For. Sci. 61(6):1068–1078
http://dx.doi.org/10.5849/forsci.14-223

forest management

Aerial Detection of Seed-Bearing Female *Ailanthus altissima*: A Cost-Effective Method to Map an Invasive Tree in Forested Landscapes

Joanne Rebbeck, Aaron Kloss, Michael Bowden, Cheryl Coon, Todd F. Hutchinson, Louis Iverson, and Greg Guess

We present an aerial mapping method to efficiently and effectively identify seed clusters of the invasive tree, *Ailanthus altissima* (Mill.) Swingle across deciduous forest landscapes in the eastern United States. We found that the ideal time to conduct aerial digital surveys is early to middle winter, when *Ailanthus* seed clusters persist and there is no interfering leaf cover. Because of the color, quantity, and seedpod arrangement, female seed-bearing *Ailanthus* trees are very conspicuous from the air. With use of digital sketchmapping technology from helicopters, seed-bearing *Ailanthus* trees were mapped at a rate of 2,000–4,000 acres/hour (809–1,618 ha/hour). We estimated mapping costs at approximately $0.40/acre ($1.00/ha). We were able to relocate, within 100–200 ft, 88–95% of the aerially mapped seed-bearing *Ailanthus* trees using handheld consumer-grade global positioning systems (GPS) units. This provided enough accuracy to locate seed-bearing *Ailanthus* for single-stem injection herbicide treatments. To apply these methods to map seed-bearing *Ailanthus*, land management agencies that already use digital mapping technology (equipment and software) for surveys of insect and disease outbreaks will have minimal costs beyond helicopter time.

Keywords: woody invasive control, digital mapping technology, forest management

Invasive species management is a natural resource priority with cost estimates in the United States exceeding $120 billion annually (Pimentel et al. 2005). The negative impacts of invasive plant species traverse landscapes, ownerships, and jurisdictions. It is becoming increasingly important to coordinate scarce resources for invasive species control across these boundaries. To be effective, invasive plant populations need to be identified before control and management plans can be prioritized and implemented, and aerial detection surveys provide an efficient technique to map certain invasive plants across large forested landscapes.

Aerial detection surveys are widely used throughout the United States to map insect and disease outbreaks and other disturbances that affect forest health (Johnson and Wittwer 2006). Such methods include the use of intensive and costly ground surveys and high-resolution remotely sensed spectral imagery, which often requires intensive postcollection processing (Joshi et al. 2004). In recent years, mapping has become computerized and integrated with global positioning systems (GPS) technology. A digital aerial sketchmapping system (DASM) runs on a laptop computer with a touch screen display and stylus, allowing the manual recording of sketched features onto a base map (US Department of Agriculture [USDA] Forest Service 2015a). Features can be points, lines, or polygons coded with attributes through user-defined keypads. Georeferenced map bases and aircraft position are shown on the screen and are refreshed on input from an attached GPS unit. Data files created during a survey flight are exported to ArcGIS shape files (ESRI,

Manuscript received December 6, 2014; accepted July 13, 2015; published online September 3, 2015.

Affiliations: *Joanne Rebbeck (jrebbeck@fs.fed.us), USDA Forest Service, Northern Research Station, Delaware, OH. Aaron Kloss (aaron.kloss@dnr.state.oh.us), Ohio Department of Natural Resources, Division of Forestry. Michael Bowden (michael.bowden@dnr.state.oh.us), Ohio Department of Natural Resources, Division of Mineral Resources Management. Cheryl Coon (ccoon@fs.fed.us), USDA Forest Service, Wayne National Forest. Todd F. Hutchinson (thutchinson@fs.fed.us), USDA Forest Service, Northern Research Station. Louis Iverson (liverson@fs.fed.us), USDA Forest Service, Northern Research Station. Greg Guess (Gregory.Guess@dnr.state.oh.us), Ohio Department of Natural Resources, Division of Forestry.*

Acknowledgments: *We thank Joe Barber, Buster Keaton, Tom Shuman, Danzil Walker, and Courtney Streithorst, ODNR Divisions of Forestry and Wildlife, for assistance in the aerial mapping. We greatly appreciate the support of William Borovicka, Levi Miller, Timothy Fox, and Richard Craig for assistance in the field. We thank Tim Fox and Joan Jolliff for assistance with data entry. We thank Aurora Roemmich and Nicole Stump, USDA Forest Service, Wayne National Forest for their support and cooperation. We appreciate the support and cooperation from Robert Boyles, Dan Balser, and Chad Sanders of the Ohio Department of Natural Resources, Division of Forestry. We thank Robert Long and William Oldland for technical reviews and John Stanovick for biometrics review. Funding was provided by the Joint Fire Science Program and the USDA Forest Service, Northern Research Station.*

This article uses a metric unit; the applicable conversion factor is: hectares (ha): 1 ha = 2.47 ac.

Redlands, CA) for immediate use in a geographical information system (GIS) environment for various management and planning purposes. Data are easily downloaded to handheld GPS units for ground crews to navigate to infested areas.

Typically, fixed-wing aircrafts, flying at elevations of 1,000–3,000 ft aboveground at speeds of 130 mph, are used for DASM forest health surveys. Because helicopters are more maneuverable and can safely travel at slower speeds and lower elevations than fixed-wing aircraft, we wanted to determine whether they could be used to efficiently map nonnative invasive trees across large (>1,000 acres) forested landscapes. Because helicopters are often used by public agencies in the Central Appalachian region for radio telemetry wildlife surveys and for aerial ignitions of prescribed burns, they could also be available for efficient mapping of invasive plants in these same topographically challenging forest landscapes. In Idaho, The Nature Conservancy uses helicopters to digitally map the invasive weed leafy spurge (*Euphorbia esula* L) (Schrader-Patton 2003) from fixed-wing aircraft. The National Park Service mapped invasive species such as Australian pine (*Casuarina* spp.), Melalauca (*Melaleuca quinquenervia*), and old world climbing fern (*Lygodium microphyllum*) in the Florida Everglades (Pernas and Rodgers 2010) from a helicopter at a cost of $0.06 per acre. A total of 2.9 million acres were mapped in 162 hours with costs to include helicopter rental ($950/hour), two observers ($120/hour), and 80 hours of GIS data analysis ($30/hours) (Pernas and Rodgers 2010).

