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Assessing the Risk of West Nile Virus on the Age 65 and Older Population Segments in Fort Collins, Colorado

Richard Cornell
University of Denver

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Abstract

West Nile virus (WNV) is an arbovirus whose more severe, neurologic symptoms may include seizures, paralysis, or coma. Despite a variety of possible symptoms, most people do not realize they are infected with the virus with a majority of those infected not developing any symptoms. Members of the population aged 65 and older naturally experience reduced immunity to viruses as they get older. Exposure to West Nile virus can occur around one's home, in a park, natural area, alongside a source of water, or even walking along a trail. Areas exist around town that present risks of being infected or encountering large numbers of mosquitoes, which may present future infectious risk.

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ABSTRACT

West Nile virus (WNV) is an arbovirus whose more severe, neurologic symptoms may include seizures, paralysis, or coma. Despite a variety of possible symptoms, most people do not realize they are infected with the virus with a majority of those infected not developing any symptoms. Members of the population aged 65 and older naturally experience reduced immunity to viruses as they get older. Exposure to West Nile virus can occur around one's home, in a park, natural area, alongside a source of water, or even walking along a trail. Areas exist around town that present risks of being infected or encountering large numbers of mosquitoes, which may present future infectious risk.

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INTRODUCTION

West Nile virus (WNV) is an arbovirus first identified in 1937 in the West Nile subregion within the African nation of Uganda (Smithburn et al. 1940). The virus can cause moderate symptoms like body aches, rash, and/or vomiting. Severe symptoms may include neuroinvasive diseases like brain inflammation (encephalitis), tissue inflammation around the brain and spinal cord (meningitis), or neurologic symptoms like seizures, paralysis, or coma. Despite the variety of possible symptoms, most people do not realize if they are infected with the virus, 70-80% of those infected do not develop any symptoms (Centers for Disease Control and Prevention 2013).

Transmitted by mosquitoes, the virus now prevails almost entirely around the globe—South America being the least affected continent. The first recorded instance in North America occurred in 1999, in New York City (Centers for Disease Control and Prevention 1999). Within five years, WNV spread across the continental United States, Canada, Latin America, and the Caribbean islands. The year 2012 saw one of the worst outbreaks when 286 people died nationwide from the virus. The state of Texas suffered immensely with almost one-third of all deaths occurring there (Allison Bradshaw 2013).

In the state of Colorado, specifically within the county of Larimer, no deaths were reported; however, eight human disease cases were recorded (Centers for Disease Control and Prevention 2013). In 2003, however, the state became a focal point, accounting for almost 30% of the country's reported WNV infections (Patnaik 2006). Patnaik's follow-up study illustrated West Nile infection during that epidemic caused considerable, long-lasting illness and led to substantial economic impact concerning healthcare and missed work.

Older population segments (generally regarded as age 50 and older) of people tend to be more responsive to the virus, with the likelihood of the severity of symptoms increasing with age (Healthwise 2013). This revelation has become somewhat of a concern in the city of Fort Collins, located in Larimer County. Fort Collins has become a popular destination for retirees. According to the 2012 U.S. Census data, the 50 and older age group saw a 6.3% increase between 2010 and 2012 (U.S. Census Bureau 2013). Census forecasts predict that number to increase to 20.3% by 2017.

No distinct environmental factors singularly associate with West Nile virus. Land cover, weather, number of mosquitoes, number of birds acting as hosts, and human behavior all influence the potential virus prevalence. A connection exists between land cover to areal distributions of the virus, although the exact nature of the connection is still unclear. Wetlands have been the focus of several research studies to determine any correlation with the mosquito-borne virus. Distance also can be an unclear factor since transportation of the virus may cover many miles by the infected birds (Brownstein et al. 2002, Allen and Wong 2006).

The mosquito species, *Culex pipiens*, acts as one of the principal carriers of the virus. Interestingly, this species does not prefer to dwell among wetlands. Rather, they prefer urban and human-created settings. These settings may encompass birdbaths, gutters, and lagoons. The other mosquito species common in the Fort Collins area, *Culex tarsalis*, prefers to breed in clean water sources like healthy wetlands (Pratt and Moore 1993, U.S. Environmental Protection Agency 2004). Temporally identifying when, as well as where, these species exist aids in comparing their impacts on the virus.

Since West Nile virus has been locally popular, within the past several years, in public discussions of possible impact areas and associated spraying treatments, private and public agencies have performed diverse methods of spatial analysis. Government officials, from multiple levels, have attempted various means of presenting the dangers of the virus to the public. Despite these efforts, public awareness of West Nile virus has experienced limited and mixed results.

This research study, cursory in nature, focuses on whether West Nile virus poses a threat for the older population segments (age 65 and older). More specifically, this research identifies the areas where they live, outdoor areas they may frequent, as well as possible weather conditions favorable for increased virus activity. The study area is limited to the city of Fort Collins and focuses on two mosquito species (*Culex pipiens* & *Culex tarsalis*), based on available mosquito collection data and known linkage to the virus. However, the analytic methods discussed here allow for easy modification and employment for larger geographic areas.

The four questions this study attempts to be answer are:

1. Is West Nile virus (and/or its vectors) uniformly distributed throughout the City of Fort Collins, CO?
2. In what areas of the city do the older populations reside and frequently recreate?
3. Is there a spatial correlation between weather conditions and West Nile virus?
4. What, if any, areas of the city and/or weather conditions present the most risk for the older population segments?

LITERATURE REVIEW

A plethora of West Nile virus-related research studies and data collected in the field exist on the Internet, typically represented in the form of maps. The Centers for Disease Control and Prevention (CDC) aggregates all of the collected data received from each state. Based on this data, the U.S. Geological Survey provides maps pertaining to humans, birds, and mosquitoes; as well as in sentinel (animals kept in

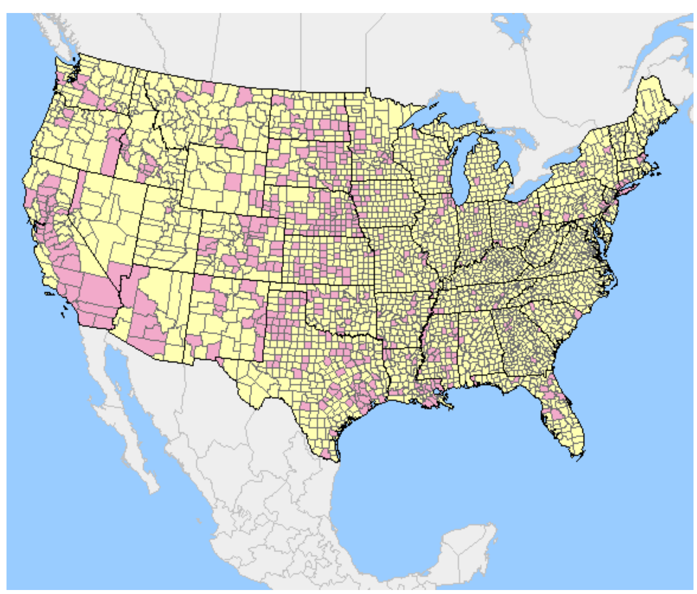


Figure 1. 2014 Cumulative West Nile Virus Data for Humans in the United States at the county level (U.S. Geological Survey, 2015).

a known location, e.g. chickens and horses), and veterinary (non-human clinical) cases (U.S. Geological Survey 2015). Figure 1 shows the cumulative human data from 2014.

Specific knowledge of the virus continues to expand with plentiful ongoing research. In spite of the increased knowledge, one aspect of the virus continues to elude explanation—the origin of the virus. Despite the virus's transmission cycle being widely acknowledged (see Figure 2), whether the pathogen originates in a mosquito or a bird is unknown. Those two carriers seemingly play a game similar to that of the children's game of tag—passing the pathogen back and forth. Fortunately, humans and horses differ from them and are considered "dead-end hosts"; that is, they can only receive the virus and not transmit it to another animal.

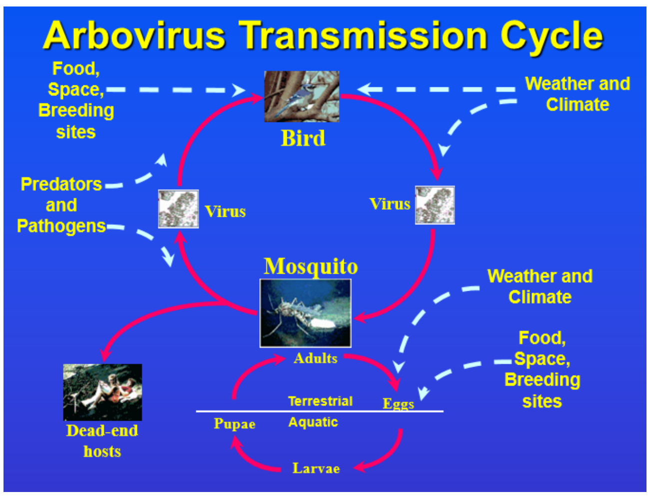


Figure 2. Typical arbovirus, like West Nile virus, transmission cycle (Dr. Chester Moore, 2014).

Another nugget of WNV knowledge, but is being expanded upon, focuses on how land cover types may influence the presence of mosquitoes. Multitudes of studies have performed examinations of relationships between land cover and the West Nile virus. One study found no significant correlation between wetland areas and mosquito density (Ezenwa et al.

2007); however, a trend observed increasing mosquito density together with increasing wetland area. Human-altered landscapes appear to be favorable for the transmission of the virus.

General research has explored weather conditions and their relationship to West Nile virus. One study focused on the impact of WNV transmission to humans (Soverow 2009). Warmer temperatures, increased humidity, and heavy precipitation increased the infection rate. Assessments of human WNV cases and weather measurements between 2001 and 2005 contributed to these results.

However, regardless of weather conditions influence, research indicates only a small number of bird species act as hosts. Within a localized area, one or two mosquito species are the troublemakers and only a few bird species participate in the transmission cycle (Stephens 2011). One such species is the American Robin, abundant year round throughout the continental United States. All the same, the robin's abundance does not appear to be the major factor in the spreading of the virus; rather, it is their peculiar feeding habits.

The transmittal process is but one aspect in the concern for battling WNV. Combating the virus at the receiving end of the process is of more concern that is public. The virus does not affect all persons in the same way. More specifically, not everyone is as susceptible. Several studies have explored how the virus affects people of different ages.

The virus affects all ages; although, those 50 years old and older generally experience higher incidence levels of the more severe neuroinvasive disease symptoms. In fact, ArboNET, the arboviral surveillance system managed by the Centers for Disease Control and Prevention (CDC), has found a positive relationship between age groups and WNV-related neuroinvasive disease incidence levels (see Figure 3). Data on less severe cases is limitedly available since few states report them to the CDC.

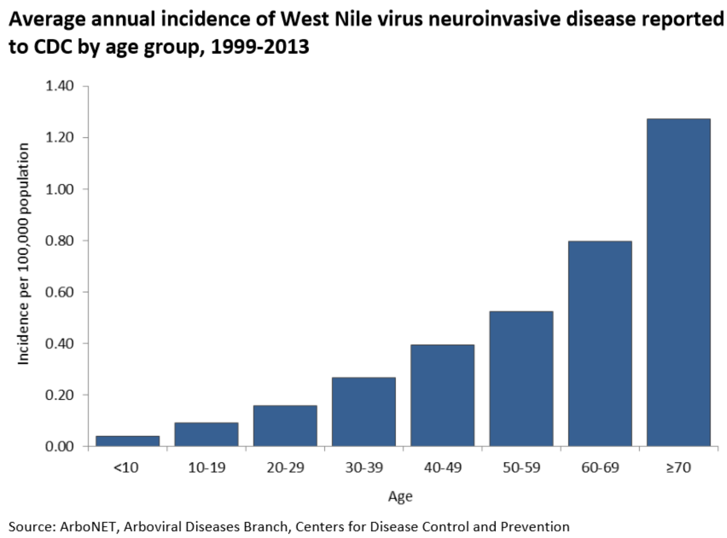


Figure 3. West Nile virus incidence levels by age group.

