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Invasive Plants and Biocontrol:
The Tree of Heaven

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Abstract

The Tree of Heaven (TOH) is an invasive plant that is commonly found in the northeastern United States where it has become established. Biocontrol, the introduction of a predator to control the population of an undesirable species has been identified as a possible method of control for the TOH. Government reports show that the TOH is responsible for minor infrastructural damages. More significantly TOH is a host of some dangerous pests such as the Spotted Lanternfly, which causes significant damage to agricultural crops. Current research suggests that the Tree of Heaven can be controlled with biocontrol without significantly damaging other flora. Local botanical scientists contend that the TOH is an invasive plant but that the damage associated with the TOH is contained in areas already environmentally degraded by other invasive plants and damage caused by property development. The majority of scientists supported biocontrol as a good, yet time-consuming method of control for some species under certain circumstances.

Keywords: tree of heaven, invasive plants, ailanthus, biocontrol

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Invasive Plants and Biocontrol:

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Introduction

Invasive plants can have catastrophic effects on the environments that they are introduced to. Invasive plants are non-native plants that cause damage to their new habitat. Invasive non-native plants have particular qualities that make them better suited to their environment than native plants; thus they compete with the native plants for needed resources. The invasion of an environment by a non-native plant creates a context that reflects Darwin's theory of evolution by natural selection. Once established, invasive plants outcompete and displace their native counterparts and change the local ecosystem drastically. Invasive plants are difficult to remove; they can, however, be controlled.

There are several ways that invasive plants are controlled. These controls include mechanical control, chemical control, and more recently, biocontrol. Biocontrol is the introduction of a pathogen or predator of a sort to a population of undesirable species. It is typically very effective because the reason that an invasive species becomes quickly established is that they have no natural predators in their new environment.

However, once the invasive plant is established, removal may have implications for its environment. It is possible that removal of an invasive species could have a negative impact on the local environment if it has entrenched itself in the ecosystem. Invasive species may take on important functions after outcompeting natives, and its removal would, therefore, impact other plants and animals that have come to depend on it (Voss, 2016).

Biological controls may also have non-target outcomes, as native plants can be negatively affected by the introduction of a biocontrol agent. However, in the long run, the population of

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threatened native plants remains either stable or increases (DePrenger-Levin, Grant, & Dawson, 2010; Meyer & Fourdrigniez, 2011).

Many invasive species, such as the Tree of Heaven, or *Ailanthus altissima* are introduced through commercial ornamental trade. Invasive ornamental plants are planted in one area, and then continue to spread beyond the desired range if they have qualities like high seed production quantity that are conducive to spread. This also holds true for the Tree of Heaven.

The Tree of Heaven is an invasive species that is widely established in the Lower Hudson Valley in New York State. The Tree of Heaven was introduced by William Hamilton in 1784 and has since spread throughout the Lower Hudson region throughout the decades. Some documented negative effects of the widespread establishment of the Tree of Heaven have been the suppression of the population of native plants, aiding the introduction of other invasive species, and changes in the chemical composition in the soil (Sladonja, Susek, & Guillermic, 2015). Currently, limited research is available concerning the impact of removing the Tree of Heaven. The aim of this project is to determine whether biocontrol is an effective and practical method for controlling the Tree of Heaven through the documentation of expert opinion.

Statement of the Problem

While the Tree of Heaven is an invasive plant that causes ecological problems, more research is needed to determine how the Tree of Heaven should be controlled, as effective methods of control can have unintended environmental consequences.

Invasive plants are a major issue in the global environment. After their introduction into an environment, invasive plants outcompete native plants resulting in changes that impact the environment. Some significant changes associated with the establishment of non-native plants

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are disruptions in the food chain and the loss of habitat for other species dependent on native plants (City of Portland, 2016).

In the Hudson Valley, the Tree of Heaven is a highly invasive plant that has been difficult to control. Like many invasive plants, the Tree of Heaven was introduced to the United States during the 18th century as an ornamental plant. The tree is estimated to be present in 44 states. The Tree of Heaven is currently ranked as a moderate-risk category (68) invasive plant by the New York Invasive Species invasive plant ranking system. The ranking system scores a non-native plant's risk to the environment based on ecological impact data, biological characteristics such as seed production, distribution, and ease of control. Biocontrol is a relatively new form of weed control that has been used successfully to combat other invasive plants such as Tamarix, a genus of flowering plants native to Africa and Knapweed, a type of thistle (Seastedt, 2015).

Research Question/Hypothesis

For the purposes of this documentary on the Tree of Heaven, the following questions will be addressed:

1. Based on their current expertise in the field of conservation and botany, will experts support the removal of the Tree of Heaven?
2. Will experts support biocontrol as the best method of control?

Based on prior studies (Harris, Cannon, Smith, & Muth, 2013; DePrenger-Levin, Grant, & Dawson, 2010; Meyer & Fourdrigniez, 2011) the researcher expects the scientists to support the use of biocontrol to address the growth and expansion of the Tree of Heaven

Definition of Terms

An invasive plant refers to non-native plants that have been introduced to an environment that have become noxious weeds. Biocontrol is a method of weed control that involves the

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introduction of a pathogen or an insect to control undesirable species. Pathogens are viruses or organisms such as parasites or bacteria that infect a host with a disease.

Literature Review

Theoretical Framework

Darwin poses that “[a] grain in the balance will determine which individual shall live and which shall die - which variety or species shall increase in number, and which shall decrease, or finally become extinct.” (Darwin, 1859, p.554). Invasive species have attributes, refined over years of evolution, that enable them to survive and multiply, outcompeting the native inhabitants (Berkeley, 2014). Offspring of surviving individuals are more likely to possess those traits associated with increased ability to survive, and these traits are passed down to succeeding generations. In the absence of natural predators, the invasive species can continue to grow and thrive unchecked.

The introduction of non-native species, whether plant or animal, may be disruptive to the environments in which they are introduced. This disruption may ultimately be beneficial for the local ecosystems as the local flora and fauna adapt to the alien species and may come to depend upon the intruder. The threats and costs of a non-native organism may outweigh benefits. This study examines the implications of altering a natural environment and the costs and benefits of biologically-based interventions. The theoretical framework for the proposed study is grounded in ecological theory and the relationships between the organisms in the ecosystem.

