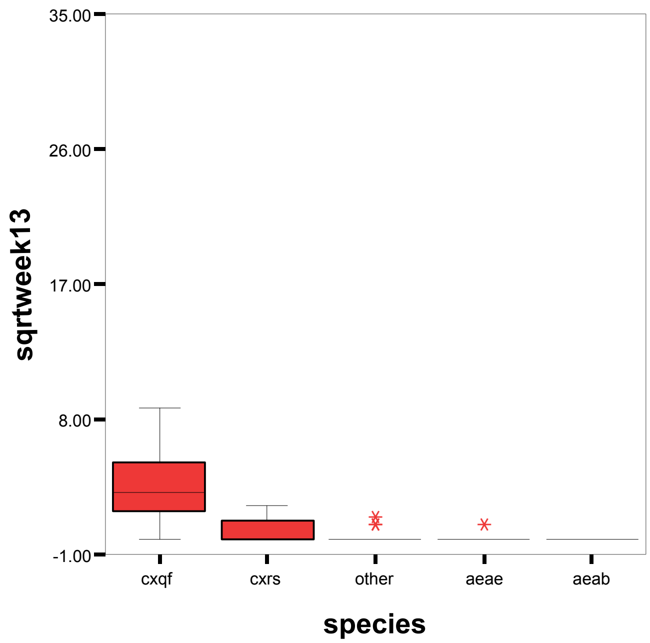
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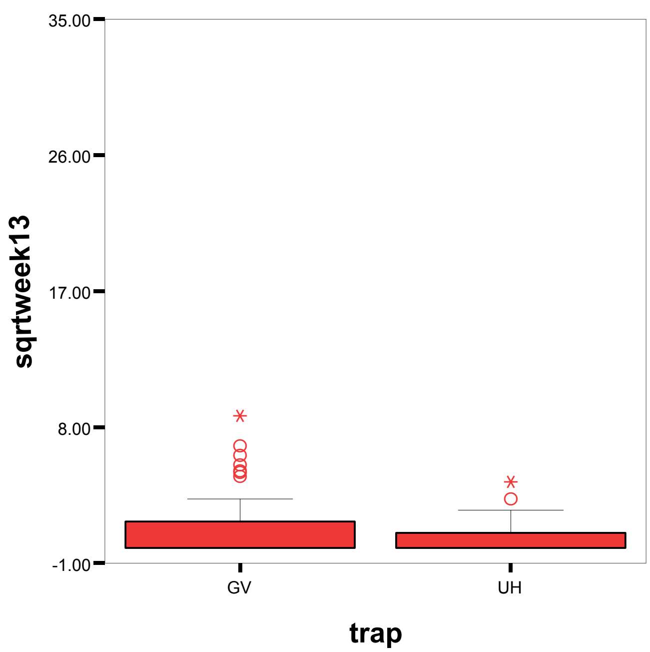
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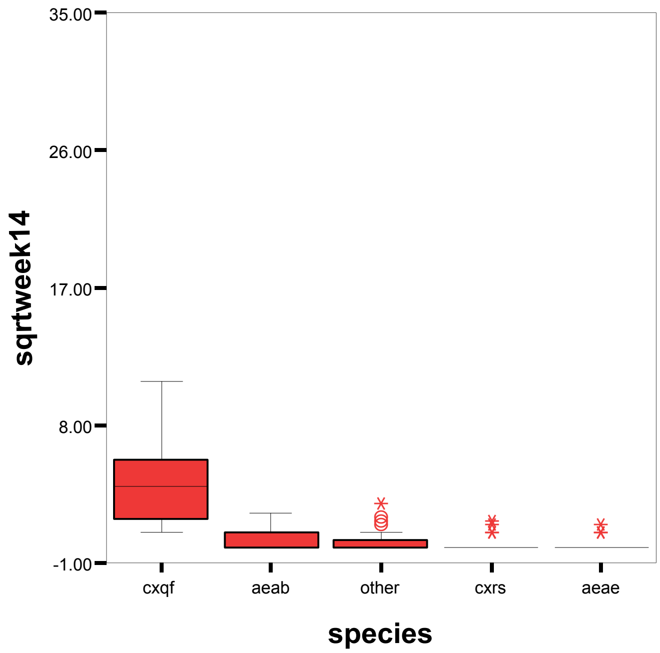
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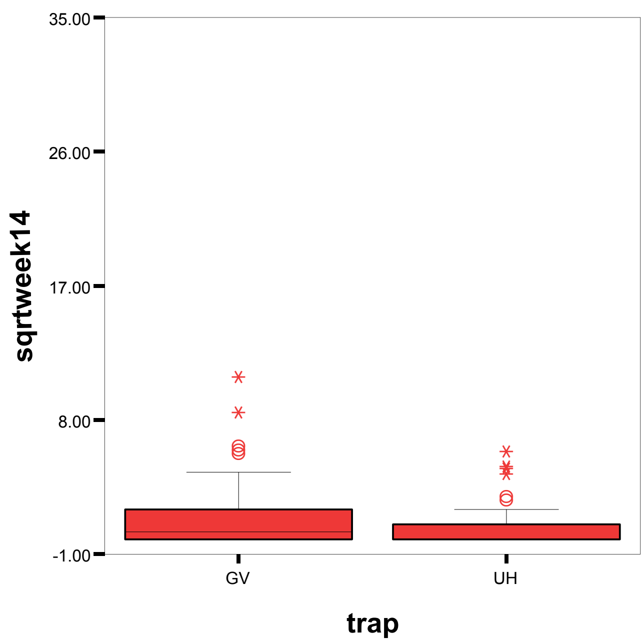
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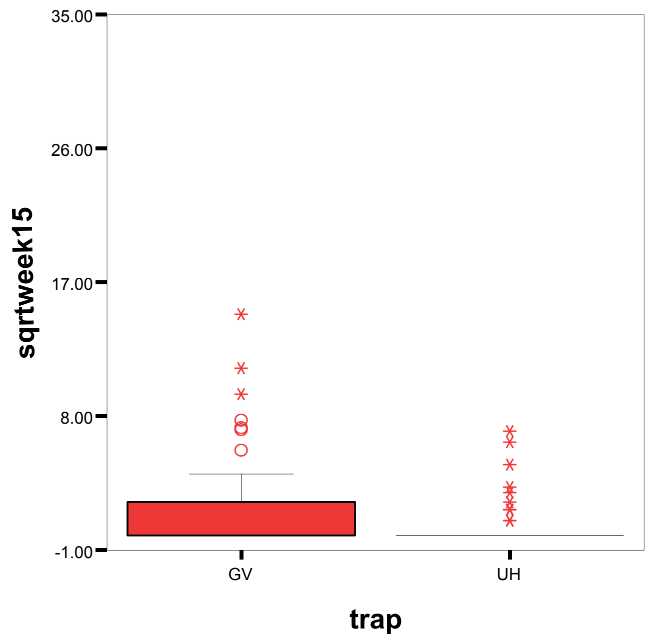
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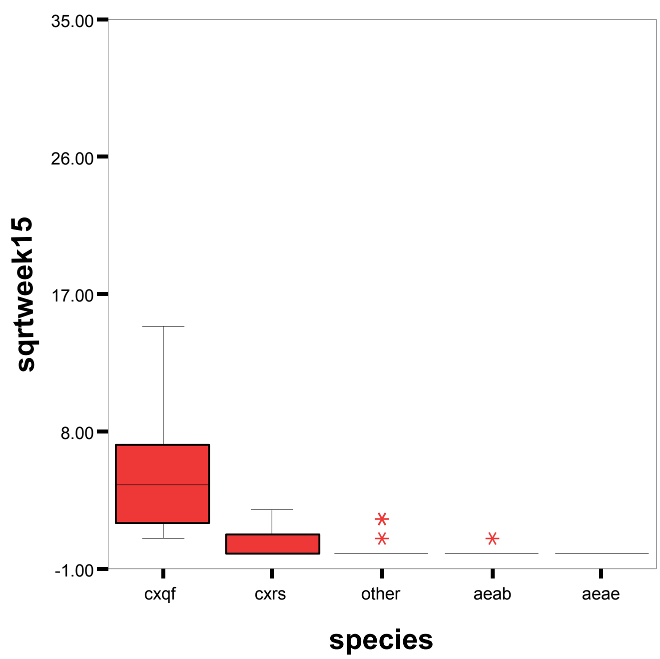
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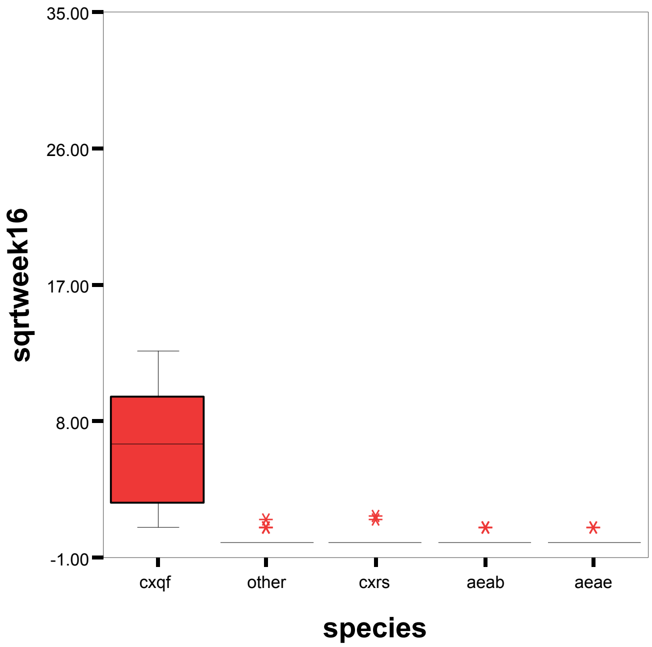
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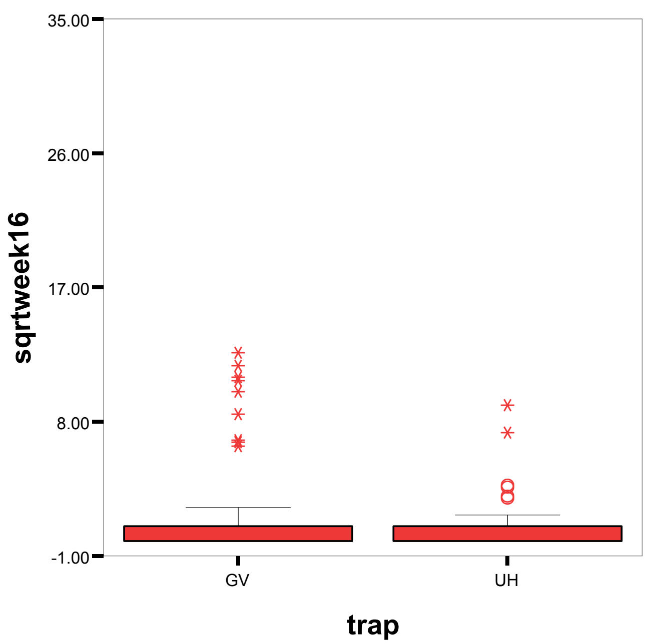
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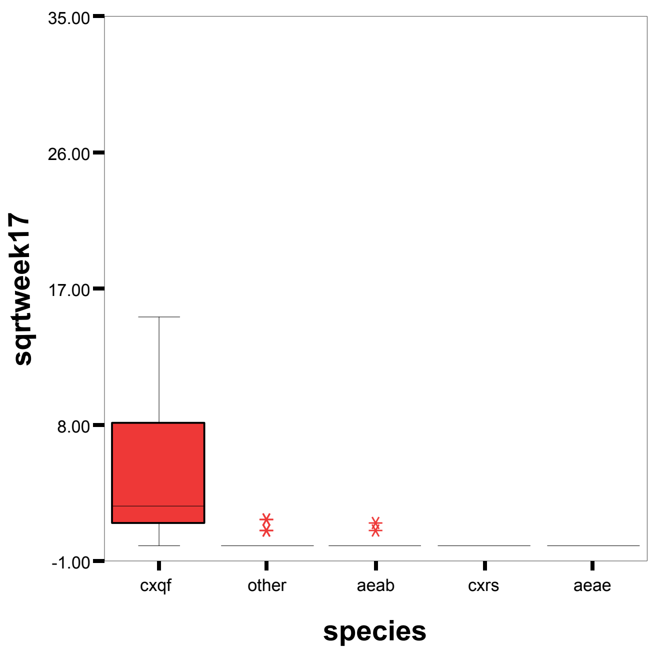
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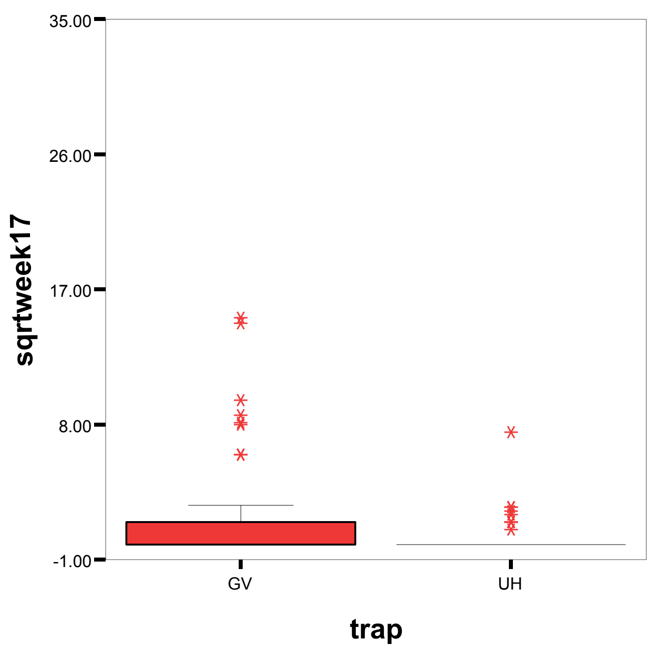
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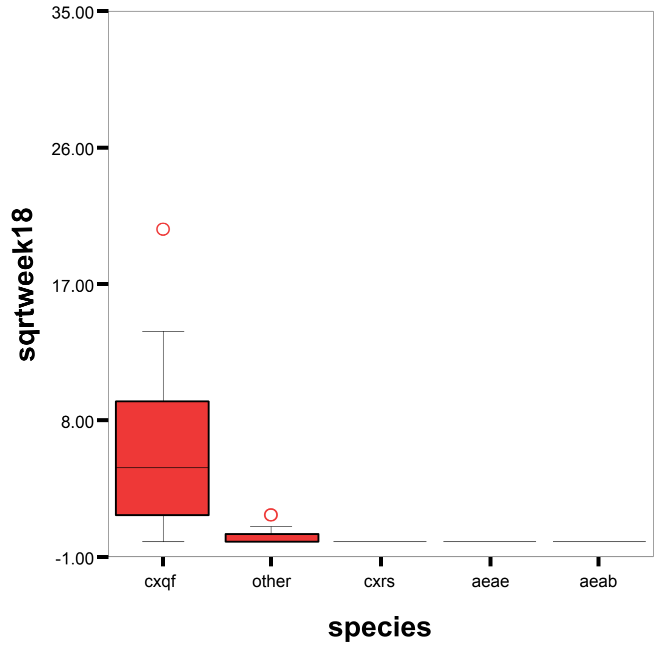