Ailanthus altissima (Mill.) Swingle (hereafter referred to as *Ailanthus*; also known as tree of heaven), an invasive tree native to China, has been present in North American landscapes for more than 200 years (Hu 1979) and is widely distributed throughout the eastern United States. The Eastern and Southern Regions of the USDA Forest Service rank it in Weed Category 1: an exotic species known to be invasive and persistent throughout much of both regions (USDA Natural Resources Conservation Service 2015). Although it is most often abundant in open sites such as roadsides (McAvoy et al. 2012), it frequently invades and establishes within disturbed forest sites. Kasson et al. (2013) report recent widespread *Ailanthus* invasions in Pennsylvania forests following salvage cutting in the aftermath of extensive gypsy moth (*Lymantria dispar*) outbreaks. Most of Ohio's southeastern forestlands have a history of agricultural use and natural resource extraction, which may have facilitated the spread of *Ailanthus* and other nonnative invasive plants (Parker et al. 2010). *Ailanthus* is capable of aggressive clonal spread, creating dense thickets and is fast growing, reaching heights of 60–70 ft in 10 years (Knapp and Canham 2000). Kasson et al. (2013) report a 40-year-old open-grown *Ailanthus* with a diameter of 31.5 in. dbh. *Ailanthus* has a negative impact on native tree regeneration because of its competitive traits and production of the allelopathic compound ailanthone (Heisey 1996, Gómez-Aparicio and Canham 2008). Although considered shade intolerant, clonal sprouts attached to a parent tree can persist in a shaded forest understory for up to 20 years (Kowarik 1995, Knapp and Canham 2000). It is dioecious, with up to 325,000 wind-dispersed seeds produced per female tree in a single growing season (Bory and Clair-Maczulajitys 1980). Prominent dense seed clusters, often more than 800 clusters/tree, can persist throughout the winter although they are more dependably present in early winter (Figure 1) and disperse long distances over several months. Landenberger et al. (2007) reported that *Ailanthus* seed travel in excess of 330 ft within intact deciduous forests. Mapping seed-bearing (female) *Ailanthus* by aerial detection of these persistent clusters is the subject of this article.

Our goal was to capitalize on conspicuous seed clusters of *Ailanthus* and test whether application of DASM technology from helicopters could be used as a fast and cost-effective tool to map seed-bearing *Ailanthus* in forested landscapes. We conducted these tests across 289,000 acres of public and private forestlands. Field crews assessed the accuracy of the aerial surveys through ground reference data collection. Crews also conducted aerial surveys during the leaf-on season to determine whether *Ailanthus* foliage and seed clusters were distinguishable from those of other species. Finally, we developed mapping protocols for use by the forest management community. The georeferenced data could be used as a management strategy to identify high priority areas to target the removal of *Ailanthus* seed sources to minimize its dispersal and slow its spread.

Materials and Methods

Survey Areas

Tar Hollow State Forest (THSF)

Approximately 9,600 acres (3,900 ha) of the 16,046-acre (6,500 ha) THSF (39°21′ N and 82°46′ W) within Hocking, Vinton, and Ross Counties in Ohio were mapped (Figure 2). This area falls within the Unglaciated Allegheny Plateau where topography is highly dissected, consisting of sharp ridges, steep slopes, and narrow valleys (Beatley and Bartley 1959). The uplands are typically dominated by mixed-oak forests, whereas the lower slopes and coves are mixed mesophytic. The forest has had a history of timber harvesting and farming since European settlement in the late 1700s. The land became severely eroded and unproductive from more than 100 years of exploitation and poor management practices. In the 1930s, the Ross-Hocking Land Utilization Project funded the relocation of subsistence farming families to more productive land. The abandoned land has since been managed by the Ohio Department of Natural Resources (ODNR), Division of Forestry. THSF was reforested primarily by natural regeneration. It currently has an active timber harvesting program, a component of its multiple-use management. It also has an active prescribed fire program designed to improve oak regeneration; more than 2,000 acres have been treated since 2001. Several woody invasive plants are present and common, but *Ailanthus* is the most prevalent and of most concern to forest managers.

Athens, Marietta, and Ironton Units of the Wayne National Forest (WNF)

These units are also located within the Unglaciated Allegheny Plateau, across portions of 12 Ohio counties (Figure 2). The WNF Proclamation Boundary covers 833,990 acres. However, 71% of the land within those boundaries is in private ownership. It is a diverse landscape but is primarily represented by mixed oak-hickory forests. All three units have a long history of past disturbance including deforestation for farming, livestock grazing, and charcoal production, as well as mineral, gas, oil, and coal extraction, which began in the early 1800s. Long-term impacts show a decreased diversity of plant species in heavily grazed areas compared with clearcut or other timber-harvested areas, and lowered water quality in those areas heavily surface mined. Today, disturbances on the WNF include some limited timber harvesting, prescribed burning, recreation trails, and oil/gas extraction.