The CDC received 2,469 WNV cases in 2013. Of those, 51% (1,267) involved neuroinvasive cases. The median age of the afflicted was 55 years old. Recorded neuroinvasive cases, connecting to WNV, increased with age. The highest number of cases included those people 70 years old and older (Lindsay et al. 2014).

DESIGN AND IMPLEMENTATION

Study Area

The city of Fort Collins, nestled along the Northern Colorado foothills (see Figure 4) provides an opportune study area for the impact of West Nile virus based on the existing mosquito collection process and the increasing population of residents over the age of 65. Colorado State University's Department of Microbiology, Immunology, and Pathology (CSU/DMIP) and statewide-based Colorado Mosquito Control, Inc. (CMC) maintain mosquito traps around the city and conduct weekly surveys on behalf of the City of Fort Collins. This data is publicly available and provides a strong foundation for spatial analysis covering the city limits.

Figure 4. Location of Fort Collins, Colorado.

With numerous honors and recognition from Forbes magazine and CNNMoney.com (among others), Fort Collins has enjoyed significant increases among the older age groups. Coupled with many opportunities to spend time recreating or simply relaxing outdoors, this area provides favorable conditions to explore not only where the virus presents potential high-risk areas, but also how older generations may be affected.

Methods

The framework for attempting to answer the research questions consists of four components: mosquito/West Nile virus distribution, human-related, weather, and (potential) at risk areas/weather conditions. Mosquito/West Nile virus distribution deals with the areas where mosquitoes are abundant (or not) and which areas represent the highest estimated representation of virus infection.

The human-related aspect looks at where the desired population segment lives and potentially recreates outdoors. Weather provides the third component to understand what the existing conditions during the trapping of the mosquitoes. Finally, what outdoor areas may present risk to mosquito abundance and increased viral infection, as well as what weather conditions may present possible increased mosquito-related risks.

Since 2006, the CMC has managed mosquito traps across the city. Currently, weekly surveys and maintenance occur on 43 CO_2-baited light traps and 9 CDC gravid traps during the mosquito season (June – September). Four of the sites contain both trap methods. CO_2-baited light traps selectively collect female mosquitoes attracted by CO_2, which simulates respiratory gases of birds or mammals. Gravid traps selectively collect female mosquitoes ready to lay eggs ("gravid") based on a water source and fan-induced suction. Overall, the distributed traps present a nice coverage across a significant majority of the city (see Figure 5).

The surveys consist of data representing mosquito species and sex, number of mosquitoes collected (aggregated in pools of up to 50 females), number of pools tested positive with the virus, trap ID, the method of how the mosquitoes were trapped, and survey date. The collected mosquitoes are sent to the Arthropod-Borne & Infectious Diseases Laboratory (AIDL) at CSU/DMIP to for tests on the presence of West Nile virus RNA. The AIDL then furnishes the test results to the city, state, and federal health agencies. The agencies combine field-collected data along with related data from health records (e.g. neuroinvasive disease cases). For the purposes of the study, calculated infection rates and vector indices determine distribution of the virus based solely on the collected mosquito data.

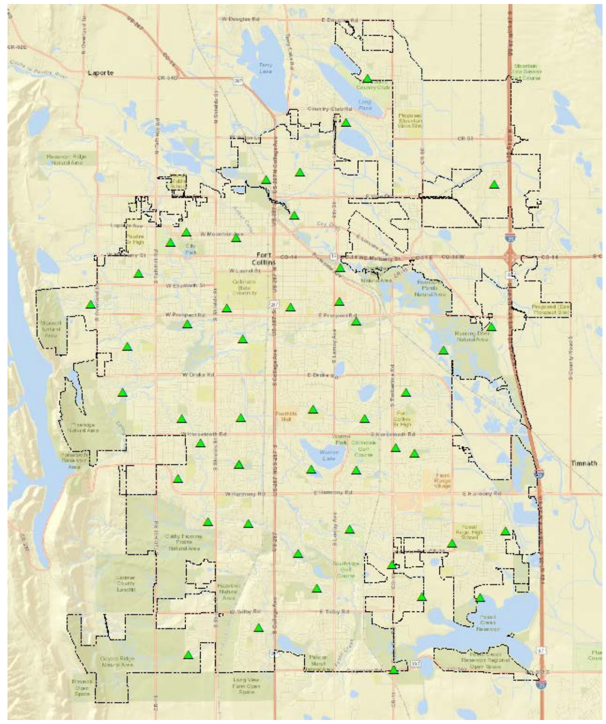


Figure 5. Location of mosquito traps within the Fort Collins city limits.

The located mosquito traps, despite the intention of aiming at a maximum coverage of the city, afford a low sample size with spatial gaps in their coverage, restricting effective geostatistical analysis. Forty-eight traps across the relatively small study area with over a hundred mosquitoes collected on a given week per trap may appear sufficient; however, positive counts of the virus are based on the number of mosquito pools, which generally consist of a maximum of 50 mosquitoes. The number of positive pools are quite small on a weekly basis. Longer timeframes (e.g. biweekly, monthly, annual) offer larger sample sizes for analysis; however, they also allow the possibility of unaccounted environmental and human factors to affect the abundance and infection rates.

Sample size limitations aside, data amassed in the current year was compared with data from previous years using spatial analysis and mapping techniques. The results included temporal views (consisting of weekly, monthly, and yearly windows) and spatial (locational) views. Geographic Information Systems (GIS) provided the tools to effectively analyze and map how data attributes (non-spatial in nature) related to their surroundings (spatial). The Colorado StatePlane North coordinate system afforded the most convenience for the localized study area due to its frequent usage with data sources.

This study incorporated GIS software developed by Environmental Systems Research Institute (Esri). The suite of software includes desktop

(ArcMap) and web-based applications. Both applications support spatial analysis and mapping techniques. The Spatial Analyst extension provides tools aiding visualization of patterns and modeling areas of risk. Incorporating the Spatial Analyst extension with ArcGIS 10.2.2 for Desktop, supplied the structure for effective analysis of the West Nile virus.

Mosquito/West Nile Virus Distribution Component

One method of analysis involved estimates of mosquito presence (i.e. abundance), and those positively tested with the virus (i.e. vector index), in areas not directly being surveyed. The light-type traps factored in determining abundance, while both light- and gravid-type traps provided the data for calculating infection rate and vector index (Moore 2015).

Calculating infection rates relied on two methods. The 'minimum likelihood estimation' (MLE) method produced the best rates when not all pools of mosquitoes from a site, on a given collection date, were positive. The MLE method finds the most likely function, which explains the observed data. The 'minimum infection rate' (MIR) method was most effective when either all or none of pools from a site were positive. This traditional means is a more generalized approach than MLE (Biggerstaff 2009).

The two most common statistics associated with West Nile virus are abundance and vector index. Abundance derives from the number of mosquitoes collected from a site as a weekly event (i.e. "Trap Count per

Night"). The vector index (VI) is a measure of how the virus spreads between the host species and takes into account species population density and infection rate. The formula for VI is:

$$\mathbf{VI = \Sigma_{\mathit{i=species}} N_i P_i}$$

N = average number of species collected per night

P = estimated infection rate

This initial method of analysis, called hot spot analysis, was performed using inverse distance weighted (IDW), an interpolation method based on a rasterized format of the collected data. Waldo Tobler's First Law of Geography ("Everything is related to everything else, but near things are more related than distant things.") serves as the basis for IDW. The outcome provided an "across the board" perspective of the virus' prevalence in the area.

The Geostatistical Wizard within ArcMap offers the IDW tool. The 'Smooth' neighborhood type was selected which incorporates a sigmoidal function ('S' shape) to adjust the weights for a smoothing factor. The 'Power' option optimized known values' influence on interpolated values, based upon distance.

The limitations encountered with the IDW method included its inability to provide prediction (or accuracy) errors. In addition, this method tends to create a 'bulls-eye' effect around the sample sites. Despite these limitations, IDW supplied suitable results with the data after comparative tests with other interpolation methods.

The resulting IDW models were exported into raster form due to its greater effectiveness in retaining the data values over a vector form. The rasters then were classified, using the Natural Breaks (Jenks) method, into five classes. These rasters made up the mosquito/West Nile virus component in this study's comparative analysis.

Human-Related Component

Properly assessing the areas around Fort Collins that pose a risk for the studied segment of population requires knowledge of where they both reside and recreate, in addition to the known mosquito trap locations. As mentioned earlier, the city of Fort Collins has become a popular location for retirees. As such, they can reside anywhere, whether in a single home, an independent apartment complex, senior facility/community, or a long-term nursing facility.

To best assess where they may live, data from the population census comes in handy. Statistics pertaining to the local populace, concerning this study, are readily available to the public courtesy of the U.S. Census Bureau. The Census Bureau conducts approximately 100 surveys every year. A more in-depth census occurs every 10 years (U.S. Census Bureau 2013).

The survey/census results are publicly available as a combination of spatial as well as non-spatial data. Data pertaining to where various age groups live, gathered at the census block group level, is provided in the form of polygons.

In addition to the summarized census data, twenty-eight residential and nursing care facilities were identified to provide more exact of locations where large numbers of the older population live. Numerous smaller facilities exist, however, they were not included since they generally provide short-term stays. The selected facilities were generally classified as active lifestyle, independent living, assisted living, continuing care, and nursing care.

The classifications furnish a simple overview of mobility; that is, the extent of how the residents may go outside their facility and travel around the city. For the purpose of this study, the extent of how far they travel locally is considered. For the primarily independent living facilities, buffers created around the facility properties represent a short walking range (arbitrarily set at 100 feet from the property boundary). Those living in an active lifestyle community/facility can travel readily anywhere; therefore, similar buffers are unnecessary.

> **Active Lifestyle** – integrates physical activity into daily lives (e.g. biking, frequent long walks, playing tennis or golf); often lives in a separate house/townhome; often gets out and travels around town.

Independent Living – enjoys some freedom and cares for themselves in most areas; may live in a separate unit—however, generally lives in a facility-based apartment; may travel around town or take walks around their immediate neighborhood.

Assisted Living – receives personal care and services (e.g. bathing and medication management); lives in a facility-based unit (e.g. apartment or studio); does not travel around town much, may walk or be guided around the facility property.

Continuing Care – combination of independent and assisted living, as well as nursing care; offer increased levels of care as needs change; may initially live in home/apartment then move into assisted living/nursing care units.

Nursing Care – receives nursing assistance in order to maintain health and quality of life; lives in a facility-based unit (e.g. room); seldom travels around town, and may be guided around the facility property.

In addition to living facilities, areas and locations where the studied population may visit and recreate were examined. Parks, natural areas, and trails exemplify areas they may frequent. Specific locations they may travel to include popular community buildings, such as the senior center, the Lincoln Center (for concerts/plays), and libraries.

Shopping areas and restaurants were not included in this study due to practicality. These areas tend to exist predominately across the city and do not provide significantly distinguishable boundaries for spatial analysis.

Weather Component

Another form of analysis looks at possible correlations of weather conditions and mosquito presence. Weather elements gathered from the Weather Underground network of personal weather stations during the summer included air temperature, dew point temperature, relative humidity, and wind direction. The goal involved aligning the weekly-averaged data with the weekly mosquito collection process. Mostly weather data captured on a Monday of the week was selected to coincide with the frequent mosquito collection dates on Tuesday.

