JOURNAL OF THE NACAA

ISSN 2158-9429

VOLUME 18, ISSUE 1 – JUNE, 2025

Editor: Linda Chalker-Scott

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Public Health Risk of Invasive Fire Ants As Monitored Through Allergy Cases and Climate Patterns in Oklahoma from 2015 to 2022

Abstract

The red imported fire ant (RI FA), *Solenopsis invicta*, has become a concern for Extension clientele. RI FA's aggressive behavior poses public health and economic threats. Since its introduction to the U.S. in the 1930s, RI FA has spread and caused damage to agriculture, infrastructure, and public health. This study investigated the correlation between climate factors—such as average air and surface temperatures, and drought indices—and the distribution of RI FA-related medical cases in Oklahoma from 2015 to 2022. Despite moderate correlations, no statistically significant relationships were found. Geospatial analysis revealed that most cases occurred in areas known for RI FA presence. Although climate factors did not predict RI FA spread, the study emphasizes the importance of continued monitoring and integrated pest management to mitigate RI FA's impact. As these ants adapt to colder climates, it is crucial for Extension professionals to educate clientele on the risks and appropriate control measures to prevent further expansion of the RI FA.

Introduction

Red imported fire ants *Solenopsis invicta* (RI FA) have had a wide-ranging impact on Extension clientele, particularly in the southeastern US). RI FA have had negative impacts on various sectors of the agricultural industry and the environment and have become a growing public health concern. Their aggressive behavior and stinging ability can lead to damage to crops, livestock, and wildlife, and their venom can pose health risks to humans and other animals.

Red imported fire ant history and spread

During the 1930s, red imported fire ants *S. invicta* (RI FA) were inadvertently introduced to Mobile, Alabama, likely from a cargo ships ballast (USDA-APHIS, 2023). Originally from South America, the ants steadily spread into any areas where conditions were favorable through 1940-1960, often displacing native ant and ground dwelling species (Jemal and Hugh-Jones, 1993). RI FA first appeared in Oklahoma in 1985 near Waurika (OSU Extension, 2023). Today, RI FA colonies infest 250 million acres in the US and have been found in 40 Oklahoma counties (Rebek, 2008). Most of these infestations were found to be the result of the movement of hay bales between producers to farmers in need (Dekker, 2021).

Public health and economic concerns to Extension clientele

Although little data exists specifically for ants, insect sting hypersensitivity affects approximately 5-7% of the U.S. population (Steigelman and Freeman, 2013; Tankersley, 2008). Fortunately, only a very small percentage of the population is severely allergic and only 40-100 fatalities are recorded annually (Bilò and Bonifazi, 2009). An increasing public health concern is RI FA building nests indoors in long-term care facilities and other locations with vulnerable populations. Fatalities have been reported because of indoor contact with RI FA as well as incidents involving young children that include morbidities and fatalities (Amador and Busse, 1998; Carroll and Villa, 2003; Hardwick et al., 1992; Rupp and DeShazo, 2006). In addition, RI FA are known for their ability to damage infrastructure such as sidewalks, roads, parks, and similar locations because of their nesting preferences (Salin et al., 2000). They have caused major damage to roadways in southern states (Banks et al., 1990). A report from Texas A&M University, on the economic impacts of RI FA, estimated the annual expenditures caused by RI FA to be over $575 million per year in addition to colony control efforts of $581 million per year (Salin et al., 2000). These public health and economic challenges present concerns for clientele served by Extension.

Quarantine and control

Historically, Oklahoma has represented the northwestern limit for the spread of RI FA in the central region of the US. At present, the southern border and southeastern portion of Oklahoma are all under USDA quarantine guidelines for the RI FA. The quarantine was first enacted in 1988 and has been extended three times, including recently in 2021 to add Pittsburg County (Figure 1).

