

Project Title: Prescribing fire in managed oak forest landscapes: interactions with the invasive tree

Ailanthus altissima

Final Report: JFSP Project 08-1-2-07

Principal Investigator:

Joanne Rebbeck, Ph.D., Northern Research Station, USFS, 359 Main Road,
Delaware, OH 43015; Phone: 740-368-0054; fax: 740-368-0152;
email: jrebbeck@fs.fed.us

Co-Principal Investigators:

Todd Hutchinson, Ph.D., Northern Research Station, Delaware, OH

Daniel Yaussy, M.S., Northern Research Station, Delaware, OH

Louis Iverson, Ph.D., Northern Research Station, Delaware, OH

State Cooperators:

Robert Boyles, Ohio DNR, Division of Forestry, Columbus, OH

Michael Bowden, Ohio DNR, Division of Forestry, Columbus, OH

Chad Sanders, Ohio DNR, Division of Forestry, Perrysville, OH



FIRESCIENCE.GOV
Research Supporting Sound Decisions

Abstract: *Ailanthus altissima* (tree-of-heaven, Chinese sumac, stink tree) is a nonnative invasive tree that is common throughout much of the Eastern United States. It can invade and expand dramatically when forests are disturbed. Anecdotal evidence suggests that fire might facilitate its spread, but the relationship between fire and this prolific invasive tree is poorly understood. To better understand the impacts of fire on *Ailanthus* we conducted studies at Tar Hollow State Forest in southeastern Ohio, where *Ailanthus* is widely distributed within the forest and where prescribed fire has recently been applied to 2,300 acres within a 9,600 acre portion of the forest.

Our first objective was to gain a better understanding of how the distribution and abundance of *Ailanthus* is related to recent fires, harvesting activity, seed sources, and other landscape and stand characteristics. Our experimental approach was to efficiently locate *Ailanthus* seed-sources across this highly dissected forested landscape. To accomplish this, we successfully employed digital aerial sketch mapping technology to geo-reference adult female trees (seed-producers) during the dormant season from helicopters. In addition, we quantified the abundance and demography of *Ailanthus*, as well as other stand attributes (e.g., fire, harvesting, stand structure) using a systematic grid (400 m) of sample plots (N=280). Based on Random Forest and CART modeling for the Tar Hollow study site, the most important predictor of *Ailanthus* presence was a timber harvest within the last 25 years. In all, 62 variables were considered in the models, including variables related to management activities, soil characteristics, topography, derived topographic measures, vegetation structure (derived from LiDAR), and measures of possible seed-contributing areas up and downslope. It is also informative to mention the variables that did not factor either way in the models. Importantly, prescribed fire was not a significant predictor of *Ailanthus* presence or absence in any of the models of the Tar Hollow State Forest. None of the soil variables were significant either.

The second objective was to quantify the direct effects of prescribed fire on the demography of *Ailanthus* populations, with and without the pre-burn application of stem-injected herbicide. We quantified demographic attributes (survival, topkill, sprouting, and establishment) of *Ailanthus* in a field experiment with four treatment combinations: 1) no fire and no herbicide, 2) herbicide, 3) fire, and 4) herbicide plus fire. After one dormant spring burn, we determined that pre-burn herbicide application of *Ailanthus* stems >1 inch d.b.h. was highly effective killing large saplings and trees with no sprouting after three growing seasons. Small *Ailanthus* saplings and

seedlings increased in the season immediately after the burn with and without herbicide treatment, but did not persist. After the fire, *Ailanthus* germinants and sprouts from top-killed saplings and trees were poor competitors with faster-growing post-fire woody regeneration as forest floor shading increased over time. This study, the first to quantify the direct effects of fire on *Ailanthus*, demonstrates that prescribed fire alone may not facilitate the spread of *Ailanthus*. Recent harvest activity (<25 years) was the most important predictor of *Ailanthus* presence suggesting that further empirical studies are needed to address the combined impacts of fire and timber harvesting on *Ailanthus* invasions in Eastern US forests.

Background and Purpose

Throughout much of the central hardwoods region, the sustainability of oak forests is threatened by poor regeneration and ever-increasing abundances of shade-tolerant and/or fire-sensitive tree species. In response, the use of prescribed fire on public lands has increased rapidly in the last decade. While prescribed fire can favor oak regeneration, its use may also increase the risk of invasion and expansion of non-native plant species. *Ailanthus altissima* (tree-of-heaven) is a shade-intolerant tree that is widely distributed in the eastern U.S. and can be highly invasive. It invades disturbed habitats via establishment from prolific wind-dispersed seed and it can persist and expand via clonal growth. *Ailanthus* is present in many oak forest landscapes in which the use of prescribed fire is increasing. At Tar Hollow State Forest, located in southeastern Ohio, the rapid expansion of *Ailanthus* after thinning and burning treatments on the Fire and Fire Surrogates Study has prompted the Ohio Department of Natural Resources (ODNR) Division of Forestry to place more emphasis on NNIS management. However, little is known about the effects of fire on *Ailanthus*, and it is not clear whether fire was the primary cause of the observed expansion. The ODNR Division of Forestry has implemented an aggressive prescribed fire program aimed at sustaining oak forests. They wish to continue the use of prescribed fire while minimizing the expansion of NNIS such as *Ailanthus*. Tar Hollow provides an ideal location to study the interactions of *Ailanthus* and fire. Given that *Ailanthus* is widely distributed throughout the central hardwoods region and the use of prescribed fire as a forest management tool is growing rapidly, our findings are applicable across a large region. Our goal was to better understand how prescribed fire alters the susceptibility to invasion of *Ailanthus* and to develop prescriptions for managers to reduce the threat of post-fire invasion.

Fire has often been shown to favor NNIS in the western U.S. (Zouhar et al. 2008). In the eastern U.S., nonnative invasive species are abundant and are a major management concern. However, because large and high severity wildfires are infrequent and the widespread use of prescribed burning has begun only recently, much less is known about the effects of fire on invasives in this region (Dibble et al. 2008). Given that fire was an important process historically, the use of prescribed fire to sustain oak ecosystems has been widely promoted and is now being used more frequently as a management tool (Dickinson 2006). Many National Forests in the eastern U.S. have adopted the sustaining of oak forests as an important objective in their revised Forest Management Plans (Yaussy et al. 2008). Many state agencies are also embracing the use of prescribed fire to sustain mixed oak forests, enhance wildlife habitat, and reduce fuel buildup. A better understanding of how *Ailanthus* and other NNIS respond to prescribed fire in the Eastern United States is important, so that proactive control strategies can be developed and integrated into prescribed fire and timber management programs at a landscape level.

