

NASA/TM-2009-000000



Climate Change Impacts on Vector Borne Diseases at NASA Langley Research Center

Stuart K. Cole

Langley Research Center, Research Directorate, Mail Stop 164D, Hampton, VA 23681,

Russell J. De Young

Langley Research Center, Science Directorate, Mail Stop 401A, Hampton, VA, 23681

Ahmed Kamel

Langley Research Center, Science Directorate, Mail Stop 401A, Hampton, VA 23681

Marc A. Shepanek

*NASA Headquarters, Office of the Chief Health and Medical Officer, Mail Stop QA000,
Washington DC, 20546*

Month Year

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.
- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, and organizing and publishing research results.

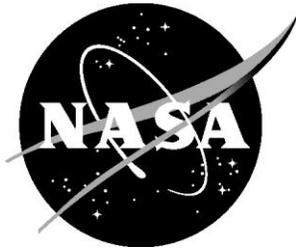
For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at <http://www.sti.nasa.gov>
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA STI Help Desk at 443-757-5803
- Phone the NASA STI Help Desk at 443-757-5802
- Write to:
NASA STI Help Desk

NASA Center for AeroSpace
Information

7115 Standard Drive
Hanover, MD 21076-1320

NASA/TM-2009-000000



Climate Change Impacts on Vector Borne Diseases at NASA Langley Research Center

Stuart K. Cole

Langley Research Center, Research Directorate, Mail Stop 164D, Hampton, VA 23681,

Russell J. De Young

Langley Research Center, Science Directorate, Mail Stop 401A, Hampton, VA, 23681

Ahmed Kamel

Langley Research Center, Science Directorate, Mail Stop 401A, Hampton, VA 23681

Marc A. Shepanek

*NASA Headquarters, Office of the Chief Health and Medical Officer, Mail Stop QA000,
Washington DC, 20546*

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

Month Year

Abstract

Increasing temperature patterns, above average precipitation and storm intensities, and higher sea levels have been identified as phenomena associated with climate change. As a causal system, climate change could affect vector borne diseases in humans. These vectors may originate from the immediate vicinity of Langley Research Center (LaRC), local, regional, nationwide, or from outside the continent of the United States. The vector borne diseases of concern in Virginia include: Dengue Fever, West Nile virus, Ehrlichiosis (Rocky Mountain spotted tick fever), Malaria, and Lyme disease. Mosquito count data from Langley Air Force Base and local precipitation data for years 2005-2012 are used to predict mosquito populations for 2080-2100. Recognizing the conditions vector borne diseases need to propagate under climate change conditions, and understanding the conditions in which they may exist or propagate, presents opportunities for mitigating their potential impacts through communication, monitoring, and adaptation. As personnel comprise a direct and fundamental support to NASA mission success, continuous and improved understanding of climatic conditions, and the resulting consequence of disease from these conditions, helps to reduce employee risk.

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

Month Year

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
443-757-5802

I. Introduction and Background

Climate change is impacting the NASA Centers in both expected and unexpected ways. These impacts include sea level rise, changing weather patterns, intensity of weather patterns, increased ambient temperatures and environmental conditions conducive to increased populations of insects or other disease carrying vectors. The cumulative effect of these conditions may affect both the near and long term operation of NASA Langley Research Center (LaRC) and potentially directly, or indirectly, the capability to meet mission requirements.

This investigation was initiated to help identify the potential for increase of disease vectors due to climate change, recognition of those vectors as a risk to personnel directly and consequentially NASA missions, and to suggest activities that may reduce or eliminate the consequences of disease vectors.

Global average temperature and sea level have increased, and precipitation patterns have changed. The ecological results of recent climate change show changes in ideal habitat for a range of plants, insects and animals resulting in migration of species across substantial territory (Walther et al.). Global temperatures are projected to continue to rise over this century depending on heat-trapping gas emissions and how sensitive the climate is to those emissions. Precipitation has increased an average of about 5 percent over the past 50 years. Projections of future precipitation generally indicate that northern areas will become wetter, and southern areas, particularly in the West, will become drier [Karl]. Shifting ranges for disease vectors such as mosquitos, ticks and fleas, including their disease-causing pathogens may have some of the most devastating impacts for wildlife [Staudt].

With any change in the climate, there are expected changes to environmental conditions resulting in opportunities for emergence of insect populations and thus pathogens. One example is the pattern of infection from West Nile Virus on the East Coast of the United States that was directly related to the culex mosquito, which has a short life cycle of several weeks, can only develop in the presence of water within a limited temperature range, and has a very limited flight range (CDC, 2013). Much of the mid-Atlantic, including the state of Virginia was hard hit by the virus after an unusually mild winter and warm summer. The loss of life, extended hospital stays and expense of educating the public, aerial and truck spraying areas of standing water with chemicals to interrupt the life cycle of the mosquito had substantial human and economic impact (CDC, 2013). The virus moved across the United States, starting on the East Coast of the US in 1999 and reached Sacramento, CA. in 2005. The expense of treating the disease, lost wages and expense of aerial spraying for one outbreak was estimated to be 2.98 million dollars (Barber 2010).

Another example is shown in Figure 1 where the number of cases of dengue fever from 1995 to 2005 in the U.S is reported [NRDC]. The Natural Resource Defense Council (NRDC) found that two types of mosquitoes capable of transmitting dengue fever can now be found across at least 28 states. As temperatures rise, the potential for transmission of this dangerous disease may increase in vulnerable parts of the United States.

Even slight changes in temperature can have a substantial impact on the presence of an environment conducive to the development or movement of a pathogen in hosts such as insects, birds or amphibians. Insects and pathogens causing disease in humans respond to different environmental influences that create conditions for disease transmission to vertebrate animals and humans. Gage, et al. (2008) addressed the variable influence of environmental conditions with the associated disease vectors, and is summarized in Table 1.

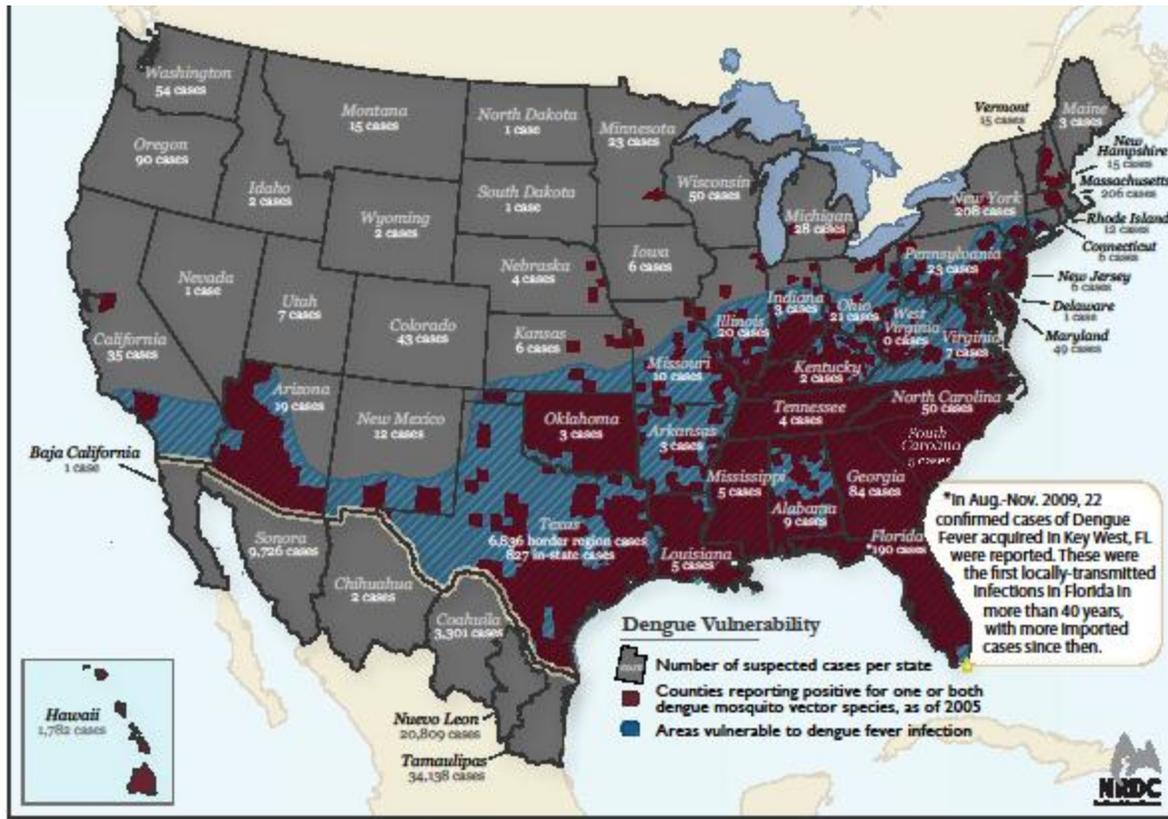


Fig. 1 Dengue fever reported cases from 1985 to 2005 and the vector disease range in the U.S. Red areas have reported the presence of dengue fever mosquito species. (Natural Resources Defense Council)

Vector	Climatic	Effective Climatic variability or	Selected Notes on etiology
Mosquitoes	Temp., rainfall, humidity, El Niño	Disease distribution; pathogen development in vector; development, reproduction, activity, distribution, and	Although no single factor can explain levels of human malaria risk, climatic factors clearly can affect the transmission and geographic range of this disease. Temperature influences both the speed of
Mosquitoes	Temp., precipitation	Outbreaks, mosquito breeding, abundance,	The northward reach of dengue, yellow fever, West Nile virus disease, and Chikungunya is not
Mosquitoes	Temp.,	Transmission rates, pathogen	
Ticks	Temp., precipitation	Vector distribution, phenology of host-seeking by vector	Human exposure to tick-borne pathogens is restricted to geographic locations where both vector tick populations and the tick-borne pathogens are established. The time of onset and frequency of tick-borne diseases in humans is determined, in part, by seasonal patterns of activity by vector ticks. The incidence of tick-borne diseases is a function of tick abundance, prevalence of infection in ticks, and contact rates between humans and infected ticks
Ticks	Temp., precipitation, humidity	Frequency of cases, phenology of host-seeking by vector, vector distribution	
Ticks	Temp., precipitation	Vector distribution, phenology of host-seeking by vector	
Ticks	Temp., precipitation	Phenology of host-seeking by vector	
Fleas	Temp., precipitation, humidity, El Niño-related events	Development and maintenance of pathogen in vector; survival and reproduction of vectors and hosts; occurrences of historical pandemics and regional outbreaks, distribution of disease	Parmenter and others demonstrated that human cases of plague in New Mexico occurred more frequently following periods of above average winter-spring precipitation. A later study demonstrated that time-lagged late winter- early spring precipitation was positively correlated with the frequency of human plague in northeastern Arizona and northwestern New Mexico. The number of days above certain threshold temperatures (35°C, 195°F) and 32°C

	Disease	Parasitic vector borne diseases Malaria	Arboviral diseases West Nile	Tick-borne encephalitis	Bacterial and rickettsial diseases	Human granulocytic	Human monocytic	Plague (Yersinia pestis)
--	---------	--	---------------------------------	-------------------------	------------------------------------	--------------------	-----------------	--------------------------

Gage, et.al. (2008) summarizes that the determination of the effects of climate change on the incidence, spread, and geographic range of vector borne diseases can be challenging. Although past outbreaks have sometimes been associated with extreme climate events and climatic variability, confidence in using these studies for predicting future events is often low. This is partly because of the lack of adequate long-term data sets tracking relevant variables in most regions, including the distribution and abundance of vectors and the past incidence of vector borne diseases. If a particular vector or vector borne disease suddenly appears in an area, additional efforts should be undertaken to determine whether this range extension is temporary or represents an actual establishment of the vector or a focus of infection. In fact, communication and coordination of health authorities could help ameliorate conditions affecting the pathogen, disease vector and relevant environmental variables.

To aid in the elimination or reduction of any vector borne diseases, vigilance by NASA health services and personnel should be increased to a level of routine awareness. This awareness includes gaining knowledge of any local (<http://www.vdh.state.va.us/LHD/Hampton/index.htm>), state (<http://www.vdh.virginia.gov/epidemiology/DEE/Vectorborne/>), or national (<http://www.cdc.gov/>) public health disease surveillance programs which serves to provide early intelligence on the emergence of vector borne disease [IWGCCH, 2010]. With global trade and travel, disease flare-ups in any part of the world can potentially reach the United States [St. Louis]. As the world gets closer to Langley Research Center and NASA's personnel and resources continue to be integrated into the world's scientific, engineering and economic community, monitoring activities will need to include global ongoing surveillance strategies for early, accurate and reliable detection of risk factors or health effects that may result from or be related to climate change, especially where vector borne disease is of concern [Gaines].

The Virginia Department of Health (VDH) monitors vector borne diseases and alerts the public when new outbreaks occur. Based on discussions with VDH, the following information was gathered:

- The Gulf Coast tick, Asian tiger mosquito and the Lone Star tick are of serious interest to watch in Virginia and we must be mindful that these insect populations change with climatic conditions. Mild winters could induce increased populations and these insects are known vectors for disease.
- Controlling tick populations by controlling endemic populations of deer is important. Deer hunting is a viable method for control of zoonotic carriers of disease (i.e. deer), and populations of deer within a reserve cannot be suitably or totally inoculated against tick infestation with measures such as four posted feeding stations as they do not prove

effective with naturalized populations of animals that have learned to forage within a reservation.

- Migration of new species of insects does occur in Virginia and some mosquitos have been known to migrate from northern latitudes of New York State to the south.
- Full understanding of movements of insects cannot be fully or solely attributed to climatic conditions and more study is needed on climate change impacts effecting migration. [Frumkin].

This paper will attempt to suggest the potential role of climate change on mosequito vector populations near Langley Research Center, Hampton, VA. This is possible due the the historic mosquito count records kept by langley Air Force Base, VA for use in mosequito abatement porgrams. Specifically the influence of precipitation and summer temperture will be invesigated in a climate senerio for 2080-2100.

II. Climate Change and Langley Disease Vectors

Langley Air Force Base [Will] has maintained counts of summer mosquito populations in the Langley area from 2005 to the present. The data consisted of the type of trap that was used, as well as the mosquito count the trap had for various summer days. Using Google Earth the location of the various traps was plotted as shown in Figure 2. The traps are located in populated and well as unpopulated areas thus there is good representation of mosquito environments.

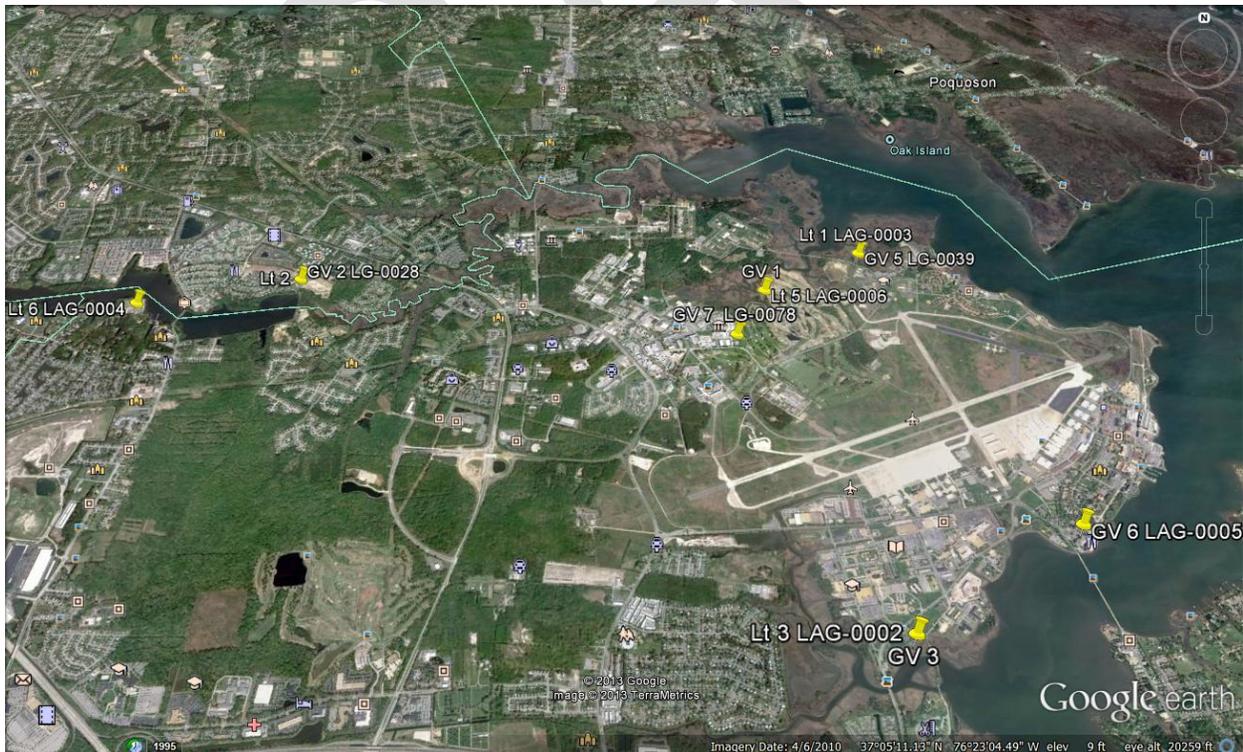


Fig. 2. Location of Langley Air Force Base mosquito traps.

The mosquito count data was graphed in Appendix figures A1-A8 and show count data for various trap locations for the years 2005 to 2012. The trap LT-1 had the highest counts for all the years recorded while location GV-1 has the least counts and was not plotted on all figures except figure 3. Location LT-1 is an unpopulated marsh area whereas GV-1 is located near a more populated area of Langley. The variation of the trap counts with location shows the strong dependence of the effect of the local environment on mosquito populations.