Weather data is restricted to the year 2015, since limited numbers of weather stations existed prior to 2015. Thirty-one stations supplied ample data and afforded a broad coverage across the study area (see Table 1). Only 19 and 11 stations were available during the mosquito season in 2014 and 2013, respectively. In addition to low sample sizes, the accessible stations did not provide sufficient areal coverage. From the 2015 season, all of the desired weather elements were suitably included, with only two stations who did not collect wind data

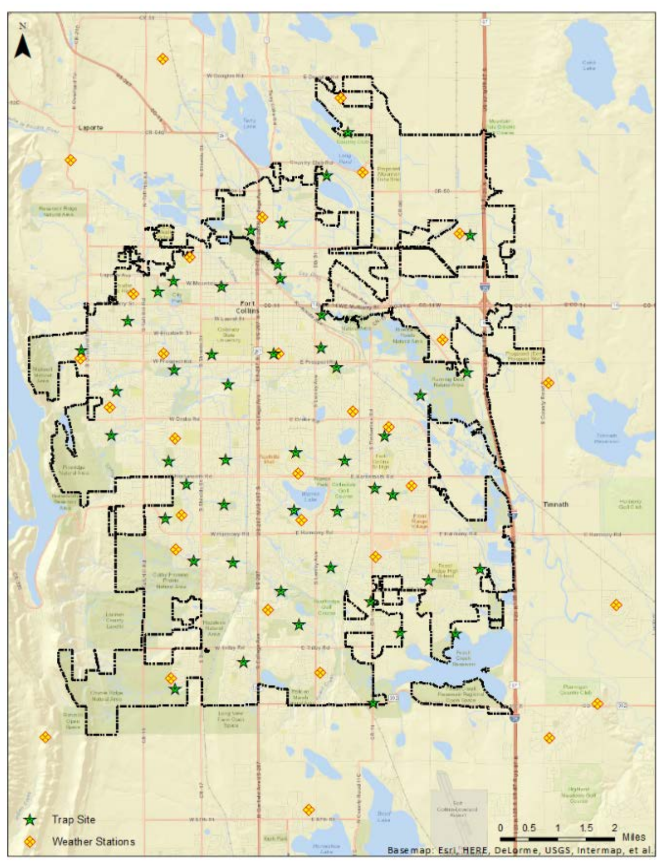


Figure 6. Location of weather stations concerning mosquito traps.

and five who did not collect precipitation data. Twenty-two of the stations contributed all of the elements, while the remaining nine contained one to two days with less than a full 24-hour recording cycle.

The weather stations provide satisfactory coverage concerning the trap sites (see Figure 6). Twenty-three of the 31 stations fall within the city limits and eight neighboring stations, which furnish a glimpse of conditions around the study area. Only six of the twenty-three city-based stations represent close neighbors to the trap sites (within a quarter-mile); however, fifteen are within a half-mile and all 23 are within one mile.

Hot spot analysis, also employing the inverse distance weighted interpolation method, was conducted on five of the seven weather elements. Monthly and annual timeframes provided the temporal basis for analyses. Time constraints of this research project prevented weekly comparisons of all seven elements. Wind direction and speed were the only two elements studied at the weekly timeframe due to the nature of their data. Monthly and annual summations have no real meaning for them.

Wind direction, based on degrees or vectors, required calculating zonal and meridional velocities. These velocities incorporate wind speed in their equations. This process was accomplished using pseudo code formulated for Microsoft Excel, developed by Ton Snoei (Snoei 2014).

Following the hot spot analysis, spatial and temporal analysis between wind conditions and mosquito data identified possible correlations.

Comparison of these results to other related studies determined any potential correlations between infection rates and certain weather conditions.

A caveat accepted working with the weather data was that collection occurred on a single day every week; however, the mosquito collection occurred across several days during a given week. This prevents accurate comparisons between the two subjects. Also, limiting the possible effectiveness of the weather data: not every day surveyed fell on the same day of the week (e.g. Monday) and not every surveyed day consisted of 24 hourly readings.

Wind generally plays a significant factor in mosquito presence, affecting where they may drift, complicating the study of weather's influence. Considering winds from the southeast are prevalent during the summer, mosquitoes can be 'blown in' from outside the study area, distorting their numbers, particularly in the southeastern region.

At Risk Areas/Conditions Component

Assessing where people live is an important step. Determining possible popular locations that these people visit is also pertinent. Parks, trails, and water body-related data layers serve as the basis for appropriate comparative risk analysis. Natural areas (including open spaces), parks, and water bodies, both in the form of polygons, may reveal a correlation with mosquito population density and infection rates. Waterways (e.g. rivers and ditches) may also concede possible relationships with components of West Nile virus.

The Larimer County GIS department provided water bodies, streams and ditches, along with parcel data containing city- and county-owned parks. The City of Fort Collins' GIS Department furnished natural areas and trail data. All of the datasets were clipped to fit the approximately 141 square mile study area.

The initial plan for conducting comparative analysis involved converting the mosquito abundance and vector index rasters to polygons. However, that conversion process involved recalibrating the floating point-based raster cells to integers to accommodate for the 'Raster to Polygon' tool. By transforming the cells to integers, the data values resulted in the hot spots becoming too generalized (i.e. accentuating the 'bulls-eye' effect).

The chosen alternate process, in order to save time, settled on digitizing the outlines of the rasterized hot spots. Overlaying these polygon-based outlines upon the data layers of the other study components determined where both sets co-exist spatially. The 'Select by Location' tool filtered out the spatially connected areas and added them to one of newly created at risk areas (polygon) or at risk trails (polyline) feature classes.

RESULTS

Several challenges and/or obstacles arose during this research study. These challenges included, among others, analyzing the accuracy of the mosquito collection data, re-projecting the census data to the study area, inconsistent gaps in weather data, and the redundant process of performing interpolation. Despite the interpolation process following repetitive steps, adjustments were required at each step to accommodate time periods and data fields for the inverse distance weighted tool. These adjustments allowed for possibilities of input error.

The primary objective of this research study focused on West Nile virus distribution. This objective was the most important as it is the foundation for all of the other research objectives. Analysis conducted followed along the research objectives, compartmentalized into the aforementioned components. The analyses focused on, in addition to mosquito dispersion, impacts with the virus on frequent locations of the select human population and relationships with weather conditions, if any.

Mosquito/West Nile Virus Distribution Component

The collection of the mosquitoes, by trap, occurred on a more balanced period throughout the week than initially expected. Past years' collections frequently transpired on Tuesdays. This year however, obtaining the specimens stretched out somewhat evenly Monday through Thursday. Wednesday saw the busiest activity, accounting for 38% of the total collection days. Monday, Tuesday, and Thursday each accounted for approximately 21% of the days.

The distribution of the virus, based on the collection data, examined two factors: temporal and geographical. The temporal factors included annual, monthly, and weekly views. On an annual basis, mosquitoes were generally most abundant in the eastern half of the study area (see Figure 7). A notable exception were pockets of higher apportionment in the north central region in 2013 and 2015. The year 2014 saw the broadest areas with higher concentrations compared to other years.

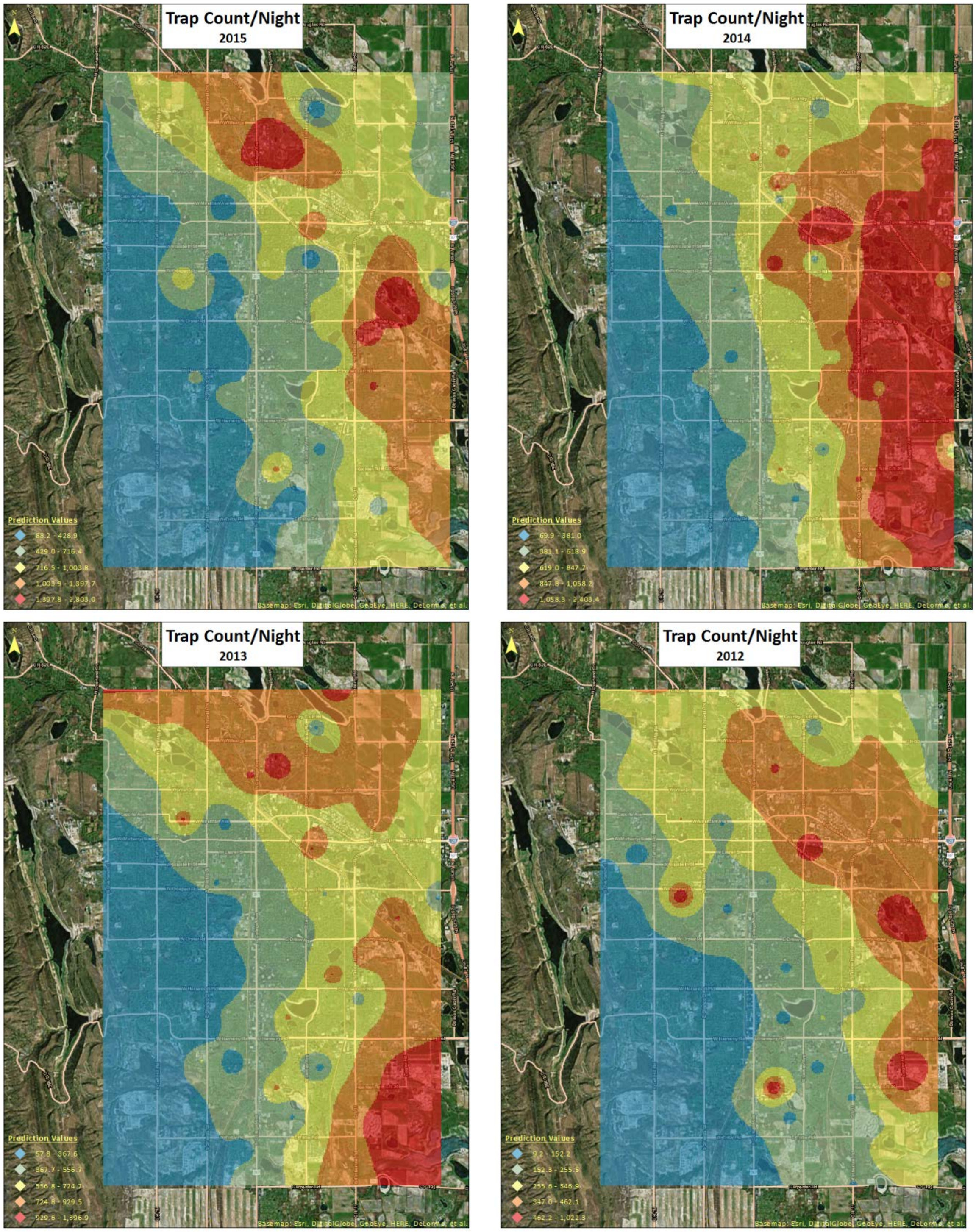


Figure 7. Concentrated areas of mosquitoes based on total number of those collected at each trap site on an annual (seasonal) basis.

On a monthly perspective, July experienced the high points for three of the years (2015 = 16,737; 2014 = 18,393 and 2013 = 14,764) (see Table

2). August saw the highest concentration in 2012. Despite no collection dates in the month of September, the year 2014 still gathered more individual mosquitoes than 2015 (33,797 to 32,679). The years 2013 and 2012 saw significantly fewer mosquitoes, even with fewer traps in service (42). Mosquito totals per trap for the season averaged, in chronological order (2015 ->2012): 681, 704, 573, and 246. A different collection process may have attributed to the year 2012's lower numbers.

Number of Individuals - 2015

Month	Total	Highest Site Total
June	5,011	510
July	16,737	1,400
August	10,087	1,205
September	844	149
Total	**32,679**	

Number of Individuals - 2014

Month	Total	Highest Site Total
June	1,907	369
July	18,393	1,635
August	13,497	1,066
September	n/a	n/a
Totals	**33,797**	

Note: no collection in September

Number of Individuals - 2013

Month	Total	Highest Site Total
June	1,467	304
July	14,764	965
August	7,825	567
September	n/a	n/a
Total	**24,056**	

Note: no collection in September

Number of Individuals - 2012

Month	Total	Highest Site Total
June	1,060	101
July	4,253	478
August	4,713	687
September	309	101
Totals	**10,335**	

Table 2. Number of collected individuals for each month and year. Also, the highest site for each month is listed.

