



A Social Media-driven Digital Twin of an Invasive Species

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Abstract

The digital twin concept and technology is helping improve life and business in many ways. Manufacturing, health, and supply chain systems benefit from digital twins' predictive capacity to better plan and utilize costly and recently scarce resources. This research utilizes social media to drive a digital twin and model the propagation of an invasive species in the United States. 11,723 social media conversations considering the Spotted Lanternfly, an invasive species of insect that poses significant risk to crops and forests within the U.S., were utilized in the natural language processing and modeling. Converging the theory of sociomaterial assemblage and the emerging technology of digital twins, we have created machine learning models and an initial digital twin that predict the paths of these pests. This research advances modeling and simulation by applying the digital twin concept to the application of protecting industry against further natural disasters of crop destruction, resource and food shortage, and forest damage due to invasive species.

Keywords: Digital twins; invasive species; applied analytics; social media

1. Introduction

The spotted lanternfly (*Lycorma delicatula*) is native to areas within China and North Korea and feeds on a range of plants including almonds, apples, grapes, apricots, peaches, plums, and walnuts, as well as hardwood trees (Durham 2019, Otto 2020). This invasive species was first recorded in the US by the Pennsylvania State Department of Agriculture in 2014 (Dara et al. 2015, Barringer et al. 2015). In 2021, the bug was detected in Kansas (Grimmett 2021), Indiana (IDNR 2021), and Rhode Island (RIDEM 2021). States having the spotted lanternfly at the time of this research, as reported by the Animal and Plant Health Inspection Service (APHIS) within the U.S. Department of Agriculture, include Connecticut, Delaware, Indiana, Maryland, Massachusetts, New Jersey, New York, Ohio, Pennsylvania, Virginia, and West Virginia (APHIS).

Kansas and Rhode Island are not found in the list provided by APHIS.

The spotted lanternfly poses economic damage to multiple organizations and industries. A report funded by a grant from the Center for Rural Pennsylvania found that the mitigation efforts, such as education, monitoring, inspection, phytosanitation, among other efforts, would cost \$219.6 million for the state of Pennsylvania (Harper et al. 2019). The same report estimated agricultural losses for Pennsylvania to be \$99.1 million. The economic impact estimate for the forestry industry for Pennsylvania was found to be more costly, \$236.3 million. Of course, there are many downstream economic effects such as lost wages, reduction in state tax income, and increased expenses for social programs. Research conducted in 2019 found that the value from ornamental tree and grape



production industries were worth a combined \$3.515 billion in the states where spotted lanternflies were already present (Urban 2020).

There are many conversations regarding spotted lanternflies occurring in social media, including the identification and detection of the insect. Between September and December of 2021, we collected and analyzed 11,723 tweets on the spotted lanternfly. The distributed and sociomaterial aspects of social media can aid in the acquisition and dissemination of information regarding invasive species and other potential disasters. We aim to utilize humans-as-sensors and tweets-as-signals to construct a low-fidelity digital twin of the propagation of the spotted lanternfly (SLF).

Digital twins are virtual representations of their physical counterparts. Digital twins are useful across the lifecycle of their physical twin, such as in design, operation and retirement phases. Digital twins offer the ability to monitor, model, predict and sometimes control their physical counterparts. By constructing a low-fidelity digital twin of the progression of an invasive species, we can offer commercial and government organizations awareness and predictive capabilities to better prepare for the losses associated with the spread of the spotted lanternfly.

2. State of the art

2.1. Background Literature on Utilizing Social Media

While our low-fidelity digital twin uses many information sources, the model greatly benefits from signals coming from social media. Social media analysis is frequently utilized in consumer and academic research.

Customer service behavior has been found to change based upon the clout a customer has on social media platforms (Gunarathne et al. 2018). This same study found that airline customer service responses to complaints created on social media technologies were answered more quickly when the customer had more followers.

While having a strong social media presence can help expedite customer service (Gunarathne et al. 2018), it has also been found to help service providers generate more positive reviews (Huang et al. 2017). When organizations integrate social media into their technology platforms, the number of their product and service reviews and the positive sentiment in reviews have been found to increase (Huang et al. 2017).