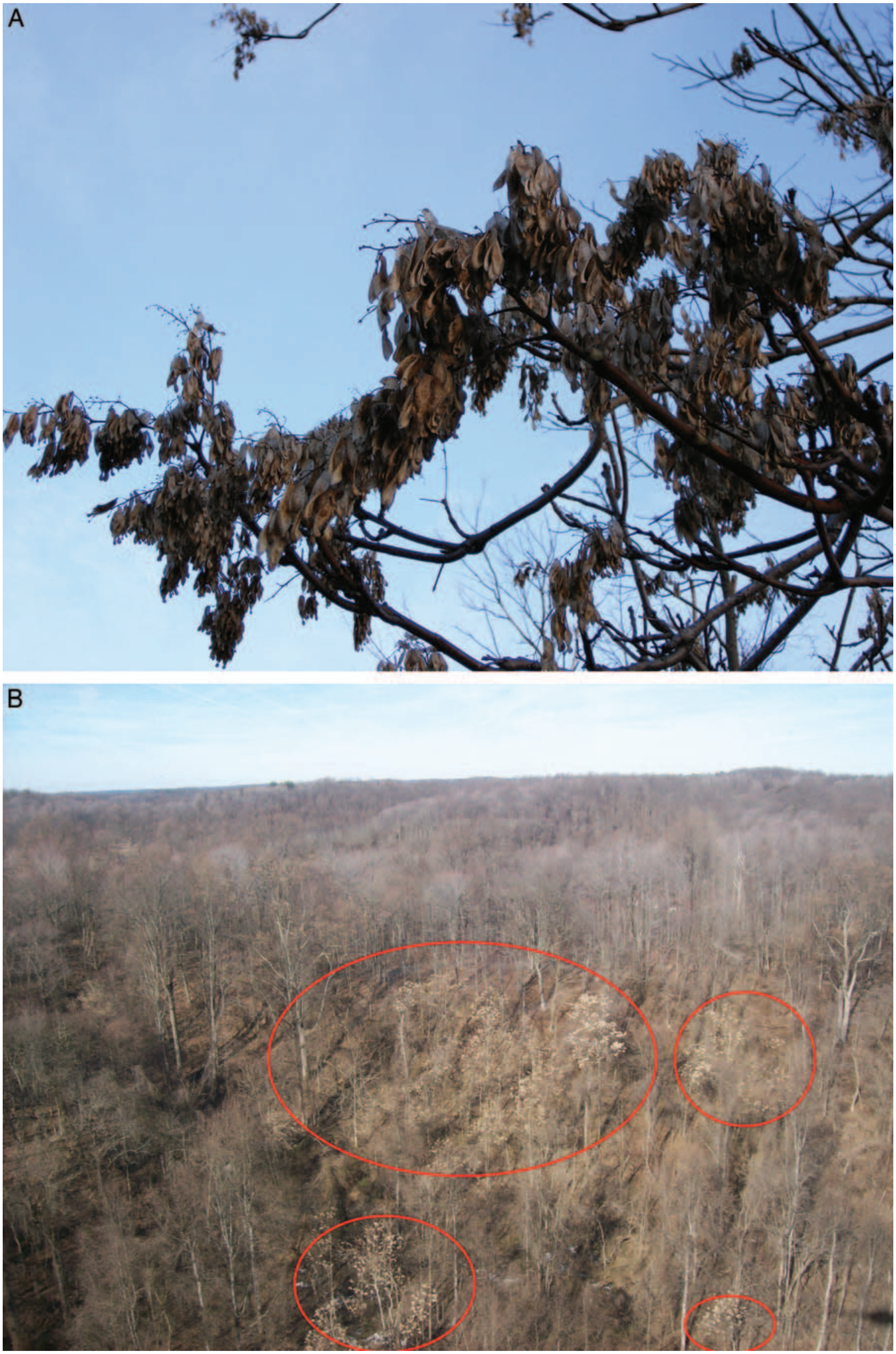

Figure 1. Close-up (A) and aerial view (B) of *Ailanthus* seed clusters during the dormant season. Red polygons show clusters of females.

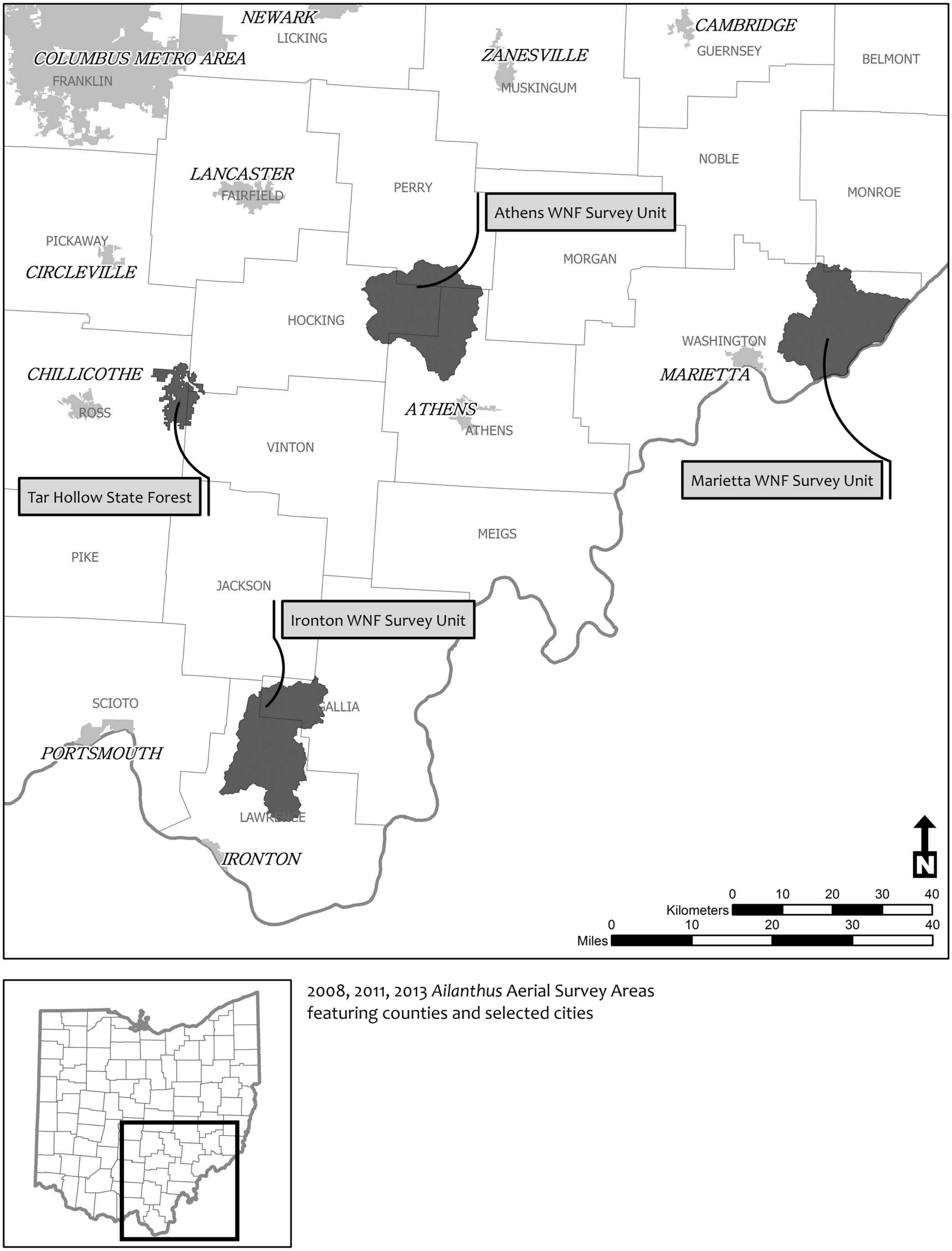

Figure 2. Location of aerial survey areas within THSF and three units within the WNF in southeastern Ohio from December 2008 through January 2013.

Table 1. Summary of *Ailanthus* aerial surveys conducted on THSF and three units on the WNF in Ohio between 2008 and 2013.

Survey unit	Survey year/month	No. of days/hours of mapping	Total area surveyed	Mapped infested area	No. of mapped female *Ailanthus*	No. of mapped polygons	Size of mapped polygons (acres) Range	Mean ± SD
			. . . . . .(acres)				. . . .(acres).	
THSF	2008/December	1/2.25	9,600	363	96	42	0.4–33	21.4 ± 8.0
Athens	2013/January	2/10	87,307	41	259	23	0.3–7.8	1.8 ± 1.88
Ironton	2011/March	2/12	83,522	65	18	20	0.3–10.2	3.6 ± 3.28
	2013/January	2/10	112,832	4	39	3	0.9–1.6	1.3 ± 0.47
Marietta†	2011/January, February	6/18	79,734	6,388	NA	1,356	0.1–71.6	4.7 ± 7.16

NA, not available.
† No ground reference data collected.

Aerial Survey Methods

A preliminary survey in early November 2008 determined whether *Ailanthus* seed clusters could be recognized from a helicopter. Known GPS coordinates of seed-bearing *Ailanthus* were provided for a mixed-oak stand at THSF. Helicopter crew members were able to identify and map *Ailanthus*; however, during this preliminary survey, many tree canopy leaves, primarily oaks, had not yet fallen, making it difficult to distinguish *Ailanthus* seed clusters where leaves had persisted. A second flight occurred on Dec. 11, 2008, when all hardwood trees were devoid of leaves. A Bell 206 B3 JetRanger helicopter owned by the ODNR Division of Wildlife was used for all surveys. The crew included an ODNR helicopter pilot, one spotter, and one sketchmapper. The spotter sat directly across from the pilot and provided the sketchmapper sitting in the rear seat with a description and approximate location of the *Ailanthus* trees.

