Screening the Michigan Forest Inventory and Midwest Invasive Species Network databases to locate host plants of *Lycorma delicatula* (Spotted Lanternfly) in Michigan

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Cover: Tree of Heaven (*Ailanthus altissima*) from Penn State University species fact sheet.

Contents

List of Tables

List of Figures

Introduction

Lycorma delicatula (Spotted Lanternfly) is an exotic insect pest that originates from eastern Asia and was first introduced to Pennsylvania in 2014. It has since spread to Delaware, Maryland, New Jersey, and Virginia (Wakie et al. 2019), and poses a significant risk to managed and natural landscapes in the United States (Barringer et al. 2015, USDA-APHIS 2017, Urban 2019) (Figure 1). It is an easily distinguishable planthopper with a black head, grey forewings with characteristic black spots, brightly red hindwings, and a black and yellow abdomen (Figure 2). As a phloem feeder, it feeds primarily on the stems and leaves of its host, causing sap leakage and mold growth (Dara et al. 2015). With a lack of natural biological control agents in the United States, populations of *L. delicatula* are likely to increase throughout the range of its host plants and where environmental conditions are suitable for growth and reproduction (Jung et al. 2017, Moylett and Molet 2018, Wakie et al. 2019).

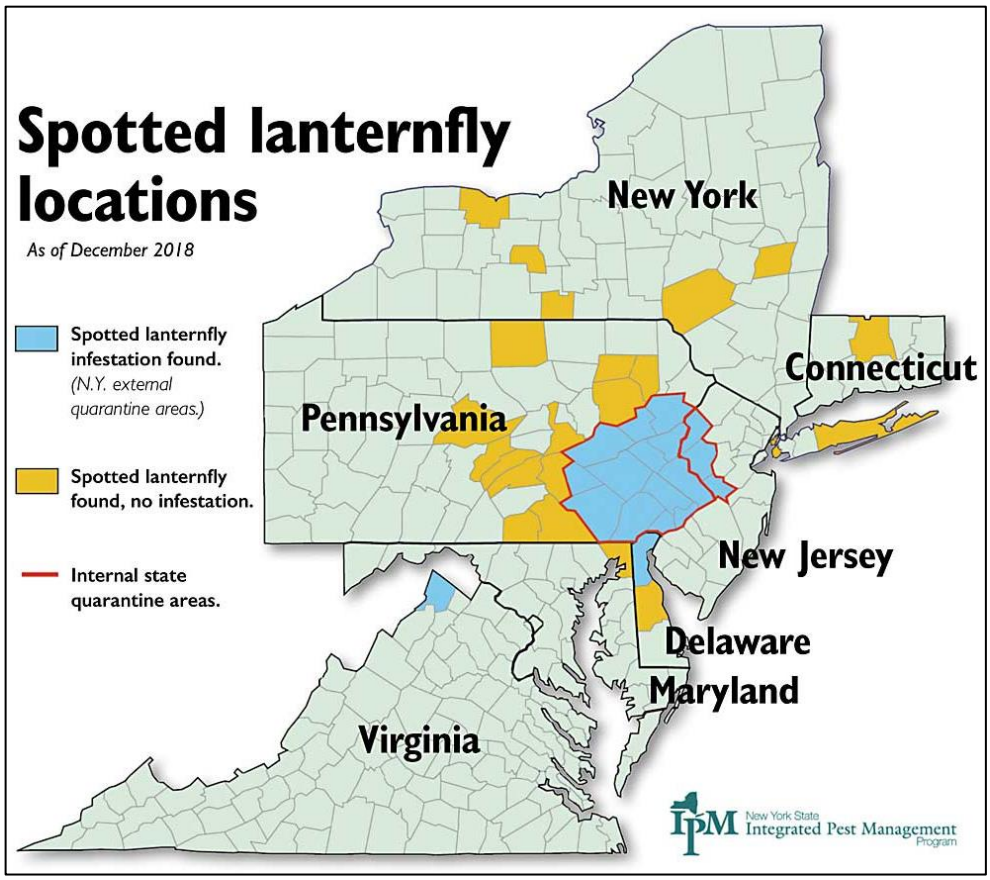

Figure 1. Distribution of *Lycorma delicatula* (Spotted Lanternfly) in the United States as of 2018. Image source: New York State Integrated Pest Management Program.

Lycorma delicatula has been observed feeding on more than 70 plant species throughout its range (Dara et al. 2015). Its primary host is the exotic species *Ailanthus altissima* (tree of heaven), which was introduced to the United States in the late 1800s as an ornamental shade tree

(Ding et al. 2006, Dara et al . 2015) and has since become widely invasive in forest edges and other non-forested habitats (Kok et al. 2008). Additional hosts include numerous agricultural crops including *Vitis vinifera* (grape), *Malus domestica* (apple), and *Prunus* spp. (cherry) and multiple forest tree species including *Acer* spp. (Maples), *Juglans* spp. (Walnuts) and *Liriodendron tulipifera (*Tulip poplar) (USDA-APHIS 2019). Populations of *L. delicatula* and the associated damage due to *L. delicatula* feeding are likely to be of greatest concern in agricultural systems specializing in the production of known host plant crops, and forests with host plant species, particularly *A. altissima*.

Figure 2. *Lycorma delicatula* (Spotted Lanternfly). From Dara et al. 2015.