The role of social media in diversity of thought versus the creation of an echo chamber has been studied (Pariser 2011, Kitchens et al. 2020, Shore et al. 2018). Average social media posts containing links tend to reference more moderate sites and information (Shore et al. 2018). A different and multidimensional social media platform study of nearly 200,000 U.S.

adults over four years has found that Facebook and Reddit increase the diversity of information sources presented to users (Kitchens et al. 2020). Both the social media platforms and the users of these platforms wield power (Miranda et al. 2016). Social media platforms have been found to be both emancipatory to content creators as well as enabling to a core group of influencers to shape, control, and wield hegemony (Miranda et al. 2016).

Emancipatory use of social media coincides with use during social protest cycles. Social protest theory research has uncovered three intra-actions in social protest tweets: consolidation, expansion, and intensification (Tarafdar 2021). During the consolidation phase, the discussions tend to share a language and purpose of solidarity. The expansion intra-action includes practices of recruitment and coordination. The last phase, intensification, included the practices of conflict and propagation.

Social media has a role in rumor generation during social crisis. Factors that have been found to propagate rumors during crisis over social media include unourced information, shared personal experience, and the sentiment of anxiety (Oh et al. 2013). The likelihood that a tweet will be retweeted is 3.1% higher given the person retweeting follows the original poster (OP) but is not followed by the OP (Shi et al. 2014). This finding confirms the weak tie theory, that acquaintances may be more influential than close friends (Granovetter 1973).

Social media can be utilized to improve personal branding and career success (Chen et al. 2021). Goffman's theory of self-preservation(1959) exists in the use of social media background checks by hiring managers. Our public and potentially negative behavior is of interest to hiring managers who don't want to be embarrassed and can evaluate applicants by reviewing their free and publicly facing posts (Chen et al. 2021).

Twitter data was helpful in a study covering the human behavior during hurricane evacuation and the effects of demographics on evacuation activity (Martin et al. 2019). The same study utilized the geolocation data of tweets as input into their model and found that the average age of their Twitter research population was younger than their traditional survey respondents and thus reduced overall age bias in the study.

Our research and incorporation of social media is different than the common use cases that question whether social media has a positive effect on society or business. Rather, we accept the commonality of the social media phenomenon and leverage it as a signal to inform a digital twin of the propagation of an invasive insect.

2.2. Background Literature on the Spotted Lanternfly

Spotted lanternflies can only fly limited distances. Thus, it is human related activities, such as shipping infested products or packaging, that has led to their

spread into the United States (APHIS 2014). Now present in the US, it is estimated that the population of Spotted lanternflies will grow at 447% annually (Strombom and Pandey 2021). Methods to slow the population growth have been studied for their efficacies. Chipping and insecticides were found to offer a decline in the SLF population, while egg parasites and entomopathogens can reduce growth rate but not to the point of population reduction (Strombom and Pandey, 2021). Entomopathogens are viral, fungal, or bacteria pathogens that have been shown to successfully reduced populations of other invasive species, such as the *Lymantria dispar* moth (Hajek and van Frankenhuyzen 2017). While the chipping method was found to be effective in reducing the SLF population, it also requires the destruction of the infected wood. The destruction of the wood may be permissible when the SLF is attaching non-native trees such as the tree of heaven, but the bugs also feast on apple, plum, cherry, grape, and other fruit bearing and woody plants that are raw materials to many industries. When destruction of the affected tree is permissible, mid-winter chipping to a standard 1-inch to 2-inch size reduced the presence of live SLF nymphs by 100% (Cooperband et al. 2018).

Another study compared the effectiveness of 31 insecticides on SLF egg masses. Chlorpyrifos caused 100% mortality in all treated egg masses while paraffinic oils offered the second highest mortality up to 71%. When chlorpyrifos gets into the soil, it can take years to break down and if the human body absorbs the insecticide a toxic is created that attacks the nervous system. Exposure of chlorpyrifos to children has been linked to developmental delays (Christensen et al. 2009). For chemical application requiring direct contact, the SLF adults are most active during the afternoon hours and populations have been found to peak in early to mid-September (Myrick and Baker 2019). While the treatments to reduce population growth have downsides, permitting the SLF population to grow is also not a feasible solution.