Ailanthus altissima has been present in North American landscapes for over three hundred years (Hu 1979). It is most often abundant in open sites such as roadsides but can invade disturbed sites in forests. *Ailanthus* is widely distributed throughout the East and Midwest. Very little is known about the direct and immediate effects of fire on *Ailanthus*. Saplings are easily topkilled by fire, but resprouting is prolific (Lewis 2007). Managers have reported observing increases in *Ailanthus* via seed germination immediately following fires. However, in landscapes with very small populations of *Ailanthus*, it may not invade burned sites (e.g., Hutchinson et al. 2005). It remains unknown whether a post-burn *Ailanthus* expansion will inevitably occur if the propagule pressure is high. It may be that fire, by reducing litter and increasing light, creates improved conditions for *Ailanthus* establishment, as other disturbances have been shown to do (Kota et al. 2007).

Project Objectives:

1. Determine how the distribution and abundance *Ailanthus* is related to recent prescribed fires, other management activities, and landscape features.
2. Document the direct effects of prescribed fire on the demography of *Ailanthus* populations.
3. Provide science delivery of the knowledge gained.

Study Description, Experimental Design and Approach

The site for this study is Tar Hollow State Forest, the third largest State Forest in Ohio. It is located within the Southern Unglaciaded Allegheny Plateau. The topography is dissected, consisting of sharp ridges, steep slopes, and narrow valleys.

Objective 1: Determine how the distribution and abundance *Ailanthus* is related to recent prescribed fires, other management activities, and landscape features. We characterized the distribution and abundance of *Ailanthus* across a 9,600 acre forested landscape that has had a series of recent (2001-2008) prescribed fires on more than 2,200 acres (Figure 1). We determined the distribution, abundance, and demographic attributes of *Ailanthus* by two methods: 1) digital aerial sketch mapping; and 2) field sampling plots spaced in a 400 x 400 m grid ($n = 280$) and seed-bearing “mother” trees ($n = 30$).

Tar Hollow State Forest: Prescribed Burn History

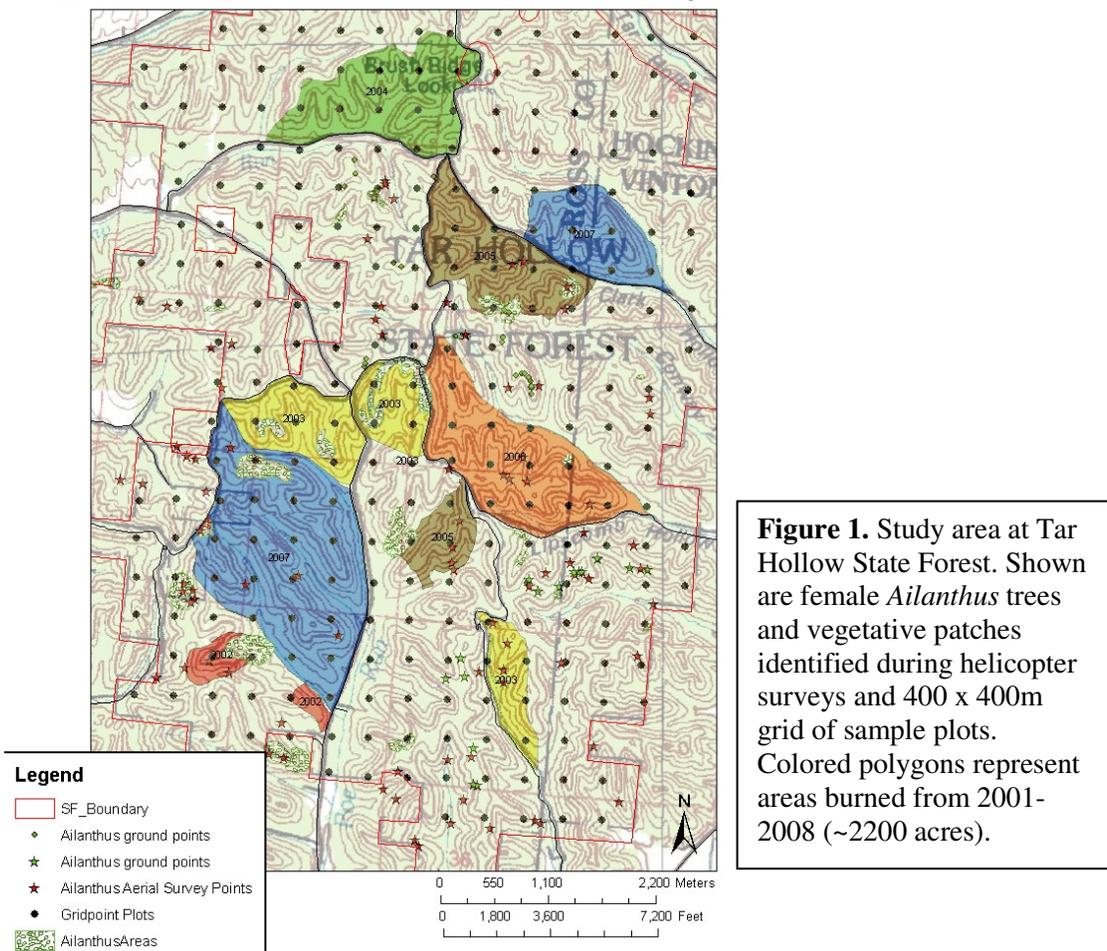


Figure 1. Study area at Tar Hollow State Forest. Shown are female *Ailanthus* trees and vegetative patches identified during helicopter surveys and 400 x 400m grid of sample plots. Colored polygons represent areas burned from 2001-2008 (~2200 acres).

Digital Aerial Sketch Mapping: A standardized, cost-effective methodology was developed to map the location of seed-producing *Ailanthus* in the study landscape. Aerial surveys were conducted in the winter months (December 2008) to map the location of *Ailanthus* patches with seed-producing female trees. Surveys will be conducted by ODNR Division of Forestry personnel using digital aerial sketch mapping (DASM) from a helicopter. Identified patches with seed-producing trees was incorporated into a GIS with multiple layers for the study area, including soils, 10-m digital elevation model, Integrated Moisture Index (Iverson et al. 1997), fire management, imagery, and various landscape features. Ground-truthing of 70 of the 98 aerially-identified female *Ailanthus* (seed-bearing) trees occurred in January-February 2009. Other site and tree data was collected for each tree. To estimate potential seeding potential of a given female tree, a fecundity index was calculated:

$$\text{Fecundity Index (FI)} = (\text{tree DBH} \times \text{seed crop vigor}) \times (\# \text{ Females} \times \text{Distance Class to nearby Females})$$

Grid points and Seed-bearing “mother” trees sampling

At each grid point plot, a 20-m radius area (0.25 ha) was surveyed to record the presence of *Ailanthus* by size class to include trees, saplings, seedlings and new germinants. Attributes of forest structure (overstory and understory) were sampled. For plots in burned areas, past fire intensity was determined. Other GIS data were captured for the plot locations including recent management history and distance/direction from seed-producing trees. After the adult seed-bearing trees were aerially mapped, we conducted a more intensive sampling grid surrounding approximately 30 individual trees or small clumps of trees within burned and unburned areas. Transects radiating in eight cardinal directions from a given tree were installed to a maximum distance of 100-m or until it intersects with another adult tree or a 400-m grid plot.