Introduction

Non-native plants are flora that establish themselves in environments that are alien to them. These plants are typically introduced to address a demand for ornamental shrubs and trees not available in a particular region. If the non-native plant threatens the new environment, it is

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considered invasive. Popular examples of invasive species include the Norway Maple Tree, the Yellow Iris flower, and Japanese Honeysuckle. In the United States, there are approximately 50,000 non-native species (both plants and animals.) Of these, 4300 are considered invasive. Invasive plants pose numerous environmental threats with serious implications for the environment they have “invaded.” Invasive plants have contributed, either directly or indirectly to the decline of 42 percent of endangered or threatened plants. In 18 percent of the cases, the main cause of the decline is invasive species (US Department of Agriculture Forest Service, 2016).

Invasive plants compete with native plants, threatening biodiversity and the ecosystem of the local region (City of Portland, 2016). Biodiversity is critically important for the earth. Some of the effects of the loss of native plants may impact other species. The impact on one species impacts other species resulting in a domino effect. This impacts the environment at large which has negative consequences for crops and animals that are used in agriculture. Some are responsible for erosion and general environmental degrade. Invasive plants may also harbor pathogens and pests further threatening biodiversity.

Not all non-native plants pose serious threats to the local environment. The Tree of Heaven is an example of an invasive plant introduced for its ornament properties. The Tree of Heaven may have introduced threat but the threat may be offset by risks related to its removal or by its possible associated benefits.

Evolution by Natural Selection

In Darwinian terms, invasive plants are able to withstand the challenges of the environment. As Darwin posits, “One general law, leading to the advancement of all organic beings, namely, multiply, vary, let the strongest live and the weakest die.” (Darwin, 1859,

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p.109). Darwin proposes that over the course of their evolution, some species develop the traits to promote their survival and competitive edge. Invasive plants are equipped with characteristics that enable them to outcompete other species for the resources necessary to survive and thrive. Darwin (1859) observed that because “natural selection acts by competition, it adapts the inhabitants of each country only in relation to the degree of perfection of their associates”, such that, “we need feel no surprise at the inhabitants of any one country, although on the ordinary view supposed to have been specially created and adapted for that country, being beaten and supplanted by the naturalized productions from another land.” (Fridley and Sax, 2014). Not only do invasive species possess the ability to survive in its new environment, but they also have no natural predators. Without natural predators in the new environment, there would be nothing to control the growth of the invasive species. The invasive plant thus outcompetes the native plants (National Geographic Society, 2012).

Origin of the Tree of Heaven as an Invasive Plant

The Tree of Heaven was introduced to the United States as an ornamental planting in the late 18th century. The Tree of Heaven was also imported as a possible food source for silkworms for United States silk production (Ohio Department of Natural Resources, n.d.). Its popularity in city landscapes grew due to its resilient nature. Other trees might not thrive due to atmospheric pollution and other city conditions (Dirr, 1990). The Tree of Heaven’s resilient nature, so valuable in its vitality, has allowed it to overpopulate the Hudson Valley Region. It is the tree that is referred to in Betty Smith’s novel, *A Tree Grows in Brooklyn* (1943). During the mid-19th century, the Tree of Heaven fell out of favor with urban planners because of some undesirable qualities inherent in the Tree of Heaven’s biology.

Biology of the Tree of Heaven

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The Tree of Heaven is found as both a tree and a woody shrub. The leaves are green and pinnate. A pinnate leaf is feather-like in structure. Pinnate leaves are arranged along a common axis (see Figure 1 in the Appendix). The Tree of Heaven is deciduous, meaning it loses its leaves in autumn. The Tree of Heaven is also dioecious, meaning that each tree only has either male or female flowers, not both. In other words, there are distinct male and female trees (Fryer, 2010). The flowers of the Tree of Heaven are typically creamy orange (see Figure 1 in the Appendix). The Tree of Heaven blooms in the summer in the local area (New York).

The Tree of Heaven is a eudicot (a category based on pollen structure) belonging to the family Simaroubaceae. The Tree of Heaven has unique biology. Some of its biological features most likely evolved to help its chances of survival in its native environment of China. When the Tree of Heaven grows, it has a propensity to sucker (which is the creation of shoots far from the trunk). Related to its ability to sucker, the Tree of Heaven can regrow new shoots from cut stumps and from its root system. The Tree of Heaven also is phytotoxic and produces phytotoxic, allelopathic compounds. A phytotoxic nature means that a plant releases herbicidal chemicals into the surrounding environment. The highest concentration of these chemicals exists within the bark of the tree (Heisey, 1997).

The Tree of Heaven also grows extremely quickly both above ground and below ground. The Tree of Heaven has a radial (width) growth of 1.96-3.70 mm per year in New York and has a very high rate of seed production and seed success (Knapp & Canham, 2000). The Tree of Heaven has clearly evolved special qualities to make it extremely competitive in the environment, to the detriment of other plants.

Current Concerns Regarding the Tree of Heaven

Risks Associated with the Tree of Heaven

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The adaptations that the Tree of Heaven has developed to thrive in its native environment have various negative effects in non-native regions such as the Hudson Valley. Much of the Tree of Heaven's resilience can be attributed to its unique biology. Some of the biological adaptations that the Tree of Heaven has developed have created problems in its non-native environment. For one, its propensity to sucker (the growth of shoots far from the mother plant) makes the plant undesirable as a landscaping plant (Sladonja, Susek, & Guillermic, 2015). This ability most likely evolved to stunt competition around the tree.

Additionally, while helpful to the existence of the Tree of Heaven in its native environment, the extremely high seed production of the Tree of Heaven created too many trees in its non-native environment (Sladonja, Susek, & Guillermic, 2015). The Tree of Heaven's phytotoxic nature also has negative implications for other plants. Because it toxifies the area around the tree, it disallows other plants from growing and developing. In addition to being harmful to other plants and biodiversity, the Tree of Heaven also has a tendency to damage infrastructure such as sidewalks and sewers due to its fast growth rate (Sladonja, Susek, & Guillermic, 2015).

