Urban Naturalist

No. 20 2019

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Cover Photograph: A nadir unmanned aircraft systems (UAS) image of *Phoradendron leucarpum* (American Mistletoe) in a hardwood tree. Photograph © Reid A. Viegut.

URBAN NATURALIST

The ***Urban Naturalist*** (ISSN # 2328-8965) is published by the Eagle Hill Institute, PO Box 9, 59 Eagle Hill Road, Steuben, ME 04680-0009. Phone 207-546-2821, FAX 207-546-3042. E-mail: office@eaglehill.us. Webpage: www.eaglehill.us/urna. Periodical postage paid in Steuben, ME and additional mailing offices. **Special issue proposals are welcome**. On-line secure subscription ordering: rate per year - $20 regular, $15 students, $80 organizations. **Authors**: submission guidelines are available at www.eaglehill.us/una. **Co-published journals:** The *Northeastern Naturalist* (ISSN 1092-6194 [print], ISSN 1938-5307 [online]), the *Southeastern Naturalist* (ISSN 1528-7092 [print], ISSN 1938-5412 [online]), and the *Caribbean Naturalist* (ISSN 2326-7119), journals with separate Boards of Editors. The Eagle Hill Institute is a tax exempt 501(c)(3) nonprofit corporation of the State of Maine (Federal ID # 010379899).

Using Unmanned Aircraft Systems (UAS) to Quantify Mistletoe in Urban Environments

David L. Kulhavy[1], Christopher M. Schalk[1,*], Reid A. Viegut[1], Daniel R. Unger[1], Schaeffer W. Shockley[1], and I-Kuai Hung[1]

Abstract - *Phoradendron leucarpum* (American Mistletoe) is a hemiparasitic plant that infects deciduous trees across the United States. We examined the feasibility of using an unmanned aircraft system (UAS) to detect and quantify American Mistletoe in an urban environment compared to ground-count surveys. On average, regardless of tree height, we detected more American Mistletoe plants using the UAS compared to the ground-count surveys; our estimates of American Mistletoe load nearly doubled when we used the UAS. In the ground-count surveys, our ability to accurately count the number of American Mistletoe plants decreased with increasing tree height. These results demonstrate that UAS can help researchers and managers to accurately predict the parasite load of trees to produce a more accurate hazard rating as well as help quantify the resource availability for wildlife in urban environments.

Introduction

Mistletoes (order Santalales) are hemiparasitic plants that infect deciduous trees and rely on the sap from the xylem of their host trees for water and essential elements (Gairola et al. 2013, Sangüesa-Barreda et al. 2012). A mistletoe plant produces photosynthetic products and can alter the carbon balance in the host tree, leading to drought stress and water deficits (Gairola et al. 2013, Sangüesa-Barreda et al. 2012). Tree infection results from a 6-step process that includes seed deposition, germination with growth of a radicle attached to a twig, plant attachment, initial infection with the haustoria (Year 1), shoot and sinkers for plant establishment (Year 2), and plant growth (Year 3) (Coder 2016). Fruit matures in the winter and is consumed by birds that carry the seeds to other trees via defecation (Coder 2016, Whittaker 1984). Infections are greatest in open forest stands with tall, open-crowned trees, and infections are usually concentrated at the top outer branches of the host trees (Coder 2016). On a tree, mistletoes are generally distributed in clumps in the upper and outer parts of the crown due to initial dispersal patterns by birds (Overton 1996, Sangüesa-Barreda et al. 2012, Sayad et al. 2017). Mistletoe plants may be aggregated in individual trees; infestations increase in trees with established mistletoe plants that disperse seeds within the same canopy (Ward and Paton 2007). If abundant enough, mistletoe infection can affect branch integrity due to girdling or breakage, and even cause mortality of the host tree (Mathiasen et al. 2008).

[1]Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962, USA. [*]Corresponding author - schalkc@sfasu.edu.

Manuscript Editor: Leonie K. Fischer

Traditionally, surveys of mistletoes have been conducted using ground counts to quantify the number of plants (Coder 2016, Hawksworth 1977, Smith 1969). The use of small unmanned aircraft systems (UAS) is increasing in natural-resource management. Components on a UAS include a GPS receiver for global navigation of the aircraft position and airspeed, inertial navigation to measure aircraft altitude, an internal barometer to measure altitude above the takeoff location for each flight, controls for both the camera and the UAS, and a flight-data recorder for UAS position and altitude values for each image (Hugenholtz et al. 2012, Whitehead and Hugenholtz 2014, Whitehead et al. 2014). These components allow UAS to measure a number of natural-resource parameters. For example, Kulhavy et al. (2016) compared data collected by a UAS with those collected by conventional ground surveys of urban forest-tree condition rating using the Council of Tree and Landscape Appraisers (CTLA) method with no difference in measurements of 6 variables—trunk condition, growth, crown structure, insects and diseases, crown development, and life expectancy. Dwyer and Tincher (2018) used a UAS to view nest contents of *Pandion haliaetus* (L.) (Osprey), which would normally be impossible to assess from below.

