



Climate Change and Vector Borne Diseases on NASA Langley Research Center

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Abstract

Increasing global temperature, weather patterns with above average storm intensities, and higher sea levels have been identified as phenomena associated with global climate change. As a causal system, climate change could contribute to vector borne diseases in humans. The vectors of concern for this paper originate from the immediate vicinity of Langley Research Center (LaRC) such as insects including mosquitos and ticks that transmit disease that originate regionally, nationwide, or from outside the continent of the United States. The vector borne diseases of concern in Virginia include: Dengue Fever, West Nile virus, Eastern equine encephalitis, Ehrlichiosis (Rocky Mountain spotted tick fever), Malaria, and Lyme disease. Recognizing these changing conditions, vector borne diseases propagate under climate change conditions, and understanding the conditions in which they may exist or propagate presents opportunities for monitoring their progress and mitigating their potential impacts through communication, continued 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 risk in terrestrial space technologies, ground operations, and space technology research and development. This research addresses conditions which are attributed to climatic conditions which promote environmental conditions conducive to the increase of disease vectors. Included in this investigation is the evaluation of local mosquito population count and rainfall data for statistical correlation and identification of planning recommendations unique to LaRC and other NASA Centers to assess adaptation approaches and Center-level planning strategies.

I. Introduction and Background

Climate change may impact 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 may make conditions conducive to increased populations of insects or other disease carrying vectors. The cumulative effect of these environmental conditions may affect both the near and long term operation of NASA Langley Research Center (LaRC) potentially directly or indirectly, and consequently impact the capability to meet mission requirements.

This research investigation was initiated to help identify the conditions to be observed for an increase of disease vectors due to climate change and to create opportunity for recognition of those vectors as a risk to personnel. In support of this investigation, mosquito counts from Langley Air Force Base (AFB) were analyzed with National Oceanographic and Atmospheric Administration (NOAA) average monthly rainfall data to determine statistically if any correlation could be identified. Further, it is necessary to educate personnel concerning strategies that may reduce the risk of disease vectors.

Walther et al. identified that 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.⁽¹⁾ 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. U.S. average temperature has risen more than 2° F over the past 50 years and is projected to increase in the future. Precipitation has increased an average of about five percent over the past 50 years. Karl et al. indicated that projections of future precipitation generally indicate that northern areas will become wetter, and southern areas, particularly in the West, will become drier.⁽²⁾ Shifting ranges for disease vectors such as mosquitos, ticks and fleas, including their disease-causing pathogens may adversely impact wildlife.⁽³⁾

With any change in the climate, there are expected changes to environmental conditions that result in opportunities for emergence of insect populations, and concomitant emergence of harmful pathogens may occur. Outbreak events that have occurred recently requires continued observation which helps in understanding the propensity to the further spread of disease. These events should be continuously monitored including the pattern of infection. As an example, we note the outbreak that was identified for the West Nile Virus that occurred on the East Coast of the United States. In this case, the Center for Disease Control (CDC) identified that the vector for infection for the West Nile Virus was directly related to the culex mosquito. The culex mosquito has been noted to possess a short life cycle of several weeks, develops in the presence of water within a limited temperature range, and has a very limited flight range.⁽⁴⁾ Much of the mid-Atlantic, including Virginia was exposed to the virus after an

unusually mild winter and warm summer. It was noted that 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 resulted in a substantial human and economic impact.⁽⁴⁾ The virus moved across the United States, starting on the East Coast of the US in 1999 and reached the U.S. West Coast, Sacramento, California, in 2005. Barber et al. estimated that the expense of treating the disease, lost wages and expense of aerial spraying for one outbreak was estimated to be \$2.3 million.⁽⁵⁾ Based on the observations made in this case, continuous monitoring of disease outbreaks and the climatic condition in which they occur should help to reduce their impact by knowledge of their status and condition thus improving the posture for preparedness.

Another event that has been identified as an example for the spread of disease is shown in Figure 1 where the number of cases of dengue fever from 1995 to 2005 in the U.S was reported.⁽⁶⁾ Knowlton et al. found that two types of mosquitoes were capable of transmitting dengue fever can now be found in at least 28 states.⁽⁷⁾ Suggesting long-term trends as temperatures rise, it becomes necessary to understand the potential for transmission of dangerous diseases to other parts of the contiguous United States. At the same time, the specific types of mosquitoes that can transmit dengue fever have become established throughout 28 states and the District of Columbia, and across the south and mid-Atlantic regions. The establishment of mosquitos and the prescence of disease bench rests the opportunity for local disease transmission to LaRC personnel.