The Tree of Heaven is also the preferred host for several pests including the Spotted Lanternfly which causes significant agricultural damage (USDA, 2018.).

Advantages Associated with the Tree of Heaven

The Tree of Heaven has traditional uses in China. The bark of the Tree of Heaven has been and is still sometimes used in traditional medicine to treat dysentery and other digestive issues (Shiu-ying, 1979).

There has been some discussion recently in the scientific community if the phytotoxic compounds in the Tree of Heaven could be harnessed to create natural weed killer and inhibitors.

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One of the main compounds present in the Tree of Heaven, ailanthone (the allelopath), has been found to have antimalarial attributes (Burrows & Tyrl, 2001). The Tree of Heaven may also have compounds that may be able to be used as herbicides (Heisey, 1997). However, Sladonja, Susek, & Guillermic (2015) found that the toxicity of the active compounds is too toxic for use as an herbicide/insecticide.

Environmental Benefits

The benefits that the Tree of Heaven has to the environment seem nominal, but since the Tree of Heaven is very tolerant of pollution, it can be successfully planted in locations where no other trees could grow and therefore improve the ecosystem in these select, very degraded areas (Chokkalingam, Zhou, Wang, Toma, as cited in Sladonja, Susek & Guillermic, 2015).

Essentially, the Tree of Heaven can be used as a colonization plant in extremely degraded and polluted environments to aid in reclaiming these spaces.

Possible Environmental Implications for the Future

At some point, invasive plants may become too enmeshed in the environment and thus too environmentally costly to remove them (Seastedt, 2015). The environmental cost is not associated with financial costs but rather with a negative impact on the environment. The removal of invasive plants has implications for the rest of the community. For example, the removal of honeysuckle, considered an invasive species in Pennsylvania could result in a lack of food for native birds that through adaptation, now use the honeysuckle as a food source (Voss, 2016). These birds are important in the ecosystem for native plants. They eat fruits and other plant parts and then spread their seeds. If these plants were absent, both the birds and native plants would be negatively impacted (Voss, 2016).

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The impact of a change in an environment cannot always be predicted. The degree to which the Tree of Heaven fulfills an environmental niche (outside of extremely degraded environments) has yet to be determined. In other words, the degree to which the Tree of Heaven supports any native plants and animals is unclear, although there is research that suggests that the Tree of Heaven does change the local environment to which it is introduced. Gomez-Aparicio & Canham (2008) have found that the Tree of Heaven, along with the Norway Maple, have the ability to transform a local environment by influencing the nutrient cycles in the soil thus changing which other trees will thrive. Sladonja, Susek, & Guillermic (2015) suggest that the Tree of Heaven is a negative influence on the local ecology and that any benefits of the Tree of Heaven are outweighed by the damage it causes. Little data is available to determine the environmental cost (or potential benefits) of its removal from environments where it is already established.

Biocontrol and its Past Uses and Successes

Biocontrol is the introduction of a control agent such as a virus, bacteria, fungus, or insect to control the population of an undesirable species. Biocontrol is an evolving method of control for invasive species. In essence, Biocontrol is the introduction of a predator to control a non-native species which has no natural predators in its new environment, therefore, balancing the ecosystem.

Biocontrol has had repeated past successes in controlling invasive plants throughout the world. Ding, Wu, Zheng, Fu, Reardon, & Liu, (2006) identified a multitude of possible biocontrol agents that could be used on the Tree of Heaven. Harris, Cannon, Smith, & Muth (2013) have shown that the Tree of Heaven is controllable using Verticillium Wilt. Verticillium Wilt was introduced in several experimental sites in Pennsylvania where the Tree of Heaven was

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present. While the Tree of Heaven's population was reduced significantly by the biocontrol agent, other weeds did not replace the Tree of Heaven after the treatment. Significant damage to other plants that coexisted with the Tree of Heaven in the experimental sites did not occur. This suggests that there do exist safe biocontrol agents to combat the Tree of Heaven.

Currently, there is not enough empirical evidence to determine whether biocontrol is more effective than other types of control for the Tree of Heaven. Many invasive plants (including the Tree of Heaven) are controllable by other means such as chemical control (herbicides) or manual control, which entails physically pulling up a plant from the ground (USDA, 2014). Physically pulling up the Tree of Heaven is most likely not an effective method of control for the Tree of Heaven because of its ability to regrow from the root system (USDA, 2014).

Concern Regarding the Use of Biocontrol

Biocontrol Risks

The use of biocontrol to control invasive species comes with significant risks. The greatest risk associated with the use of biocontrol is that the control agent can have unintended consequences for plants other than the invasive plant. Biocontrol agents may not be host-specific enough for long-term use or even any use. In other words, biocontrol agents have the ability to cause collateral damage to other plants in the environment. It has been demonstrated the biocontrol agents may be a threat to endangered plants. Both Louda, Rand, Arnett, McClay, Shea, & McEachern (2005) and Seastedt (2015) have shown that threatened native thistles had the ability to be or were victims of rogue biocontrol agents. However, DePrenger-Levin, Grant, & Dawson (2010) and Meyer, & Fourdrigniez (2011) determined that populations of native plants will not be adversely impacted after the introduction of a carefully

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curated biocontrol agent. Junmin, Zexin & Wenjing (2012) also found that parasitic plants (a possible biocontrol agent) do more damage to non-native plants than native plants.

Additionally, there is the possibility that the biocontrol agent itself could over-populate and become a problem. If a biocontrol agent is able to establish itself and proliferate excessively, it could create some of the very problems that other invasive species introduced. In other words, a biocontrol agent that is not carefully chosen can become an invasive species. Therefore, authorities should be careful that they do not introduce a control agent to an area that is too hospitable to its growth.

Alternatives to Biocontrol

Chemical and mechanical means of controlling invasive plants have been successfully used in the past. The most common form of chemical control is herbicide. Mechanical control involves a type of machine such as a lawnmower. Another type of popular control is the aforementioned manual control which includes a person physically removing a plant. Another type of manual control is controlled fires. Lindenmayer et al (2015) have shown that the *Chrysanthemoides monilifera* was most effectively controlled using a combination of herbicide application and burning. While also very effective herbicides also may have non-target outcomes (such as toxic pollution or damage to threatened plants).