Phoradendron leucarpum (Rafinesque) Reveal and M.C. Johnston (American Mistletoe, hereafter, Mistletoe) is a native mistletoe that infects deciduous trees across the US, including those in urban environments. It is important to quantify mistletoe accurately in urban areas, as an increased infection load on a tree can cause limb breakage, drought stress, and mortality of part of the crown of the host tree. For example, Coder (2016) proposed a hazard-rating system for Mistletoe in the southeastern US based on the number of plants in the tree, but application of that hazard rating is dependent on being able to accurately know the number of plants present on a host tree. By using a small UAS, we wanted to quantify the number of plants seen by the UAS and compare this number to ground-based counts. We sought to examine the feasibility of employing a UAS to detect and count Mistletoes in an urban environment because the aircraft can be maneuvered for both nadir (straight down) and oblique (not straight down) imagery that can be recorded for analysis in a laboratory setting. We predicted that the UAS would provide a more accurate estimate of the number of Mistletoe in a tree because it would be able to document plants present on the crown of the host tree that would otherwise be obscured when using ground-count surveys.

Field Site Description

We conducted the study in the city of Nacogdoches, Nacogdoches County, TX, USA. Nacogdoches (31°36'12.6504"N, 94°39'19.7532"W) has a population of 33,900 (as of 2017) in an area of 69.9 km^2 (Kendig Keast Collaborative 2017). The area is characterized by a subtropical humid climate with hot summers and mild winters. Average annual precipitation is 1213 mm, and average annual temperature is 18.8 °C (Chang et al. 1996). The trees (n = 100) used in the study are located

Figure 1 (following page). Location of 100 host hardwood trees of *Phoradendron leucarpum* (American Mistletoe) in the city of Nacogdoches, TX, USA.