Even slight changes in climatic temperature can have a substantial impact on the presence of environmental conditions 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. addressed the variable influence of environmental conditions with the associated disease vectors, and is summarized in Table 1.⁽⁸⁾

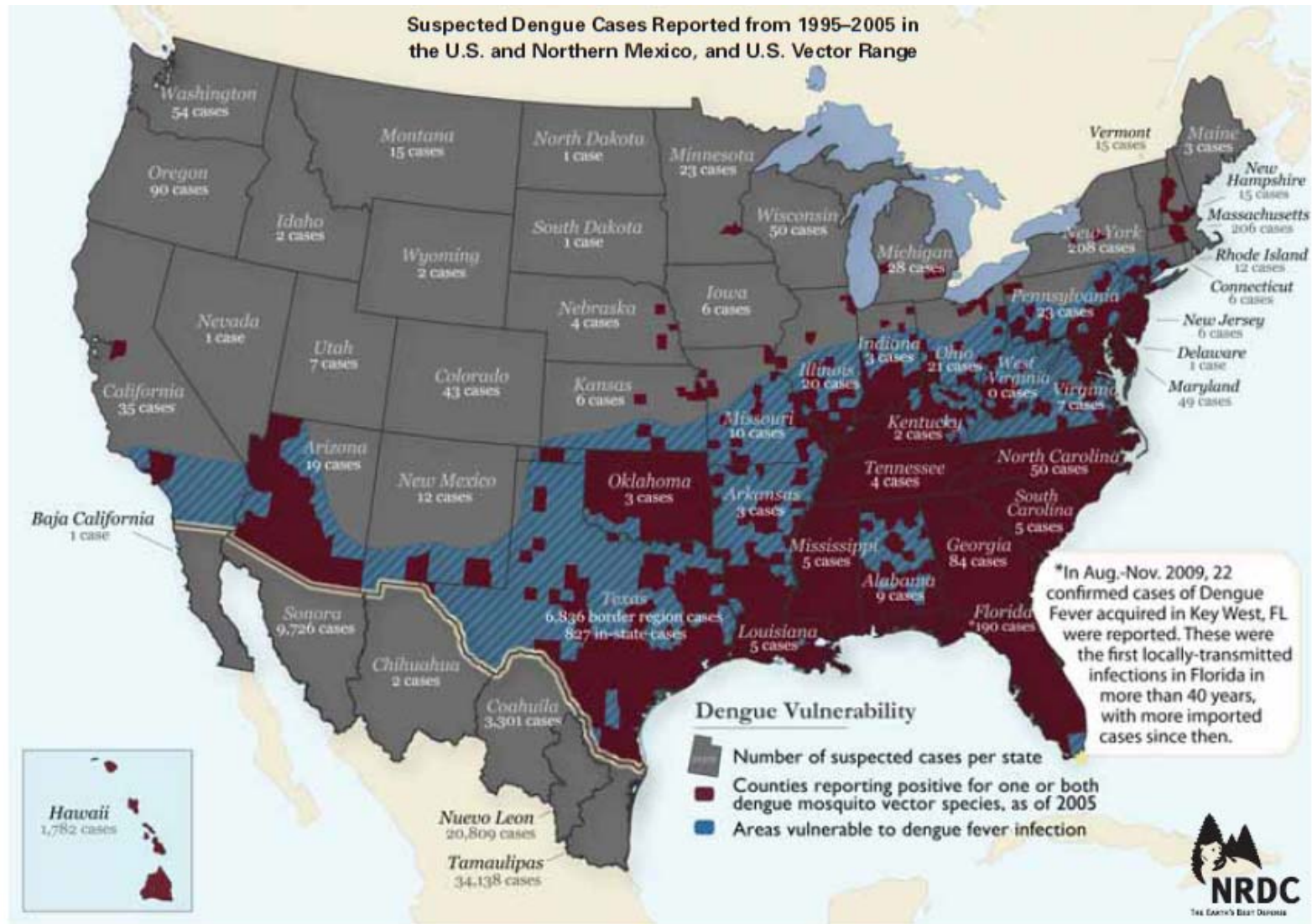


Figure 1. Dengue fever reported cases from 1985 to 2005 and the vector disease range in the U.S. Red areas have reported the presence of dengue fever mosquito species.(6)