There are currently no reported records of spotted lanternfly in Michigan. However, recent models suggest Michigan as being at high-risk for invasion and infestation due to Michigan having similar 1) environmental conditions as the historic range of *L. delicatula* and 2) cropping systems as to where this species is currently a pest (Wakie et al. 2019). Regions of Michigan with high densities of preferred host plant crops are likely at greatest risk of invasion (USDA-APHIS 2018, Wakie et al. 2019) (see Figure 3). Because the migration of *L. delicatula* over long distances is primarily mediated by unintentional human transportation, initial occurrences of *L. delicatula* will likely be associated with roadsides, woodland edges, and adjacent suitable cropping systems. Currently, there are few preventative measures for *L. delicatula* infestation in Michigan, and most treatment options include pesticides applied directly to the insect or host plant (USDA-APHIS 2018, Leach et al. 2019). Michigan currently lacks documented occurrences of *L. delicatula*, but early detection of this species requires knowledge of the distribution of preferred host plants within both agricultural and non-agricultural contexts. Due to the explosive potential for populations of *L. delicatula* in Michigan, early-detection will be essential to effective long-term management (Epanchin-Niell 2017). In partnership with the

Michigan (Department of Natural Resources) DNR Wildlife Division, Michigan Natural Features Inventory (MNFI) collects forest community data associated with the Michigan Forest Inventory (MiFI) project. This long-term project aims to document and sustainably manage areas of high conservation significance on state lands. Over the years it has developed a rich dataset full of unique landcover types, high quality natural communities, and plant species lists for distinct ecosystems (Cohen et al. 2014). These extensive plant lists include numerous occurrences of *L. delicatula* host plants on state lands. In addition, MNFI works closely with the Midwest Invasive Species Network (MISIN) to document the locations of invasive species and provide early detection and response resources for state agencies, conservation organizations, and the general public. The data within the MISIN database comes from a variety of sources, including Cooperative Invasive Species Management Areas (CISMAs), and numerous citizen scientists. Invasive species occurrences in the MISIN database largely account for areas that are actively managed for conservation and restoration purposes and areas visited by the general public, as opposed to locations rigorously surveyed by academic researchers. Long-term datasets, such as the MiFI and MISIN datasets, provide unique opportunities to assess the distribution of preferred *L. delicatula* host plants in Michigan, and to identify locations for early detection of *L. delicatula* in Michigan.

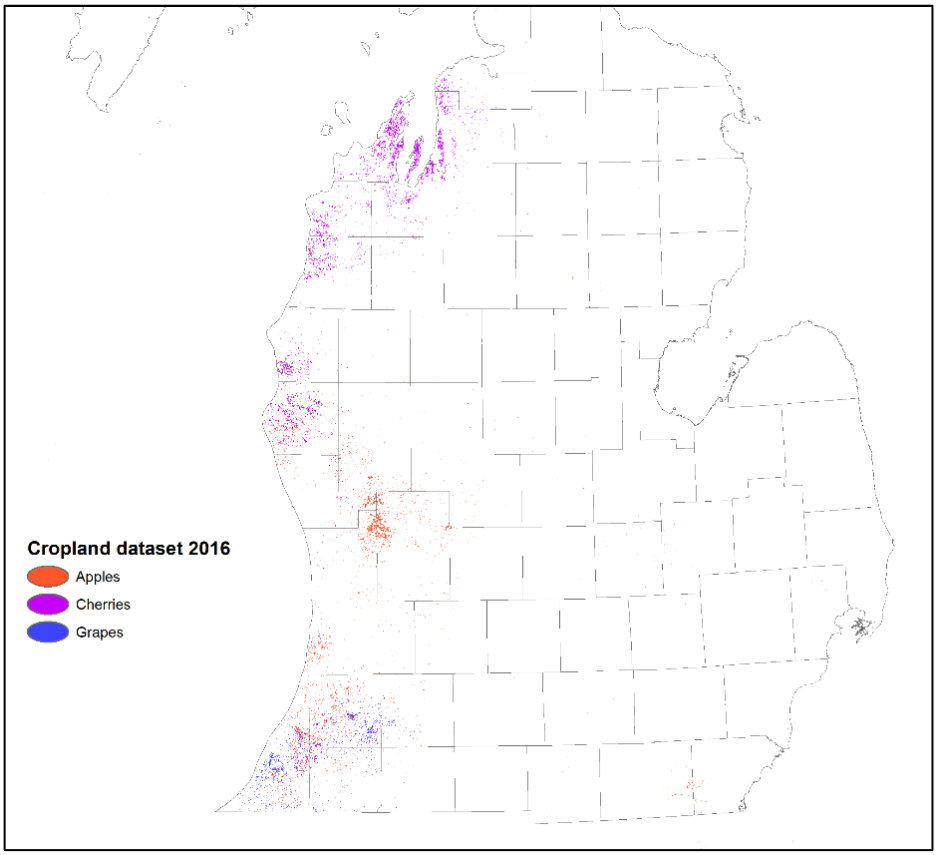

Figure 3. Crop layers for preferred agricultural host plants of *L. delicatula* (Spotted Lanternfly).

In this project we utilize the MiFI and the MISIN plant databases to gather spatial occurrences of known preferred host plants documented in Michigan on state and public lands. We focus on

four taxa: *Malus* spp. (apple), *Prunus* spp. (cherry), *Vitis* spp. (grapevine) and the preferred host plant *A. altissima* (tree of heaven). We first use these occurrences to map currently documented host plant distributions on state and public lands. Second, we use the MiFI dataset to summarize habitat associations for each of the preferred host plants (Table 1). Third, we use the MISIN dataset to determine the abundance and density of *A. altissima* populations found in Michigan and recorded in the MISIN database. Lastly, we describe how these data sets can inform early detection of *L. delicatula* in Michigan.