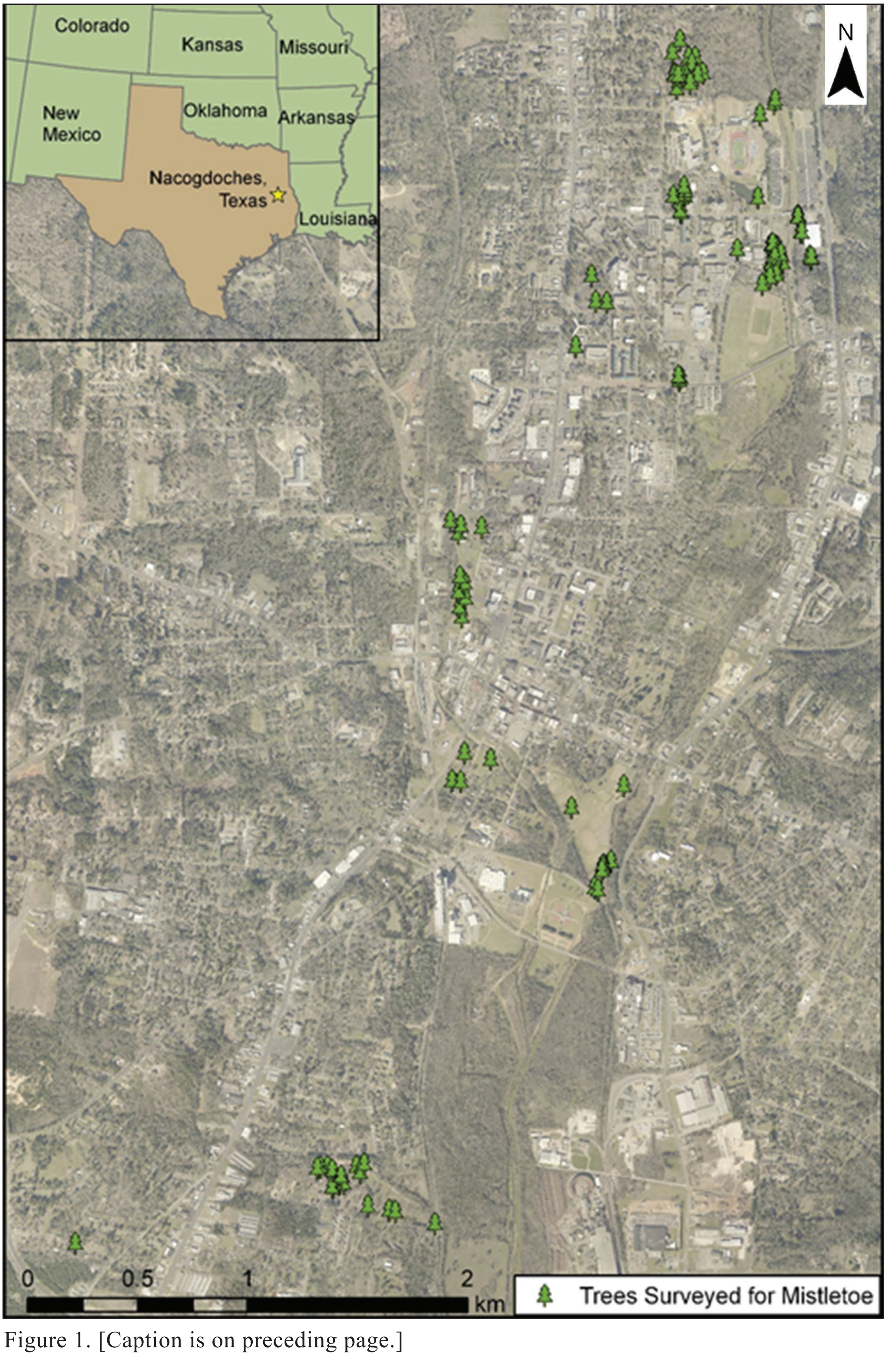

Figure 1. [Caption is on preceding page.]

in urban green spaces including the campus of Stephen F. Austin State University, Banita Creek Park, Festival Park, Pecan Park, Pioneer Park, and in downtown Nacogdoches (Fig. 1). In Nacogdoches, there are 22 parks totaling 158.4 ha. For this study, we surveyed hardwoods in community parks that were evenly distributed across the city (Kendig Keast Collaborative 2017).

Methods

We surveyed 100 hardwood trees from 6 January 2018 to 14 March 2018, allowing for maximum visibility of Mistletoe plants during leaf-off of the host trees. For each tree, we recorded species, trunk diameter (cm) at 1.4 m in height, and total height. Ground surveys consisted of 1 observer slowly walking around each host tree and counting the number of Mistletoe plants observed. Following the ground count, we flew a UAS DJI Phantom 4 Pro (Dà-Jiāng Innovations Science and Technology Co., Ltd., Shenzen, China) around each tree using the 20-MP camera to record both nadir and oblique imagery in both video and still images (Fig. 2). We took the imagery from the Phantom 4 to the GIS Laboratory in the Arthur Temple College of Forestry and Agriculture for analysis and to count Mistletoe plants. We also determined the average time and costs associated with each survey method.

To avoid missing or double-counting plants, we counted the crown and oblique images of the tree from the north in a clockwise direction. We also uploaded representative aerial images that are freely available from an iNaturalist.org project entitled "Mistletoes of Nacogdoches" (https://www.inaturalist.org/projects/mistletoes-of-nacogdoches). These records provided locality data for each tree, as well as a visual record of both the Mistletoe and the host tree. We used linear regression to assess the relationship between ground-based and UAS-based surveys, on both Mistletoe count and infestation rate. In order to determine if detectability of Mistletoe plants was affected by tree height, we separated the observations into 2 groups based on the total height of each host tree. The break value was the average height (16.7 m) of the 100 host trees surveyed, resulting in the "tall trees" group of 51 and the "short trees" group of 49. We then conducted the same regression analysis on each of the 2 groups.

Results

We surveyed a total of 100 hardwood trees for Mistletoe (Table 1). They ranged in diameter from 25 cm to 122 cm and in height from 10.6 m to 33.5 m. Ground counts of Mistletoe plants per tree ranged from 1 to 81 plants; counts from the UAS ranged from 1 to 158 plants. The UAS method required a larger initial investment compared to the ground-count method (Table 2). However, both methods were comparable regarding the time spent to assess the Mistletoe load in each tree (Table 2). On average, regardless of tree height, when we used the UAS, we detected more Mistletoe plants than we identified during ground counts.

