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RARITAN VALLEY COMMUNITY COLLEGE
CENTER FOR ENVIRONMENTAL STUDIES

Analysis of Invasive Species Cover and Canopy Gaps on Readington Township Open Space Properties Using Multispectral Drones

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Summary

We surveyed a total of 1,004 acres of Readington Township Open Space, including 33 parcels in ten locations, in July 2023 using high-resolution multispectral drone imagery. Maximum likelihood classification was used to isolate targeted invasive species from the imagery, including mugwort (*Artemisia vulgaris*), autumn olive (*Elaeagnus umbellata*), Chinese bush clover (*Lespedeza cuneata*), and Japanese honeysuckle (*Lonicera japonica*). Dead trees (snags) were also isolated, which primarily consisted of dead ash (*Fraxinus* spp.) trees affected by the invasive emerald ash borer (*Agrilus planipennis*) and/or other pathogens. Attempts to identify the distribution of other target species, including callery pear (*Pyrus calleryana*), beech (*Fagus grandifolia*) and living ash trees, were unsuccessful as the training samples collected for this and other species proved insufficient to distinguish them from other areas in the maps at this time. Other species had some degree of over sampling, resulting from excessively broad training samples of canopy and meadow vegetation collected for classification. Follow-up surveys delineating dominate vegetation covers would likely allow for more accurate and comprehensive results in species classification.

Introduction

Since the 1960s, Readington Township has participated in the New Jersey Green Acres Program, obtaining over 162 parcels of land totaling over 4,500 acres, or 14.9% of the municipality. Over the years, these properties have been evolving to support recreational needs (parks, hiking, and horse trails) and natural resources that provide valuable ecological services, including habitat for pollinators, endangered species, and other wildlife, improvements to water quality, and carbon sequestration.

Meadow habitats play a particularly important role in contributing to the overall species diversity on Readington open space. A 2020 survey of municipality-owned open space meadows, for example, found six state-listed rare plant species, four threatened breeding grassland bird species, and one vulnerable butterfly species across in Readington Township meadows (Ray et al. 2020). However, non-native invasive plant species contributed to 25 - 63% of the species composition in Township-owned meadows, and approximately 40% of the 74 meadows studied had poor ecological integrity as determined by a floristic quality index. Exotic invasive species are among the top five threats causing direct changes to both global and local biodiversity (Scheiner 2020), resulting in increased competition or mortality of native plant species, altered nutrient cycling (Swearingen et al. 2010), and degradation of conditions needed for invertebrates and other wildlife (Tallamy 2007, Burghardt and Tallamy 2009, Clark and Seewagen 2019). Eliminating or controlling invasive species populations should therefore be a priority when managing meadow habitats (Packard and Mutel 1997). However, because the baseline inventories conducted in 2020 did not include measurements of species abundance or distribution, the relative significance of invasive species as a priority for open space stewardship within each site remains unknown.

Protected forestlands provide another key component for harboring biodiversity within Readington Township. Studies of the forests in town documented major increases in invasive plant species since the mid-Twentieth Century, along with significant declines (>70%) in tree regeneration and native plant communities in forest understories due to increased pressure from deer herbivory (Kelly 2019, Ray and Kelly 2023). The lack of regeneration presents a major concern for the continued integrity of forest health in the future, especially given the increased rates of tree mortality from invasive pests and diseases such as emerald ash borer (*Agrilus planipennis*), beech bark and beech leaf diseases. Ash trees, like many other native plants, support a wealth of biodiversity and host just under 150 insect species in the mid-Atlantic region (Tallamy and Shropshire 2009) and the loss of these other species to introduced pests and diseases therefore bears important significance for native invertebrates, fungi and other wildlife that depend on them. The increased prevalence of light gaps in the forest canopy that result are also likely to lead to increased invasive species populations, which are less palatable to deer than their native counterparts and tend to favor increased light. In addition to implementing more aggressive deer management, these severe tree recruitment deficits may also be partially addressed by installing protective exclosures around young native tree growth, especially in areas with present or imminent light gaps from tree mortality, in order to facilitate forest regeneration and recovery.

In order to address these pressive local needs for stewardship of preserved public lands, we experimented with the use of multispectral drones to collect custom, high resolution aerial imagery of Township-owned open space properties. GPS data was then collected to locate areas with forest canopy gaps as well as the presence of different native and invasive plant species in forests and meadows. The goal of these efforts was to determine whether these canopy gaps and target species were detectable using their respective spectral signatures in the images collected in order to map and quantify their precise locations and abundance in each area. We hope that these preliminary efforts would help identify and prioritize the actions needed to advance the ecological stewardship of Readington Township open space and to aid in monitoring the success of future actions taken to address these important concerns impacting the biodiversity and ecological integrity of public lands.

Methods

High-resolution sUAS (small unmanned aerial vehicle) drone images were collected in ten areas of Readington Township (**Figure 1, Table 2**), including 1,073 acres on 33 parcels, or 24% of township-owned open space properties. All flights were conducted with an FAA-certified drone pilot and were flown at or below 400 ft elevation. Drone flights were completed between July 11th and July 26th in 2024 with a WingtraOne Drone with a MicaSense RedEdge-P camera. Flights were restricted to two hours before and after solar noon to reduce shadows created in the imagery. The MicaSense RedEdge-P camera collects information for five spectral bands: Blue (475 ± 32 nm), Green (560 ± 27 nm), Red (668 ± 14 nm), Red Edge (RE) (717 ± 12 nm), Near Infrared (NIR) (842 ± 57 nm). Flight areas covered the following Readington open space properties: Lazy Brook, Pleasant Run, Vislocky, Round Mountain, Indian Purchase, Holland Brook Headwaters, and Cole Road Properties (**Figure 1, Table 2**).

All images went through a post-processed kinematic location correction in WingtraHub, using the nearest base station located at 40°30'05.8"N, 74°54'04.0"W. This process negated the use of on the ground control points for mapping. All images were then imported into Pix4DMapper software. Image corrections were made using a standardized reflectance panel picture taken at the beginning of each flight and were further corrected from a downwelling light sensor fixed to the top of the drone, collecting sun intensity and angle data. **ADD IN DEFINITION OF GSD** The resulting maps had an average ground sampling distance between 5.5 to 6.9 cm. One exception includes the Whitehouse Greenway property, which had an average ground sampling distance of 17cm.

The merged reflectance raster bands (for all five bands) were imported into ArcMap 10.8.2. The composite bands tool was used to merge reflectance bands, creating a five-band composite imagery (Blue-Green-Red-RE-NIR). The bands on the MicaSense sensor are often used to assess plant health, which is determined by some conditions controlled for, including sun angle and sun intensity. However, soil conditions (i.e. drought, saturated, or in-between) were not constant during the surveys due to changes in topography and time since last rainfall. Since soil conditions could not be controlled for, day and location images were analyzed separately to account for these conditions as much as possible. All imagery is displayed using false color imagery (RE-Green-Blue), rather than true color imagery (Red-Geen-Blue), to better display changes in vegetation.

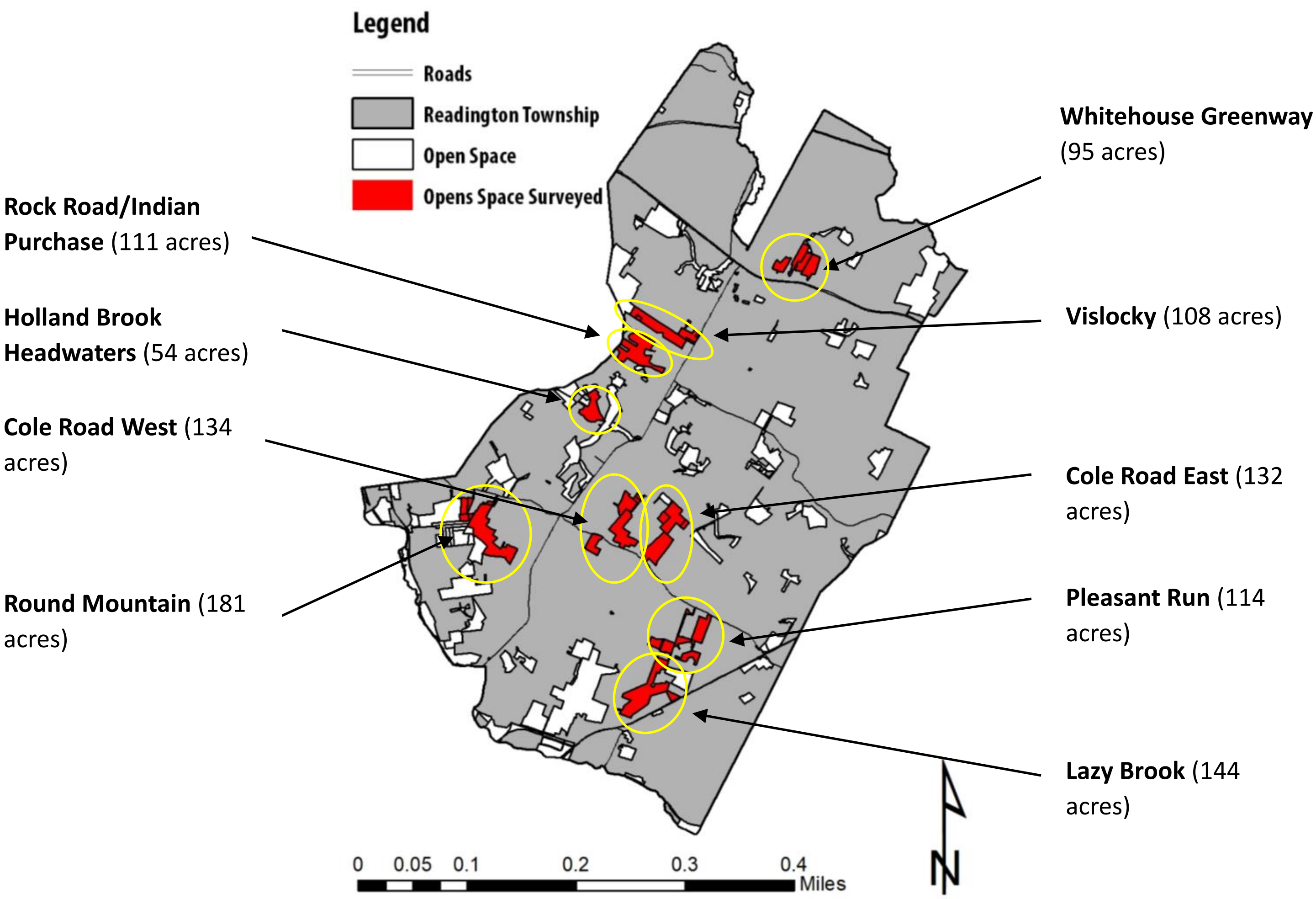

Figure 1. Township-owned open space properties surveyed using high resolution multispectral drone imagery in Readington Township. Locations with multiple parcels were circled in yellow and are identified by name and the total acreage surveyed.