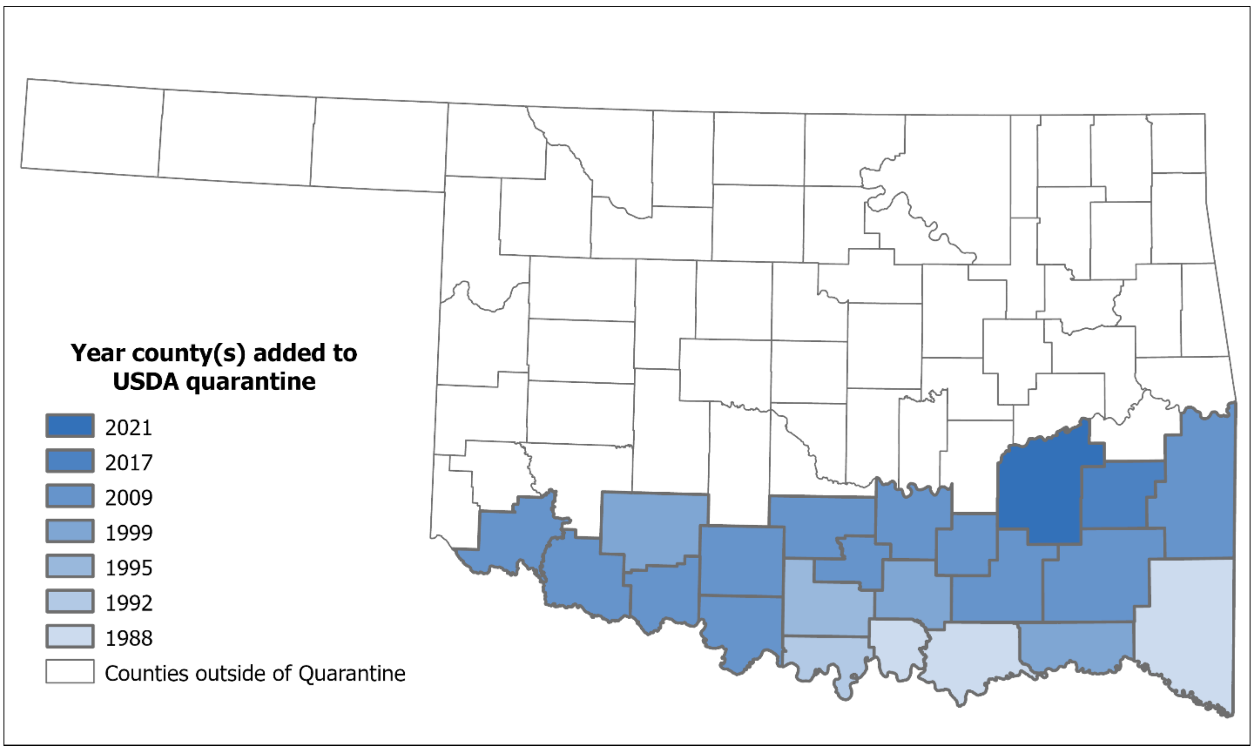

Figure 1. Additions to Oklahoma RI FA quarantine over time.

These quarantine regulations are aimed at slowing down accidental transportation of these ants and their colonies from the movement of soil and soil moving equipment, hay, nursery stock, and plants with attached root system (USDA-APHIS, 2017, USDA-APHIS, 2022; USDA-APHIS, 2023). Evidence also suggests disruption of the colony by plowing and soil moving machinery is also a cause of the spread of RI FA forcing them to relocate and potentially creating multiple colonies (King and Tshinkel, 2008).

Climate impact on fire ants

RI FA are difficult to distinguish from other native red ants. The biggest differences are the RI FA's ability to outcompete native species and their tendency to defend their colonies in large numbers (Jemal and Hugh-Jones, 1993). As the ants are native to South America, the original consensus was the climate requirements needed for ant survival were similar to their native country, and that the ants would not survive cold winters in the US (Francke et al., 1986). These climate patterns alone are not their limiting factor and RI FA have begun to adapt to colder climates (James et al., 2002). RI FA also move deeper within the colony to maintain favorable brood temperature in colder months (LeBrun et al., 2012).

Methods

This study aimed to investigate the potential spread of RI FA in Oklahoma by analyzing cases of confirmed RI FA venom immunotherapy patients over the last seven years with regional temperature averages and drought index, as well as to provide new knowledge to the previously assumed temperature ranges of RI FA, indicating the likelihood of RI FA expanding their ranges within as a result of climate changes, and to suggest new quarantine limits.