Table 1. Variables provided by the Michigan Forest Inventory database used to summarize habitat associations for host plant species of interest. Each variable is determined at the habitat (stand) level.

Variable	Description
Land Cover Type	Land cover type as determined by the Michigan Forest Inventory system. Forested and non-forested habitats receive a land cover classification based on the plant species present.
Upland/Lowland	Whether the habitat is comprised primarily of lowland or upland plant species or retains characteristics of upland or lowland habitats.
Overall Size	For forested habitats, overall size (Sapling→Pole→Log) describes the age of the forested habitat.
Tree Cover	Density of trees within the habitat.

Methods

We utilized the MiFI 'stand level' database to gather information on host plant occurrences on state lands. Stands are defined as unique landcover types embedded within, and distinct from the surrounding landscape. Each stand is surveyed on an approximately 10-year cycle by MNFI ecologists and/or DNR foresters. During stand surveys, data collection includes a plant species list with relative species abundance and associated stand level variables. The stand level variables include (but are not limited to) stand age, mature tree density, canopy closure, cover type, acreage at the stand level, and associated natural community classification using the criteria defined in Cohen et al. 2015. For this project, data collected between 2000-2018 is used (i.e., first documented occurrences of host plants within the database – most current data). We mined the MiFI database to only include stands with host plants of interest. For *Vitis* spp., *Malus* spp., and *Prunus* spp., we filtered the database using these taxa names. *Ailanthus altissima* was not a recorded species during MiFI data collection until 2017, and instead was generally included in the notes section of occupied stands. Therefore, we searched the notes section for each name variation included in the database for *A. altissima*: *Alianthus altissima*, tree of heaven, tree-of-heaven, Ail alt, AILALT, Ailanthus alt, Ailanthus, and A. alt. In total, the MiFI database accounts for approximately 350,000 acres of state-owned lands surveyed using standardized survey methodology. In addition, we pulled all documented occurrences of *A. altissima* in Michigan from the MISIN database. Data entry in the

MISIN database requires species identification and a drop-down selection of patch size and density options. Patch size is described using the following categories: individual/few/several, <1000 sq ft, 1000 sq ft to 0.5 acres, 0.5 acres to 1.0 acre, and > 1.0 acre. Patch density is characterized using the following categories: sparse, patchy, dense, and monoculture. The resulting dataset included all MiFI stands with at least one occurrence of one of the four host plants of primary interest, as well as all recorded Michigan occurrences of *A. altissima* in the MISIN database.

Occupied locations for each host plant were visualized independently (ArcMap, Version 10.6) to determine the spatial distribution of each host plant in Michigan. For *Vitis* spp., *Malus* spp., and *Prunus* spp., locations are shown at the stand level. For *A. altissima,* stand level occurrences and MISIN occurrences are combined into a single map, but differentiated by color. Data collected using the MiFI framework were used to assess the relationships between stand level variables and host plant occurrence, and included land cover type, upland/lowland, forest age (Overall Size), and % canpy cover. Data collected using the MISIN framework were evaluated to assess *A. altissima* patch size and density.

Results

We documented a total of 1,105 stands with occurrences of *Malus* spp. (Figure 4), 38,132 stands with *Prunus* spp. (Figure 5), 617 with *Vitis* spp. (Figure 6), and 73 with *A. altissima* in the MiFI database (Figure 7). In addition, a total of 690 occurrences of *A. altissima* were documented in the MISIN database (Figure 7). Four occurrences of *A. altissima* were documented in high-quality natural communities (MNFI Natural Community Element Occurrences), including dry-mesic southern forest (3 occurrences) and floodplain forest (1 occurrence). Based on the data here, *Alianthus altissima* generally occurs in greatest abundance in the southern lower peninsula but also occurs up the western coast of Michigan, and sparsely in the upper peninsula.