We detected an average ± SD of 10.2 ± 14.6 plants per tree in the ground surveys and 17.1 ± 27.6 plants per tree from the UAS surveys (nearly a 60% increase in the number of Mistletoe plants detected). For all trees (n = 100), the number of

Mistletoe plants observed in UAS surveys per tree can be predicted from ground counts using equation 1 (R^2 = 0.7379; P < 0.001; Fig. 3A).

UAS count = 1.623(ground count) + 0.5333 Equation 1

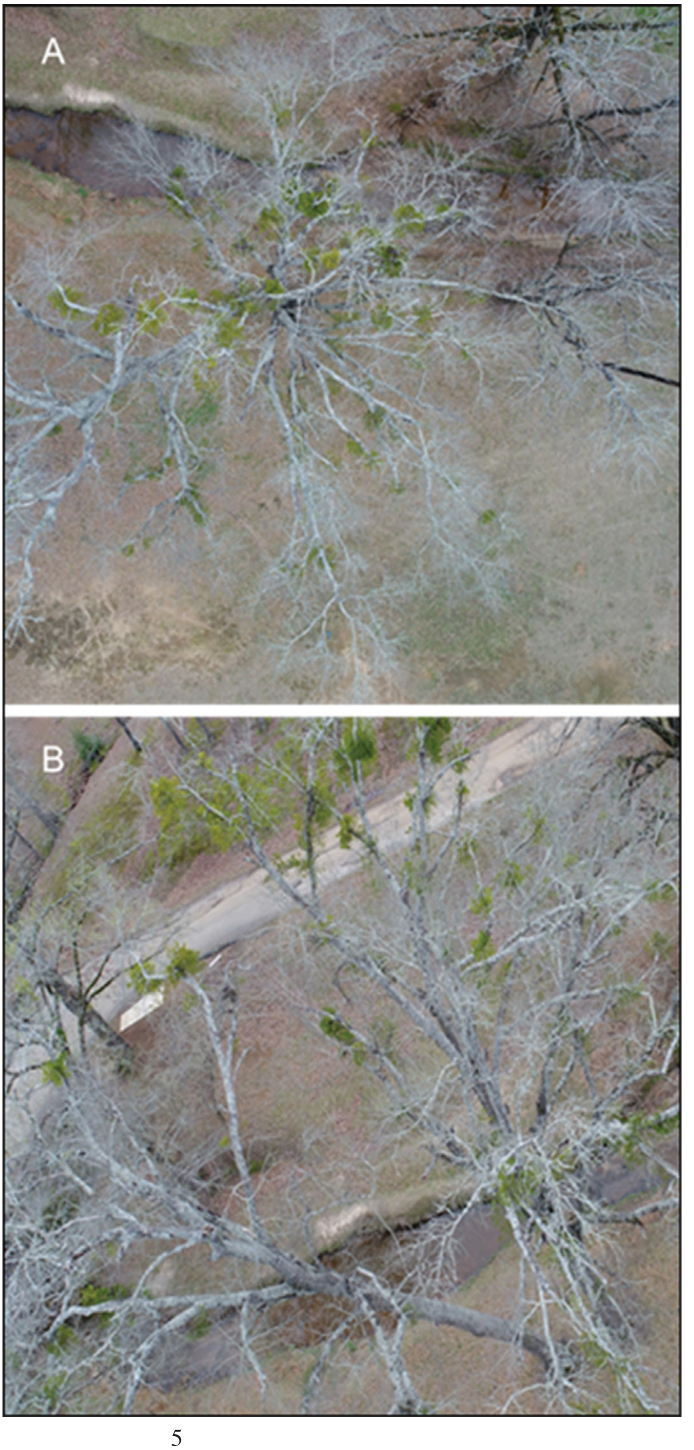

Figure 2. An example of (A) a nadir, and (B) oblique UAS image of *Phoradendron leucarpum* (American Mistletoe) in a hardwood tree.

For tall trees, we observed an average of 12.6 ± 15.6 Mistletoe plants in the ground surveys and 22.0 ± 30.0 plants from the UAS (nearly a 57% increase in the number of Mistletoe plants detected). For tall trees (n = 51), the number of Mistletoe plants observed in UAS surveys per tree can be predicted from ground counts using equation 2 (R^2 = 0.6484; P < 0.001; Fig. 3B).

UAS count = 1.5217(ground count) + 2.7551 Equation 2

For short trees (n = 49), we observed 7.7 ± 12.9 Mistletoe plants per tree in the ground surveys and 12.0 ± 24.2 plants from the UAS (~64% increase in the number of Mistletoe plants detected). For short trees, the number of Mistletoe plants per tree observed in UAS surveys can be predicted from ground counts using equation 3 (R^2 = 0.8694; P < 0.001; Fig. 3C).