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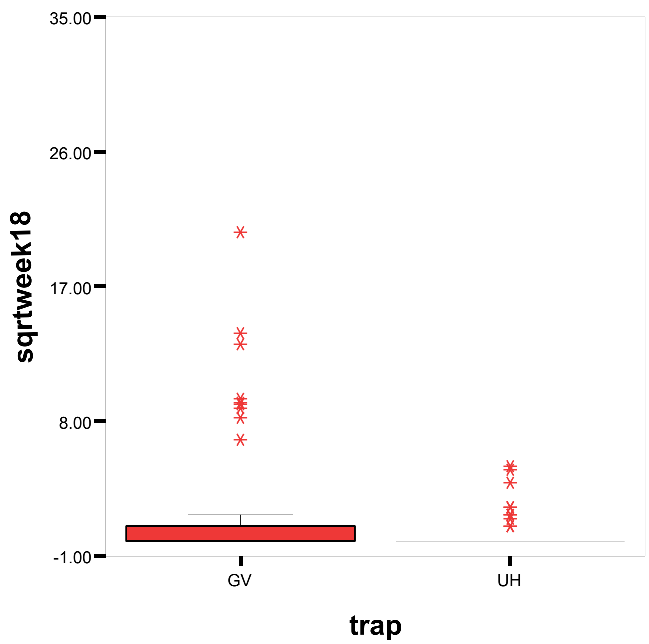
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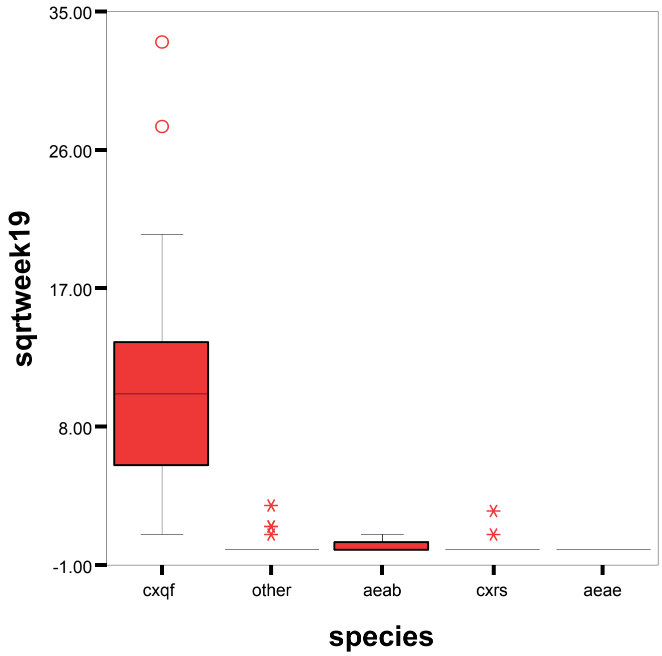
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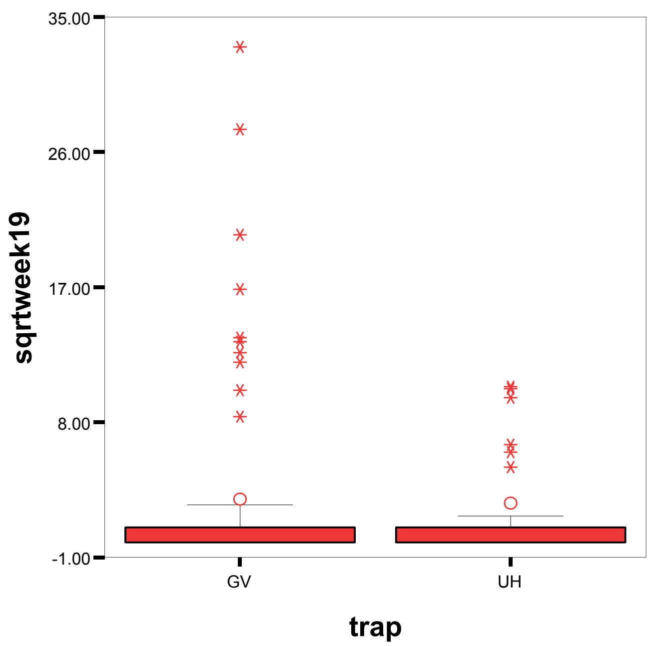
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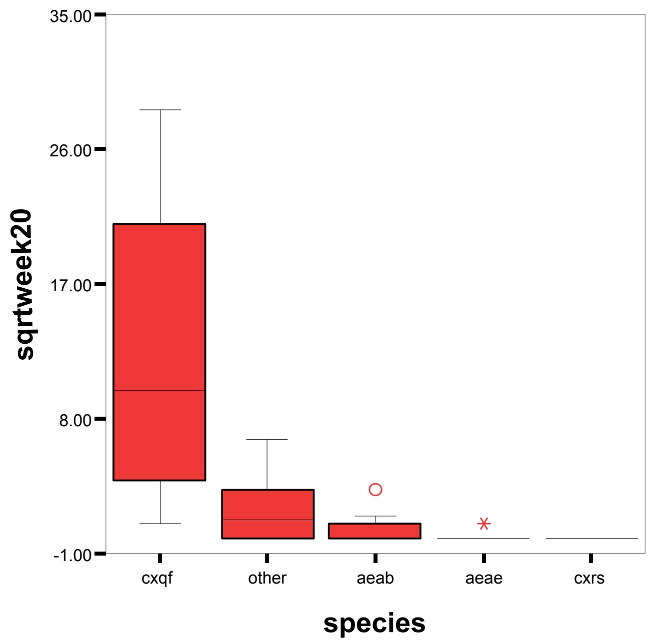
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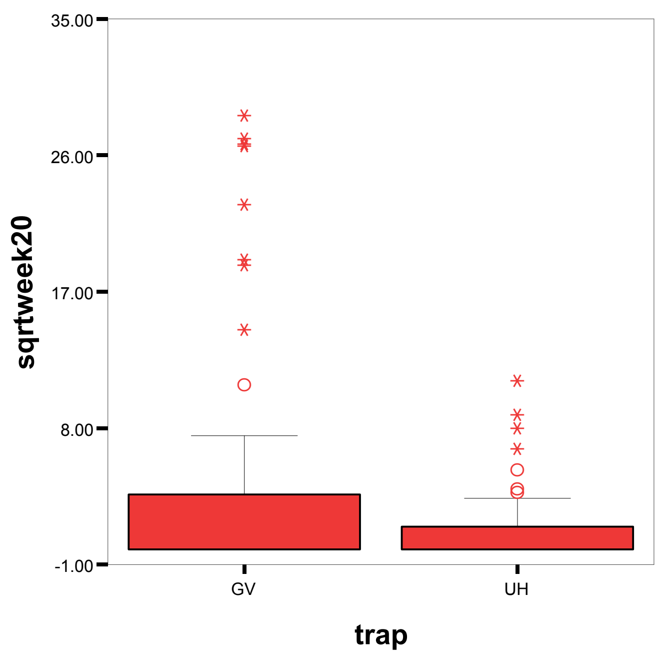
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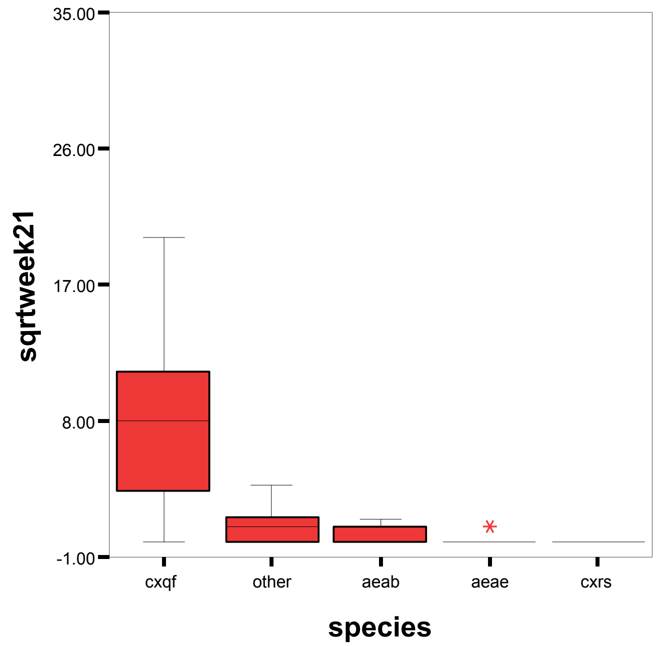
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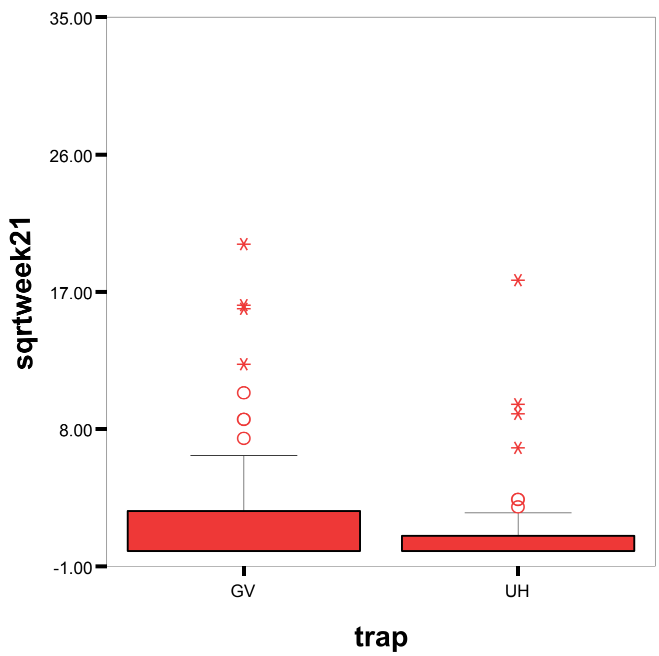
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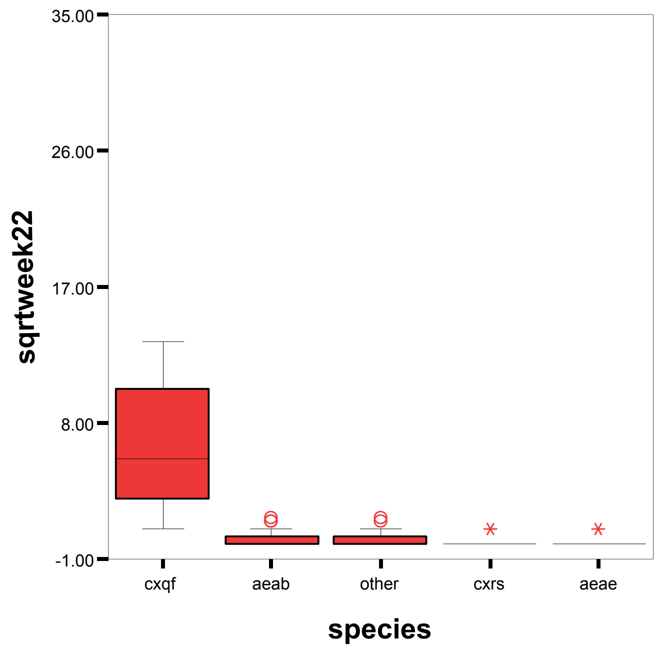
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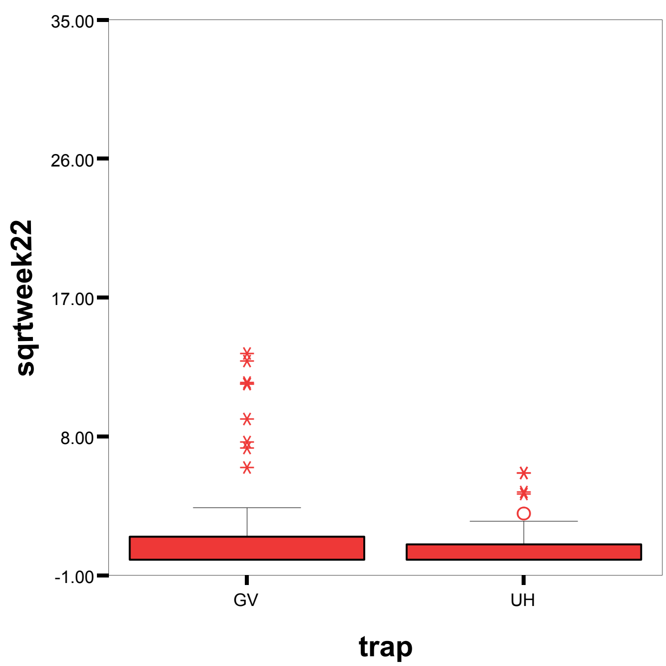
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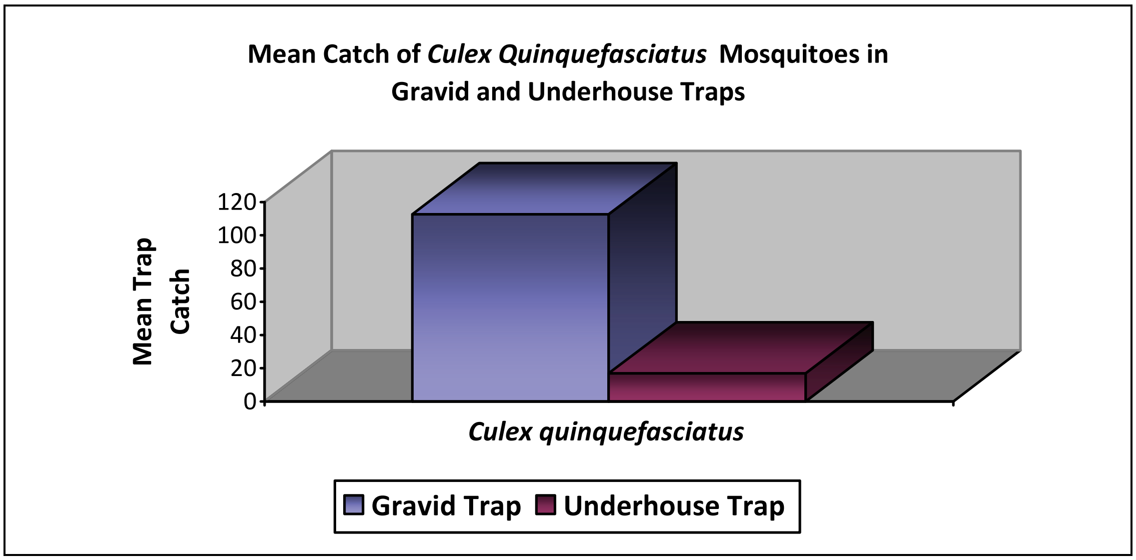
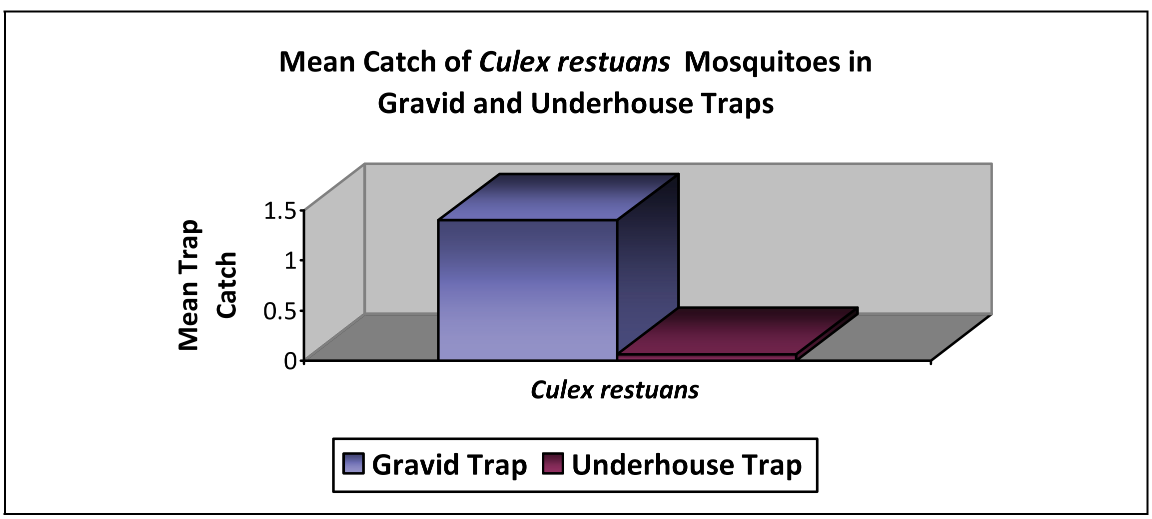
APPENDIX D