Table 1 Selected examples of climatic factors influencing the transmission and distribution of vector borne diseases ⁽⁸⁾				
Disease	Vector	Climatic Factors	Effective Climatic variability or climate	Selected Notes on etiology
Parasitic vector borne diseases Malaria (<i>Plasmodium vivax</i> , <i>P. falciparum</i>)	Mosquitoes	Temp., rainfall, humidity, El Niño–related effects, sea surface temperatures	Disease distribution; pathogen development in vector; development, reproduction, activity, distribution, and abundance of vectors; transmission patterns and intensity; outbreak occurrence	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 development of the malaria parasite in the mosquito vector and the rate of development of the mosquito (and hence the number of potential mosquito generations per season and, therefore, vector abundance). <i>Plasmodium falciparum</i> transmission is limited by temperatures below 16°–19°C (61°– 66°F), whereas <i>P. vivax</i> development can occur at temperatures as low as 14.5°–15°C (58°–59°F). Malaria parasite development also cannot occur above temperatures of 33°–39°C (91°–102° F) for <i>P. falciparum</i> and <i>P. vivax</i>
Arboviral diseases Dengue fever (Dengue virus)	Mosquitoes	Temp., precipitation	Outbreaks, mosquito breeding, abundance, transmission intensity (extrinsic incubation period)	The northward reach of dengue, yellow fever, West Nile virus disease, and Chikungunya is not attributable to global changes in climate but rather to importation of the etiologic viruses into receptive ecosystems during times when local climate is favorable for their transmission.
West Nile virus disease (West Nile virus)	Mosquitoes	Temp., precipitation	Transmission rates, pathogen development in vector, distribution of disease and vector	
Tick-borne encephalitis (Tick-borne Encephalitis virus)	Ticks	Temp., precipitation, humidity	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
Bacterial and rickettsial diseases Lyme borreliosis (<i>Borrelia burgdorferi</i> , <i>B. garinii</i> , <i>B. afzelii</i> , or other related <i>Borrelia</i>)	Ticks	Temp., precipitation, humidity	Frequency of cases, phenology of host-seeking by vector, vector distribution	
Human granulocytic anaplasmosis (<i>Anaplasma hagiccytophilum</i>)	Ticks	Temp., precipitation	Vector distribution, phenology of host-seeking by vector	
Human monocytic ehrlichiosis (<i>Ehrlichia chafeensis</i>)	Ticks	Temp., precipitation	Phenology of host-seeking by vector	
Plague (<i>Yersinia pestis</i>)	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 [95°F] and 32°C [90°F] in the Arizona and New Mexico models, respectively) was inversely correlated with human case numbers and it was suggested that high temperatures might adversely affect flea survival or transmission of <i>Y. pestis</i> by fleas. Parmenter proposed a trophic cascade model to explain the positive effect of precipitation on the frequency of human plague. According to this model, increased rainfall in this semi-arid region leads to enhanced availability of rodent food sources and heightened rodent reproduction, factors that are likely to increase risk of plague epizootics among rodents and the spread of the disease to humans.

Gage, et.al. 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.⁽⁸⁾

The challenging nature of the effects of climate change on disease vectors was noted based on an analysis performed as a part of this investigation as it relates to local rainfall and mosquito count data for Hampton, Virginia and Langley AFB.

To aid in the elimination or reduction of impacts from 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 information sources such as:

- Hampton, Virginia (<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.

These programs serve to provide early warning on the emergence of vector borne disease. With global trade and travel, disease flare-ups in any part of the world can potentially reach the United States and vice versa.⁽¹⁰⁾ As the world gets closer to LaRC 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.⁽¹¹⁾

The spread of vector disease in the United States and Virginia has occurred recently and ongoing activities are engaged for monitoring the spread of disease. Prior to 1999, there was no mosquito-borne virus in the U.S. that caused mortality in birds in such high numbers as West Nile virus. Since the introduction of West Nile into the United States, the monitoring activities used in many states include testing dead birds for the presence of the virus.⁽¹²⁾ Continued reporting of disease outbreaks in humans and the environment, public awareness campaigns, and individual responsibility to remain informed help avert further spread of disease.