UAS count = 1.7522(ground count) – 1.4402 Equation 3

Discussion

We found that UAS provided a more accurate count of the parasite load of Mistletoe on their hardwood hosts in eastern Texas compared to ground surveys. In general, ground surveys underestimated the number of Mistletoe plants found in the crowns of these trees; our estimates of Mistletoe load nearly doubled when we used the UAS. Though our best-fit lines were likely influenced somewhat by influential outliers of trees with large mistletoe counts, we nevertheless suggest when only ground surveys can be conducted (e.g., when a UAS is unavailable or airspace

Table 1. List of 100 trees surveyed for *Phoradendron leucarpum* (American Mistletoe).

Scientific name	Common name	Count
Quercus nigra (L.)	Water Oak	56
Quercus falcata Michaux	Southern Red Oak	15
Celtis laevigata Willdenow	Sugarberry	8
Fraxinus pennsylvanica Marshall	Green Ash	7
Betula nigra (L.)	River Birch	5
Ulmus americana (L.)	American Elm	3
Carya illinoinensis (Wangenh.) K. Koch	Pecan	3
Ulmus alata Michaux	Winged Elm	2
Carya tomentosa Sargent	Mockernut Hickory	1
Total		100

Table 2. Average time and cost per assessment method assuming a $20.00-per–hour pay scale for hourly wages. N/A = not applicable.

	Method completion time (min)		Method cost ($)	
Item	UAS	Ground survey	UAS	Ground survey
Initial equipment purchase	N/A	N/A	1500.00	100.00
Field assessment per tree	3	8	1.00	2.66
Lab assessment per tree	5	N/A	1.66	N/A
Totals per tree assessed	8	8	2.66	2.66

restrictions prevent the use of a UAS), our models can help provide a more accurate estimate of the number of Mistletoe plants present. In particular, this method may be particularly useful for taller trees where accurate ground-based assessments of Mistletoe load are more difficult to obtain compared to those on shorter trees. While the UAS method was more accurate compared to ground surveys, the UAS was more expensive overall due to the initial cost of a UAS purchase, but the time spent to assess Mistletoe load was equivalent between both methods.

In the US, UAS are flown under 2 Federal Aviation Administration (FAA) regulations: FAA 336, the Special Rule for Model Aircraft that can be used for training