The spotted lantern fly poses economic damage. A report funded by a grant from the Center for Rural Pennsylvania found that the mitigation efforts, such as education, monitoring, inspection, phytosanitation, among other efforts, would cost \$219.6 for the state of Pennsylvania (Harper et al. 2019). The same report estimated agricultural losses for Pennsylvania to be \$99.1 million. The estimate for forestry economic impact for the state was found to be even more, \$236.3 million statewide. Of course, there are many downstream economic effects such as lost wages, reduction in state tax income, and increased expenses for social programs.

3. Materials and Methods

3.1. Data acquisition and preprocessing

This study involved a collection of 11,723 tweets from September of 2021 until the end of December of the same year. Acquisition of tweets was accomplished using Twitter's API while the preprocessing involved data cleaning, preparation, and new metadata creation.

During the social media analysis, we utilized *shinyapp* and other R libraries to generate an initial digital twin of the propagation of SLF in the U.S. Our analysis includes geo-location identification, network analysis of followers and re-tweeters, time series analysis, sentiment analysis, and predictive modeling.

The data tidying and analysis begins with preprocessing the tweets. We labeled the tweets with geolocation and sentiment metadata to ease data visualization. We built a network graph plotted by the relationships between original posters (OP), who they follow, and other accounts which retweeted the OP's messages. We labeled 989 tweets that indicate an SLF was killed or prescribed to be killed using simple bag of words technique. A naïve Bayes model was created to determine whether our labeled factors can predict the death of an SLF by a human. Using the factors of tweets being a favorite, retweeted, the sentiment within the tweet, and the poster's location, we could predict the death of a bug with an accuracy of 92.28%. The R programs and a compressed CSV file of the 11,723 tweets are available publicly at a Gitlab site (<https://gitlab.com/jimscheibmeir/spottedlanternfly>). The following diagram illustrates the methodology of our research process and outcomes.

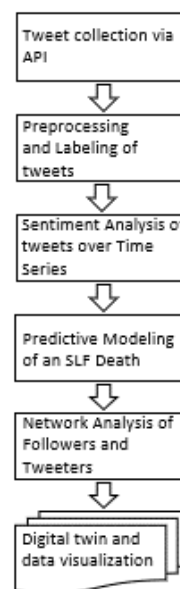


Figure 1. Social media-driven digital twin research method

4. Results and Discussion

4.1. Time Series Analysis

Spotted lanternfly adult populations have been found to peak in early to mid-September (Myrick and Baker.

2019). Our time series analysis of the SLF related tweets follows the adult SLF peak activity. Human observations of the SLF are the input signals into this time series. Using the sociomaterial aspects of human-sensor to twitter-signal, we confirm the increased

adult SLF behavior during early to mid-September compared to the later months. Figure 2 illustrates the SLF tweet volume over time, from September (peak activity) to December of 2021.

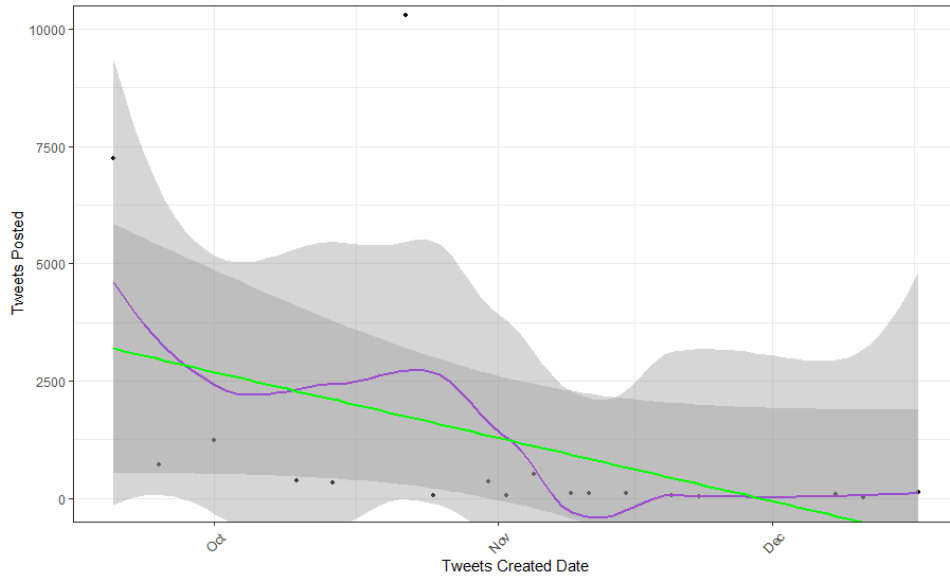


Figure 2. Time series analysis of SLF tweets confirming peak adult SLF activity

While the tweets referring to the SLF decrease from the most active mid-September period into the winter, we have found that the sentiment in the messages change

variably over time. To normalize the sentiment variance, we convert the tweet sentiment over time series using a z-score. Then we plot the sentiment z-score timeseries in Figure 3.