For our outcome variable we used RI FA cases as defined by a patient who has been tested for or currently receives treatment for RI FA allergy at our partner clinic. We obtained this data on venom testing and venom immunotherapy (VIT) cases between January 2015 and December 2022 from the Oklahoma Allergy and Asthma Clinic (OAAC). The OAAC is the largest allergy care clinic in Central Oklahoma. Due to their expertise, many of their patients also come from southern Oklahoma and from neighboring states of Texas and Arkansas. Upon request or referral to the clinic, patients are evaluated and entered into their electronic medical records (EMR) database system and classified by ICD-10 code. For inclusion in our study, patients must have been tested for suspected RI FA allergy or had begun treatment for VIT for confirmed RI FA exposure. We included only the first encounter. We excluded patients who were tested for general insect allergy as it was not possible to ascertain the species of insect that was causing the allergy. We also excluded any duplicate records of patients who switched doctors but continued treatment for VIT at OAAC. A database containing all cases and climate variables as described per year was created in Excel.

For our explanatory variables we assessed the number of days, based on climate temperatures, where the weather was favorable for RI FA to forage for food and a drought index to assess possible relationship with water needs, or lack thereof, of RI FA. Temperature data for each of the nine climate divisions of Oklahoma were obtained through Oklahoma Mesonet daily averages (Oklahoma Mesonet, 2023). Average daily air temperatures and average daily surface temperatures were converted to a count of days during each year from 2015 to 2022 where the average daily temperature was within the range of foraging tolerance (50°F-104°F).

Drought information was accessed via the US Drought Monitor (Pugh, 2023) and broken into the nine climate divisions in Oklahoma. Drought data are given as a Drought Index Score. The drought score ranges between 0-500 with higher values indicating a more severe drought condition. These scores were then averaged by month and year. We then categorized the temperature and drought data from the nine climate regions into three major categorical regions of north, central, and south.

For statistical analysis, we used a Pearson correlation analysis to investigate possible correlation between cases and the three climate variables. Next, we followed up with a linear regression analysis. For all our statistical tests a standard level of significance of $P<.05$ was used. Finally, a geospatial analysis was performed in ArcGIS Pro. For each patient, we were provided with the billing zip code. We then used this data to geocode their approximate location by creating centroids based on the patients billing ZIP code and superimposed that on the current USDA Oklahoma quarantine map. To further investigate the geographical area, satellite Land Use/Land Cover from USDA Cropland Data Layer (CDL) (USDA-NASS, 2023) was used to investigate areas where potential agricultural soil disruption may increase RI FA movement. The geographical location (billing ZIP code) for each reported case was overlaid on this map and the percentage of cases residing within each land use category calculated.

Results

Throughout the study period, 64 cases of VIT were reported in the OAAC system for an average of 8.12 cases per year (±2.64). The minimum was four cases in 2018 and maximum in 2022 of 12 cases (Figure 2). The average number of favorable days has been abbreviated TAVG to signify air temperature-based counts and SAVG to signify surface temperature counts (Table 1).