Controlled fires may not remove the underground root system of the Tree of Heaven which would continue to grow and create new trees. Mechanical control could be effective, but one would have to continually mow the new shoots coming from the still intact roots system as these new shoots would grow into new trees (USDA, 2014).

Use of Regulations to Control Spread of Invasive Plants

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Since many invasive plants are spread through the ornamental trade, one could argue that stricter regulations on plant-selling industries could prevent further problems. Barbier, Knowler, Gwatipedza, Reichard, & Hodges (2013) have found that the preferred form of regulation is a mandatory ban on invasive plants. Other possible policies include a tax on selling certain plants to pay for potential damages they may cause. Barbier, Gwatipedza, Reichard, & Hodges (2013) suggest that this type of plan would be ineffectual because it is nearly impossible to calculate economic damages caused by particular plants.

Summary

The impact of invasive plants is an important consideration for a variety of stakeholders. Environmentalists recognize the potential threats in removing the invasive plant which has become a part of the ecosystem. An ecosystem is a delicate network. Any disturbance may result in unexpected and potentially expansive consequences. Other plants and wildlife adapt to invasive plants and may depend on them.

Additionally, invasive plants serve an economic function. While some are detrimental, others provide economic benefit. Knapweed, for example, is an invasive plant but it is considered by many to be too important to the honey industry to eradicate (Seastedt, 2015). These questions are important for policymakers to consider as well as those involved in agriculture and botany.

Methods

This documentary examines the degree to which the invasive plant, the Tree of Heaven, poses risks or benefits for the environment and economy. Data supports that invasive species introduce risks for the environment. However, research also points to the benefits associated with some invasive species. Additionally, research suggests that there are inherent risks in removing

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the invasive species because the ecosystem may evolve to depend upon it. Finally, there are risks inherent in biocontrol. The risks in controlling or removing the invasive plant must be weighed against the risks the invasive species introduced.

This documentary will further the understanding of the impact of the Tree of Heaven, an invasive species, on the environment; the role of biocontrol in controlling the Tree of Heaven, and the economic impact that this invasive species has had. The project will attempt to answer the two research questions: Should the Tree of Heaven be removed, controlled or ignored and, if removal is favored, will experts support biocontrol?

The researcher selected the Tree of Heaven as an example of an invasive species of plant that is well established in the Hudson Valley region. Its locality made it available to the researcher as it grows locally and thrives in the Hudson Valley environment. The Tree of Heaven grows rapidly thus making it a practical choice for studying its growth and vulnerability. Although the scope of the project focuses on local environmental impact, conclusions drawn from the results will be generalizable to other similar environments.

The researcher used several methods to gather information regarding the possible environmental and economic effects of biocontrol on the Tree of Heaven. The methods used include consultations with plant experts; an examination of existing data related to the Tree of Heaven's environmental and economic impact; and existing data on the cost of the Tree of Heaven to the public, and finally an observation of the growth of the Tree of Heaven from seeds will provide insights into the research question.

To gather existing data, the researcher searched the Purchase College library using the database search services EBSCOhost, Proquest, and Opposing Viewpoints in Context by the Gale Group. Additionally, the researcher used Google Scholar to find additional articles that

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were not listed in the Purchase College library. The researcher searched the aforementioned databases using the keywords biocontrol, Tree of Heaven, native plants, and invasive plants in various combinations.

To assess expert opinion, the researcher conducted three 10 minute consultations with three experts in plant sciences. The researcher then examined the consultation responses to determine preferences about the Tree of Heaven and biocontrol. To assess the growth patterns of the Tree of Heaven, the researcher planted 15 seeds for the Tree of Heaven in 4 pots to observe their growth and heartiness over a three-month period beginning February 2019. The rate of germination, growth rate and growth patterns were observed. These observations will contribute to the understanding of the growth patterns of the Tree of Heaven. Any observed vulnerabilities may be useful in understanding its control. Additionally, the data from growth observations will also be used to determine the amount of time it takes for a Tree of Heaven seed to mature into a seedling and establish itself. In addition to the seeds, the researcher also collected three large dormant Tree of Heaven seedlings to monitor for additional data on growth patterns. The dormant seedlings were observed from late-February to April.

Research Design

This mixed methods research design includes qualitative data collection via consultations with local experts. The study also includes an observational component during which the Tree of Heaven seedlings will be observed for growth patterns. The researcher chose consultations as the means of data collection because it allows the researcher to delve deeply into questions, and provides a clear window into scientists' rationale for supporting or refuting the risks inherent in the Tree of Heaven. New questions and insights may be revealed in conversations and discussions during consultations that may not be accessible via a survey. The data will include

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expert opinions from an environmental perspective and will reveal the ecological benefits of the Tree of Heaven, and the risks and benefits associated with the use of biocontrol to address the Tree of Heaven.

The participants were asked questions about the effectiveness of biocontrol, possible complications related to the introduction of biocontrol agents, environmental benefits of the Tree of Heaven. Additionally, the participants were asked questions about their opinions on what methods of control (if any) would be most appropriate for the Tree of Heaven.

In addition to the consultations with the local scientists and botanists, existing data from the Harris, Cannon, Smith, & Muth, (2013) study on plant restoration was examined and compared to the data from the consultations. This study addressed the role of biocontrol on the Tree of Heaven and on native plants. This study aligns with the research question and can serve as additional data supporting or refuting the risk in the Tree of Heaven, its environmental impact, and the impact of biocontrol on the Tree of Heaven and the environment. Existing data was selected because it is a practical approach to examining evidence; there is limited to no cost to obtain the data, and it offers insights that may generalizable to the current question.

Additionally, existing data on the environmental and economic impact of the Tree of Heaven was examined to gauge any potential effects of the removal of the Tree of Heaven. Eight reports were assembled from government sources (U.S., PA, MN, MO, NY, NH, CA, MI) with a focus on the Tree of Heaven and its cost to the country. These sources are reliable and will provide insights as to the economic impact of the Tree of Heaven.