Spatially, the southeastern corner of the study area generally acted as the onset location in June with an additional localized hot spot occurring in the north central region (see Appendix). A common pattern of hot spots moving to the north and northwest existed as the season progressed. The southwestern corner experienced less abundance of mosquitoes throughout the season, possibly due to fewer trap sites.

Double peaks appear in the weekly numbers of individual mosquitoes for each year with the years 2012 and 2013 seeing more pronounced peaks (see Figure 8). In contrast, 2015 saw a small initial bump in number of

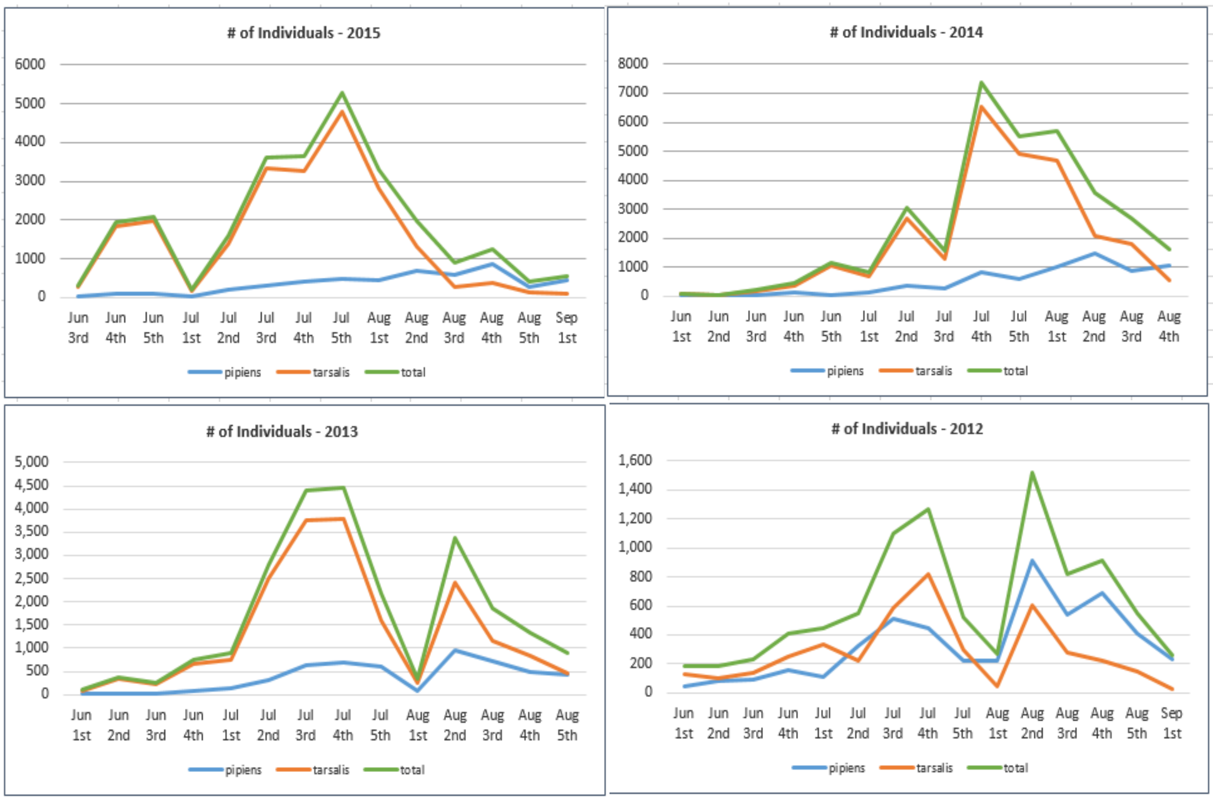


Figure 8. Number of individuals, by species and total, collected during each month and week period for 2012-2015.

individuals in mid-June and the initial bump occurred later in mid-July in 2014.

Each year saw differing weeks for their high points. The year 2015 experienced its heaviest abundance from mid-July through early August. The summit for 2014 appeared later from late July to mid-August. Initially encountering high numbers of mosquitoes throughout the month of July, the year 2013 saw a serious drop in the first week of August. Differing from the other years, 2012 experienced more peaks and valleys; however, its overall weekly numbers were significantly lower than the other years.

A little under 1,600 individuals were collected in the final week of collection (Aug 4th), indicative of the persistent heavy mosquito population during the second half of the 2014 season. In comparison, the next highest year (2013) collected 1,349 mosquitoes during that time. The year 2015 amassed 1,234 and 2012 saw only 917 individuals. The years 2012 & 2013 involved only 42 traps; nonetheless, 2014 experienced the heaviest presence of mosquitoes. For most years, *Cx. tarsalis* was the dominant species in most weekly periods with *Cx. pipiens* more abundant in the later weeks of the season. The conflicting year, 2012, observed the two species alternating throughout the months.

Switching to examination of vector index values, the limitations of the inverse distance weighted interpolation method became more obvious. Low sample sizes negatively affect interpolation methods in general; IDW was no exception. Hot spots occasionally appeared as 'bulls-eyes' resulting in a distorted localized appearance. Three of the four years studied exemplified this undesirable effect.

The southeastern region of the city saw the highest annual incidence levels of mosquitoes, which tested positive with the West Nile virus in 2013 and 2014 (see Figure 9). In contrast, only a handful of sites scattered across the town saw increased incidence rates over the study area during the 2012 and 2015 seasons. Looking at monthly vie

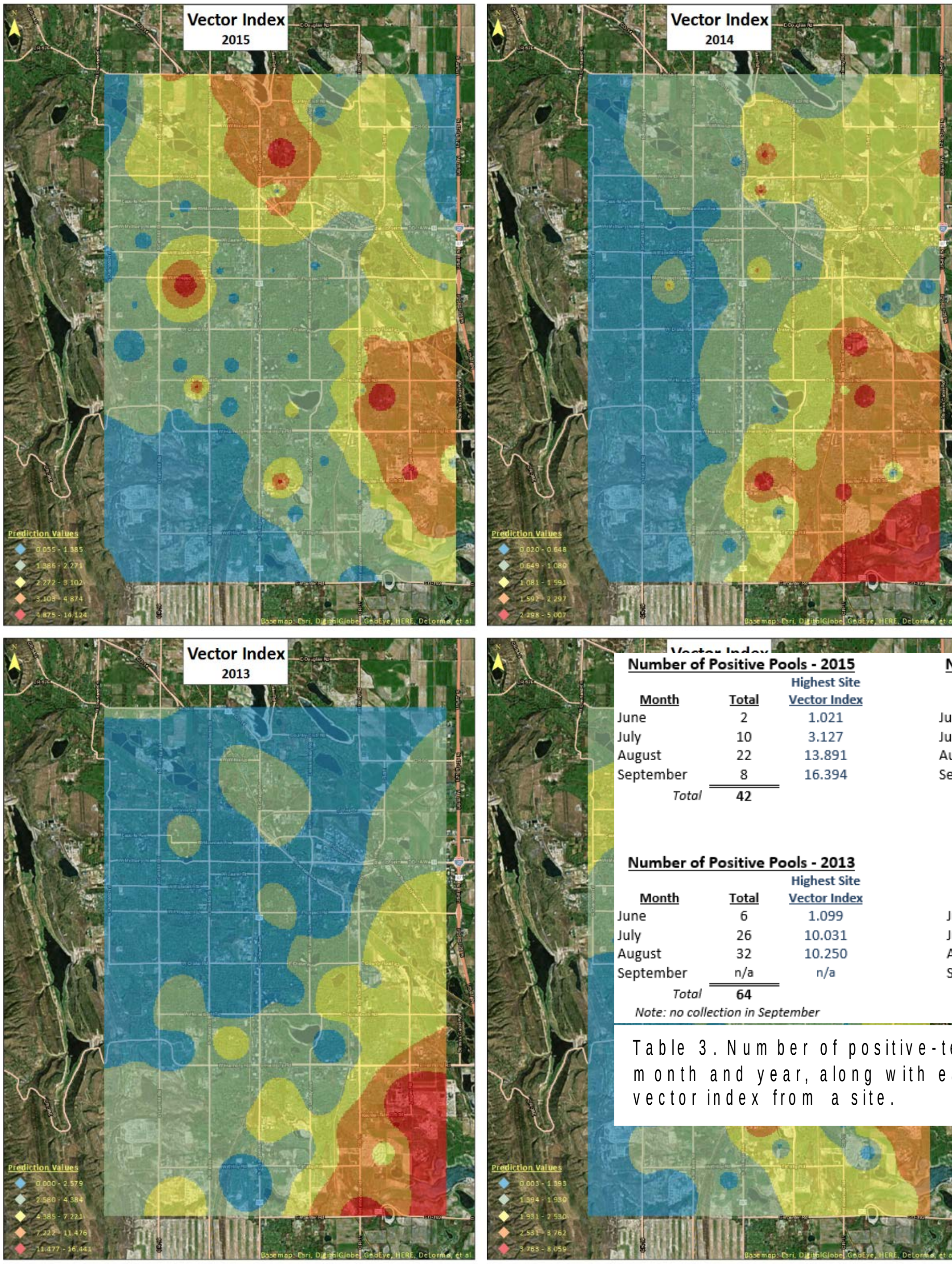


Figure 9. Concentrated areas of mosquitoes based on estimated vector index of those collected at each trap site on an annual (seasonal) basis.

Number of Positive Pools - 2015

Month	Total	Highest Site Vector Index
June	2	1.021
July	10	3.127
August	22	13.891
September	8	16.394
Total	42	

Number of Positive Pools - 2014

Month	Total	Highest Site Vector Index
June	0	0.000
July	11	2.151
August	19	5.902
September	n/a	n/a
Total	30	

Note: no collection in September

Number of Positive Pools - 2013

Month	Total	Highest Site Vector Index
June	6	1.099
July	26	10.031
August	32	10.250
September	n/a	n/a
Total	64	

Note: no collection in September

Number of Positive Pools - 2012

Month	Total	Highest Site Vector Index
June	2	0.913
July	5	2.243
August	30	9.412
September	2	4.555
Total	39	

Table 3. Number of positive-tested pools for each month and year, along with each month's highest vector index from a site.

ws, June of 2014 saw no positive pools collected. This translates to a 0.000 vector index for the month. June of 2015 was similarly slow, with only two sites containing positive pools and vector indices of only 1.005 and 1.021 for both sites (see Table 3). The most infective June occurred in 2013, with six positive pools. The year 2012 experienced a similar June as 2015 with only two positive pools.

Contrary to the trap counts, more sites contained positive pools in the month of August, rather than in July. This appears to be a common trend as the summer progresses up until September. Although, the final month of the mosquito season saw the highest vector index for a site in any month, which occurred in 2015. Despite only two positive pools in September of 2012, a relatively high vector index was calculated for that month. No collection of mosquitoes took place in 2013 and 2014.