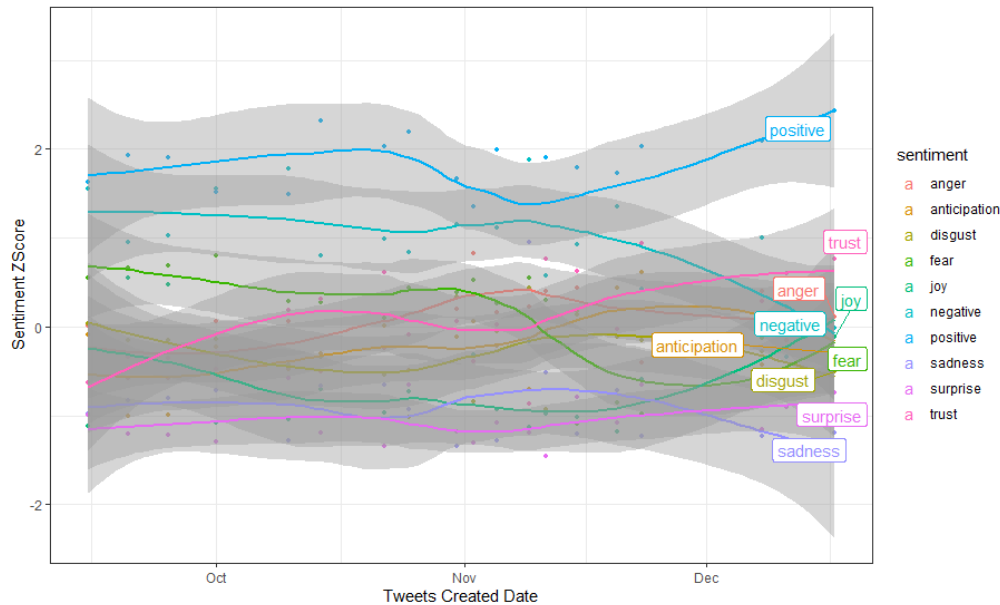


Figure 3. Sentiment z-score over time series

From the most active period to the least active period, we notice three stages of sentiment change that reflect the three intra-actions found in social protest cycles. Social protest theory research has uncovered three

intra-actions in social protest tweets: consolidation, expansion, and intensification (Tarafdar, 2021). During the consolidation phase, the discussions tend to share a language and purpose of solidarity. The expansion intra-action includes practices of

recruitment and coordination. The last phase, intensification, includes the practices of conflict and propagation. In our sentiment analysis over time series, from when the SLF adults have heightened activity into less active winter months, we observed a reduction in social media volume and variance in message sentiment.

In the first sentiment-change stage, trust and positivity are both increasing in message presence and are within the top four sentiments by volume. This coincides with the consolidation phase of a social protest cycle. During the consolidation phase, when a community is fighting the dangers that invasive species pose on economy, agriculture, and food security, conversations must build on solidarity against the threat. However, during the second sentiment-change stage, anticipation, anger, disgust, and negativity begin swelling in presence while the trust and positivity sentiments are both in decline. During this second phase, we see indication of the second intra-action of *expansion*. Social activity of coordination and recruitment are evidenced in the tweet posted on October 26, 2021, titled “Spotted Lanternfly, What you should know” (@BergenCityParks, 2021). The tweet continues to invite the public to a virtual seminar hosted by the Bergen County Department of Health Services and the New Jersey Department of Agriculture.