While the figures show the distribution of mosquitoes near Langley, for climate impacts all mosquito counts were combined together for each month of the year and plotted in Appendix Figures B1-B8. These figures show the total mosquito count over a summer period and how it changes with time. Using this data an attempt was made to project what the mosquito counts could be in 2080-2100. The assumption was that mosquito count projection has two main contributing factors. The first factor being precipitation, and the second being the increase in the number of days in each year with higher than average temperatures.

For the precipitation contribution, precipitation data was gathered from the NOAA Williamsburg station over the same period that mosquitoes were counted. This data is shown in Appendix figures C1-C8. A linear relationship between the average mosquito count for the summer months and the corresponding average precipitation, for the same count period, in inches per month was generated for each year between 2007 and 2012 and shown in figure 3. NASA Goddard Institute for Space Studies (GISS) [NASA] has run regional climate models for the region surrounding Langley and has made projections for precipitation and temperature out to 2100. Their projections conclude that this area could experience a maximum annual precipitation increase of 8 inches (36% increase) over current rates and a 60-150 % increase in degree days per year above 90 F. Averaging the precipitation for mosquito count months for years 2007-2012 results in an average annual precipitation of 21 inches. If 8 inches is added to this then 29 inches is the average maximum annual precipitation for 2080-2100. From the linear relationship of figure 3, an 80% increase in mosquito counts would be implied for 2080-2100 due to precipitation only. The major assumption is that there are no land use changes over this period.

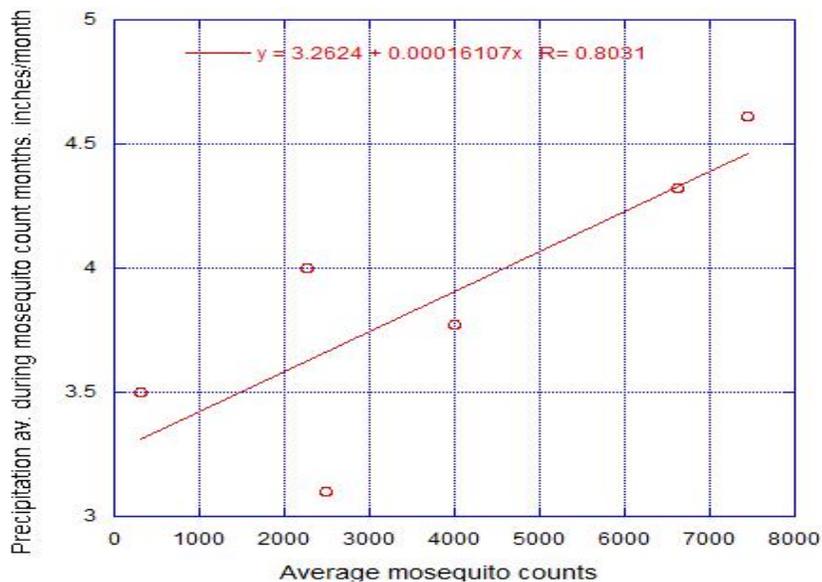


Fig. 3. Average measured percipation during mosequito count months vs Langley average mosequito count for years 2007-2012.

Another contributing factor to the growth in population of mosquitos is the increase in the number of the summer days above 90 F. As the length of summer increases the time for higher temperatures and mosquito's to hatch is increased as well.

In order to determine the increase in the length of summer days, projected temperature degree days information was used from the GISS [NASA] regional climate model. Their projections stated that in the 1980's there were 34 degree days with temperature above 90 F whereas the 2080-2100 projections indicated that there would be 55-86 days annually above 90 F. This corresponds to a 61 to 153 % increase or an average of 107% increase in the number of days over 90 F in 2080-2100. While mosquito counts may not increase by this factor it does indicate the likely hood that populations will substantially increase.

Although mosquitos play a big role in spreading of diseases, ticks also contribute. There are three conditions that would be considered ideal for the growth of ticks. Once these conditions are met, ticks are able to thrive through their multiple life cycles as shown in Figure 4. These three conditions are: humidity, temperature, and availability of blood [Suss].

The first factor, humidity, is crucial because without it the ticks would dry out and die. The *Ixodes Scapularis*, better known as deer tick, absorbs moisture from the air around it. Higher humidity is also ideal for the deer tick because it does not retain moisture in its body very well, so the higher the humidity the easier it is to stay hydrated. Due to the tick not being able to retain moisture, it also tries to avoid direct sunlight. So an area with shade and high humidity would be the favored conditions. In order for the ticks to thrive they would need a humidity level of at least 85% or higher [Suss].

The second main factor is temperature. Ticks prefer higher temperature over cold temperature, which is why in winter tick activity is low as they are molting into their new form, either going from larva to nymphs or from nymphs to adult [Integrated]. As long as the temperature is above 7C, they are able to survive [Suss]. As the temperature increases they are able to better look for a host to feed off to reproduce, the eggs that they lay will hatch faster, and the larva will be able to develop faster. Due to having warmer winters, the ticks will be able to thrive and hatch in the winter time. This will cause an increase in the time period in which ticks are actively seeking hosts.

The third ideal factor for the best tick environment would be the availability of a host. The ticks feed off of the blood of their host to be able to molt into their new form. In the processes of feeding they can attract diseases from their host, or transfer diseases to their host. For example in the woods at Langley Research Center, there are animals all around such as squirrels and deer that ticks are able to attach to. From there they can either stay on that animal as a host and reproduce or use that host as transportation to get to another location were a more viable host may be available.

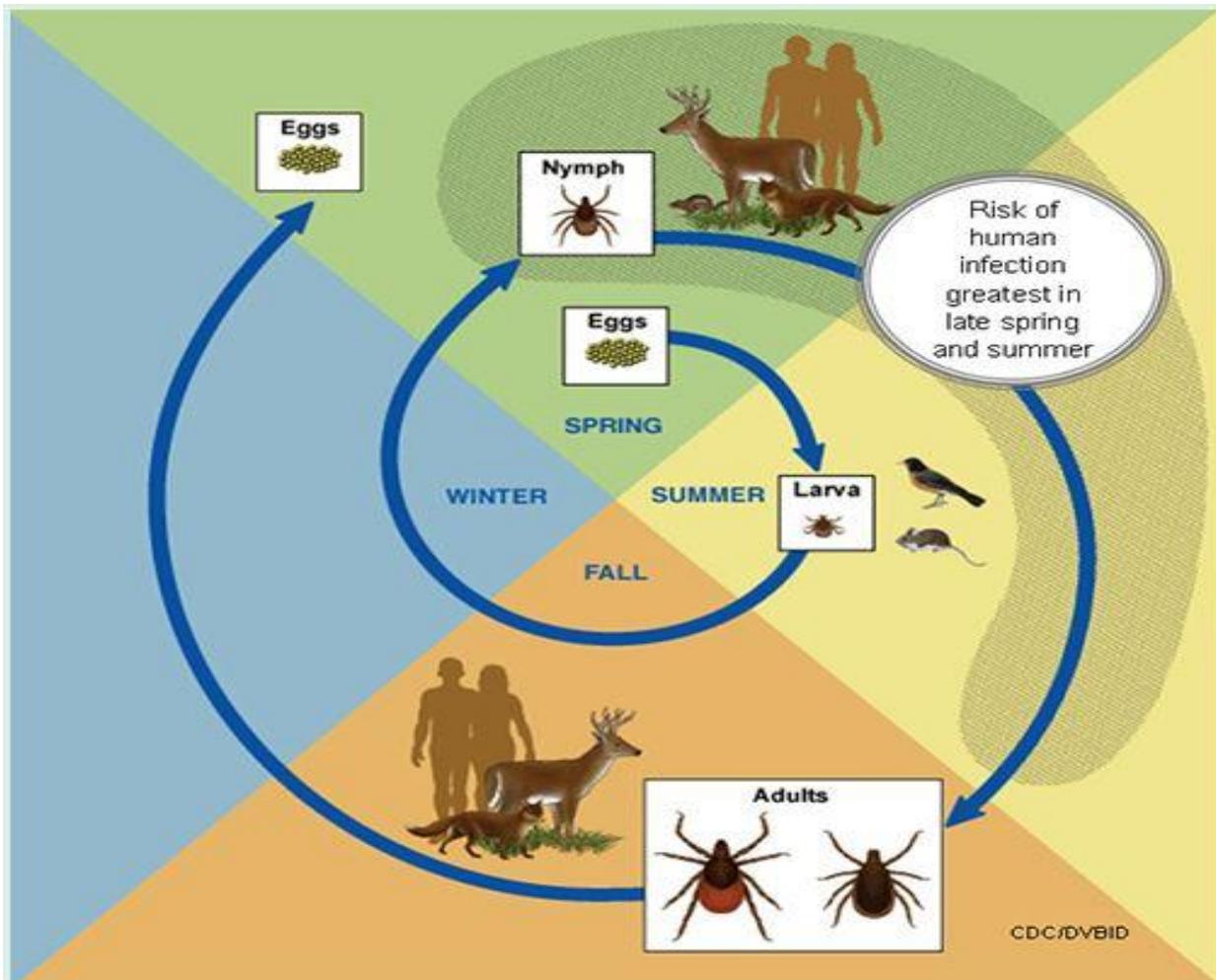


Figure 4 shows the life cycle of ticks throughout the year. The primary risk to humans of infection is from late spring through summer [Life Cycle].

Ticks stand on the very edge of leaves, tree branches, grass, or anything that can be used to elevate them. They do this because they cannot fly or jump onto their host. Then they latch onto any creature walking by using their front legs [Life Cycle]. After that some ticks may attach instantly to the closest available skin, and some wander to an ideal spot where they would not be detected.

III. Mitigation of Vector Risks

The risk of Langley employees becoming sick from either zoonotic borne or vector sources such as mosquitos and ticks is likely to increase in the future due to climate change impacts. The goal is that all personnel represent a high value asset, and that their continued good health remains significant to the overall success of the NASA mission. Given that disease exposure will occur there is an increased possibility that personnel could become infected and sick thus affecting the outcome of NASA missions which can result in a delay or significant adverse impact to the mission.

The following is a list of potential mitigation strategies that could be used to reduce the risk of vector borne disease.

- NASA Langley is moving to a more integrated infrastructure called “New Town”. This will be a more campus like environment where employees will be closer to those in other buildings and thus encouraged to be able to walk between buildings. This will result in more exposure to outside vector borne diseases.
- When thinking about expanding the paths at Langley into the woods, the paths should be constructed wide enough so that individuals walking on them should not be brushing up against them. Ticks are likely to hang off the leaves that are on the side of the paths so that they can latch onto anyone walking by. For the trees that are above the path, they should be trimmed to the point where they cannot come in contact with the individual walking in front of them.
- A campus like environment has the advantage of a smaller outside vegetation area to maintain. Shrubs will need to be cut back from walkways and grass cut short to discourage mosquito populations.
- Be familiar with local sources of information:
<http://www.vdh.virginia.gov/epidemiology/DEE/Vectorborne/>
http://ccrm.vims.edu/coastal_zone/climate_change_db/examples/health_page.html.
Take the information home and share with family and friends
- At peak mosquito and tick seasons, personal protection repellent clip-ons could be provided for outside use. Also clothing treated with permethrin can kill ticks as they travel across the fabric. The treatment will last from 2 to 6 weeks and withstand weekly detergent washing. Permethrin works equally well on mosquitoes, chiggers and other arthropods.
- For severe conditions, enclosed walkways may be required to protect employees..

IV. Conclusions

Climate change will impact NASA Langley requiring personnel to change behaviour for how we protect ourselves from disease vectors such as ticks and mosquitos. Regional climate models can now predict the future trends in temperature and precipitation, conditions that enhance mosquito and tick populations, for our area. A maximum of 8 inches additional precipitation for 2080-2100 over current levels is predicted by the models and this may lead to a 80% increase in mosquito population assuming land use and other factors remain constant. Also the annual number of degree days above 90 F will increase by 107% allowing mosquito populations longer growth periods.

Tick populations are more difficult to predict but they are anticipated to increase in a more humid environment which climate change will enhance. Carbon sequestration though enhanced growing of forest at Langley could place employees in more direct contact with ticks and

associated disease. Awareness that local deer populations, while although aesthetically pleasing, represent a hazard in the form of zoonotic vectors for disease and thus would need be controlled.

A number of mitigation strategies can easily be used to reduce the risk of vector borne diseases. Individuals must be made aware of the continued hazards for disease carrying pests and must continually educate themselves and others of the hazards that exist.

Acknowledgements

This work was performed as a collaboration between the LaRC Science Directorate and Research Directorate to fulfill the need for meeting the Center's sustainability and energy conservation goals, furthering technological advances and research, and promoting opportunities for inter-departmental working relationships. The NASA HQ funded this research through the Climate Adaptation Science Investigator (CASI) program.

References

Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.), Cambridge University Press, 2009.

Wildlife in a Warming World, A. Staudt, C. Shott, D. Inkley, I. Ricker, National Wildlife Federation, 2013.

Climate and Vector borne Diseases, K. L. Gage, T. R. Burkot, R. J. Eisen, E. B. Hayes, *Am J Prev Med*, 35(5):436–450, Elsevier Inc., 2008.

Mosquito-Borne Dengue Fever Threat Spreading in the Americas, Kim Knowlton, Dr.P.H.Gina Solomon, M.D., M.P.H. Miriam Rotkin-Ellman, M.P.H., Natural Resources Defense Council (NRDC), 2009.

A Human Health Perspective On Climate Change, A Report Outlining the Research Needs on the Human Health Effects of Climate Change, The Interagency Working Group on Climate Change and Health¹ (IWGCCCH) Environmental Health Perspectives and the National Institute of Environmental Health Sciences, 2010.

Climate Change Impacts on and Implications for Global Health, M. E. St. Louis, J. J. Hess, *Am J Prev Med*, 35(5) 0749-3797/08/ 527Published by Elsevier Inc. on behalf of American Journal of Preventive Medicine doi:10.1016/j.amepre.2008.08.023, 2008.

Telephone conversation, dated 4/30/2013 with VDH, David Gaines, PhD - State Public Health Entomologist phone 804-864-8112, email: david.gaines@vdh.virginia.gov, Expertise in the areas of arthropod-borne disease, vector ecology/biology and control, insecticide usage, nuisance or biting and stinging arthropod pests.

Climate Change and the Health of the Public, H. Frumkin, A. J. McMichael, J. J. Hess, *Am J Prev Med* 35(5) 0749-3797/08/ 401, Published by Elsevier Inc. on behalf of American Journal of Preventive Medicine, doi:10.1016/j.amepre.2008.08.031, 2008.

Ecological Responses to Recent Climate Change, Gian-Reto Wlather, Eric Post, Peter Convey, Annette Menzel, Camille Parmesan, Trevor J. C. Beebee, Jean-Marc Fromentin, Ove Hoegh-Guldberg & Franz Bairlein., *Nature* 416 March 28 2002.

West Nile Virus, Centers for Disease Control and Prevention <http://www.cdc.gov/westnile/index.html> accessed June 23, 2013.

Economic cost analysis of West Nile virus outbreak, Sacramento County, California, USA, 2005. Barber LM, Schleier JJ III, Peterson RKD, 2010 Mar. <http://www.cdc.gov/eid/article/16/3/09-0667.htm>, DOI: 10.3201/eid1603.090667.

James B. Will Jr. "Mosquito Counts." Langley Air Force Base.

"NASA Goddard Institute for Space Studies: Climate in Hampton Roads: Today and in the future." NASA.

Suss, Jochen, Christine Klaus, Friedrich W. Gerstengarbe, and Peter C. Werner. "What Makes Ticks Tick? Climate Change, Ticks, and Tick-Borne Diseases." *Journal of Travel Medicine* 15.1 (2008): 39-45. Wiley Online Library. National Reference Laboratory for Tick-borne Diseases, Friedrich-Loeffler-Institute, 21 Jan. 2008. Web. 19 June 2013. <<http://onlinelibrary.wiley.com/doi/10.1111/j.1708-8305.2007.00176.x/full>>.

"Integrated Pest Management Manual." *Nature & Science » Biology Resources » Integrated Pest Management Manual*. N.p., 19 Jan. 2010. Web. 20 June 2013. <<http://www.nature.nps.gov/biology/ipm/manual/ticks.cfm>>.

"Life Cycle of Hard Ticks That Spread Disease." Centers for Disease Control and Prevention. Centers for Disease Control and Prevention, 26 July 2012. Web. 20 June 2013. <http://www.cdc.gov/ticks/life_cycle_and_hosts.html>.

Appendix A Yearly mosquito counts for specific traps from 2005 to 2012.