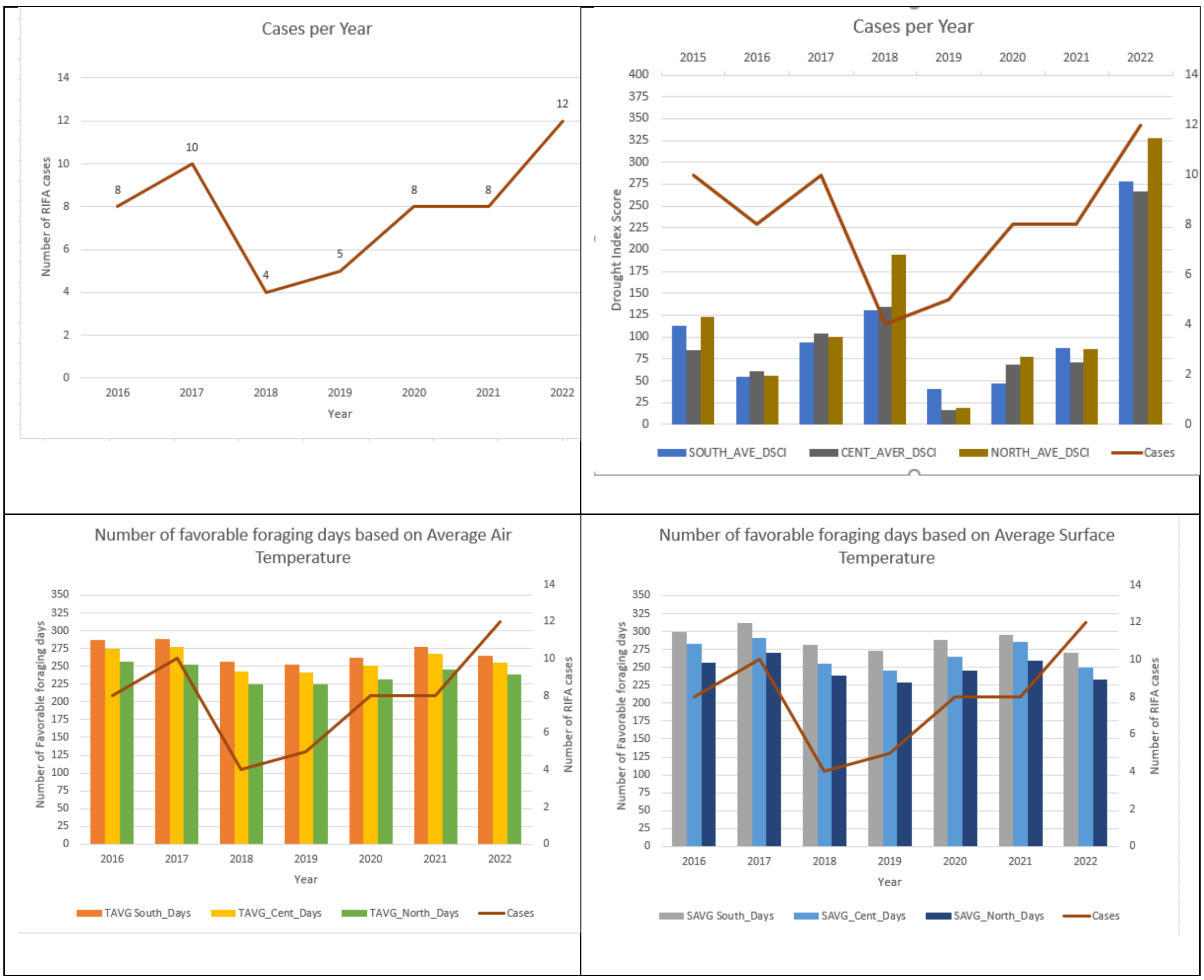

Figure 2. Yearly cases, air and surface temperatures, and drought index (DSCI) during the study period.

Table 1. Descriptive statistics for climate variables.

Variable	Minimum	Mean	Maximum	Std Dev
Cases	4.00	8.13	12.00	2.64
TAVG Southern Region	253.00	270.63	288.00	13.53
SAVG Southern Region	266.00	285.88	312.00	15.95
Drought Index Southern region	40.00	105.63	279.00	77.13
TAVG Central Region	241.00	259.63	278.00	14.08
SAVG Central Region	245.00	267.25	291.00	17.43
Drought Index Central Region	16.00	100.75	267.00	75.33
TAVG Northern Region	224.00	240.38	256.00	12.97
SAVG Northern Region	229.00	246.88	271.00	14.22
Drought Index Northern Region	18.00	122.63	327.00	97.24

The climate graphs show the relationship over time with the drought index, the average days where the air temperature was within 50°F-104°F, and the number of days where the average surface temperature was also in range along with the number of cases on the secondary axis (Figure 2). For our Drought Index variable, the minimum average

DSCI score was 16 in the central region recorded in 2019, and the highest average DSCI score of 327 was found in the northern region in 2022. DSCI scores for each region were similar and showed the most annual variability among our climate variables. The northern region was on average the driest portion of Oklahoma. The number of days where the air temperature was favorable for RI FA to leave the colony were relatively stable across regions (Figure 2). The minimum TAVG was 224, measured in the northern region in 2018 and 2019. The maximum TAVG was 288 in the southern region in 2017. The mean TAVG between regions only varied 15 days per year with the most variation in TAVG between years being in the central region. Surface temperatures followed the trend of air temperature but with less variability. Surface temperatures overall remained more stable than air temperature, which was reflected in the calculation of number of favorable days (Figure 2).

