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Technical Working Group Summary Report

Spotted lanternfly, *Lycorma delicatula* (White, 1845)

2017

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Cover: *Lycorma delicatula* adult. Credit: Lawrence Barringer, Pennsylvania Department of Agriculture
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Draft Log

October 2017: Draft report submitted to the spotted lanternfly Technical Working Group (SLF TWG) for review.
November 2017: Comments from SLF TWG received. New information from PDA program staff obtained; revisions of this report begun.
December 2017: SLF TWG first draft.
January 2018: PPQ S&T internal review,
February 2018: draft TWG report updated and forwarded to TWG members for review.
February 2018: TWG report finalized.

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Executive Summary

This report is intended to provide recommendations from the Technical Working Group concerning management of Spotted lanternfly (SLF), *Lycorma delicatula* (Hemiptera: Fulgoridae), an exotic species native to Asia. The original report by the TWG was edited by PPQ S&T to ensure clarity, technical consistency and focus on evidence and non-policy discussions.

SLF was confirmed in Pennsylvania in September, 2014. It is considered reportable/actionable by USDA APHIS PPQ. This discovery and its known pest status in Korea where it was also introduced prompted Pennsylvania Department of Agriculture (PDA) to establish an internal quarantine with restrictions on the movement of many commodities, and evaluate options for managing this pest. Survey results in Pennsylvania show that populations are increasing rapidly with abundant host plants and no natural enemies to suppress populations. At the time of this report (December 2017), the quarantine area was limited to 13 counties, however human assisted spread, primarily through movement of materials with egg masses, is likely to transport SLF to areas outside of the quarantine as SLF densities increase.

Spotted lanternfly is known to feed on plants in more than 20 families (Appendices A, B), and has been reported to be a serious pest of grape vines in Korea (Appendix A). SLF has a strong host preference for *Ailanthus altissima*. More research is needed since SLF may be able to complete its lifecycle on other host plants (research still pending).

The relationship between *Ailanthus altissima* and SLF provides an opportunity to reduce populations using a combination of pest population reduction and host removal (e.g., using systemic insecticide treatments and removal or herbicide treatment of some *A. altissima*, when appropriate). The strategy recommended here relies on the treatment of *A. altissima* with the insecticide dinotefuran using a bark spray application and when appropriate, herbicide treatment or removal of untreated *A. altissima* on known infested properties in the quarantine area. Results from insecticide trials in 2016 found bark sprayed dinotefuran treatment to be very effective in providing a high control level with good residual activity lasting through the time period that SLF would be feeding. There are also a number of effective contact products that could be used by homeowners to reduce populations.

The TWG recommends pursuing suppression of *Lycorma delicatula* populations within the existing quarantine area. The TWG believes that eradication of spotted lanternfly is likely if human-assisted movement is addressed and improvements in detection methods occur. To facilitate suppression and containment of SLF populations the TWG recommends that:

- Survey should continue along the perimeter of existing finds to delimit the population;
- Continued suppression of populations within the core by PDA and others to reduce the potential for human-assisted movement of SLF;
- PPQ and PDA use the *Ailanthus altissima* trap tree/host insecticide or herbicide treatment/removal method, working from the perimeter to the core to contain and suppress the population and reduce the risk of movement outside of the quarantine area, beginning in the southeastern quarantine area northwest of Philadelphia and the Southwestern area in Lancaster County,

- Continue outreach to inform affected citizens and businesses on available detection, identification, and control methods.
- Continue research on:
  - optimizing traps, lures and attractants to enhance survey and control tools,
  - Identifying and characterizing potential biological control agents,
  - developing a colony to support research,
  - confirm that alternate hosts exist and are able to support viable subsequent generations
  - explore areawide approaches to host management and viability of local or areawide eradication of preferred hosts, to include environmental assessments.
  - improving survey methods,
  - improving treatment methods and establishment/use of trap trees, and,
  - Identifying treatments for affected industries.
  - Exploring, modeling and managing human-assisted pathways
  - Explore trade pathways, specifically to limit new introductions

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I. Introduction

The purpose of this report is to present recommendations of the Technical Working Group (TWG) tasked with evaluating the best available options for managing Spotted lanternfly (SLF), *Lycorma delicatula* (Hemiptera: Auchenorrhyncha: Fulgoridae). The TWG considered current strategies and ongoing research in formulating these recommendations. Additional supporting information on methods for survey and control, forecasts, research (ongoing and gaps), and biological information are provided in this report.

Background

Initiating event

On September 22, 2014, the Pennsylvania Department of Agriculture (PDA) received a report from an employee of the Pennsylvania Game Commission (PGC) of an unusual insect infesting tree of heaven, *Ailanthus altissima* (Simaroubaceae) (Spichiger, 2014). SLF was found infesting tree of heaven on three residential properties and one commercial property within a two-mile radius in Boyertown, Berks County, Pennsylvania in September of 2014 (NPAG, 2014; Spichiger, 2014). This was the first detection of SLF in the United States (NPAG, 2014). A specialty stone business located on the commercial property received over 150 shipments from China, India, and Brazil each year (APHIS PPQ SPRO-DA-2014-55). It is suspected that shipments of stone from China arrived infested with SLF eggs.

Regulatory status

USDA APHIS PPQ designates the spotted lanternfly as a quarantine pest and it is considered reportable/actionable at U.S. ports by USDA APHIS PPQ (PestID, 2017). The spotted lanternfly is not currently regulated by additional domestic quarantines (O'Toole, personal communication, 2017).

Current Distribution

As of November 18, 2017, the quarantine area includes thirteen counties, including Berks, Bucks, Carbon, Chester, Delaware, Lancaster, Lebanon, Lehigh, Monroe, Montgomery, North Hampton, Philadelphia, and Schuylkill comprising 6,928.9 sq. miles (4,434,496 acres / 17,945.8 sq. km) encompassing 1,404,544 properties. Survey methods are described in Appendix C.

Survey grid summary as of November 18, 2017	
Total Quarantine Area (Sq. kilometers)	17,945.8
Grids Positive (1 km^2) in Quarantine Zone	882
Grids SLF not detected (1 km^2) in Quarantine Zone	5,040
Properties Positive	1,685

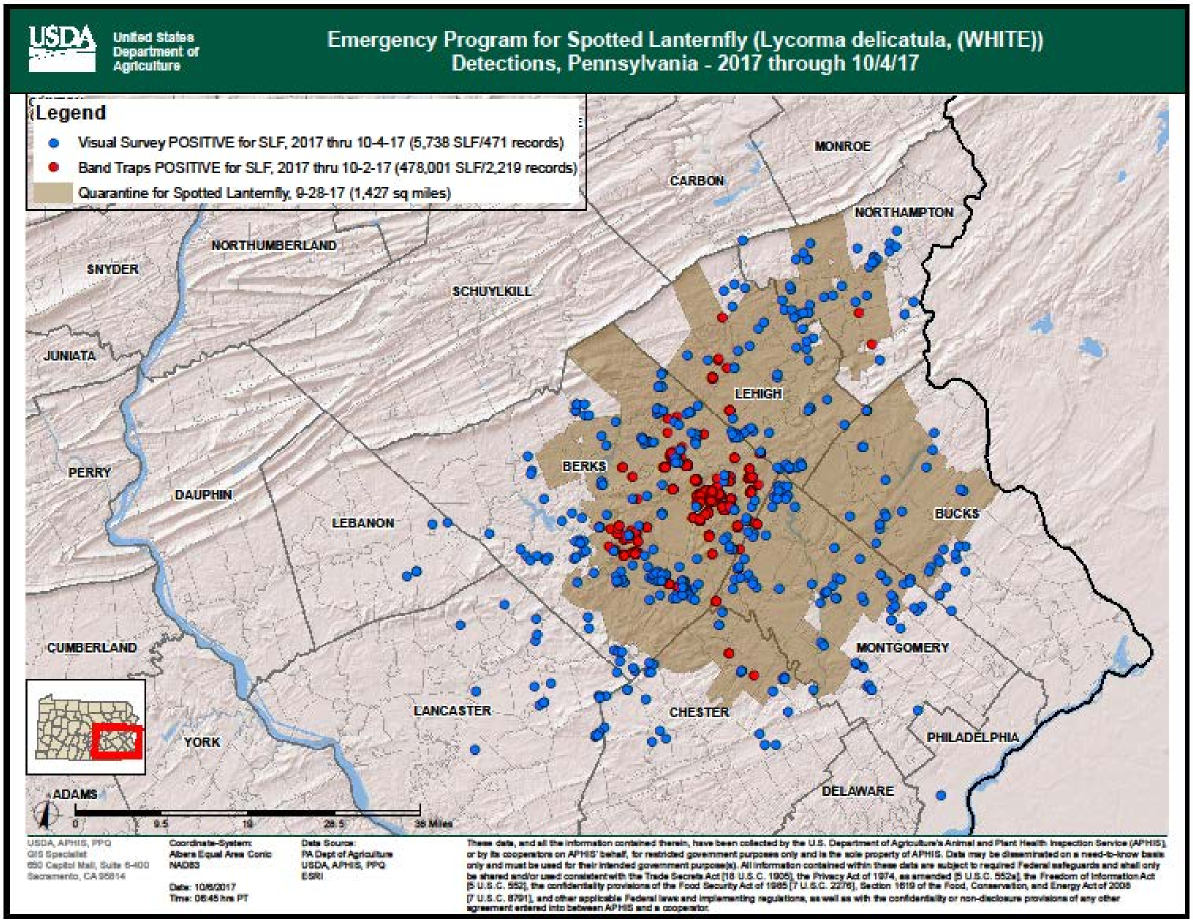

Figure 1 Detections of SLF through visual (blue dot) and band trap (red dot) positives through 10/04/2017. Note that since this map was created in September, the quarantine area has increased to over 6,928 sq. miles based on new detections.

Likelihood of Eradication

Under ideal circumstances, eradication of newly introduced pests is an option for selected scenarios. Multiple factors contribute to whether eradication programs are successful or not. Tobin et al. (2013) published a review of over 600 different arthropod eradication programs encompassing 130 species in 91 countries to examine the effect of different factors on success or failure on eradication. They concluded that factors that most strongly influenced success included the size of the infested area, relative detectability of the target species, method of detection, and the primary feeding guild of the target species. More specifically, they concluded that:

- as size of the infested area increases, the likelihood of successful eradication decreases;
- the availability of detection tools positively influences likelihood of successful eradication, particularly when species specific lures and traps are used and when methods such as including private citizen reporting programs are used;
- host range can influence probability of success where species with broad host ranges were found to be more likely to be eradicated; however the authors acknowledge that this could

be skewed by the number of fruit fly eradications included in the analysis, where the species had broad host ranges;
- pest specific control tools positively influenced success, such as using pest specific lures, mass trapping and sterile insect technique (SIT), whereas non-specific methods such as host removal tended to have lower success rates.

At this time, there are gaps in available information for SLF that would help inform the likelihood of success for eradication of SLF.