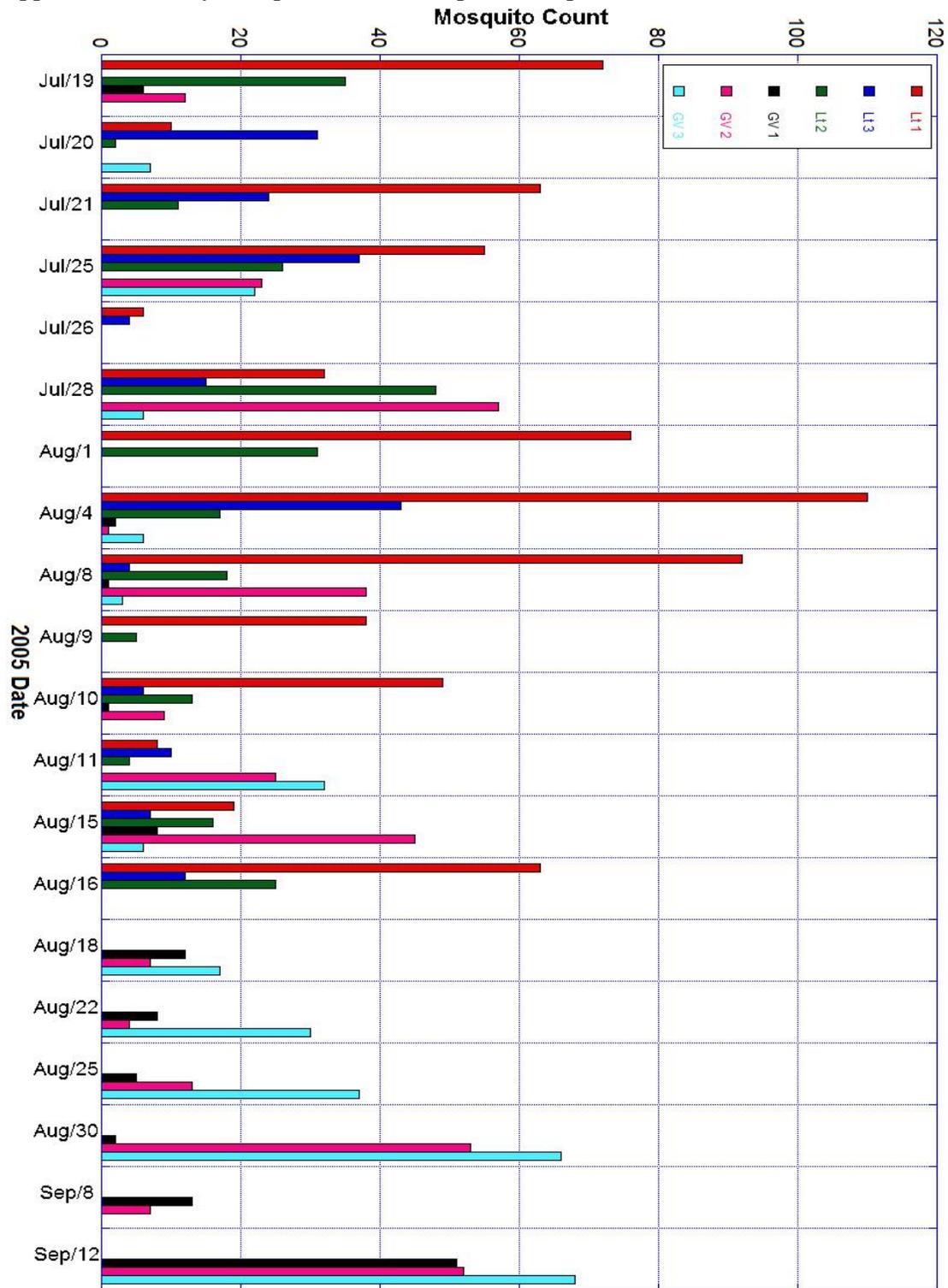


Fig. A1. Mosequito counts for the designated traps for summer months of 2005.

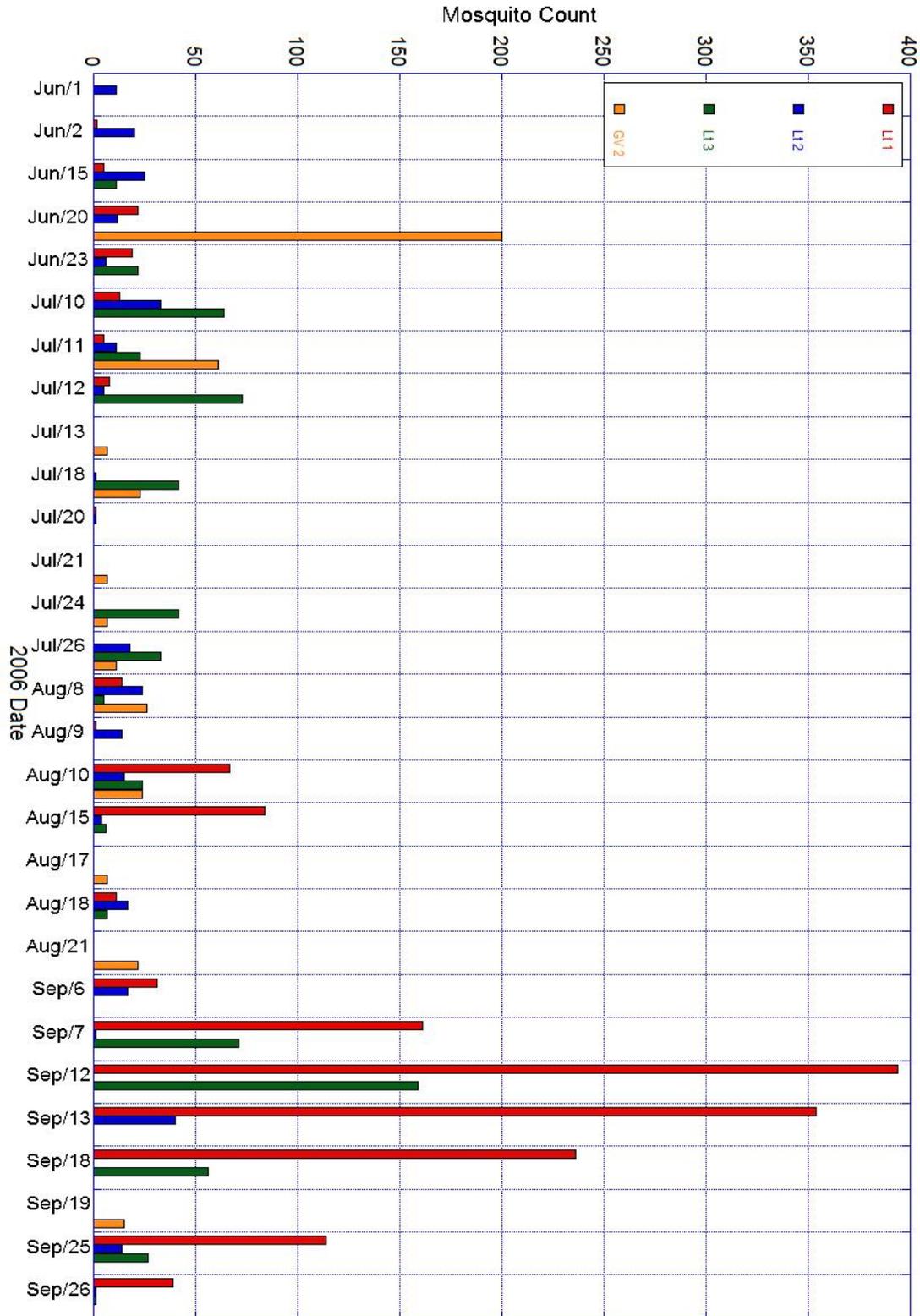


Fig. A2. Mosquito counts for the designated traps for summer months of 2006.

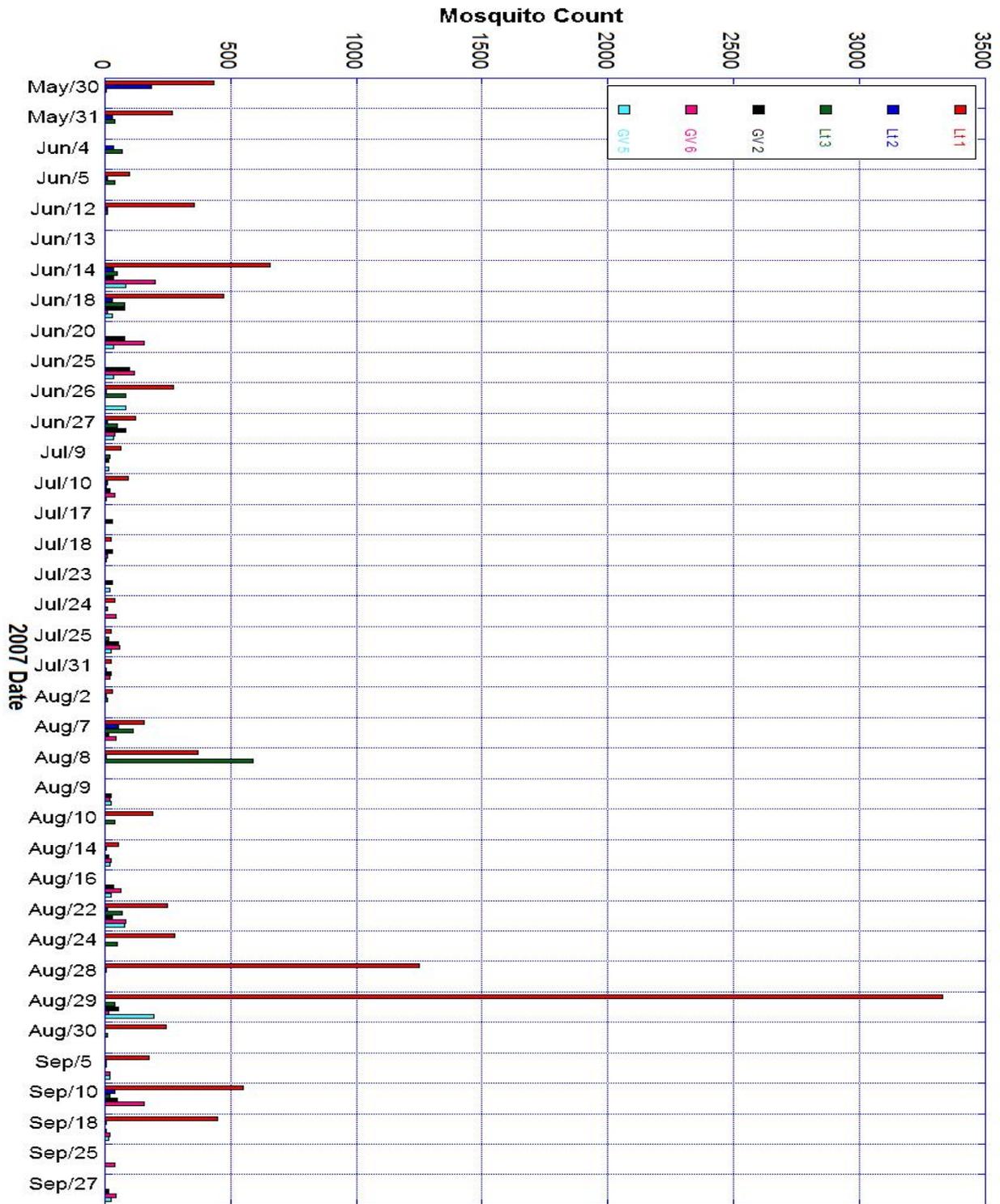


Fig. A3. Mosequito counts for the designated traps for summer months of 2007.

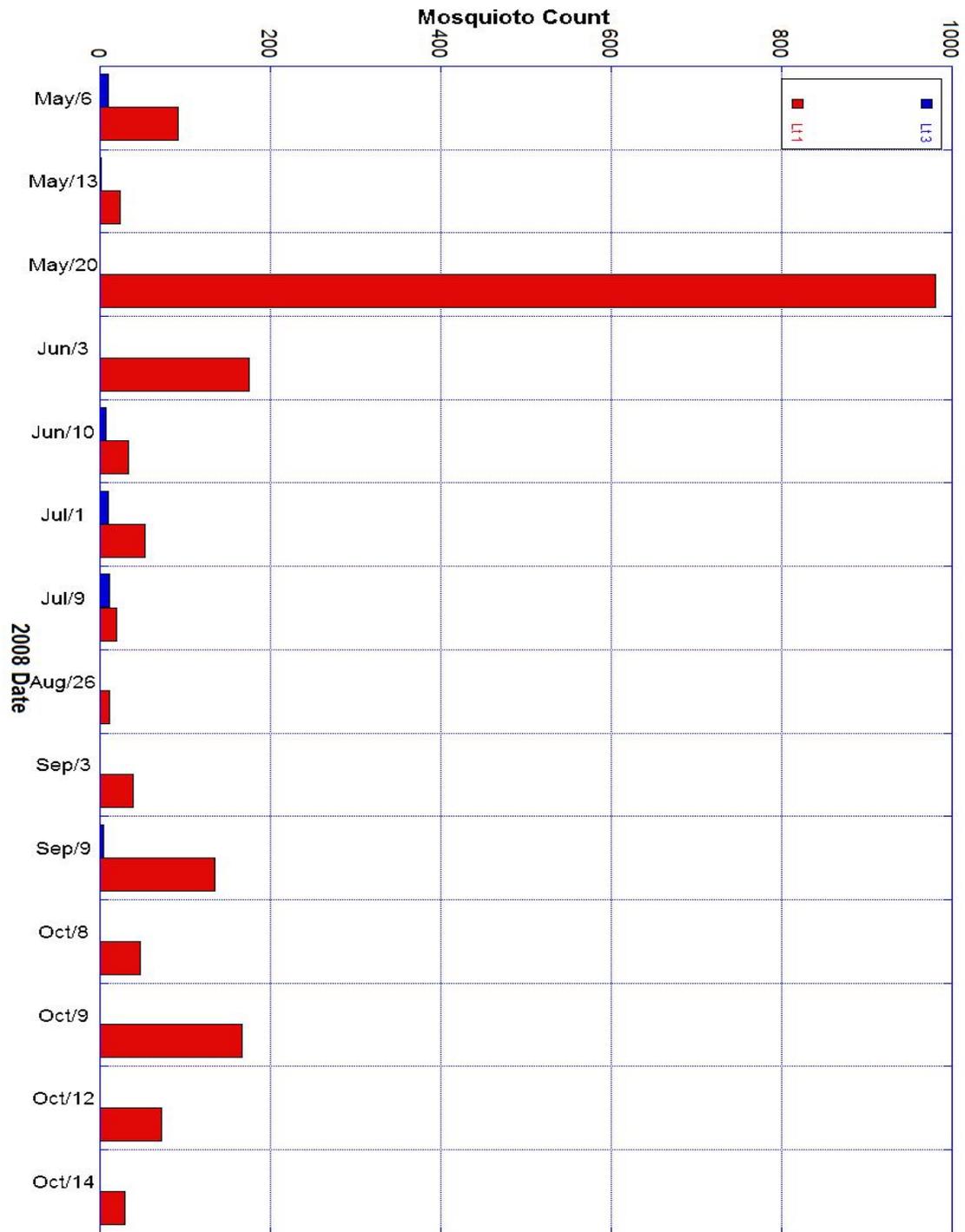


Fig. A4. Mosequito counts for the designated traps for summer months of 2008.

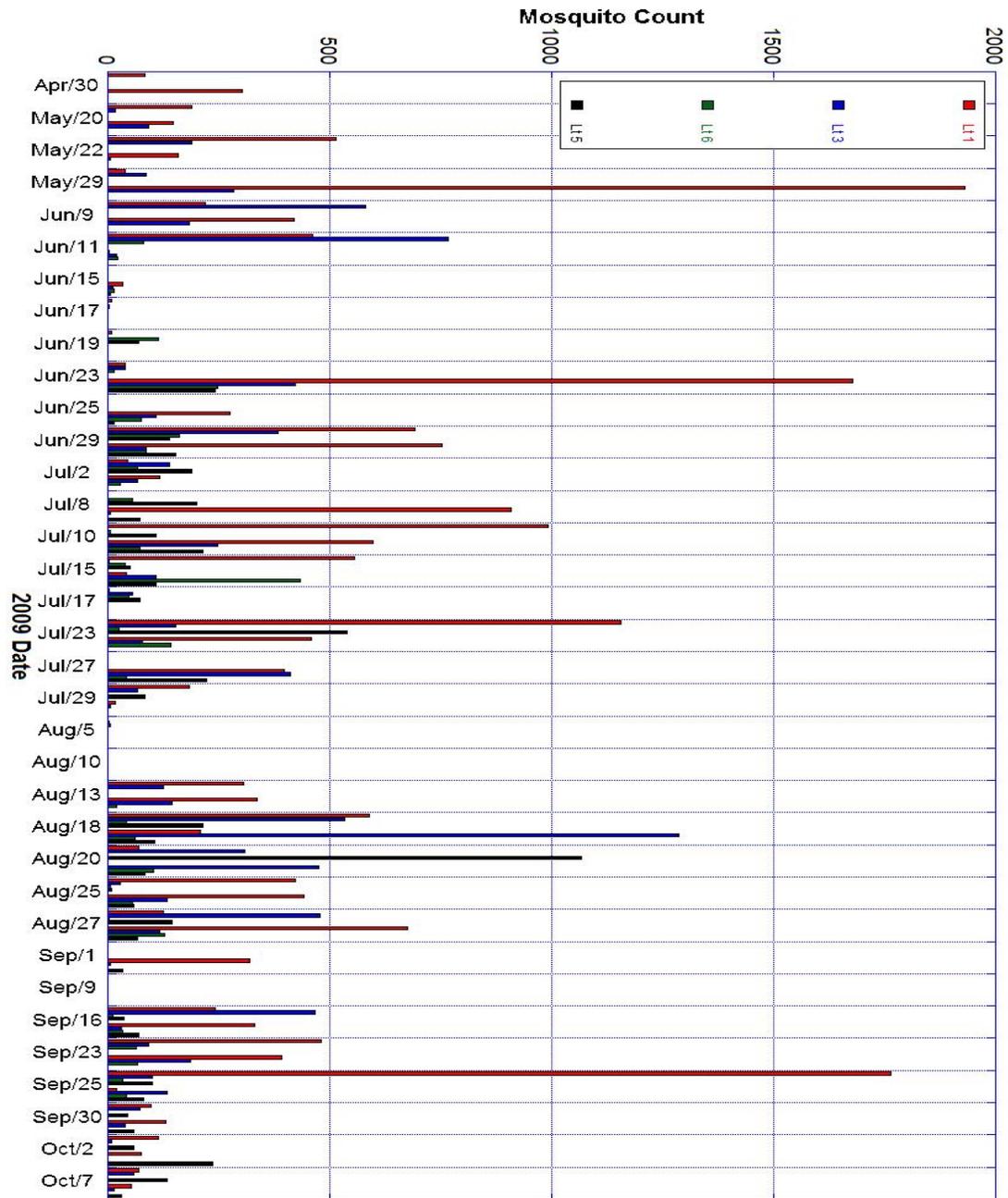


Fig. A5. Mosequito counts for the designated traps for summer months of 2009.