Data analysis and modeling included several GIS and statistical techniques to determine the relationships of *Ailanthus* presence and abundance to distance and direction from seed-producing trees, fire, timber harvest, and other landscape attributes. Relationships were tested based on distance-time dimensions to determine the extent to which burning and/or harvesting favored the spread of the *Ailanthus*, and the mechanisms of its expansion in this landscape. Statistical tools include classification and regression trees (CART), Random Forests (Prasad et al. 2006), and maximum entropy (Maxent) modeling of species distributions.

GIS Data

Digitizing timber harvest records and development of GIS database: Working cooperatively with ODNR Division of Forestry, all existing digital and paper records of harvests done at Tar Hollow State Forest were summarized into a database to include the following information: sale year, acres harvested, type of harvest (uncut, select, thinning, clear cut), and volume harvested.. A 10-m Digital Elevation Model (DEM) obtained from ODNR was used to generate an Integrated Moisture Index (IMI), curvature, flow direction, flow accumulation, hillshade, downslope influence, and upslope dependence grids for the study area. Two sets of multiple elliptical buffers were generated around each female tree at distances of 200, 300, 400, and 500-m and rotated based on the direction of the downslope influence area and the most frequent wind direction between Nov-Feb (NW). A single 100-m buffer was also created around each point. Ignoring the area of the ellipses upslope and upwind, each buffer was manually inspected to determine the number of grid points each contained. Light detection and ranging (LiDAR) data was obtained from the Ohio State Imaginary Program (OSIP) to estimate canopy heights.

KEY FINDINGS

*Objective 1. Distribution of *Ailanthus* in relation to fire and other factors*

- **Development of a leaf-off aerial surveying of seed-bearing *Ailanthus*:** We successfully developed a standardized, cost-effective methodology to map the location of seed-producing *Ailanthus* in the study landscape. A survey was conducted in December 2008 to map the location of *Ailanthus* patches with seed-producing female trees. Surveys were conducted by Ohio Department of Natural Resources (ODNR) Division of Forestry cooperators using digital aerial sketch mapping (DASM). During a two hour flight, 98 seed-bearing females and 42 patches, ranging in size from 0.18 to 13.4 ha, were identified within a 3885 ha (9600 acre) area. Aerially-identified females were ground-truthed (N=75 trees at 95.7% accuracy) using hand-held GPS units in January-February 2009. The methodology developed in our study is being used by ODNR Division of Forestry and Wayne National Forest to map *Ailanthus* and *Paulownia tomentosa* (Princess tree) infestations within Ohio public lands.

- Distribution of *Ailanthus* across an actively managed public forest:** 93% of the female *Ailanthus* trees were found in harvested areas across the 9600 acres. *Ailanthus* stems (seedlings, saplings, or trees) were present on 39% of plots with a past harvest history (0 to 80 years since harvest) (Figure 2). *Ailanthus* was present in over half of the plots within the 2200 acres burned between 2001 and 2008.

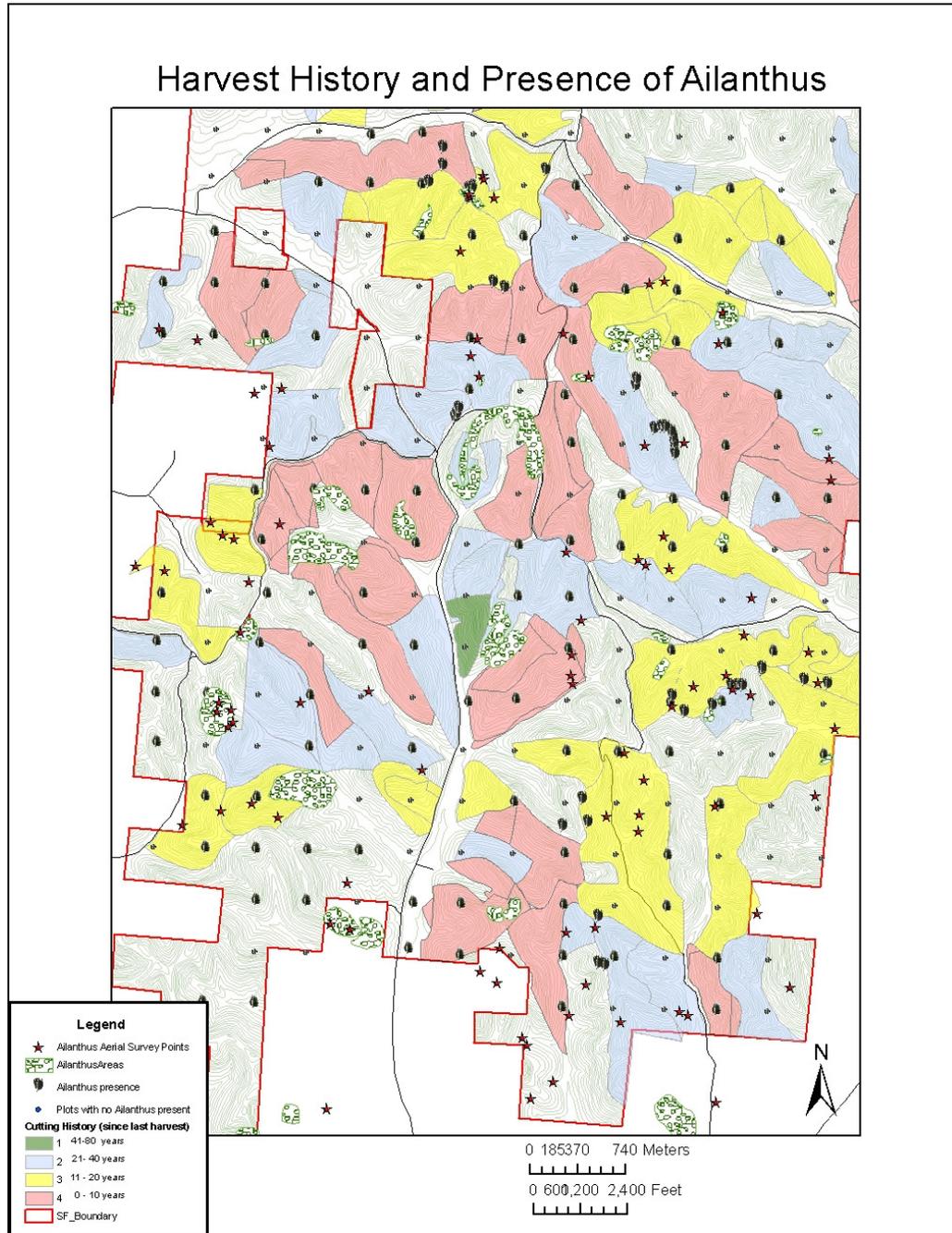


Figure 2. Distribution of *Ailanthus* trees and timber harvest history

- **Model development to predict presence and absence of *Ailanthus* across forested landscape**