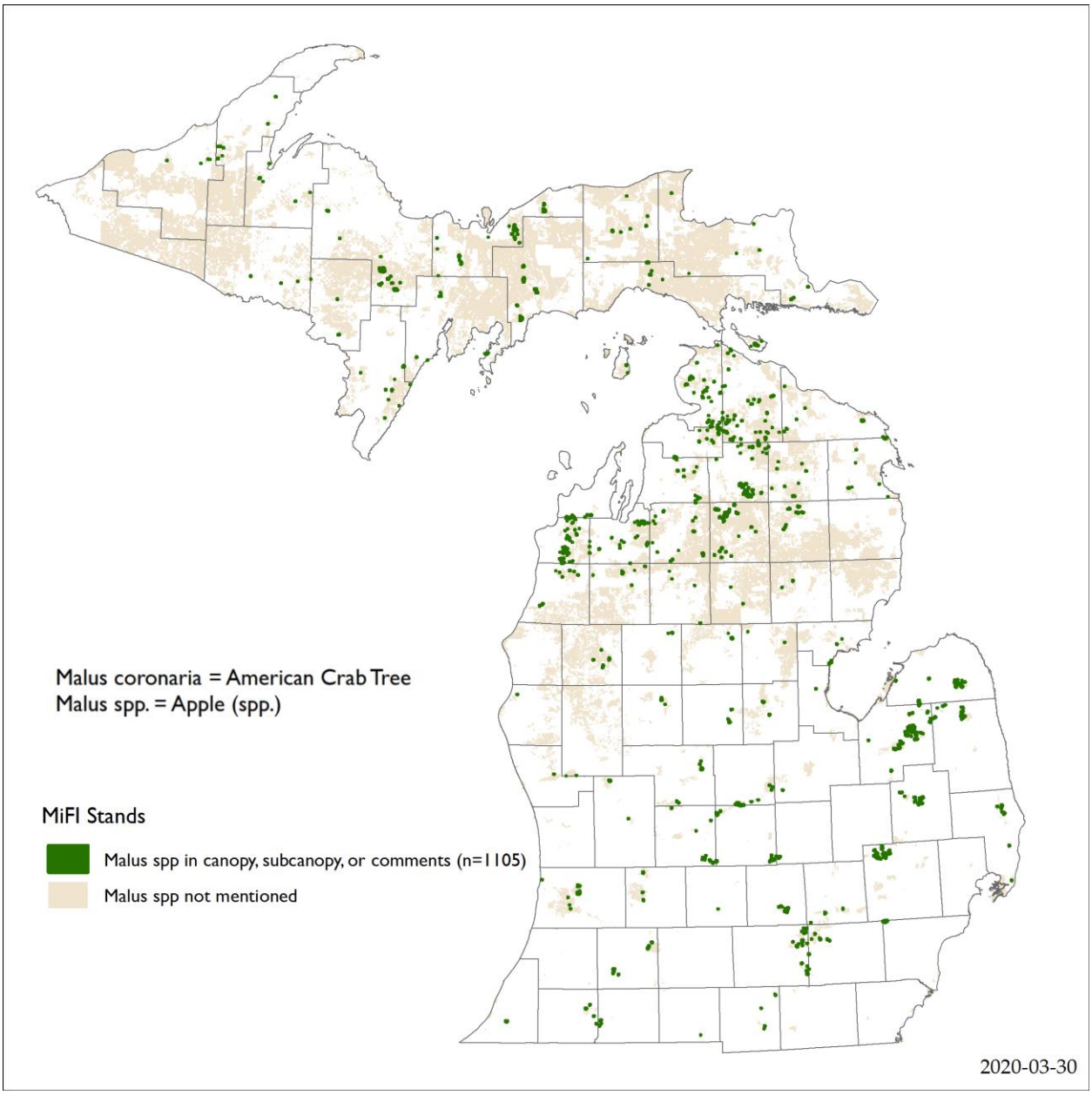

Figure 4. Michigan Forest Inventory stand occurrences of *Malus* spp. on Michigan state lands are shown in green. Occurrences were documented in the Michigan Forest Inventory database between 2000 – 2018. Species occurrences were recorded in either the forest canopy, subcanopy, or mentioned in the notes during data collection.