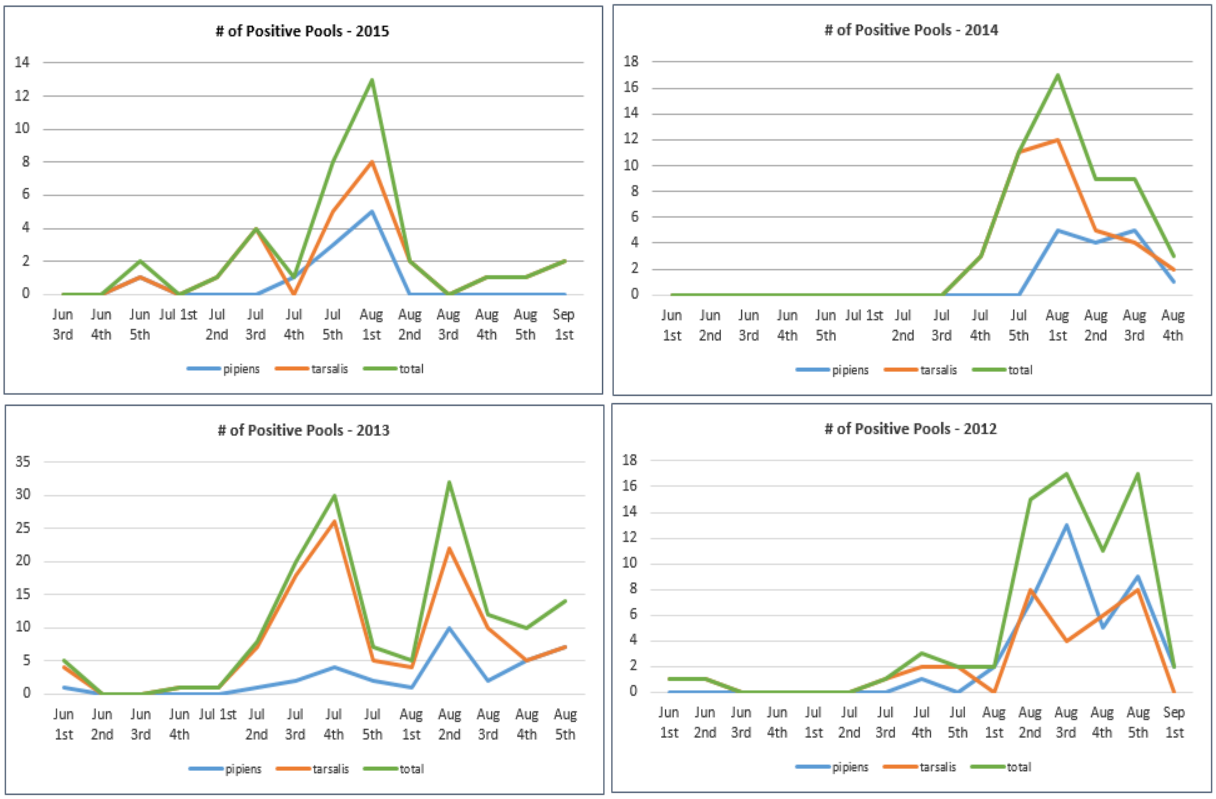


Figure 10. Number of pools tested positive collected during each month and week period for 2012 - 2015.

On a weekly basis, the high points for number of positive pools lagged one to two weeks behind the number of individuals' summits for every year except 2013 (see Figure 10). That year contained two pinnacles for positive pools, similar to its number of individuals; however, the number of positive pools increased greater than the individual count. Interestingly, the surge of positive pools in 2012 happened considerably later than the uptick in individual counts.

Looking at the particular species, *Cx. tarsalis* was the dominant species in most weekly periods with the exception of the late August 2012.

Cx. pipiens generally became more abundant in the later weeks of the season, excluding in 2015, when its maximum took place during late July and early August.

Human-Related Component

After performing the mosquito-related analysis, focus shifted to humans. Not only discovering the distribution for mosquitoes was important, but also human distribution. Knowing where the target population segment lives and what areas around town they may travel to, aids in determining potential risk areas for viral infection (as well as what areas to try and avoid due to dense mosquito presence).

Based on 2012 U.S. Census Bureau's data, Figure 11 shows the areas

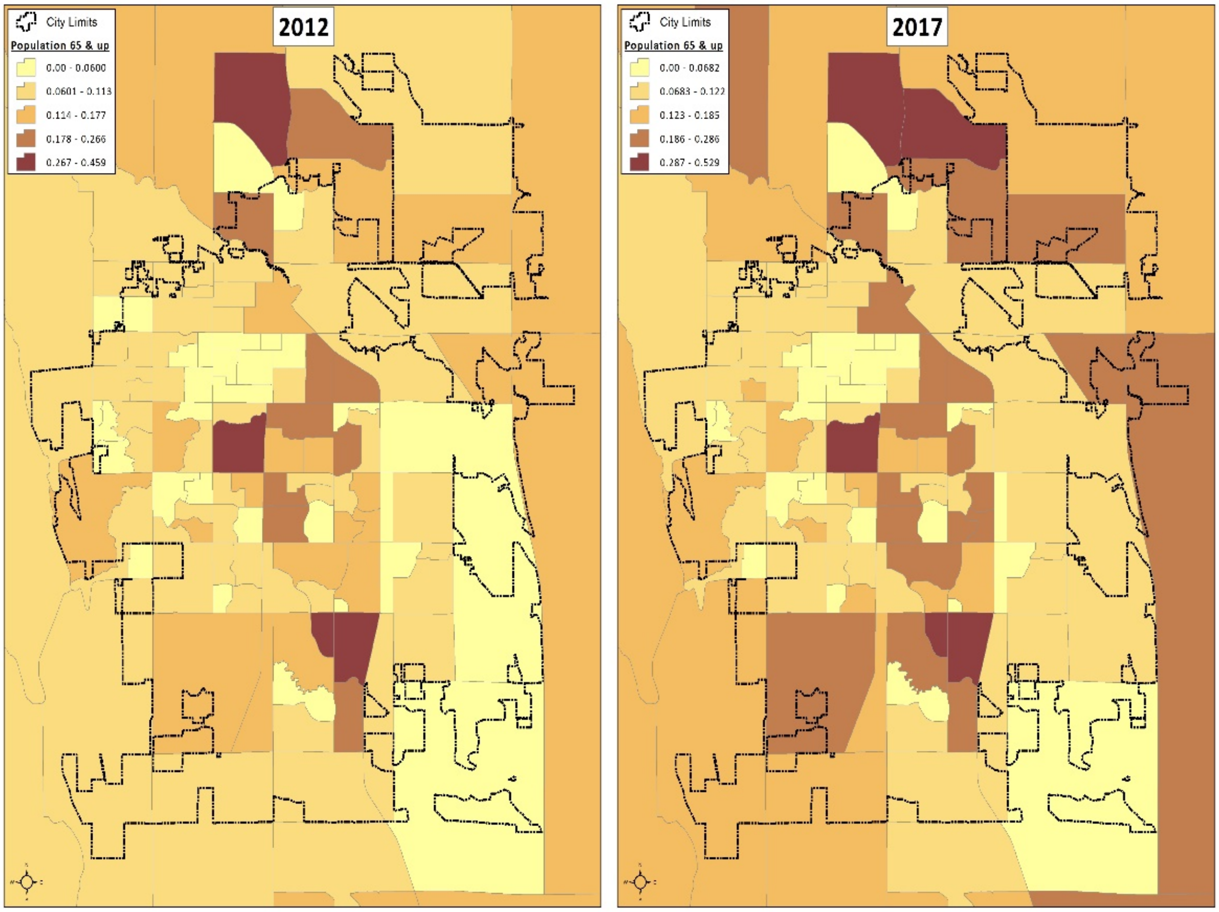


Figure 11. Populations of age 65 and older, based on total population in the Fort Collins, CO area. The years displayed reflect projected increases among older populations [U.S. Census Bureau, 2012].

populated by those age 65 and older in the years 2012 and 2017, as normalized by the total population of the respective areas. The designated areas align with census block groups and represent where they live. The 2017 data represents a five-year estimate established from census data surveyed from 2007 – 2011.

Data on the locations of senior living establishments and likely recreational facilities provided detailed information on where the study subjects lived and frequently visited. A map of the residential and recreational facilities studied appears in the Appendix.

After researching, through general conversations and observations, although the mapped indoor recreational locations accommodate frequent visits, those 65 and older often tend to travel around town. In short, there were too many possible social sites to map. Therefore, the recreational focus of this study shifted to outdoor opportunities only. Nonetheless, an abbreviated analysis revealed some of the frequented indoor sites existing within the mosquito hot spots. This revelation may encourage a future study in itself.

Considering the popularity of short walks for exercise, especially for those living in senior communities and facilities, exposure to potential infection can occur anywhere within property boundaries. This leads to a greater value incorporating parcels compared to point locations. To determine appropriate parcels, the 'Select by Location' tool filtered out the parcels that spatially contained the residential and recreational point locations. These parcels then became the spatial component for analysis with the mosquito-related hot spot polygons.

Weather Component

As indicated earlier, the majority (222 out of 228 total) of the weather collection days occurred on a Monday to account for expected mosquito collection transpiring on Tuesday (and Wednesday). The difference between the mosquito and weather collection days fell within zero to three days. The most frequent difference was two days (36%).

Due to the small daily sample sizes of the traps, as well as the low number of nearby (within a quarter-mile) weather stations, comparing the estimated vector indices with the weather data result in statistically insignificant values.

No visually apparent correlation exists between the observed weather conditions (excluding wind data) and mosquito abundance or infection rates (vector index) in either the monthly or the annual periods. This is not surprising considering the frequently changing weather conditions known to occur around the city of Fort Collins.

A weekly spatial comparison between these five weather elements and trap counts may possibly provide a clearer picture of any spatial correlation (see Figure 12).

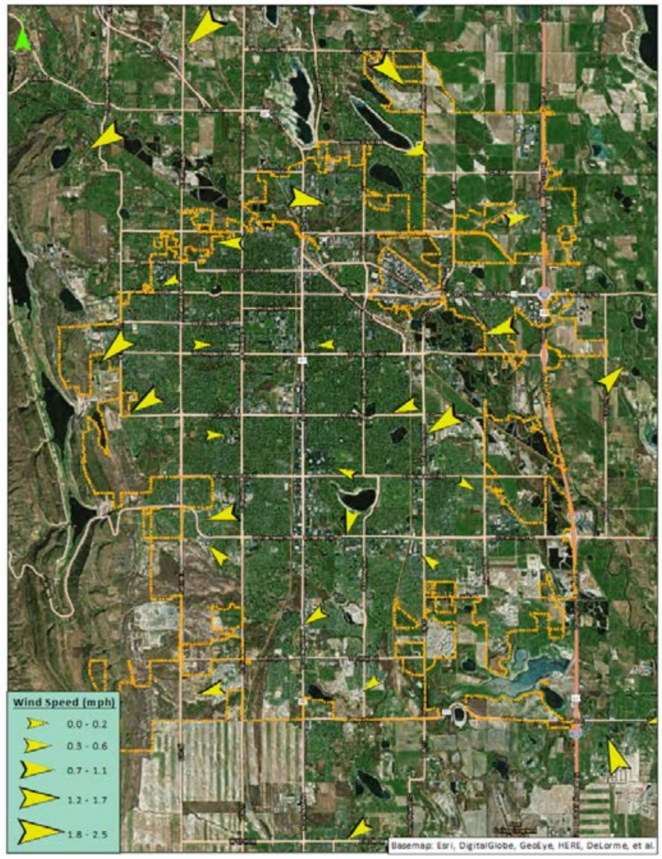


Figure 12. Example of a weekly wind direction and speed map. Data represents the first week of August 2015.

Even looking at a weekly timeframe, confidence in the wind directions and speeds is somewhat low. Each reporting station's hourly data indicate multiple changes in direction and speed throughout the day (see Table 4). Proper assessment of possible correlation between the wind and trap counts requires a shorter timeframe. Perhaps a daily window will provide acceptable results.