When assessing past Oklahoma Mesonet data, there was no timeframe within our study where the sustained soil temperature was below 24.8°F for longer than two days. The Pearson correlation matrix showed moderate relationships between cases and air temperature and drought index variables. However, none were statistically significant. This finding was similar when analyzing relationships between cases and surface temperatures as well as drought index. A linear regression analysis was also run. However, none of our variables showed a statistically significant relationship between cases and climate variables. The geocoding of cases by ZIP code centroid showed a large cluster around the Oklahoma City area with 22 cases (34% of our data sample, Figure 4). Also, 92% of cases fell within areas of known RI FA presence. Among those, 18% of cases were in areas currently under USDA quarantine.

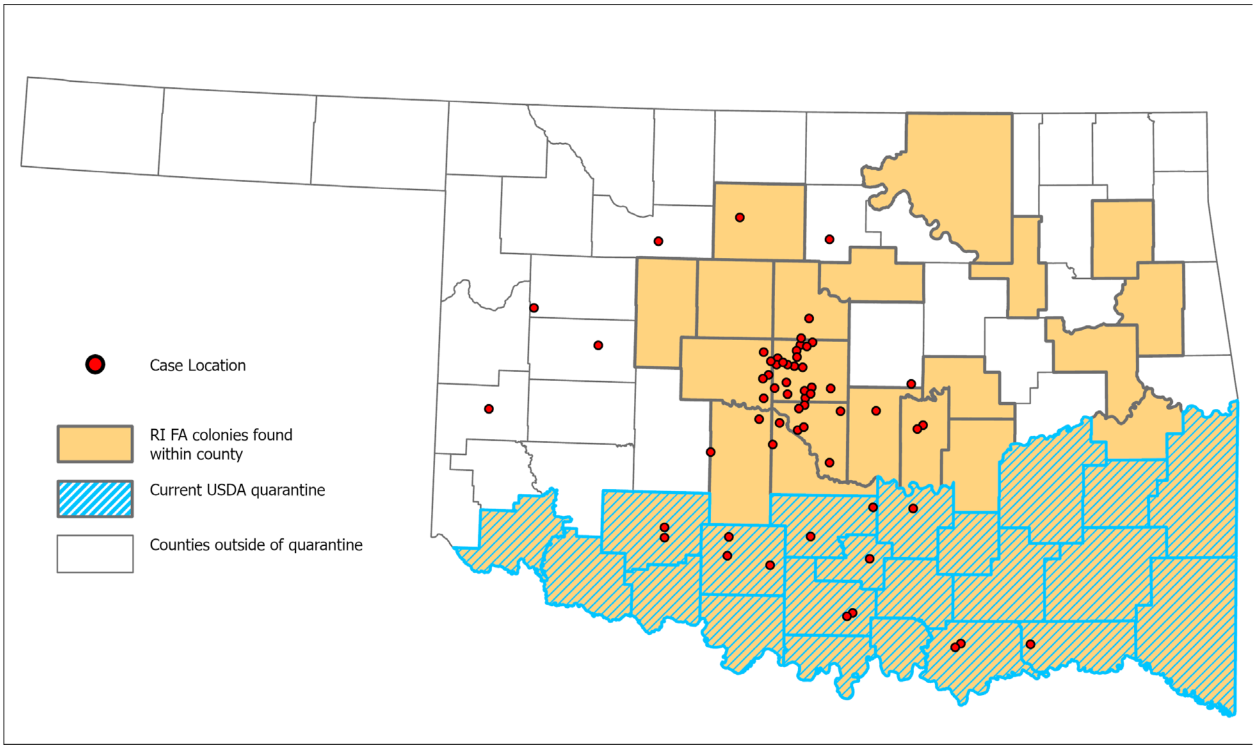

Figure 3. Oklahoma counties with known RI FA colonies and geographical location of ant allergy cases.

The geospatial analysis of Oklahoma land use showed that 19% of the state is covered by specific agricultural land cover that is prone to soil disruption due to agricultural practices. Almost 53% of Oklahoma is covered by non-agricultural environments favorable to ants with low likelihoods of soil disruption. Thirty-two percent of the ZIP codes with reported cases were those with agricultural activity making up more than 15% of the area. Thirty-four percent of ZIP codes with reported cases were in areas that were more than 25% developed.