Random Forest Modeling

Based on Random Forest and CART modeling, the most important predictor of *Ailanthus* presence was a history of harvest within the last 25 years. Similar to other studies on invasive plants, disturbance facilitated invasion by *Ailanthus*, provided a seed source was present. Within those harvested areas, the model suggests that a medium amount of afternoon sun (or solar drying) is most favorable to *Ailanthus* presence. That is, if the solar intensity was <90th percentile or >30th percentile of all positions in this highly dissected area, conditions were conducive to *Ailanthus* presence. A caveat to this point is that non-dissected (flat) areas may model as suitable as the area of ground points was dissected only. The models also suggest that *Ailanthus* prefers areas with a mid-canopy <10 ft in height and with higher levels of soil moisture. If the area was not recently harvested (>25 years), the models suggest places more likely to find *Ailanthus* include middle elevation sites with little afternoon sun (north-facing slopes).

The models also suggest conditions where *Ailanthus* presence would not be likely. Primarily, if the area was not recently harvested, *Ailanthus* is less likely. But also locations with very intense or very low afternoon sun are less likely, whether the area was harvested or not. Finally, tall, closed forests are less likely to host *Ailanthus*.

In all, 62 variables were considered in the models, including variables related to management activities, soil characteristics, derived topographic measures, vegetation structure characters (derived from LiDAR), and measures of seed-contributing areas up and downslope. It is also informative to mention the variables that did not factor either way in the models. Importantly, prescribed fire was not a significant predictor of *Ailanthus* presence or absence in any of the models of the Tar Hollow State Forest. In addition, soil variables were not significant in any of the models. When the CART model was applied via the significant predictors to the Tar Hollow landscape, a map of presence vs. absence can be generated (Fig. 3). The map shows approximately 43% of the ground as 'present' and 57% as 'absent' for *Ailanthus*.

The 'present' locations can be interpreted as locations with a higher probability of finding *Ailanthus*, not that it is necessarily present.