Station ID	Station Name	Date	Hour	Wind Direction [Degrees]	Wind Speed [mph]
KCOFORTC53	Boxelder Est	6/1/15	00	313	0.1
KCOFORTC53	Boxelder Est	6/1/15	01	340	0.0
KCOFORTC53	Boxelder Est	6/1/15	02	0	0.0
KCOFORTC53	Boxelder Est	6/1/15	03	0	0.0
KCOFORTC53	Boxelder Est	6/1/15	04	336	0.0
KCOFORTC53	Boxelder Est	6/1/15	05	0	0.0
KCOFORTC53	Boxelder Est	6/1/15	06	0	0.0
KCOFORTC53	Boxelder Est	6/1/15	07	0	0.0
KCOFORTC53	Boxelder Est	6/1/15	08	276	0.4
KCOFORTC53	Boxelder Est	6/1/15	09	173	2.0
KCOFORTC53	Boxelder Est	6/1/15	10	176	1.9
KCOFORTC53	Boxelder Est	6/1/15	11	165	2.2
KCOFORTC53	Boxelder Est	6/1/15	12	150	1.4
KCOFORTC53	Boxelder Est	6/1/15	13	166	4.9
KCOFORTC53	Boxelder Est	6/1/15	14	135	5.0
KCOFORTC53	Boxelder Est	6/1/15	15	158	3.9
KCOFORTC53	Boxelder Est	6/1/15	16	264	0.4
KCOFORTC53	Boxelder Est	6/1/15	17	356	0.3
KCOFORTC53	Boxelder Est	6/1/15	18	357	0.1
KCOFORTC53	Boxelder Est	6/1/15	19	170	0.4
KCOFORTC53	Boxelder Est	6/1/15	20	177	0.2
KCOFORTC53	Boxelder Est	6/1/15	21	317	0.9
KCOFORTC53	Boxelder Est	6/1/15	22	290	1.0
KCOFORTC53	Boxelder Est	6/1/15	23	136	1.2

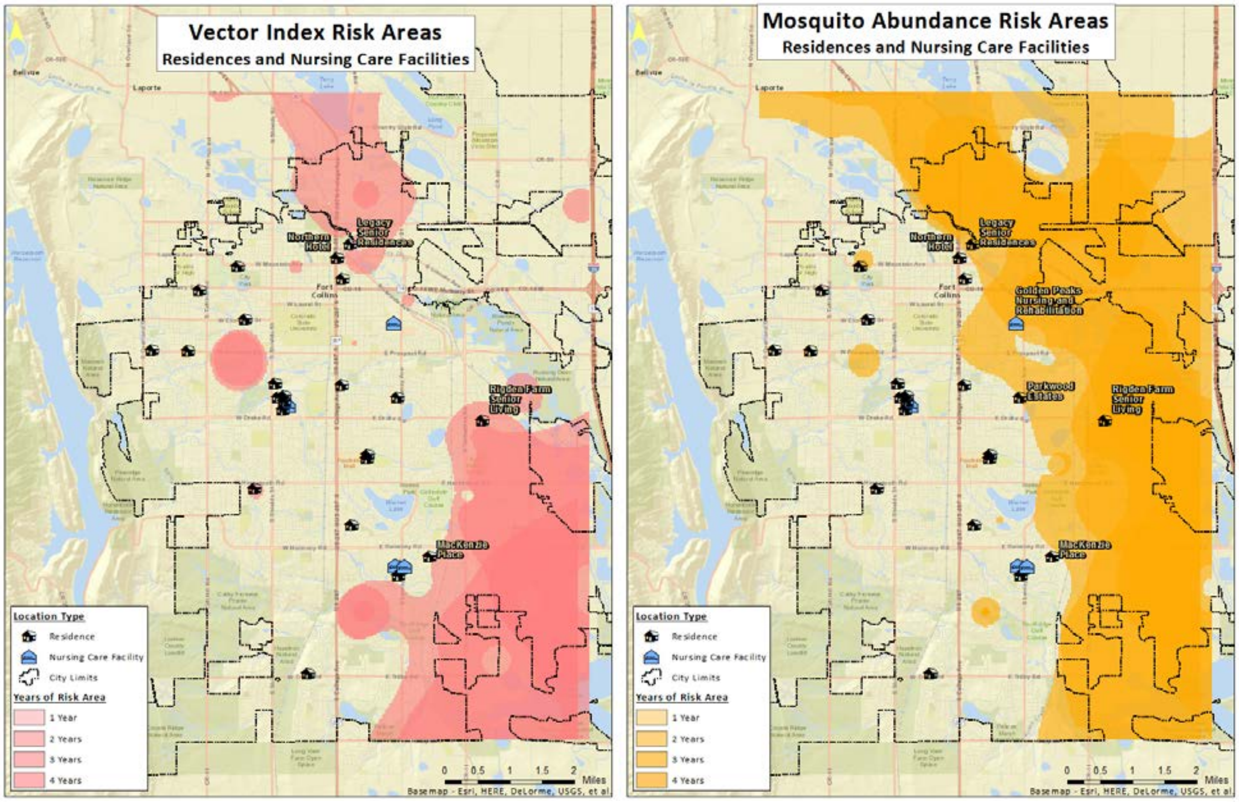
Table 4. Example of changes in hourly wind direction and speed data.

At Risk Areas/Conditions Component

Two sets of maps were created for each comparative analysis: 'Vector Index' - relating to the increased risk of West Nile viral infection and 'Mosquito Abundance' - relating to areas of heavy mosquito populations. These latter areas may represent a potential incidence of infection in the future, or at the very least, areas to avoid from getting multiple mosquito bites. Establishing a potential history of where incidences occurred in the past can improve predictions of likely locations of potential incidences in the future.

The 'at risk' areas represent a color range-based compilation of risk areas of annual data from 2012 to 2015. The darker shades signify where risk areas from multiple years overlap. These areas represent a combination of the top two classes from the original five-class rasters. The cells from these chosen classes signify anywhere from 9% of all cells to 46%, depending on if the raster embodies vector indices or trap counts. Separate maps were created for each category: residence and nursing care facilities, city/county parks, natural areas, water bodies and waterways, and trails.

Two senior residences and nursing care facilities fall within the overall moderate risk areas: Legacy Senior Residences (Legacy) and Rigden Farm Senior Living (see Figure 13[a]). None of the facilities resides in regions of multiple high vector index estimates.



[a] [b]

Figure 13. Vector index [a] and mosquito abundance [b] risk maps for senior living residences and nursing care facilities.

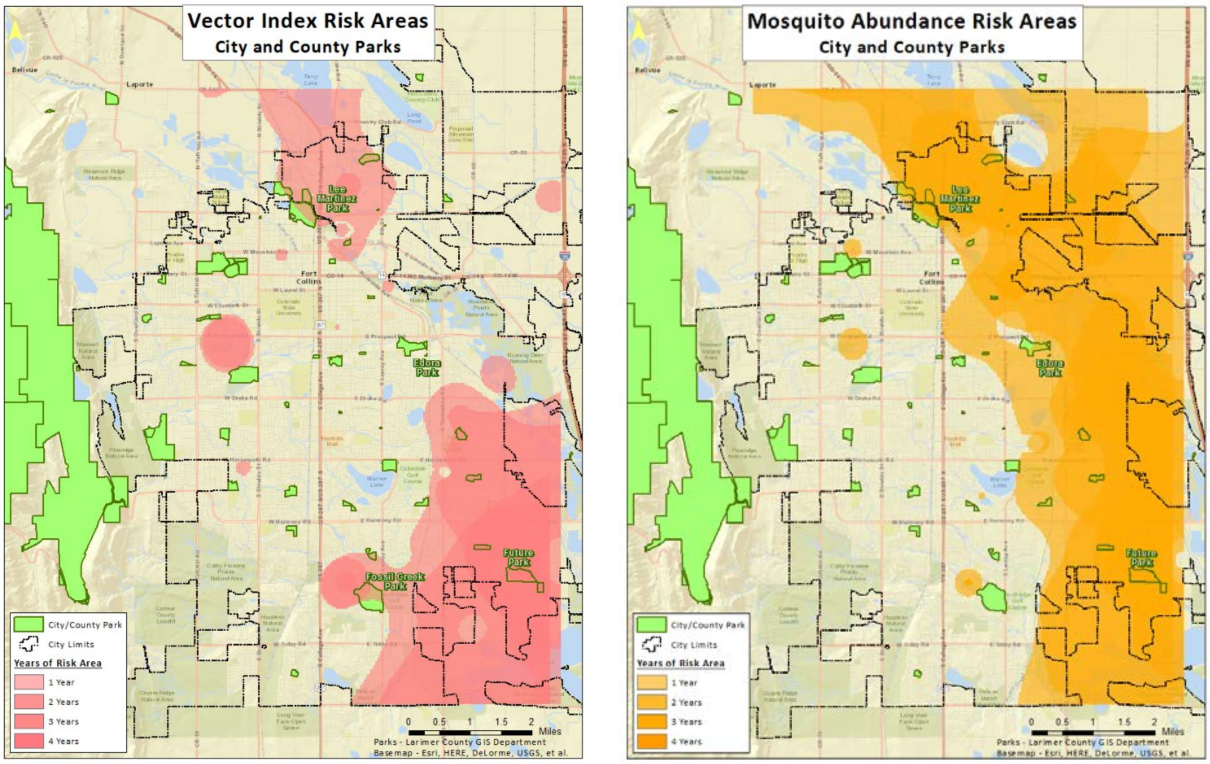
The MacKenzie Place, Northern Hotel, and a couple of other facilities rest on the edges of the hot zones. Due to the relatively large numbers of mosquitoes in the eastern half of the city, most of the institutions in that area likely dealt with them. Golden Peaks Nursing and Rehabilitation joins Legacy and Rigden Farm Senior Living in being located in moderately high abundance areas (see Figure 13[b]). The Parkwood Estates community, with its moderately sized lawn area, lies along the abundance hot zones with MacKenzie Place and Northern Hotel.

MacKenzie Place and Rigden Farm consist of 'campuses' made up of a single primary building with several outlying homes. Considerable walking may occur between the buildings as well as around their properties. Both also enjoy retail establishments located nearby and within walking distance. Because of amble walking opportunities, these two communities allow for increased chances of infection.

Parkwood Estates, like most other residential (and a couple nursing care) facilities, consists of a multi-wing building which allows walking and sitting areas around its property. The smaller in size facilities, like Northern Hotel (and most nursing care facilities); contain small lot sizes, which restrict walking options to around their immediate neighborhoods.

Looking at possible outdoor venues, three city parks fall within moderately high risk vector index areas across town: Fossil Creek Park and a future park (tentatively called Southeast Community Park) in the south and Lee Martinez to the north (see Figure 14[a]). Several smaller parks, in addition to the future park, situate in areas where relatively high vector indices occurred for all the years analyzed.

Two of the well-visited parks, Edora and Lee Martinez, appear to be contributory with the mosquitoes as well. Lee Martinez Park contains a variety of penned animals for visiting and ponies to ride for children, which may partially explain the dense mosquito population (see Figure 14[b]).