The Commonwealth of Virginia, Department of Health (VDH) monitors vector borne diseases and alerts the public when new outbreaks occur. Based on discussion with the VDH⁽¹¹⁾, the following information was gathered:

- The Gulf Coast tick, Asian tiger mosquito, and the Lone Star tick have been identified as pests that should be closely monitored in Virginia.
- 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.
- Movements of insects cannot be fully or solely attributed to climatic conditions. More study is needed on climate change impacts effecting migration.⁽¹³⁾

II. Climate Change and Langley Disease Vectors

Langley Air Force Base (AFB) has maintained counts of summer mosquito populations in the Langley area from 2005 to the present.⁽¹⁴⁾ The data includes the trap type, date, mosquito count, and mosquito classification. 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.

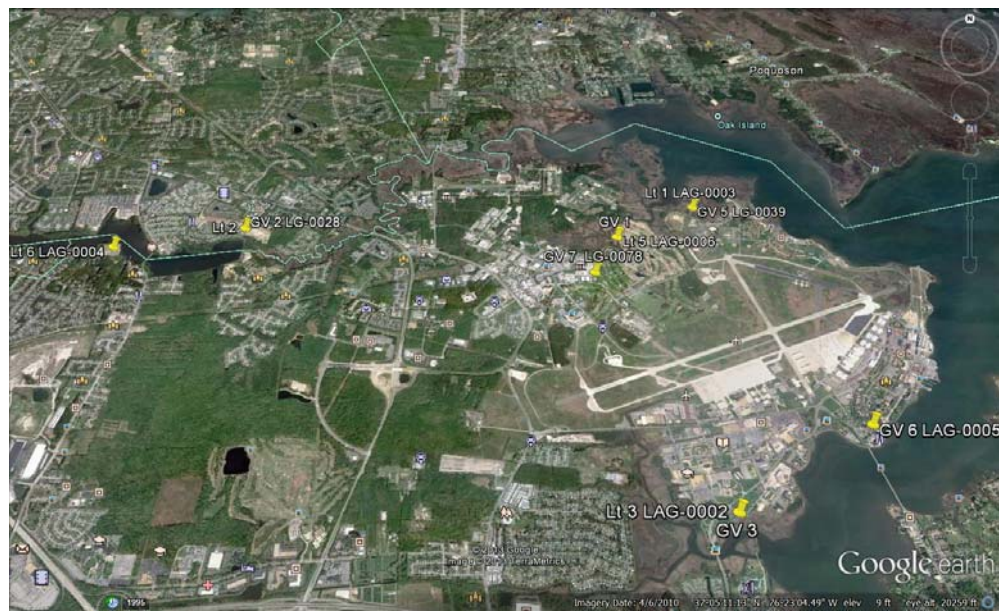


Figure 2. Langley Air Force Base Mosquito Trap Locations

The mosquito count data was evaluated for location versus total mosquito count data for the trap locations for the years 2005 to 2012. It was noted that the trap Lt-1 had the highest total counts for all the years recorded while location trap GV-1 exhibited the least counts. Trap Lt-1 is an unpopulated marsh area whereas GV-1 is located near a more populated area of Langley AFB.

Studies have been performed which indicate that heavy rainfall data does have a correlation to incidence of dengue fever.⁽¹⁵⁾⁽¹⁶⁾ To evaluate the potential impact of precipitation on mosquito populations at LaRC, the National Oceanographic and Atmospheric Administration (NOAA) total average monthly precipitation for Hampton, Virginia, and the total monthly mosquito counts were evaluated for the period from 2005 to 2012, and during the months of May to October.

The mosquito count and rainfall data were analyzed statistically on an annual basis using correlation and regression techniques for the period from 2005 to 2012. No significant statistical relation could be ascertained for this limited set of data for annual counts. An analysis was then conducted on a monthly average of mosquito counts and corresponding average monthly precipitation. A trend was found for years 2007-2012 as shown in the Figure 3. The data suggests that over a long period of time there is a correlation between mosquito counts and precipitation.