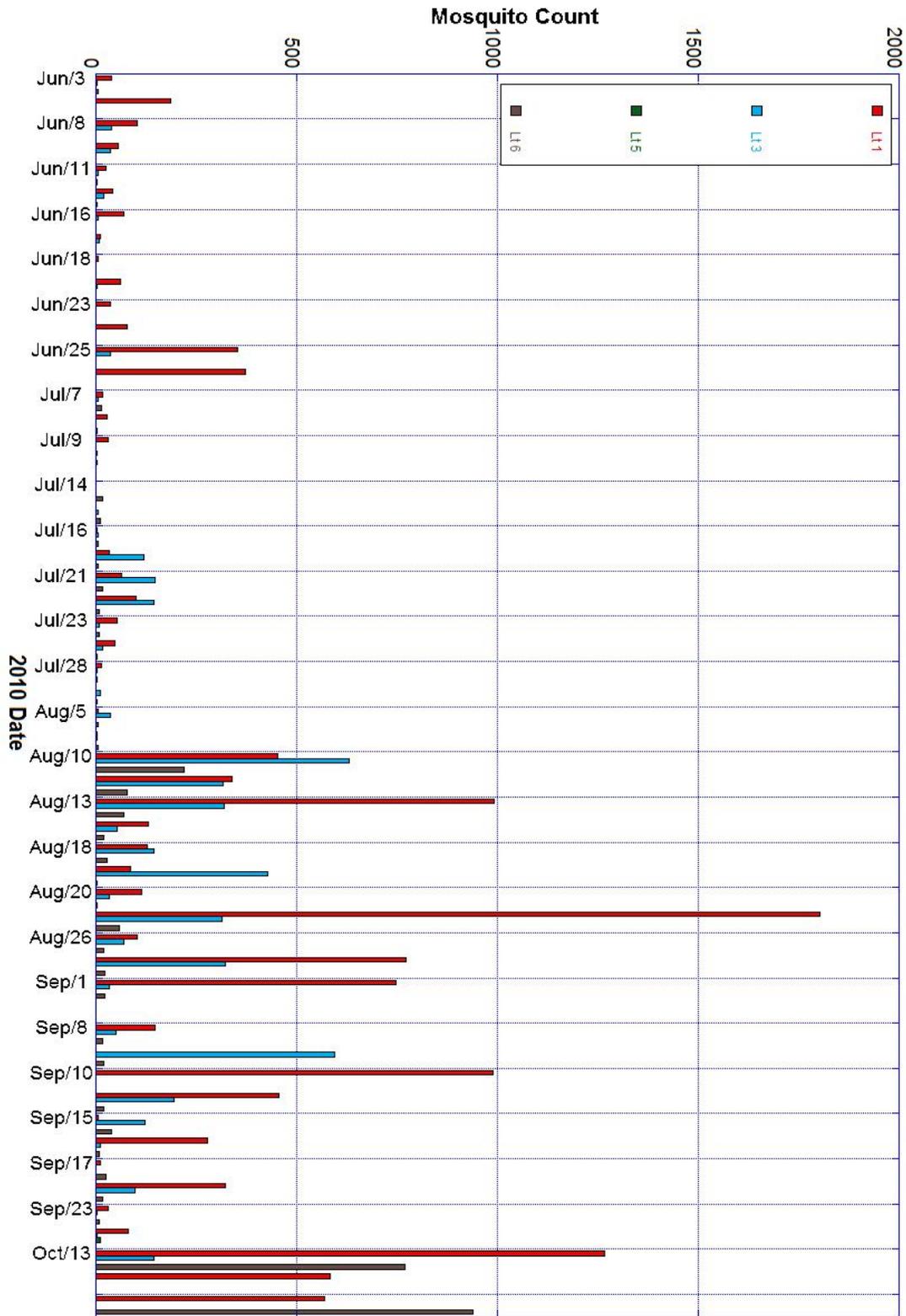


Fig. A6. Mosequito counts for the designated traps for summer months of 2010.

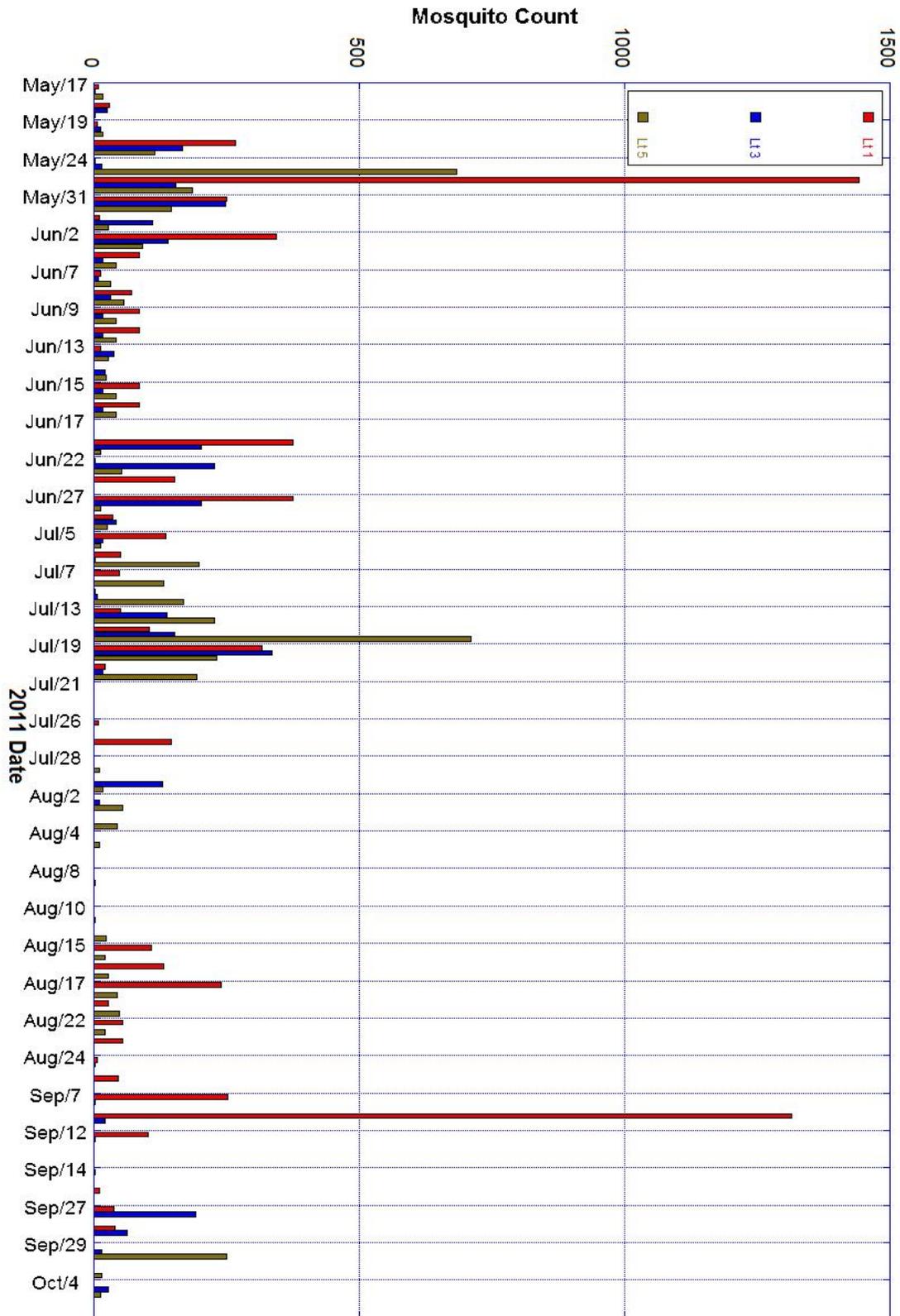


Fig. A7. Mosequito counts for the designated traps for summer months of 2011.

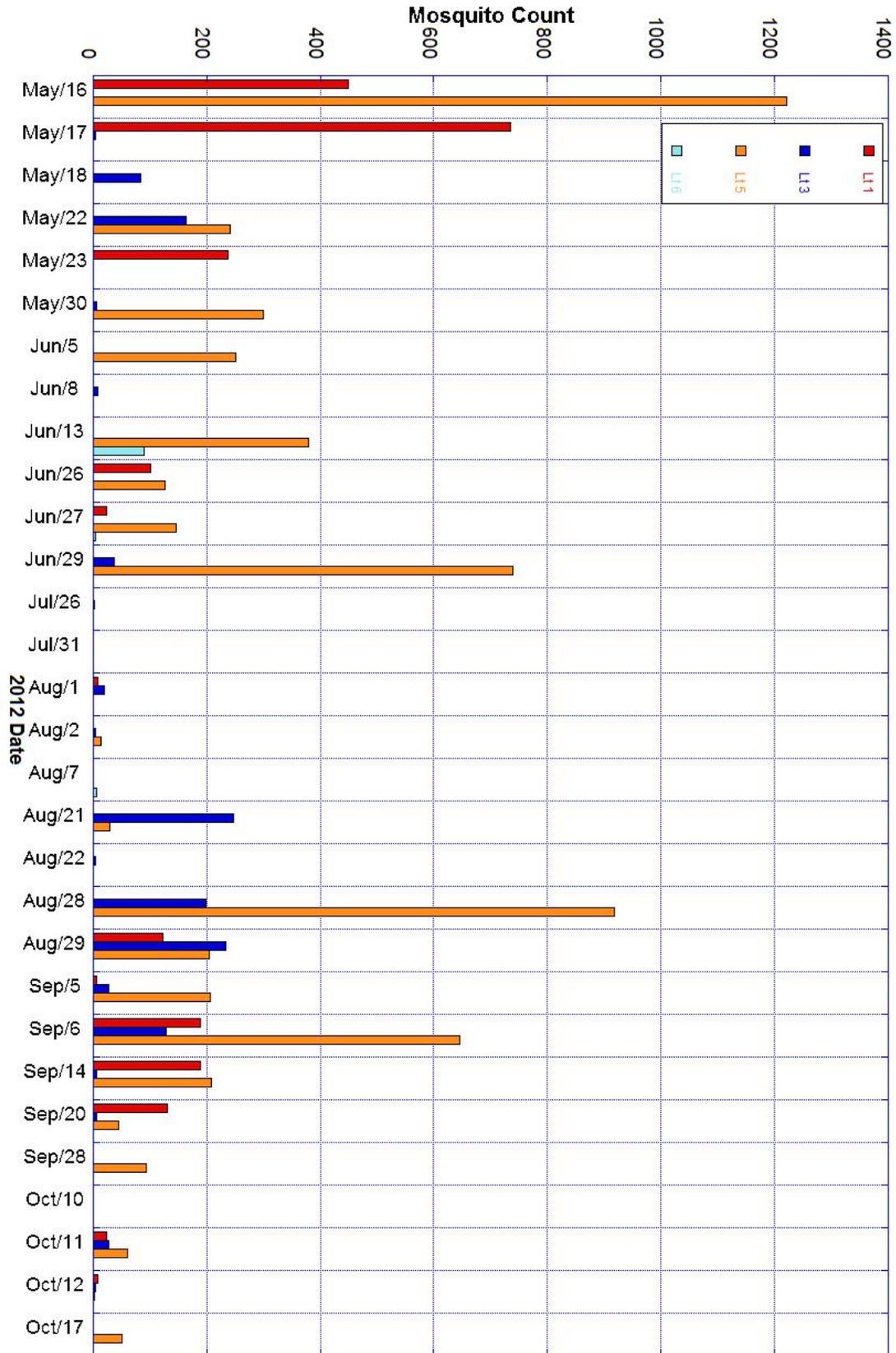


Fig. A8. Mosequito counts for the designated traps for summer months of 2012.

Appendix B: Total monthly mosequito counts for 2005-2012.

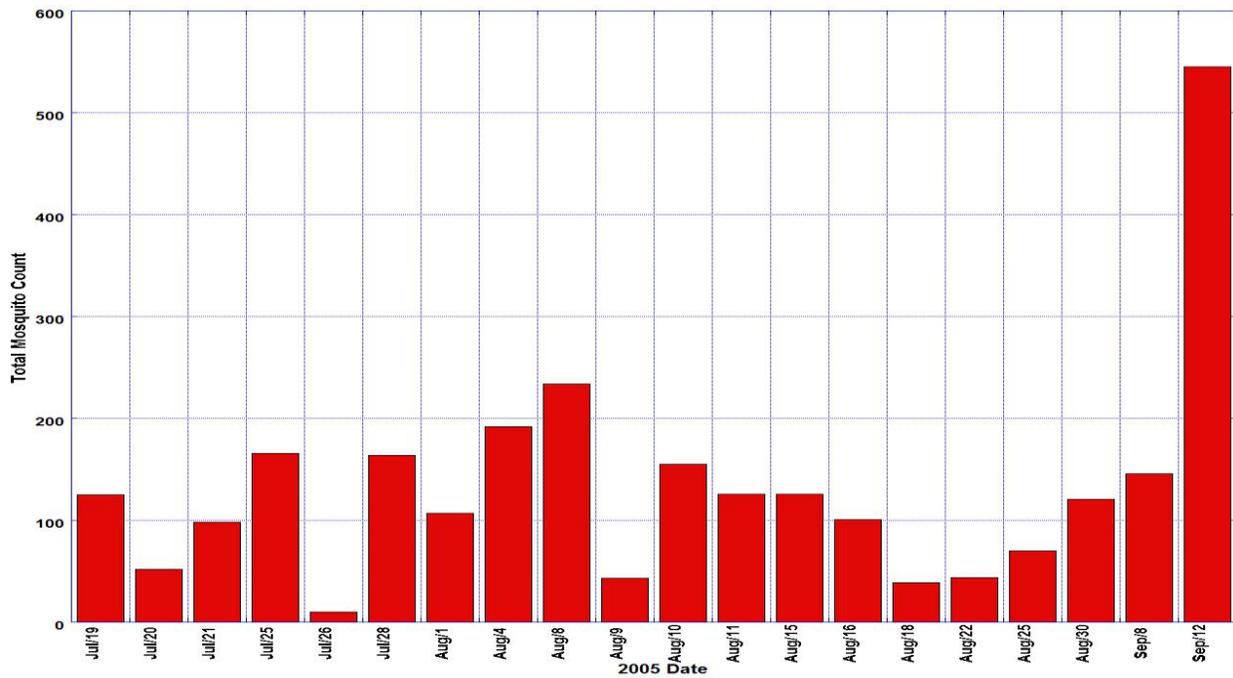


Fig. B1. Total mosequito counts vs month for 2005.

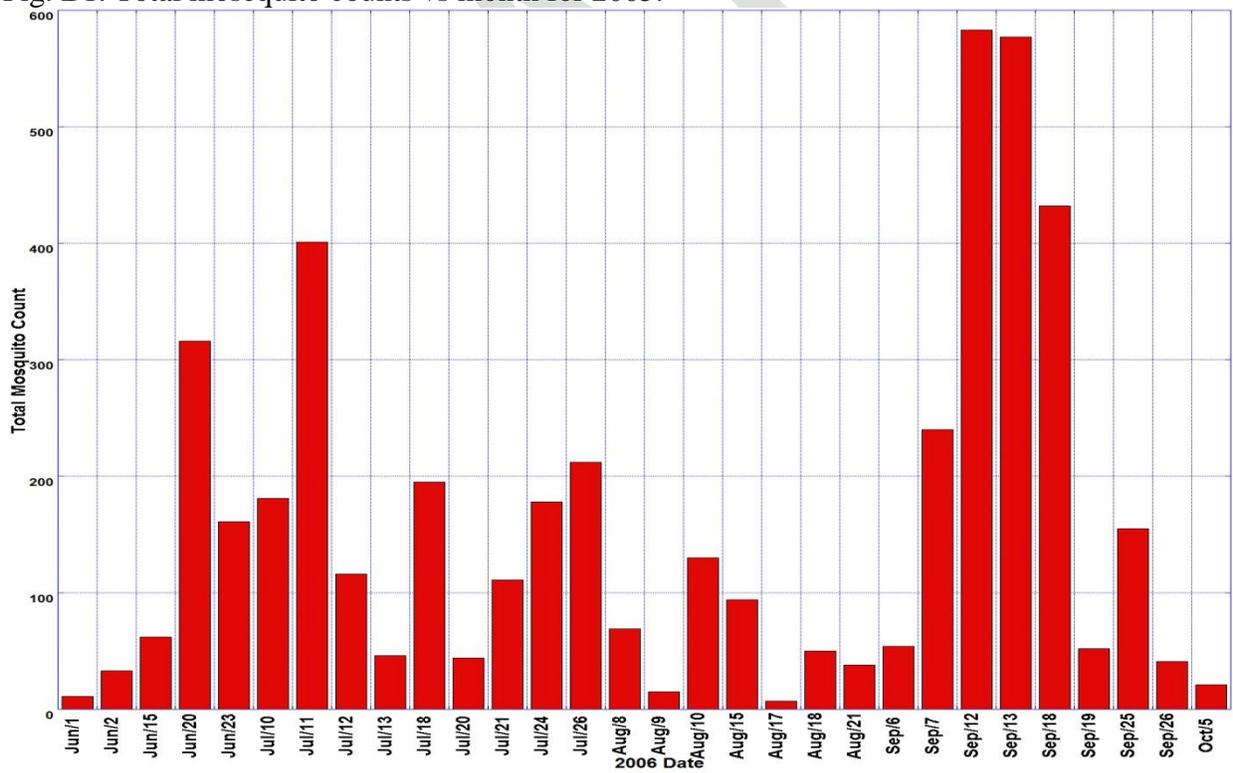


Fig. B2. Total mosquito counts vs month for 2006.