The third and final intra-action phase of a social protest cycle is intensification and includes propagating and conflict. During December of 2021, sentiments of joy, positivity, and trust were on the rise. While these sentiments do not align to the social

protest cycle intra-action of conflict, tweets and communications do include themes of intensification and propagation. In an example tweet from this phase, the tweet’s heading utilizes all upper-case letters and deems the spotted lanternfly as “notoriously invasive” (@TownWilmMA, 2021).

4.2. Social Network Analysis

The most retweeted tweet was posted by CBS News (@CBSNews, 2021). At the time of this research, the tweet was retweeted three hundred and fifteen times. We analyzed the twitter users who retweeted as compared to the user’s that the CBS News twitter account follows. Only two of the retweeting accounts were being followed by the CBS News account. This lack of bi-directional or mutualism confirms the weak tie theory (Granovetter, 1973); that one-way acquaintanceship may be more influential through tweets and retweets, than close friends or those that have bi-directional following on the Twitter platform.

A network graph is a type of data visualization that illustrates relationships between nodes in classes. From the popular @CBSNews tweet referenced above, only two of the three-hundred and fifteen re-tweeters had been followed by the tweet poster, the CBS News account. In Figure 4, the central node is the CBS News twitter account, and the nodes completing the ring are those twitter account names that retweeted the popular tweet. This visualizes a characteristic of weak ties, that they are mostly one-way and non-reciprocal (Rademacher and Wang, 2014).

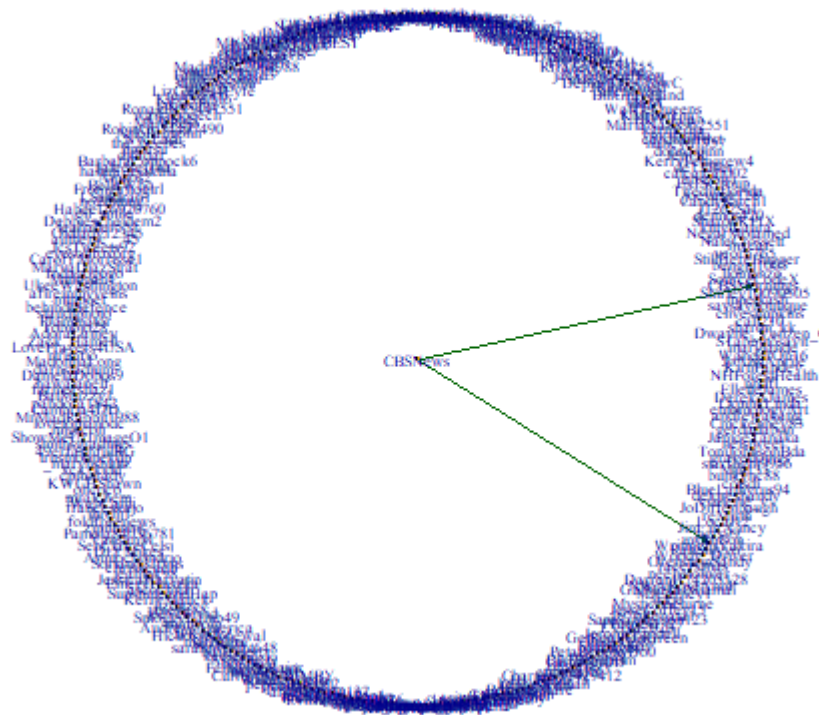


Figure 4. Network graph of the original poster centered surrounded by the mostly unfollowed retweeting accounts of their popular post

4.3. Predicting the Death of a Bug

In our research, we utilize a naïve Bayes model to understand relationships between tweet meta data and whether an SLF was killed or prescribed to be killed in the tweet. Our model considered factors including the tweet’s sentiment, whether it was favored or retweeted, and the location of the twitter user. Researchers studying protein interaction have successfully predicted the protein link interactions using naive Bayes modeling (Singh, 2017). Naive Bayes has also been utilized to accurately predict arson, burglary, and theft (Niu, 2019). Here, we utilize the naïve Bayes model to predict the death of an invasive insect.

Using the factors of tweets being a favorite, retweeted, the sentiment within the tweet, and the poster’s location, we could predict the death, or prescription of death, of a bug with an accuracy of 92.28%. We also found that given a tweet is labeled as towards the death of a bug, there is a greater than 19% probability that the twitter’s location is New Jersey. The same model found that such tweets indicating SLF death also had the sentiment probabilities of negativity(28.4%), fear(21.6%), and sadness(15.5%). The illustration below explains the naïve Bayes formula for this use case and data set.