Sampling

Prior to the consultations with the scientists, the researcher contacted the education director of multiple institutions to identify one or more scientists knowledgeable in the field of

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biocontrol. The researcher arranged for consultations based on suggestions from the director for individuals with relevant expertise. The researcher questioned three scientists.

The discussions from the consultations were conducted with botanists and other environmental and conservation experts to gather data related to their experience with the Tree of Heaven and biocontrol. The scientists have advanced degrees in the field of botany or related fields.

Instrumentation

To assess the beliefs of the botanical experts, the researcher led discussions about the Tree of Heaven. The questions for the discussions were developed by the researcher to identify and address gaps in the existing literature.

Instrument #1

Consultation Procedure

The consultations lasted for approximately 10 minutes and included approximately 5 questions specific to the environmental impact of Tree of Heaven, and environmental and economic cost and benefit of biocontrol on this plant. The information from the consultations was used to determine expert opinions on how the Tree of Heaven should be controlled and regulated and also the Tree of Heaven's effect on the local environment. The consultations were conducted by phone, in person, or by email depending on the preference of the participant. Questions for the discussions were developed by the researcher based on the current knowledge of the Tree of Heaven as an ornamental plant and as a potential environmental and economic danger. The researcher conducted the discussions. The discussion questions are based on the issues connected to invasive plants and biocontrol reviewed in the current literature on biocontrol with a specific focus on the Tree of Heaven. The scientists had opportunities to expand on the questions and the researcher will have the opportunity to ask follow-up questions. The list of

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questions asked in order can be found in Tables 3-7 in the Appendix. The consultations were recorded with a smartphone and transcribed using the service wreally.com. The identities of the botanists and scientists will not be made available.

Data Collection and Analysis Procedures

The information from the consultations was evaluated for environmental and economic advantages of biocontrol of the Tree of Heaven and environmental and economic risks in biocontrol for the Tree of Heaven. The information was coded for whether or not the participant believes that 1) the Tree of Heaven is a harmful or not; 2) the Tree of Heaven supports the local environment; 3) the Tree of Heaven supports the economy; 4) the Tree of Heaven should be ignored; 5) biocontrol is the best practice for controlling the Tree of Heaven; 6) alternative means of controlling the Tree of Heaven are better. Additional categories were created based on the responses to the questions.

For purposes of interrater reliability, the researcher engaged another individual knowledgeable of plants to review the data and code as well

Ethical Issues and Protection of Human Rights

Information collected from the consultations will remain confidential. The participants will remain unnamed and the data will be stored in a locked folder. The participants will be able to end the consultation at any time. The participants will be named A, B, and C. All information was obtained lawfully and all information was reported accurately.

Results

Data were collected from several sources: from consultations with scientists from a local botanical institutions; from data from the Harris, Cannon, Smith, & Muth, (2013) study on plant restoration; from reports of infrastructure damage caused by the Tree of Heaven; and from

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observation of the growth of the Tree of Heaven seeds as they grew into plants over a 12-week period in order to better understand its growth patterns.

Scientists' Opinions of Tree of Heaven and Biocontrol Results

The information from the consultations with botanical scientists was analyzed by coding utterances addressing the impact of the Tree of Heaven on the local ecology and infrastructure, and the impact of biocontrol on the local ecology.

Scientists A & B reported that the Tree of Heaven (TOH) had a slightly to moderately negative impact on the environment. These scientists posed that while the TOH was invasive, it was less noxious and disruptive than other noxious plants as the areas it inhabits are already very disturbed and degraded. Scientist C said that in New York, the TOH was mostly localized to the Lower Hudson Valley. Scientist C also cited the New York State Department of Environmental Conservation's 2016 Plant Assessment file on the Tree of Heaven concerning its invasiveness. According to the assessment shared by Scientist C, TOH significantly impacted the local environment by creating dense canopies which could damage native plants. TOH also increased the fuel loads in a forest (which would intensify forest fires).

None of the scientists described infrastructural issues. All of the scientists described the interactions the TOH had with other plants and animals as harmful, mainly because the TOH hosted the Spotted Lanternfly. Scientists A & B & C agreed that the TOH had negatively impacted other plants and animals.

When asked about removal, Scientists A & C believed that removal was not possible as the Tree of Heaven was too well established. Scientist B was also hesitant about TOH removal considering that urban trees help address climate change.

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Scientist A supported biocontrol as a good (but time-consuming) method of control but also believed that biocontrol could have unintended consequences if not practiced carefully. Scientist C also supported biocontrol for certain invasive species. Both scientists A & C cited the successes that biocontrol had when targeting Purple Loosestrife, but also noted the long process of selecting a suitable biocontrol agent. Scientists A & C were both familiar with biocontrol efforts to control the Tree of Heaven. Scientist B was unsure about biocontrol for the TOH.

On the subject of future research, Scientist A believed that most of the information about control was already heavily studied but that more research on the relationship between the TOH and the Spotted Lanternfly would be helpful for Lanternfly control. Scientist B believed that more research was needed about the TOH in its natural environment in order to study its natural niche, its life cycle, and its natural predators. Scientist B believed that this data could be useful in terms of control. Scientist C believed that further studying the relationship between the Spotted Lanternfly and the Tree of Heaven would be the most helpful future research, especially in the context of improving Spotted Lanternfly detection surveys.

Transcriptions of the discussion questions and responses are viewable in Tables 3 through 7 in the Appendix.

Existing Data Results

Data from existing studies can provide valuable insights that support findings in a new study. A study by Harris, Cannon, Smith, & Muth, (2013) identifies the effect of the removal of the Tree of Heaven on local fauna. The Harris, Cannon, Smith, & Muth study supported that removal of the Tree of Heaven does not harm native plant communities and that native (not

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simply other invasive plants) take the place of Tree of Heaven plants that have been removed.

See Table 1 below.