MEAN TRAP CATCH BY MOSQUITO SPECIES

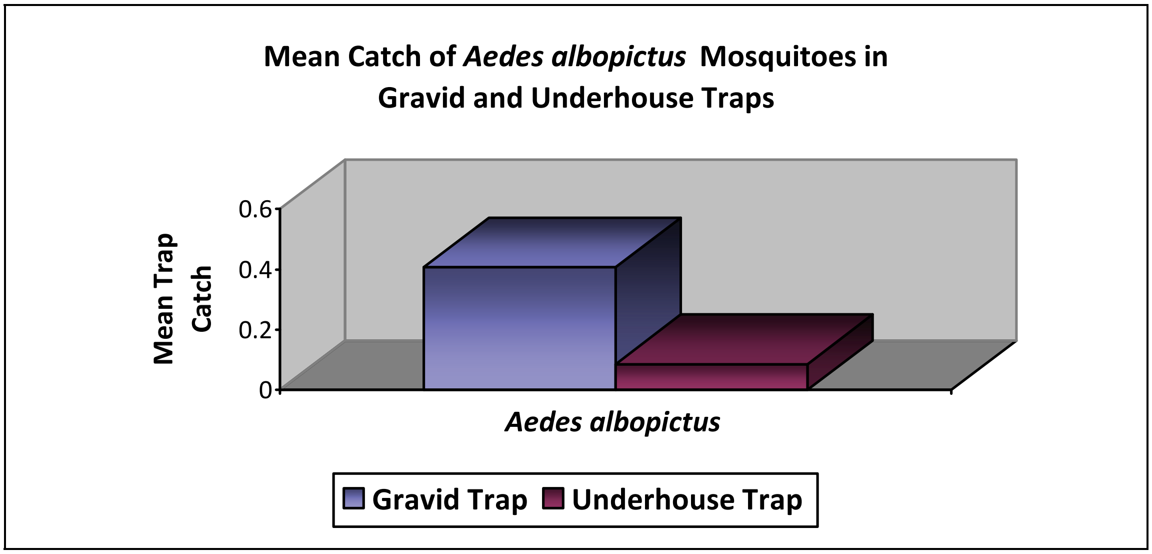
Mean Catch of *Culex quinquefasciatus* Mosquitoes in Gravid and Underhouse Traps



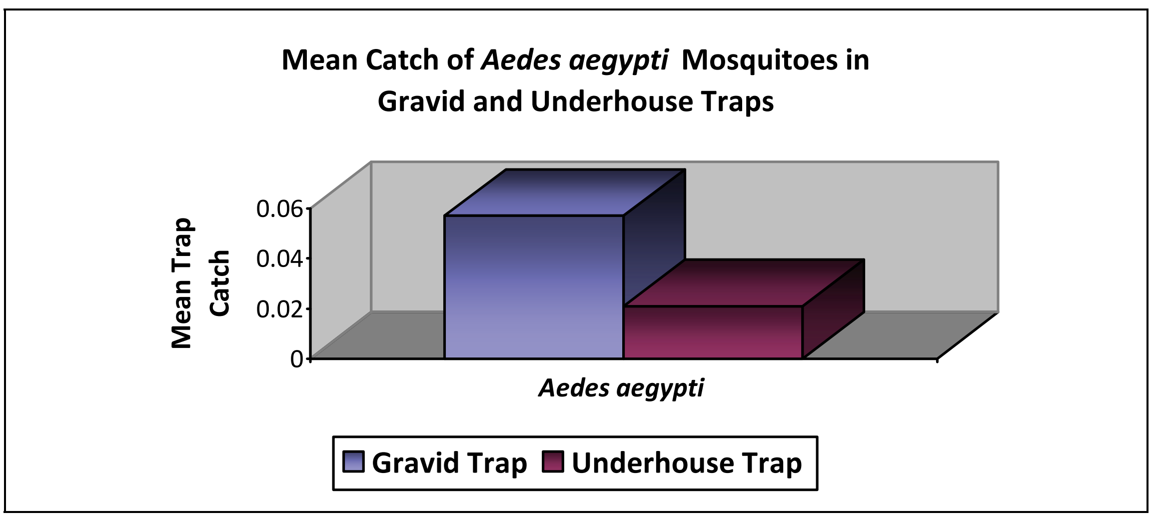
Mean Catch of *Culex restuans* Mosquitoes in Gravid and Underhouse Traps



Mean Catch of *Aedes albopictus* Mosquitoes in Gravid and Underhouse Traps



Mean Catch of *Aedes aegypti* Mosquitoes in Gravid and Underhouse Traps



APPENDIX E

PAIRWISE COMPARISONS OF WEEKLY *CULEX QUINQUEFASCIATUS* CAUGHT IN GRAVID TRAPS**

Week	9	10	11	12	13	14	15	16	17	18	19	20	21
9	–	–	–	–	–	–	–	–	–	–	–	–	–
10	.201	–	–	–	–	–	–	–	–	–	–	–	–
11	.090	.449	–	–	–	–	–	–	–	–	–	–	–
12	.048	.104	.170	–	–	–	–	–	–	–	–	–	–
13	.153	.807	.580	.079	–	–	–	–	–	–	–	–	–
14	.239	.809	.200	.113	.463	–	–	–	–	–	–	–	–
15	.328	.116	.076	.031	.059	.138	–	–	–	–	–	–	–
16	.082	.015	.002	.001	.004	.002	.432	–	–	–	–	–	–
17	.059	.069	.041	.019	.059	.071	.526	.936	–	–	–	–	–
18	.130	.038	.027	.019	.032	.066	.266	.417	.446	–	–	–	–
19	.012	.014	.013	.012	.013	.013	.012	.027	.019	.116	–	–	–
20	.001	.001	.001	.001	.001	.001	.002	.002	.003	.002	.398	–	–
21	.018	.011	.013	.009	.013	.017	.010	.153	.141	.791	.026	.013	–
22	.029	.011	.006	.001	.006	.016	.239	.505	.381	.577	.040	.003	.307

**Table numbers represent the associated P values from the LSD Pairwise Comparisons and the significant comparisons are in bold print.

APPENDIX F

PAIRWISE COMPARISONS OF WEEKLY *CULEX RESTUANS* CAUGHT IN GRAVID TRAPS**

Week	9	10	11	12	13	14	15	16	17	18	19	20	21
9	–	–	–	–	–	–	–	–	–	–	–	–	–
10	.189	–	–	–	–	–	–	–	–	–	–	–	–
11	.887	.190	–	–	–	–	–	–	–	–	–	–	–
12	.678	.156	.599	–	–	–	–	–	–	–	–	–	–
13	.321	.068	.285	.442	–	–	–	–	–	–	–	–	–
14	.036	.044	.089	.063	.117	–	–	–	–	–	–	–	–
15	.327	.121	.434	.745	.686	.163	–	–	–	–	–	–	–
16	.013	.020	.016	.014	.039	.443	.019	–	–	–	–	–	–
17	.016	.019	.022	.005	.009	.066	.033	.343	–	–	–	–	–
18	.016	.019	.022	.005	.009	.066	.033	.343	*	–	–	–	–
19	.093	.039	.128	.049	.158	1.0	.127	.583	.271	.271	–	–	–
20	.016	.019	.022	.005	.009	.066	.033	.343	*	*	.271	–	–
21	.016	.019	.022	.005	.009	.066	.033	.343	*	*	.271	*	–
22	.016	.017	.027	.006	.011	.111	.044	.555	.343	.343	.343	.343	.343

*No data (zero counts) collected for Weeks 17-18 and 20-21 for *Culex restuans* in Gravid traps, no pairwise analysis available

**Table numbers represent the associated P values from the LSD Pairwise Comparisons and the significant comparisons are in bold print.

APPENDIX G

PAIRWISE COMPARISONS OF WEEKLY *AEDES ALBOPICTUS* CAUGHT IN GRAVID TRAPS**

Week	9	10	11	12	13	14	15	16	17	18	19	20	21
9	–	–	–	–	–	–	–	–	–	–	–	–	–
10	*	–	–	–	–	–	–	–	–	–	–	–	–
11	*	*	–	–	–	–	–	–	–	–	–	–	–
12	.343	.343	.343	–	–	–	–	–	–	–	–	–	–
13	*	*	*	.343	–	–	–	–	–	–	–	–	–
14	.004	.004	.004	.016	.004	–	–	–	–	–	–	–	–
15	.343	.343	.343	1.0	.343	.004	–	–	–	–	–	–	–
16	.081	.081	.081	.343	.081	.007	.168	–	–	–	–	–	–
17	.175	.175	.175	.343	.175	.046	.509	.825	–	–	–	–	–
18	*	*	*	.343	*	.004	.343	.081	.175	–	–	–	–
19	.037	.037	.037	.193	.037	.038	.081	.591	.577	.037	–	–	–
20	.042	.042	.042	.076	.042	.523	.101	.305	.165	.042	.341	–	–
21	.040	.040	.040	.175	.040	.008	.087	.456	.509	.040	.864	.486	–
22	.044	.044	.044	.151	.044	.161	.090	.409	.416	.044	.570	.388	.831

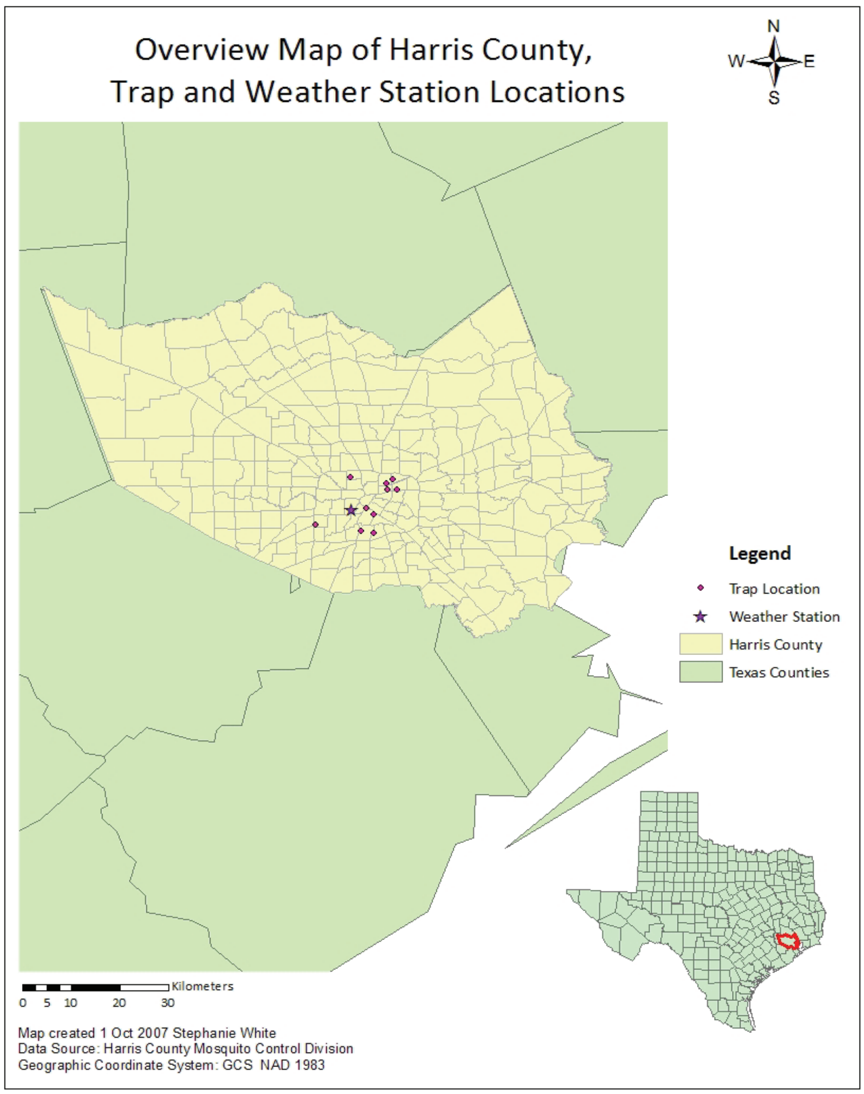
*No data (zero counts) collected for Weeks 9-11, 13 and 18 for *Aedes albopictus* in Gravid traps, no pairwise analysis available

**Table numbers represent the associated P values from the LSD Pairwise Comparisons and the significant comparisons are in bold print.