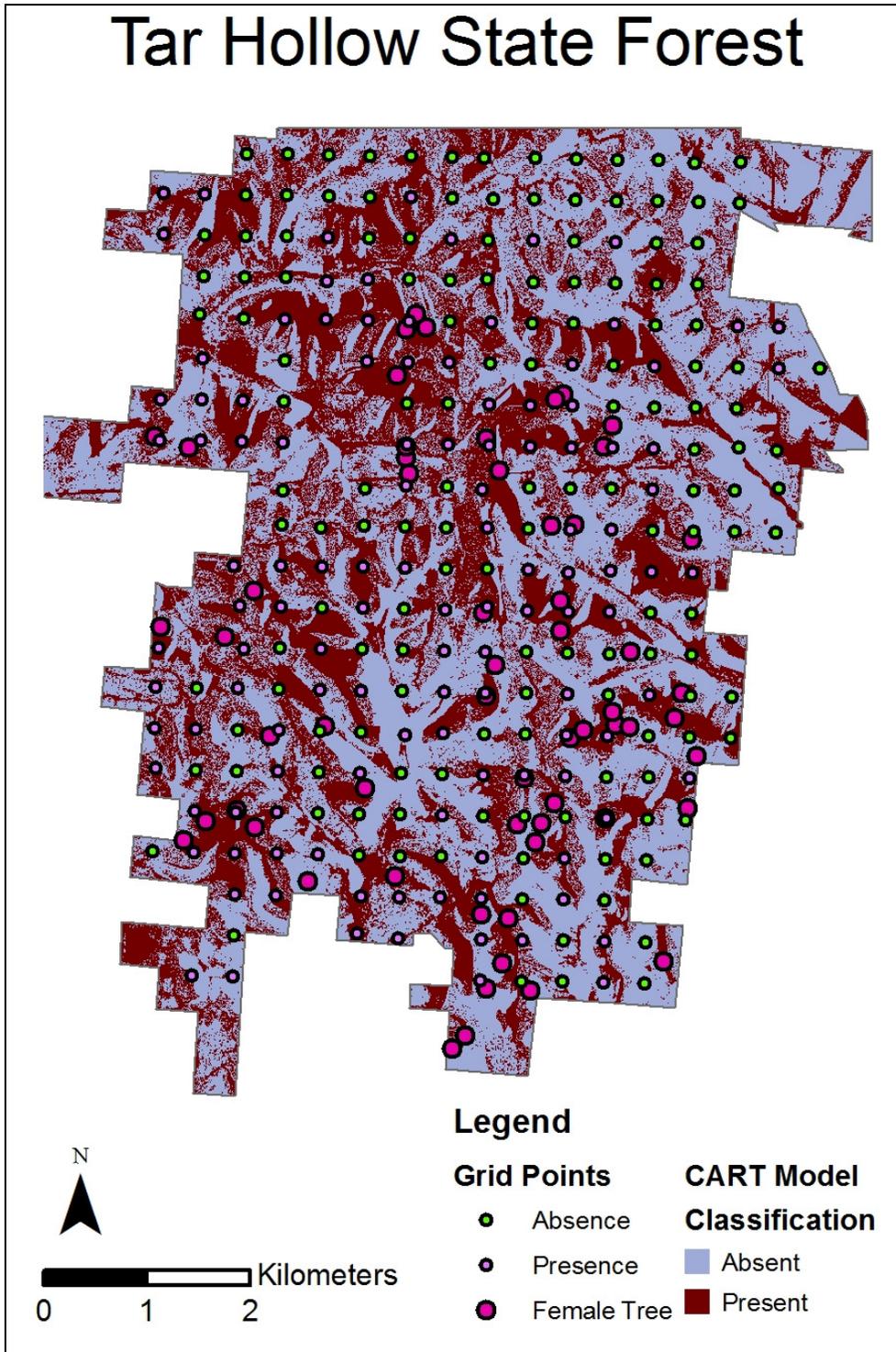


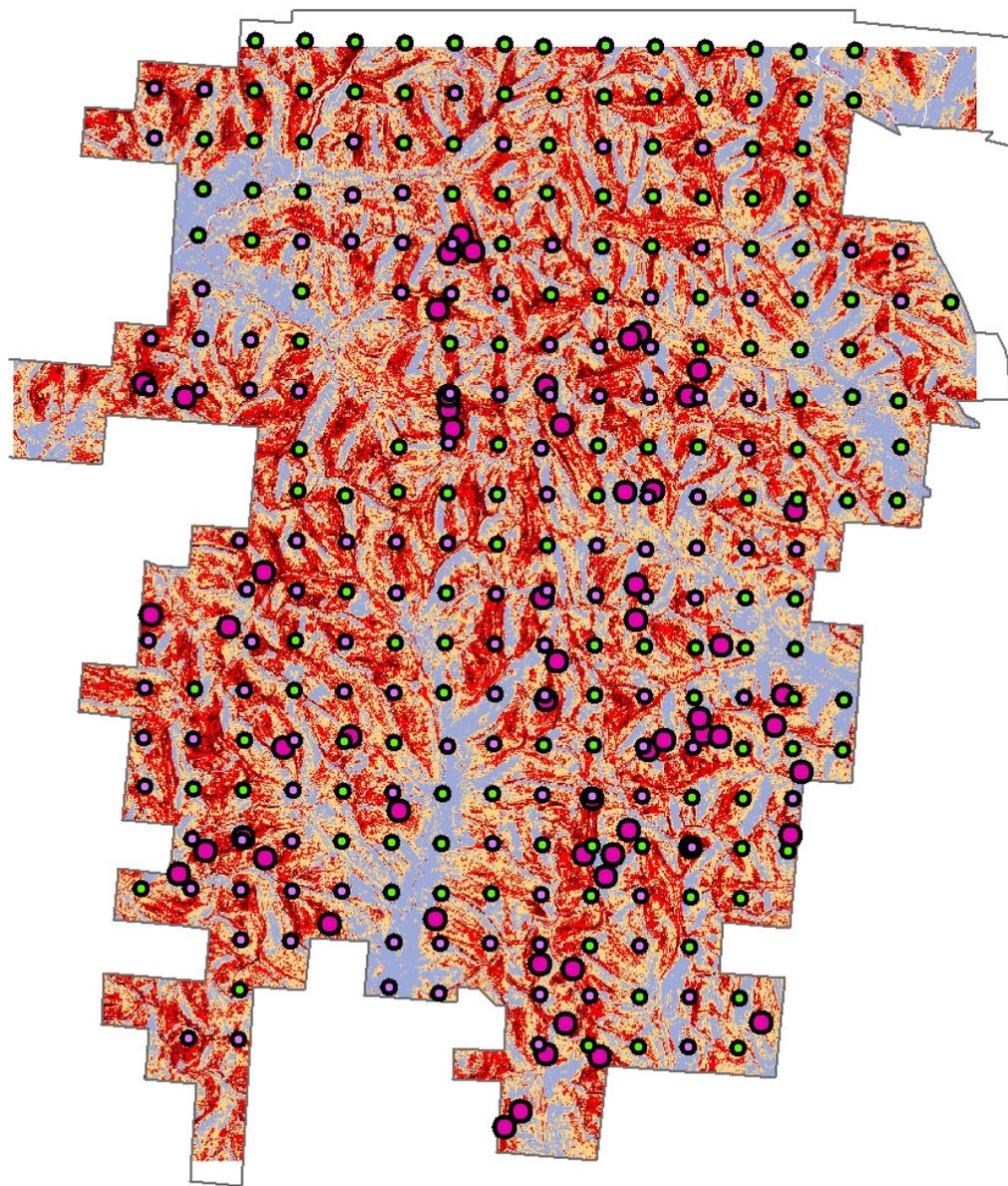
Figure 3. Classification and Regression Tree (CART) model for Tar Hollow State Forest with presence (red) and absence (blue) of potential suitable habitat for *Ailanthus*. Presence and absence at grid points and the locations of female trees are also shown.

Maximum Entropy Modeling

A maximum entropy (Maxent) distribution was calculated from the known locations of female *Ailanthus* trees and grid points where *Ailanthus* was present. A suite of 38 predictor variables were used to test and build a Maxent model, of which elevation and percent slope had the highest contribution in the final version. Maxent produces a probability distribution which can be interpreted as likelihood of occurrence, and classifying the modeled values into least (0-20%), low (21-35%), moderate (36-50%), and high (51-100%) resulted in 5.3, 21.7, 42.8, and 30.3% of the known locations of *Ailanthus* (female trees and present at grid points) to be predicted among these categories respectively (Fig 4).

The probability values produced by Maxent can also be used to identify areas where *Ailanthus* is least likely to occur. The area associated with the four classes accounted for 26, 39, 27, and 8% (least to high respectively) of the entire study area; these probabilities can help in planning field surveys and treatment to manage the spread of *Ailanthus* across Tar Hollow and surrounding areas. However, as previously mentioned, areas with a higher probability of occurrence may not currently have *Ailanthus* present. For example, we found that 44% of the grid points reporting absences were modeled to have a moderate to high probability of occurrence; they could be suitable for *Ailanthus* invasion but the propagules have not (yet) reached those locations. Therefore, local knowledge should be used to help interpret the Maxent output and make decisions related to management.

Tar Hollow State Forest



Grid Points

- Absence
- Presence
- Female Tree

Maxent Model

Prob. of Occurrence

- High
- Moderate
- Low
- Least



Figure 4. Maxent model for Tar Hollow State Forest showing the probability of occurrence for *Ailanthus*. Female trees and presence/absence at grid points are indicated by colored dots.

Objective 2: Direct effects of fire and herbicide on the demography of Ailanthus

We studied the direct effects of fire and herbicide on *Ailanthus* populations in a factorial design in which the short-term demography of *Ailanthus* was quantified. Sample plots (experimental units) were established in areas to be burned and in areas to remain unburned. Each treatment combination (herbicide + burn, burn, herbicide, and control [no burn + no herbicide]), was replicated in ten 10-m radius plots. Herbicide application using 6% Imazapyr solution (53.1% active ingredient) via stem injections (hack and squirt) was completed in fall 2009. Dormant season prescribed fires were conducted in April 2010 by ODNR Division of Forestry (Appendix 1). Within each plot prior to treatments (2009), all *Ailanthus* trees >2.9 cm dbh were evaluated, permanently tagged and mapped to monitor post-treatment survival. Data on *Ailanthus* populations were collected during the pre-treatment (2009) and in three consecutive post-treatment years (2010-2012).