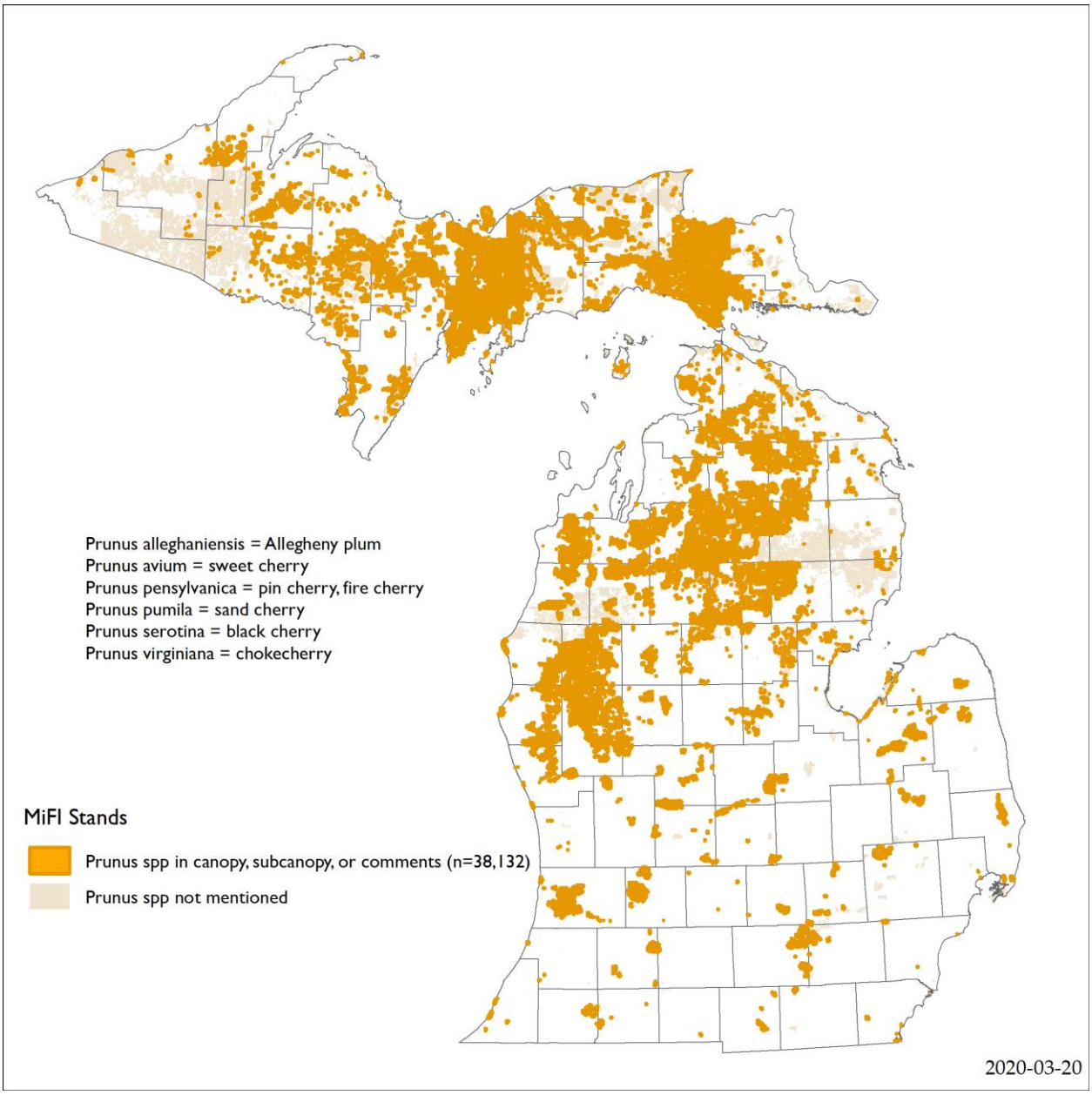

Figure 5. Michigan Forest Inventory stand occurrences of *Prunus* spp. on Michigan state lands are shown in orange. Occurrences were documented in the Michigan Forest Inventory database between 2000 – 2018. Species occurrences were recorded in either the forest canopy, subcanopy, or mentioned in the notes during data collection. Multiple species of *Prunus* were recorded.

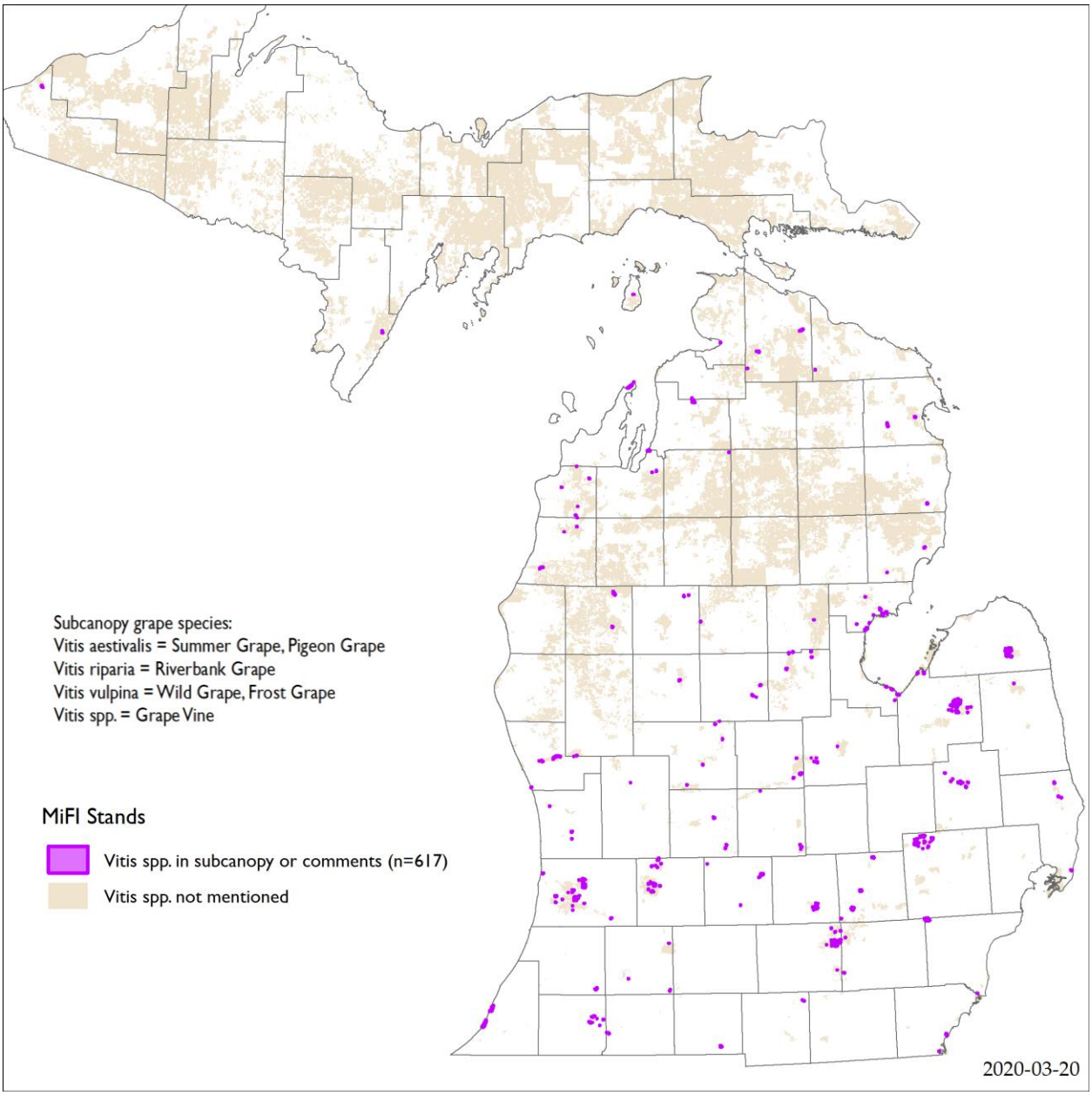

Figure 6. Michigan Forest Inventory stand occurrences of *Vitis* spp. on Michigan state lands are shown in purple. Occurrences were documented in the Michigan Forest Inventory database between 2000 – 2018. Species occurrences were recorded in either the forest canopy, subcanopy, or mentioned in the notes during data collection.