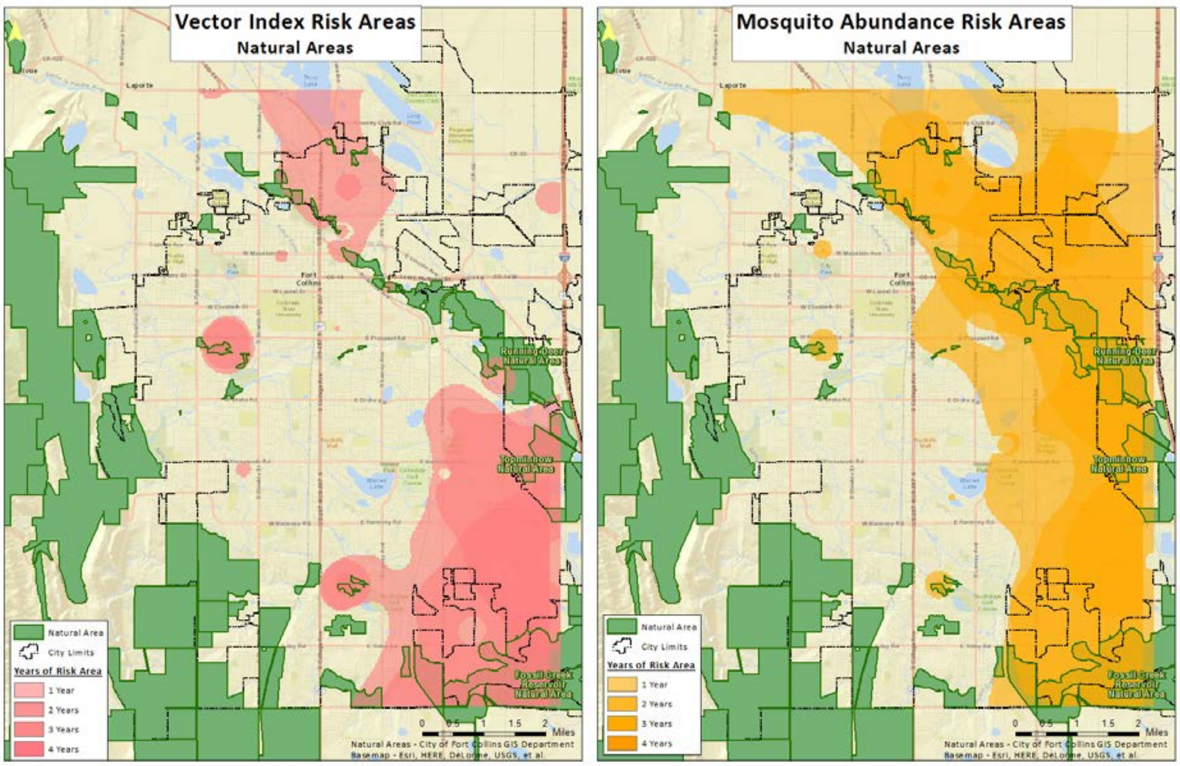


[a] [b]

Figure 14. Vector index [a] and mosquito abundance [b] risk maps for city- and county-owned parks.

The three distinct zones of vector index-related risk areas encompass a large number of natural areas for people to visit. In a different way, an abounding bundle of natural areas covers the expansive stretch of high mosquito abundance. In either regard, electing to take a stroll in the eastern natural areas puts one at risk and strongly urges the need for mosquito protection.

The risk areas appearing each surveyed year envelope the Fossil Creek



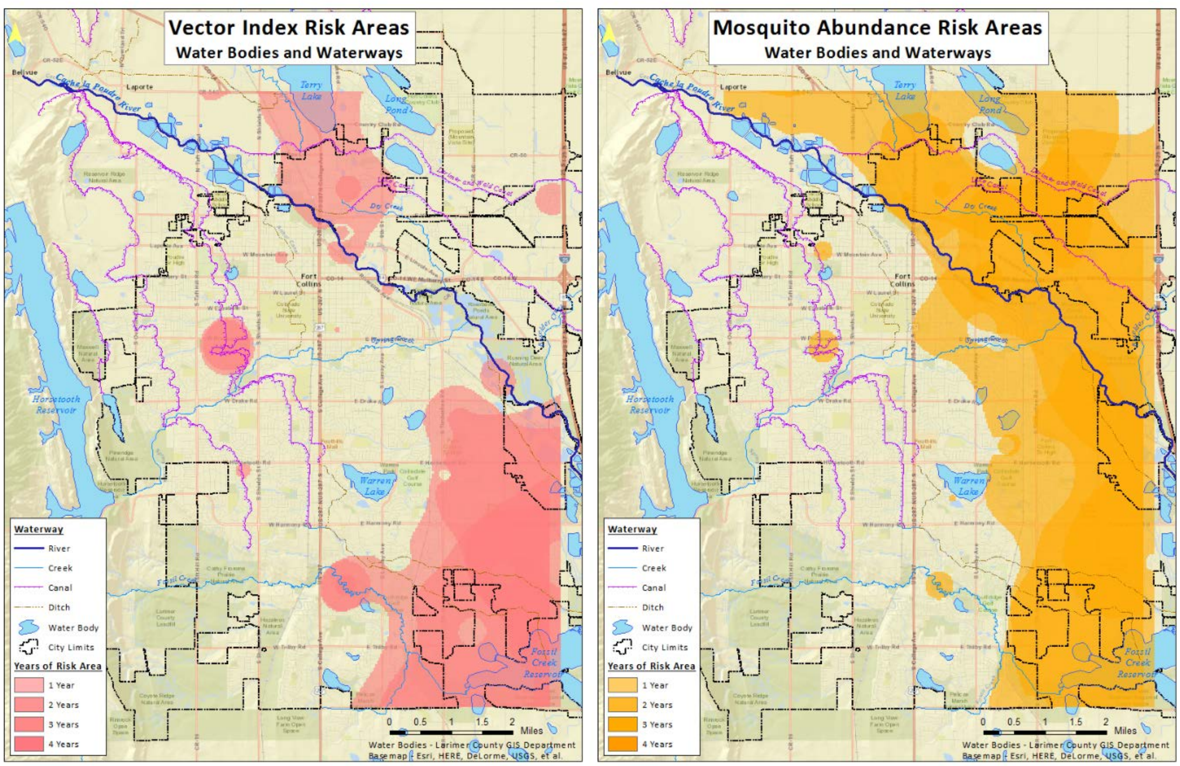
[a] [b]

Figure 15. Vector index [a] and mosquito abundance [b] risk maps for natural areas.

Reservoir Natural Area (see Figure 15[a]). Several surrounding natural areas, within a mile to the west and three miles to the north, accommodated positive-tested mosquitoes for one to three years. A second, rather large, impacted region occurred in the northern part of the city. This region included approximately a half dozen small natural areas. A third risk area locally covered the Fischer and Red Fox Meadows natural areas.

All of the natural areas along the eastern edge, save one or two, landed within the cumulative mosquito abundance-related risk area (see Figure 15[b]). Stretching from the Fossil Creek Reservoir Natural Area in the southeast northward, to the northern city limits, then westward, sizable counts of mosquitoes prevailed, putting countless open spaces in danger of mosquito bites and possible infection.

Two popular water bodies fall within vector index-related risk areas:



[a] [b]

Figure 16. Vector index [a] and mosquito abundance [b] risk maps for water bodies and waterways.

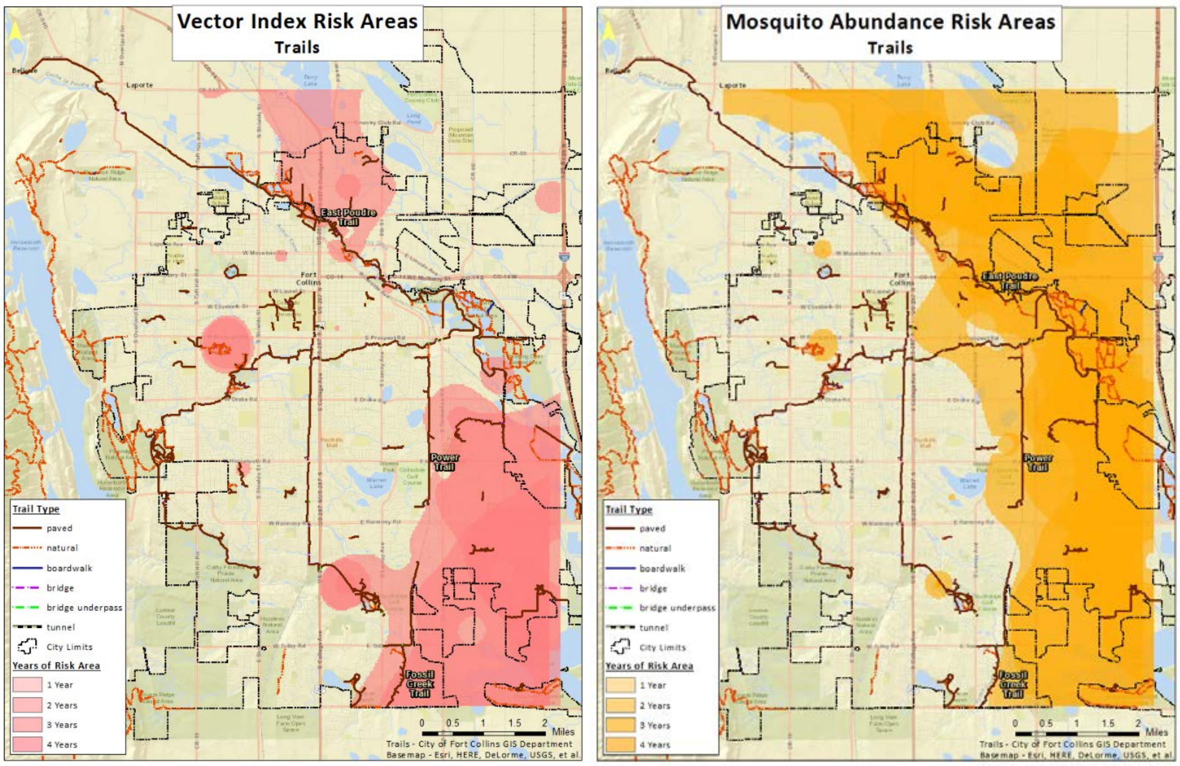
Fossil Creek Reservoir and Terry Lake (see Figure 16[a]). Neither allows boating, but ample shorelines to walk along, as well as sit and observe wildlife. A few canals and creeks traverse into danger areas as well, including an isolated risk area near two canals. Only a small segment of the Cache la Poudre River crosses into risky infectious area.

As expected, the previously mentioned water bodies and waterways similarly fell within the mosquito prevalence-related risk areas, plus more. The combined abundance risk areas extended to including the southern half of Long Pond to the north and the eastern edge of Warren Lake (see Figure 16[b]). Additional canals, creeks, and ditches are now covered. Almost half the length of the Poudre River fell within the risk area.

Three primary trails put their users into potential risk of infection: East Poudre Trail, Fossil Creek Trail, and Power Trail (see Figure 17[a] on the next page). East Poudre trail is the longest trail, connecting Fort Collins with neighboring towns, so it is not surprising it contains segments that present chances of a mosquito infection.

It is also not surprising to see Fossil Creek Trail listed, since it stretches near the reservoir which shares it name and the surrounding area represents the highest levels of vector index values. Power Trail lies along the western edge of its risk area, acting as a sort of gateway.

Anyone wishing to walk, bike, or ride their horse on a trail will best be served taking advantage of the trails in the western half of town. If they have a strong desire for one of the eastern trails, they should express equal desire in bringing along some form of mosquito protection. Hardly a trail exists in the eastern half not surrounded by large volumes of mosquitoes, based on the four-year summation of annual trap counts (see Figure 17[b]).



[a] [b]

Figure 17. Vector index [a] and mosquito abundance [b] risk maps for trails.

The lengthy East Poudre Trail experienced over 50% coverage of heavy mosquito prevalence. Power Trail saw 100% coverage, as well as the eastern half of East Spring Creek Trail, which Power Trail runs into. Fossil Creek Trail acts as a western boundary for one of the most abundant expanses of mosquito abundance.

A couple much-localized hot spots occur elsewhere covering unnamed trails and paths. In fact, an innumerable number of name-less trails/paths exist around water sources, ideal for leisure strolls or horseback riding. These pathways, often constructed of natural material (e.g. dirt), may promote elevated mosquito populations, which leads to potential infectious opportunities.

When considering mapping monthly views for risk areas, a slightly different approach was achievable because of fewer data layers under consideration. The top two classification levels (again, based on the five-class Natural (Jenks) method), were separated and assigned “Moderate” and “High” risk levels. Similar to the annual maps, separate maps were created (for 2015 only) based on vector index and mosquito abundance for each category: residence and nursing care facilities, city/county parks, natural areas, water bodies and waterways, and trails (see Appendix for the 2015 maps).