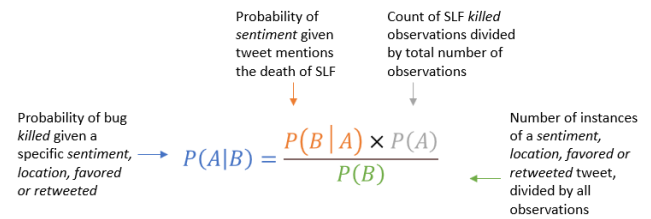


Figure 5. Naïve Bayes formula explained for the death of an SLF prediction model

4.4. Digital Twin of the SLF Propagation

Digital twins help organizations by modeling, monitoring, and predicting physical things. Digital twins may utilize highly visual user interfaces, such as augmented reality (Schroeder et al., 2016). Our digital twin of the propagation of the SLF is of an initial maturity (Scheibmeir, 2021). The digital twin does not utilize 3D elements. This digital twin utilizes humans as sensors and their tweets as signals to monitor the SLF propagation. Using social media analytics and agriculture import and export data (Dall’Erba, Chen, Z., and Nava, N. J., 2021), we predict the movement of the SLF. Figure 5 is output of our SLF propagation digital twin model found at <https://spottedlanternfly.shinyapps.io/spottedlanternflypropagation/>