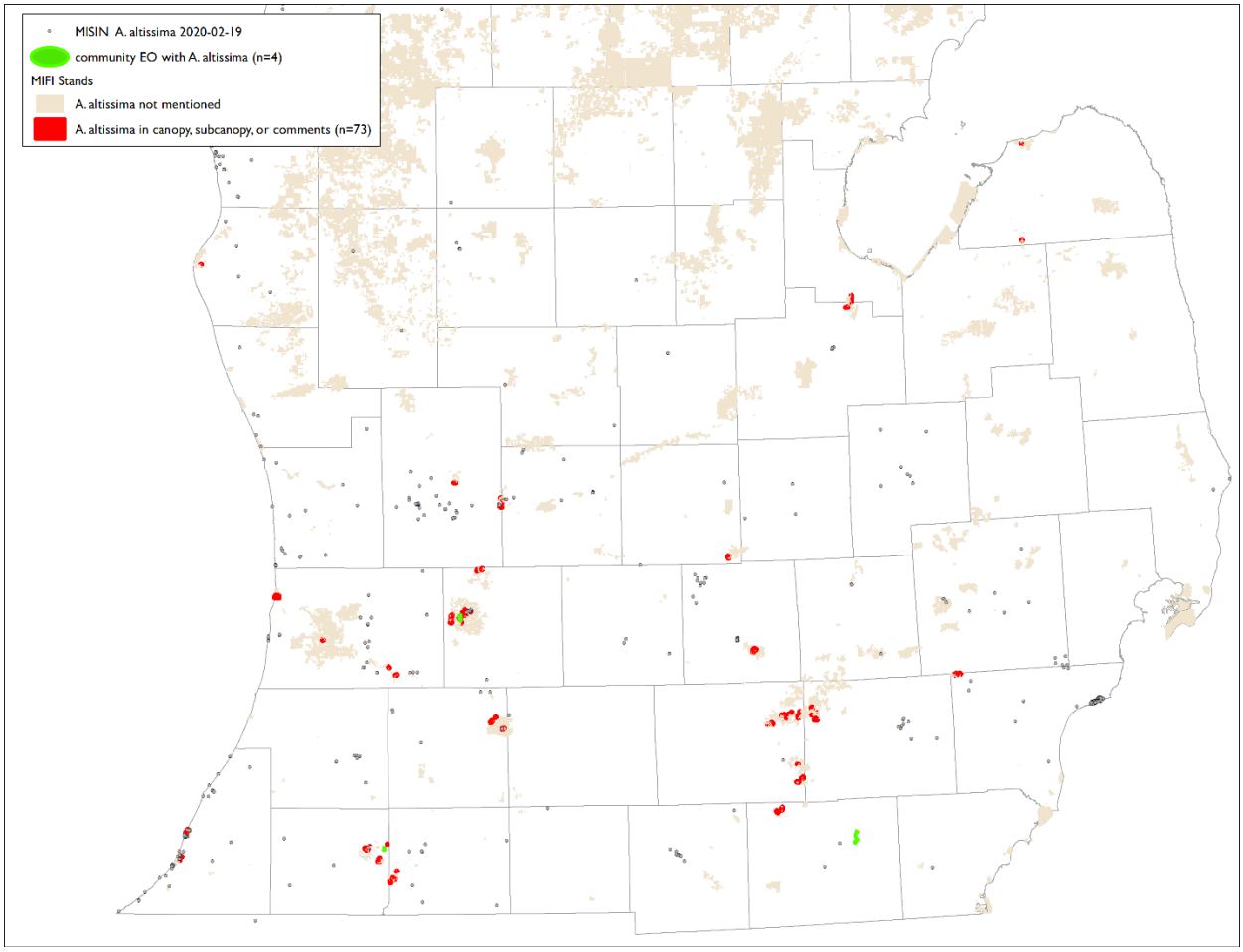

Figure 7. Michigan Forest Inventory stand occurrences of *Ailanthus altissima* on Michigan state lands are shown in red. Occurrences documented in the Midwest Invasive Species Network are show in grey. Occurrences that fall within high quality natural communities on state lands are shown in green.

For each species of interest, a relatively high proportion of host plant occurrences occur within mixed upland deciduous forests and herbaceous openlands (Table 1). The remaining land cover types tend to be weakly related to the presence of host plant taxa, and the level of overlap between taxa in similar land cover types is limited. In general, host plant species are strongly associated with upland community types. Furthermore, for each host plant, occurrence tends to be weakly related to forest age and percent canopy closure, where there is a greater proportion of occurrences in both mature and non-forested habitats, as opposed to younger forests. The primary host plant species of interest, *A. altissima*, is more commonly found in both older forests (overall size = "Log", 47% of occurrences) and non-forested habitats (30% of occurrences) (Table 3).

The majority of *A. altissima* occurrences in the MISIN database are records of a small number of plants (abundance category: Individual/Few/Several plants, 48% of occurrences; density category: sparse, 45% of occurrences). Large populations of *A. altissima* are documented at a much lower frequency (abundance category: >1.0 acre, 3% of occurrences; density category: monoculture, 4% of occurrences) (Figure 8).