Training samples were drawn around a minimum of three locations for one or more of the following invasive species for each map: mugwort (*Artemisia vulgaris*)*,* autumn olive (*Elaeagnus umbellata*)*,* Chinese bush clover (*Lespedeza cuneata*)*,* Japanese honeysuckle (*Lonicera japonica*), and callery pear (*Pyrus calleryana*)(**Table 1, Figure 2**)*.* Training samples were also drawn around dead trees (snags) that were often identified on the ground as dead ash (*Fraxinus spp.*). In addition to these species, training samples were also drawn around impervious surface cover, general meadow habitats, mowed grass, and general forested habitats. Additional species targeted were milkweed (*Asclepias* spp.), beech (*Fagus grandifolia*), and ash (*Fraxinus* spp.), but technical difficulties and low species frequency at sites visited resulted in insufficient GPS data collected for analysis.

While large datasets of image classification today are often refined using deep learning neural networks to perform with a high degree of accuracy (Shingh and Tyagi 2021), these methods are not practical for our use due to a lack of data points and processing capacity. Image classification was generated using the maximum likelihood classification (MLC) tool in

ArcMap. MLC is a widely used supervised classification method, based on estimated probabilities of the estimated means and variances for each class (Perumal and Bhaskaran 2010). This method often performs well with accurate training data. Statistical ground truthing analysis was not conducted for any species mapped due to time, logistical and funding constraints. Ground surveys were conducted to determine the general validity of the results and will be discussed in the results section. All raster files were converted to shape files and were shared with the township.

Table 1. Prevalence of target invasive plant species in Readington Township meadows. Species were chosen based on their growth form, and the number of meadows where species were identified reported in Ray et al. (2020).

Species	Growth Form	Observed Fields
Elaeagnus umbellata	Woody	73 (99%)
Lonicera japonica	Woody	73 (99%)
Pyrus calleryana	Woody	27 (36%)
Artemisia vulgaris	Herbs	50 (68%)
Lespedeza cuneata	Herbs	29 (39%)

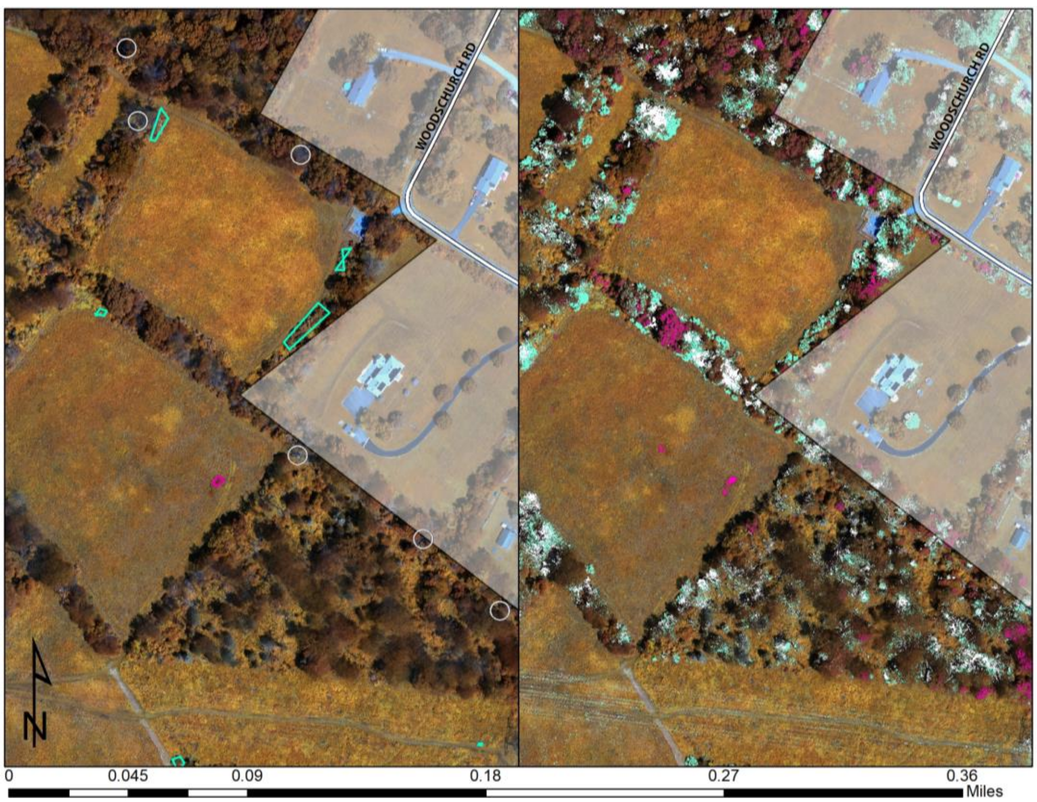

Figure 2. Example of training sample points collected at Round Mountain (left) and resulting classification (right). Autumn olive (teal polygons), dead trees (white circles), and Chinese bush clover (pink polygon) (bottom left). None of the polygons visualized in the bottom left image were used to train the data, except for the Chinese bush clover. Results are shown below, correctly identifying all areas of interest, and picking up potential early invasion of Chinese bush clover. Background drone imagery is displayed in RE-Geen-Blue.

Results

Of the 1,073 acres targeted for surveys, 1,004 acres were successfully mapped. Map processing was not successful for some forested areas of Whitehouse Greenway, Round Mountain, Cole Road West, and Cole Road East, as well as a small portion of the eastern corner at the Vislocky site (**Table 2**). Multiple species were targeted in most sites, except for Whitehouse Greenway, where only dead trees were targeted. The absence of a target species at a given site does not indicate that that species is not present, only that training samples for that species were not collected during the time of surveys. In most cases, training samples were sufficient to successfully identify the target species. However, in many locations, additional areas were inaccurately identified. This was especially true for a) dead trees mapped the presence of dead trees and shadows along hedge rows, b) shrubby and herbaceous meadow species (autumn olive, Chinese bush clover, and mugwort), which were correctly identified in meadows but incorrectly in forested locations, and c) meadow species (Chinese bush clover and mugwort), which were identified incorrectly in areas dominated by goldenrod (*Solidago* spp.). Additionally, callery pear was not correctly identified at the Lazybrook property. Refer to the discussion section for possible explanations for these misidentifications. Attempts to collect GPS data for other target species (live ash, beech, milkweed) were not successful due to logistical and technical difficulties combined with low frequency of living trees at the sites visited. The remainder of the results section presents each site in detail.

Table 2. Drone survey details for the ten areas of Readington Township open space studied. Ground sampling distance (GSD) is measured in cm/pixel. Target and achieved coverage areas are recorded in acres.

<table>
<tr><th></th><th># of flights</th><th>Avg GSD</th><th>Target Coverage</th><th>Achieved Coverage</th><th>Species Targeted</th></tr>
<tr><td>Whitehouse Greenway</td><td>1</td><td>17.9</td><td>95</td><td>73</td><td>dead trees</td></tr>
<tr><td>Vislocky</td><td>3</td><td>6.9</td><td>108</td><td>99</td><td>Chinese bush clover, autumn olive, and dead trees</td></tr>
<tr><td>Rocky Road</td><td>3</td><td>6.6</td><td rowspan="2">111</td><td rowspan="2">111</td><td>autumn olive and dead trees</td></tr>
<tr><td>Indian Purchase</td><td>1</td><td>5.8</td><td>Chinese bush clover, mugwort, and dead trees</td></tr>
<tr><td>Holland Brook Headwaters</td><td>1</td><td>6.2</td><td>54</td><td>54</td><td>Chinese bush clover, autumn olive, and dead trees</td></tr>
<tr><td>Round Mountain</td><td>3</td><td>5.7</td><td>181</td><td>156</td><td>Chinese bush clover, autumn olive, and dead trees</td></tr>
<tr><td>Cole Road West</td><td>3</td><td>5.8</td><td>134</td><td>122</td><td>Chinese bush clover, autumn olive, and dead trees</td></tr>
<tr><td>Cole Road East</td><td>3</td><td>5.9</td><td>132</td><td>131</td><td>autumn olive and dead trees</td></tr>
<tr><td>Pleasant Run North</td><td>1</td><td>5.8</td><td rowspan="2">114</td><td rowspan="2">114</td><td rowspan="2">Japanese honeysuckle, mugwort, autumn olive, and dead trees</td></tr>
<tr><td>Pleasant Run South</td><td>1</td><td>5.6</td></tr>
<tr><td>Lazy Brook</td><td>1</td><td>5.5</td><td>144</td><td>144</td><td>Japanese honeysuckle, mugwort, autumn olive, callery pear, dead trees</td></tr>
</table>

Summaries of total area covered and percent coverage for species identified in each are presented in **Table 3**. Across all sites forested areas experienced between 3 – 18 % light gaps. Cole Road West south of CR 629, Holland Brook Headwaters and Whitehouse Greenway had the greatest light gap presence where dead trees were observed at 11%, 15%, and 18%, respectively (**Table 2**). Autumn olive was most abundant in Pleasant Run South, with 20% coverage in forested areas, which also included emergent scrub-shrub or early-successional forest cover. While Chinese bush clover and mugwort were identified in forested areas, these are likely false positives. Holland Brook Headwaters had the greatest presence of Chinese bush clover, covering 15% of open areas and mugwort was most abundant at Pleasant Run South (**Table 2**).