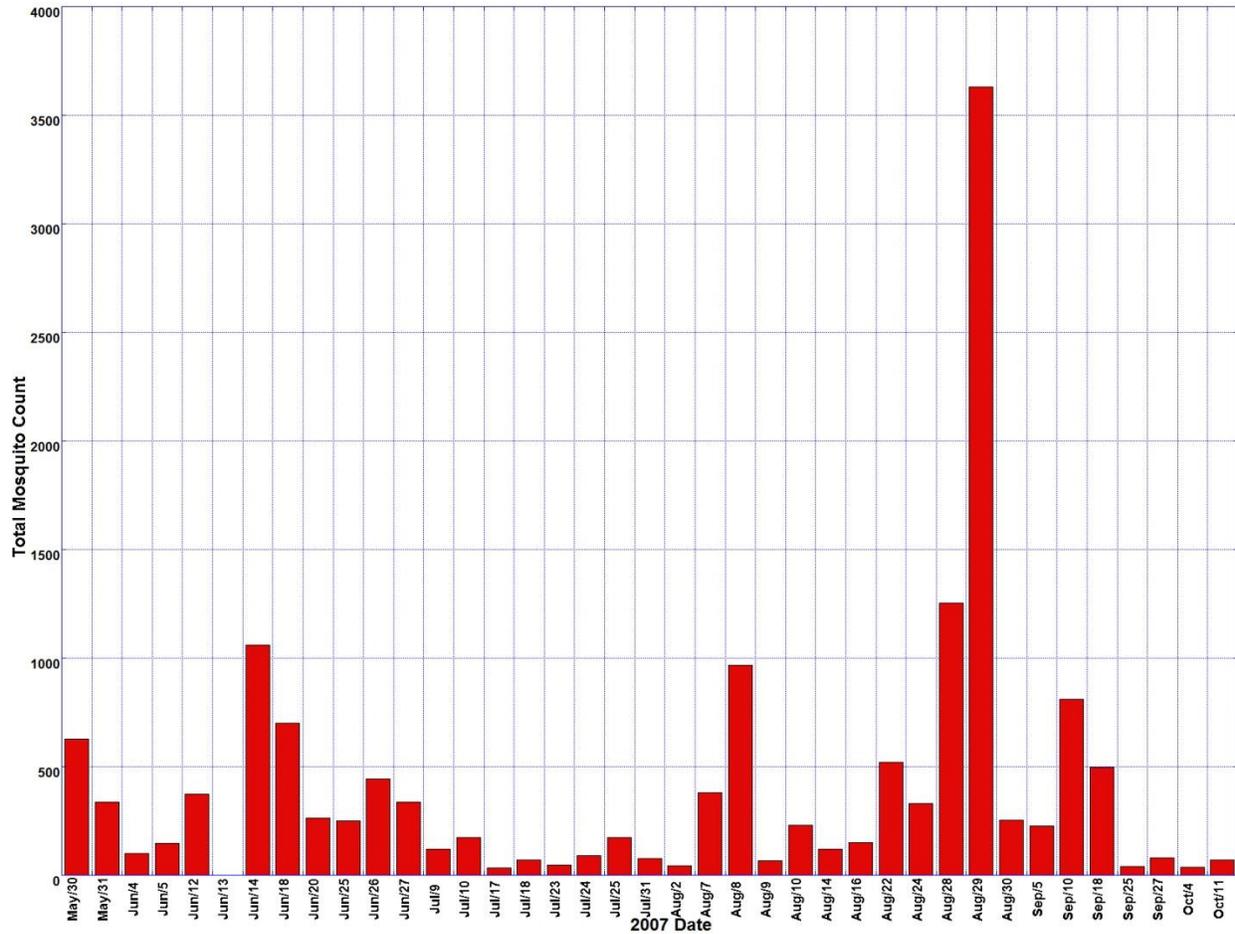


Fig. B3. Total mosequito counts vs month for 2007.

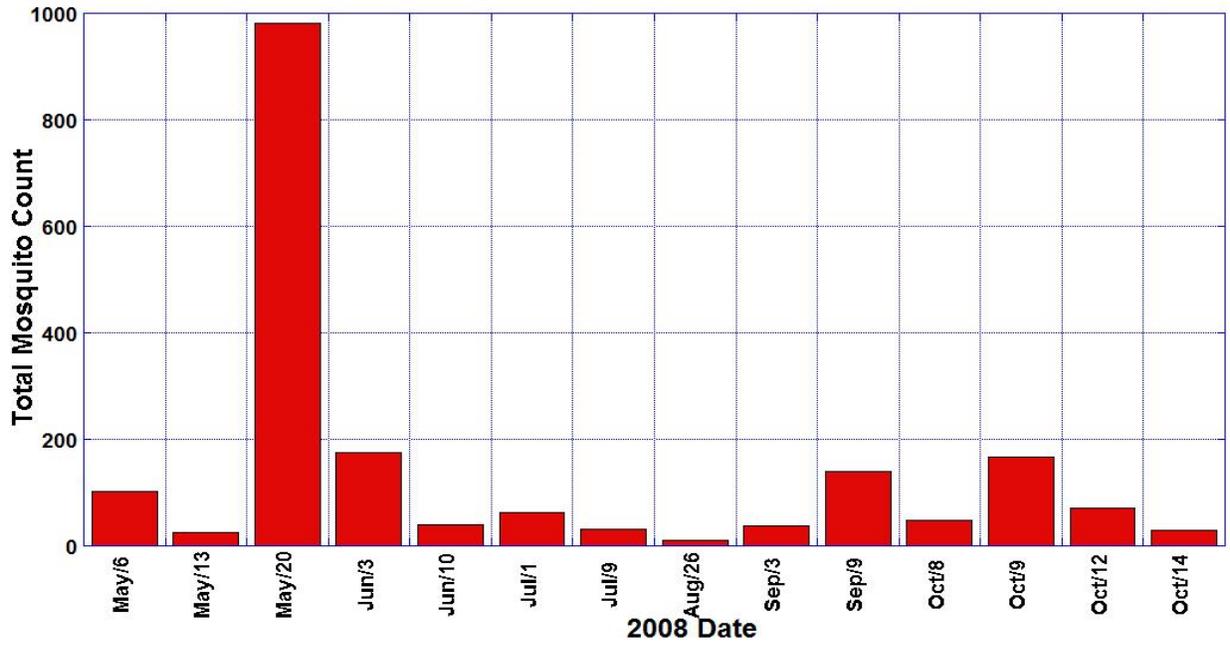


Fig. B4. Total mosequito counts vs month for year 2008.

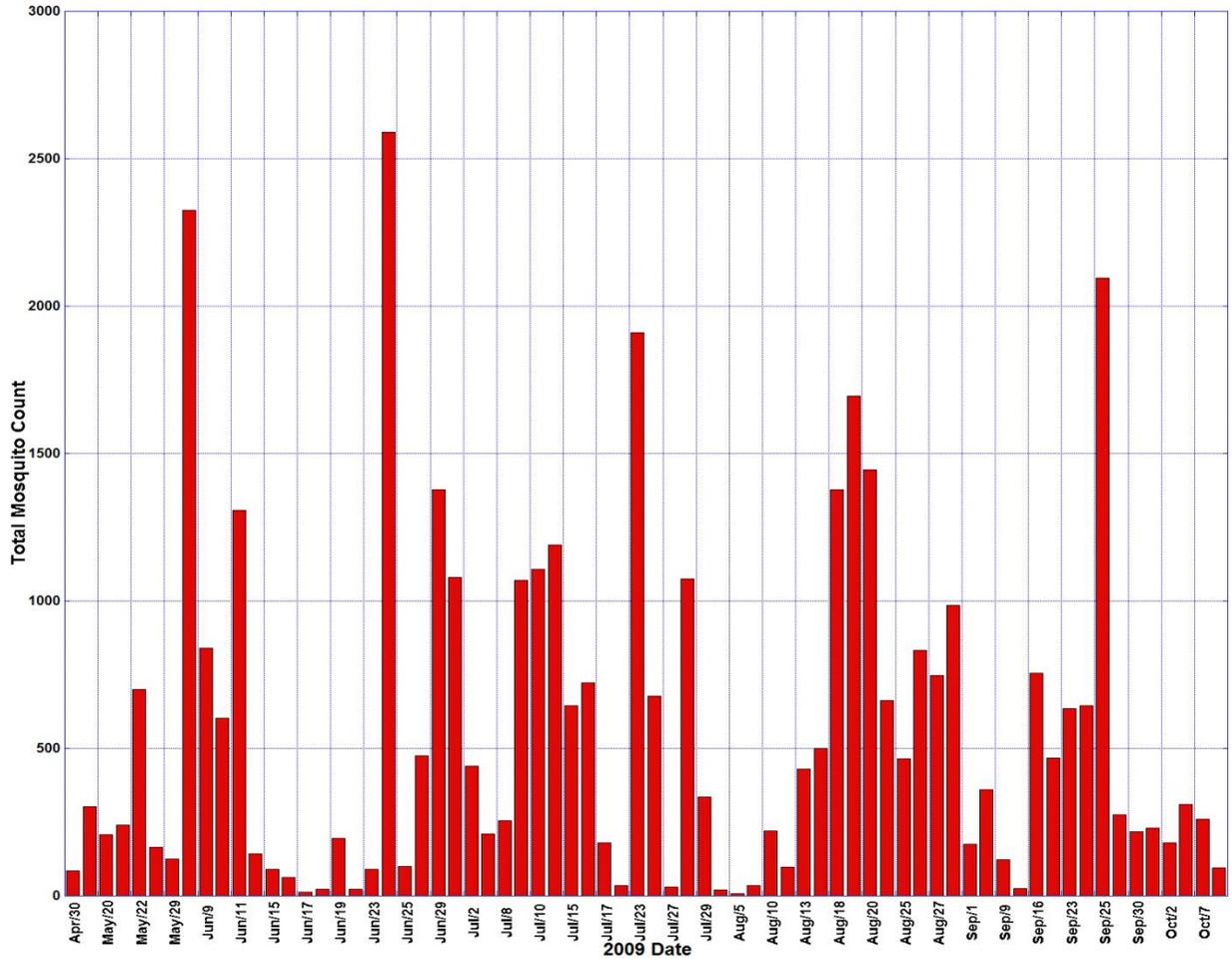


Fig. B5. Total mosquito counts vs month for the year 2009.

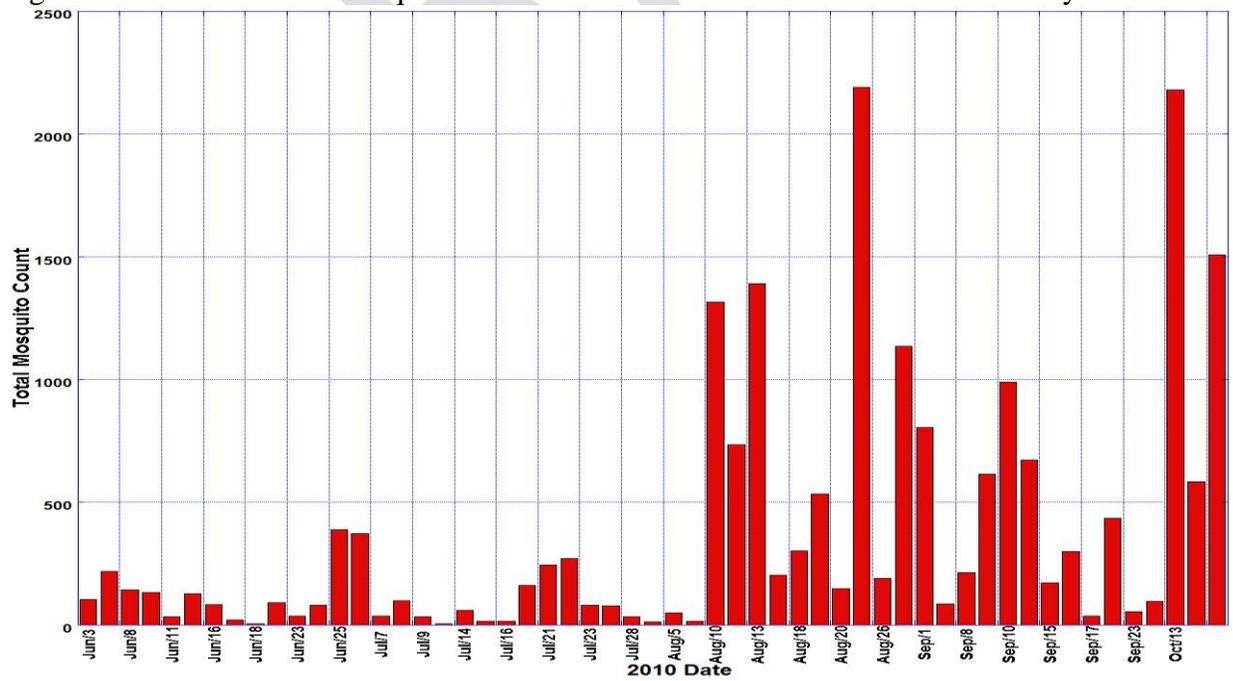


Fig. B6. Total mosquito counts vs month for the year 2010.

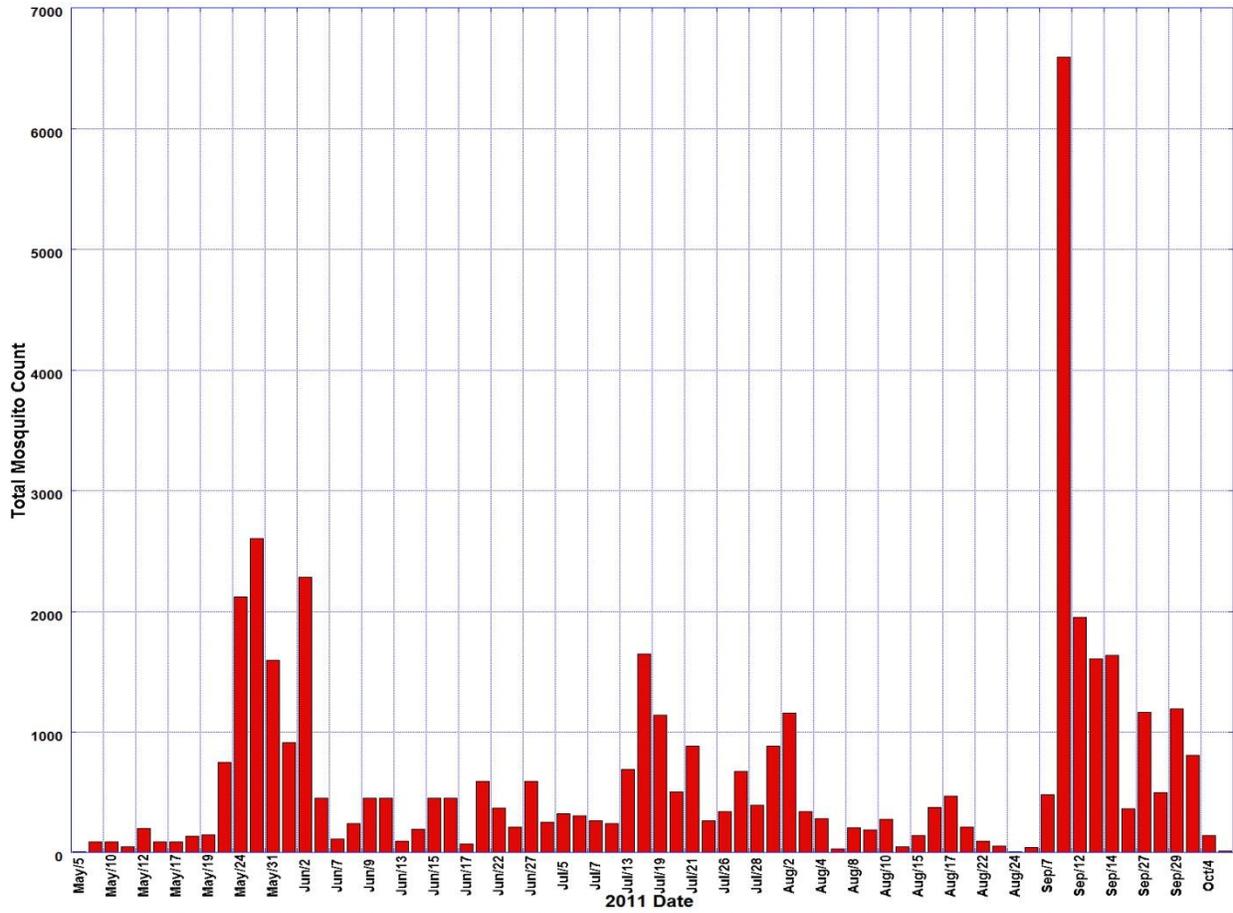


Fig. B7. Total mosquito counts vs month for the year 2011.