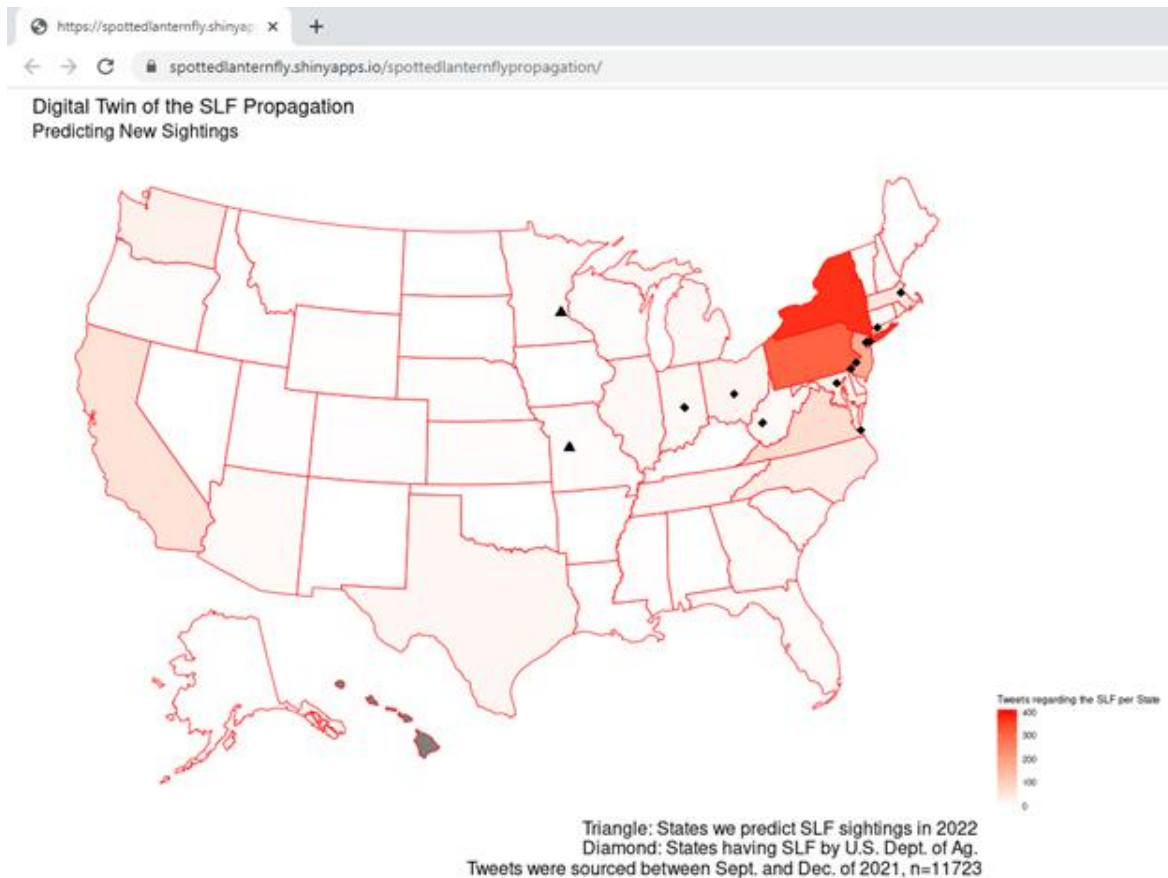


Figure 6. Initial and low-fidelity digital twin of SLF propagation

The states having the highest amount of imported agricultural products include California, Illinois, Iowa, Indiana, Minnesota, Missouri, New York, Nebraska, Texas, Wisconsin, and Georgia (Dall’Erba, Chen, Z., and Nava, N. J., (2021). Import reasons might be for the purpose of local use or to further trade through export. Trade theory suggests that local factors, such as weather, soil, livestock feed, among other factors, will influence agriculture exchange among regions (Feenstra, 2015). Eight of those ten high-import states already have populations of SLF as noted by the U.S. Dept. of Ag. (APHIS) and indicated on Figure 9 by the diamond shape. Based on our social media analysis, the dependency of SLF spread via shipping and transport, and the import of agricultural goods, we predict that Minnesota and Missouri will have SLF sightings in 2022, indicated by the triangle icon illustrated Figure 6.

5. Conclusions

The digital twin concept and technology is helping improve life and business in many ways. This research utilizes social media to drive a digital twin of the propagation of an invasive species in the United States. We collected and analyzed 11,723 tweets posted between September and the end of December of 2021. Converging the theory of sociomaterial assemblage and the emerging technology of digital twins, we created an

initial digital twin.

This research contributes to environmental and agriculture sciences by applying the digital twin concept to protect against natural disasters (crop destruction, food shortage, dead and burning forests). Using the sociomaterial aspects of human-sensor to twitter-signal, we confirm the increased adult SLF behavior during early to mid-September compared to the later months. From the most active period to the least active period, we notice three stages of sentiment change that reflect the three intra-actions found in social protest cycles. In the first sentiment-change stage, trust and positivity are both increasing in message presence and are within the top four sentiments by volume. During the second sentiment-change stage, anticipation, anger, disgust, and negativity begin swelling in presence while the trust and positivity sentiments are both in decline. During December of 2021, sentiments of joy, positivity, and trust were on the rise. While these sentiments do not align to the social protest cycle intra-action of conflict, tweets and communications during this stage included themes of intensification and propagation.

We may be the first to approach creating digital twins regarding an invasive species of insect with concepts of human emotion and sentiment. The posting account of the most retweeted tweet was only

mutually following two of the three-hundred and fifteen accounts that retweeted their popular tweet. This exemplified the weak-tie theory. We found that given a tweet is labeled towards the death of a bug, there is greater than 19% probability that the twitter's location is New Jersey. The same model found that tweets indicating SLF death also had the sentiment probabilities of negativity(28.4%), fear(21.6%), and sadness(15.5%). Most importantly to the agriculture and forestry industries, and towards environmental science, our digital twin predicts sightings of spotted lanternflies will occur in Missouri and Minnesota in 2022.

Our methods and outcomes can assist researchers, practitioners, and public organizations. Researchers can utilize our shared code and data file to mimic, reproduce, or extend the research into future dates to continue to elaborate on the potential of social media as input signal into digital twins. Practitioners within agriculture and forestry industries and environmental science can alter our approach to unlock observations and predictions regarding other social activities and phenomena as related to the risks and availability of their raw materials. Public organizations can use our research and outcomes to better prepare the agriculture and forestry industries and the public on awareness and education regarding the SLF.

This study is limited in multiple facets. First, the only social media platform utilized in the research is Twitter. Future research should utilize other common platforms to better acquire the human signal regarding sensing the SLF. This study was U.S. specific but there are other international locations that are dealing with invasive species and have different threat models. Lastly, our timeline for research was only three months in the year 2021 and a more extensive research timeline may uncover more depth or novel findings regarding social behavior and the phenomenon of invasive species.

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