Discussion

This study set out to determine the spread of RI FA in Oklahoma in relation to climate variables derived from average air temperature, surface temperature, and drought measures. The study used reported data on RI FA allergy cases either tested for or treated with venom immunotherapy. During the study period, 64 cases of reported bites from RI FA were within the eight years investigated, ranging from 4-12 cases per year with the highest number recorded in 2022 and the lowest in 2018. The number of days with temperatures suitable for foraging as well as the official drought index recorded each year remained relatively constant between regions during the study period. The analysis of ant-related cases in relation to climate factors did not show a significant association. Among our investigations we tried multiple different forms of analysis, including several types of linear regression and generalized linear modeling, and none showed statistically significant results.

Previous findings have suggested a link between temperatures and RI FA presence (Korzukhin et al., 2001); however, our study did not confirm this. This discrepancy is most likely due to a few different limitations as discussed in detail below. In addition, temperature differences for favorable foraging days in Oklahoma on average are minor. Between the southernmost region and the northernmost regions, the difference in days that are not within the range for foraging was only 30-45 days. A month is not a long enough period to truly show a substantial change. This difference would be a noticeable concern if RI FA were associated with flowering plants timelines. However, because the ants do not need a specific food source, this is not a limitation to them. RI FA will forage everything from seeds and plant matter, carrion, and farm honeydew from aphids (Coppler et al., 2007; Drees et al., 2009).

Our geospatial analysis showed although the entire state is not under quarantine most of our RI FA cases were within areas known to have RI FA colonies. Within these areas, about a fifth of cases were distributed in locations that are currently under quarantine. When examining the spatial relationship between land use and RI FA case distribution, we observed that only 12 of the 49 ZIP codes with RI FA cases had neither significant percentage of active soil disruption from agriculture nor developed land. Since 34% of our sample resides in the Oklahoma City metro area, it is unsurprising these ZIP codes experience frequent disruptions from lawn mowing to other soil moving activities (Castillo-Guevara et al., 2019).

Limitations

The greatest limitation of this study is the small sample size per year of ant specific venom testing or VIT patients. Additionally, our data do not extend far enough back to look at this interaction over multiple decades. Using temperature data introduced a significant amount of collinearity to our model. The data of SAVG and TAVG are very highly correlated as they are both temperature recordings. To address this, surface temperature is the better measure of temperature than air temperature for RI FA. If we were to investigate wasps and hornets whose nesting sites are open to the air, TAVG would be the better variable to assess temperature change for them.

A further limitation of the data used is the large data gap pertaining to identifying insect specific incidents. This is because the clinical presentation of an allergic reaction in an emergency room does not vary between insect species. These instances are often coded as ICD-10 code T63.4 “Toxic effect of venom of other arthropods” but also “Allergic Reaction” or “Anaphylactic Shock” as the treatment between the types of stings are the same (Clark et al., 2005). Also, those with milder symptoms may not seek treatment for this type of allergy and instead avoid the allergy-causing insect. Consequently, ant bite incidents may go underreported compared to bees, wasps, or hornets (Baker et al., 2014).

Implications for Extension clientele

Despite the lack of association between RI FA bite cases and climate factors within this study, RI FA constitute a public health concern. In a 2001 publication (Korzukhin et al., 2001), the USDA-ARS reported significant expansion possibilities for RI FA in Oklahoma (Figure 4).