In subsequent flights, the spotter was replaced with a second sketchmapper to determine whether any efficiency could be gained. After the pilot learned to identify seed-bearing *Ailanthus* trees, he served as a spotter. Before the start of each surveying session, sketchmappers reviewed mapping protocols, use of digital sketching software, and aerial photographs of seed-bearing *Ailanthus* trees. At the beginning and end of each flight, both sketchmappers collected data on the same trees to assess sketchmapper consistency. Each recorded the position of seed-bearing *Ailanthus* on one of the following tablet laptop computers: a rugged Hammerhead XRT, a Dell XF (nonrugged tablet), or a rugged Dell XT tablet which used a Holux M-241 GPS logger. All were equipped with stylus-touchable screens and loaded with GeoLink Powermap software (Michael Baker Jr., Inc., Jackson, MS). Reference base maps included US Geologic Survey (USGS) 7.5-minute quadrangle maps (digital ortho quads at a 1:24,000 scale and the survey boundaries. Laptops were linked to a Bluetooth-enabled Garmin EMTAC GPS receiver and an onboard Garmin 496 GPS unit (Garmin, Olathe, KS). Survey altitudes were 150–600 ft above ground level at a speed of 55–80 mph, depending on environmental conditions, forest density, and structure. Initially survey lines ranged from 373 to 1,600 ft apart (average = 1,000 ft) in a general east-west orientation. Spacing of survey lines was determined by the distance of visibility, environmental conditions, and vegetation attributes (forest density and structure). After determination that a 1,000-ft distance between survey lines was adequate for sketchmappers to detect seed-bearing *Ailanthus* with no lapse of visual coverage, fixed flight lines of 1,000 ft with an north-south orientation were routinely loaded with reference maps for all subsequent flights. When a dense area of seed-bearing *Ailanthus* trees was spotted, the pilot would circle back around the infested areas to gain a better look and facilitate mapping of the area. Single points were collected when one to several trees was spotted, and polygons were collected for larger clusters of trees. ESRI ArcGIS (version 10) software was used for postprocessing of data.

Surveys were expanded to include portions of the WNF in 2011 and 2013 (Table 1). In those initial 2011 surveys, because only polygon data of seed-bearing *Ailanthus* were collected and *Ailanthus* cover was not estimated, Marietta Unit data are not presented. In the 2013 surveys, mapping techniques were modified to include single-point and multipoint data. If multipoints were not feasible (e.g., large areas with dense clusters of seed-bearing trees), a polygon was recorded instead and the estimated percent cover of *Ailanthus* within a given polygon was assigned into cover classes of ≤25, 26–50, 51–75, or 76–100% cover. Because low numbers of seed-bearing *Ailanthus* were detected at the Ironton Unit in March 2011, the entire unit (112,832 acres) was surveyed in January 2013 to determine whether the optimal surveying window had been missed in March 2011 (e.g., due to seed clusters falling off). A portion of the Athens Unit (87,307 acres) was surveyed in January 2013 (Table 1).

Ground Reference Data

Coordinates of single waypoints were downloaded to consumer-grade handheld GPS units (Garmin GPSmap 76CSx) so that the mapping accuracy of individual seed-bearing females could be accessed during ground reference data collection. The handheld units included 2.0-GB microSD storage cards with a GPS accuracy of <33 ft and a digital GPS accuracy of 10–16 ft. Ground reference data collection was conducted 6–8 weeks after aerial surveys at THSF on a subset of 62 randomly mapped seed-bearing *Ailanthus* with 31 points randomly selected within 10 separate management units burned between 2001 and 2008 (total of 2,300 acres) and 31 points within unburned areas (7,337 acres) (Rebbeck et al. 2014). Aerially identified polygons of *Ailanthus* were not ground referenced. After navigation to an aerially mapped point using handheld GPS units, the following ground data were collected: a georeferenced waypoint of the largest female tree, dbh of the largest female, number of nearby females, population form (single tree, clump of multiple trees, or dense thicket), and seed crop abundance classes (none, sparse, moderate, or heavy). Georeferenced locations of any seed-bearing *Ailanthus* that had not been aerially mapped were collected at this time. The accuracy of aerially mapped locations was assessed by overlaying the ground reference data locations for each of the 60 seed-bearing females within ArcMap (ESRI, version 10). The distance between each pair of georeferenced points was measured. Ground reference data were not collected on the Ironton unit, but georeferenced ground surveys of *Ailanthus* and other nonnative invasives done by WNF field crews between 2011 and 2013 were compared with the aerially mapped points and polygons. The Athens Unit was ground referenced in June and July 2013 using protocols similar to those described for THSF. The ground referencing areas were identified within ArcGIS ArcMAP 10.1 for aerial points mapped either within WNF boundaries or within 82 ft of all classes of roads and trails.

Results

In December 2008, the 9,600-ac area within the THSF was surveyed in 2 1/4 h, with 96 seed-bearing females and 42 areas (polygons) mapped (Table 1; Figure 3). Sixty of the aerially identified seed-bearing females were ground-referenced from mid-January to late February 2009 with handheld GPS units (Table 2). In all, only two trees were misidentified as *Ailanthus*: a sourwood (*Oxydendrum arboretum*) that had persistent seed clusters, and a fruit-bearing grapevine (*Vitis* sp.) growing within the canopy of a sugar maple (*Acer saccharum*). During the ground referencing, one of the aerially mapped *Ailanthus* was not located, and field crews found six seed-bearing *Ailanthus* that were undetected in the aerial surveys (6% underreporting). GPS points taken at the ground-referenced seed-bearing *Ailanthus* trees differed from 12.9 to 336.1 ft from aerially mapped points. The mean ± SD aerial mapping accuracy was 118.2 ± 81.9 ft. Thirteen percent of the ground-referenced points were within 32 ft of the aerially mapped points, whereas 75% of the points fell within the standards and guidelines of 164 ft accuracy of the USDA Forest Service Forest Health Technology Enterprise Team aerial detection survey guidelines (Schrader-Patton 2003).