Potential factors that could potentially positively influence successful eradication of SLF include:

- the insect is readily identifiable and relatively easy to detect visually since it is an external feeder. Detection is facilitated because of strong association with a preferred host.
- "citizen science" has been effectively used to encourage private citizens to become involved in control efforts.
- Effective chemical controls have been identified
- The pest has only one generation per year
- The insect is not a strong flier
- The insect shows strong preference for one host, tree of heaven, *Ailanthus altissima*, which aids in both its control and detection.
- *Ailanthus altissima* tends to occur in disturbed areas or where there is ample sunlight.
- The emergence of the pest is highly synchronized as are the subsequent phenological stages
- Outreach has been confirmed to be effective and aid in detection
- Awareness of the pest is very high especially in the infested counties
- Agricultural production area managers and other private sector concerns are already establishing control procedures (contact pesticides) against the pest.

On the other hand, there are factors that negatively affect the potential for successful eradication:

- In Pennsylvania, the insect has spread to 13 counties; and as of January 2018, it has been detected in other states such as Virginia, New Jersey and Delaware (the detections do not imply an established population).
- there are currently no specific lures or traps available for SLF
- there are currently no species-specific control methods (such as pheromone trapping).
- Effective pesticide products are not yet labelled for use against this pest.
- The preferred host is widespread and difficult to destroy.
- Human, physical and economic resources are limited.

Until more specific information is available to address information gaps related to specific detection and control methods, there is a high degree of uncertainty as to whether eradication is feasible for SLF. Where there have been new detections (e.g. New Jersey, Virginia, Delaware), eradication of small populations with limited distribution may have a higher chance of success.

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II. Summary of Recommendations from SLF TWG Q&A

Recommendations for SLF management

The TWG considered all available information on SLF in September 2017, including existing information in the scientific literature, ongoing research and current efforts aimed at managing the pest. Information the TWG used in developing these recommendations is included in this report after this section. The original recommendations included using trap trees, herbicide treatments and removal of most remaining trees. However, since September 2017, the quarantine area has increased from 1,400 square miles to over 6,900 square miles. Complete host tree removal from a large portion of the infested area would require removing and chipping millions of trees within the infested area.

- The TWG recommends pursuing suppression of SLF populations within the existing Pennsylvania quarantine area and outlier areas that are discrete and delimited. The TWG considers likelihood of eradication to be low pending availability of improved detection methods and availability of new control methods that do not rely as heavily on the use of trap trees and host removal. In addition, there is currently incomplete information on the biology, economic impacts (from damage and control) and pest management of SLF to fully inform the feasibility of eradication. Result of research recommendations below may justify future review of the current TWG recommendations.
  A. To facilitate containment and suppression of SLF populations the TWG recommends that:
  - Survey should continue along the perimeter of existing finds to delimit the population;
  - Continued suppression of populations within the core by PDA and others to reduce the potential for human-assisted movement of SLF;
  - PPQ and PDA use insecticide and herbicide treatments to contain and suppress SLF. The pesticide/herbicide method requires the following:
    1. Surveying a SLF positive property for all *A. altissima* trees; marking for treatment with systemic insecticide to within labeled rate per acre; and treating the remaining trees with herbicide. Trees that are not treated with herbicide nor otherwise removed should preferably be male to prevent introduction of new *Ailanthus* seedlings. The maximum number of trees per property allowed by the insecticide label should be treated. Trees/seedlings slated for herbicide treatment should not be large enough to be considered hazard trees. Removal of *Ailanthus* trees where possible (e.g., by homeowners, private sector, PDA) is consistent with pest population reduction.
    2. Prior to or at the onset of first emergence (could begin in May and extend into August), apply a bark spray of systemic insecticide, dinotefuran (a neonicotinoid) to *Ailanthus*. While all spotted lanternfly stages can be found on *A. altissima*, 4^{th} instar nymphs and adults show a strong preference for them, so the insecticide-treated trees serve as "trap trees". Ailanthus trees are also banded to monitor the population present. Ailanthus trees should be re-treated annually.
    3. Ideally, treat trees marked for destruction are treated with the herbicide Garlon (Triclopyr).

B. The TWG recommends the insecticide/herbicide method be applied by working from the perimeter towards the core, beginning in the southeastern quarantine area northwest of Philadelphia and the Southwestern area in Lancaster County. While working through the perimeter area working inwards, continue efforts to reduce the population inside the core.

1) Conduct survey beyond the perimeter of the known infested area (500m around the edge of the currently known infested area constitutes the perimeter) to delimit the population, accounting for a potential 17 km/year spread rate (Appendix G). Survey can be conducted by using visual surveys and sticky bands around *A. altissima* tree trunks. Capture can be enhanced with the use of kairomone lures. Survey should incorporate citizen reporting using social media as a cost-saving measure and to increase the survey area coverage.
2) A perimeter, initially at least 500 m wide, outside and around the infested zone, should be drawn where the maximum label rate of dinotefuran is used on *A. altissima* trees and the remainder (mainly small *A. altissima* trees) treated with herbicide. The trap trees should be spaced within the perimeter as frequently and as continuously as possible/permissible to maximize the likelihood that SLF traveling past them would encounter one. Only the largest male trees should be used as trap trees. All small *A. altissima* trees should be herbicide treated.
3) Treat the maximum number of Ailanthus per property as allowed by the insecticide label. Intensive trapping/survey should continue outside that perimeter.
4) A perimeter around railways and along major roadways (in cooperation with PennDOT and the rail companies) should be made by requesting the rail companies and PennDOT remove *Ailanthus* trees with the exception of trap trees treated with dinotefuran.
5) Once perimeters are in place, work inwards treating properties by removing *Ailanthus* as much as possible and recording and treating all *Ailanthus* left untreated with herbicide and uncut.

C. Additional recommendations for SLF management:
- Continue PDA and volunteer tree banding with brown sticky bands on *Ailanthus*
- Continue and increase PDA outreach and volunteer program to engage property owners in egg scraping and tree banding to kill all life stages and to report any findings.
- Continue research to improve and develop survey and detection tools such as improved lures for more sensitive trapping on sticky bands. This will support the suppression and containment effort by targeting resources to have the highest impact.
- To reduce the risk of human-assisted movement of egg masses, consider inspections of trains, trucks, and other conveyances that have been stationed for extended periods in the quarantine zone during the oviposition season. When appropriate and effective ovicides have been identified, their use on conveyances

that have been in the quarantine area for extended periods of time should also be considered. Unitl ovicides are determined, egg scraping should continue.

The TWG considered ongoing research and information gaps. Additional recommendations with regard to research needs are provided later in this report in the section "Research – Ongoing and Needed".

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III. Additional Supporting Information

PDA Response efforts

Following the detection in Pennsylvania, PDA conducted a delimiting survey from October through December 2014. This survey indicated that the initial infestation was limited to a small area of eastern Berks County and had likely been present for two to three years prior to the detection (known as the infested core). A Pennsylvania Order of Quarantine for SLF was issued on November 1, 2014, which established an internal quarantine, identified regulated articles, and placed restrictions on the movement of the regulated articles (see Appendix E, F) (PDA, 2014). New counties or areas are added to the quarantine areas following confirmed SLF detections. In order for commodities to move out of the quarantined area they must either be accompanied by a certificate indicating they are free of *L. delicatula* or meet requirements that prevent infestation (PDA, 2014).

PDA has actively engaged with other government agencies, Pennsylvania State University (PSU), PSU extension personnel, and the general public through activities such as educational outreach, survey, research, tree banding, trap tree establishment and host removal, and egg scraping aimed at preventing further spread of SLF (PDA, 2017). Extension personnel have provided additional information on useful treatments to prevent the establishment of SLF to new areas (Appendix G).

Current SLF Control

PDA has developed and implemented a pest management strategy to suppress the SLF population focusing on the core of the infested area and working outward using the trap tree/host removal method. This approach has not been fully validated, but preliminary results show that populations are significantly reduced in the areas where tree removal and traps tree treatments have been completed. The TWG acknowledges that PPQ will not interfere with PDAs efforts to conduct many operations in the core and further notes that support for farmers, homeowners and others in the core are appropriate-especially if labelled pesticides can be made available and communicated through outreach campaigns.

Volunteer Programs

Two official volunteer programs are currently underway, comprising 57 volunteers. Volunteer programs include egg mass scraping and tree banding. PDA and Pennsylvania State University are organizing the volunteer efforts.

Volunteer Egg mass scraping program

Volunteers look for and scrape viable egg masses from September through July. Volunteers record the number of eggs masses scraped on the PDA website. As of October 7, 2017, an estimated 1,538,740 spotted lanternflies have been reported killed by egg mass scraping.

Volunteer tree band program

The volunteer tree banding is in addition to the large-scale tree banding program employed by PDA to mitigate populations in areas known to be positive for SLF (S.-E. Spichiger, personal communication, 2016). Brown, sticky tree bands are placed around *A. altissima* trees (≥ 6" dbh) at 5 feet above the ground. Every two weeks, volunteers or PDA staff count the number of SLF individuals captured and replace the bands. Volunteers record the number of SLF captured on bands on the PDA website. As of October 7, 2017, a total of 1,010,751 spotted lanternfly have been killed through the combined PDA and volunteer tree banding efforts (PDA, 2017).

Outreach

PDA has conducted informational meetings with townships and municipalities in and outside the quarantine area to inform the public about SLF, the quarantine, the survey and control effort, and to answer questions. PDA staff and Penn State Extension have also been presenting information at outreach events, schools, to Master Gardeners and through radio interviews and online videos. The PDA website provides links to information for the public and for affected groups within the quarantine. Specimens for outreach and identification purposes have been distributed to numerous states, USDA PPQ offices, Customs and Border Protection, and other interested groups. Signs have been placed within the quarantine and in areas of the perimeter displaying the insect life stages and restrictions on movement of material out of the quarantine area. PDA staff have been identifying and meeting with non-agricultural industries which pose a risk for movement of egg masses to inform them how to properly safeguard their material. Penn State extension outreach recommendations are listed in Appendix E.

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Analysis and modeling

Economic Analysis

PERAL, (2016a) stated the following:
"There is evidence to suggest that occasional outbreaks of SLF have caused damage to grape vine trunks and fruit in South Korea; however, these reported damages have only been described qualitatively. The degree of damage SLF causes to agriculture, specifically grapes, its main economic host, does not appear to have been quantified. Given the lack of a quantitative estimate of impact of the SLF in the United States and other areas where it is currently found, we were unable to conduct a purely quantitative benefit-cost analysis to form a clear direction on action. The predictive impact model we use for the Objective Prioritization of Exotic Pests (OPEP)[1] process indicates that SLF is likely to be a low-impact pest in the United States."

"The major at-risk commodity in the United States is grape, and the annual value of grape production at risk (based on where this pest can establish climatically) is over $5.5 billion. Therefore, even if the pest is likely to cause only minor losses, the program may still be warranted if it can prevent or limit spread of the pest to other vineyards in Pennsylvania and the introduction of the pest to other grape-producing states. Additionally, SLF has the potential to be a major nuisance pest in urban areas."

PERAL recommends that the program be re-evaluated using a cost-benefit or cost analysis when additional information on damage, spread, and management costs are available. Damage estimates for the infested commodities are essential for completing this analysis and are not available from the literature at this time. Jayson Harper (Penn State) is currently assessing the damage on grape in Pennsylvania. Damage estimates are not available for apple at this time. The hardwood industry will also be impacted by SLF in the quarantine area due to egg masses on trees, but the impact is currently unknown.