Table 3. Total and percent area occupied by target species in each survey area in Readington Township in 2023. Area summaries for each location broken down by forested areas (top) and meadow or other open areas (bottom). All areas are shown in acres. Percent cover relative to the area surveyed is shown for each table.

Forested Areas

Sites	Area Surveyed	Japanese honeysuckle	Chinese bush clover	Mugwort	autumn olive	dead trees
Whitehouse Greenway	**74.4**					8.47 (11%)
Vislocky	**45.4**		1.76 (4%)		1.93 (4%)	1.73 (4%)
Rocky Road	**89.5**				4.35 (5%)	5.5 (6%)
Indian Purchase	**6.2**		0.27 (4%)	0.13 (2%)		0.28 (4%)
Holland Brook Headwaters	**16.5**		2.27 (14%)		1.15 (7%)	2.53 (15%)
Round Mountain Properties	**94.2**		2.53 (3%)		4.51 (5%)	2.94 (3%)
Cole Road West	**71**			0.19 (<1%)	7.13 (1%)	5.54 (8%)
Cole Road East	**69**				6.54 (9%)	2.68 (4%)
Cole Road West South of CR 629	**25**					4.53 (18%)
Pleasant Run North	**17.3**	0.13 (1%)		1.72 (10%)	1.55 (9%)	1.23 (8%)
Pleasant Run South	**66.4**	0.45 (1%)		6.75 (1%)	12.95 (20%)	1.92 (3%)
Lazy Brook	**27.6**	0.64 (2%)		0.85 (4%)	2.17 (8%)	1.32 (5%)

Open Areas

Sites	Area Surveyed	Japanese honeysuckle	Chinese bush clover	Mugwort	autumn olive	dead trees
Whitehouse Greenway	**8.7**					0.67 (8%)
Vislocky	**53.5**		7.46 (14%)		1.44 (3%)	2.14 (4%)
Rocky Road	**10**				0.17 (2%)	0.14 (1%)
Indian Purchase	**5.5**		0.54 (10%)	0.13 (2%)		0.14 (3%)
Holland Brook Headwaters	**36.7**		5.49 (15%)		1.15 (3%)	1.55 (4%)
Round Mountain Properties	**54.3**		0.44 (1%)		1.8 (3%)	0.75 (1%)
Cole Road West	**23**			0.43 (2%)	1.4 (7%)	0.53 (2%)
Cole Road East	**62**				1.2 (2%)	0.86 (1%)
Pleasant Run North	**26.8**	0.14 (1%)		1.3 (5%)	1.32 (5%)	1.37 (5%)
Pleasant Run South	**14.3**	0.48 (3%)		1.28 (9%)	0.61 (4%)	0.13 (1%)
Lazy Brook	**115.5**	2.67 (2%)		3.15 (3%)	2.26 (2%)	5.58 (5%)

Lazy Brook

The following species were mapped at the Lazy Brook preserve: mugwort, autumn olive, Japanese honeysuckle, callery pear, and dead trees (**Figure 3**). While a statistical ground truthing analysis was not conducted, ground visits were made to qualitatively assess the validity of the results. Mugwort (yellow) patches were easily picked up from the imagery and correctly identified both problem areas where dense clusters exist and emergent areas where sparse cover was present. This can be seen by the sizeable dense cluster visible on the northwest side of the trailhead with emergent patches just east of the trail and parking location (**Figure 3**); there are also numerous scattered emergent areas along the woodland edges of the meadows as seen in **Figure 3, submaps 2 and 4**. The latter locations may not fully represent the entirety of the population extent due to the canopy layer present during the survey period. Furthermore, the dense cluster (**Figure 3, submap 1**) occurs in an area that does not receive regular mowing. It is possible that the historic haying of these meadows on the map is suppressing other small invasion areas from being detected.

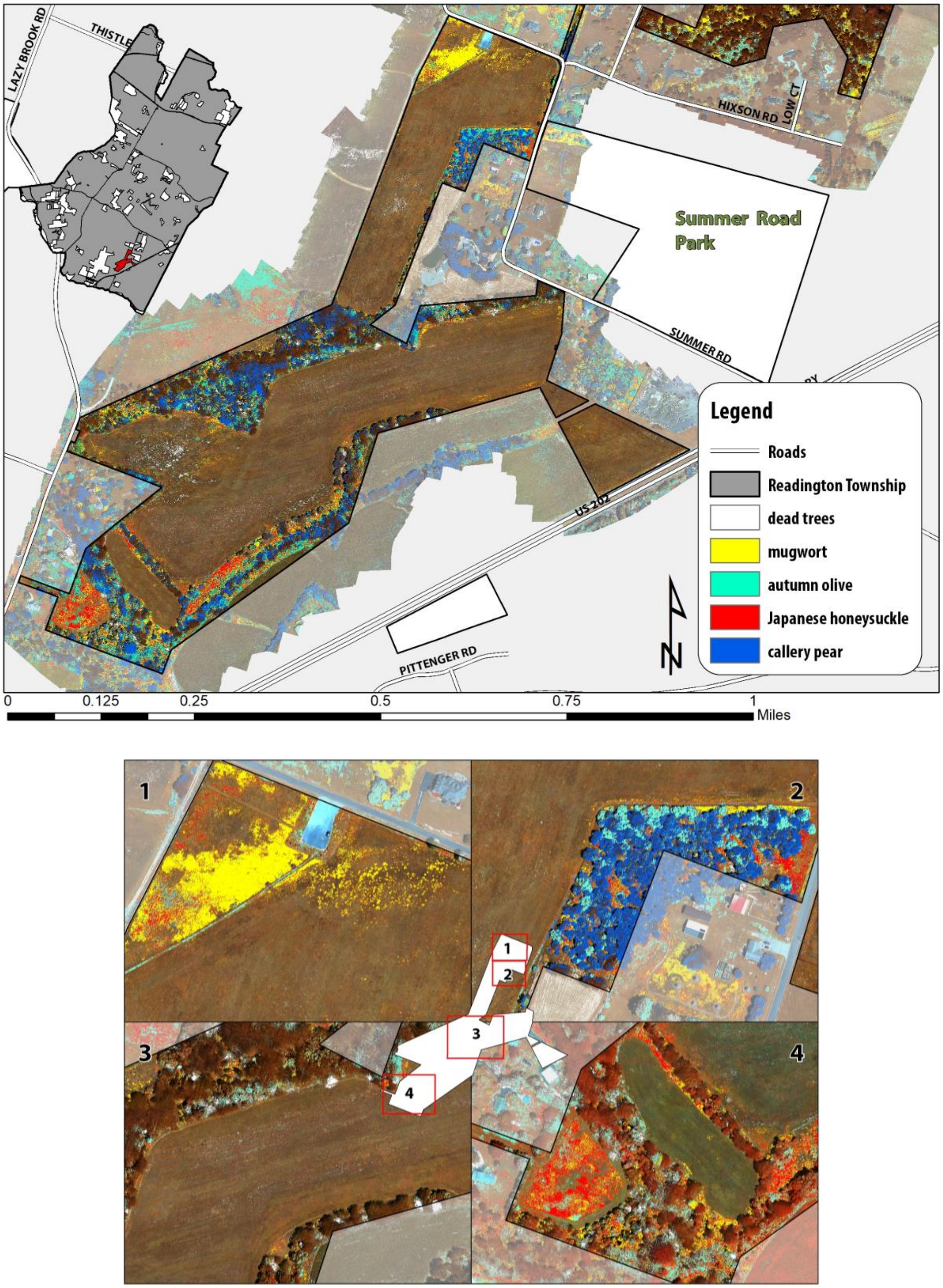

Figure 3. Image classification results for Lazy Brook (top) and select focal areas (bottom). Images identify dead trees (white), mugwort (yellow), autumn olive (teal), Japanese honeysuckle (red), and callery pear (blue). Due to the miss identification observed from callery pear, it was removed from submaps 1, 3, and 4. Background drone imagery for these and subsequent figures below consists of multispectral RE-Geen-Blue.

Similarly, autumn olive (teal) was easily identified from the imagery in most locations. These invasive bushes were easily differentiated (**Figure 3, submap 2**) in an emergent shrubby woodland dominated by autumn olive, callery pear, and honey locust (*Gleditsia triacanthos*). However, callery pear (blue) was misidentified throughout the map, including in **Figure 3 submap 2**, and should not be used for management planning purposes with this imagery. Lastly, dead trees were correctly identified, and are represented as white clumps in the tree line surrounding the meadows (**Figure 2, submap 3**). Japanese honeysuckle was correctly identified along the edges of the meadow and forested areas in **Figure 2, submap 4**; however, it is unlikely that identification in the middle of the field is correct.