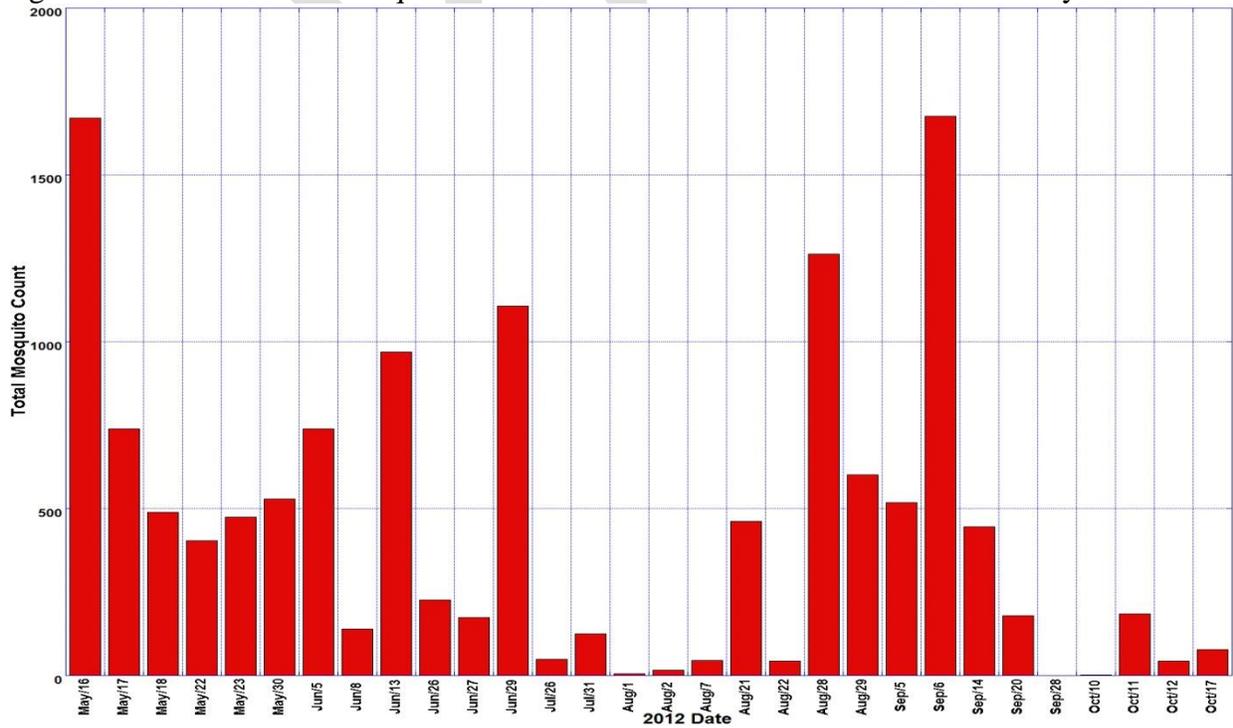


Fig. B8. Total mosquito counts vs month for the year 2012.

Appendix C: Monthly percipitation and mosequito counts for 2005-2012.

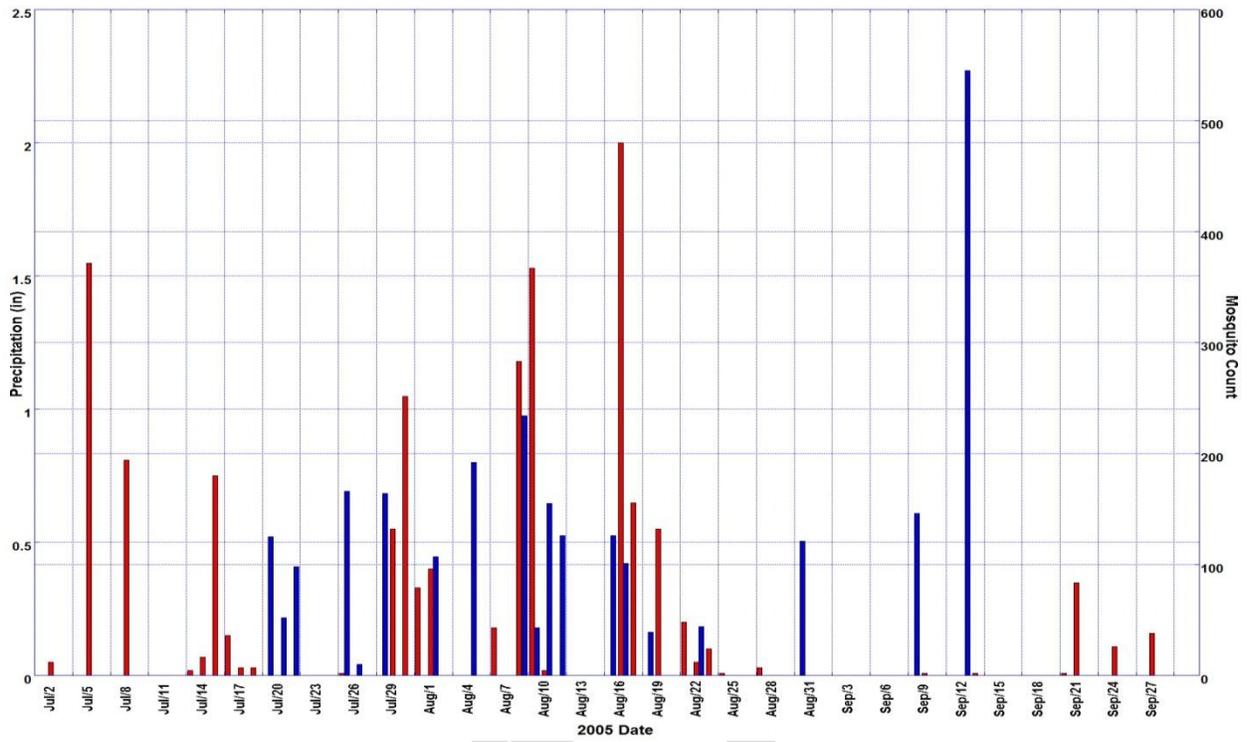


Fig. C1. Total monthly mosquito counts and precipitation for year 2005.

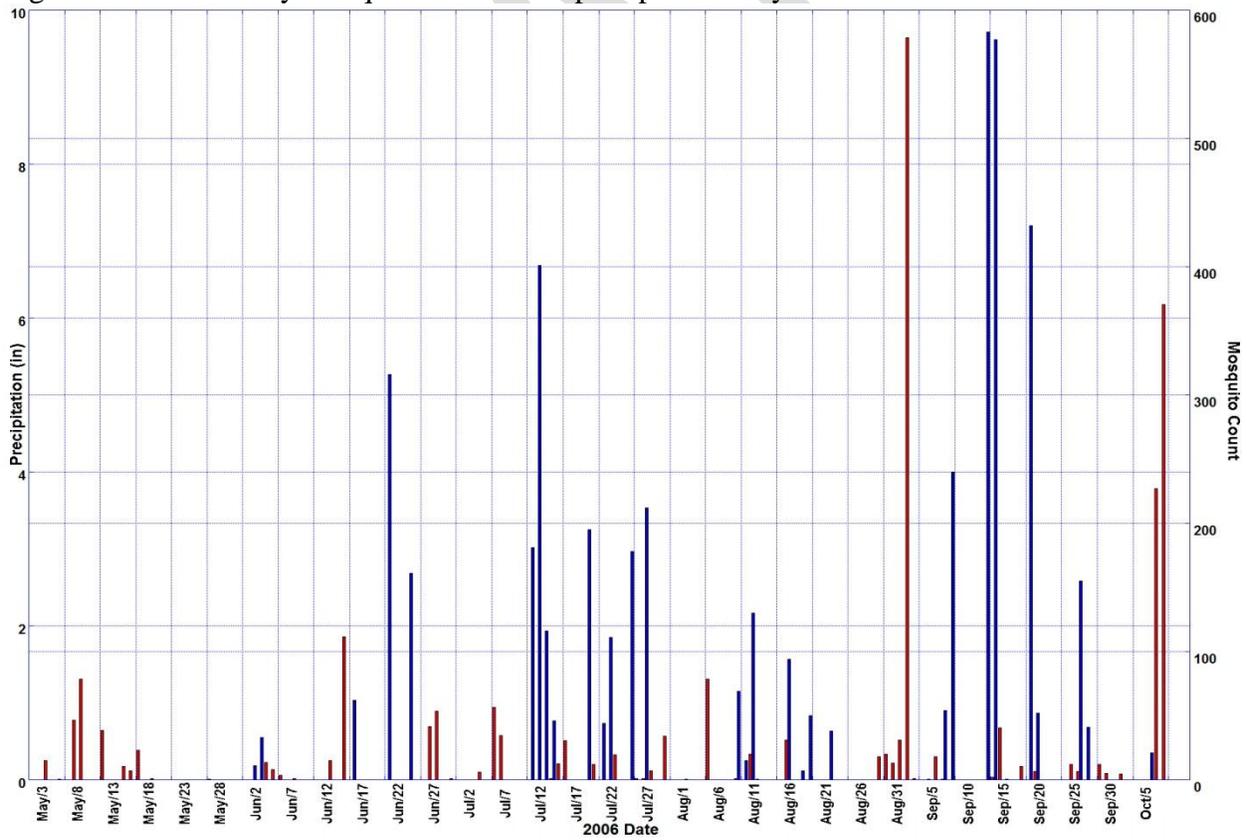


Fig. C2. Total monthly mosquito counts and precipitation for the year 2006.

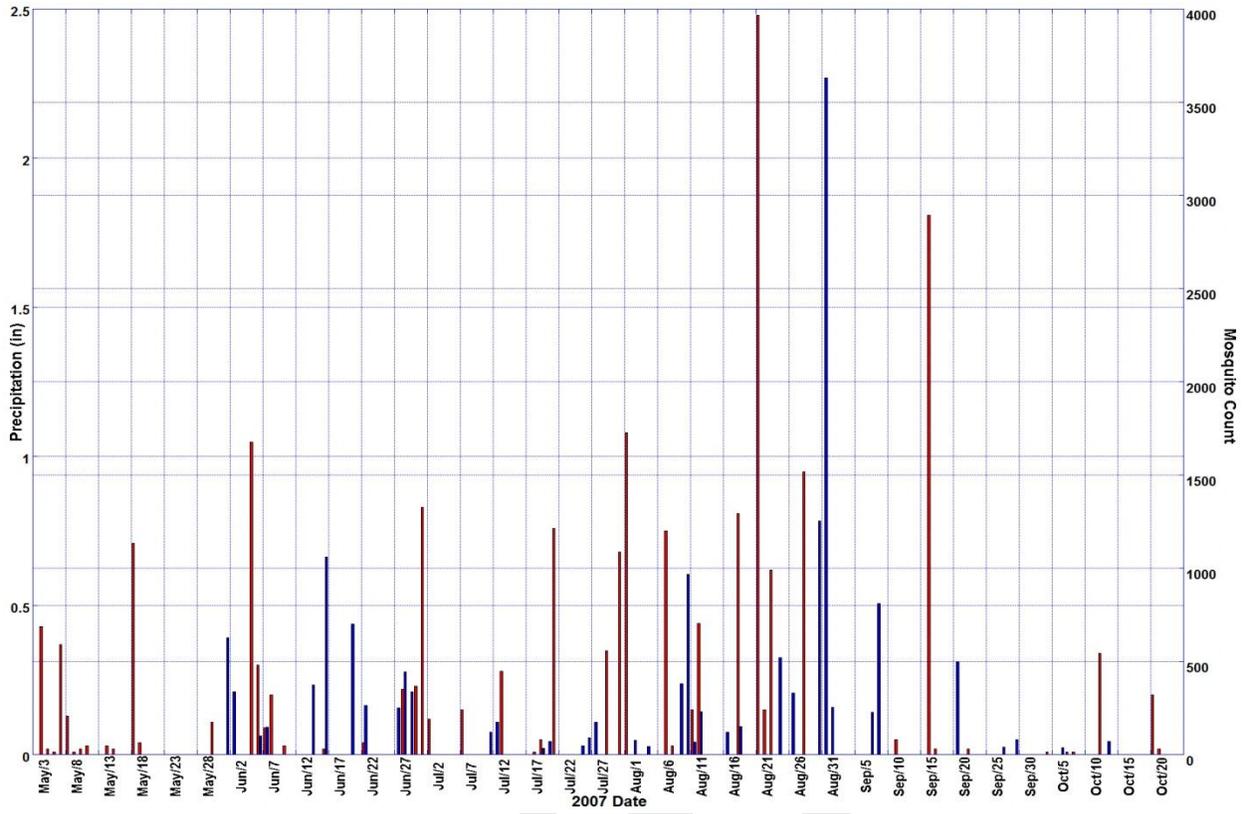


Fig. C3. Total monthly mosquito counts and precipitation for the year 2007.

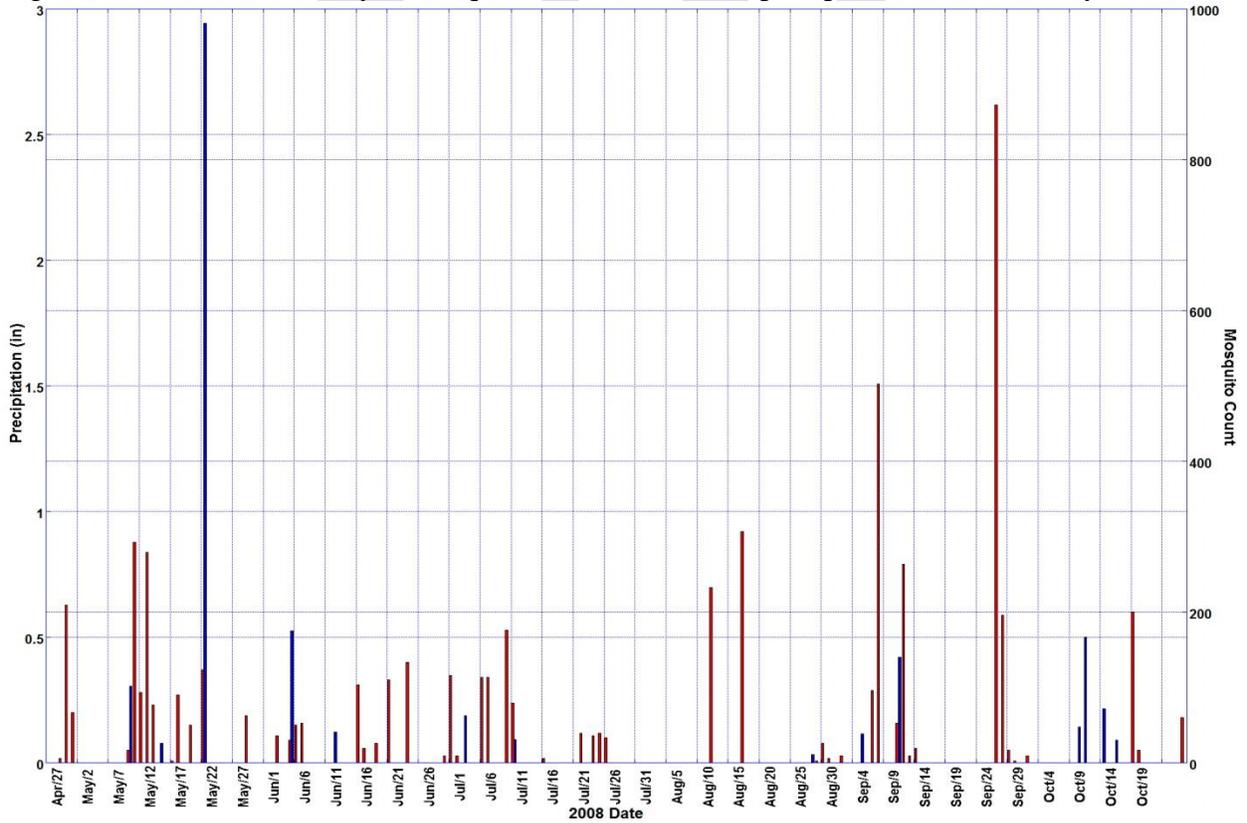


Fig. C4. Total mosquito counts and precipitation for the year 2008.

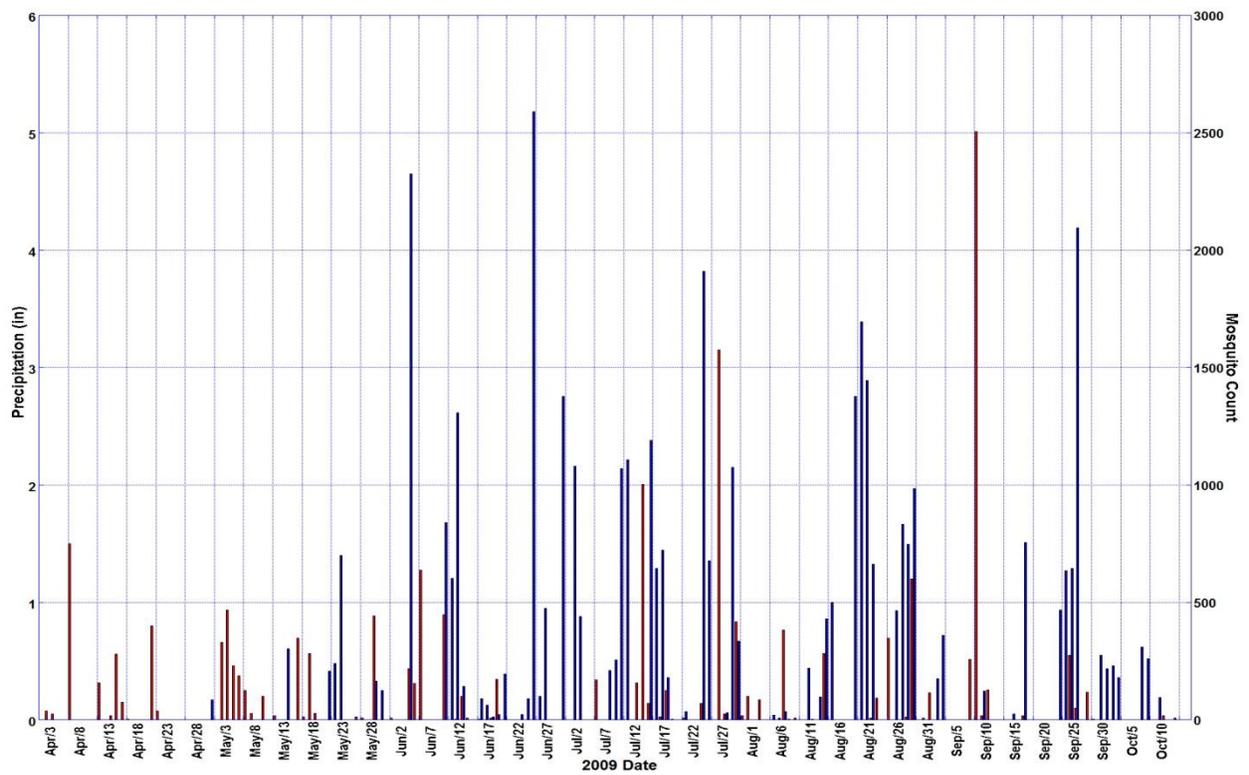


Fig. C5. Total monthly mosquito counts and precipitation for the year 2009.