Of the 83,522 ac (74% of the entire unit) surveyed on the Ironton Unit of the WNF in early March 2011, only 65.2 acres (0.08% of the surveyed land) were mapped as infested with *Ailanthus* (Table 1). We had suspected that these late winter flights failed to detect areas of infestation due to seed abscission. In January 2013, the entire Ironton Unit (112,832 acres) was surveyed, and the results confirmed that, indeed, few seed-bearing females were present on that landscape with 39 female trees and 3 polygons aerially mapped (Table 1). Fifteen of the 19 polygons mapped in 2011 were not remapped in 2013, and some were mapped as individual trees in 2013. More than 68% of the 2011 polygons that were not remapped in 2013 were small, ranging in size from 0.3 to 2 acres. Field crews created georeferenced polygon data within the Ironton Unit during herbicide treatments of *Ailanthus* and other invasive plants between 2011 and 2013. Of those 5,440 acres treated, areas infested with *Ailanthus* ranged in size from 0.03 to 353 acres. A wide range (0–65%) of *Ailanthus* stem densities within a given treatment area was observed. By comparing these georeferenced treated areas to our aerially mapped *Ailanthus* polygons from 2011, we found that five of the "missing" *Ailanthus* polygons were located within herbicide-treated areas. The two remaining missing polygons (1.6 and 2.0 acres) may have been too small or had no visible seed clusters in 2013.

Within the Athens Unit survey area, 259 seed-bearing female *Ailanthus* trees and 23 polygons were sketchmapped (Table 1). Of the 23 polygons, 6 had *Ailanthus* cover of ≤25%, 8 had 26–50% cover, 3 had 51–75% cover recorded, and 3 were not assigned an *Ailanthus* cover value. Ground referencing surveys covering approximately 50 miles of roads and more than 4,400 acres were conducted in summer 2013. Within the ground reference area, 62 of the 70 aerially mapped females were located, 8 were not found, and 12 additional seed-bearing trees were mapped (Figure 4). These seed-bearing females ranged from 3.6 to 20.5 in. dbh and averaged 8.2 ± 7.2 in. dbh. Estimating the ratio of seed-bearing (female) to non-seeding (presumably male) trees was outside of the scope of the study and not calculated. However in the Athens Unit, non-seed-bearing male trees were identified as individuals or in clumps for 8% of total ground-mapped points, but most occurred mixed with seed-bearing females (33% of total ground-mapped *Ailanthus*). The actual location distance of ground-mapped seed-bearing *Ailanthus* ranged from 3 to 492 ft from the aerially mapped location. Approximately 20% of these exceeded the 164 ft accuracy recommended by the USDA Forest Health Technology Enterprise Team.

Given our initial mapping results during the dormant season at THSF, we conducted preliminary leaf-on summer surveys to determine whether *Ailanthus* foliage and developing seed clusters could be distinguished among the other canopy trees. The goal was to determine whether the mapping window could be expanded beyond the winter months into August and September. Over the course of 4 flight days in September 2009, approximately 40,000 acres were aerially mapped within five ODNR state forests. Sketchmappers were able to identify canopy seed-bearing *Ailanthus* during those test flights. The observed yellowish-green seeds provided a good contrast with the still green foliage, but sketchmappers recommended that future leaf-on surveys be conducted before any changes in autumn leaf color. Ground reference data collection indicated that many polygons identified as non-seed-bearing *Ailanthus* patches were actually sumac (*Rhus* spp.) or black walnut (*Juglans nigra* L.) stems, and in other cases, some polygons contained mixtures of sumac and *Ailanthus*. This resulted in an overestimation of *Ailanthus* infestations within some stands. Another drawback is that the helicopter had to fly at low altitudes (100–200 ft aboveground) to accurately map infestations, resulting in less area surveyed per hour, compared to the dormant season aerial surveys. Approximately 12,000 acres were surveyed per day at an average of 2,000 acres/hour (Greg Guess, ODNR Division of Forestry, pers. comm., Apr. 2, 2010).

Discussion

We have demonstrated that helicopter digital sketchmapping technology can be used to map locations of visually located seed-bearing *Ailanthus* in forested landscapes during the dormant season, when staff and aircraft may be more readily available. We found that the ideal time to conduct aerial surveys for female *Ailanthus* is early to middle winter (December and January), based on the persistence of seed clusters into the months when there is no interfering leaf cover. Because of the color, quantity, and seedpod arrangement, female seed-bearing *Ailanthus* trees were very conspicuous from the air. Although female seed-bearing trees as small as 1.2 in. dbh were aerially detected, the inability to detect low seed producers or those that drop seeds prematurely is a potential limitation of this technique. Because this methodology is restricted to identifying only seed-bearing trees, it underestimates the total number of *Ailanthus* stems within the surveyed areas. However, it does identify high-priority areas to target for removal treatments to minimize seed dispersal and future expansion to uninfected areas.

The horizontal accuracy of sketchmapped seed-bearing *Ailanthus* locations was assessed using ground reference data. We were able to locate, within 100–200 ft, 88–95% of the aerially mapped female *Ailanthus* trees using handheld consumer-grade GPS units. These inexpensive units provided enough accuracy to locate the general vicinity of a given infestation. However, it should be noted that the