Table 1	
<i>Impact of Removal of Tree of Heaven using biocontrol (verticillium wilt) on Plant Communities: Existing Data from Study by: Harris, Cannon, Smith, & Muth, (2013)</i>	
Plant	Impact
Tree of Heaven	Completely removed.
Grass	Non-native population decreased (not statically significant), the native population increased (not statically significant).
Forbs	Non-native population stable (slight decrease, no statistical significance), the native population increased with significance.
Shrubs	Non-native population increased (no statistical significance) and native populations decreased (not statically significant).
Vines	Non-native population mostly stable (not statically significant), the native population increased (not statically significant).
Trees	Non-native population decreased and the native population decreased very slightly. No statistical significance.
Combined Vegetation	Non-native population decreased (not statically significant), the native population increased (not statically significant).

Government Reports on Tree of Heaven Results

Research exists to support the damage that the Tree of Heaven introduces to a community, both environmentally and to infrastructure. While specific figures could not be found to document the cost to cities of the damage attributed to the Tree of Heaven, the government research supported that the Tree of Heaven was associated with infrastructure

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damage because of the powerful roots that break open sidewalks and damage sewers and other infrastructure. See Table 2 below.

Table 2	
<i>Tree of Heaven economic and environmental damages according to government sources. (Fryer, 2010, Pennsylvania Department of Conservation and Agricultural Resources n.d., Minnesota Department of Agriculture, n.d., Missouri Department of Conservation, n.d., New York State Department of Environmental Conservation, n.d., California Department of Fish and Wildlife, n.d., NH Department of Agriculture, n.d., Michigan Departments of Agriculture & Rural Development, Environmental Quality and Natural Resources, n.d).</i>	
Damage	Conversation
Damages to Infrastructure/Costly for community	Yes. Damage to sewers common.
Hosts Parasites	Yes. Spotted Lanternfly (SLF). SLF has the potential to cost \$358. 4 million to New York in crop losses.
Crowds out other Plants	Yes.

Tree of Heaven Growth Pattern Results

The dormant seedlings were 82.5 cm (C), 26 cm (D), and 80 cm (E), at the start of the observation on February 26th. All three seedlings ended their dormancy during the observation time. Seedling C grew 30 cm by April 1st. Seedling D grew 10 cm. Seedling E grew 7.5 cm. See Figure 2 in the Appendix.

Discussion

The present research provided information and guidance to stakeholders impacted or potentially impacted by the Tree of Heaven, one of the most common of the invasive plants. The research addressed the ecological status of the Tree of Heaven and how it interacts with the environment and local infrastructure. Data from the local scientific community illuminated the

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problems associated with invasive plants, and specifically with the Tree of Heaven, and posed solutions to address its growth and expansion.

Although the Tree of Heaven is an invasive plant, the findings of this research support cautionary approaches in decision making related to control efforts. While the scientists acknowledged the environmental risks associated with the Tree of Heaven, including negative implications for other plants, and a role as a host for damaging pest, removing the Tree of Heaven using biocontrol poses potential consequences for the environment. Removing the Tree of Heaven opens the vacant land for other invasive plants. Additionally, in an era of climate changes, any tree may be a valuable resource.

The cautious but open outlook of the scientists concerning biocontrol was expected based on past, conflicting research about biocontrol. The opinions of the scientists concerning the Tree of Heaven was somewhat less negative than expected suggesting that the Tree of Heaven may not be a control priority under limited control resources. The information from the scientists also showed that the greatest priority concerning Tree of Heaven control was not the tree itself, but the Spotted Lanternfly. However, the Tree of Heaven did still pose some negative effects on the environment aside from the Spotted Lanternfly.

The government data strongly supported that there are numerous negative infrastructural and environmental consequences that an out of control Tree of Heaven population can cause. The existing data showed that biocontrol could be a viable choice for Tree of Heaven control. The data on Tree of Heaven growth patterns showed how vigorous the Tree of Heaven is. The data from the Muth study concluded that certain strains of Verticillium wilt may be able to be used as a biocontrol agent to control the Tree of Heaven without significant damage to other plants in the treatment area.

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These findings are generalizable across environments that support and sustain the growth of the Tree of Heaven. These findings can be used to inform organizations and individuals considering biocontrol as a mechanism to address the impact of the Tree of Heaven. The research obtained in this study from existing studies and from the current study has the potential to educate the general public about the Tree of Heaven, biocontrol, and the environmental impact of invasive plants.

Limitations

Several limitations have implications for the reliability, validity, and generalizability of the research. A true experimental study could not be conducted due to a variety of obstacles including the accessibility of biocontrol mechanisms and access to mature Tree of Heaven specimen. In the absence of a true experimental study, the researcher is not able to directly determine the probability of causal relationships between biocontrol measures and the vitality of the Tree of Heaven. Data describing the impact of the Tree of Heaven on the environment, and the efficacy and risk associated with biocontrol are obtained from interviews with experts in the field of botany and existing data from other studies.

Only three scientists were selected for the interviews and all come from the same location which may have introduced a bias. Scientist A had to be interviewed a second time a few days later for clarification as the transcription service did not recognize particular sentences and thus left out words that needed later clarification. Additionally, the exact wording of questions may have had minor variation between interviews.

No data was found on the monetary costs of infrastructure damage associated with the Tree of Heaven to cities and communities. Although research supports the fact that the Tree of Heaven is responsible for damage to sidewalks and sewers, no exact figures for the cost of this

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damage were available. Additionally, a variety of non-invasive trees may also cause this damage, confounding the ability to assign costs specifically to the Tree of Heaven.

The researcher obtained data on the growth patterns of the Tree of Heaven through the germination and growth of Tree of Heaven seeds. These plants were observed for two months and were planted in isolation. After multiple attempts using various stratification techniques, the seeds did not germinate. While an understanding of growth patterns in a specimen is important in making predictions about the general growth of the Tree of Heaven, this experimental condition did not include other plants and did not include evidence of the impact of the Tree of Heaven on other plants or on infrastructure.

Further Research

Further research on the benefits of the Tree of Heaven is needed to better understand the possible appeal of the Tree of Heaven and possible support to leave it alone or further its growth. The Tree of Heaven is a hearty plant that thrives in a variety of environments; its robustness coupled with its ornamental appeal may make it a good choice for environments needing greenery. It may have other properties not explored in this research that support potential value.