For the vector index-related risk areas, the month of July saw the broadest extent, as 10 of the 48 traps registered vector index values. Despite that fact, only one senior residential facility (Rigden Farm Senior Living) dwelled within a risk area (estimated vector index (EVI) of 3.127 at a nearby trap). The sole other occasion where one or more facility were perilously located happened during the month of August, along the northern edge of the city. Legacy Senior Residences appeared immersed in a risk area (11.887 EVI), with Northern Hotel and DMA Plaza riding the edge.

With the much-localized highly infectious areas, only one or two city parks occupied at risk areas for most months. Future Park and Stewart Case Park (2.040 and 3.127 EVI, respectively) fell within these areas during the productive July. August saw a different, more separated combination of Lee Martinez Park in the north (11.887 EVI) and Ramah Park (13.891 EVI, located just south of the larger) Stewart Case Park in the southeast. Only one parkland, Future Park again, faced endangerment in June (1.021 EVI).

The most impacted parks occurred in September with a western exposed area landing in the middle of a trio. All three parks ranged from partial to complete coverage. These open spaces included Avery Park, Blevins Park (next to a middle school, of note), and Rolland Moore Park. Of relevancy, Rolland Moore Park rests next door to the senior center—a popular hangout for the 65 and older age group.

Several natural areas experienced moderately high nearby infection rates during July: Arapaho Bend, Fossil Creek Reservoir, Running Deer, and Topminnow. All of these, including some smaller ones, are located along the city's eastern edge, affected primarily by trap # FC-027 with its EVI of 3.127.

One important locale falling in the risk area is the Environmental Learning Center. The Center, co-managed by Colorado State University and local government agencies, acts as an outdoor classroom for the public to learn about the local ecosystem. An enclosure on site offers opportunities to see flight-restricted raptors up close.

This is relevant as several raptors in Northern Colorado tested positive for West Nile in 2005 (Nemeth 2007). Due to the purposes of this specific study, however, no suitable collected data either supports or refutes any possible correlation between WNV and raptors. August contained the second highest number of impacted open spaces with widely distributed influenced areas. Several small northeastern natural areas, including Gustav Swanson (named after a noted ornithologist and Colorado State University professor), run along the Cache la Poudre River and a sewage treatment plant. Surrounding EVIs of 11.887, 6.231, 2.060, and 0.970 influenced these areas. In a rare occurrence, a trap site (FC-063) in the western half of the city, adjacent to the Red Fox Meadows Natural Area, collected nine pools of infected mosquitoes for a vector index of 12.411.

Water bodies and waterways exposed to elevated vector index values were limited to a few small pockets. These pockets consisted of Fossil Creek Reservoir during the month of July (nearby EVIs of 2.040, 1.002, and 1.001) and separate segments of Cache la Poudre in June and August. Only trap numbered FC-063, located near the Larimer County Canal No. 2 and New Mercer Canal, registered positive pools (3) near water for the month of

September. This is the same trap just mentioned which neighbors the Red Fox Meadows Natural Area.

Finally, July and August saw two heavily used traps (FC-036 and FC-040) in the northern region of town with multiple shared positive pools between them (1 and 2, respectively). These traps near the East Poudre Trail represent the only significant overlap between months. Traveling south along the trail, traps FC-006 and FC-092 contribute six positive pools to aid in influencing the immediate region. Further south, another hot spot (trap FC-067), albeit small (one positive pool out of 14 total) appeared in the month of June. A large number of short-distance, unnamed trails crisscross several risk areas.

As expected, the mosquito abundance-related risk areas cover a lot more real estate and affect more places of interest than the vector index-related risk areas. After a slow, uneventful start to the mosquito season, senior living facilities started appearing in the abundance risk areas by late July. Rigden Farms was the first affected (over 1,200 mosquitoes collected in the month), and then the mosquitoes must have decided to visit relatives up north around the Legacy apartments throughout August (over 2,400 mosquitoes). By September, four trap sites gathered over 100 mosquitoes each, as the overall numbers dwindled in the waning days of the season.

Large numbers of mosquitoes affected several city or county parks throughout the summer. The aforementioned 2,400 mosquitoes collected in

August to go along with the 2,812 July mosquitoes likewise affected Greenbriar Park, Lee Martinez Park, and McMurray. Also in July, the Ramah-Stewart Case Park region received 1,121 collected bloodsuckers. The extreme southeastern parks experienced a quick start in June with over 1,600 mosquitoes tested.

The aforementioned 1,600 *Culex* species primarily affected the Fossil Creek Reservoir Natural Area during the same time. The 'at risk' area extended north, fueled by the 2,415 studied insects through Topminnow and up into the Environmental Learning Center (ELC) and Running Deer Natural Area (RDNA). By the end of July, the monthly swarm of 3,900 mosquitoes had drifted north, localizing around the ELC and RDNA, with a second distinct group (numbering over 2,800) centered on the Gustav Swanson and McMurray natural areas. Towards the end of August, the significantly largest gathering (2,402) took place around the Gustav Swanson and McMurray natural areas.

The only water bodies significantly affected by large numbers of mosquitoes were Fossil Creek Reservoir (in the south), in June and July, then Terry Lake (in the north) from July through August. A portion of Warren Lake sat in an 'at risk' area in September. Waterways, largely, followed the same directional drift, with the exception of September.

A couple small spots along the Cache la Poudre River saw localized highly populated areas (1,131 total scattered among five traps) in June. By end of July, those trap totals swelled to 3,141 for the month. August saw the trap count total drop to 2,201. Things changed drastically in September as the mosquitoes along the river essentially disappeared and pockets (ranging from 75 to 149 mosquitoes) appeared along canals, ditches, and a creek. There were only three collection days in the month of September, so overall numbers were expectedly low. The abrupt drifting away from the river to 'inland' canals and ditches, as well as Fossil Creek with its likely low water level (nearby weather stations collected little precipitation in late August into September), may indicate locations where females were laying their eggs before cold temperatures arrive.

As oppose to the many nameless trails, mosquito abundance-related risk areas affected very few of the major trails. The northeastern portion of East Poudre Trail passes by four traps who collectively totaled 920 mosquitoes in June. The southeastern segment was also in a moderately high-risk area, with a nearby trap count of 211. The only other trail crossing a threat area was Fossil Creek. A couple nearby traps totaled 510 and 234.

In July, two prominent risk areas hovered over portions of the East Poudre Trail. The adjacent trap FC-066 and its 1,219 count influenced one portion, along with nearby trap FC-027 (1,273). The northeastern portion was again a hot spot with nearby traps totaling 2,812 mosquitoes. August saw a similar spatial pattern as July, the exception being FC-066 collected only 653 and FC-027 was not a factor.

As with the other mapping categories, trails saw a big spatial shift in September. East Poudre Trail (running along Cache la Poudre) did not cross any 'at risk' areas. Instead, several previously untainted trails suddenly had to deal with relatively large mosquito numbers. Pleasant Valley and West Spring Creek trails, in the study area's western half, went from extremely low nearby trap totals to 149 and 124, respectively.

A couple traps near Fossil Creek Trail escalated their combined total to 129 mosquitoes. The middle section of Power Trail, aptly named for traversing under a power line, experienced increases of four nearby traps increase collectively to 216 mosquitoes. The southeastern region of the study area consisted of a large threat area totaling over 500 collected specimens out of 844 for all sites in September.

Three of the major trails referenced earlier: East Poudre, Power, and West Spring Creek are popular for walking and biking. They are also suitable for horse riding. Numerous smaller, nameless trails afford other options for horse riding, especially those unpaved and away from popular travel paths.

Considering horses are a viral host for WNV, like humans, concern for trails crossing into areas at risk for increased infection rates, doubles for those in the age 65 and older group who like to spend time outdoors riding their horses. Not only do they have to consider themselves, but also their four-legged companion.

DISCUSSION

West Nile virus is an interesting disease in that there appears to be somewhat of a mixture of known factors derived from studies and recognizable unknown influential factors yet unidentified. The virus' transmission cycle is widely accepted; however, its origin remains a "the chicken or the egg" causality dilemma—origin point in the bird or the mosquito? In addition, two infected people standing next to each other at the same time; nonetheless, for yet unexplained reasons, only one of them develops symptoms.

Age has found to factor into susceptibility of the West Nile virus. As we get older, our natural immune system starts to lessen. Our chances of becoming infected increase, which hampers desires to spend time outdoors. Concerns may grow with every mosquito bite as we age.

Increases in reported cases in recent years may appear indicative of an escalating course of WNV incidences. On the other hand, these higher numbers may also derive from an upsurge in medical and research studies. Expanded public awareness may have also encouraged symptomatic people to see their doctors for a proper diagnosis in a more promptly fashion. To assist in battling the virus requires a continually developing knowledge base, both for the medical community and the public.

To strengthen overall knowledge of West Nile virus requires ongoing studies relating to the mosquitoes, virus hosts, and possible environments conducive for WNV prevalence. Regardless of geographic levels (local or national), performing spatial analysis can significantly aid in determining both mosquitoes prevalence in an area, as well as the human risk level based on infection rates. Knowing which environmental settings (e.g. presence of water, human-altered vs. natural, climate) may present potential risk, drives further research studies, which leads to more effective public awareness methods and, in turn, awareness of one's surroundings. To examine how spatial analysis can benefit this research study, employing the inverse distance weighted (IDW) interpolation method determined if the mosquito collection data could produce hot spots of mosquito abundance and infection rates. Despite IDW's limitations, as discussed earlier, this method provided a suitable generalized picture. Multiple timeframes including: weekly, monthly, and annually provided the basis for spatial analysis.

Upon creation of the rasterized hot spots, comparative analysis followed focusing on the WNV impact with the other study components. These components included where the targeted human subjects live and where they may recreate outdoors, in addition to possible correlations with weather conditions.

After the analysis, certain senior residential and nursing care facilities were identified that existed in areas of elevated infection rates and/or increased mosquito prevalence. The number of years studied, four, provided a small sample size; however, enough data existed to form a suitable starting point, upon which future mosquito collection data can be easily added and strengthen designated hot spots.

Coinciding with the facilities, enough data was available to present potential risk areas associating with outdoor locations the human subjects may frequent. Whether these locations be local parks, natural areas, lakes or ponds to sit beside or boat on, waterways to picnic alongside, or trails to walk along, information is available to aid in alerting visitors of a possible health danger at a given time. Additionally, senior communities and facilities can provide suitable warnings for those residents wishing to stroll around the property or neighborhood.

Unfortunately, analysis of correlation between weather conditions and mosquito abundance and/or infection rates did not reveal clear results of possible interrelationship between each other. Primarily, the generalization of the weather data tainted the results. That is, the weather elements fluctuated too often to provide reasonably accurate monthly or seasonal totals. Additionally, as mentioned earlier, aggregation of wind direction and speed data is not possible, as they can vary considerably during a 24-hour period, much less for a month or season.

AREAS FOR FURTHER RESEARCH

The spatial analytical methods outlined in this research study represent only a few possible courses of studying West Nile virus. Other relative methods meriting further exploration, but not included in this general study are:

1. **In-depth Weather Study** – various study results indicate possible relationships between West Nile and weather, advocating a more in-depth examination within the study area (Soverow 2009).

2. **Dead Birds Study** – studies have shown certain dead birds are carriers of West Nile virus (Duggal et al., 2014; Shuai et al., 2006; Yaremych et al., 2004).

3. **Land Use** – do certain land use classifications foster mosquito abundance or infection rates?

4. **Landscaping Impacts** – does xeriscaping help reduce mosquito prevalence?

5. **Other Environmental Factors** – models have been developed estimating WNV risk concerning climate (Cooke III et al., 2006). Are there significant differences between urban and rural living (Barrera et al., 2010)?

6. **Other Factors** – does WNV has a meaningful effect on human or equine pregnancies?

Subsequent studies, based on the results of this research study, can take the next steps in identifying detailed spatial correlations between positively infected mosquitoes and their surrounding environment, including a more in-depth study of weather conditions. Further studies may also be relevant in exploring effects on different age groups.

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