Pleasant Run

The following species were mapped at Pleasant Run: mugwort, autumn olive, Japanese honeysuckle, and dead trees (**Figures 4 and 5**). Autumn olive was correctly identified, showing large, dense clusters in shrubby successional areas on the southern end of the property (**Figure 4, submaps 3 and 4**), as well as along tree line edges (**Figure 4, submaps 1 and 2**). Sparse coloration on the map was incorrectly identified, however, and only solid clumps should be considered correct identification for this species at this site.

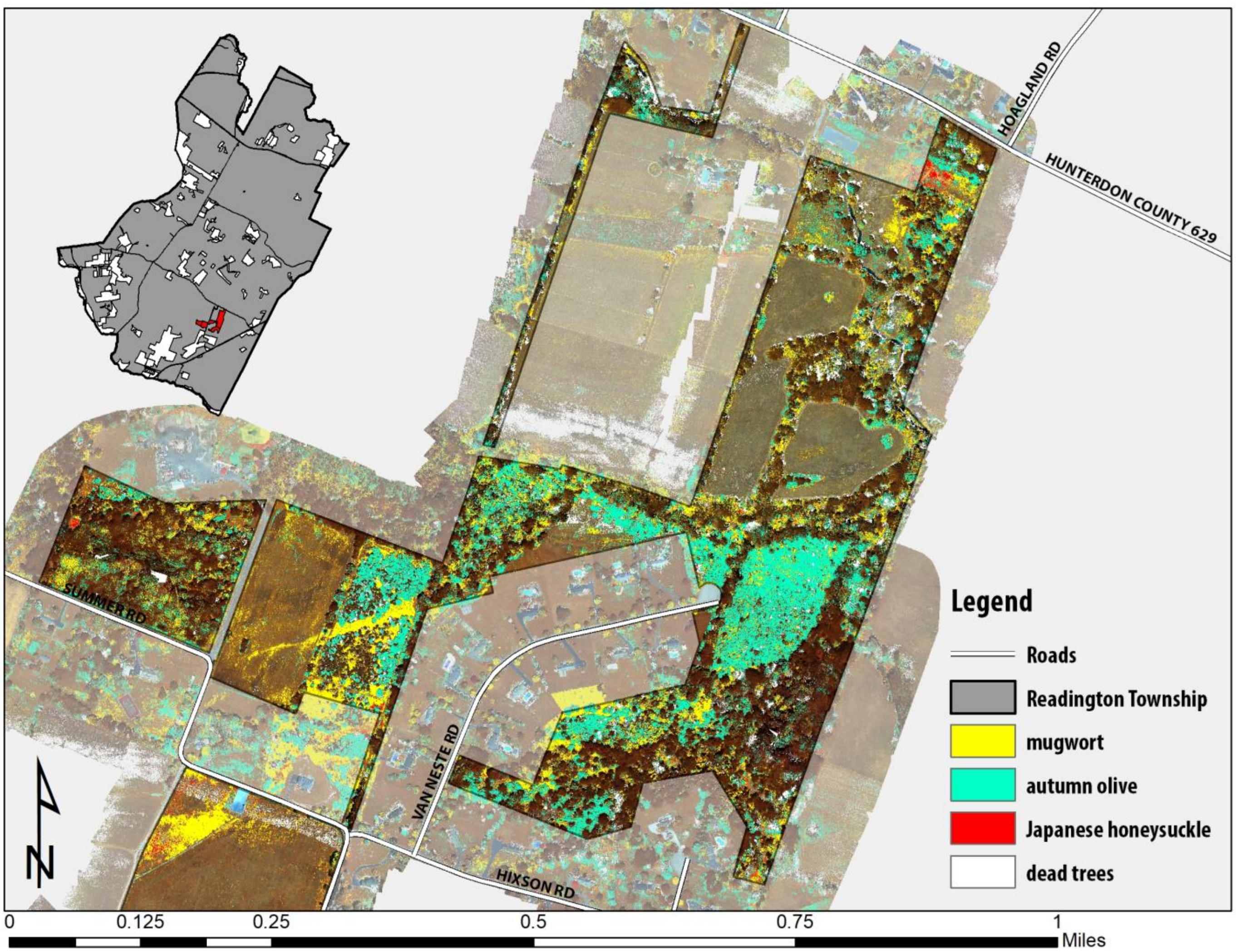

Figure 4. I**mage classification results for Pleasant Run**.

Mugwort was identified along the edges of the meadow, where less mowing occurred, and in successional areas where autumn olive also occurred. Ground visits confirmed that this species was growing in small light gaps under autumn olive, and the invasion in these areas is likely much more significant than depicted from the imagery as some plants were under the foliage of the canopy layer. Meadows not left to later successional stages had the least invasion. However, substantial invasion occurred along the edges of the fields. One location on the map incorrectly identified mugwort (**Figure 5, submap 1, circled red**), where goldenrod (*Solidago spp*.) occurred. Areas on the map where sparse mugwort coloration appeared were incorrectly identified, especially in forested areas. Only solid clumps should be considered as reliable identification for this species at this site.

The classification methods were able to correctly identify dead trees. However, some shadows of trees along the edges of forested areas were incorrectly identified as dead trees (e.g., **Figure 5, submap 2**). A site visit was not made to this location, but these may be predominantly ash trees. There is also some indication of invasion from autumn olive in this area already. This example shows further urgency that if these light gaps are left unmanaged, many will result in colonization by invasive species.

Japanese honeysuckle was identified in the northeastern corner of the property, in a small area leading to the entrance of the southern property, and in the light gap in a forested area on the southeasternmost property. There is likely a worse invasion of this species under the canopy layers on the properties mapped, but these are not displayed due to the presence of tree canopy foliage at the time surveys were conducted.

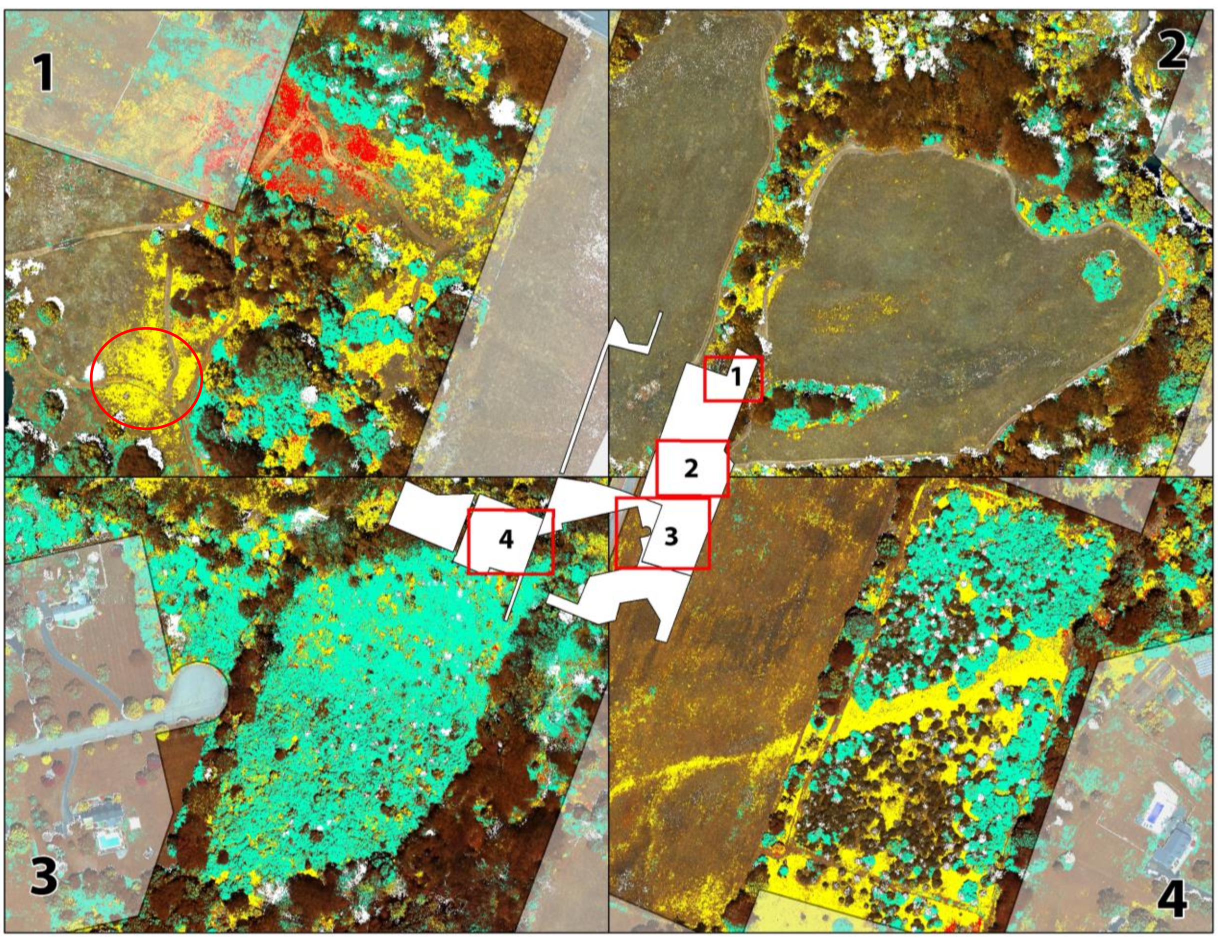

Figure 5. Image classification results from select areas of Pleasant Run. Maps are subsets from Figure 2, depicting the locations of dead trees (white), mugwort (yellow), autumn olive (blue), and Japanese honeysuckle (red).