Based on the consultations with the scientists, more research may be needed on the relationship the Tree of Heaven and the Spotted Lanternfly. Finally, little research is available determining public recognition and perception of the Tree of Heaven and public understanding of biocontrol. Understanding people's perception of the Tree of Heaven illuminates the rationale behind current measures taken to control it. Perceptions, as much as factual evidence, often drive policy making at the community level.

The Tree of Heaven is one of many invasive plants. This research may further interest in future research into invasive species, their benefits and costs, and approaches to maintain healthy

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ecosystems. The knowledge obtained from this and other similar studies should inform decisions across a broad base of invasive species and environments.

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Appendix



Figure 1. (Image Credit: Luis Fernández García L. Fdez.)



Figure 2.

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Table 3	
<i>Q1: How do you believe the Tree of Heaven (Ailanthus altissima) has changed/influenced the environment (or even infrastructure) in non-native regions?</i>	
<u>Scientist</u>	<u>Conversation</u>
Scientist A	<p>It has encroached on Native Plant areas. So it does displace some native plants, but mainly in Westchester. We see it along roadsides and other Disturbed areas. So it mainly colonizers Disturbed areas here [lower Hudson valley].</p> <p>[on infrastructure damage]</p> <p>I do not get reports/calls about it and in my travels, I see them on the roadside but I do not see any more injury than from any other big tree that happens to be near a sidewalk or something like that so it's not something that jumped out at me as a problem.</p> <p>First, we should review a few things we know about <i>Ailanthus altissima</i>:</p> <ul style="list-style-type: none"> - it is native to temperate and subtropical China, - the seeds germinate well at high temperatures, such as the temperatures in city lots, and - it is moderately invasive.
Scientist B	<p>While it is common in urban environments, it is less so in natural habitats. It can be moderately invasive, especially in disturbed forests where it will colonize light gaps. But compared to other non-native species (e.g., Norway maple), it is much less invasive.</p>
Scientist C	<p>Okay, some of the information that I will provide to you may be in written form so I may have to correspond to you in email with attachments you could read and gather more information. And in New York State we have a Regulated and a prohibited list of plant and animal species called part 575 and in preparation for developing our 575, we completed a number of plant assessments through several contractors.</p> <p>And so one of the documents I think you may find of interest if you send a short email and I'll respond with the documents is the assessment for that species, which goes into a number of ecological and social economic issues regarding each of the species that were assessed.</p> <p>So I may not be able to answer all your questions directly. The first time you ask them if we can get to the bottom of most of the questions by a little bit more Communications, but you're having a non-native species, but it is fairly... I don't know if I want to say the word common but its distribution is more</p>

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abundant in the lower Hudson Valley and the more Southern parts of New York State.

And so basically we have a database system called. Imap invasives which we use to document invasive species in New York state and I can refer you to that database to look at the distribution of Tree of Heaven in New York as per our most current records.

Table 4

Q2: How do other plants or animals interact with the tree

Scientist

Conversation

We don't have the spotted Lanternfly here yet as we know it. The Spotted Lanternfly is an invasive insect that has been found in Pennsylvania, New Jersey, and Delaware. It's quarantined there and the Ailanthus [Tree of Heaven genus] is the main host that they believe at least at this time for the Spotted Lanternfly. So spotted Lantern fly also affects a number of economic crops in the state plus ornamentals and forest trees. So, it [Ailanthus] is a big concern here as a host that may attract them [flies]. It could be a big problem, you know because they're here in Pennsylvania.

Scientist A They do use these [ailanthus] as trap trees to try to lure spotted Lantern fly away from other plants and they have a method where they can kill them and you can look at the Penn State website and check for a spotted Lantern fly and that will come up. There's also the New York State IPM program website, which is NYSIPM. And that also has links to a lot of information about the spotted Lanternfly. So I would say that that's probably the biggest concern we're having with Ailanthus at this point. I know Ailanthus also does have some compounds that researchers were looking at for medicinal and other properties, so it may not be all bad but it is certainly a host that can support the spotted Lanternfly.

Scientist B It is a preferred host of a newly invasive insect, the Spotted Lantern Fly, a potentially serious pest on grapes and apples. We don't yet know how the Lantern Fly and Ailanthus interact.

Scientist C The Tree of Heaven can be a host for Spotted Lanternfly which is a new invasive species in the Horizon over the last five years. There's a population in Pennsylvania and while we have not detected any populations in New York state. We have detected individual specimens that have come up on transport from various mechanisms into New York over the last year and we're diligently

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surveying to be able to detect any initial populations that may form in the next year or two. So we have a survey crew and a survey protocol to watch out for Spotted Lanternfly and Tree of Heaven is one of the host species for that invasive. So while Tree of Heaven itself is non-native, it also can be a host to other non-native species.

Also, are there any would you order it also in addition to spotted? When's your flight or any other plants or animals that have any relationship with the tree? That you would know of.

That's a good question and the assessment I'll send you may have a bit of information about that but that's more of an academic question and some of our foresters may know more about that aspect of the tree. I don't have a lot more information for you regarding the Ecology of the Tree of Heaven, but I think you can probably find a lot of information published in the literature and some of the assessment documentation. I'll send you may get into that a little bit.

Table 5

Q3: Can/Should the Tree of Heaven be Removed? What would be the environmental impact?