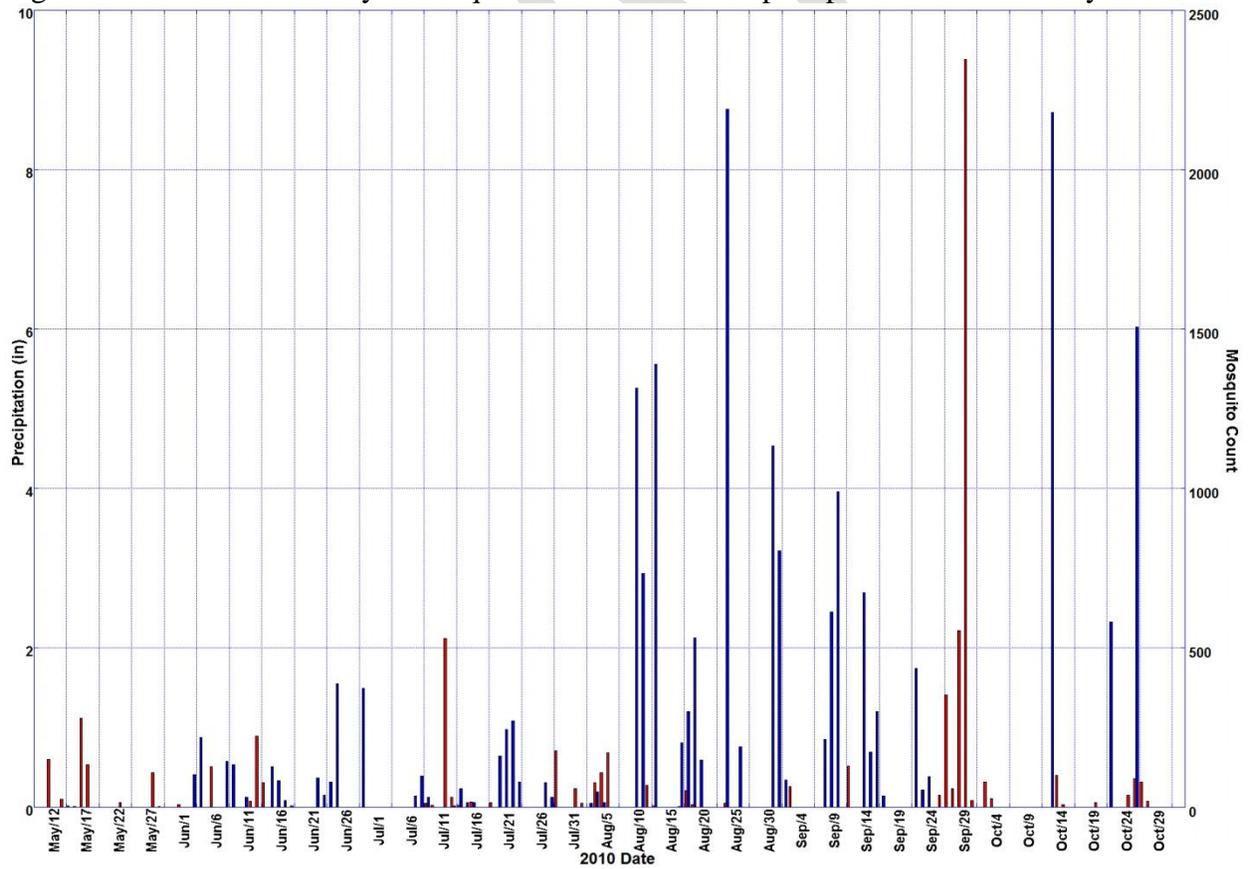


Fig. C6. Total mosquito counts and precipitation for the year 2010.

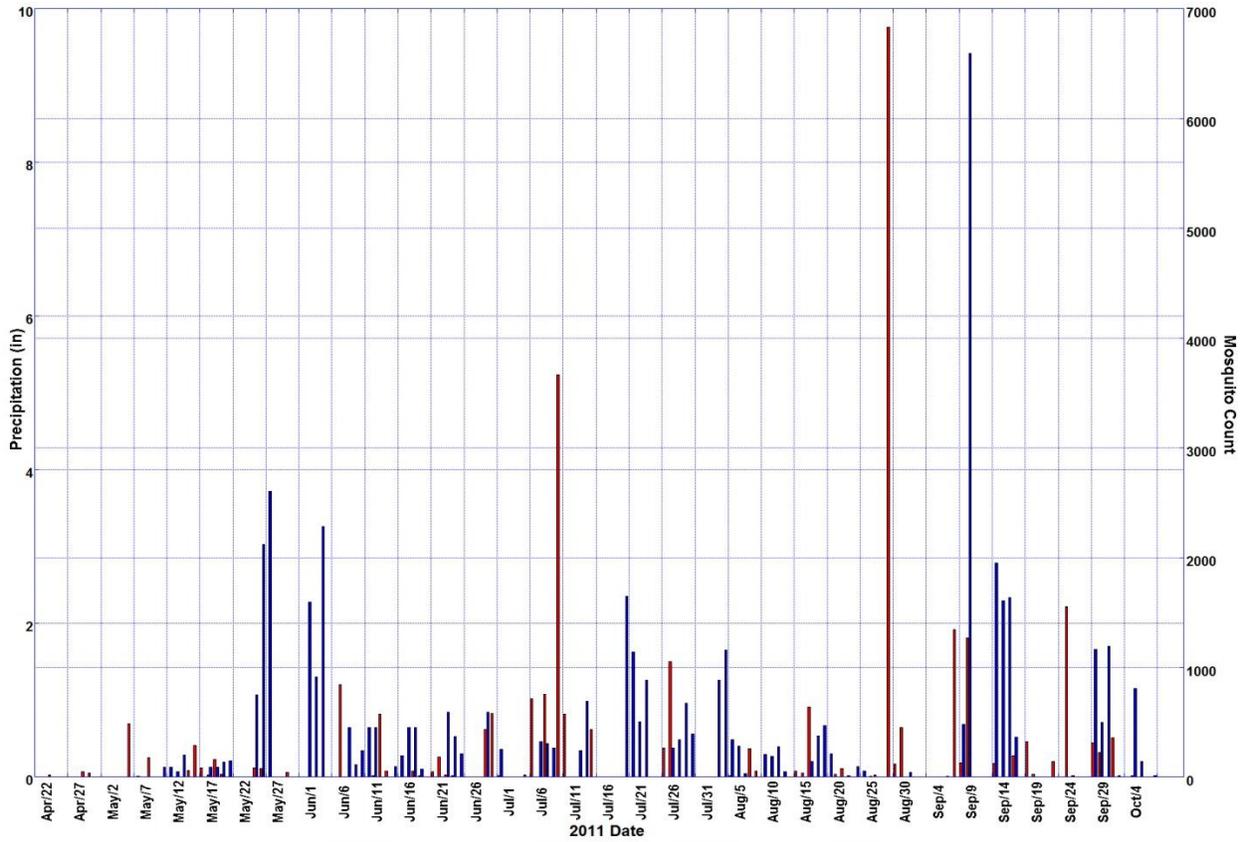


Fig. C7. Total mosquito counts and precipitation for the year 2011.

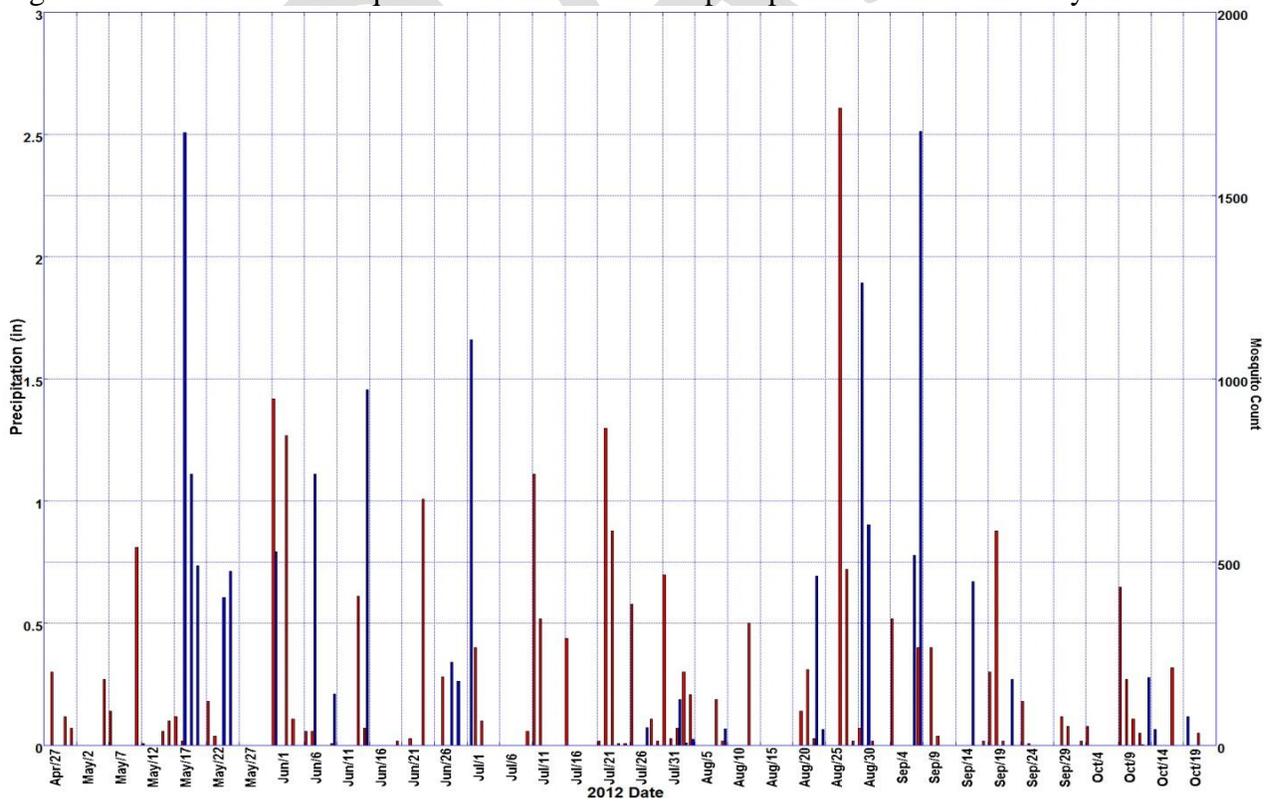


Fig. C8. Total mosquito counts and precipitation for the year 2012.

Appendix D: Daily average temperature for years 2005-2012. The black bars mark the mosquito count time period of each year.

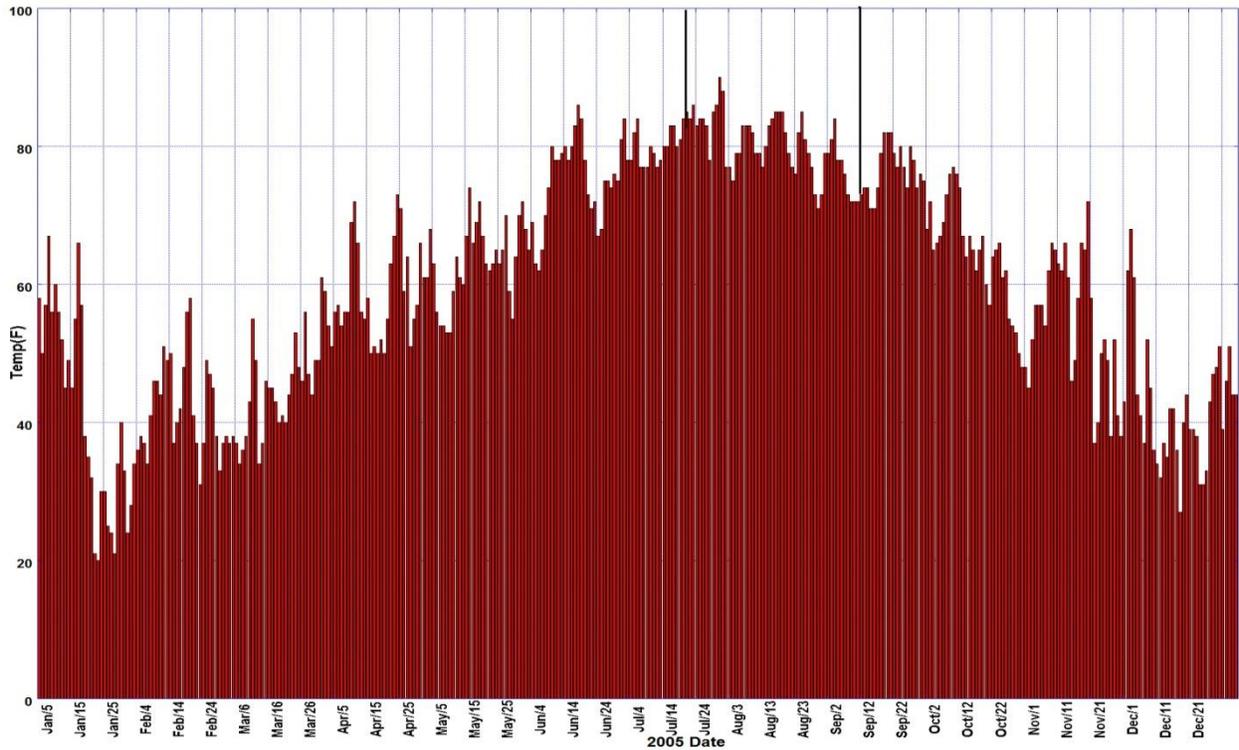


Fig. D1. Daily average temperature for 2005 with bars showing mosquito count interval.

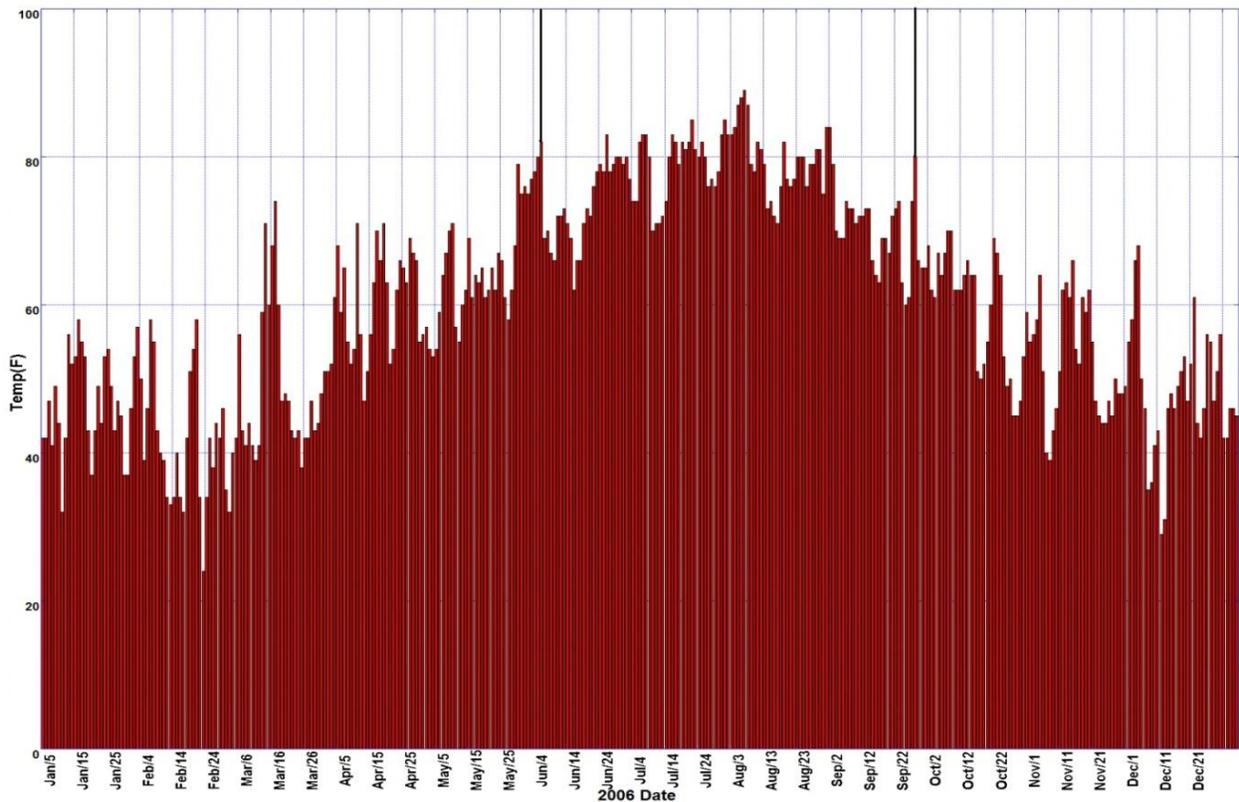


Fig. D2. Daily average temperature for 2006 with bars showing the mosquito count interval.