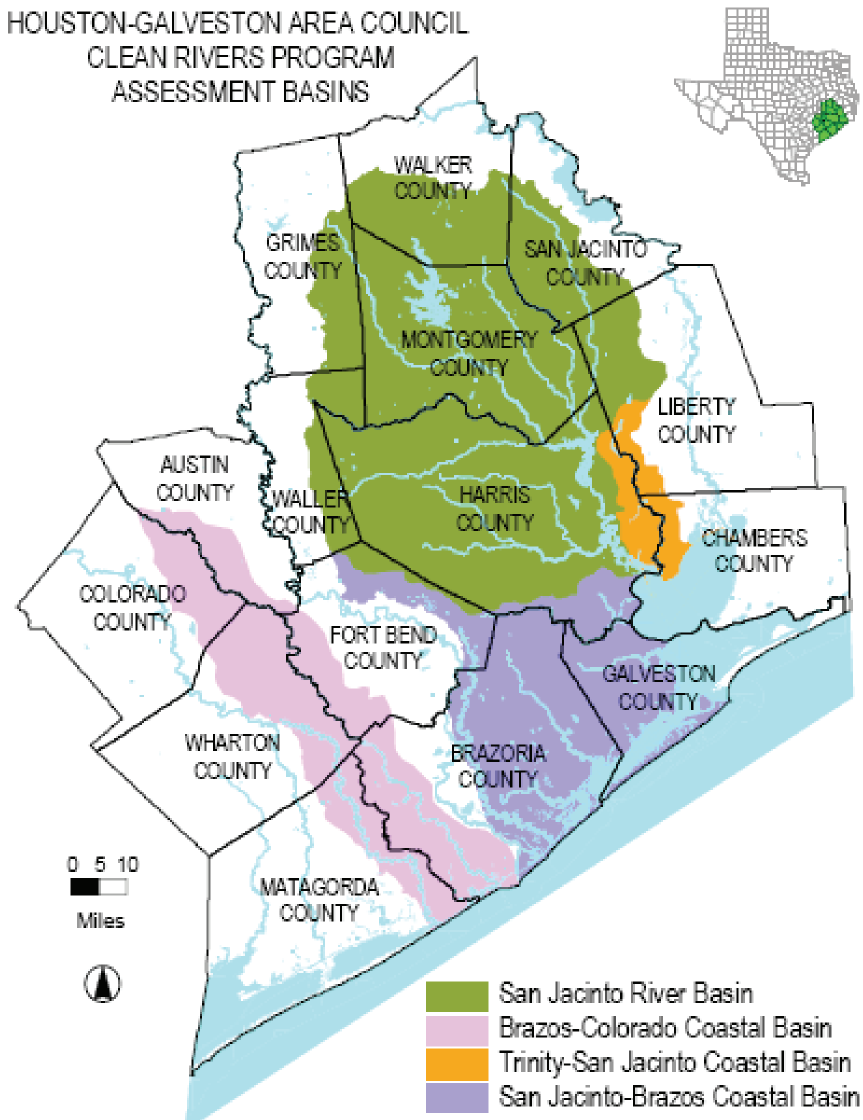
APPENDIX H

GEOGRAPHIC INFORMATION SYSTEM MAPS OF HARRIS COUNTY, TRAP AND WEATHER STATION LOCATIONS AND HARRIS COUNTY LAND COVER CLASSIFICATION

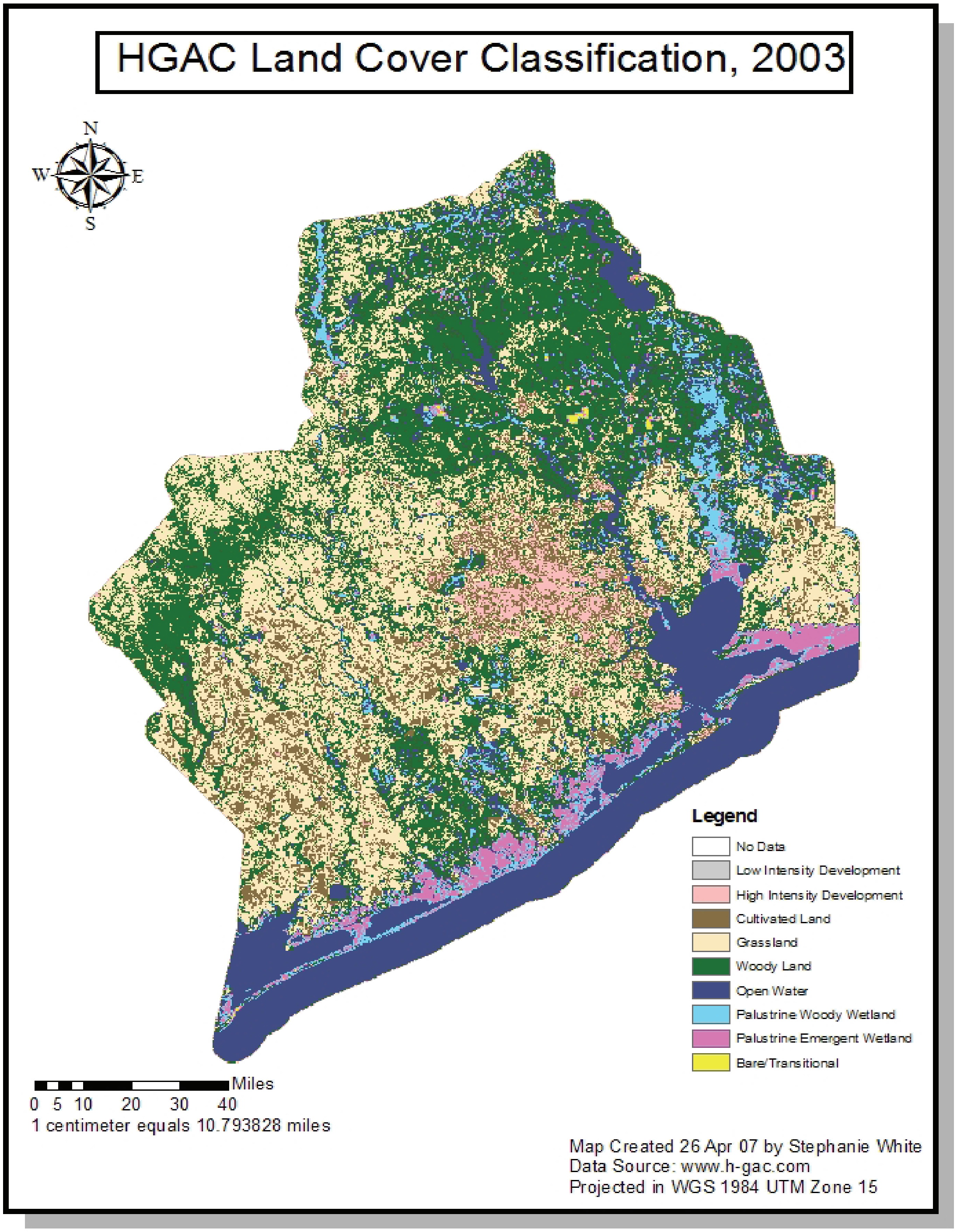
Map of Houston-Galveston Land Area, including Harris County, TX



Houston-Galveston Area Council Clean Rivers Program Assessment Basins Map

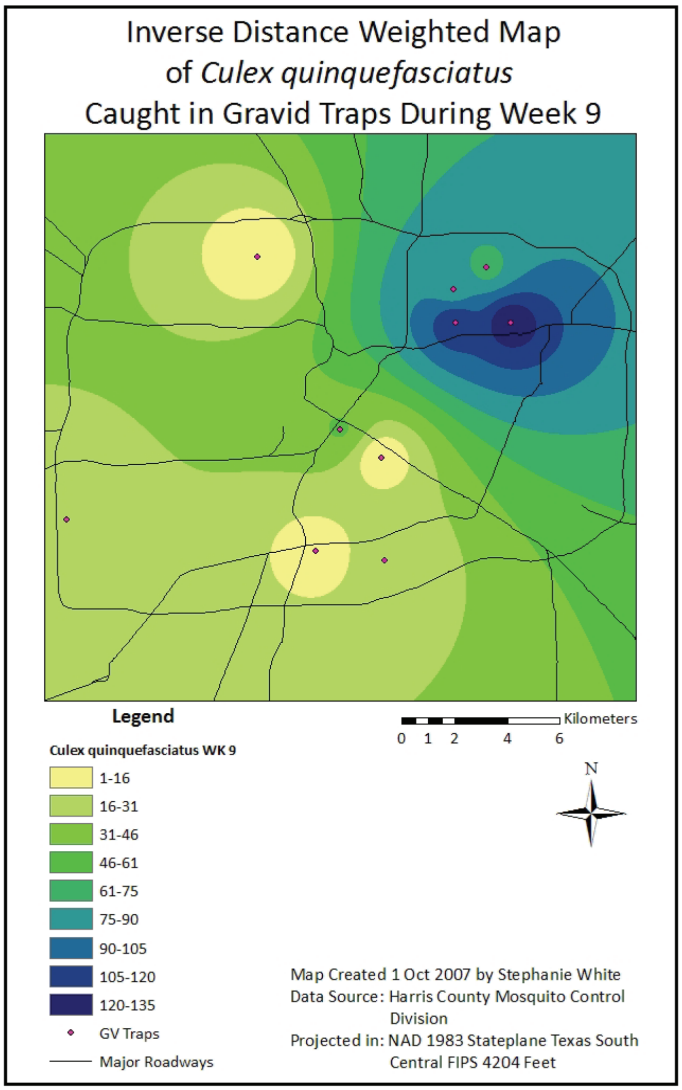


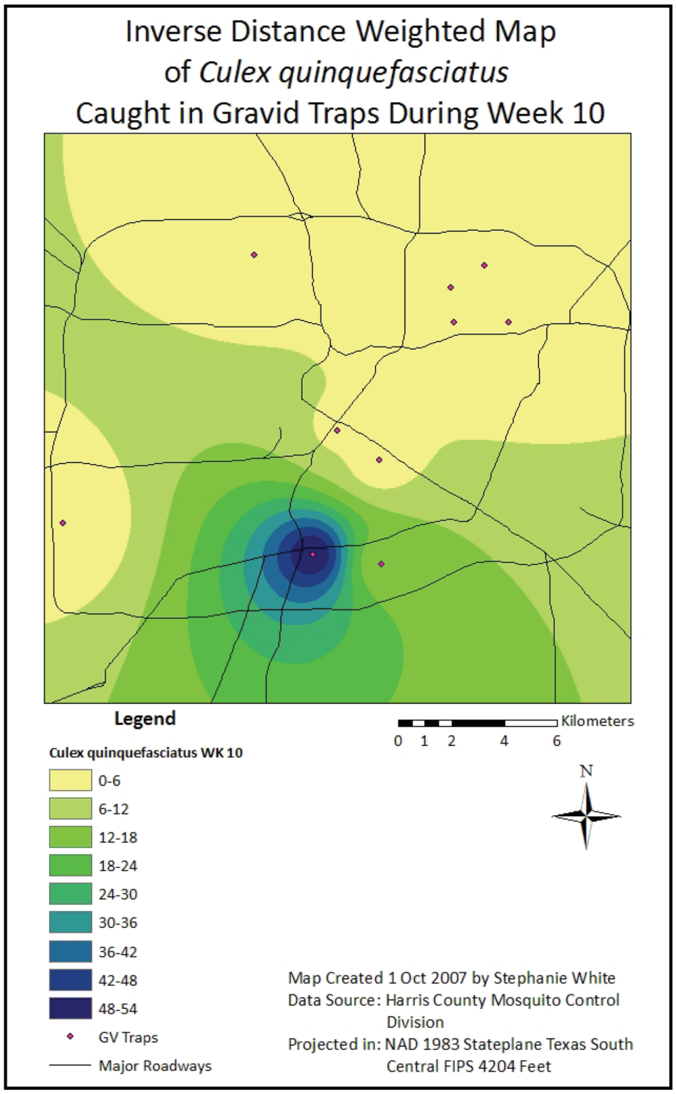
Map Layer of Land Classification, 2003, of Houston-Galveston Area