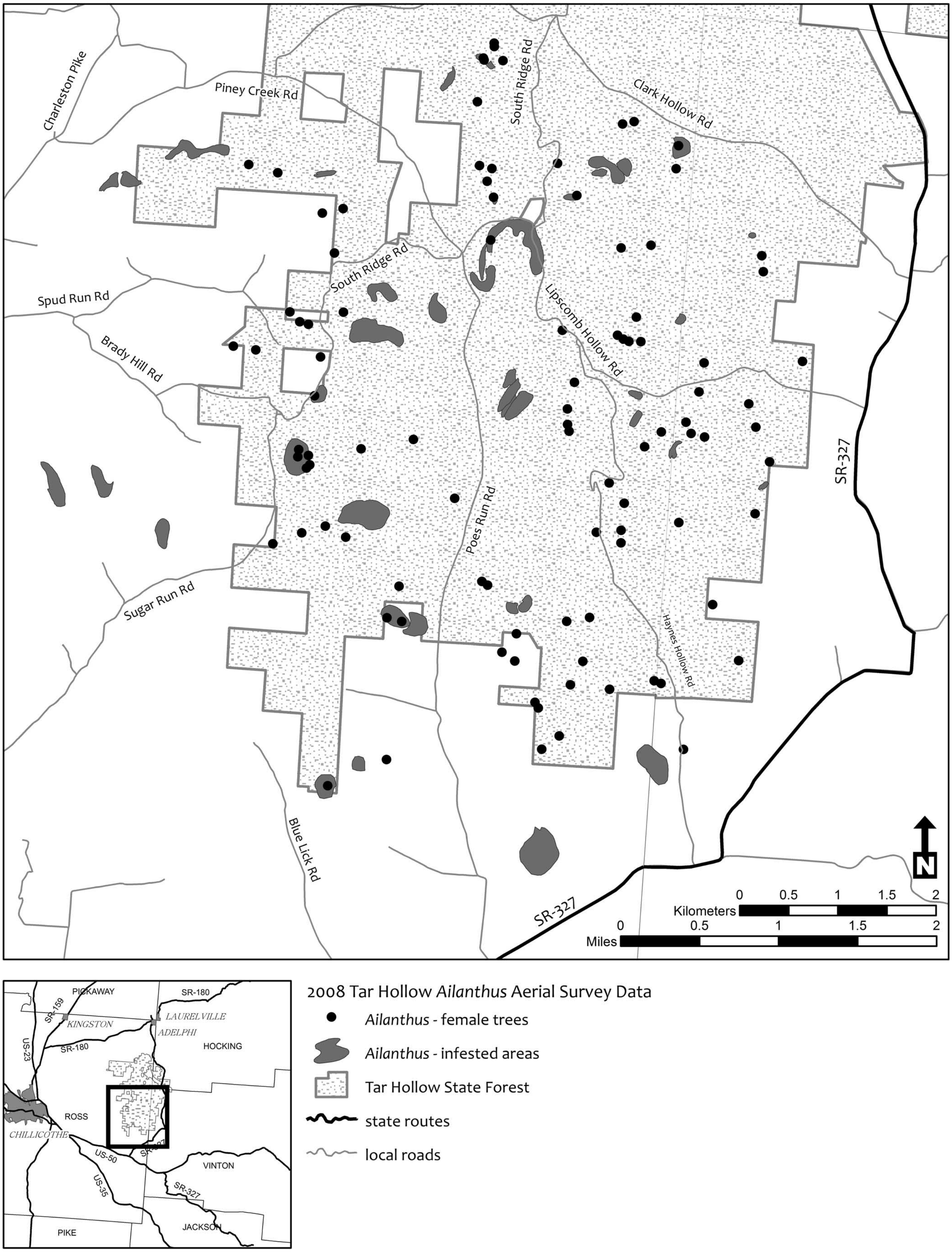

Figure 3. Locations of *Ailanthus* female trees and polygons during aerial mapping at THSF in December 2008.

Table 2. Summary of December 2008 helicopter survey and January–February 2009 ground referencing of female *Ailanthus* trees within 9,600 acres at THSF, Ohio.

Parameter	Value
No. of female *Ailanthus* aerially mapped	98
No. of female *Ailanthus* ground referenced	62
Aerial mapping accuracy (ft)*	120 ± 81
Range of mapping accuracy (ft)	13–336
Aerially mapped female trees not found	1
Misidentifications†	2
Unmapped females‡	6
Ground referenced female tree dbh (in.)	
Range	1.2–15.0
Mean ± SD	7.4 ± 8.0
Seed crop abundance (% of trees)	
No seeds	11.7
Sparse	25.0
Moderate	33.3
Heavy	30.0
Ailanthus population structure (% of trees)	
Single tree	18.3
Clump	46.7
Dense thicket	35.0

* Distance of aerial location from ground-referenced location of female tree (mean ± SD) using ESRI ArcMap.
† A sourwood (*Oxydendrum arboretum*) tree and a sugar maple (*Acer saccharum*) tree covered with grape vine were misidentified as *Ailanthus*.
‡ These represent *Ailanthus* female trees located during ground truthing but were not aerially mapped.

on-ground location of seed-bearing trees was slower and less accurate when a full canopy was present, as was the case for ground reference data collection in the Athens Unit. This was attributed to viewing obstructions of seed clusters from the ground and the limited number of accessible satellite signals under canopy cover. However, if locations were measured in late summer to early winter, finding aerially mapped female *Ailanthus* would probably be less impeded. If ground locating of *Ailanthus* must be done under full canopy, we recommend the field crews be trained to identify its bark, which should facilitate faster relocation of *Ailanthus* stems. We developed color photo guides of bark, flower, seed, and leaf scars characteristics of both *Ailanthus* and sumac for field use.

There is a distinct cost advantage to this sketchmapping technique over ground-based detection only. Our survey costs were estimated at $0.40/acres ($1/ha). Additional populations of non-seed-producing *Ailanthus* were often found during ground searches of seed-bearing *Ailanthus* for chemical treatments. This suggests that a multistage approach of conducting local ground searches near aerially detected seed-bearing *Ailanthus* may be even more cost-effective. We based our costs on a commercial rate of $960/hour, which included helicopter rental ($800/hour) and hourly wages for the pilot ($60/hour) and two sketchmappers ($100/hour) for an average 8-hour day. This estimate included round-trip flight time to and from the airport and survey area (1–2 hours/day), as well as a midday aircraft refueling and crew break at the closest airport. Additional costs for training, setup, and postdata processing time were minimal since we retooled an existing methodology currently used by the ODNR Division of Forestry. However, we estimate that an additional 16 hours ($50/hour) is required annually. Estimates of coverage ranged from 2,000 to 7,000 acres/hour, depending on the level of *Ailanthus* infestation and flight altitude. If more *Ailanthus* was present, then more time per acre was required for mapping. Another advantage of this mapping tool is quick access to the data. Very little postflight processing is needed to generate georeferenced maps and/or downloadable point data onto GIS devices. It should be noted that downloading polygon data onto handheld units requires more storage capacity than waypoint data.

Another benefit of using this digital aerial sketchmapping technology for mapping woody invasive plants is that many forest management agencies already use the equipment and software for forest health insect and disease surveys. In addition, there is readily available support and training through the USDA Forest Service Forest Health Technology Enterprise Team and the Forest Service State and Private Forestry Forest Health Monitoring Program. Public domain materials including DASM manuals, aerial detection survey standards and guidelines, software, and other documentation are available online (USDA Forest Service 2015b).

Management Applications

The georeferenced data collected in this project are being used to develop and prioritize management plans to chemically treat *Ailanthus* on ODNR (Greg Guess, ODNR Division of Forestry, pers. comm., June 26, 2010) and on WNF (Steven Blatt, USDA Forest Service, pers. comm., July 14, 2014) lands. Based on our success, the ODNR Division of Wildlife has been conducting annual helicopter mapping surveys of the nonnative invasive perennial grass, *Phragmites australis*, in wetland areas along Lake Erie since 2010. Because of the flat topography within the Lake Erie Basin, National Agriculture Imagery Program (NAIP) aerial imagery maps are used as base maps instead of USGS quadrangle maps. Sketchmappers find it easier to remain oriented and mapping accuracy is much improved relative to that with topographic maps (Mark Witt, ODNR Division of Wildlife, pers. comm., Apr. 7, 2014). This same approach could also be used to aerially map invasive bush honeysuckles (*Lonicera* spp.) by using their unique phenology of being the first to leaf-out and last to abscise each growing season (Hutchinson and Vankat 1998). Our sketchmappers were able to distinguish and map the prominent seed clusters of the nonnative species princess tree (*Paulownia tomentosa*). Its seeds were clearly visible and distinctive from those of *Ailanthus* during these leaf-off surveys. Early indications show great promise for detection of this problematic nonnative species as well. Unfortunately, not all invasive species can be mapped at the same time because of differences in their phenology. For successful mapping, timing of surveys must be linked to a prominent and distinctive feature of the target species. In the case of *Ailanthus* and *Paulownia*, winter leaf-off surveys are the most appropriate time but would be inappropriate for mapping bush honeysuckle.