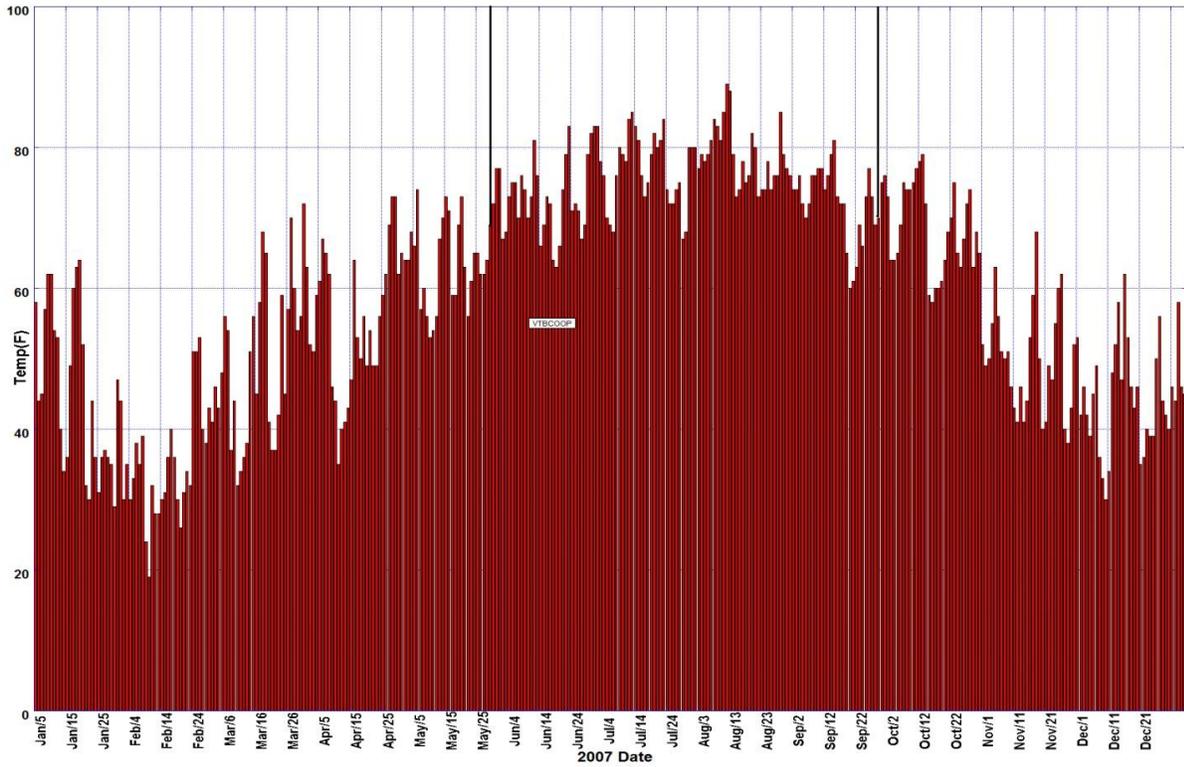


Fig. D3. Daily average temperature for 2007 with bars showing mosquito count interval.

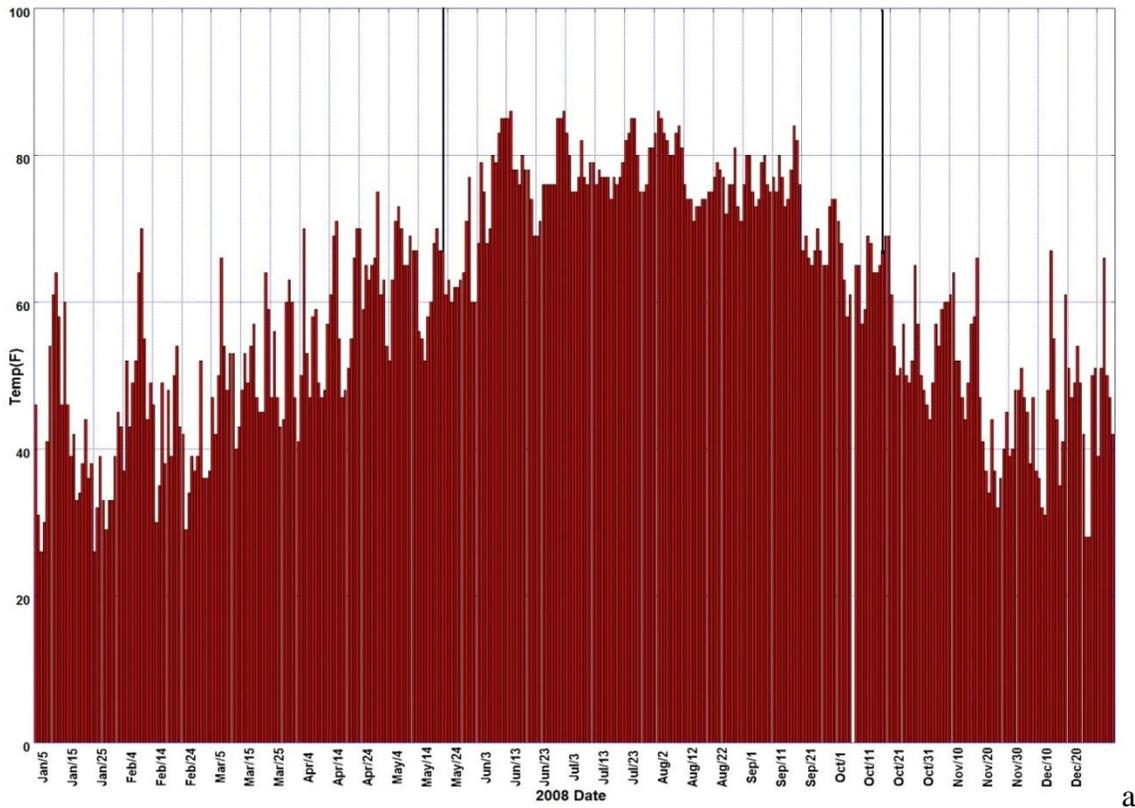


Fig. D4. Daily average temperature for 2008 with bars showing the mosquito count interval.

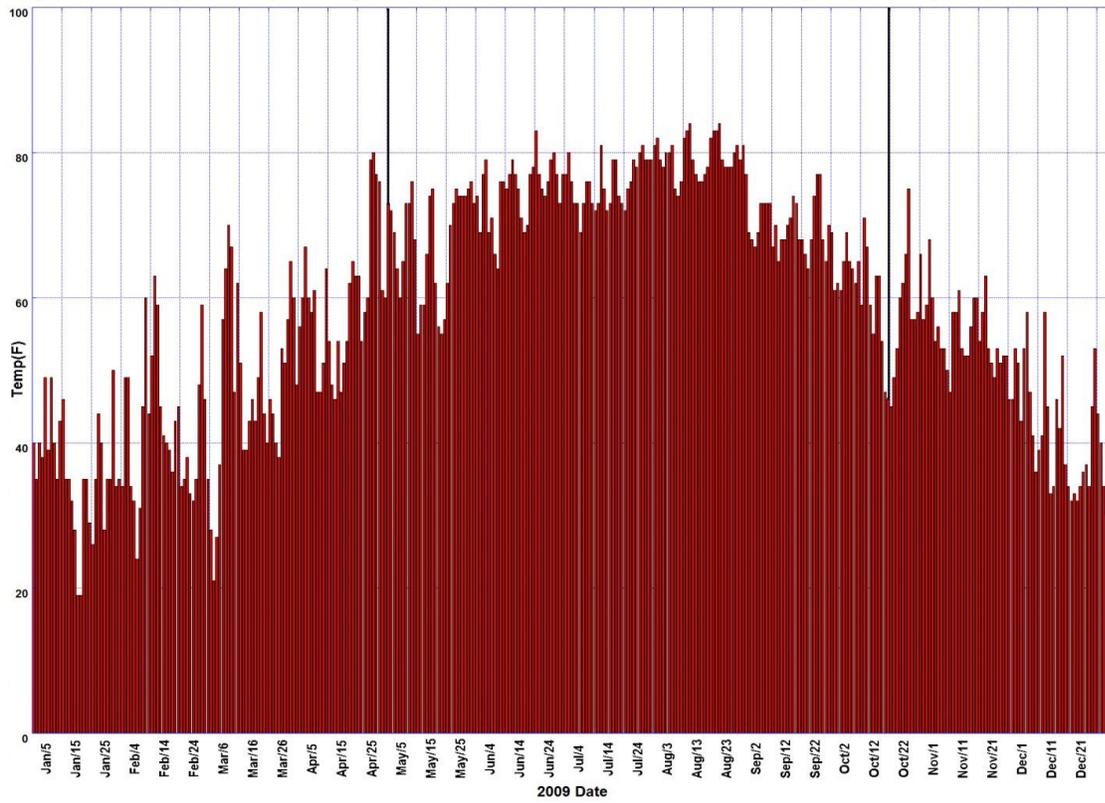


Fig. D5. Daily average temperature for 2009 with bars showing the mosquito count interval.

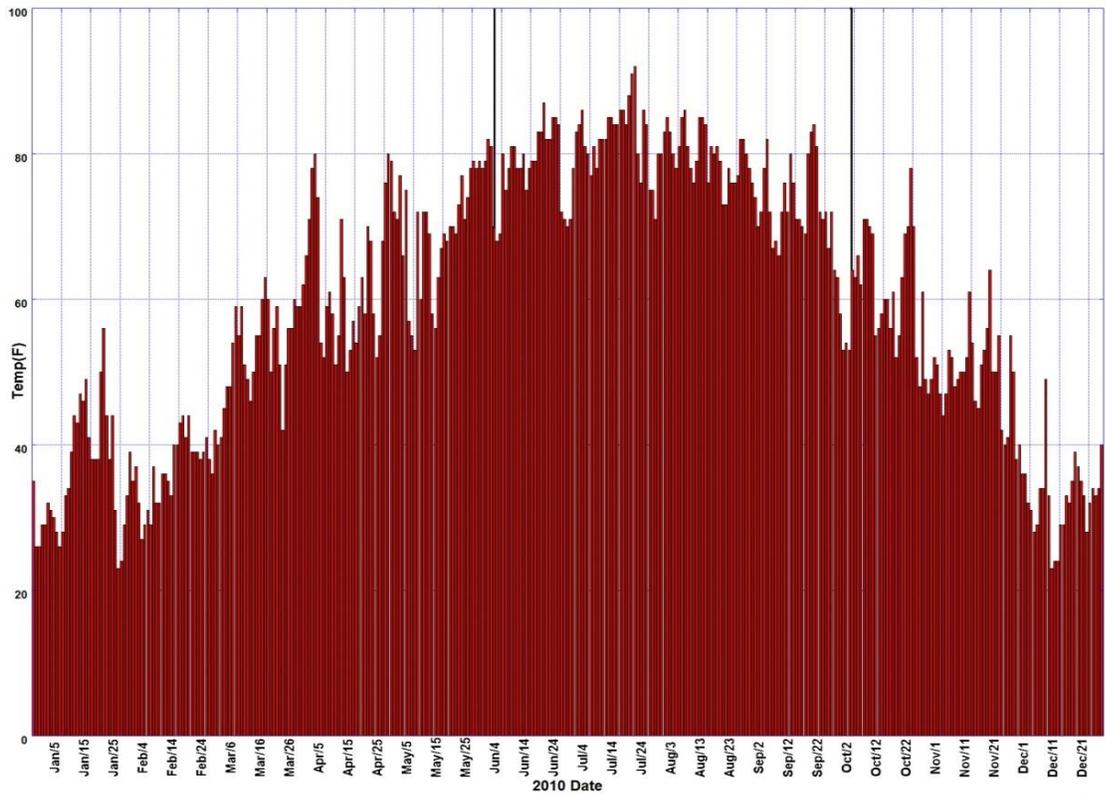


Fig. D6. Daily average temperature for 2010 with bars showing the mosquito count interval.

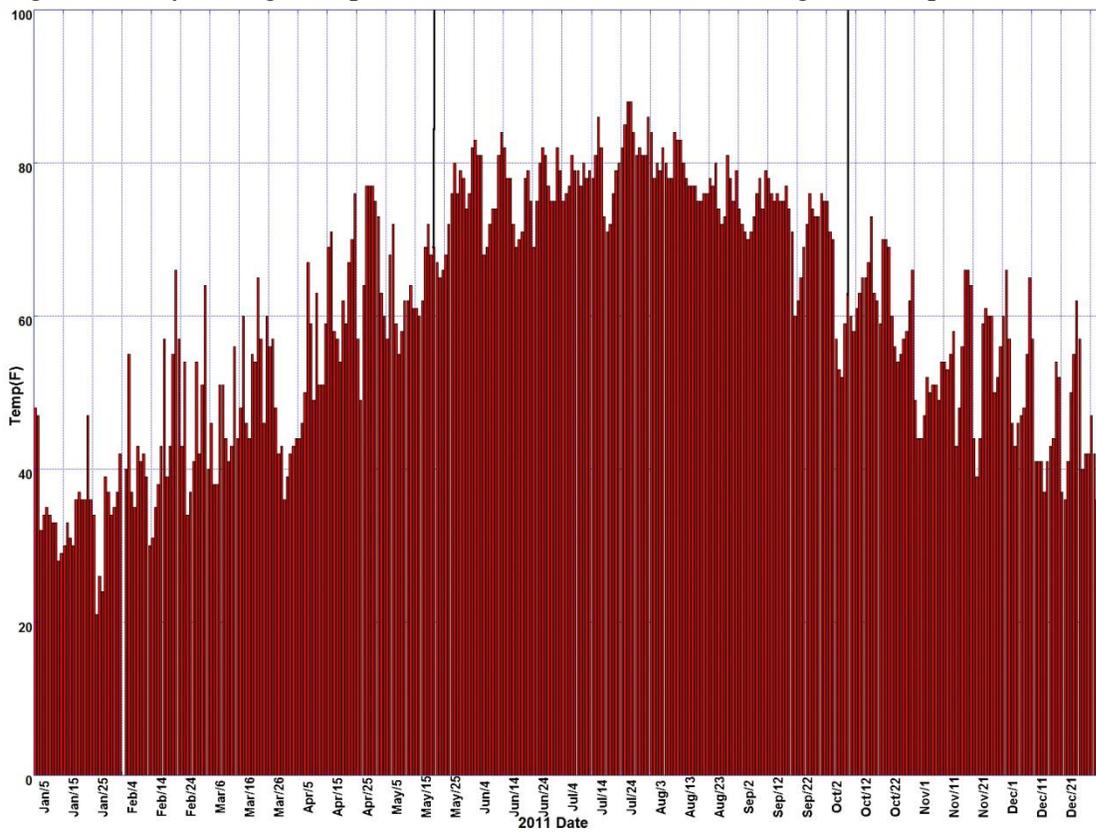


Fig. D7. Daily average temperature for 2011 with bars showing the mosquito count interval.

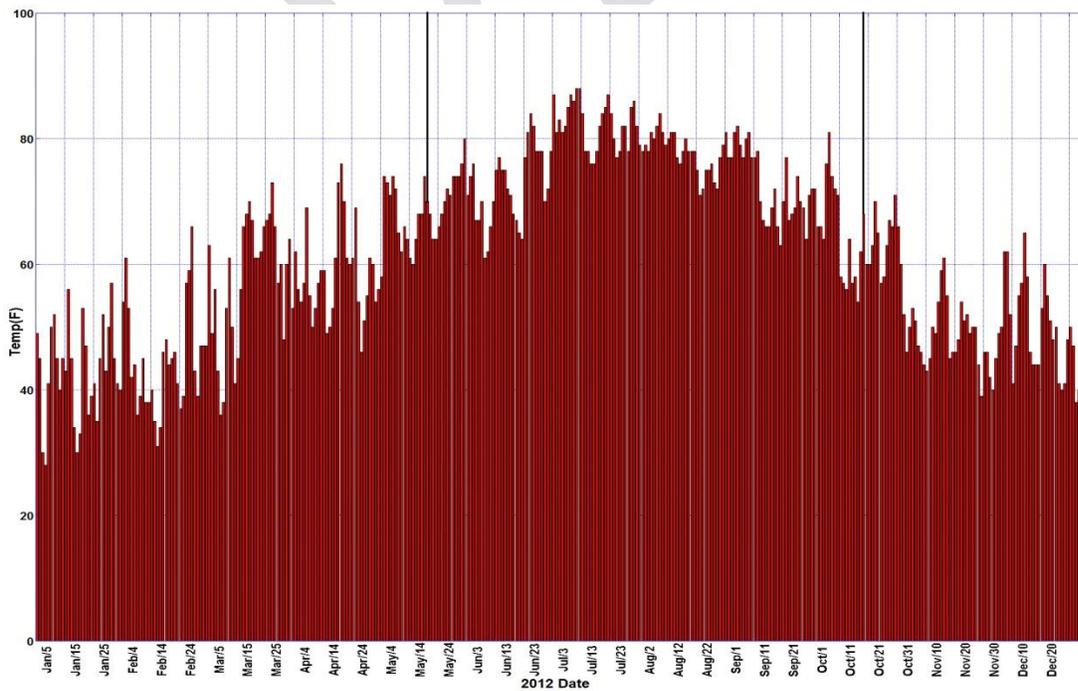


Fig. D8. Daily average temperature for 2012 with bars showing the mosquito count interval.