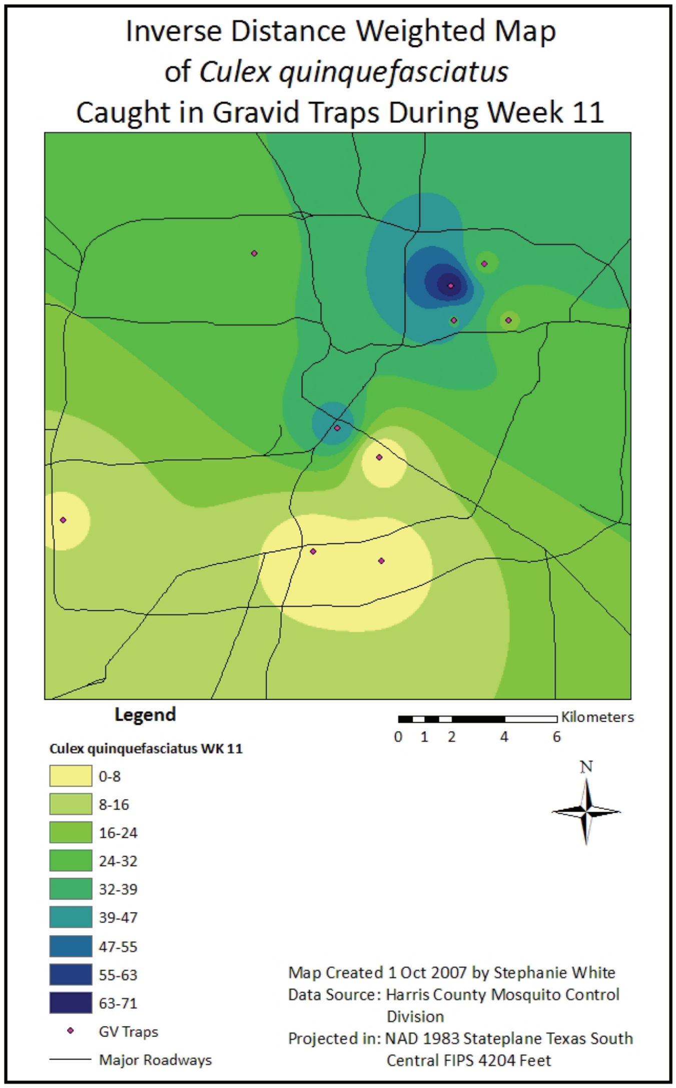


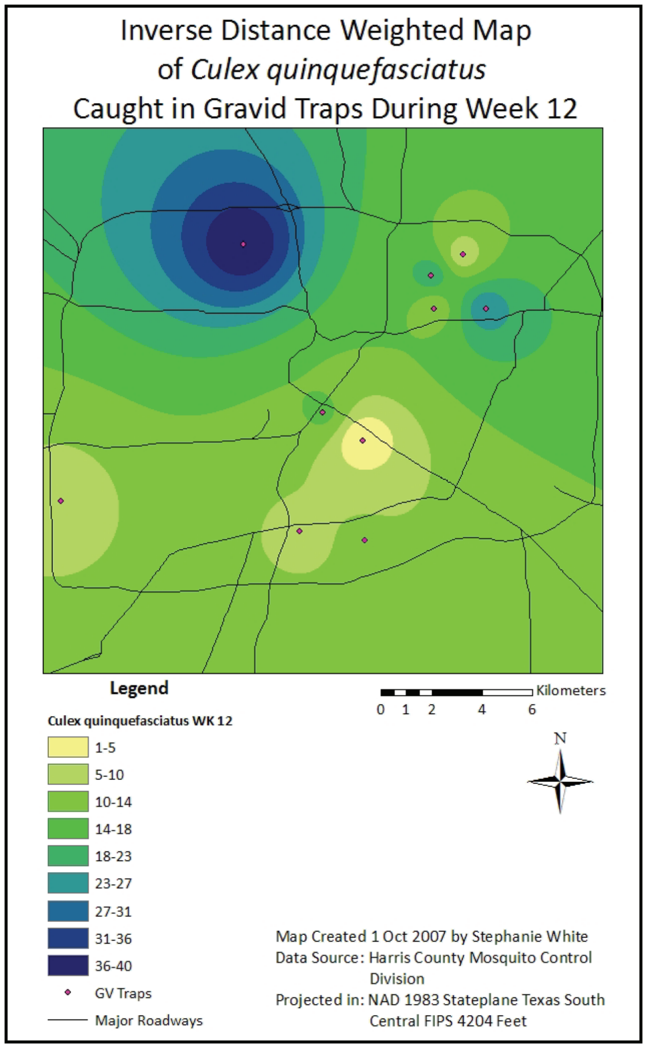
APPENDIX I

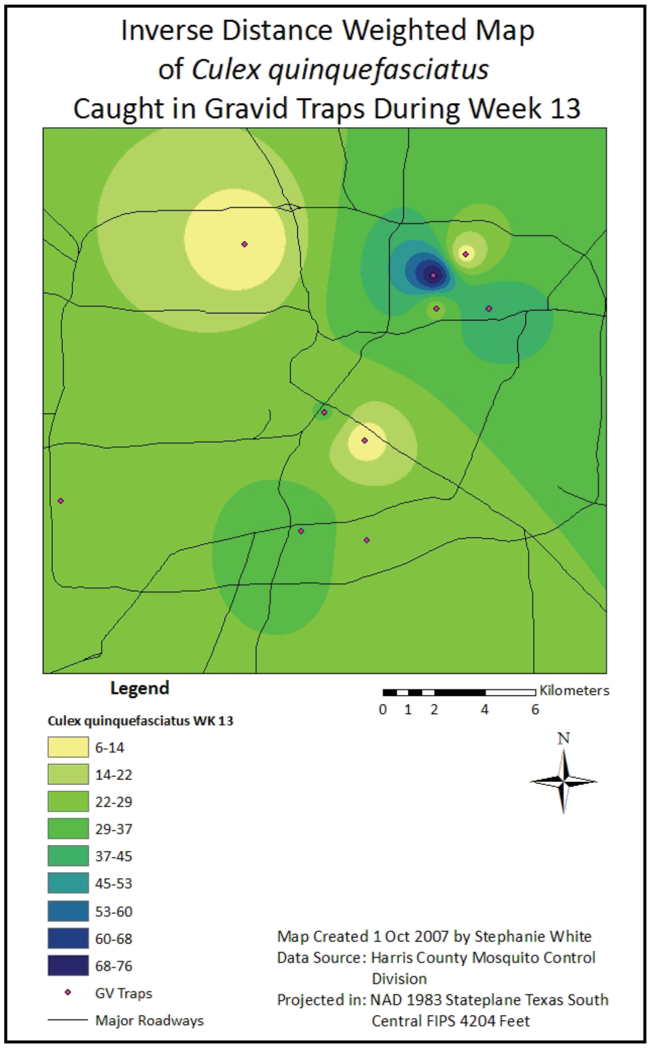
GEOGRAPHIC INFORMATION SYSTEM INVERSE DISTANCE WEIGHTED-INTERPOLATION MAPS FOR *CULEX QUINQUEFASCIATUS* CATCHES IN GRAVID TRAPS

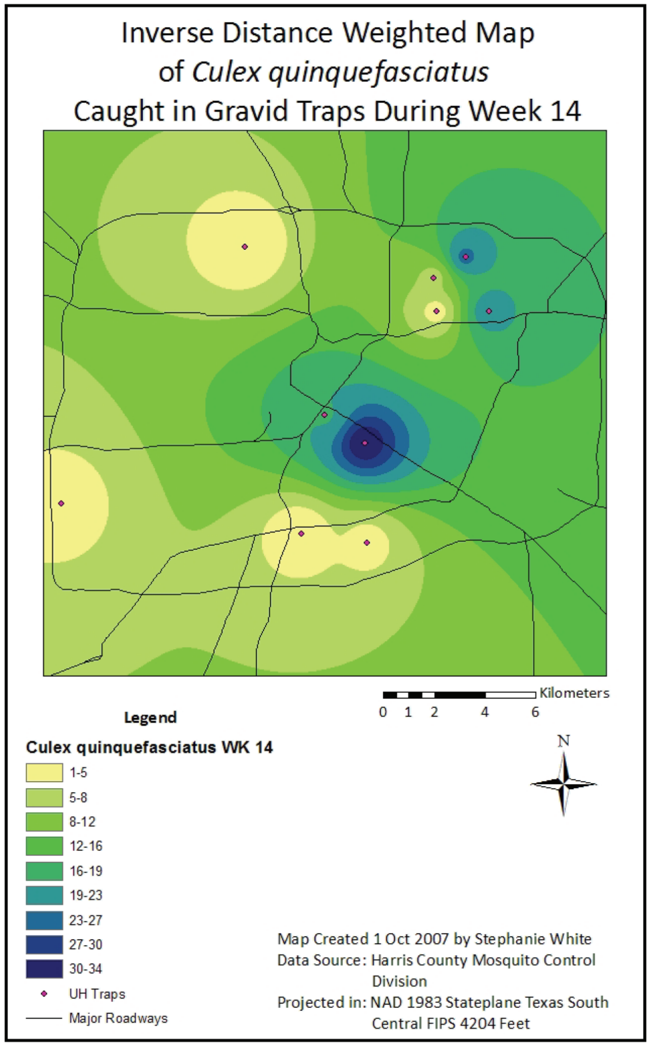


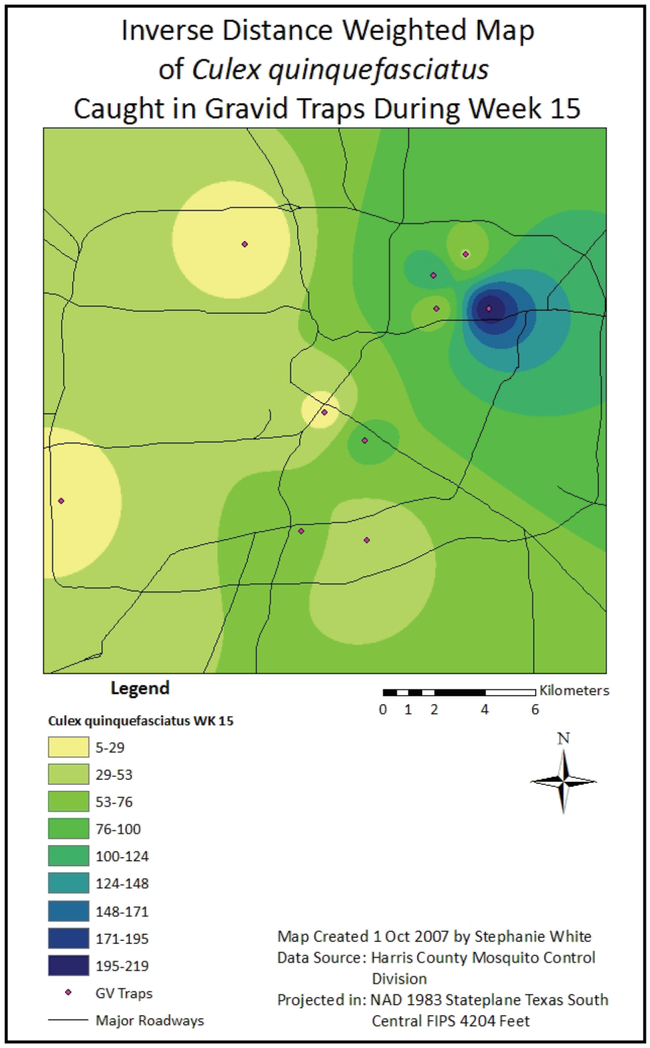

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Gravid Traps During Week 10
Legend
Culex quinquefasciatus WK 10
0-6
6-12
12-18
18-24
24-30
30-36
36-42
42-48
48-54
GV Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

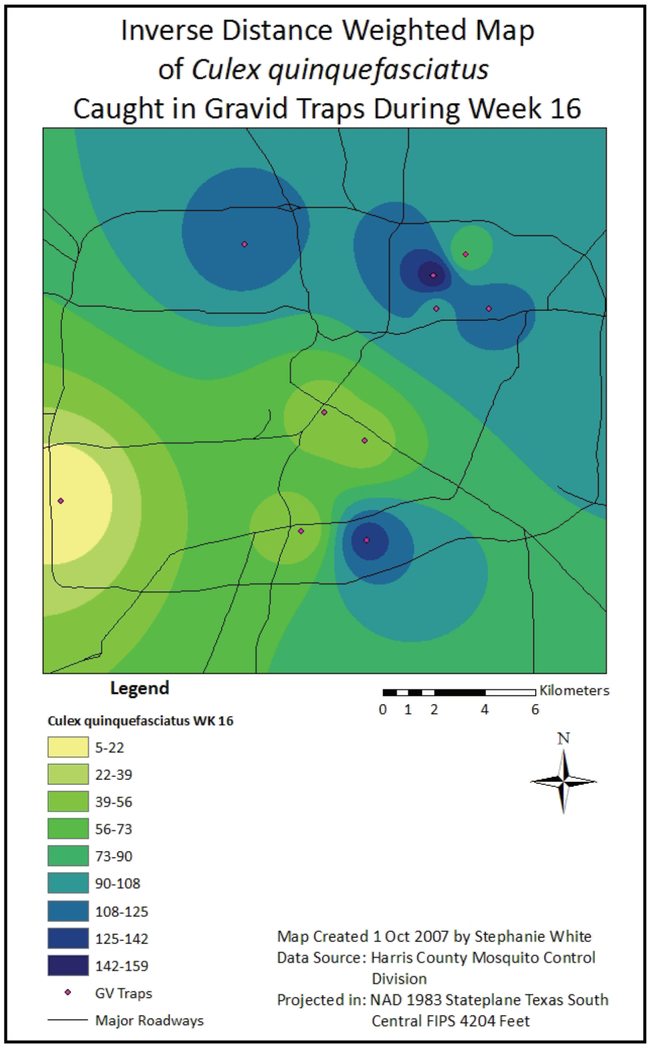

Inverse Distance Weighted Map
of Culex quinquefasciatus
Caught in Gravid Traps During Week 11
Legend
Culex quinquefasciatus WK 11
0-8
8-16
16-24
24-32
32-39
39-47
47-55
55-63
63-71
GV Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

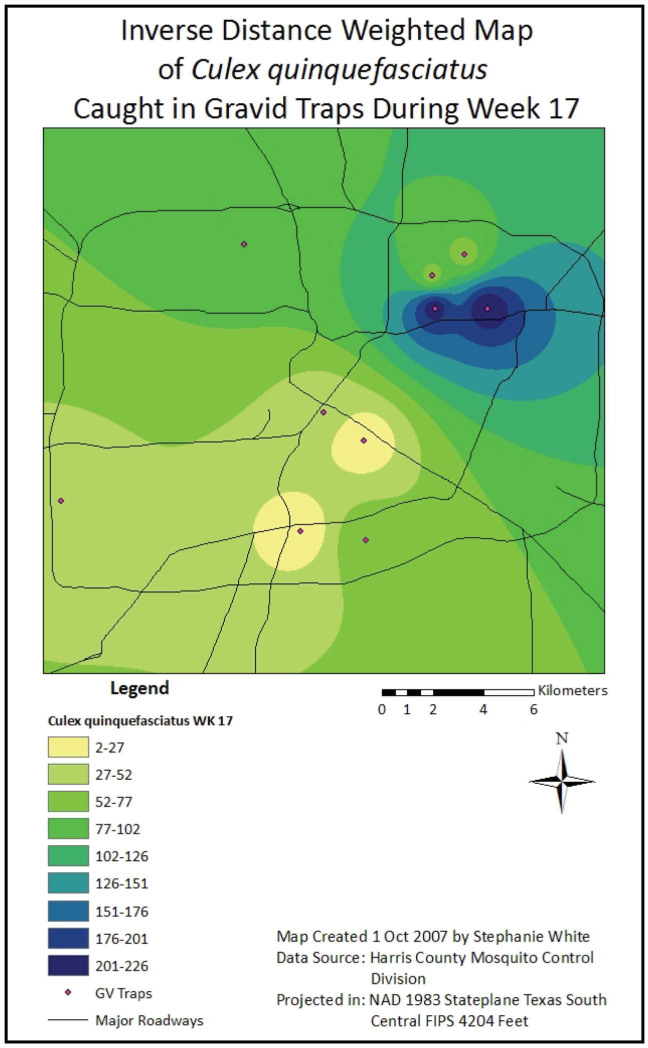

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Gravid Traps During Week 12
Legend
Culex quinquefasciatus WK 12
1-5
5-10
10-14
14-18
18-23
23-27
27-31
31-36
36-40
GV Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

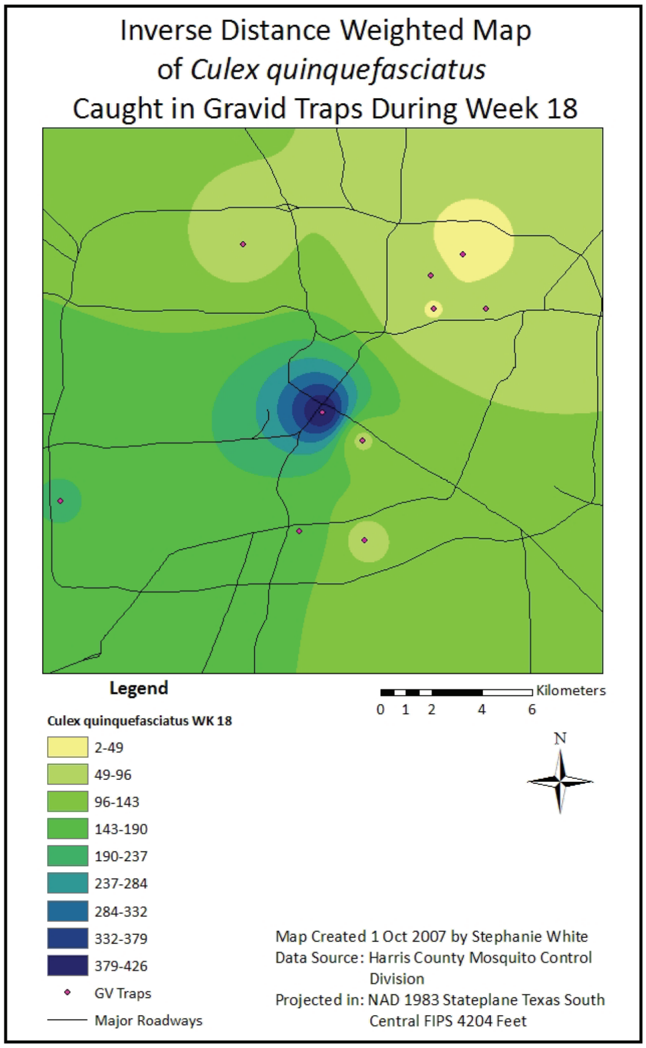

Inverse Distance Weighted Map
of Culex quinquefasciatus
Caught in Gravid Traps During Week 13
Legend
Culex quinquefasciatus WK 13
6-14
14-22
22-29
29-37
37-45
45-53
53-60
60-68
68-76
GV Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

