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Multispectral unmanned aerial system remote sensing to detect Dalmatian toadflax in a mixed sagebrush steppe on the South Fork of the Shoshone River

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Abstract Management of invasive plant populations is most successful when infestations are identified and managed quickly, but detection of small populations of plants can be difficult. In rangelands of Wyoming, Dalmatian toadflax *(Linaria dalmatica)* is a competitive invasive forb well-adapted to rocky, dry soil, allowing it to colonize steep slopes and rugged terrain. In the Shoshone National Forest, Dalmatian toadflax populations continue to spread in the nursery slopes of big horn sheep and elk, so Unmanned Aerial Systems (UAS) are being employed for the remote detection of small populations of Dalmatian toadflax. Multispectral profiles of Dalmatian toadflax plants were taken through the growing seasons of 2018 and 2019 to build a spectral signature of the plant. Multispectral imagery of Dalmatian toadflax infested study areas were collected with a UAS, and imagery was classified using a random forest machine learning approach. Spectral signatures of Dalmatian toadflax plants change through the growing season, which provides challenges as neighboring species bloom and senesce. Overall, classification results from this study suggest remote detection of Dalmatian toadflax with UAS is possible but must exploit a priori understanding of the phenology of the invaded plant community.

Introduction

Invasive plants are a concern in the valley and hillsides of the South Fork of the Shoshone River in Park County, Wyoming, where steep grades, high elevation, and large expanses of open land in the Absaroka, Beartooth, Gallatin, Red, and Washburn mountains make weed scouting and management difficult. Dalmatian toadflax *(Linaria dalmatica)* is a perennial forb from the Mediterranean coast that was introduced to North America as an ornamental that can produce high amounts of seeds, establishing a deep taproot, and adapting to a wide range of environments in the Western United States (Jacobs and Sing, 2006). Dalmatian toadflax invasions have been shown to have little forage and utilization value for native wildlife and insects and the plant outcompetes native vegetation for water and nutrient resources in degraded rangelands through its extensive root system (Sing et al., 2016). When blooming, Dalmatian toadflax has bright yellow flowers, which makes it a good candidate for spectral identification using remote sensing imagery.

In a 2007 study, individual plants and small populations of Dalmatian toadflax were identified using visual human classification of real-color aerial images from Cheyenne, Wyoming (Blumenthal et al.,

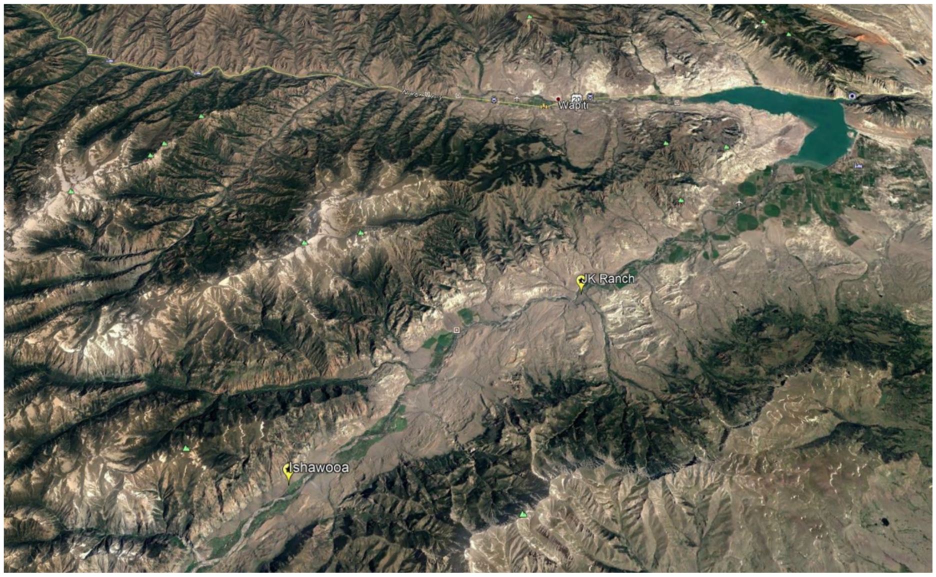

Figure 1. Map of two study sites, JK Ranch (44°19'36"N, 109°23'53"W) and Ishawooa (44°11'49" N, 109°34'19"W), shown with labels and yellow star indicators.