Pathway Analysis

Excerpts from PERAL, 2016b:
"The insect naturally disperses slowly, but is an excellent hitchhiker in commerce due to its propensity for laying egg masses on flat surfaces (Dara et al., 2015; NPAG, 2014; PDA, 2014). For example, it is thought to have been introduced into the United States on Chinese stone imports and into South Korea on Chinese plant materials for planting or solid wood packaging material (Hong et al., 2012; NPAG, 2014)."

"If SLF were to enter to other U.S. areas it would likely be able to establish based on climate suitability and host presence. When Pennsylvania shipment volumes, climate, and host presence were taken into account, the most likely states for *L. delicatula* introduction, if it were to move in commerce, were Pennsylvania, New Jersey, Ohio, Maryland, Indiana, Delaware, Virginia, and West Virginia. The most likely mode of *L. delicatula* entry in commerce was trucks. Human

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[1] The Objective Prioritization of Exotic Pests (OPEP) process uses information available on the organism to determine the economic impact and the likelihood of the organism to cause damage in the US. Based on the amount of damage that the organism may cause, the pest is listed as "High," "Medium" or "Low."

mediated movement presents the highest risk for long distance movement compared to natural spread."

A pathway analysis characterizing the potential movement of SLF via maritime ships from Asian countries and traffic flows within continental United States has been requested from PERAL (10/13/17) and is forthcoming. This analysis will help to identify additional pathways of introduction into the United States. Furthermore, human-assisted movement of SLF was documented in New York, with a single adult find in a shipment of medical equipment shipped from Berks County, PA. Spotted lanternfly detections have also been noted recently in Delaware, across the river from Philadelphia, with a specimen officially collected and identified and several pictures submitted. Appendix F shows maps of annual shipments from PA received by state overlaid on suitable areas for SLF establishment.

Modeling

Models to estimate the impact of proposed mitigations, characterize the pathways (into the United States and domestic pathways), and identify at-risk areas are needed to understand spread potential. Melissa Warden, Glenn Fowler, Sunil Kumar (USDA APHIS PPQ CPHST), and Yu Takeuchi (NC State CIPM) are assisting in this effort. Modeling efforts will provide information on predictive dispersal as well as identifying areas to be prioritized based on risk of spread, impact of spread, stands of *A. altissima*, impact of trap trees, SLF populations, and impact of all efforts in the infested area.

Climate Suitability for SLF in the US

Yu Takeuchi, USDA APHIS PPQ

Based on published information from S. Korea (Lee, et al., 2011), lethal temperature data for overwintering of egg masses was used to generate a map of the US indicating areas where SLF would not be able to establish based on inability for the eggs to survive (Figure 2). Average monthly temperatures in January were used to create the map. The creation of the map did not include information related to presence of hosts. (see Page 15)

Summary of results:

Identification of states and areas of states considered unsuitable for overwintering if SLF was found present is shown below, based on the literature (Lee, et al., 2011).

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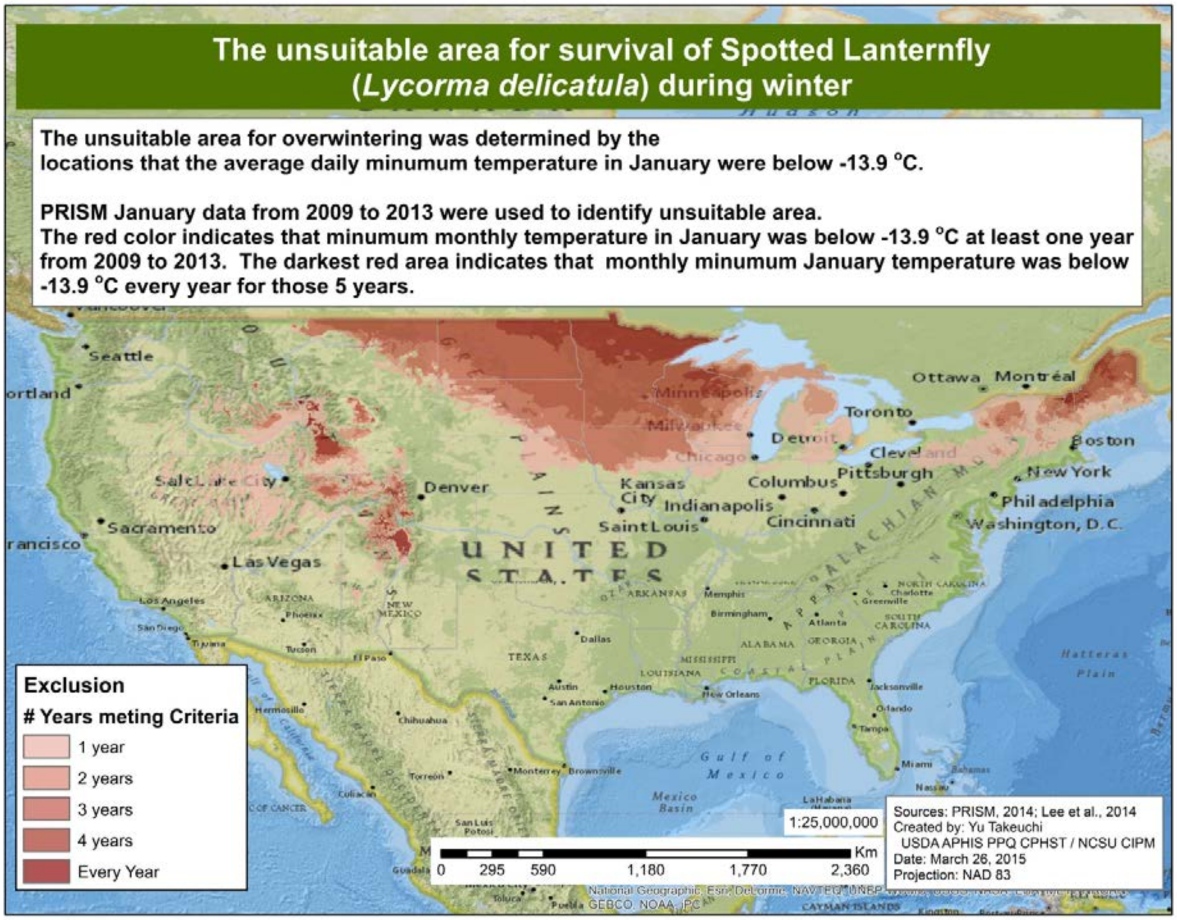

Figure 2. Areas within the Continental United States that would be unsuitable for the survival of spotted lanternfly based on a minimum daily average temperature of below -13.9 °C (Takeuchi, 2015).

Simple spread analysis of SLF data in Pennsylvania

Melissa Warden, USDA APHIS PPQ

In order to understand the potential spread of spotted lanternfly (*Lycorma delicatula*) in 2018, Warden estimated the mean annual expansion of quarantined municipalities, based on distance and direction from the ground zero treatment property. She then applied the average annual directional spread distance to the outer edge of the current quarantine boundary to estimate a potential 2018 quarantine boundary (Appendix H and Figure 1).

Summary of Results: The average spread rate was approximately 12.1 km (7.5 mi) per year. Accounting for direction, the average spread rate ranged from 6 km to 17 km (3.7 mi to 10.6 mi) per year.

The total number of SLF reported from survey and sticky bands per square kilometer in 2017 (Figure 1 and Appendix I) and since first detected are presented in heat maps (Appendix J).

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Short-term and long-term modeling goals
Short-term (1-6 Months)

1) Update the SLF annual spread rate in the pathway analysis with the additional spread data that has been gathered. Then apply a radial buffer around the final detection data for this year before SLF die off and overwinter as egg masses to determine where to set the initial survey distance prior to egg hatch in 2018.
2) Use SAFARIS near real time mapping and forecast capabilities to determine when and where to survey in 2018.
3) Update the SLF population density maps within the quarantine area that were made in 2016, with the most recent data to help inform survey and control decisions.
4) Calculate the areas affected and simulate potential spread areas for 2018 by changing the efficacy of treatments. Construct a simple simulation model to evaluate how fast/slow SLF would spread after applying specific treatment.
5) Prepare a MaxEnt model with the latest SLF information, and prepare SLF habitat suitability model for conterminous US.
6) Use time-series SLF abundance data from US and develop an Autoregressive Integrated Moving Average (ARIMA) model using temperature, precipitation and humidity data. This ARIMA model can be used to forecast future SLF abundance.

Long-term (3-9 months)

1) Use a stochastic spread model, like that being developed for SAFARIS by NCSU, to model the SLF spread out of the quarantine area using the tree of heaven distribution data acquired via remote sensing if possible.
2) If possible, use the control option efficacy data in the stochastic spread model to compare the effects on SLF spread independently and in combination vs. no controls.
3) Conduct a pathway analysis to characterize potential movement of SLF via maritime ships from Asian countries and traffic flows within continental United States.
4) Run species distribution models (other than MaxEnt) to identify suitable areas within the continental United States (or at global scale) and evaluate uncertainty associated with the outcomes.
5) Construct a temperature driven population dynamics model to estimate field population levels.
6) Prepare a CLIMEX model (a semi-mechanistic ecological niche model)

Data needs for modelling efforts

- Detailed distribution of host species
- Survey data (coordinates, collection date, number trapped, trap density)
- SLF phenology data (temperature-dependent development/reproduction study)
- SLF temporal abundance data with GPS coordinates of the sampling locations/sites
- Find out if tree of heaven can be picked up via remote sensing (this may already be known). If so, then try to get its distribution in the quarantine counties and surrounding areas.
- Efficacy data on life stages for the control options being proposed.

IV. Research – ongoing and needed

The following research on elements of the biology and control of *Lycorma delicatula* are currently being conducted:

Chemical control

- Efficacy of pesticides on SLF in orchards and vineyards (Appendix D).
  - There are already a number of insecticides that have been tested, especially in orchards and vineyards. Many products are effective. Please see the appendices for more information.
- Efficacy studies of systemic insecticides for trees looking at dead insects under *A. altissima*
  - Imidacloprid, dinotefuran, emamectin benzoate are being researched
  - Trunk-injected dinotefuran remained at effective levels for 2 months following application.
  - Application methods: bark spray, tree injection
- Residue analysis of foliage from systemic insecticide-treated trees
  - Bark sprayed dinotefuran application to *A. altissima* demonstrated season long residual activity

Trap and Lure Development

- Kairomone discovery and lure development:
  - Discovered 39 antennally active compounds for SLF and identified 19 of them, tested and found 8 of them to be attractants (based on electroantennograms, mass spectrometry, and Y-tube bioassays). Those 8 have been incorporated into a blend that is highly attractive to SLF in Y-tube olfactometer testing.
- Field testing a single-component lure that catches more SLF than no lure.
- Pheromone investigations are ongoing.
- Recording SLF to determine if this species uses substrate-borne vibration in mating or other communication behavior.

Biological Control

- *Ooencytrus kuvanae* (Howard) (Hymenoptera: Encyrtidae)
  - An egg parasitoid of *L. delicatula* discovered in Pennsylvania in 2016 (Liu and Mottern 2017).
  - Use 6.8% host egg masses with an average parasitism of 30.8% (2.4 - 64%) in the field.
  - Augmentative release after impact evaluation and genetic diversity studies.