Table 2. Proportion of host plant taxa detected within land cover types as classified by the Michigan Forest Inventory Framework. The top 3-4 cover types associated with each host plant taxa are bolded.

Land Cover Type	***A. altissima***	***Prunus* sp**	***Vitis* sp.**	***Malus* sp.**
Aspen	0.05	**0.27**	0.08	0.04
Cedar	0.00	0.00	0.01	0.00
Cropland	0.03	0.00	0.00	0.02
Herbaceous Openland	**0.18**	0.04	**0.11**	**0.19**
Jack Pine	0.00	0.06	0.00	0.00
Low-Density Trees	0.07	0.03	0.05	**0.12**
Lowland Aspen/Balsam Poplar	0.00	0.02	0.07	0.05
Lowland Conifers	0.00	0.01	0.00	0.00
Lowland Deciduous	0.01	0.03	**0.15**	0.05
Lowland Mixed Forest	0.00	0.00	0.01	0.00
Lowland Shrub	0.04	0.00	**0.10**	0.02
Marsh	0.00	0.00	0.04	0.00
Mixed Upland Deciduous*	**0.32**	**0.11**	**0.15**	**0.19**
Natural Mixed Pines	0.00	0.02	0.00	0.01
Northern Hardwood	0.07	**0.15**	0.05	0.07
Oak	**0.08**	0.07	0.02	0.02
Planted Mixed Pines	0.00	0.01	0.00	0.01
Red Pine	0.03	0.06	0.01	0.02
Sand, Soil	0.01	0.00	0.01	0.00
Upland Conifers	0.00	0.01	0.01	0.00
Upland Mixed Forest	0.00	0.04	0.01	0.03
Upland Shrub	0.04	0.02	0.09	**0.12**
Upland Spruce/Fir	0.00	0.01	0.00	0.00
Water	0.00	0.00	0.01	0.00
White Pine	0.01	0.02	0.01	0.01
Unspecified	0.05	0.02	0.01	0.01

Table 3. Proportion of host plant taxa detected within categorical variables describing upland/lowland/ overall size, and tree cover. The top 2-3 variables associated with each host plant taxa are bolded.

Variable		*A. altissima*	*Prunus* sp.	*Vitis* sp.	*Malus* sp.
Upland/Lowland					
	Lowland	0.04	0.05	**0.34**	0.12
	Lowland w/Up	0.02	0.01	0.04	0.03
	Upland	**0.85**	**0.87**	**0.53**	**0.82**
	Upland w/Low	0.09	0.06	0.08	0.03
Overall Size					
	Log	**0.47**	**0.31**	**0.37**	**0.33**
	Pole	0.14	**0.36**	**0.28**	**0.30**
	Sapling	0.09	**0.28**	0.07	0.04
	Non-forested	**0.30**	0.05	**0.28**	**0.34**
Tree Cover					
	0-25%	**0.37**	0.10	**0.41**	**0.48**
	25-50%	0.11	0.08	0.13	0.10
	50-75%	**0.23**	0.19	0.20	0.21
	75-100%	**0.29**	**0.64**	**0.26**	0.21

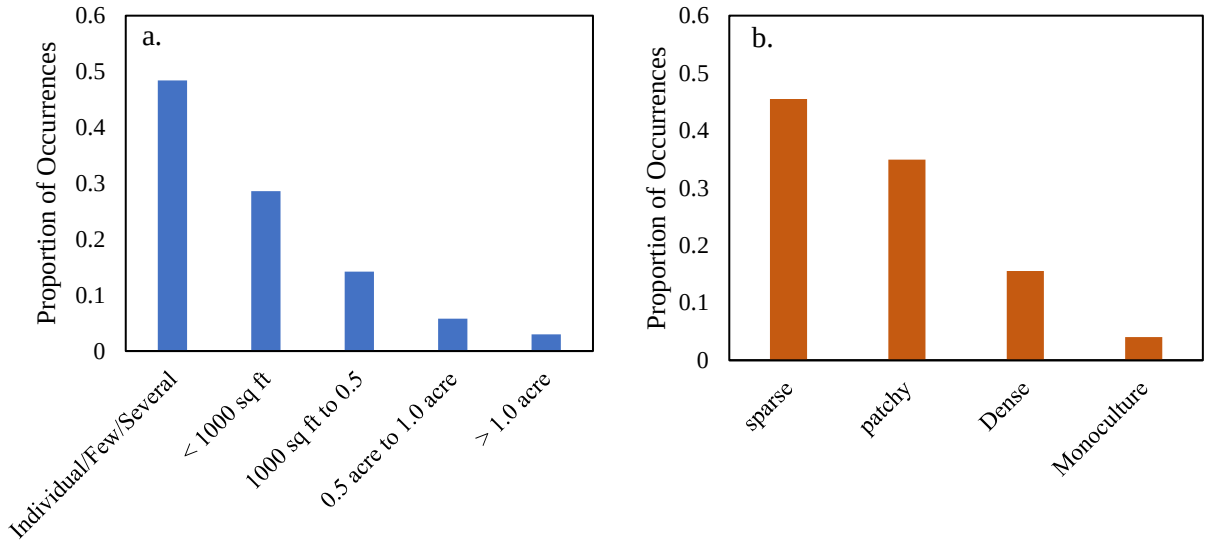

Figure 8. The proportion of *A. altissima* occurrences in the MISIN database in terms of it's a) patch size and b) density during each reported observation.