Key Findings for Objective 2: Direct response of *Ailanthus* to prescribed fire.

***Ailanthus* saplings and trees:** Late summer stem-injection of herbicide followed by early-spring moderately-intense fires was the most effective treatment in reducing numbers of *Ailanthus* stems, 2.9 cm d.b.h. and larger. Four months post-burn, 99% of those *Ailanthus* stems which were stem-injected with herbicide prior to the burns were completely dead, while 66% of *Ailanthus* saplings and trees in the burn-only plots were top-killed and sprouting. Two seasons after the fire in the burn-only treatment, mortality of large saplings (3-10 cm d.b.h.) increased to 75%, while only 37% of trees (>10 cm dbh) were dead. Of those trees remaining alive in the burn-only treatment, 34% were top-killed and sprouting and in generally poor vigor. This finding suggests that a stem-injection herbicide treatment of *Ailanthus* in the fall prior to a dormant spring burn can significantly reduce its survival and reproduction.

***Ailanthus* seedlings and small saplings:** The density of smaller *Ailanthus* stems (up to 1 in dbh) increased dramatically from 14,868 stems/acre to 53,080 stems/acre immediately following prescribed fires in the burn and burn+ herbicide plots. This was due to the increased light levels resulting from the high mortality of canopy *Ailanthus* trees as well as the burning off of leaf litter which stimulated germination. However this response was short-lived. In 2012, three growing seasons post-fire, these smaller *Ailanthus* stems declined to levels below pre-

burn levels. *Ailanthus* seedlings and sprouts produced immediately following the prescribed fire were poor competitors as forest floor light levels declined with increases in other vegetation that was stimulated by the fire.

Management Implications

Public land managers now have an effective tool to aerially map infestations of *Ailanthus* and *Paulownia* across large forested landscapes at costs ranging from \$1-4 per acre. Depending on the level of infestation, 2,000 to 5,000 acres can be mapped per hour. With this geo-referenced information in hand, managers can develop treatment target areas for ecological restoration. This tool will be useful for adaptive management priorities and strategies for future silvicultural treatments such as fire and timber harvesting. Having these geo-referenced data will aid in developing short-term and long-term plans to target treatments to minimize the spread of NNIS.

As with native plant species, many factors contribute to *Ailanthus*'s response to prescribed fire. These include the timing and intensity of fire, season of burn, landscape position (slope, aspect), pre- and post-fire disturbances (such as logging, ice/wind damage, repeated fire), initial stem density and stem size, competing vegetation, as well as proximity of *Ailanthus* seed sources. *Ailanthus* prefers mid- to lower slope mesic sites that are often favored by sugar maple (*Acer saccharum*)-spicebush (*Lindera benzoin*) communities where fires typically have minimal impact in the Central Appalachian region.

Relationship to other recent findings and ongoing work

Aerial mapping of *Ailanthus* and *Paulownia*. The ONDR Division of Forestry has adopted this newly developed helicopter survey technique to locate and geo-reference *Ailanthus* and other woody exotic invasives within Ohio State Forests. They mapped approximately 45,000 NNIS locations in Autumn, 2009. These geo-referenced locations are downloadable into hand-held GPS units and can be used by herbicide field crews to locate female *Ailanthus* trees to eliminate seed sources. In 2009-2011, ODNR Ohio Woodlands Job Corp Program staff (2009 American Recovery and Reinvestment Act) chemically treated the aerially mapped *Ailanthus* in several State Forests. Currently the Wayne National Forest (Region 9) and the Ohio DNR Division

of Forestry are partnering with PI Rebbeck to refine and test this technology to map populations of *Ailanthus* and *Paulownia* across 160,000 acres on the Wayne National Forest.

***Ailanthus* response to fire**, if resources are available, ODNR Division of Forestry will continue collaborations to implement a second prescribed burn in 2014. This would allow us to study the effects of multiple burns on the *Ailanthus* populations over 5 years or more.

Development of *Ailanthus* management guidelines in mixed oak forests. The primary deliverable for the management community was a workshop in the third year of the project that brought together the science of this project with the experiences of managers across the region. The workshop was held on September 12, 2012. The objective of the workshop was for participants to gain a better understanding of the interaction of fire and *Ailanthus* in oak forests to develop tools and strategies that will aid in fire management programs. The next goal is to complete a short publication of management guidelines for wide distribution.

GIS landscape scale-modeling. The initial modeling via CART and Maxent show promising results towards identifying sites more (or less) suitable for *Ailanthus* invasion. We next intend to test the model in another location, by utilizing aerial *Ailanthus* survey data collected on the Wayne National Forest. Applying the CART or Maxent models to other landscapes requires adequate GIS data for environmental predictions to be made. Provided suitable data are available, the models could then be used to predict values into the new landscapes based on the training data set used for Tar Hollow.

Future Work Needed

The results of this study have contributed to our understanding of the direct impacts of fire on *Ailanthus* as well as the role fire plays in *Ailanthus* expansion. We have demonstrated for the first time that a pre-burn herbicide treatment is extremely effective in killing large *Ailanthus* trees with minimal to no resprouting after fire. This is very significant given *Ailanthus*'s high propensity for suckering and root sprouting. However, the long term effects of multiple fires combined with major disturbances such as timber harvesting need to be assessed.

With the GIS landscape scale-modeling, additional data and further testing are desired. Data preparation for the landscape scale-model requires LiDAR data to be processed to estimate forest canopy heights, elevation data to produce an Integrated Moisture Index and other terrain related indices, along with solar variables, and timber harvest information. In addition to processing the data for the models, field surveys will need to be conducted to evaluate the model's performance.