Holland Brook Headwaters

The following species were mapped at the Holland Brook Headwaters open space property: Chinese bush clover, autumn olive, and snags (**Figure 6**). Ground surveys confirmed the prevalence of Chinese bush clover in this image, especially in fields 3 and 6 where it was dominant. There is also some substantial invasion occurring along the margins of field 4. Misidentification of this species did occur in field 2, and much of what is highlighted are trees in the area.

Autumn olive was identified along most field margins with a few smaller patches in the middle of field 2. Ground surveys confirmed these results. Furthermore, snags were densely clustered along the east side of fields 4 and 5 and the southern edge of field 3 (**Figure 7**). Special consideration should be given to these areas to confirm the presence of dead ash trees and to implement management actions to reduce invasive species presence. It is likely that that these areas will be colonized by nearby autumn olive as seen throughout other sections of the property if left unattended.

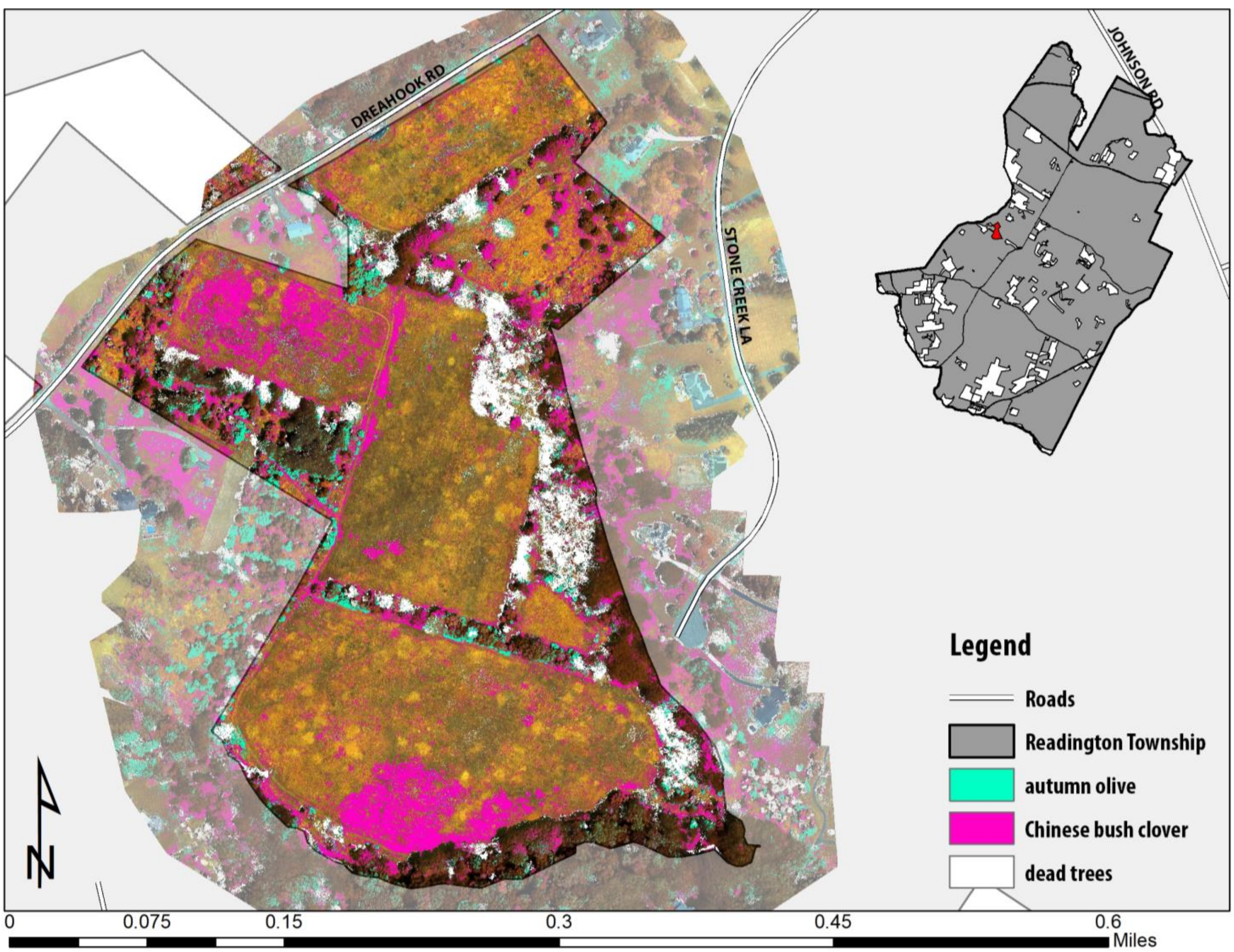

Figure 6. Image classification results for Holland Brook Headwaters.

Indian Purchase

The following species were mapped at the Indian Purchase open space property: Chinese bush clover, mugwort, and dead trees (**Figure 7**). As seen in previous maps, some shadows, including ones created by the street trees were identified as dead trees. However, it is easy to distinguish dead trees from shadows on the property in image interpretation. Furthermore, Chinese bush clover dominates the vegetation in the drainage basin, with many patches of invasion on the eastern side of the property. The Chinese bush clover appeared to be misidentified on the western side of the map in a wetland area, likely due to a lack of training samples of wetland vegetation in the image classification process. The mugwort patches identified along the drainage basin and the eastern meadows seemed to be correctly identified.

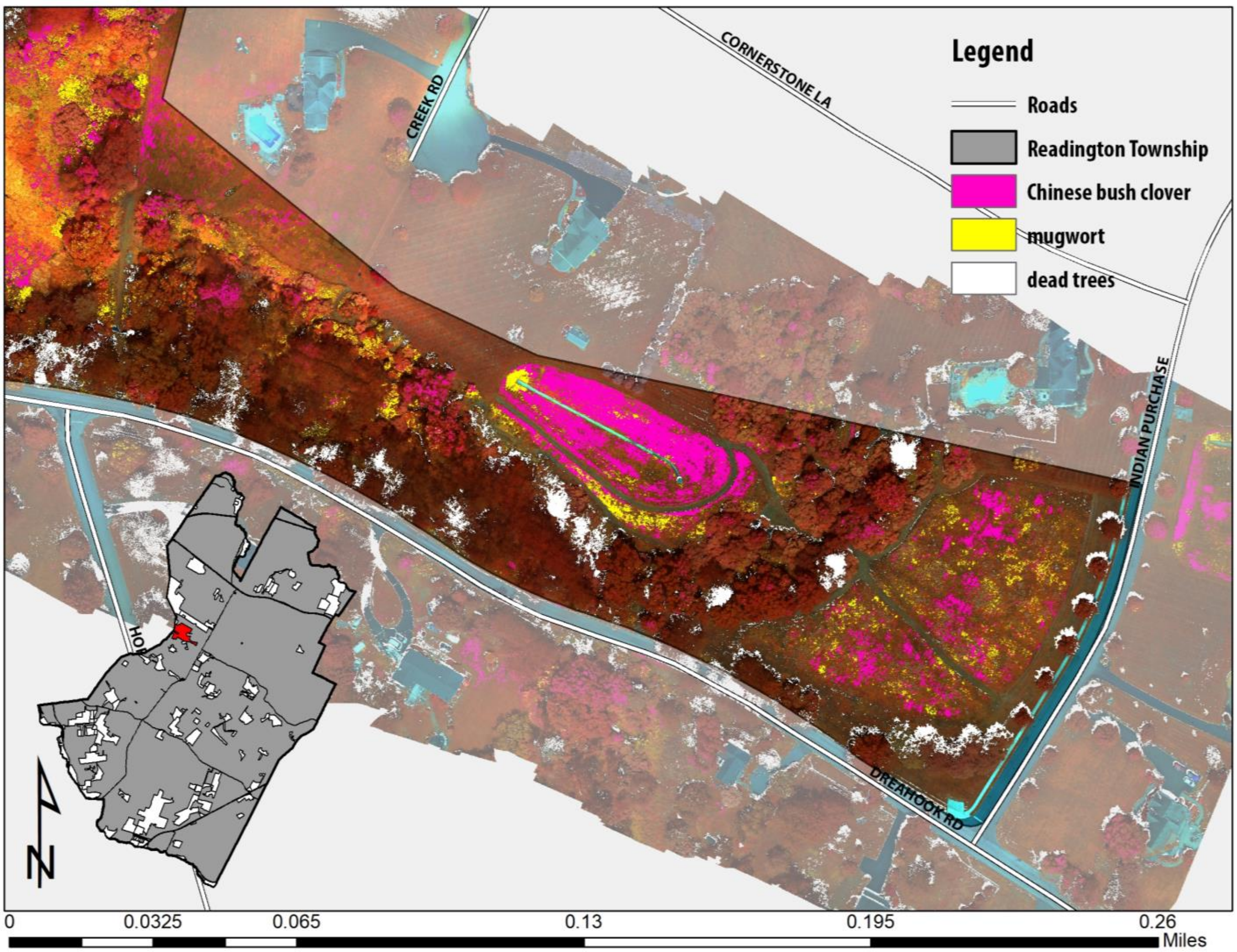

Figure 7. Image classification results for Indian Purchase.

Rocky Road

The Rocky Road site is connected to the Indian Purchase site, though maps were analyzed separately due to the different flight dates. The following species were mapped at the Rocky Road open space property: autumn olive and dead trees (**Figure 8**). Autumn olive was picked up correctly in the eastern portions of the property where shrubby successional areas exist. However, there are sparse teal colorations in other forested areas of the map, and without ground surveys, the authors are confident that this identification is incorrect. White clusters throughout the map indicate dead trees with a few dense clusters present. These areas were not visited on foot, however, and follow-up ground surveys are needed to determine if these are predominantly ash trees.