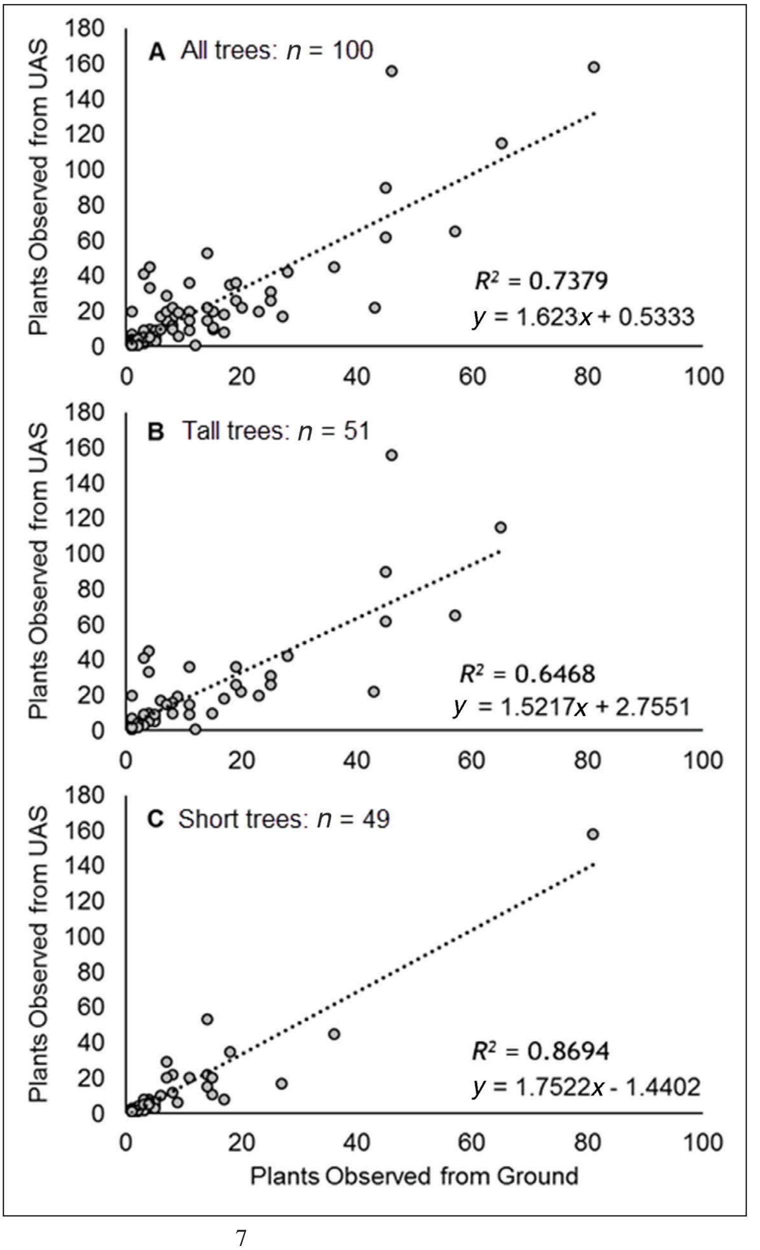

Figure 3. Comparison of *Phoradendron leucarpum* (American Mistletoe) counts observed from the ground to those observed from a UAS for: (A) all trees surveyed, (B) trees that were greater than 16.7 m in height, and (C) trees that were ≥16.7 m in height.

pilots; and FAA 107 is the UAS license after completion of an exam at a certified FAA center. UAS flight rules include maintaining the UAS in the pilot's line of sight, flying only during daylight hours, flying less than 122 m above the ground, using a UAS that weighs less than 25 kg, and not flying over people without their knowledge (FAA 2016a, 2016b, 2018). For this UAS method to be utilized, it is important that personnel adhere to both FAA and local regulations. For example, for this project, pilots flew under FAA 107 and obtained permission from the entities that controlled the area.

Mistletoes are an important resource for wildlife because they provide food in the form of nectar and fruit, as well as habitat for nest sites for insects and birds (Watson 2001, Whittaker 1984). Mistletoe is dispersed primarily by birds; thus, more-accurate counts of plants may provide evidence of increased resource use of Mistletoe by birds in urban environments that previously estimated (Whittaker 1984). When these plants are established, accurate counts may provide insights as to their use by host-restricted insect herbivores (Whittaker 1984). Trees already infected are more likely to be continually infected from seeds in the crown (Coder 2016). Taller trees have more Mistletoe plants (Carlo and Aukema 2005, Coder 2016), which underscores the value of these taller trees for birds as a reliable resource for both food and nesting sites. For our study, the taller-tree model (Fig. 3B) highlighted the value of using UAS for counting Mistletoes.

With our method, the applicability of using a UAS to survey for Mistletoe in other environments depends on the ability of the UAS to capture images of the tree from different aspects, which was feasible at our study site as the trees often occurred in urban greenspaces, were spaced far apart, and were assessed during winter when tree leaves did not obscure Mistletoe plants. The utility of this survey method is most applicable in similar situations. The utility of using a UAS to capture oblique images of tree crowns in large urban forests may be more challenging, depending on factors such as tree density, spacing, and timing. However, if oblique images cannot be obtained, there is still utility in being able to capture nadir images of tree crowns in these forests (Fig. 2A), as the tops of trees are otherwise difficult to examine and incorporate into rating systems (Smith 1969).

Tree symptoms appear with increasing Mistletoe infections including branch dieback, branch girdling, breakage, and even death of the host tree (Mathiasen et al. 2008). If the parasite load is high enough, Mistletoe infection sites are a platform for fungal and insect infection that can further degrade the branches (Mathiasen et al. 2008). Further, trees under drought stress are more prone to branch breakage with Mistletoe infections (Coder 2016). Coder's (2016) rating system, based on the number of Mistletoe plants in a host tree, could be used to make management decisions and prioritize treatment efforts. Underestimates of counts and parasite load may delay treatment for Mistletoe, including potential tree removal, highlighting the importance for UAS to aid in the evaluation of Mistletoe load on trees in urban environments.

Acknowledgments

We thank USDA NIFA McIntire-Stennis and Stephen F. Austin State University for funding. We also thank E. Lozano for creating Figure 1, C.P. Randle for informative discussions on mistletoe taxonomy and systematics, and L. Fischer and 2 anonymous reviewers for their constructive comments on the manuscript.

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