- Systematics of *Anastatus* (Eupelmidae), with emphasis on those parasitizing Hemiptera.
  - *A. orientalis* appears to be well synchronized with *L. delicatula*. Two generations per year, the first generation hatches in April/May and attacks unparasitized SLF egg masses, the next generation emerge after SLF egg laying in October to parasitize newly laid egg masses.
- Native Dryinidae

    - An unidentified species parasitized *L. delicatula* nymphs in Pennsylvania
- Potential impact of spotted lanternfly biocontrol organisms on non-target Hemiptera.
- A fungus found infecting nymphs and adults is being identified.

Biology and population dynamics

- The average duration for the four instars is between 20-30 days at 22 degrees Celsius under laboratory conditions.
- Egg hatching started in early May and ended in early June in the field, with nymphs found from early May to late August.
- Adults first appeared in late July and started to lay eggs in early October.
- Duration and growing degree-days (DDs) for each life stages are being worked out.
- SLF dispersal pilot study has been concluded. Data analysis now complete.
- Field studies on mating biology are being conducted.
- Development and use of novel genetic markers (microsatellite loci) to genotype SLF individuals from the Pennsylvania population of SLF and specimens from Korea, Vietnam, and multiple locations within China.
- Characterization of the bacterial and fungal associates of SLF.
- Monitor the microbial communities on multiple economically important host plants to assess changes in composition and abundance of bacteria and fungi due to SLF feeding and honeydew deposition.
- Host suitability studies have revealed that SLF can develop from 1st instar to adults exclusively on *Ailanthus*, chinaberry (*Melia azedarach*), black walnut (*Juglans nigra*), and hops (*Humulus lupulus*) (during no choice host tests—although adults on control plants died and no eggs were laid). (Cooperband, unpublished). Other species were ruled out as exclusive host plants.
- Additional observations in the field this summer revealed that flying was exhibited mainly from Mid-September to late September. Flight dynamics include indiscriminant climbing on the nearest vertical surface, facing the direction of the wind and flying from 10-80 meters (J. Baker, pers. comm.)
- Mating behavior was observed for the first time this fall. The courtship seems to consist of the male and female sitting still side-by-side on the trunk for several hours followed by a very short mating interval and 2-4 hours of coupling (John Baker, pers. comm.)

Proposed treatment studies to support SLF control.

- Insecticide treatment longevity
- Treatment efficacy of adult SLF, nymphs, and egg masses
- Toxicity studies on different insecticides to kill the nymphal stages and adults (lab and field trials).
- Chemical treatment of the outlying SLF populations.
- Continued host testing, to include testing of insecticides on non-targets (i.e. honeybees and others)

The TWG considered ongoing research efforts and identified areas where additional research is needed.

Additional research that has not been accomplished yet but is needed
Needed and planned (funded):

i. Continued development and field test lures
ii. Trap development and optimization for adults (intercept, light, attract & kill, other)
iii. Trap development for nymphs (insecticide treated materials, attract & kill, other)
iv. Gather mating behavior data and information (where, when, how, what cues are used to locate mates and whether pheromones exist)
v. Explore if any pheromone exists (mating, feeding, aggregation, sex, etc.)
vi. Learn how far SLF travel/disperse when *Ailanthus altissima* is not present
vii. Additional host plant studies (butternut, apple, oriental bittersweet, grape, Ailanthus, milkweed, black cherry, alfalfa, cucumber, red oak)
viii. Egg mass treatment efficacy (insecticide and oil treatments)
ix. Determine the available amount of the toxin cantharidin or other defensive compounds in all life stages.
x. Additional host plant studies
xi. Determine draw of trap trees

Needed and not planned:

xii. More detailed sex ratio and timing of aggregation of adults studies on different host species
xiii. Use of controlled atmosphere storage to control SLF in apple and other commodity shipments
xiv. Repellents
xv. Evaluate mating behavior in canopy vs on trunk (and by host plant)
xvi. Evaluate differences in SLF behavior by host plant
xvii. Density dependent behavioral differences (do they disperse more/farther when at higher densities?)
xviii. Dissections to look for wing polymorphism and flight muscles between individuals this year, and compare to adults that were collected during the first year SLF was detected (26 Sept. 2014). A comparative study of internal musculature may illuminate differences across and between years, which may inform differences observed in flight behavior.
xix. Systemic insecticides for ornamental and/or timber trees, efficacy studies of materials, application methods and application timing against different life stages.
xx. Contact insecticides for ornamental and/or timber trees, efficacy studies of materials, including some of the newer biologically-derived insecticides against different life stages. Determine recommended rates and helpful adjuvants.
xxi. Materials with potential to destroy egg masses
xxii. Pathology research to characterize the white fungal substance which accumulates at the base of A*. altissima* with heavy feeding. How might this affect timber and ornamental trees?
xxiii. Pathway analysis

xxiv. Mitigation of trade pathways
xxv. Deterrence and outreach
xxvi. Population dynamics research, modeling and forecasting

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V. References

Anderson L.A., A. Harris, J.D. Phillipson. 1983. Production of cytotoxic canthin-6-one alkaloids by *Ailanthus altissima* plant cell cultures. Journal of Natural Products 46: 374–378. Animal Behavior Society. 2012. Guidelines for the treatment of animals in behavioural research and teaching. Animal Behaviour 83: 301–309.

APHIS. 2014. PPQ-391 report, Interception Number APEPA142670956001. Pest identification report for *Lycorma delicatula* (Fulgoridae). Agricultural Quarantine Activity Systems. United States Department of Agriculture, Animal Plant Health Inspection Service (APHIS), Plant Protection and Quarantine. https://mokcs14.aphis.usda.gov/aqas/login.

Choi, D. –S., D. –I. Kim, S. –J. Ko, B. –R. Kang, J. –D. Park, S. –G. Kim, K. –J. Choi. 2012. Environmentally-friendly control methods and forecasting the hatching time Lycorma delicatula (Hemiptera: Fulgoridae) in Jeonnam Province (abstract only). Korean J. Appl. Entomol. 51(4): 371-376.

Chou I. 1946. A study on Lycorma delicatula White (Hemiptera: Fulgoridae). Entomologia et ARS, 1(2-4):31-54. (In Chinese)

Dara, S. K., L. Barringer, and S. P. Arthurs. 2015. *Lycorma delicatula* (Hemiptera: Fulgoridae): A New Invasive Pest in the United States. Journal of Integrated Pest Management 6(1):20.

Ding, J. Y. Wu, H. Zheng, F. Weidong, R. Reardon, and M. Liu. 2006. Assessing potential biological control of the invasive plant, tree-of-heaven, *Ailanthus altissima*. Biocontrol Science and Technology 16(6): 547-566.

EPPO. 2016a. New additions to the EPPO A1 and A2 Lists. European and Mediterranean Plant Protection Organization (EPPO). October 1, 2016. Last accessed October 11, 2017, from http://archives.eppo.int/EPPOReporting/2016/Rse-1610.pdf.

EPPO. 2016b. Pest risk analysis for *Lycorma delicatula*. European and Mediterranean Plant Protection Organization (EPPO). Paris.

Feng, Y., M. Jiangi, L. Zhongren, and G. Tianpeng. 1988. A preliminary investigation on the cantharidin resources of Shaanxi Province. Journal of Northwest Sci-Tech University of Agriculture and Forestry – Natural Science Edition 16(3) 23-27.

Han, J.M., H. Kim, E.J. Lim, S. Lee, Y.-J. Kwon, and S. Cho. 2008. *Lycorma delicatula* (Hemiptera: Auchenorrhyncha: Fulgoridae: Aphaeninae) finally, but suddenly arrived in Korea. Entomological Research 38: 281-286.

Hong, K.-J., J.-H. Lee, G.-S. Lee, and S. Lee. 2012. The status quo of invasive alien insect species and plant quarantine in Korea. Journal of Asia-Pacific Entomology 15(4):521-532.

Jang, Y., H. –G. An, H. Kim, and K. –H. Kim. 2013. Spectral preferences of *Lycorma delicatula* (Hemiptera: Fulgoridae). Entomological Research 43: 115-122.

Kang, C. –K., S. –I. Lee, and P. G. Jablonski. 2011. Effect of sex and bright coloration on survival and predator-induced wing damage in an aposematic lantern fly with startle display. Ecological Entomology 36: 709-716.

Kang, C., H. Moon, T. N. Sherratt, S. –I. Lee, and P. G. Jablonski. 2016. Multiple lines of anti-predator defence in the spotted lanternfly, *Lycorma delicatula* (Hemiptera: Fulgoridae). Biological Journal of the Linnean Society. DOI: 10.1111/bij.12847.

Kim, J. G., E. –H. Lee, Y. –M. Seo, and N. –Y. Kim. 2011. Cyclic behavior of *Lycorma delicatula* (Insecta: Hemiptera: Fulgoridae) on host plants. J. Insect Behav. 24: 423-435.

Kim, H., M. Kim, D. H. Kwon, S. Park, Y. Lee, J. Huang, S. Kai, H. –S. Lee, K. –J. Hong, Y. Jang, and S. Lee. 2013. Molecular comparison of *Lycorma delicatula* (Hemiptera: Fulgoridae) isolates in Korea, China, and Japan. Journal of Asia-Pacific Entomology 16: 503-506.

Kim, S.-K., G.-Y. Lee, Y.-H. Shin, and G.-H. Kim. 2010. Chemical control effect against spot clothing wax cicada, *Lycorma delicatula* (Hemiptera: Fulgoridae) nymphs and adults. The Korean Journal of Pesticide Science 14(4): 440-445.

Lee, J.S., I.K. Kim, S.H. Koh, S.J. Cho, S.J. Jang, S.H. Pyo, and W.I. 2011. Impact of minimum winter temperature on *Lycorma delicatula* (Hemiptera: Fulgoridae) egg mortality. J. Asia Pac. Entomol. 14, 123–125.

Liu, H-P., and J. Mottern. 2017. An Old Remedy for a New Problem? Identification of *Ooencyrtus kuvanae* (Hymenoptera: Encyrtidae), an Egg Parasitoid of *Lycorma delicatula* (Hemiptera: Fulgoridae) in North America. Journal of Insect Science (2017), 17(1), 18; 1–6. doi: 10.1093/jisesa/iew114.

NPAG. 2014. NPAG Report: *Lycorma delicatula* (White): Spotted lanternfly (20141009). United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Center for Plant Health Science and Technology, Plant Epidemiology and Risk Analysis Laboratory, New Pest Advisory Group (NPAG). 8 pp.

Novotny, V. and Y. Basset. 1998. Seasonality of sap-sucking insects (Auchenorrhyncha, Hemiptera) feeding on *Ficus* (Moraceae) in a lowland rain forest in New Guinea. Oecologia 115: 514-522.

O'Toole, S. J. 2017. Targeted herbicidal treatment of sprouts and saplings. Personal communication to G. Parra on September 19, 2017 from S.J. O'Toole (USDA APHIS PPQ).

Park, J. –D., M. –Y. Kim, S. –G. Lee, S. –C. Shin, J. Kim, and I. –K. Park. 2009. Biological characteristics of *Lycorma delicatula* and the control effects of some insecticides (in Korean). Korean J. Appl. Entomol. 48(1): 53-57.