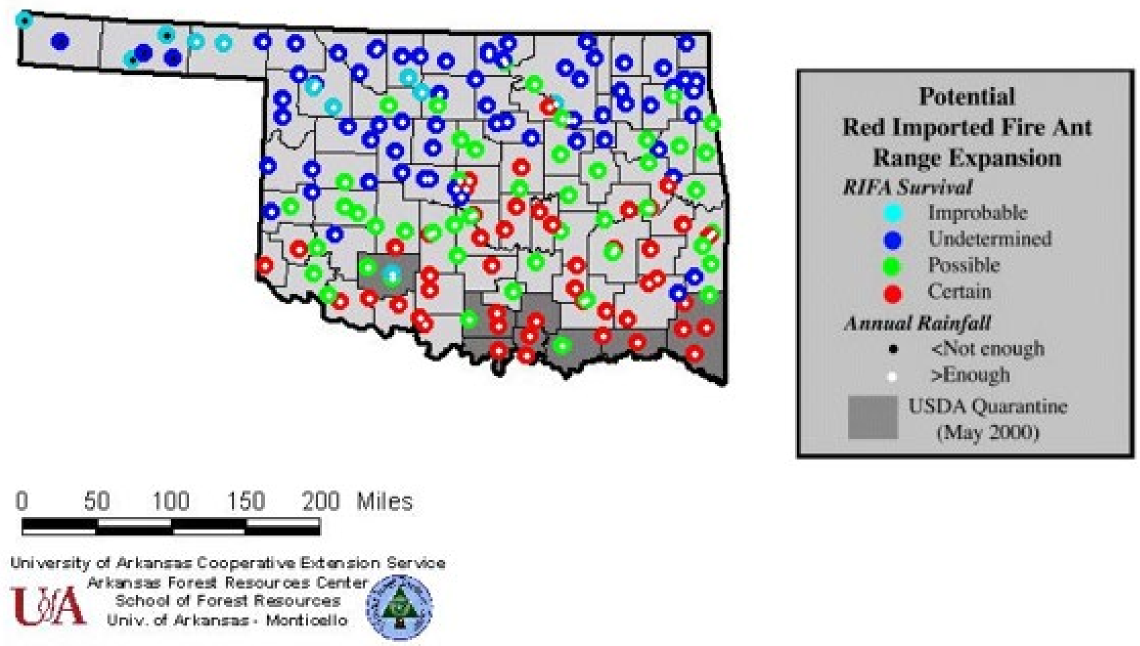

Figure 4. 2001 map of possible expansion ranges of RI FA in Oklahoma.

Within the study, Korzukhin et al. (2001) estimated a movement of 50-100 miles into Oklahoma. Our case geolocation data matches this modeled prediction well. However, this particular map is outdated, and research has shown RI FA are adapting to colder climates (James et al., 2002). Fortunately, integrated pest management and control strategies are already in place to slow the spread of these invasive ants. Every state Cooperative Extension Service in the quarantined states has guidance for the public on how to perform proper RI FA baiting and use of approved RI FA insecticides. If left unchecked, RI FA pose other unintended consequences. Firstly, RI FAs are attracted to electrical currents and will nest in and around junction boxes, traffic lights, and similar devices. Colonies of RI FA have been known to cause electrical fires because they often chew on electrical wiring (Mackay et al., 1992). RI FA get stimulated by electrical currents and produce an alarm pheromone sending more ants to the electrical source. This can cause the connections in junction boxes and pumps to fail due to the ant corpses interfering and blocking those electrical connections (Van der Meer et al., 2002).

From a disaster management point of view, RI FA are particularly insidious during flooding conditions. RI FA do not drown in their mounds during floods. Instead, they can link together to create rafts and float on top of the water (Mlot et al., 2011). Also, flooding can spread RI FA to areas that previously did not have colonies present (Nester, 2014). Other concerns are reductions in the ability to use built infrastructure like public park areas or sidewalks. The public's utilization of these spaces is often tied to whether they are considered safe (Kemp et al., 2000; Lapham et al., 2016; Salin et al., 2000).

In summary, RI FA are a public health and environmental concern for clientele served by Extension. The health implications are concerning for those who are allergic but perhaps more so to young children and the elderly who have mobility issues. Because RI FA are currently in Oklahoma and found in counties well above the current RI FA quarantine, it is likely only a matter of time before RI FA are endemic to Oklahoma. With proper preparation, we can slow down the spread of these ants and be prepared for any direct public health impacts of their continued expansion. Extension professionals should advise clients to be aware of the risks associated with red imported fire ants (RI FA). Additionally, they should emphasize the importance of proper insecticide and baiting use to prevent the spread of RI FAs. Extension professionals should also inform their clientele about the potential damage RI FAs can cause to equipment and structures, and the importance of managing ant populations to minimize these impacts.

Acknowledgments

Our gratitude goes to the members of the Oklahoma Allergy and Asthma Clinic, Dr. Bret Haymore, Reese Larson, and Ginny Taylor. Their technical help and good humor made this project a great learning experience. We would also like to acknowledge the graduate faculty of the Department of Biostatistics and Epidemiology of the University of Oklahoma Health Sciences Center, for their encouragement and always being available for any and all questions throughout the two years of this study. Last but not least, to my long-suffering editor of 20 years David Brazil for his expertise in technical writing.

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