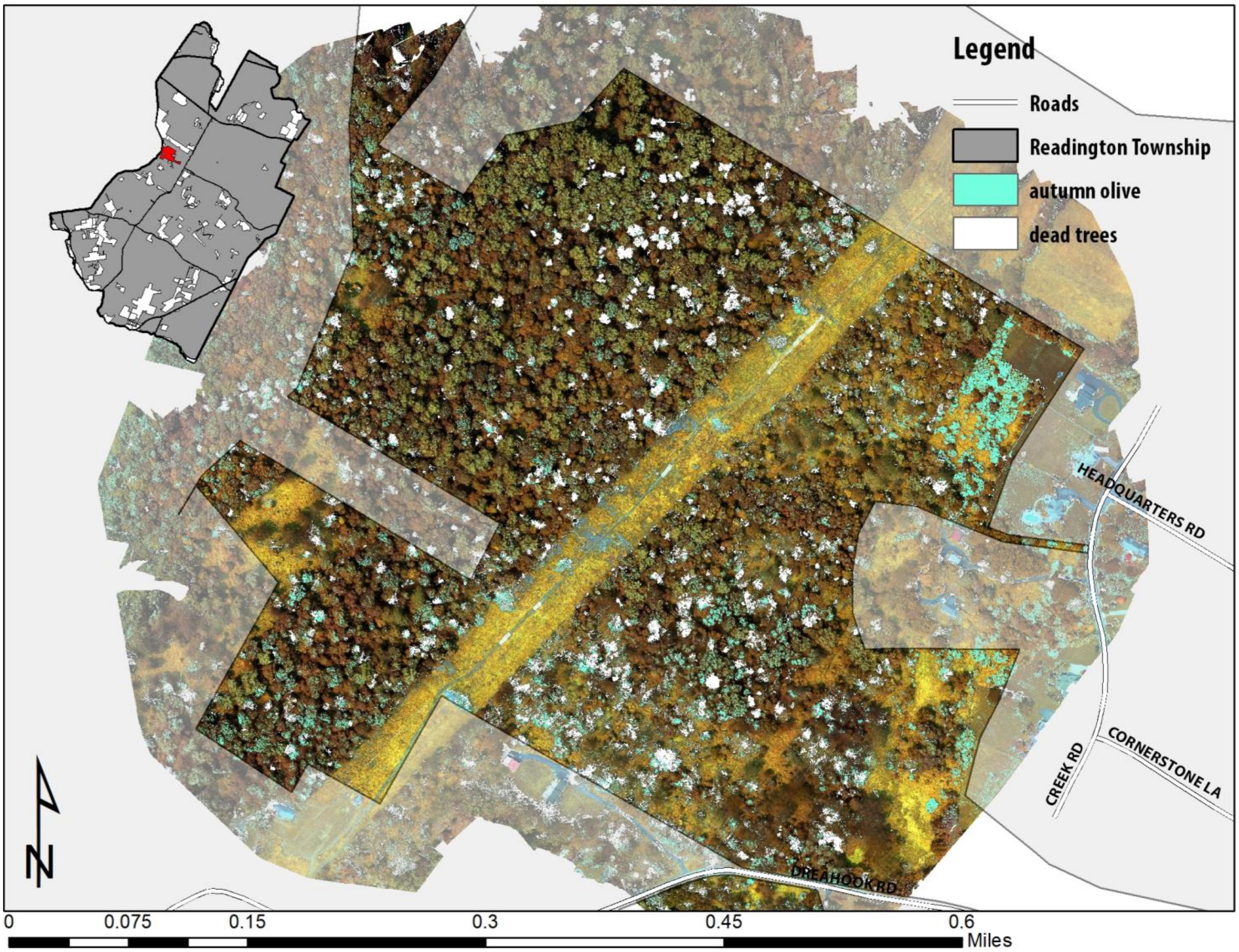

Figure 8. Image classification results for Rocky Road.

Vislocky

The easternmost portion of the property experienced some issues during processing; however, this loss was negligible considering it is not part of areas targeted for management. Chinese bush clover was correctly identified in many of the meadows (**Figure 9**). However, it is likely overestimated as determined from follow up ground surveys, not displayed in this map. Thus, while this species is a concern at this site, it is likely not as bad as this map indicates. Ground surveys revealed the presence of goldenrod (*Solidago sp.*) and grass-leaved goldenrod (E*uthamia graminifolia*) in misidentified patches of Chinese bush clover. Patches and single dead trees were correctly identified, with the ongoing issue of some shadow areas being falsely identified. Autumn olive was also correctly identified in the meadows and along the disturbed edges. However, as seen in other maps, patches were incorrectly identified in forested areas, where this species is not present. The misidentifications of autumn olive in forested areas and Chinese bush clover in meadow areas is further addressed in the discussion section of the paper below.

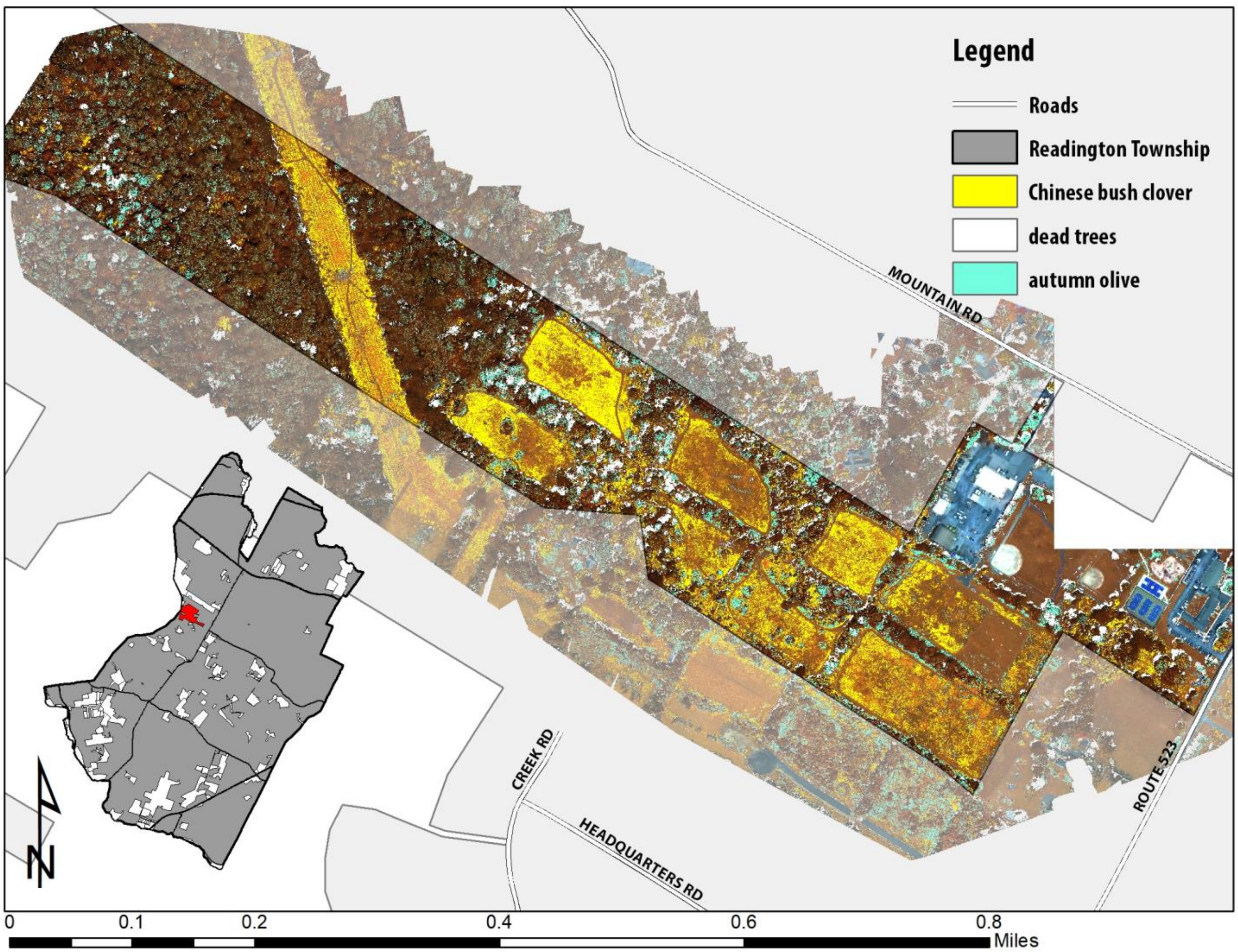

Figure 9. Image classification results for Vislocky open space.

Whitehouse Greenway

Due to a lack of aerial visibility from the canopy coverage at the Whitehouse Greenway site, training samples of meadow species were not used. Dead trees, however, were mapped based on visible locations on the western properties and the east side of the eastern property. Red circles indicate known ash tree locations collected during field sampling (**Figure 10**). These locations were not used to train the image classification but are correctly identified in the output. There is one large area at this site where image processing was unsuccessful, including 22 of the 95 acres targeted for survey (**Figure 10**).

One sample point occurred in this area, and without this chunk, the full extent of possible ash loss may not be visualized. Concerningly, there are large clumps of dead trees in both parcels of the open space property (**Figure 10**).

Figure 10. Image classification results for Whitehouse Greenway.