Challenges of Technology

There are limitations associated with this mapping methodology including access to and affordability of a helicopter and pilot. Although hourly rates for fixed-wing aircraft are considerably lower, this method does not provide the required lower speed, maneuverability, and visibility needed for high-resolution mapping. It is much easier to accurately locate, sketch, and assign attribute features at speeds of 55–80 mph in a helicopter than at the speeds of approximately 130 mph in a fixed-wing aircraft. The greatest limitation of this technology, however, is the accuracy of the sketchmapping.

According to McConnell et al. (2000, p. 15), "the most critical element in aerial sketchmapping is also the most variable: the sketchmapper." Klein et al. (1983, p. 2), states that

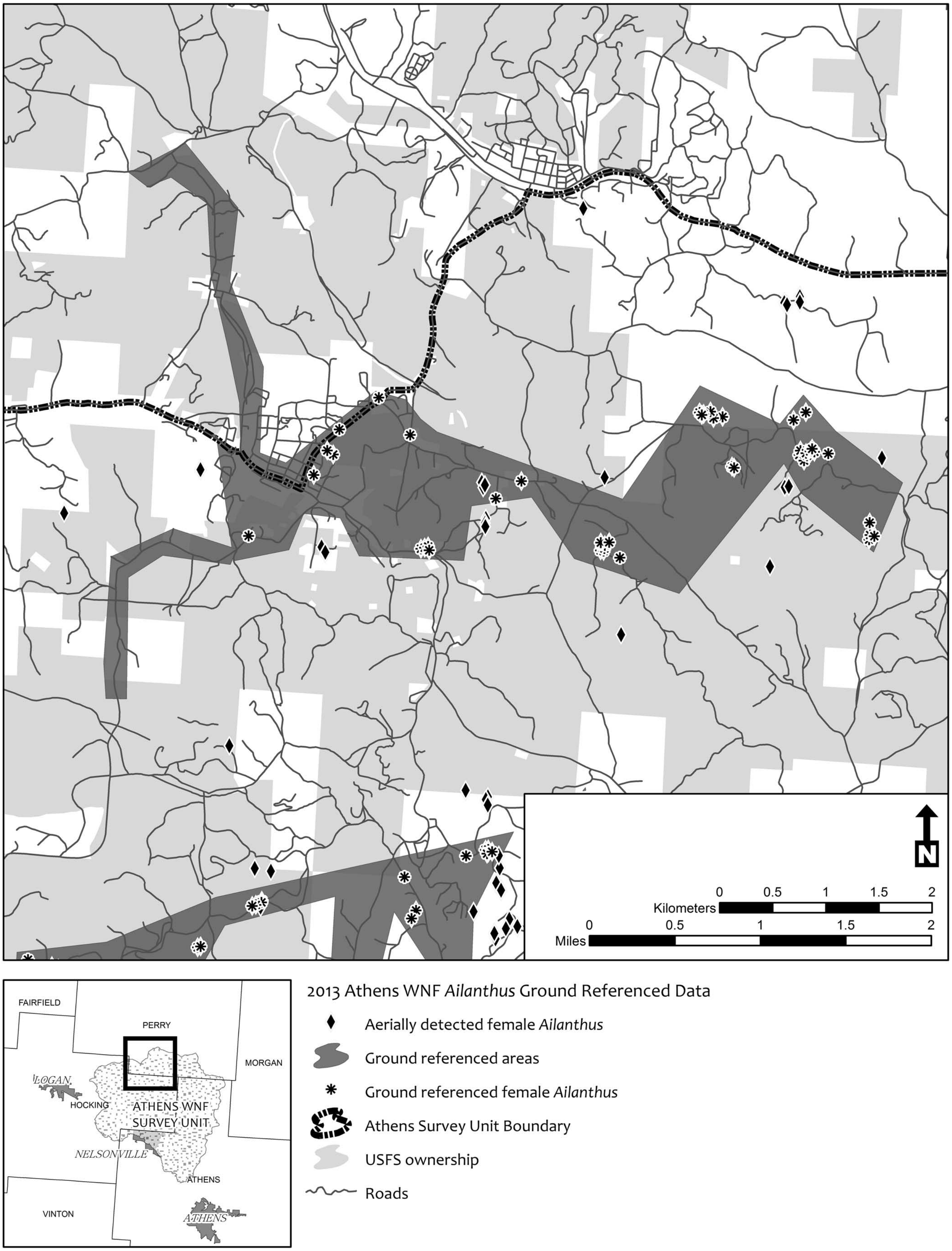

Figure 4. Area where ground-truthing occurred on the WNF Athens Unit, Ohio, in June–July 2013, conducted about 6 months after aerial mapping.

> [S]ketchmapping should be regarded more as an art than a science. Sketchmapping is highly subjective, and the resulting data can be no more accurate than the competence of the sketchmapper and the conditions under which the data were collected.

A sketchmapper should have a high level of comfort in an aircraft, tolerance to air sickness and fatigue, knowledge of forest conditions, and good map-reading skills. A sketchmap represents an observer's interpretation of what is seen on the ground. The accuracy of a sketched feature is determined by the ability of the surveyor to keep track of the aircraft's position and to correctly relate features seen on the ground to a topographic map. Given these potential limitations, some caution is still required when interpreting sketchmapping results. Luckily, advances in GPS receiver hardware and associated software allow for real-time display of the aircraft as an icon on the touchscreen monitor.

Standardization of methods is the balance to the "art" side of sketchmapping. Typically, a sketchmapper improves in performance with experience. Early surveys of the Marietta Unit were the first mapping session for many of the crew (3 of the 4). Based on preliminary comparisons of these early flights with a recent December 2013 aerial survey of a 62,530-acre subsection of the same area on the Marietta Unit, we found that approximately 45% of the 2011 *Ailanthus* infested polygons were not relocated in 2013, suggesting an initial overestimation of *Ailanthus*-infested areas (J. Rebbeck, USDA Forest Service, unpubl. data, Dec. 6, 2014). Annual training before the season is critical and should include calibration and conformity sessions. A presurvey training flight is strongly encouraged for sketchmappers. During our first flights, we did not have aerial photos of seed-bearing *Ailanthus*. They are now part of the preflight training and serve as a good calibration tool to improve mapping accuracy. During all flights, surveyors should periodically record known land features such as road intersections, bridges, or prominent structures as spatial accuracy checks. We recommend implementing the aerial survey standards and quality assurance and quality control guidelines developed by the USDA Forest Service Forest Health Technology Enterprise Team (USDA Forest Service 2015b).

Ongoing Refinements

As with any new application use of an existing technology, refinements are ongoing. As more survey flights are conducted, we continue to improve the accuracy of the sketched features. We found significant improvements in georeferencing actual seed tree locations by prioritizing the digitizing of single points or multipoints over polygons. The multipoint keypad function allowed the surveyor to map many points that have the same attribute (e.g., *Ailanthus*, *Paulownia*, and others). When the mapping of points was not feasible (or, in the case of the Marietta Unit, early in the development of protocols), a polygon was sketched and an estimate of *Ailanthus* cover was recorded. Additional improvements will be tested in upcoming *Ailanthus* aerial surveys, when the use and accuracy of utilizing USDA NAIP imagery base maps will be compared with those for USGS quadrangle maps with ground truthing after aerial mapping.