Scientist

Conversation

Eradication may not be feasible at this point as the tree has been established here for decades and it's a prolific seeder. So it would require an army pretty much to remove it. So, I don't know that that's really something that's terribly feasible to do. I guess it's possible that something else could move in once those trees are eradicated, you know, many of the invasive plants are invasive because they take over areas that have been disturbed. So in conjunction with eradication, you would have to have some plan to plant and reclaim areas where the trees are removed with Native or in a less invasive plants

Scientist A

{In terms of control do you think it should just be left alone completely or do you think that there should be some form control? Maybe not eradication, but maybe instead to cut down on the numbers of them}

That probably wouldn't be a bad idea. What they do for Spotted Lanternfly management is they identify some trees that they can inject with insecticide and then they get rid of the rest of them around it. And so that makes that tree a beacon and then the Lanternfly feeds on it and dies. That hasn't stopped the Lanternfly from spreading to some degree either. It would be one facet of

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	<p>removing invasive plants, but there are so many other invasive plants here too. I'm not sure how much of an effect it would have to remove that one. You know, the Japanese knotweed, the ampelopsis/porcelain berry, and the Bittersweet and a number of other plants are just so invasive that it's hard to say whether it would have an effect to remove one species say the ailanthus because the other ones are so prevalent here as well.</p>
Scientist B	<p>Where it occurs in urban environments, it is one of the few shade providing (tree) species. Therefore, we may want to be careful about removing an environmental cooling mechanism, especially in light of global warming.</p>
Scientist C	<p>Well, the distribution of the Tree of Heaven in the lower Hudson Valley is such that you could not eradicate the plant at this point. Its distribution is too widespread. While It's not nearly as widespread and the upstate portions of New York, It still is an established plant in New York state. So eradication is not feasible. So basically we use for Spotted Lanternfly survey protocols. We document and use the documentation of where a tree of heaven is to help plan for the surveys for Spotted Lanternfly. But at this point, the Tree of Heaven is really well established in certain portions of the state.</p>

Table 6

Q4: What is your opinion about Biocontrol as a method of control/would biocontrol be an effective or safe control for the Tree of Heaven?

<u>Scientist</u>	<u>Conversation</u>
Scientist A	<p>I know that there is a disease that attacks it, but I'm not familiar with specifics. When it works, It's a good method of control generally but you know the background work that has to be done, the biological agent has to be identified, it has to go through the quarantine process, and it has to be tested to make sure it doesn't attack anything else. It generally takes at least a decade to go from the identification of a possible biocontrol to its release and then it has to be able to become established in a certain area. So, biocontrols have to have some host plants available in order to do that. So it's sometimes it works but there could be unintended consequences. Such as there was a beetle released to control purple loosestrife years ago that went through that whole process and it didn't affect anything else and they released it. So it did manage the purple loosestrife and there are times where the beetle populations drop because they do such a good</p>

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job that there aren't as many plants around and then the loosestrife comes back a little bit and then the beetle populations come back. So it's kind of a cyclical thing where they kind of come in waves and they follow each other. But what happened in some areas where the loosestrife was removed Japanese knotweed moved in so that, you know ended up being worse in some situations.

Invasive plants are plants that can adapt to harsh conditions and as our climate changes, it's one of the reasons we have so many of them here right now but in the case of loosestrife when the loosestrife was taken out Japanese knotweed which was harder to manage moved in a number of areas.

Scientist B Biocontrol – be careful what you wish for! Is there a biocontrol agent for Ailanthus? One that doesn't affect other organisms? I don't know of any.

Scientist C Biological control is an option for some species. An example is purple loosestrife two beetles: a flower feeding insect and a root boring so there are four species total. They were released beginning in 1992 as biological control agents against purple loosestrife. The two leaf-eating beetles have become well established throughout New York State the root boring Weevil less so and the flower feeder less so more in central New York near Cornell University where the program was initiated, but the program overall has been quite successful in reducing the overall extent of purple loosestrife. Although it does not eradicate the species of biological control tends to suppress the target plant species to tolerable levels, but it does not eradicate the target. So that's an example of a successful biocontrol program in New York State. We're working on several new programs through research at Cornell University. One is on water chestnut and another is on Phragmites. So the researchers at Cornell are doing the background tests that are required for approvals from USDA to release new biocontrols for those two target species spread by water chestnut. It takes about five years of research to get a biological control program approved for release and there's a lot of background research in the native environment that has to be done and then lab work testing various related species and economically important species to make sure there are no negative impacts. So it takes at least five years of research. For program but purple loosestrife program is over 25 years old now and it's been quite successful.

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Table 7	
<i>Q5: What future research is needed related to the Tree of Heaven?</i>	
<u>Scientist</u>	<u>Conversation</u>
Scientist A	<p>It depends what the purpose of the research would be for. Such as how to use the compounds in the tree for medicine as I have seen some research on that. If you are talking about how to remove it [TOH] I think a lot is known already so I am not sure what further studies would be needed in that case? I do know also that because it is the host for the Spotted Lanternfly that there are specific ways that they are using it [TOH] and maybe that would be something that continued research would be helpful for.</p>
Scientist B	<p>The most useful future research would probably be an ecological study of Ailanthus in its native habitat (in China). There, one could understand better its natural niche, its life cycle, natural predators, etc. Perhaps that information would be useful in controlling it in the U.S.</p>
Scientist C	<p>I think as we delve into surveys for Spotted Lanternfly understanding relationships between the various hosts including Tree of Heaven and the invasive Spotted Lanternfly understanding will help us more in the future in determining questions like what percentage of Tree of Heaven might Spotted Lanternfly be attracted to and to what degree are they attracted to the Tree of Heaven. So all these questions we don't know the answer for at this time. So, they are very specific questions sometimes but they would be helpful in designing future surveys for the detection of Spotted Lanternfly.</p>

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Reflection

My interest in the Tree of Heaven began many years ago. I was fascinated by an orange flowered tree close to the Metro-North rail tracks. I took many photos of the mysterious tree and identified it as the Tree of Heaven. Upon researching it, I discovered that it was an invasive plant.

For my final project at Purchase College, I wanted to study an area that was close to my heart. One of my greatest passions is plants. I currently own a sizable plant collection ranging from Arabian Jasmine plants to Zygopetalum orchids. Naturally, I am also a frequent visitor to the local botanical gardens.

While I wanted to study an area that I am passionate about, I also wanted to work on a topic that would have meaning for the local community. Additionally, on a larger scale, environmental degradation due to a number of forces (invasive plants being only one) is most likely the greatest issue facing our century. Therefore, I thought that a study of a local invasive plant was the perfect blending of a topic that aligned with my interests, and was a visible and meaningful problem in the local community, and an important issue for society.

After reading this document, hopefully, people in the local area will be able to identify and understand the Tree of Heaven and be more aware of the delicate relationships between the organisms and the environment we share.