Park, M., K. –S. Kim, and J. –H. Lee. 2012. Isolation and characterization of eight microsatellite loci from *Lycorma delicatula* (White) (Hemiptera: Fulgoridae) for population genetic analysis in Korea. Mol. Biol. Rep. 39: 5637-5641.

Park, M., K.-S. Kim, and J.-H. Lee. 2013. Genetic structure of *Lycorma delicatula* (Hemiptera: Fulgoridae) populations in Korea: implication of invasion processes in heterogeneous landscapes. Bulletin of Entomological Research 103: 414-424.

Park, M. 2015. Overwintering ecology and population genetics of *Lycorma delicatula* (Hemiptera: Fulgoridae) in Korea. Doctoral dissertation, Seoul National University, Seoul.

PDA. 2017. Spotted lanternfly. Pennsylvania Department of Agriculture (PDA). Last accessed October 15, 2017, http://www.agriculture.pa.gov/Protect/PlantIndustry/spotted_lanternfly/Pages/default.aspx.

PDA. 2014. Order of Quarantine; Spotted lanternfly. Pennsylvania Department of Agriculture. November 1, 2014. 6 pp. http://www.agriculture.pa.gov/Protect/PlantIndustry/spotted_lanternfly/Documents/QuarantineOrder.pdf.

PERAL. 2016a. Analysis of Potential Economic Impacts of Spotted Lanternfly, Lycorma delicatula (White), and Assessment of the Eradication Program in Pennsylvania. United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Center for Plant Health Science and Technology, Plant Epidemiology and Risk Analysis Laboratory (PERAL), Raleigh. 20 pp.

PERAL. 2016b. Pathway Analysis: Intrastate and Interstate Movement of the Spotted Lanternfly, Lycorma delicatula (White), out of the Pennsylvania Quarantined Area with and without Quarantines. United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Center for Plant Health Science and Technology, Plant Epidemiology and Risk Analysis Laboratory (PERAL), Raleigh. 20 pp.

PestID. 2017. Pest Identification Database (PestID). United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine. https://mokcs14.aphis.usda.gov/aqas/login.jsp.

Shin, Y.-H., S.-R. Moon, C. Yoon, K.-S. Ahn, and G.-H. Kim. 2010. Insecticidal activity of 26 insecticides against eggs and nymphs or *Lycorma delicatula* (Hemiptera: Fulgoridae). The Korean Journal of Pesticide Science 4(2): 157-163.

Song, MK. 2010. Damage by *Lycorma delicatula* and chemical control in vineyards. Masters. Chunbuk National University. 39 pp.

Spichiger, S-E. 2014. New Pest Report, Berks County PA. Pennsylvania Department of Agriculture, Entomology. September 22, 2014. 3pp.

Spichiger, S. –E. 2016. Re: Lycorma survey questions from CAPS. Personal communication to H. Moylett on October 13, 2016 from S.-E. Spichiger (Pennsylvania Department of Agriculture).

Swackhamer, E. 2017. Time of year management chart. Penn State Extension. February 2017. Last accessed October 11, 2017, from http://www.agriculture.pa.gov/Protect/PlantIndustry/spotted_lanternfly/Documents/Time%20of%20year%20management%20chart.pdf.

Tobin, P.C., J. M. Kean, D.M. Suckling, D. G. McCullough, D.A. Herms, L. D. Stringer. 2013. Determinants of successful arthropod eradication programs. Biological Invasions 16:401-414.

Tomisawa, A, S. Ohmiya, H. Fukutomi, K. Hayashi, T. Ishikawa. 2013. [Biological notes on Lycorma delicatula (White) (Hemiptera, Fulgoridae) in Ishikawa Prefecture, Japan]. Japanese Journal of Entomology 16(1), 3-14 (in Japanese).

Tonkyn, D.W. and R.F. Whitcomb. 1987. Feeding Strategies and the Guild Concept among Vascular Feeding Insects and Microorganisms. Pages 179-199 *in* K.F. Harris (ed.). Current Topics in Vector Research, Vol 4. Springer-Verlag New York Inc, New York.

Yoon, C., S. –R. Moon, J. –W. Jeong, Y. –H. Shin, S. –R. Cho, K. –S. Ahn, J. –O. Yang, and G. –H. Kim. 2011. Repellency of lavender oil and linalool against spot clothing wax cicada, *Lycorma delicatula* (Hemiptera: Fulgoridae) and their electrophysiological responses. Journal of Asia-Pacific Entomology 14: 411-416.

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Appendices

Appendix A: Pest overview

The spotted lanternfly, *Lycorma delicatula*, (Hemiptera: Auchenorrhyncha: Fulgoroidea: Fulgoridae) is a planthopper native to China (Dara et al., 2015). Spotted lanternfly is the first member of Fulgoridae to be classified as a pest.

Biology

In China, Korea, and Pennsylvania, SLF has one generation per year with 4 non-flying nymph instars before molting to a flying adult (Park et al., 2009; Dara et al., 2015). SLF overwinters in the egg stage (Park et al., 2012).

Eggs. Egg masses comprise 30 to 50 eggs and are covered with a yellowish-brown or grey secretion that hardens into an oothecum (Park et al., 2009; Yoon et al., 2011; Dara et al., 2015). The number of eggs produced per female varies by country. Based on observations in Pennsylvania, it is estimated that a single female can produce at least 2 to 3 egg masses or 60 to 150 eggs per female. In South Korea, females have been reported to lay 5 egg masses or ~500 eggs in her lifetime (Park, 2015). The egg mass is about 25 mm (approx. 1 in.) long and may resemble a smear of mud (Dara et al., 2015). Females deposit egg masses on buildings, trees, rocks, under bark or rocks, and a variety of objects, from late September to the onset of winter. Spotted lanternfly overwinters in the egg stage. It is not clear if SLF requires a chilling period to complete development.

Nymphs. There are four instars. The first to third instars are black-bodied with white spots on the head, body, and legs. The fourth instar is red with white spots and distinct red wing pads (Park et al., 2009; Dara et al., 2015). The first nymphs begin to emerge in the spring (Park et al., 2012; Dara et al., 2015) and immediately climb trees or plants moving upward toward canopy (Kim et al., 2011). Nymphs in Korea and Pennsylvania have been observed emerging in May and molting to adults in late July (Park et al., 2012; Dara et al., 2015). Due to difficulty in determining the sex of nymphs, it is not known if male and female nymphs have different feeding preferences or requirements.

After hatching the nymphs head upwards until they reach the leaves where they feed by piercing petioles, young stem tissue, eventually moving on to branches and trunks as they develop. The nymphs engage in a cyclic behavior in which they ascend to the leaves of the trees and then fall to the ground (Kim et al., 2011). The basis/trigger for the falling-ascending behavior requires further study. One explanation may be because younger nymphs are more easily dislodged by wind or other means. *Lycorma delicatula* have arolia (tarsal adhesive pads) that that aid in climbing and jumping. The arolia become bigger and stronger with each instar, allowing them to stick to surfaces more firmly (Kim et al., 2011). The falling-ascending behavior may also be a host selection strategy (Kim et al., 2011) or a strategy to avoid intense midday heat. The behavior of the nymphs makes it possible to trap nymphs on a tree with a sticky tree band. South Korea tested this possibility and found that brown sticky bands place around trees trapped nymphs ascending and descending trees (Choi et al., 2012; Kim et al., 2011).

Adults. The fourth instar molts to the adult stage in midsummer (Park et al., 2012; Dara et al., 2015). For the first three weeks after adult emergence, females accumulate on *A. altissima* in massive aggregations, whereas males are found on a number of other plant species in smaller aggregations. Females feed for several weeks, causing honeydew to accumulate under *A. altissima* trees. Honeydew accumulation is absent from male aggregations on other host plants. Around three weeks after adult emergence, the males appear on *A. altissima* and numbers gradually shift from all female aggregations to aggregations containing roughly 50% males and 50% females. Mating has only been observed after the sex ratio shifts in aggregations (September), and has been observed to take place on *A. altissima,* grape, and other substrates. Oviposition begins several weeks after mating occurs (September to October). This is further evidence suggesting that *A. altissima* is an obligatory host for part of the SLF life cycle.

Global Distribution
Asia – China (Han et al., 2008), Japan (Hong et al., 2012), South Korea (Han et al., 2008), and Vietnam (Lee et al., 2011).

Movement/Dispersal
Lycorma delicatula aggregate as nymphs and adults and can be found in large numbers on individual host plants (Ding et al., 2006). Nymphs can be found on a wide variety of host plants. Adults are the only life stage capable of flight. The wingless nymphs move by climbing, walking, or jumping. As previously discussed, the nymphs engage in a cyclic behavior in which they ascend to the leaves of the trees and then fall to the ground. Adults are considered weak, clumsy flyers, often moving by jumping or walking if their path is obstructed or when crowded or disturbed (Kim et al., 2011; Choi et al., 2012). Adults can jump up to 1 to 3 m (approx. 3 to 10 ft) (Chou, 1946), while flight distances recorded in the literature range from 2 to 3.3 m (approx. 6.5 to 11 ft) (Tomisawa et al., 2013; Chou, 1946). In 2017, PDA observed adults forming masses at the top of buildings and telephone poles and then jumping into the wind ("cliff jumping"). Adults in Pennsylvania were observed flying up to 20 m (approx. 66 ft.) under favorable conditions (L. Donovall, personal communication as cited in the EPPO, 2016b). On September 22, 2017, Julie Urban and Erica Smyers observed adults taking flight from the ground, reaching 10 ft above the ground and traveling around 100 ft. before landing again. While observing this behavior they collected the individuals that landed on them. Out of 73 collected, 70 were males (Julie Urban, personal communication). Further study is required to understand the trigger and mechanism behind this newly recorded behavior.

In 2004, *Lycorma delicatula* was detected in South Korea; and quickly spread across the country in 5-7 years (Park et al., 2013). Based on the rapid range expansion observed in South Korea, it is thought that movement occurs through short-range expansion, likely influenced by host plant availability, and long-distance dispersal. Long-distance dispersal ability and migration patterns are not well known, but was found to be associated with ground transportation and human activity in Korea (Park et al., 2013). During insecticide fogging on *A. altissima*, Phil Lewis observed that adults higher in the canopy of the tree would take flight and disperse in response to the insecticide application (Phil Lewis, personal communication). This is consistent with the avoidance behavior observed in other fulgorid species in that the insects higher in the canopy are irritated by the application and tend to disperse before they can be affected.

Damage

Spotted lanternfly are phloem-feeders, feeding on the sugary liquid channeled through the plant's vascular system (Novotny and Basset, 1998). Phloem-feeding requires specialized morphological, physiological, and behavioral adaptation, so feeding damage is expected to result from feeding on leaves, stems, and other parts of the plant containing phloem cell bundles. Enzymes contained in the saliva may aid penetration in search of phloem cells (Tonkyn and Whitcomb, 1987).

Both nymphs and adults feed on the phloem of host plants in large aggregations (Kim et al., 2013). Early instar nymphs feed on leaves and small stems, and as they develop, begin to feed on woodier plant material, like woody stems and branches. Adults feed on woody plant parts, like branches and trunks. Feeding by aggregations of early instar nymphs creates a large amount of honeydew that covers the host plant and all surfaces and plants below it (Ding et al., 2006; Dara et al., 2015). Honeydew leads to sooty mold growth, which can cause reduced growth or death of seedlings or plants in the understory (Ding et al., 2006) due to disrupted photosynthesis. Aggregations of later instar nymphs and adults, especially in large numbers, cause weeping wounds on the trunk and can result in wilting of branches or death of the plants (Jang et al., 2013; Dara et al., 2015).