Round Mountain

The following species were mapped at the Round Mountain open space property: Chinese bush clover, autumn olive, and dead trees (**Figure 11**). A large, 25-acre, forested portion on the north side of the mountain experienced issues during processing, leaving a gap in the imagery. Similar to other sites, Chinese bush clover and autumn olive were picked up correctly in the fields and along the field edges but also showed up incorrectly in some forested areas. **Figure 11** shows training samples that were collected but not used, except for Chinese bush clover, for which all areas were successfully identified in the image classification map. The results also indicate potential areas of early invasion by Chinese bush clover, which should be addressed before it becomes more well established.

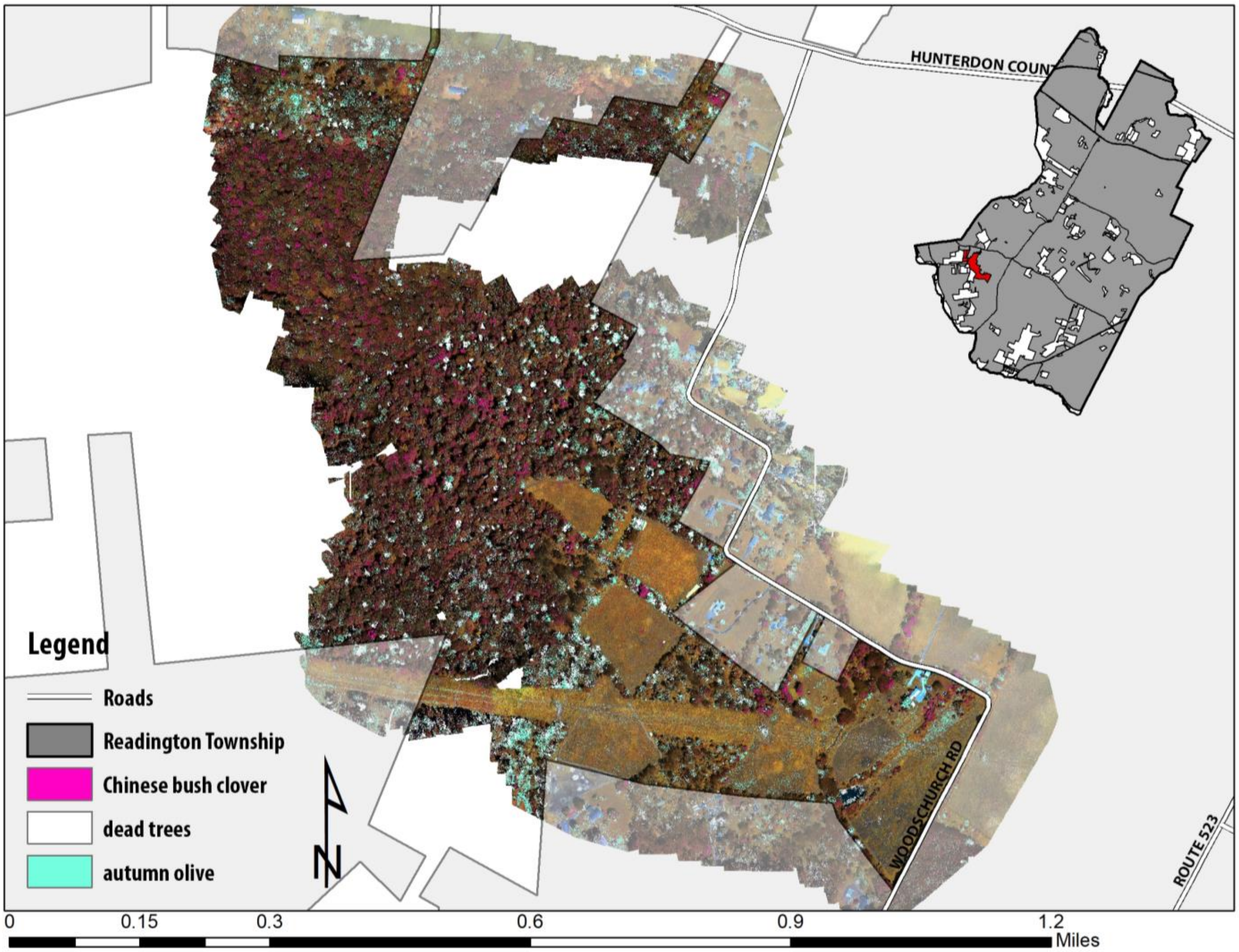

Figure 11. Image classification results for Round Mountain.

Cole Road West

The following species were mapped at Cole Road West: Chinese bush clover, autumn olive, and dead trees (**Figure 12**). The disjunct property south of County Road 629 was processed separately, and only dead trees were mapped at this location. A small < 1-acre and an 11.5-acre portion from the southern and northern end of the main survey area, respectively, are missing. These areas were unable to be processed completely. Dead trees made up a large portion of the disjunct southernmost parcel. Forest understory composition should be assessed in this location to determine the threat of invasive species in this area.

In the primary survey location, there were dead trees along the edges of the meadows and a large cluster in the mid-portions of the forested area. These areas should also be assessed for the presence of ash and the current understory composition. Additionally, there are a few large areas of mid-succession vegetation where autumn olive dominates and is also correctly identified along the meadow edges (**Figure 12**). Two locations seemed questionable for species identified, as indicated by the areas circled in red (**Figure 13**). Furthermore, the few patches in the larger field where mugwort was identified should be carefully assessed, as some seem to be in the presence of goldenrod species (see discussion).

Cole Road East

Dead trees and autumn olive were mapped at Cole Road East. Dead trees were identified in some locations (**Figure 14**); however, immediate attention should be given to the northernmost area, at the headwaters of a stream where the invasive tree of heaven (*Ailanthus altissima*) was recorded (Ray et al. 2020). Furthermore, there is already an apparent invasion along the edges from autumn olive (**Figure 14**). Autumn olive was also picked up along other meadow edges and within the early successional areas in the southern portion of this property, which seem to be dominated by this species and eastern red cedar (*Juniperus virginiana*).

Figure 12. Cole Road West open space image classification results. Only dead trees were classified in the disjunct property south of County Road 629.

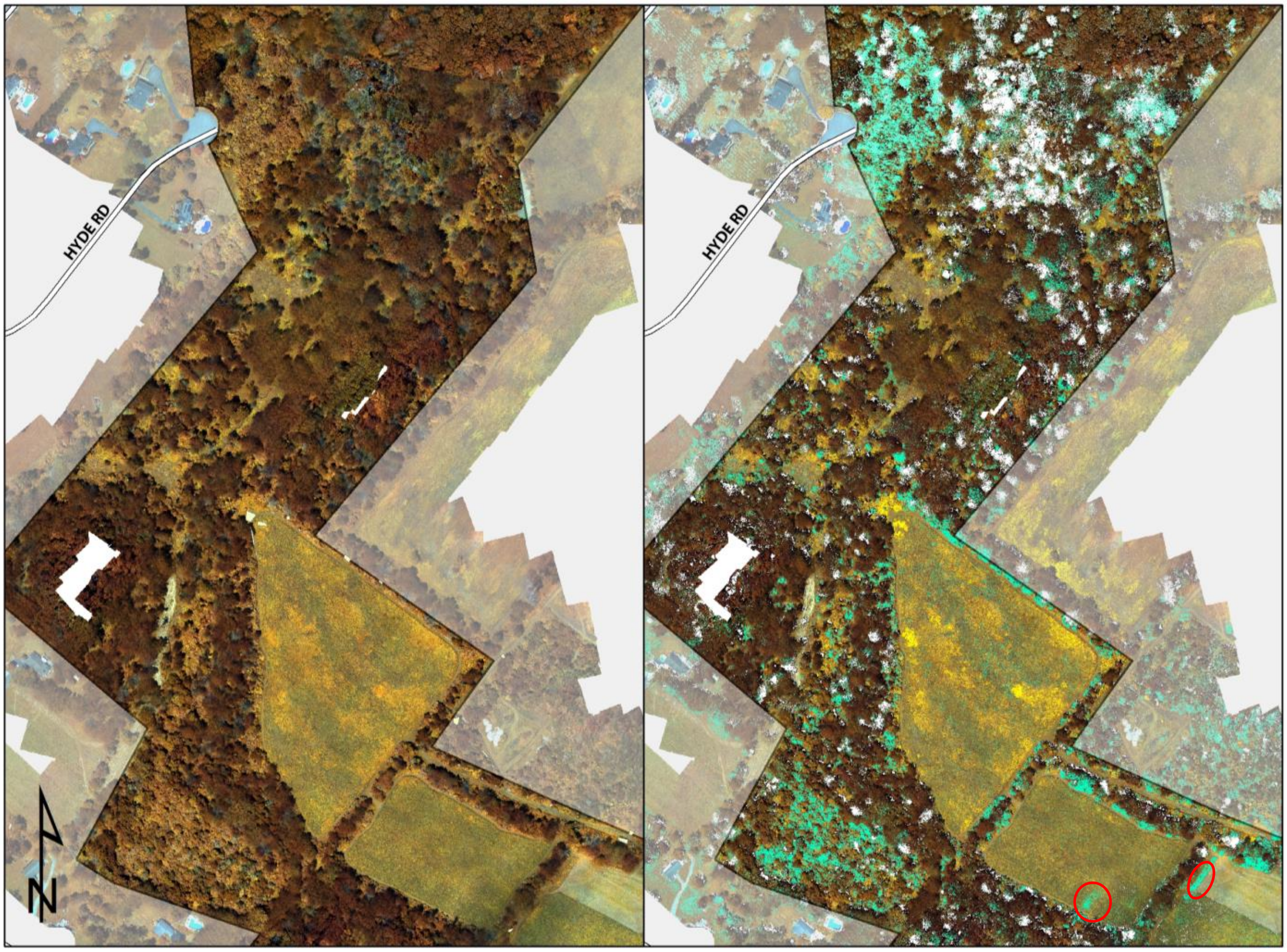

Figure 13. Image classification results for select areas of Cole Road West.