Deliverables

Deliverables Crosswalk

Deliverable Type	Delivered	Status
Website	Establish and maintain a webpage for the research project http://nrs.fs.fed.us/disturbance/invasive_species/ailanthus/	Completed in 2009
Dataset	Spatial dataset of <i>Ailanthus</i> seed-producing trees within the Tar Hollow study site	Completed in 2009
SILVAH:OAK Training Session	Incorporate <i>Ailanthus</i> project into NNIS lecture and field stop within the Ohio SILVAH:OAK Training Session	Completed in 2009
Progress Summaries	Report to JFSP on annual progress	Completed in 2009-2011
Refereed publication	Rebbeck, J. 2012. Fire management and wood invasive plants in oak ecosystems. Proceedings of the 4 th Fire in Eastern Oak Forests Conference. GTR-NRS-P-102	Completed in 2012
Presentations	Digital area sketch mapping of <i>Ailanthus</i> seed-producing trees to aid forest management. Expanded and refining technology to include partnering with Wayne National Forest and Ohio DNR Division of Forestry on other public lands. Additional surveying will be completed in 2012-2013.	Numerous presentations made; manuscript in progress
Refereed publication	Rebbeck, J., Kloss, A., Coon, C., Bowden, M. <i>Ailanthus</i> aerial mapping: methods to search, map and destroy invasive plants in forested landscapes.	Publication will be completed in Spring 2013
Refereed publication	Iverson, I., Rebbeck, J., Peters, M., Hutchinson, T., Fox, T. Predicting <i>Ailanthus</i> presence and abundance across forest landscapes: fire and timber management effects. in relation to fire and other factors	Analyses 80% complete, draft in progress
Final Report	Final results will be presented	This document completed and posted on JFSP website
Presentations and refereed publication	Rebbeck, J., Hutchinson, T. Effects of fire and herbicide on <i>Ailanthus</i> demographics and survival	Numerous presentations made. Draft manuscript in

		progress.
Workshop/Tour	Managing Ohio Woodlands: The “Challenges” of <i>Ailanthus</i> Workshop and Field Tour.	September 12, 2012
Non-refereed publication and	Factsheets, and General Technical Report: Management recommendations for <i>Ailanthus</i> and fire based on research results.	Ongoing through 2014
Computer software	Incorporation of management recommendations into SILVAH:OAK Decision Support System, FVS-FFE and FEIS	Ongoing

Acknowledgements

Invited papers and presentations

1. Rebbeck, J. 2008. Fire and Tree-of-Heaven: Does prescribed fire increase the invasiveness of *Ailanthus*? 2008. Fire and plant invasions in the Midwest Session. Midwest Invasive Plants Network and North Central Weed Science Society Annual Meeting, December 10, 2008, Indianapolis, IN. [Invited]
2. Rebbeck J. 2009. The impact of management practices on tree-of-heaven invasions in Ohio Forests. Ohio Forest Health Conference. Canters Cave, OH. April 8, 2009. [Invited]
3. Rebbeck J, Hutchinson T, Iverson I, Yaussy D, Boyles R, Bowden M and Sanders C. 2009. Managing Ohio Forests with Tree-of-Heaven Infestations: A Research Update. Managing Large Landscapes in a Public Arena. Ohio Society of American Foresters Summer Meeting, August 4-5, 2009. Portsmouth, OH. [Invited]
4. Joanne Rebbeck, Todd Hutchinson, Louis Iverson, Daniel Yaussy, Robert Boyles, and Michael Bowden. 2010. Studying the effects of management practices on *Ailanthus* populations in Ohio forests: a research update. 21st USDA Interagency Research Forum on Invasive Species, Jan.12-15, 2010, Annapolis MD. [Invited]
5. Rebbeck, J. 2011. Fire Management and Invasive Plants in Oak Ecosystems. 4th Fire in Eastern Oak Forest Conference, Springfield, MO, 17-19 May 2011. Gave invited presentation on the interactions of non-native invasive plants and fire management in oak ecosystems at the 4th Fire in Eastern Oak Forest Conference, May 17-19, 2011 in Springfield, MO. The audience of ~200 was a mix of practitioners, public land managers, wildlife biologists, policy makers and researchers. [Invited]
6. Rebbeck, J. 2011. *Ailanthus* Research in Ohio. Biological Control of *Ailanthus* Cooperators Meeting. Chambersburg, PA. Meeting was sponsored USDA Forest Service NA State and Private and Penn. State University. July 26-27, 2011.
7. Rebbeck, J. 2011. Fire Management and the invasive tree, *Ailanthus*. 3rd Annual Kentucky Prescribed Fire Council Meeting, Greenville, KY. 12-13 Sept. 2011. [Invited]
8. Rebbeck, J. *Ailanthus* and a fungal pathogen, *Verticillium* wilt. Ohio Forest Health Conference, Canter's Cave, OH March 1, 2011. [Invited]
9. Rebbeck, J. and Coon C. *Ailanthus* aerial surveying and control effects in Ohio’s public forests: a partnership with Ohio Division of Forestry, USDA Forest Service: Northern Research Station and Wayne National Forest. Ohio Forest Health Conference, Canter's Cave, OH April 11, 2012. [Invited]
10. Rebbeck J, Hutchinson T, Iverson L, and Yaussy D. Forest Management and the Invasive Tree, *Ailanthus*. Why U.S. Forest Service Research Matters. The Why Trees Matter Extension Signature Program. The Ohio State University, Columbus, OH. Nov. 29, 2011. [Invited]

11. Rebbeck J. *Ailanthus* and Forest Management Research Update. ODNR Division of Forestry Annual FSC Certification Training Session. Hocking State Forest, Ohio. May 24, 2012. [Invited]

Posters

1. Rebbeck J, Hutchinson T, Iverson I, Yaussy D, Bowden M, and Kloss A. 2009. Aerial mapping of female *Ailanthus altissima* trees in Ohio mixed oak forests. Odum Conference 2009: Understanding and managing biological invasions as dynamic processes: Integrating information across space and time. Rensselaerville Meeting Center and E.N. Huyck Preserve & Biological Research Station. April 30-May 1, 2009.
2. Rebbeck, J. Hutchinson T, Iverson I, Yaussy D, Bowden M, and Kloss A. 2010. Use of Aerial Surveys to Map and Treat *Ailanthus altissima* Trees on Large Forested Landscapes in Ohio. Presented at 2010 Ohio Invasive Plants Research Conference: Connecting Research and Land Management February 18th, 2010, Columbus, OH.
3. Rebbeck J, Hutchinson T, Iverson I, Yaussy D, Bowden M, and Kloss A. 2009. Aerial mapping of female *Ailanthus altissima* trees in Ohio mixed oak forests. AFE 4th International Congress, Fire Ecology and Management, Fire as a Global Process. Ten Years of JFSP Investments: Results, Applications, and Future Needs Session. Savannah, GA; December 1-3, 2009.
4. Joanne Rebbeck, Todd Hutchinson, Louis Iverson, Daniel Yaussy, and Timothy Fox. 2012. Predicting the importance of prescribed fire and management activities on the presence, and abundance of *Ailanthus altissima* within mixed oak forested landscapes. 18th Central Hardwoods Conference, Morgantown WV, March 26-29, 2012.