Spotted Lanternfly fourth instar nymphs and adults have aposematic coloring which serves as a signal to predators that the insects are unpalatable due to the cantharidin likely sourced from host plants like tree of heaven, which cause avian predators to vomit after consumption (Anderson et al., 1983, Kang et al., 2011 and 2016). *A. altissima* contains high concentrations of cytotoxic alkaloid chemicals (Anderson et al., 1983). Using gas chromatography, Feng et al. (1988) confirmed that nymphs (0.13-0.17%) and adults (0.05-0.07%) contain cantharidin. However, the authors refer to the numbers as "levels" without explaining what the percentages represent (e.g. percent body weight). Further chemical analysis is needed to test whether there is a significant difference between the defensive alkaloid concentration in different life stages, including early and late season adults (Kang et al., 2016). Nymphs and adults processed with grapes may contaminate the product and affect the taste due the presence of alkaloids.

Hosts

Spotted lanternfly is highly polyphagous as nymphs, known to feed on plants in more than 20 families, and has been reported to be a serious pest of grapes in Korea where it has been introduced. The annual value of grape production in the US is more than $5.5 billion, and thus the primary concern for economic damage and further spread of this pest. Pennsylvania is 5th in US grape production, 4th in wine production, and SLF is considered a significant threat to Pennsylvania's $20.5 million dollar grape industry. In addition to grapes, there are a number of other host plants and commodities of economic importance that will likely be affected by the SLF introduction and population expansion.

In Korea, Kim et al. (2011) found that the number of different trees SLF was collected from decreased from July to November. The total number of SLF on non-*A. altissima* trees began to decrease in July. The number of SLF individuals on *A. altissima* trees increased by 80 to 100% after August 30th and there were 10 to 20 times more individuals on *A. altissima* than any other tree in the survey. In September, adults were collected only on *A. altissima* and *Tetradium daniellii* trees, and by November adults were found exclusively on *A. altissima* trees. Similar observations were made in Pennsylvania. As SLF developed into fourth instar nymphs and then into adults, the numbers of individuals captured on non-*A. altissima* trees decreased and numbers captured on *A. altissima* increased (Dara et al., 2015).

Additional research is needed to determine if specific hosts (such as *A. altissima*) are required for SLF to complete its lifecycle. A current list of potential hosts is provided in Appendix B.

Appendix B: Host List of *Lycorma delicatula*

Host list of *Lycorma delicatula* based on observation of presence, feeding, of nymphs and adults, or presence of egg masses from literature and observations in Pennsylvania (* PA observation). Presence of plant on this list **does not** mean that *Lycorma delicatula* can complete its lifecycle on the plant. Research on what plants are necessary for determining reproductive host status has not yet been accomplished.

Host	Common Name	Family	Observed Feeding
Acer palmatum	Japanese maple	Sapindaceae	Yes
*Acer rubrum**	Red maple	Sapindaceae	
*Acer saccharinum**	Silver maple	Sapindaceae	
*Acer saccharum**	Sugar maple	Sapindaceae	Yes
Actinidia chinensis	Kiwi	Actinidiaceae	Yes
Ailanthus altissima*	**Tree of Heaven**	**Simaroubaceae**	**Yes, preferred**
Alnus hirsuta	Manchurian alder	Betulaceae	
Alnus incana	Grey alder	Betulaceae	
*Amelanchier Canadensis**	Serviceberry	Rosaceae	
Angelica dahurica	Chinese angelica	Apiaceae	
Aralia cordata	Udo	Araliaceae	
Aralia elata	Japanese angelica	Araliaceae	
Arctium lappa	Greater burdock	Compositae	
*Betula lenta**	Black birch	Betulaceae	
*Betula papyrifera**	Paper birch	Betulaceae	
Betula platyphylla	White birch	Betulaceae	Yes
*Carya glabra**	Pignut hickory	Juglandaceae	
*Carya ovata**	Shagbark hickory	Juglandaceae	
Castanea crenata	Korean chestnut	Fagaceae	
Cedrela fissilis	Argentine cedar	Meliaceae	
*Cornus spp.**	Dogwood	Cornaceae	
Cornus controversa	Giant dogwood	Cornaceae	Yes
Cornus kousa	Kousa dogwood	Cornaceae	Yes
Cornus officinalis	Japanese cornel	Cornaceae	Yes
Elaeagnus umbellata	Japanese silverberry	Elaeagnaceae	Yes
Evodia (=*Tetradium*) *danielii*	Korean evodia	Rutaceae	Yes
Firmiana simplex	Chinese parasol tree	Sterculiaceae	
*Fagus grandifolia**	American beech	Fagaceae	
*Fraxinus americana**	White ash	Oleaceae	
Hibiscus syriacus	Rose of Sharon	Malvaceae	
Juglans cinerea	Butternut	Juglandaceae	Yes
Juglans hindsii	Northern California black walnut	Juglandaceae	Yes
Juglans major	Arizona walnut	Juglandaceae	Yes
Juglans mandshurica	Manchurian walnut	Juglandaceae	
Juglans microcarpa	Little walnut	Juglandaceae	Yes
*Juglans nigra**	Black walnut	Juglandaceae	Yes

Host	Common Name	Family	Observed Feeding
Juglans sinensis	Walnut	Juglandaceae	
*Liriodendron tulipifera**	Tuliptree	Magnoliaceae	
Maackia amurensis	Amur maackia	Fabaceae	
Magnolia kobus	Kobus magnolia	Magnoliaceae	
Magnolia obovata	Japanase bigleaf magnolia	Magnoliaceae	
Mallotus japonicus	East Asian mallotus	Euphorbiaceae	Yes
Malus pumila	Paradise apple	Rosaceae	Yes
Malus sp.	Apple	Rosaceae	Yes
Melia azedarach	Chinaberry tree	Meliaceae	Yes
Metaplexis japonica	Rough potato	Apocynaceae	
Morus alba	White mulberry	Moraceae	
Morus bombycis	Korean mulberry	Moraceae	
*Nyssa sylvatica**	Black gum		
Parthenocissus quinquefolia	Virginia creeper	Vitaceae	Yes
*Phellodendron amurense**	Amur Cork tree	Rutaceae	Yes
Philadelphus schrenkii	Mock Orange	Hydrangeaceae	
Picrasma quassioides	Quassi-Wood	Simaroubaceae	
Pinus densiflora	Korean Red Pine	Pinaceae	
Pinus strobus	Eastern White Pine	Pinaceae	
*Platanus occidentalis**	American Sycamore	Platanaceae	
Platanus orientalis	Oriental Plane Tree	Platanaceae	
Populus spp	Cottonwoods/poplars	Salicaceae	
Populus alba	Silver poplar	Salicaceae	
*Populus grandidentata**	Big-toothed aspen	Salicaceae	
Populus koreana	Korean poplar	Salicaceae	
Populus tomentiglandulosa	Poplar	Salicaceae	
Prunus mume	Japanese apricot	Rosaceae	Yes
Prunus persica	Peach	Rosaceae	Yes
Prunus salicina	Japanese plum	Rosaceae	Yes
*Prunus serotina**	Black cherry	Rosaceae	
Prunus serrulata	Japanese flowering cherry	Rosaceae	
Prunus yedoensis	Hybrid cherry	Rosaceae	
Punica granatum	Pomegranate	Lythraceae	Yes
Pterocarya stenoptera	Chinese wingnut	Juglandaceae	
Pyrus calleryana	Callery pear	Rosaceae	
Quercus acutissima	Sawtooth oak	Fagaceae	
Quercus aliena	Oriental white oak	Fagaceae	
*Quercus montana**	Chestnut oak	Fagaceae	
Rhus chinensis	Chinese sumac	Anacardiaceae	
Rhus javanica		Anacardiaceae	
Robinia pseudoacacia	Black locust	Fabaceae	Yes

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Host	Common Name	Family	Observed Feeding
Rosa hybrid	Rose	Rosaceae	
Rosa multiflora	Mutliflora rose	Rosaceae	
Rosa rugosa	Rugosa rose	Rosaceae	
Rubus crataegifolius	Korean raspberry	Rosaceae	
*Salix spp.**		Salicaceae	Yes
*Salix matsudana**	Corkscrew willow	Salicaceae	Yes
*Salix udensis**	Fantail willow	Salicaceae	Yes
*Sassafras albidum**	Sassafras	Lauraceae	
Sorbaria sorbifolia	False spirea	Rosaceae	
Sorbus commixta	Japanese rowan	Rosaceae	
*Styrax japonicus**	Japanese snowbell	Styracaceae	Yes
Styrax obassia	Fragrant snowbell	Styracaceae	Yes
Syringa vulgaris	Lilac	Oleaceae	
Tetradium danielii	Bee-bee tree	Rutaceae	
*Tilia Americana**	Linden	Malvaceae	
Toona sinensis	Chinese mahogony	Meliaceae	Yes
Toxicodendrum vernicifluum	Chinese laquer	Anacardiaceae	
*Ulmus rubra**	Slippery elm	Ulmaceae	
*Vitis spp.**	Wild grape	Vitaceae	Yes
Vitis amurensis	Amur grape	Vitaceae	
*Vitis vinifera**	Wine grape	Vitaceae	Yes
Zanthoxylum bungeanum	Sichuan-pepper	Rutaceae	Yes
Zelkova serrata	Japanese zelkova	Ulmaceae	

EPPO, 2016b; Shin et al., 2010; Park et al., 2009; Kim et al., 2010; email from Soowon Cho.

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Appendix C: Survey activities and methods

Survey

The PDA survey protocol uses sticky bands on trees, visual survey for all life stages, and an effective outreach program with a high accuracy of the public's ability to positively identify SLF adults due to their unique coloration, size and feeding/aggregation habits. The quarantine area is organized using a 1 km^2 grid layout that is used in Emerald Ash Borer surveys. Each survey crew is assigned specific grids to sample.

From May to November, crews place and service sticky-band traps on *A. altissima* trees within their assigned areas. The use of bands was due to the falling/climbing behavior of the nymphs and adult SLF and based on information from S. Korea and data from the first 2 years of trapping in Pennsylvania. The nymphs are captured as they walk up the trunk of the tree and encounter the sticky part of the bands, filling up the bottom of the band first. Tree bands are wrapped around *A. altissima* trees (≥ 6" dbh; diameter at breast height) at 5 feet above the ground. Every two weeks, PDA staff count the number of SLF individuals captured and replace the bands (as described in the PDA Spotted Lanternfly 2016 Survey/Control Protocols). The bands used in 2014 through 2016 were effective in capturing only the first through third instar nymphs. As SLF develop, their tarsi undergo morphological changes and the insects avoid walking on and becoming stuck to the original sticky bands. The 4th instar nymphs and adults displayed avoidance behavior when encountering the original bands which resulted in little to no capture of 4th instar and adult SLF in 2015. In 2016, bands were no longer placed on trees in August/September due to reduced effectiveness. In 2016, new bands were tested and found to be effective in capturing fourth instar nymphs and adults. These bands had 180^{o} Peel Average Load: 2.61 +/- .25 lbs/inch and Loop Tack: 5.17 +/- .35 lbs/in^2. In 2017, the process of banding was changed, with the new bands being deployed only when 4th instar nymphs and adults are present to increase catch.