Conclusions

We determined that the conspicuous seed clusters of *Ailanthus* could be identified from helicopters and cost-effectively mapped using DASM technology in forested landscapes. This technology provided forest managers with readily available, landscape-level data for seed-producing *Ailanthus* populations, allowing them to develop improved control plans and direct field crews to the location of seed-bearing *Ailanthus* for treatment. Proactive control of invasive plants in advance of a natural disturbance or silvicultural treatment such as a harvest, prescribed fire, or other stand disturbance provides a huge advantage for managers in minimizing the impacts of invasive woody species, as disturbances often create opportunities for rapid invasive expansion should seed sources be available.

Literature Cited

BEATLEY, J.C., AND F. BARTLEY. 1959. The primeval forests of a periglacial area in the Allegheny Plateau. *Bull. Ohio Biol. Surv.* 1:25–166.

BORY, G., AND D. CLAIR-MACZULAJTYS. 1980. Production, dissemination and polymorphism of seeds in *Ailanthus altissima* (Mill.) Swingle, Simarubaceae. *Rev. Gen. Bot.* 88:297–311 [in French].

GÓMEZ-APARICIO, L., AND C.D. CANHAM. 2008. Neighborhood analyses of the allelopathic effects of the invasive tree *Ailanthus altissima* in temperate forests. *J. Ecol.* 96:447–458.

HEISEY, R.M. 1996. Identification of an allelopathic compound from *Ailanthus altissima* (Simaroubaceae) and characterization of its herbicidal activity. *Am. J. Bot.* 83:192–200.

HU, S.Y. 1979. *Ailanthus. Arnoldia* 39:29–50.

HUTCHINSON, T.F., AND J.L. VANKAT. 1998. Landscape structure and spread of the exotic shrub *Lonicera maackii* (Amur honeysuckle) in southwestern Ohio forests. *Am. Midl. Naturalist* 139:383–390.

JOHNSON, E.W., AND D. WITTWER. 2006. Aerial detection surveys in the United States. P. 809–811 in *Proc. of monitoring science and technology symposium: Unifying knowledge for sustainability in the Western Hemisphere*, Aguirre-Bravo, C., P.J. Pellicane, D.P. Burns, and S. Draggan (eds.). USDA For. Serv., Gen. Tech. Rep. RMRS-P-42CD, Rocky Mountain Research Station, Fort Collins, CO.

JOSHI, C., J. DE LEEUW, AND I.C. VAN DUREN. 2004. Remote sensing and GIS applications for mapping and spatial modelling of invasive species. P. 669–677 in *Proc. of ISPRS*, vol. 35, B7 (7), Istanbul, Turkey, International Society for Photogrammetry and Remote Sensing, Basel, Switzerland.

KASSON, M.T., M.D. DAVIS, AND D.D. DAVIS. 2013. The invasive *Ailanthus altissima* in Pennsylvania: A case study elucidating species introduction, migration, invasion, and growth patterns in the Northeastern United States. *Northeast. Monogr.* 20:1–60.

KLEIN, W.H., S. TUNNOCK, J.G.D. WARD, AND J.A.E. KNOPF. 1983. *Aerial sketchmapping.* USDA For. Serv., Forest Pest Management, Methods Application Group, Fort Collins, CO. 15 p.

KNAPP, L.B., AND C.D. CANHAM. 2000. Invasion of an old growth forest in New York by *Ailanthus altissima*: Sapling growth and recruitment in canopy gaps. *J. Torrey Bot. Soc.* 127:307–315.

KOWARIK, I. 1995. Clonal growth in *Ailanthus altissima* on a natural site in West Virginia. *J. Veg Sci.* 6:853–856.

LANDENBERGER, R.E., N.L. KOTA, AND J.B. MCGRAW. 2007. Seed dispersal of the non-native tree *Ailanthus altissima* into contrasting environments. *Plant Ecol.* 192:55–70.

MCAVOY, T.J., A.L. SNYDER, N. JOHNSON, S.M. SALOM, AND L.T. KOK. 2012. Road survey of the invasive tree-of-heaven (*Ailanthus altissima*) in Virginia. *Invas. Plant Sci. Manage.* 5:506–512.

MCCONNELL, T.J., E.W. JOHNSON, AND B. BURNS. 2000. *A guide to conducting aerial sketchmapping surveys.* USDA For. Serv., FHTET 00–01, Forest Health Technology Enterprise Team, Fort Collins, CO. 96 p.

PARKER, J.D., L.J. RICHIE, E.M. LIND, AND K.O. MALONEY. 2010. Land use history alters the relationship between native and exotic plants: The rich don't always get richer. *Biol. Invas.* 12:1557–1571.

Pernas, T., and L. Rodgers. 2010. *Digital aerial sketch mapping as a region-wide assessment tool*. Presented at the Greater Everglades ecosystem restoration meeting: *The Greater Everglades: A living laboratory of change*. Available online at conference.ifas.ufl.edu/GEER2010/Presentations/Wednesday/Royal%20Palm%203/am/1040%20T%20Pernas.pdf; last accessed Dec. 6, 2014.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecol. Econ.* 52:273–288.

Rebbeck, J., T. Hutchinson, L. Iverson, M. Peters, D. Yaussy, M. Bowden, G. Guess, and A. Kloss. 2014. Ailanthus and prescribed fire: Is it a volatile combination? P. 48–52 in *Proc. of the Conference on wildland fire in the Appalachians: Discussions among managers and scientists,* Waldrop, T.A. (ed.). USDA For. Serv., Gen. Tech. Rep. SRS-GTR-199, Southern Research Station, Asheville, NC.

Schrader-Patton, C. 2003. *Digital aerial sketchmapping.* USDA For. Serv., RSAC-1202-RPT2, Forest Health Technology Enterprise Team and Remote Sensing Application Center, Fort Collins, CO. 17 p.

US Department of Agriculture (USDA) Forest Service. 2015a. *Technology development to support insect and disease aerial detection surveys (D-ASM)*. USDA For. Serv., Forest Health Technology Enterprise Team, Fort Collins, CO. Available online at www.fs.fed.us/foresthealth/technology/dasm.shtml; last accessed Mar. 30, 2015.

US Department of Agriculture (USDA) Forest Service. 2015b. ADS standards and guidelines. Available online at www.fs.fed.us/foresthealth/technology/ads_standards.shtml; last accessed Dec. 6, 2014.

US Department of Agriculture (USDA) Natural Resources Conservation Service. 2014. *The PLANTS database*, National Plant Data Team. Available online at plants.usda.gov; last accessed Mar. 30, 2015.