Figure 14. Image classification results for Cole Road East.

Discussion

Overall, the Maximum Likelihood Classification (MLC) did a good job differentiating most of our target species of interest. However, it performed poorly for others, such as callery pear at Lazybrook, which was the only site it was classified. In the cases where errors occurred, most appeared to result in overestimations of species coverages rather than underestimations or missed identifications. A few examples of this included the shadow areas along forest edges, which were identified as dead trees, areas dominated by goldenrod that were identified as mugwort (e.g. Pleasant Run) or Chinese bush clover (e.g. Vislocky), and areas where shrubby and herbaceous meadow species (autumn olive, Chinese bush clover, and mugwort) were identified incorrectly identified in canopied forest locations (e.g. Round Mountain).

Despite these misidentifications, the results are still striking and highlight the extent of invasive species impacts on some of Readington Townships' open space properties. The data is an invaluable tool for land managers to 1. Identify areas of emergent invasion; 2. Identify areas with well-established invasions; and 3. Identify areas where considerable canopy dieback is occurring, likely due to the emerald ash borer or other introduced pathogens. The dataset also provides a unique opportunity to expand on this work, identify other invasive species of concern at these locations, and examine native species composition (e.g., Milkweed, Beech, Ash, etc.).

Examples of emerging invasives the presence of Chinese bush clover in small patches of one field at Round Mountain and where it is beginning to establish along the edges of field 4 at Holland Brook Headwaters. Initial management efforts to address these locations will prevent the spread of this species from further dominating these fields. These areas should be considered a high priority for management, as they will require relatively little effort to contain. Other areas with more abundant populations of this species (e.g., fields 3 and 6 at Holland Brook) are likely to require much more intensive treatments to successfully eradicate.

Such well-established invasions were observed across all sites and included all species. It is best to recognize these issues, observe the extent marked in the image classification, and adequately plan for the removal and treatment of large areas. Thus, these locations should not be approached until the proper resources and management plan have been created to tackle these areas. All these locations will likely need a multi-year approach to control or eradicate effectively. Thus, these areas may be on a lower priority for action. However, the planning stage should start immediately. Ray et al. (2020) provided possible invasive species management approaches in Appendix C.

Large, concentrated clusters and diffuse areas of dead trees were observed at nearly every site. While some of these areas may not be unusual for a typical forest, like the small density observed at Round Mountain, other areas draw immediate concern. The only location visited in person that yielded a positive species identification was Holland Brook Headwaters, where ash trees dominated the significant canopy gaps observed. However, other sites should also be visited to determine the extent of dieback due to the emerald ash borer and to observe general understory vegetation starting to colonize the area. These areas include Cole Road West, White House Greenway, and sections of Rocky Road and Pleasant Run (north). Efforts to reduce invasive species colonization and to encourage native tree regeneration are strongly encouraged in these areas. This may be achieved with a combination of large or small deer enclosures targeted around already regenerating native species and periodic invasive species removal. In the case of Holland Brook Headwaters, the urgency is further heightened by the need to maintain a viable riparian buffer along the stream's headwaters.

The misidentifications we observed in the MLC system tended to occur in areas where species diversity was greater, and general training samples of meadow vegetation or forest cover were too broad to easily separate from the more targeted training samples drawn around our species of interest. For example, below are the initial results for Cole Road West, where training samples were drawn around our species of interest, general meadow habitat, general tree cover, mowed grass, and cedar trees. There were large sections of misidentification of autumn olive that occurred in the presence of big bluestem (*Andropogon gerardi*), and mugwort was misidentified in areas dominated by goldenrod (*Solidago* spp.). A second classification was run with the addition of training samples for big bluestem, Indiangrass (*Sorghastrum nutans*), and goldenrod. These additions reduced the overestimation of our autumn olive and mugwort in the meadow area (**Figure 15**). The use of additional vegetation classes in our Maximum Likelihood Classification across meadows and forested areas will likely result in more refined maps for our species of interest, as displayed here. The latter classification was used in the results section of the paper.

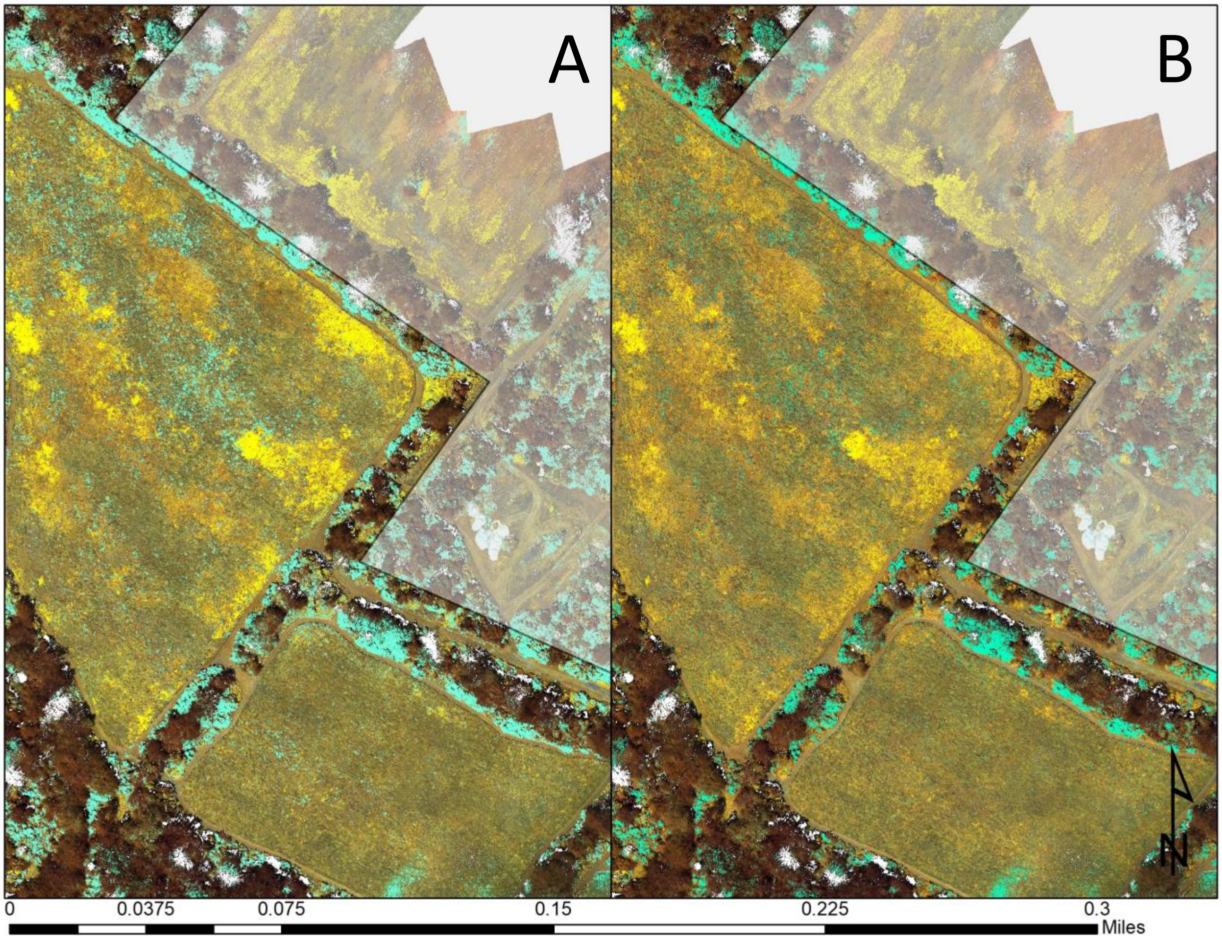

Figure 15. Example of misidentification of target species at Cole Road West. In both maps, A and B, autumn olive (teal), mugwort (yellow), and dead tree (white) classifications are displayed. Map A shows the output excluding training samples for big bluestem, Indian grass and goldenrod, whereas map B includes the additional training polygons (**see Appendix I**). Background drone imagery is displayed in RE-Geen-Blue.

We can take advantage of the above issue to better study and understand Readington's open space properties. There are forested areas and meadow areas where clear differentiation can be made among species. While this project's capacity could not survey for and delineate all areas of interest, further datasets can be collected by GPS and applied to the aerial images already developed. Revisiting sites will also allow us to identify all target species across all sites to create a more well rounded dataset that will inform future management decisions on Readington open space properties.

Also lacking thus far is a formal statistical assessment of the accuracy of results. Some ground truthing can be done by the land managers during site visits; however, it is more practical for land managers to understand the accuracy of the results prior to management in order to optimize their use. We therefore recommend a follow-up survey to collect additional samples to delineate dominant vegetation cover across sites and assess how accuracy increases when including dominant vegetation classes. To evaluate the accuracy, we will look at the precision (# true positives) and recall (# of false negatives) of a sampled proportion of pixels for a given class using a confusion matrix outlined well in Deng et al. (2016). This method is commonly used to assess image classification accuracy (Perumal and Bhaskaran 2010) and looks at randomly generated points created within the classification areas.

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Appendix I

An example of training samples created for two classification scenarios at the Cole Road West property. The results of the two scenarios are displayed in the **Discussion** section of the paper. The first image classification was run using all training sample, except for big bluestem, Indian grass, and goldenrod. The second was run using all. See **Figure 12** for results.