Visual surveys are conducted year round for adults, nymphs and egg masses to verify the presence/absence of SLF at locations considered to be "high-risk". High-risk locations include grape vineyards, tree fruit orchards, wholesale and retail distributors of natural and artificial outdoor products, energy and transportation right-of-ways, construction companies and contractors, landscapers, loggers and firewood dealers, and any other location where host trees may occur. Inspected articles include tree-of-heaven, as well as willows (*Salix* spp.), sweet birch (*Betula lenta*), and any products known to be received from known infested regions in Pennsylvania, South Korea, Japan, mainland China, Bangladesh, and Southeast Asia. Locations will typically be visited once during the season, but additional visits may be conducted if it is determined that there is a need to do so. Visual survey for SLF is required as part of inspections conducted at apiaries, nurseries, greenhouses, and survey trapping locations. The focus of the inspection changes based on predominate life stages present:

Egg masses: late September – late May
Early instar nymphs: April – late June
4th instar nymphs: mid-June – late July
Adults: mid-July – early December

(as described in the PDA 2017 LYCO Visual Survey Protocols)

Community outreach both inside and outside of the quarantine area has raised awareness of SLF and generated significant interest in PDA's program. The public reports their detections at BadBug@pa.gov and the Invasive Species Hotline.

- A digital outreach ad was posted to Facebook. Following this digital campaign, PDA received >10,000 contacts in August and September 2017.
- Public reports of new detections are confirmed by PDA. Evidence such as feeding, egg masses from current or previous years, and the visual observation of multiple individuals are used to confirm population presence/absence. Of the public reports received, >90% of reported detections have been correct.
- Volunteers involved with tree banding and egg mass scraping can report their counts online and can keep track of the updated counts for eggs at the PDA SLF site.

Appendix D: Chemical Control Options

Chemical Controls by class with life stage and host

Chemical	Life stage affected	Site
Organophosphates		
Chlorpyrifos 25 WP	1st, 2nd instars, adults	
Diazinon 34EC	1st, 2nd, 3rd instars	
Fenitrothion 50EC	1st, 2nd instars	A. a., V. v
Methidathion 40EC	1st, 2nd instars	
Phenthoate 47.5EC	1st, 2nd instars	V. v.
Carbamates		
Bensultap 50WP	1st, 2nd instars	
Furathiocarb 10EC	1st, 2nd instars	
Pyrethroids		
Bifenthrin 2WP	1st, 2nd instars	A. a., P. p., V. v.
Deltamethrin 1EC	1st, 2nd, 3rd instars	A. a.
Esfenvalerate 1.5EC	1st, 2nd instars	
Etofenprox 20EC	1st, 2nd instars, adults	A. a., V. v.
Neonicotinoids		
Acetamiprid 8WP	1st, 2nd instars	A. a., V. v.
Clothianidin 8SC	1st, 2nd instars	A. a., V. v.
Dinotefuran 10WP	1st, 2nd instars, adults	A. a., P. p., V. v.
Imidacloprid 8SC, 4SL	1st, 2nd instars	
Thiamethoxam 10WG	1st, 2nd instars	A. a., V. v.
Thiacloprid SC		A. a.
Others		
Chlorfenapyr 10SC	1st, 2nd instars	
Spinosad 10SC	1st, 2nd instars	
Sulfoxaflor WG		V. v.

Shin et al., 2010, Park et al., 2009, Kim et al., 2010, email from Soowon Cho.
A. a. = *Ailanthus altissima*, P. p. = *Prunus persica*, V. v. = *Vitis vinifera*

Insecticides currently under testing in PA in a vineyard to develop a program for growers.

Trade Name/Formulation	Active Ingredient
Assail 30SG	acetamiprid
Brigade 2EC	bifenthrin
Sniper	bifenthrin
Baythroid XL	pyrethroid
Imidan 70W	phosmet
Voliam Flexi	thiamethoxam, chlorantraniliprole
Mustang Maxx	zeta-cypermethrin
Actara	thiamethoxam
Venom	dinotefuran

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Brigadier	bifentrhin + imidacloprid
Leverage 360	imidacloprid +beta-cyfluthrin
Neem Oil Extract	neem oil extract
Natria Insect, Disease, & Mite Control	sulfur, pyrethrins
Malathion	malathion
Insecticidal Soap	potassium salts of fatty acids
BotaniGard ES	*Beauveria bassiana* strain GHA
Confirm 2F	tebufenozide
Aza-Direct	azadirachtin
Endeavor	pymetrozine
Sevin SL	carbaryl

J. Urban and E. Smyers, Penn State Entomology, 2017

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Appendix E: Pennsylvania Produced Documents and Resources

Quarantine Documents

PDA Order of Quarantine:
http://www.agriculture.pa.gov/Plants_Land_Water/PlantIndustry/Entomology/spotted_lanternfly/Documents/QuarantineOrder.pdf

How to comply with the SLF Quarantine Regulations:
http://www.agriculture.pa.gov/Plants_Land_Water/PlantIndustry/Entomology/spotted_lanternfly/Documents/How%20to%20comply%20with%20SLF%20regulations%20fact%20sheet%20June%202017.pdf

Checklist of Residents Living in Spotted Lanternfly Quarantine Areas:
http://www.agriculture.pa.gov/Plants_Land_Water/PlantIndustry/Entomology/spotted_lanternfly/Documents/SLF%20Checklist%2011-12-2014.pdf

Management Documents

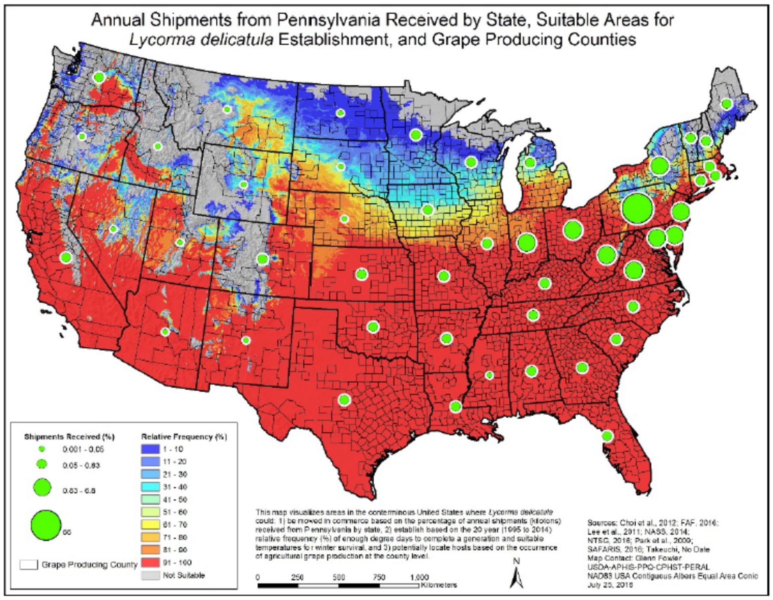
Spotted Lanternfly Management Calendar:
http://www.agriculture.pa.gov/Plants_Land_Water/PlantIndustry/Entomology/spotted_lanternfly/Documents/Time%20of%20year%20management%20chart.pdf

What to do if you find the spotted lanternfly on your property:
http://www.agriculture.pa.gov/Plants_Land_Water/PlantIndustry/Entomology/spotted_lanternfly/Documents/SLF%20Control%209-13-2017.pdf

Egg mass Identification Tips:
http://www.agriculture.pa.gov/Plants_Land_Water/PlantIndustry/Entomology/spotted_lanternfly/Documents/Egg%20Mass%20Identification%202-23-17.pptx

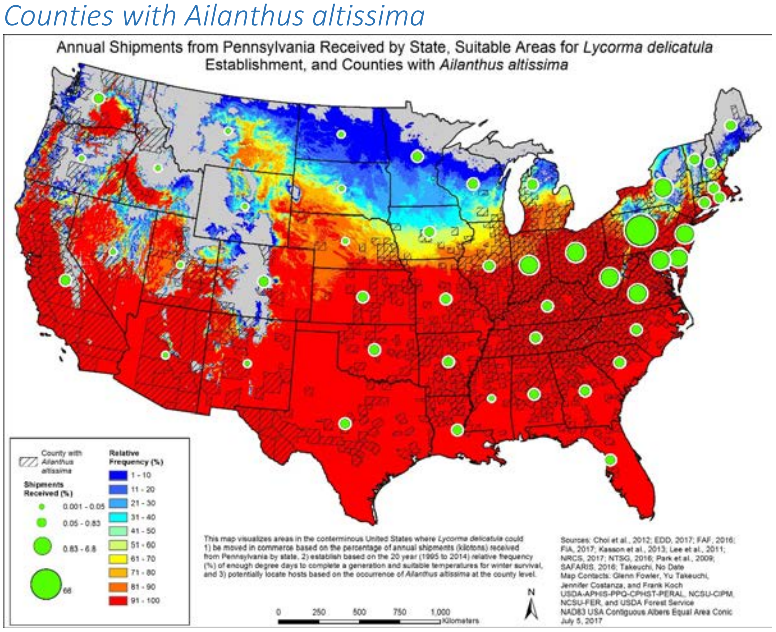
Appendix F: Annual Shipments from Pennsylvania received by state, suitable areas for establishment, and hosts

Annual Shipments from Pennsylvania Received by State, Suitable Areas for SLF Establishment and Grape Producing Counties



Areas in the conterminous United States where *Lycorma delicatula* could 1) enter based on shipments from Pennsylvania received by the state, 2) establish based on suitable climatology, and 3) locate hosts based on grape production (PERAL, 2016b).