Field Demonstration/Tours

1. Ohio Oak SILVAH Training Session, Vinton Furnace State Experimental Forest. Field tour stop: Incorporated preliminary information on the response of the invasive tree, *Ailanthus* to prescribed fire within the Ohio Oak SILVAH Training Session held at Vinton Furnace State Experimental Forest, Dundas OH, Sept. 27-29, 2010. Discussed the effects of forest management practices such as prescribed fire combined with thinning on the establishment and spread of invasive plants in eastern US mixed oak forests.
2. Forest and Restoration Field Trip EcoSummit at Vinton Furnace State Experimental Forest. Part of a day-long field tour held at Vinton Furnace State Experimental Forest for the EcoSummit 2012 - Ecological Sustainability. Presented overview of *Ailanthus* Fire project to 20 participants, 16 from foreign countries, October 3, 2012

General Public & Educators Presentations

1. Gave highlights of research project at Forestry of Ohio's Public Lands Teacher Field Days: Weeds and Pests in the Woods. June 9, 2009.
2. Rebbeck, J. Managing *Ailanthus* in Ohio Forests: A Research Update. The Paul Bunyan Show, The Ohio Forestry Association, Cambridge Ohio. October 3, 2010. Presented an overview of the challenges of controlling *Ailanthus* in Ohio Forests, as well as an update on the progress of the research project. The audience was a mixture of forestry practitioners and general public.

Workshop

Managing Ohio Woodlands: The "Challenges" of *Ailanthus* Workshop and Field Tour. September 12, 2012

PI organized entire workshop. Thirty-two professional foresters, public land managers, private consultants, researchers, forestry technicians, and extension service personnel attended the day-long workshop. Partners included: The Ohio State University Extension, Ohio Invasive Plants Council, ODNR Division of Forestry, USFS Northern Research Station and JFSP. Field tour included visits to research plots to view and discuss impacts of prescribed fire and herbicide treatments on *Ailanthus*.

Publications

1. Joanne Rebbeck, Todd Hutchinson, Louis Iverson, Daniel Yaussy, Robert Boyles, and Michael Bowden. 2011. Studying the effects of management practices on *Ailanthus* populations in Ohio forests: a research update. Proceedings, 21st USDA Interagency Research Forum on Invasive Species 2010. USDA Forest Service GTR NRS-P-75, p. 50-51.
2. Rebbeck, J. 2012. Fire management and woody invasive plants in oak ecosystems. Proceedings of the 4th Fire in Eastern Oak Forests Conference, Springfield Missouri, USDA Forest Service GTR-NRS-P-102, p. 142-155.

Deliverables in preparation

1. Rebbeck J, Hutchinson T. Effects of fire and herbicide on *Ailanthus* demographics and survival.
2. Rebbeck J, Iverson L, Peters M, Hutchinson T, Fox T. Predicting *Ailanthus* presence and abundance across forest landscapes: fire and timber management effects
3. Rebbeck, J., Kloss, A., Coon, C., Bowden, M. *Ailanthus* aerial mapping: methods to search, map and destroy invasive plants in forested landscapes.
4. Rebbeck J, Hutchinson T, Iverson L. Management guidelines for controlling spread of *Ailanthus* in mixed oak forests.

Literature cited

- Dibble, A.C., Zouhar, K., and Smith, J.K. 2008. Fire and nonnative invasive plants in the northeast bioregion. *In* Wildland Fire in Ecosystems: Fire and Nonnative Invasive Plants. *Edited by* Zouhar, K., Smith, J.K., Sutherland, S., and Brooks, M.L. USDA Forest Service, Gen. Tech. Rep. RMRS-GTR-42-volume 6: 61-89.
- Dickinson, M.B. 2006. Fire in eastern oak forests: delivering science to land managers, proceedings of a conference. USDA Forest Service, Gen. Tech. Rep. NRS-P-1.
- Hu, S.Y. 1979. *Ailanthus*. *Arnoldia* 39:29-50.
- Hutchinson T, Sutherland E, Yaussy D. 2005. Effects of repeated prescribed fires on the structure, composition, and regeneration of mixed-oak forests in Ohio. *Forest Ecology and Management* 218:210-28.
- Iverson, L.R., Dale, M.E., Scott, C.T., and Prasad, A. 1997. A GIS-derived integrated moisture index to predict forest composition and productivity of Ohio forests (U.S.A.). *Landscape Ecology* 12:331-348.
- Kota, N.L., Landenberger, R.E., and McGraw, J.B. 2007. Germination and early growth of *Ailanthus* and tulip poplar in three levels of forest disturbance. *Biological Invasions* 9:197-211.

Lewis, K.C. 2007. Control techniques and management implications for the invasive *Ailanthus altissima* (tree-of-heaven). Thesis. Ohio University, Athens, Ohio.

Prasad, A. M., L. R. Iverson, and A. Liaw. 2006. Newer classification and regression tree techniques: bagging and random forests for ecological prediction. *Ecosystems* 9:181-199.

Yaussy D, Nowacki G, Schuler T, Dey D, DeGayner E. 2008. Developing a unified monitoring and reporting system: a key to successful restoration of mixed-oak forests throughout the Central Hardwood region. In: *Proceedings of the 2007 National Silviculture Workshop*; Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Deal, R.L., ed. Gen. Tech. Rep. GTR- PNW: 281-285.

Zouher, K., Smith, J.K., and Sutherland, S. 2008. Effects of fire on nonnative invasive plants and invasibility of wildland ecosystems. In *Wildland Fire in Ecosystems: Fire and Nonnative Invasive Plants*. Edited by Zouhar, K., Smith, J.K., Sutherland, S., and Brooks, M. USDA Forest Service, Gen. Tech. Rep. RMRS-GTR42-volume 6.

APPENDIX

Appendix 1. Summary of weather data and fire temperatures during *Ailanthus* Rx burn

Weather conditions on April 13, 2010 13:00-16:00 EST

	Air Temp., °F	Relative Humidity, %	Wind Speed, mph	Wind Direction, deg
Mean	71.2	27.3	4.33	79.5
Min	70.5	24	---	---
Max	71.7	28.3	8.5	---

Summary of Rx burn temperatures

	Max Paint Temp., °F	Mean Probe Temp., °F	Probe Temp. Upslope, °F	Probe Temp. Downslope, °F	% plot area burned
Mean (± std. dev)	270.9 ± 199.2	311.4 ± 170.1	294.5 ± 167.4	324.8 ± 160.9	95.8 ± 8
Min	<175	134.2	126	142.7	75
Max	649.4	640	693.5	586.4	100

Appendix 2. Distribution of *Ailanthus* across Tar Hollow State Forest and integrated soil moisture index (IMI). Dark areas represent moist conditions. IMI and other soil variables were not a significant factor in predicting *Ailanthus* presence.