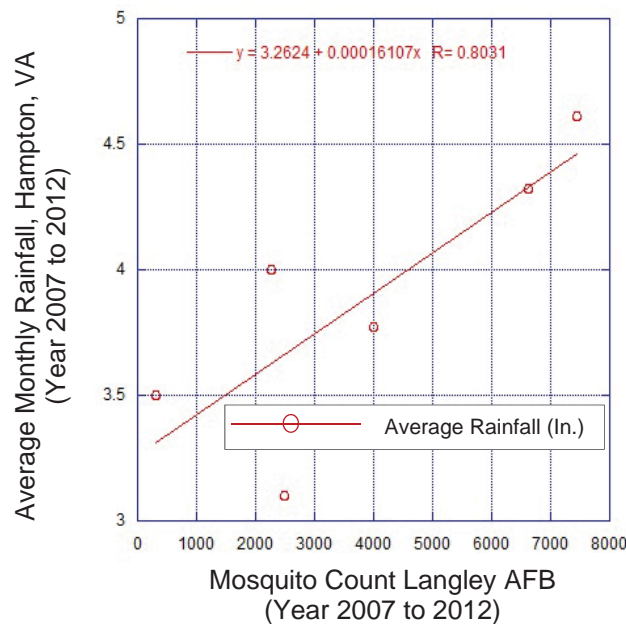


Figure 3. Trend of Mosquito Count versus Average Monthly Rainfall, Year 2007 to 2012

The results of the analysis suggest a correlation between increased rainfall and increased mosquito population for local conditions at Langley AFB. The strength of the analysis would be greater if there were more frequent sampling of mosquito counts (daily or weekly) and daily rainfall data were used. It was also recognized that additional information should be factored into future research including: mosquito spraying times

that occurs at Langley AFB, weather data to include pan evaporation data, and the number with optimum mosquito temperature days in the range of 75° F to 85° F. In addition, it is suggested that a predictive capability be used in future research using a mechanistic approach similar to the model developed by Tran et al. for the Asian tiger mosquito *Aedes (Stegomyia) albopictus* (Skuse) (Diptera: Culicidae)⁽¹⁷⁾ or by Gong et al. where mosquito population dynamics are driven by major environmental factors including temperature, rainfall, evaporation and photoperiod.⁽¹⁸⁾ The use of a predictive model would help to optimize mosquito spraying for their control.

Notwithstanding the statistical analysis performed, it is generally recognized that with increased rainfall, warming trends and low evaporation, the population of mosquitos increases with opportunities for vector born disease to flourish within warm blooded mammals. Gage, et al. indicated that prediction of the relative impact of sustained climate change on vector borne diseases is difficult and requires long-term studies that look not only at the effects of climate change but also at the contributions of other agents of global change such as increased trade and travel, demographic shifts, changes in land use, water availability, and other issues.⁽⁸⁾

Although mosquitos play a significant role in the spread of diseases, ticks also contribute to its spread. 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. These three conditions are: humidity, temperature, and availability of blood.⁽¹⁹⁾ Levia, et al. identified that Lyme disease cases have increased enormously (380% increase in Minnesota, 280% in Wisconsin, and 1,300% in Virginia from 1997 to 2007) and presented a theoretical model that illustrates how reductions in small-mammal predators can sharply increase Lyme disease risk. Deer and Lyme incidence however were uniquely positively correlated in Virginia.⁽²⁰⁾

Tick habitat includes the edge of leaves, tree branches, grass, or anything that can be used to elevate them. Then they latch onto any creature walking by using their front legs. After that, some ticks may attach instantly to the closest available skin, and some wander to an ideal spot where they become difficult to detect.⁽²¹⁾

When considering an expansion of the pedestrian walk paths at LaRC, into or adjacent to the woods, the paths should be wide enough that individuals walking on them would not have to be in contact with the foliage. Ticks are likely to position themselves on grass and leaves so that they can latch onto those passing. The trees or other foilage that are located along the path should be trimmed to the point where it cannot come in contact with the individual.

III. Mitigation of Vector Risks

The risk of personnel becoming sick from diseased vector sources such as mosquitos and ticks is likely to increase in the future. Mitigation of the vector risks therefore is of primary importance, with prevention being the first line of defense. Under

these circumstances, the goal is that facility and program design account for these risks, from the design of walking paths to schedules for spraying for mosquitos. In addition, all personnel should remain vigilant with respect to vector borne diseases and take the necessary precautions to protect their health. Personnel represent the highest value asset to NASA, and their continued good health remains significant to the overall success of the NASA mission.