Annual Shipments from Pennsylvania Received by State, Suitable Areas for SLF Establishment, and Counties with Ailanthus altissima



Areas in the conterminous United States where Lycorma delicatula *could 1) enter based on shipments from Pennsylvania received by the state, 2) establish based on suitable climatology, and 3) locate hosts based on tree of heaven presence (PERAL, 2016b).*

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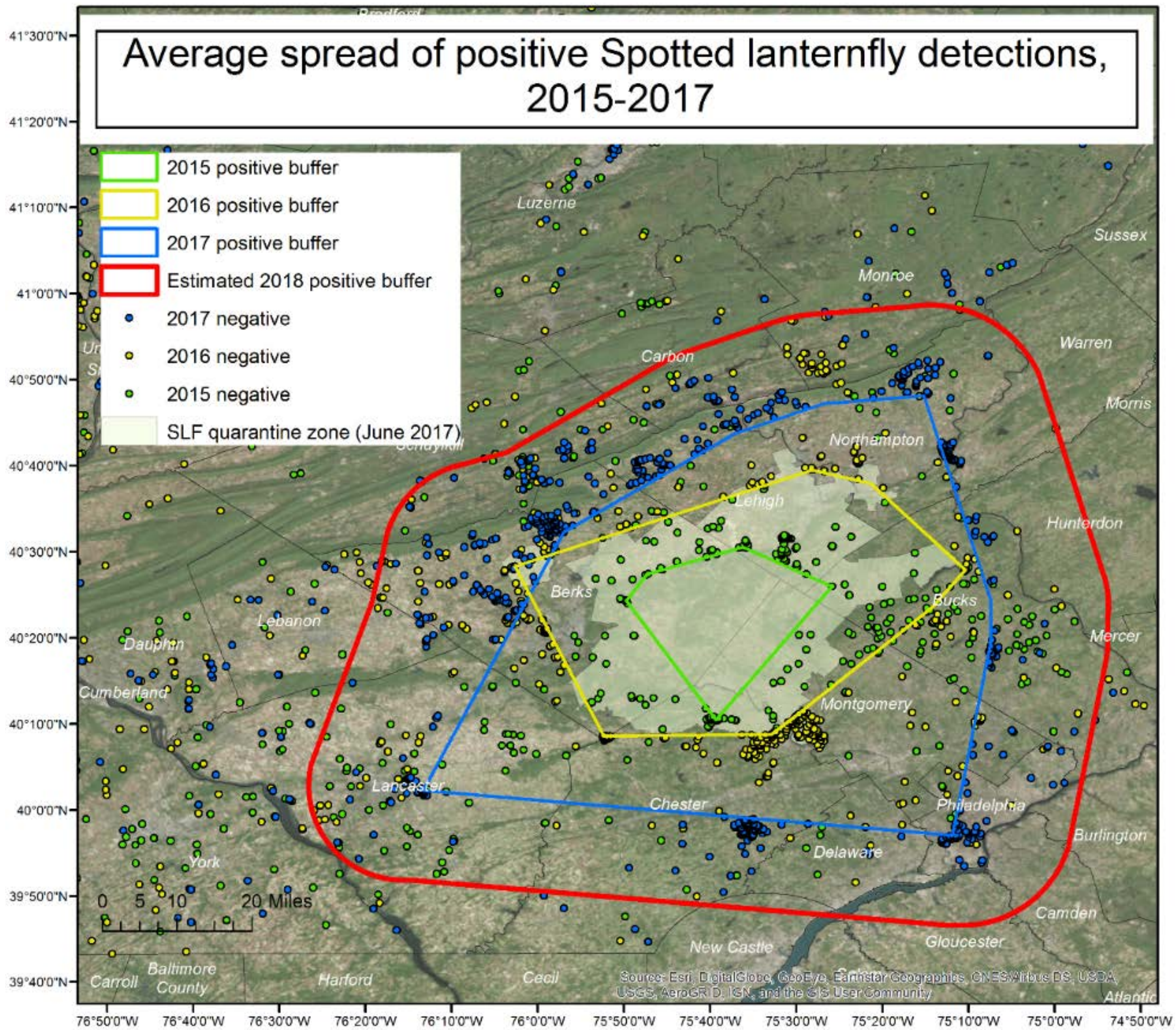
Appendix G: Estimated potential SLF spread model for 2018 based on current expansion observed in Pennsylvania

Average spread of positive spotted lanternfly detection (2015-2017)

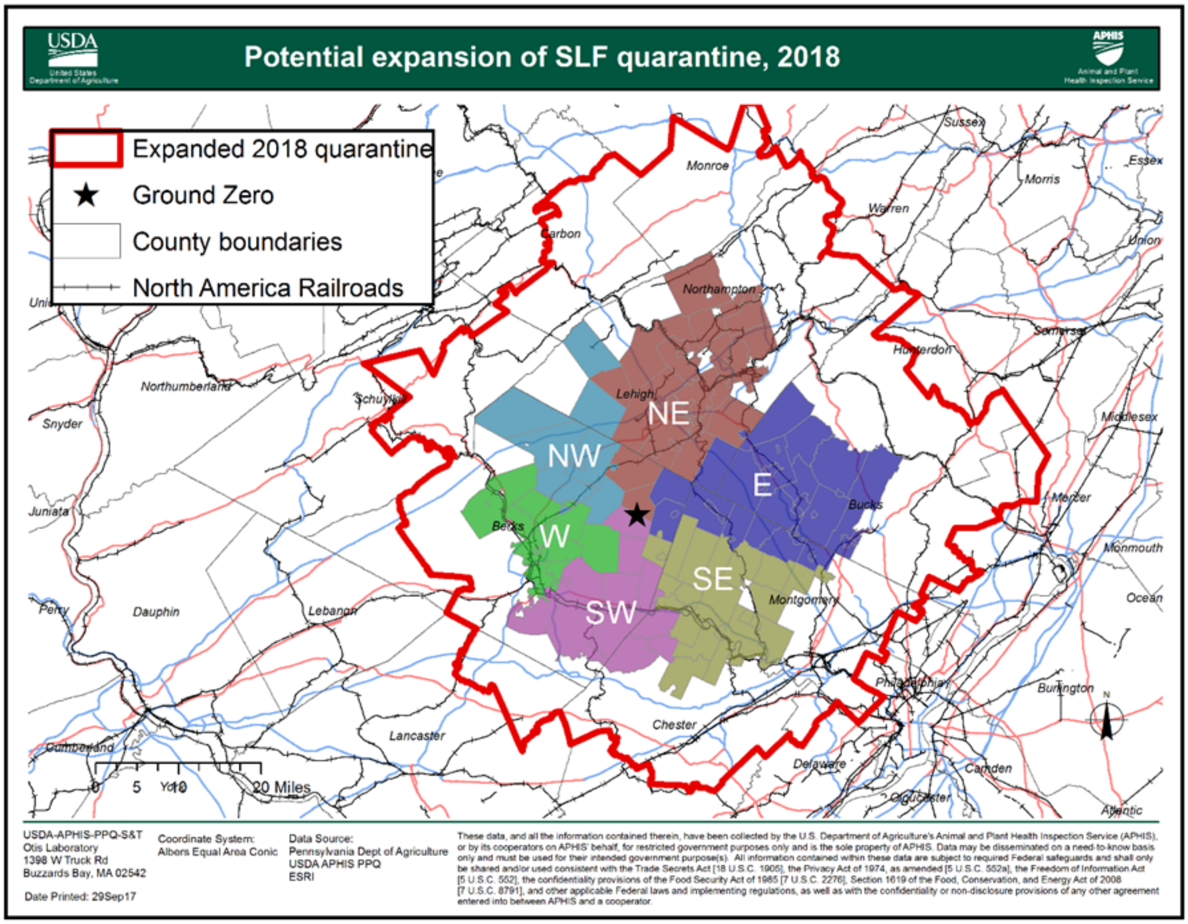


Potential spread of SLF based on previous finds of spotted lanternfly Lycorma delicatula.

On average, the positive buffer expanded about 10.6 mi (17.06 km) between 2015 and 2016, and about 12.4 mi (19.95 km) between 2016 and 2017. This is very similar to what was estimated simply from the expansion of the quarantine boundary.

The estimated 2018 positive buffer is based on a 12 mi (19.31 km) expansion from the 2017 buffer.
2015: 654 sq km (253 sq mi)
2016: 2709 sq km (1046 sq mi)
2017: 6085 sq km (2350 sq mi)
potential 2018: 13,553 sq km (5233 sq mi)

Appendix H. Potential spotted lanternfly (*Lycorma delicatula*) quarantine expansion for 2018. The current quarantine zone is depicted by color based on direction from the assumed ground zero treatment property.



Note that some potential municipalities are in New Jersey.

Summary of Results: The average spread rate was approximately 12.1 km (7.5 mi) per year. Accounting for direction, the average spread rate ranged from 6 km to 17 km (3.7 mi to 10.6 mi) per year.

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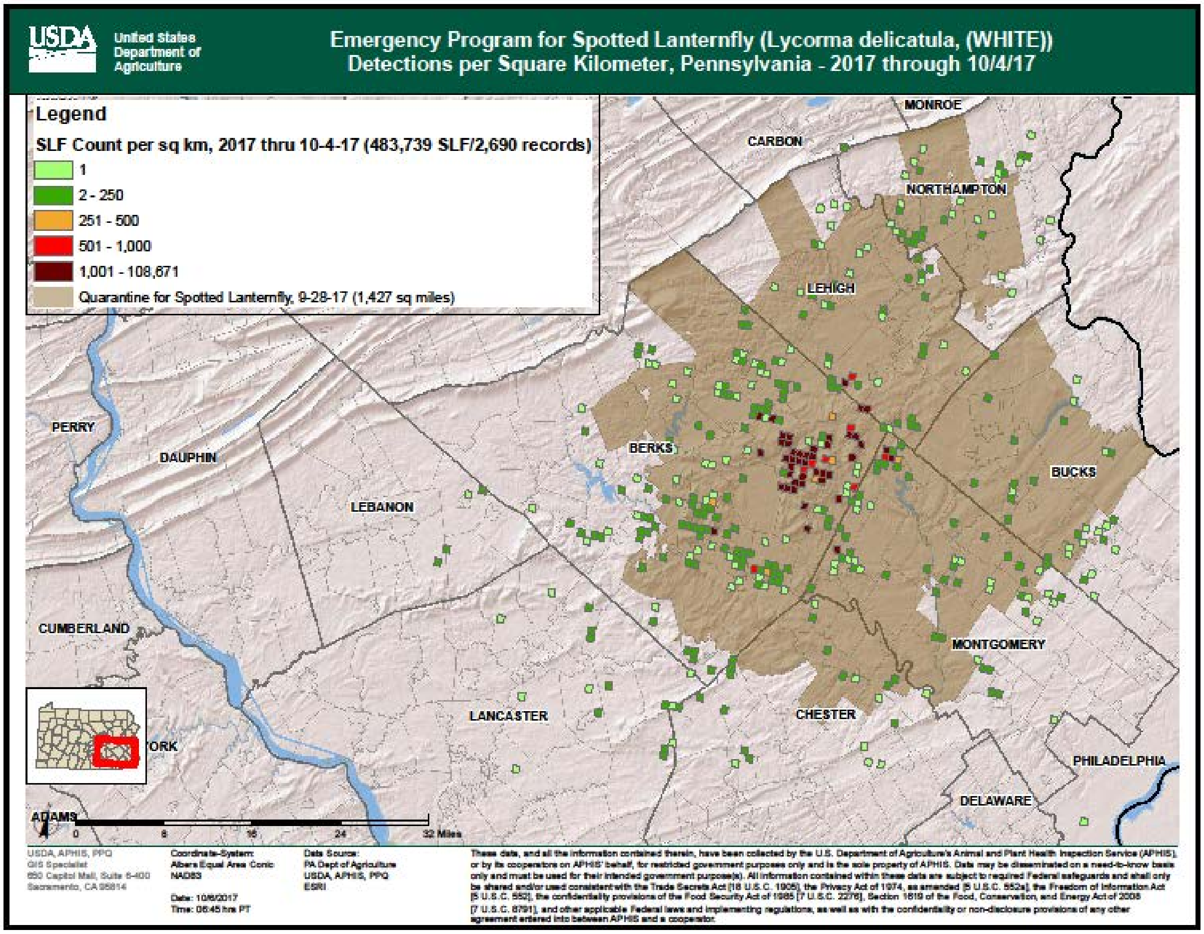
Appendix I: Heat map with total count of Spotted Lanternfly (*Lycorma delicatula*) per 1 km grid square

Total count for 2017 up to 10/04/2017



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Appendix J. *Total count of spotted lanternfly* (Lycorma delicatula) *detected per 1km grid square between 2014 and 2017*