Discussion

Regional models based on the current distribution of *L. delicatula* and associated environmental data suggest that the southern half of the lower peninsula of Michigan is at the greatest risk of *L. delicatula* invasion and infestation (Wakie et al. 2019). Areas within this region that produce crops known to be affected by *L. delicatula* invasion elsewhere in the United States are at an even greater risk due to the potential for crop related economic losses (Dara et al. 2015). We propose four ways in which early detection of spotted lanternfly in Michigan can be informed: 1) knowledge of preferred host plant distribution; 2) the habitat context in which host plants are found; 3) host plant proximity to potential points of entry; and 4) the relative abundance and density of preferred host plants at these locations (Dara et al. 2015, Jung et al. 2017, USDA-APHIS 2018, Wakie et al. 2019). In this report, we utilized two public databases to map documented occurrences of known host plants of *L. delicatula* in Michigan, including the preferred host plant, *Alianthus altissima*. Our results provide information on host plant populations in forested contexts and the relative abundance and density of populations of *A. altissima* in forested and non-forested contexts.

We found variability in the cover type associations of preferred host plants in Michigan. However, herbaceous openlands (fields dominated by non-forest vegetation) and mixed upland deciduous forests generally had greater proportions of preferred host plant occurrence. With greater rates of host plant occurrence, these cover types may be at a greater risk of invasion *by L. delicatula*. Early detection programs may benefit by focusing on these cover types in the early stages of scouting for *L. delicatula*. Furthermore, we provide evidence that the majority of *A. altissima*, the primary hostplant of *L. delicatula*, are of smaller populations as opposed to dense monocultures. Identifying the locations of and applying appropriate management actions to these populations of *A. altissima* could decrease the likelihood that they expand and provide a starting point for minimizing the occurrence of preferred host plants. Because the other host plant taxons documented in this study contain both native and non-native species, they primarily aide in the identification of natural areas that may be at risk if *L. delicatula* expands beyond points of entry.

We provide baseline data that are useful for 1) refining models that assess the potential occupancy and distribution of *L. delicatula* in Michigan; 2) developing or identifying early detection locations to begin *L. delicatula* monitoring programs; and 3) identifying potential criteria for *A. altissima* eradication programs. With the expectation that *L. delicatula* will arrive in Michigan at some point during the next few years, we suggest an immediate need to develop *L. delicatula* early detection and *A. altissima* eradication programs in regions most likely to be impacted by invasion.

Early Detection

Early detection of *L. delicatula* will be critical for tracking its spread and developing appropriate long-term management programs. The most effective early detection program will require many observation points along points of entry in high-risk areas in southern Michigan. One method to increase the likelihood of early detection involves implementing a coordinated effort among citizen scientists to continue tracking and mapping preferred hostplants such as *A. altissima*, and to regularly check locations where host plants are present.

Citizen science monitoring programs have shown success in tracking species of concern, including both beneficial insects and invasive pests (Van Der Wal et al. 2015, Maistrello et al. 2016). Because *L. delicatula* has yet to be found in Michigan, a citizen science program would be largely based on host plant presence, thus providing an opportunity to identify initial points of entry. Citizen scientists should be provided the tools to document and map *A. altissima* distribution in Michigan, and methodology to regularly monitor populations of *A. altissima*. We suggest the following criteria for selecting populations of preferred hostplants to regularly monitor: 1) host plant populations that are established and are easily accessible, 2) populations are located along possible points of entry in southern Michigan, including both non-forested cover types such as roadsides and herbaceous openlands, and forest edges; and 3) populations of the host that are larger than a single individual. Successful implementation of a citizen science program for *L. delicatula* would allow for increased effort in identifying initial populations of *L. delicatula* in Michigan and provide data to inform potential host plant eradication efforts.

Increasing Eradication Efforts for *A. altissima*

Mapping host plant distributions, particularly *A. altissima*, provides a useful starting point for identifying populations of host plants to eradicate while simultaneously establishing early detection posts. In this report, we mapped potential hostplants at the genus level, which includes both native and non-native species that have been shown to be used as *L. delicatula* larval resources (Avanesyan & Lamp 2020). Identifying populations of host plants to eradicate should prioritize non-native species, particularly *A. altissima*. We propose that initial eradication efforts be concentrated on small populations of *A. altissima* in southern Michigan in highly managed and trafficked areas, such as roadsides and both forested and non-forested areas adjacent to agricultural systems. To slow the statewide spread of *A. altissima,* eradicating populations of *A. altissima* that are outliers to the overall species range in Michigan may decrease the likelihood of *A. altissima* spread throughout the state. Once smaller populations within high-risk areas and on the outer edges of *A. altissima* range have been eradicated, efforts should focus more heavily on larger populations within Southern Michigan. Effectively controlling these populations may decrease the presence of host plant reservoirs for *L. delicatula*.

Conclusion

In the likely event that *L. delicatula* arrives to Michigan, having a framework in place for early detection and a mechanism for eradicating invasive host plants will be critical for the long-term management of this species. It is unlikely that eradication practices will eliminate host plant availability, particularly native host plants and suitable crops. However, the removal of a primary resource from hypothesized points of entry and habitats adjacent to croplands could help reduce populations to a level more manageable by land managers and crop producers. Citizen scientists could be an invaluable resource for mapping host plants. Early detection followed by a rapid management response for *L. delicatula,* including both management of the species and eradication of invasive host plant resources, will be necessary for long term management of *L. delicatula* and the habitats it occupies.

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