Informing personnel of the importance and techniques to mitigate vector risks include the reduction or elimination of conditions which promote the increase of these vectors, such as:

- Assuring good positive drainage around facilities, buildings, drainageways, or grassed areas where ponding or pooling of water can be reduced or eliminated,
- When outdoors wearing long sleeved clothing, tucking in clothing, applying appropriate insect repellents, and doing tick checks frequently,
- Wearing netting when required to work in moquito infested areas,
- Maintaining clear cut areas, avoid high grass areas, and stay on paths,
- Reporting unusual bird death,
- Reporting any health related problems from tick or mosquito bites. Carefully removing and saving the tick, if possible, and bringing the tick to the attending physician, and
- Continuing local monitoring of mosquitos and precipitation so as to apply the increased data frequency to mechanistic models for use in determining optimum mosquito spray times.

Recognizing that the public health activities will focus on adaptation through reducing harm from the effects of climate change⁽²²⁾, the planning recommendations of Interagency Climate Change Adaptation Task Force⁽²³⁾ could be followed to mitigate the consequences from changing environmental conditions. These planning activities include:

- Applying constructive preventive measures to missions and operations:
Considering what exposures personnel will have during the conduct of their work. Addressing need for personnel to monitor their habits and environment so as to be aware of their potential for disease exposure. Using effective deer population control.
- Developing, prioritizing, and implementing actions:
Emphasizing to personnel how to protect themselves from exposure to insects, and be knowledgeable of the current conditions in the field and while walking on grassed or wooded areas.
- Evaluating and learning:
Recognizing that there are monitoring activities ongoing within the Langley AFB, and obtaining information from valued news sources, and other published sources about the insect population and disease occurrence.

- Building awareness and skills:
Being 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
(24)
Taking the information home and sharing with family and friends.

IV. Conclusions

Recognizing that changing climate conditions may impact NASA LaRC needs to encourage personnel to change their behaviour including how we protect ourselves from disease vectors such as ticks and moquitos. Changing climatic conditions resulting in increased precipitation and warming trends may lead to an increase in mosquito and tick populations assuming land use and other factors remain constant. Additional monitoring of local mosquito counts would help greatly in modeling and facilitate prediction of mosquito populations. Future research involving mechanistic modeling that includes this increased data frequency should help to optimize spraying for mosquito control.

Mosquito and tick populations are often difficult to predict, but they are anticipated to increase in environments where wetter and warmer climate conditions prevail. Outdoor activities at LaRC could increase opportunities for employees to be in more direct contact with diseased pests. This includes awareness that the local deer population could represent a hazard in the form of improving the availability of food source for ticks as vectors for disease. Thus efforts to monitor and contain the deer population should be considered.

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 travel outside 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 plants. 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. 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.

Individuals must be aware of the hazards for disease carrying pests and must continually educate themselves and others of the potential hazards that exist. Health officials and personnel should continue to monitor for local and regional health concerns

and maintain awareness of any trends that express opportunities for emergence of disease.

The NASA Climate Adaptation Science Investigators (CASI) Workgroup was formulated to assist in the development of climate adaptation strategies for NASA as whole and for individual Research Centers such as LaRC.⁽²⁵⁾ The continuation of the work by the NASA CASI should result in continued positive benefits and protection of NASA personnel through continued research and implementation of activities that incur sustainability goals within the framework of continual change in the climate.

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14. ABSTRACT Increasing global temperature, weather patterns with above average storm intensities, and higher sea levels have been identified as phenomena associated with global climate change. As a causal system, climate change could contribute to vector borne diseases in humans. Vectors of concern originate from the vicinity of Langley Research Center include mosquitos and ticks that transmit disease that originate regionally, nationwide, or from outside the US. Recognizing changing conditions, vector borne diseases propagate under climate change conditions, and understanding the conditions in which they may exist or propagate, presents opportunities for monitoring their progress and mitigating their potential impacts through communication, continued monitoring, and adaptation. 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 risk in terrestrial space technologies, ground operations, and space research. This research addresses conditions which are attributed to climatic conditions which promote environmental conditions conducive to the increase of disease vectors. This investigation includes evaluation of local mosquito population count and rainfall data for statistical correlation and identification of planning recommendations unique to LaRC, other NASA Centers to assess adaptation approaches, Center-level planning strategies.					
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