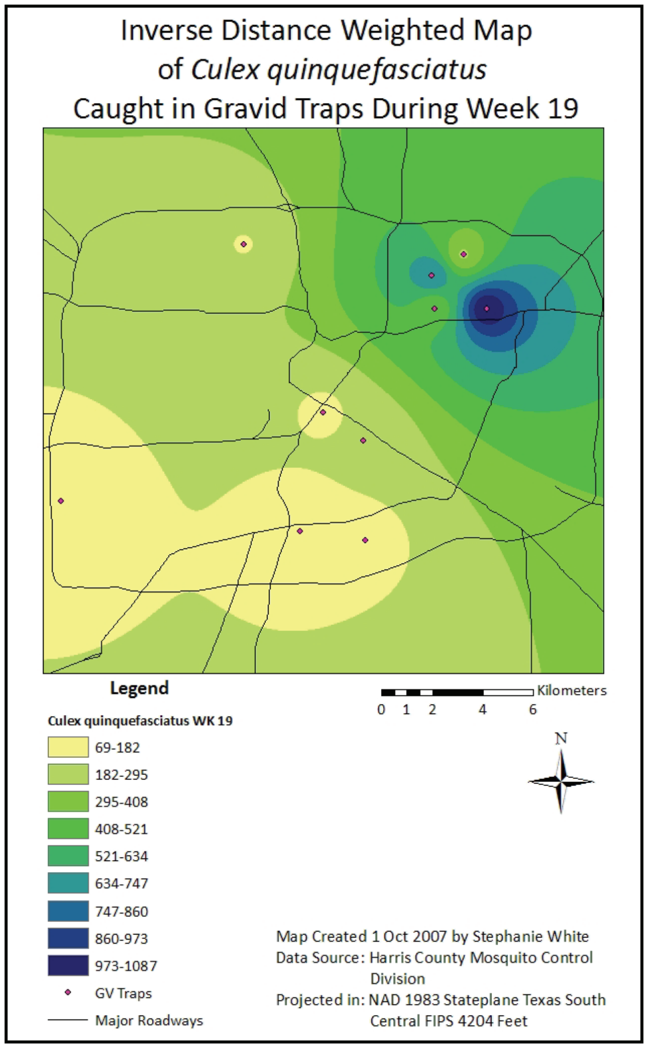

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Gravid Traps During Week 14
Kilometers
0 1 2 4 6
Legend
Culex quinquefasciatus WK 14
1-5
5-8
8-12
12-16
16-19
19-23
23-27
27-30
30-34
UH Traps
Major Roadways
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

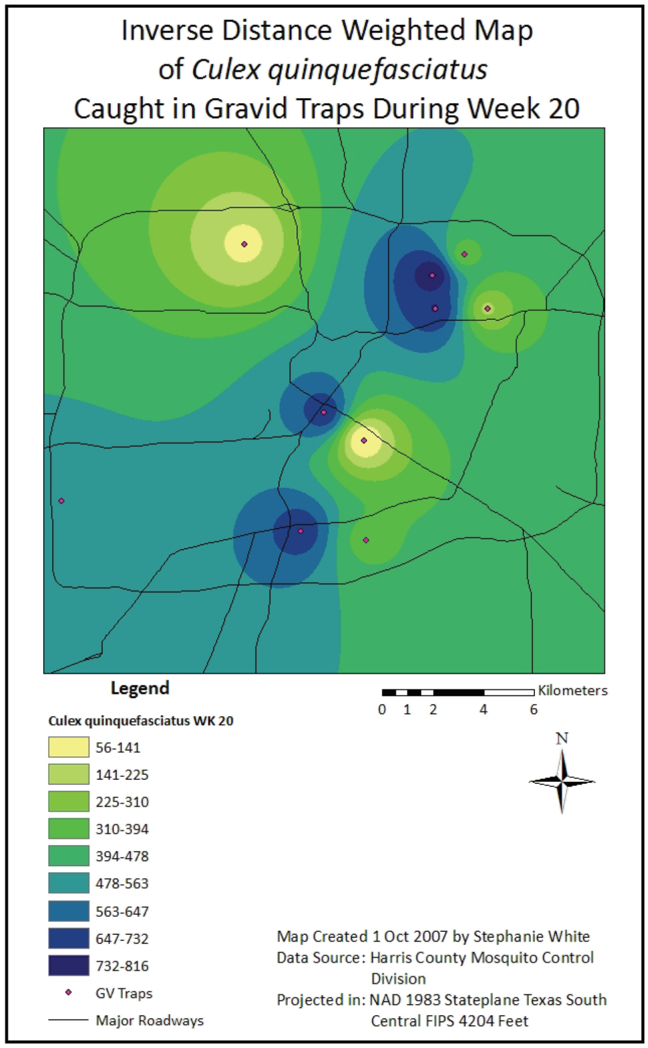

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Gravid Traps During Week 15
Legend
Culex quinquefasciatus WK 15
5-29
29-53
53-76
76-100
100-124
124-148
148-171
171-195
195-219
GV Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

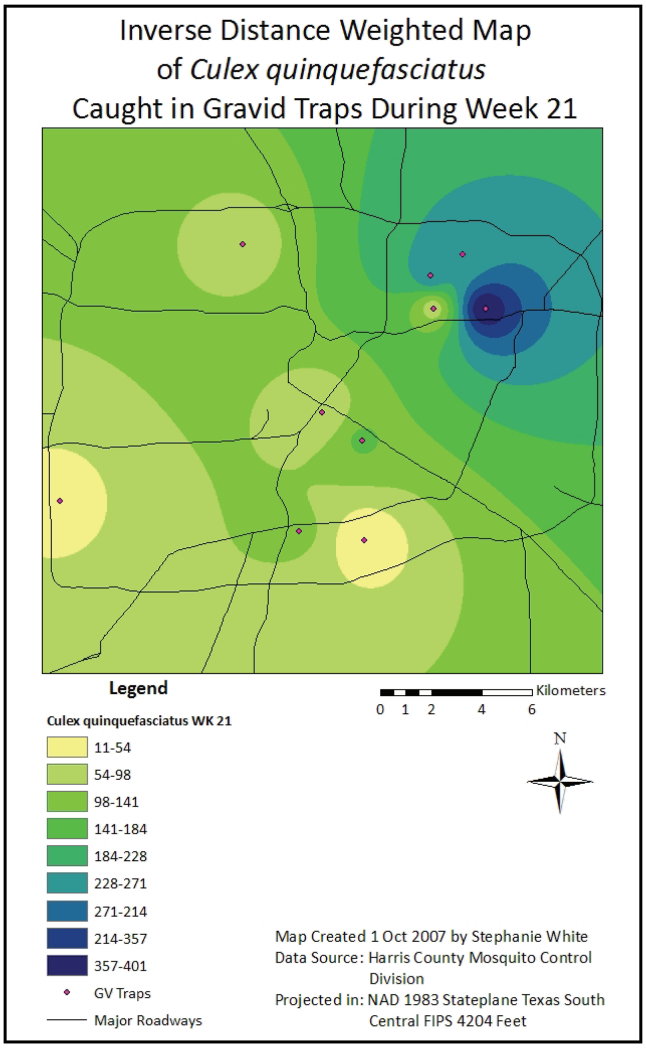

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Gravid Traps During Week 16
Legend
Culex quinquefasciatus WK 16
5-22
22-39
39-56
56-73
73-90
90-108
108-125
125-142
142-159
GV Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

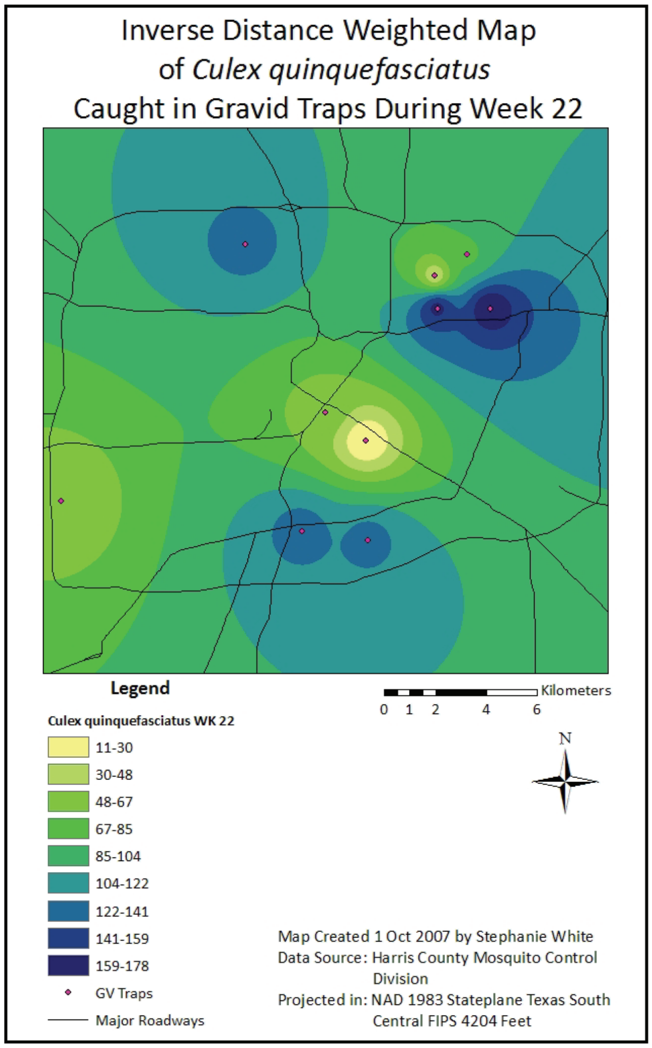

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Gravid Traps During Week 17
Legend
Culex quinquefasciatus WK 17
2-27
27-52
52-77
77-102
102-126
126-151
151-176
176-201
201-226
GV Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet


Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Gravid Traps During Week 18
Legend
Culex quinquefasciatus WK 18
2-49
49-96
96-143
143-190
190-237
237-284
284-332
332-379
379-426
GV Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet


Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Gravid Traps During Week 19
Legend
Culex quinquefasciatus WK 19
69-182
182-295
295-408
408-521
521-634
634-747
747-860
860-973
973-1087
GV Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

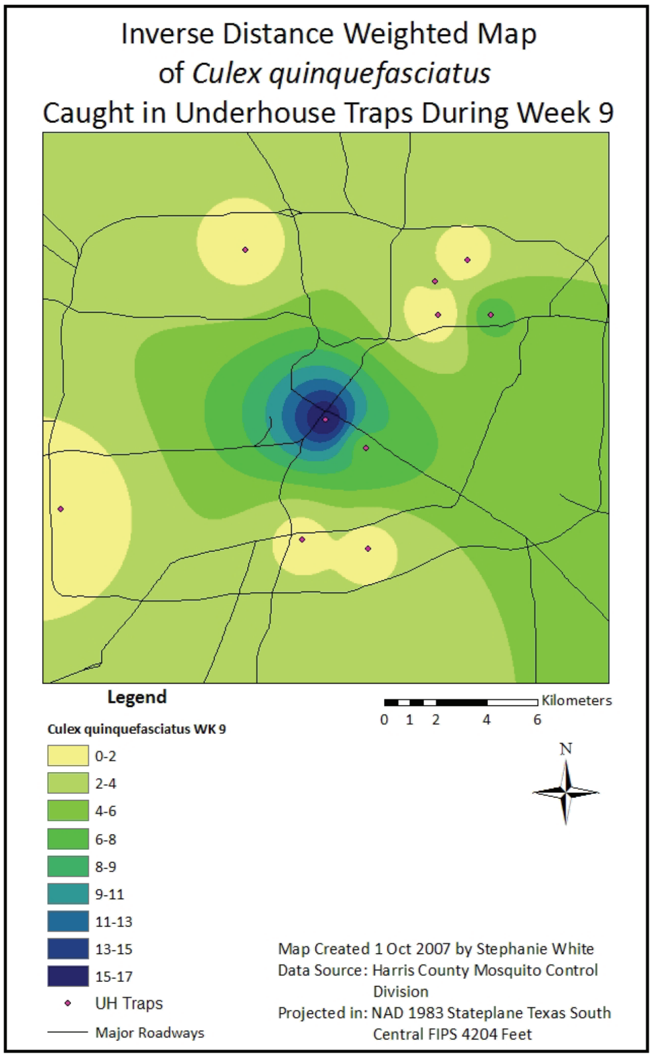

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Gravid Traps During Week 20
Legend
Culex quinquefasciatus WK 20
56-141
141-225
225-310
310-394
394-478
478-563
563-647
647-732
732-816
GV Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

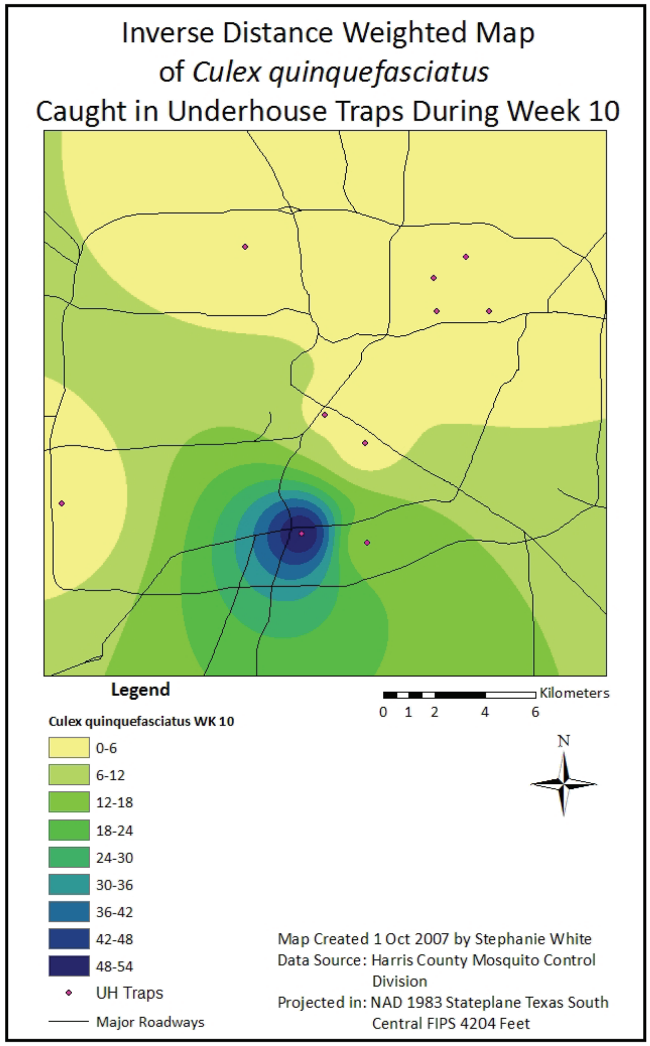

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Gravid Traps During Week 21
Legend
Kilometers
0 1 2 4 6
N
Culex quinquefasciatus WK 21
11-54
54-98
98-141
141-184
184-228
228-271
271-214
214-357
357-401
GV Traps
Major Roadways
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

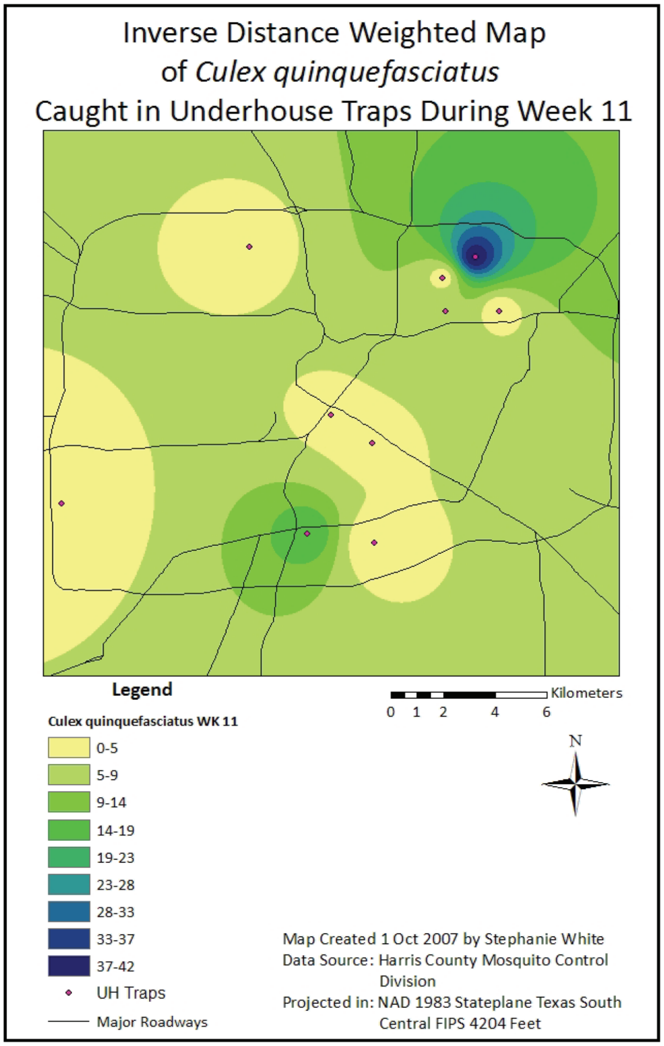

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Gravid Traps During Week 22
Legend
Culex quinquefasciatus WK 22
11-30
30-48
48-67
67-85
85-104
104-122
122-141
141-159
159-178
GV Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

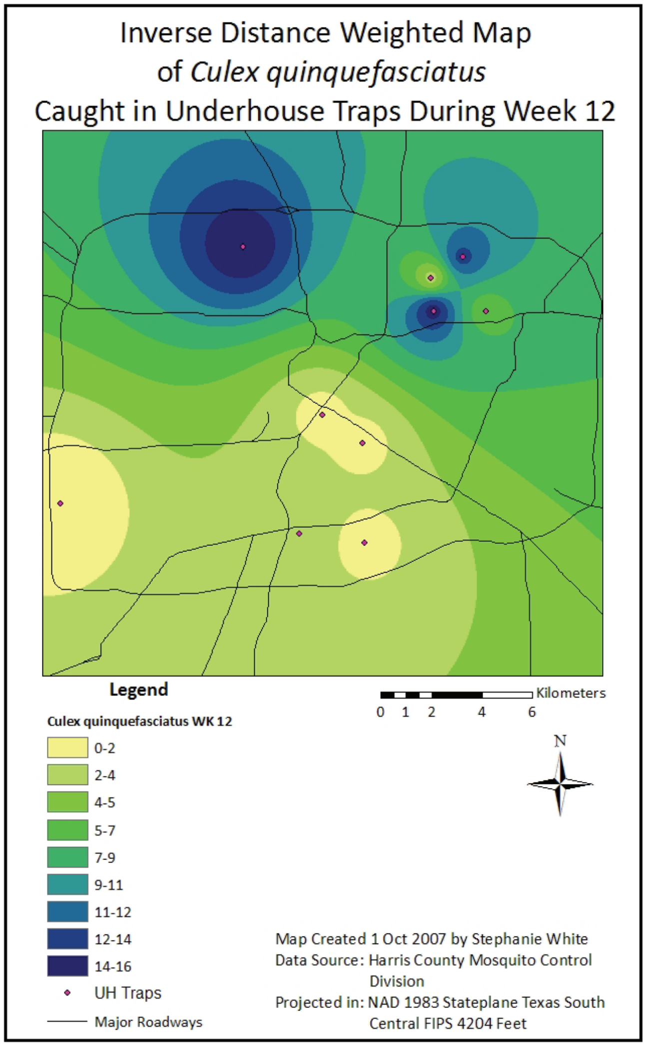
APPENDIX J

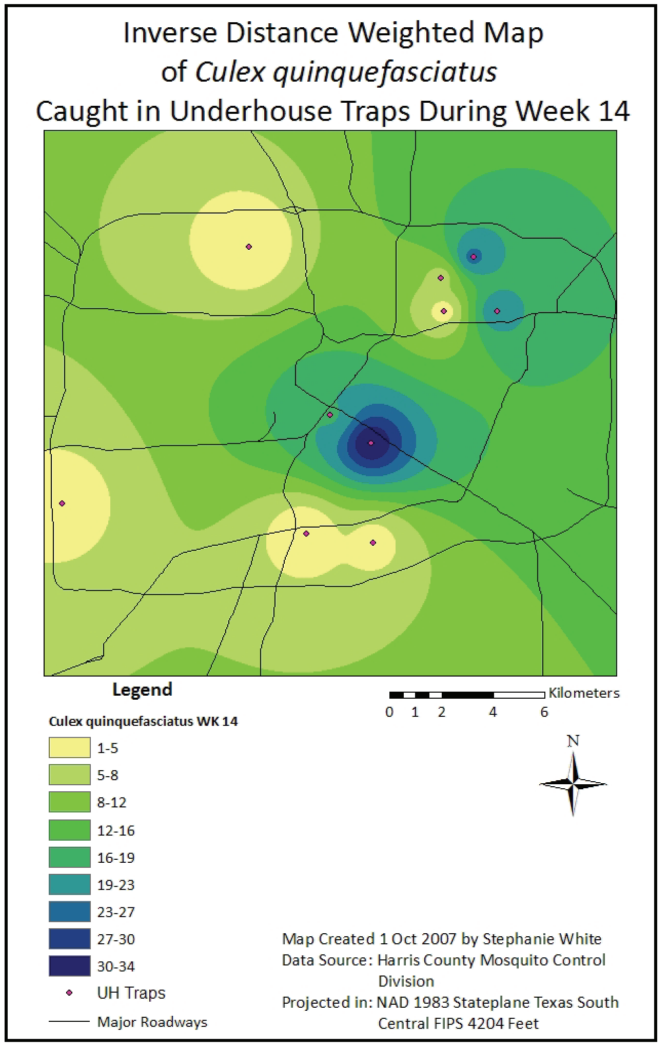
GEOGRAPHIC INFORMATION SYSTEM INVERSE DISTANCE WEIGHTED-INTERPOLATION MAPS FOR *CULEX QUINQUEFASCIATUS* CATCHES IN UNDERHOUSE TRAPS

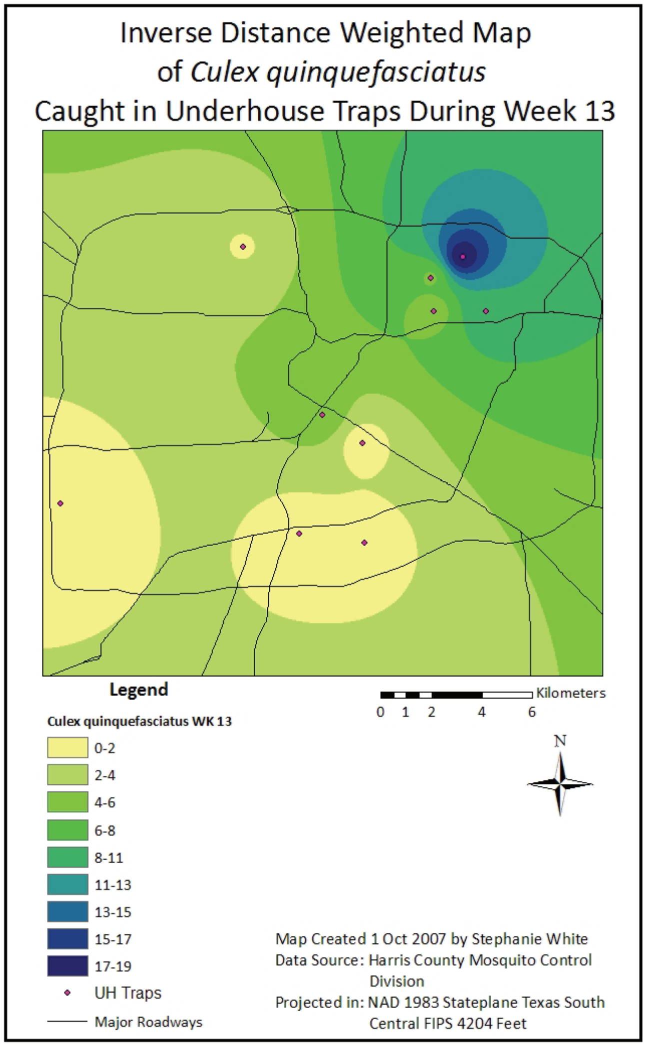


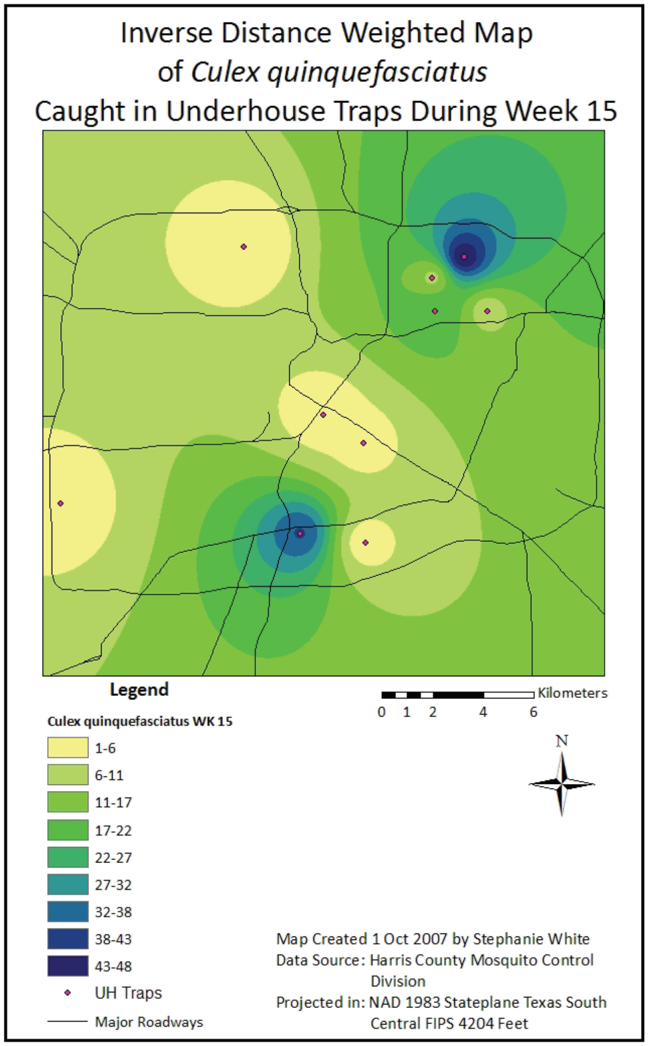

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Underhouse Traps During Week 10
Legend
Culex quinquefasciatus WK 10
0-6
6-12
12-18
18-24
24-30
30-36
36-42
42-48
48-54
UH Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

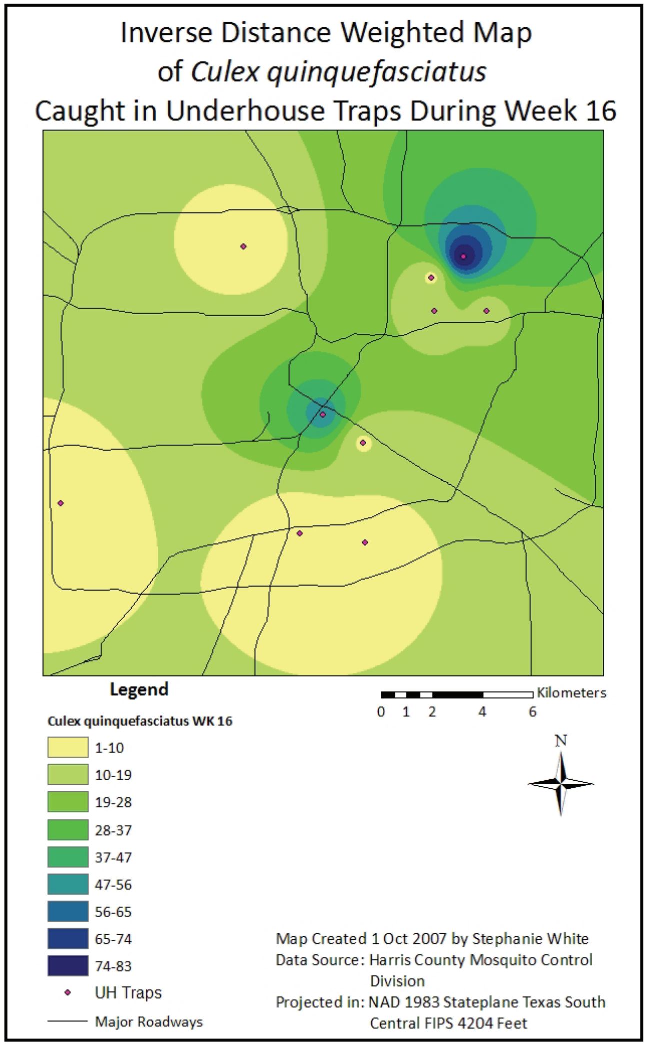

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Underhouse Traps During Week 11
Legend
Culex quinquefasciatus WK 11
0-5
5-9
9-14
14-19
19-23
23-28
28-33
33-37
37-42
UH Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

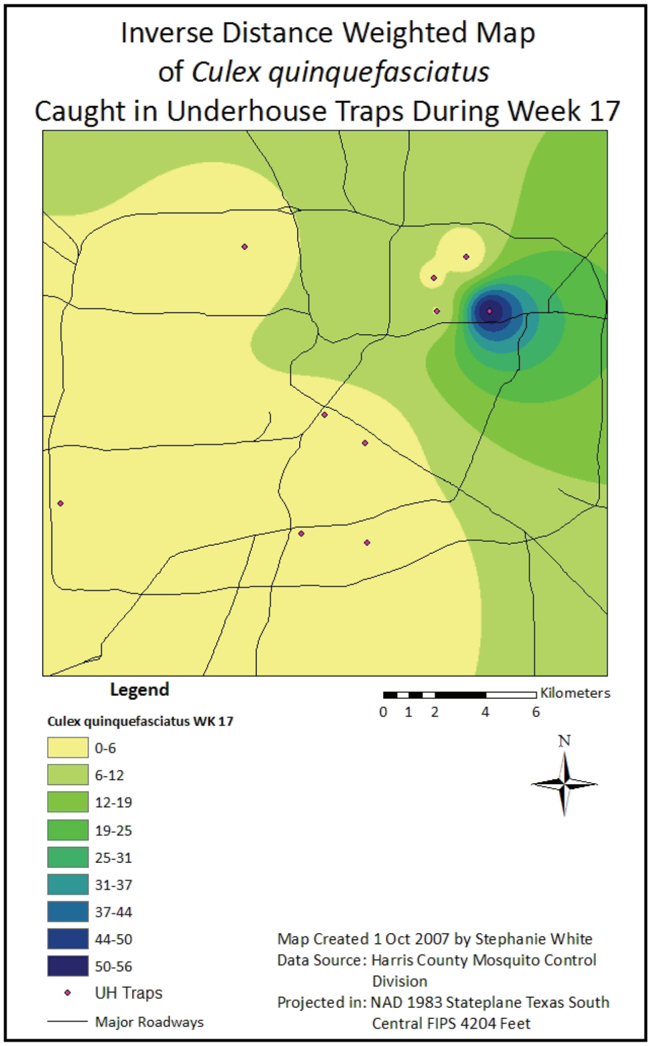

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Underhouse Traps During Week 12
Legend
Culex quinquefasciatus WK 12
0-2
2-4
4-5
5-7
7-9
9-11
11-12
12-14
14-16
UH Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

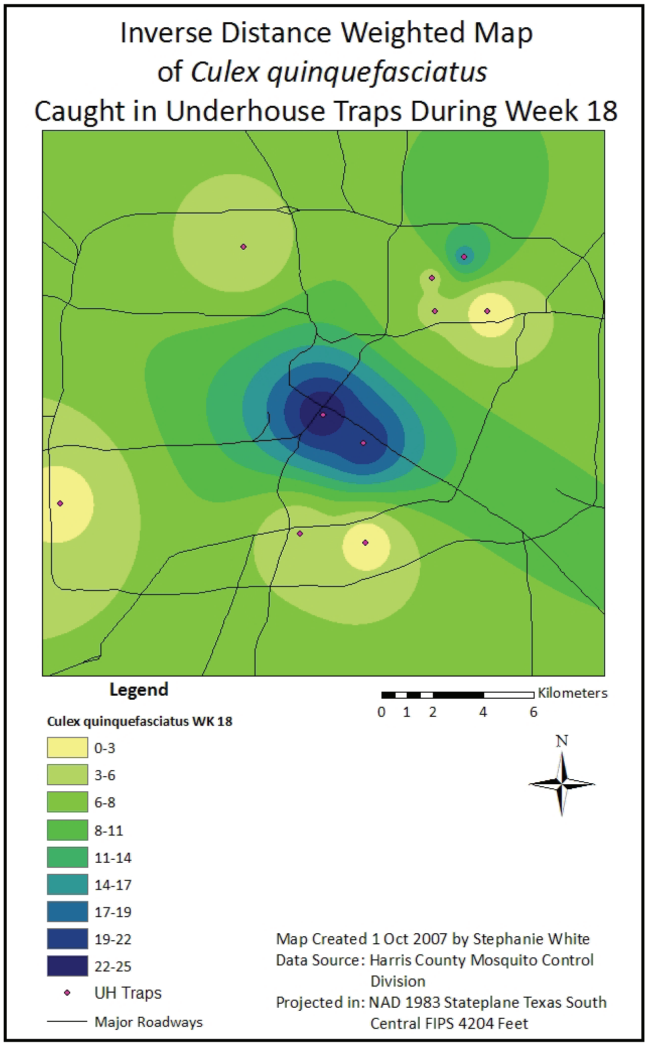

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Underhouse Traps During Week 14
Legend
Culex quinquefasciatus WK 14
1-5
5-8
8-12
12-16
16-19
19-23
23-27
27-30
30-34
UH Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

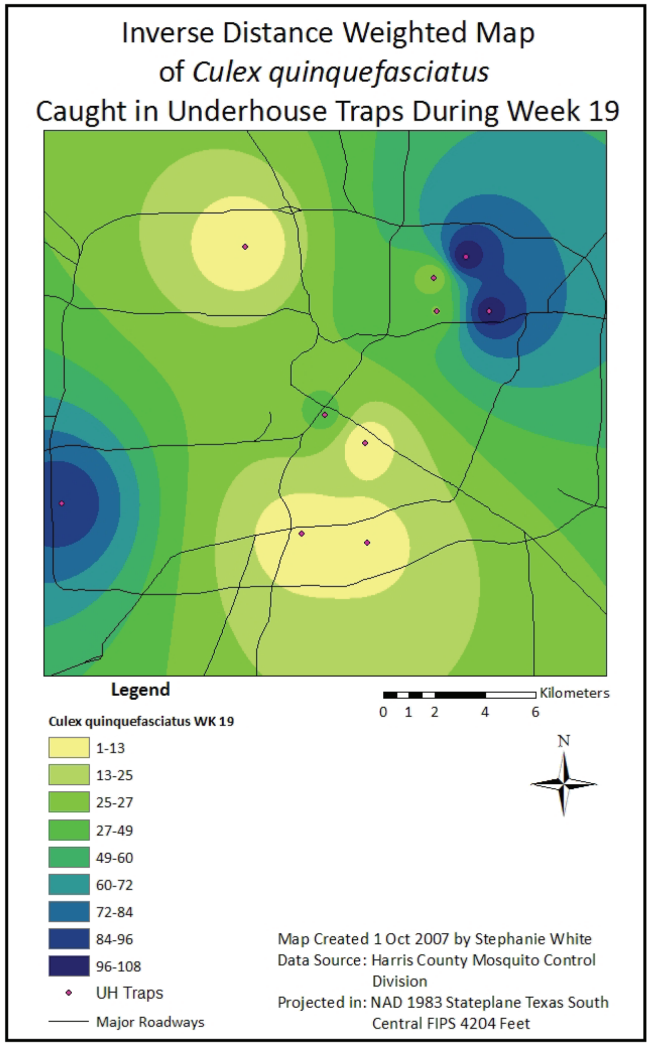

Inverse Distance Weighted Map
of Culex quinquefasciatus
Caught in Underhouse Traps During Week 13
Legend
Culex quinquefasciatus WK 13
0-2
2-4
4-6
6-8
8-11
11-13
13-15
15-17
17-19
UH Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

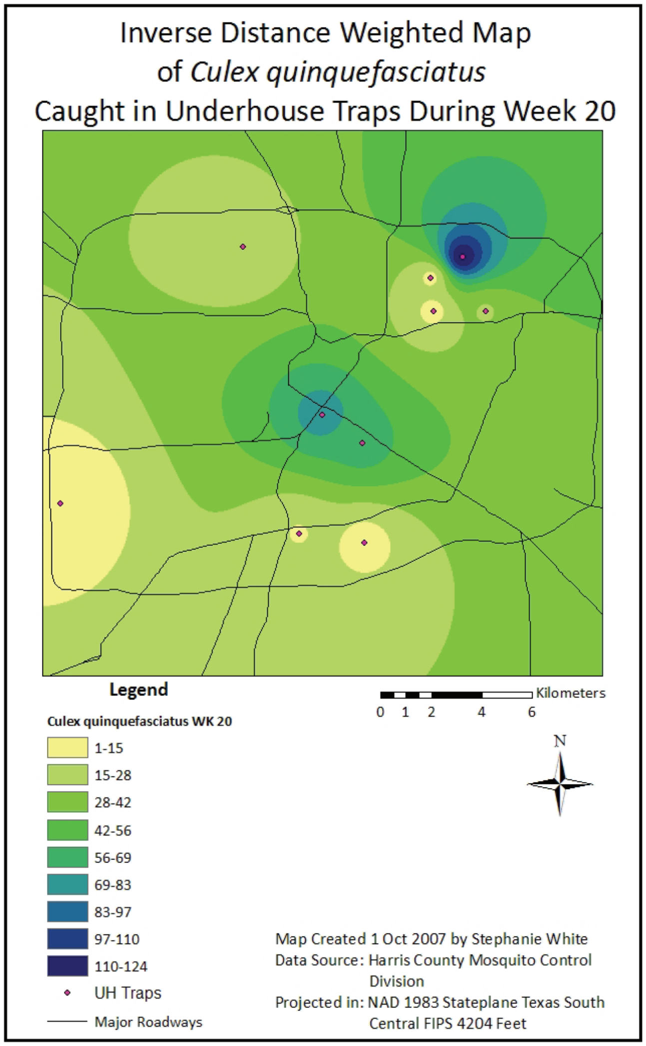

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Underhouse Traps During Week 15
Legend
Culex quinquefasciatus WK 15
1-6
6-11
11-17
17-22
22-27
27-32
32-38
38-43
43-48
UH Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet


Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Underhouse Traps During Week 16
Legend
Culex quinquefasciatus WK 16
1-10
10-19
19-28
28-37
37-47
47-56
56-65
65-74
74-83
UH Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

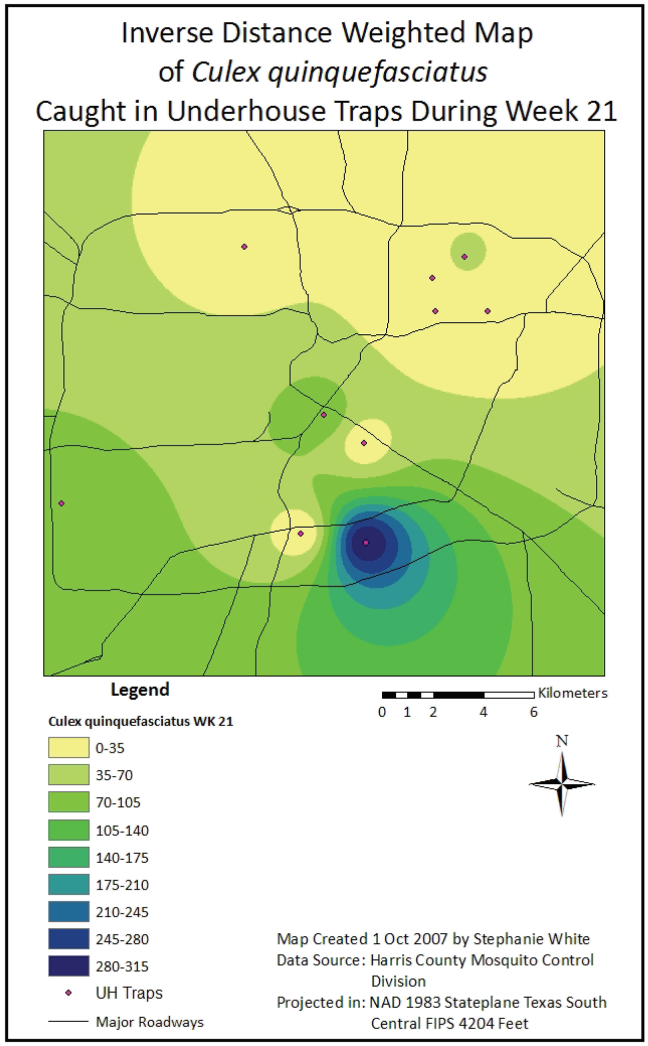

Inverse Distance Weighted Map
of Culex quinquefasciatus
Caught in Underhouse Traps During Week 17
Legend
Culex quinquefasciatus WK 17
0-6
6-12
12-19
19-25
25-31
31-37
37-44
44-50
50-56
UH Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet


Inverse Distance Weighted Map
of Culex quinquefasciatus
Caught in Underhouse Traps During Week 18
Legend
Culex quinquefasciatus WK 18
0-3
3-6
6-8
8-11
11-14
14-17
17-19
19-22
22-25
UH Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

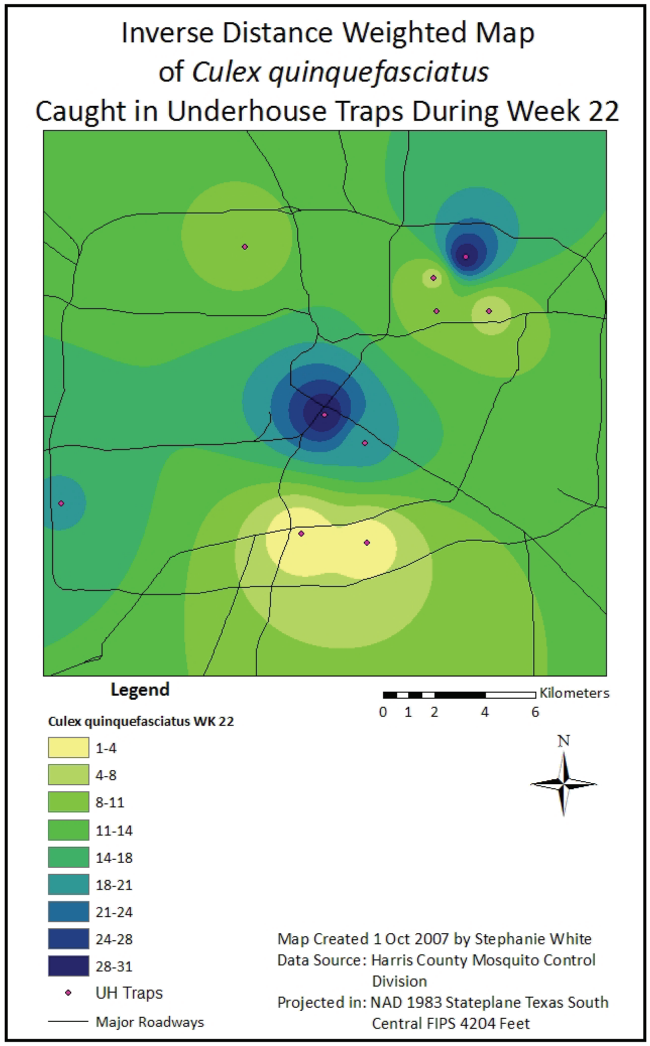

Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Underhouse Traps During Week 19
Legend
Culex quinquefasciatus WK 19
1-13
13-25
25-27
27-49
49-60
60-72
72-84
84-96
96-108
UH Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet



Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Underhouse Traps During Week 20
Legend
Culex quinquefasciatus WK 20
1-15
15-28
28-42
42-56
56-69
69-83
83-97
97-110
110-124
UH Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet



Inverse Distance Weighted Map
of *Culex quinquefasciatus*
Caught in Underhouse Traps During Week 21
Legend
Culex quinquefasciatus WK 21
0-35
35-70
70-105
105-140
140-175
175-210
210-245
245-280
280-315
UH Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet


Inverse Distance Weighted Map
of Culex quinquefasciatus
Caught in Underhouse Traps During Week 22
Legend
Culex quinquefasciatus WK 22
1-4
4-8
8-11
11-14
14-18
18-21
21-24
24-28
28-31
UH Traps
Major Roadways
Kilometers
0 1 2 4 6
N
Map Created 1 Oct 2007 by Stephanie White
Data Source: Harris County Mosquito Control Division
Projected in: NAD 1983 Stateplane Texas South Central FIPS 4204 Feet

VITA

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