2007). There were other, yellow flowering forbs in the study area, but Dalmatian toadflax was differentiated by comparing functional traits, like leaf and flower shape and size, shape, height, and spatial distribution. Though this study was focused on mapping Dalmatian toadflax cover in the study area, not classification accuracy, unsupervised classification and automated imagery analysis were suggested for future research with more sophisticated, multispectral sensors and fewer spectrally similar non-target species (Blumenthal et al., 2007). Successful identification of invasive plant populations through remote sensing imagery classification has been accomplished through varying imagery acquisition methods, sensor capabilities, imagery processing, and classification algorithms, but these methods must be developed on a case-by-case basis as plants invasions vary in population size and densities, spectral profile, spatial arrangement, texture, size, and matrix components. (Huang and Asner, 2009).

Research purpose and questions

When this project is completed, the goal is to have a complete data collection, hardware and software package, and research workflow that can be purchased and utilized by Wyoming County Weed and Pest Agencies to rapidly detect and respond to even small populations of Dalmatian toadflax in remote, rugged areas. UAS remote sensing will be applied to test the feasibility of using UAS to scout for Dalmatian toadflax in the harsh terrain of the Shoshone National Forest, near Hawkeye in Park County, Wyoming by answering the following research questions:

1. Can UAS flights with a consumer level multispectral sensor be used to identify and differentiate Dalmatian toadflax from other vegetation in a mixed sagebrush steppe?
2. Will Dalmatian toadflax classification accuracy rates vary with different UAS flight altitudes, different imagery collection dates, and Dalmatian toadflax density?

Methods

Study area

This study was conducted over three growing seasons on two sites, JK Ranch (44°19'36"N, 109°23'53"W) and Ishawooa (44°11'49" N, 109°34'19"W), along the South Fork of the Shoshone River in the Shoshone National For-

	JK Ranch	Ishawooa
Toadflax Coverage	Dense	Sparse
Ecological Site Description (ESD)	Loamy Absaroka Lower Foothills	Loamy (Ly) 15-19" Foothills and Mountains
Proportional Coverage of ESD	100%	45%
Location	44°19'36" N, 109°23'53" W	44°11'49" N, 109°34'19" W
Elevation	NA	1828.8 - 2743.2 m
Slope	<25%	0-30%
Soil Type(s)	Sandy loam/loam cap over sandy clay loams and clay loams	Loam, silt loam, and fine sandy loam over loam
Mean Annual Precipitation	25.4-35.56 cm	38.1-48.26 cm
Average Days Frost-Free	88 days frost free	120 days frost free
Vegetative Community	75% grasses, 10% forbs, 15% woody plants	75% grasses, 10% forbs, 15% woody plants

Table 1. Ecological site description information from two study sites, JK Ranch and Ishawooa.

est in Park County, Wyoming (Figure 1). These sites were selected for their differences in Dalmatian toadflax densities, as the JK Ranch site has high proportional coverage of Dalmatian toadflax and the Ishawooa site is less densely infested. Both sites are composed of primarily perennial grasses, with fewer shrubs and forbs (Table 1).

Data Collection

UAS remote sensing

UAS imagery was first collected in May, July, August, and September of 2018 to determine flight and imagery parameters (flight altitude/imagery pixel size, flight speed, shutter speed, image overlap). Through testing, 30m – 70m flight altitudes, fast flight speeds, pictures captured every 1.5m flown, and 80% imagery overlap were determined to be optimal flight and imagery parameters. Final imagery collection occurred in May, July, and August of 2019, capturing the full range of Dalmatian toadflax phenology through the growing season. The UAS flown was a Parrot Bluegrass equipped with an integrated Parrot Sequoia Multispectral Sensor (Parrot Drone SAS, Paris, France). The Sequoia sensor records ground reflectance in the red (640-680 nm), green (480-520 nm), red edge (730-740 nm), and near infrared (770-810 nm) bands of light in addition to capturing red, green, and blue composite images. Additionally, incoming solar radiation was recorded by a sunshine sensor on top of the UAS, to account for changing light conditions, these values were stored to be used for later imagery calibration. All UAS flights were performed in the morning to midday, to limit shadows in imagery and avoid windy afternoons. Flight planning and control was executed through the Pix4D Capture app on the pilot's smartphone (Pix4D S.A., Lucerne, Switzerland). Flights were logged, recording missions, flight parameters, conditions, hazards, and comments.

Ground control points

Permanent and temporary ground control points (GCPs) were established to georeference imagery between and across dates. Several identifiable rocks were marked with reflective tape and marked with Emlid Reach RS+ GPS, to serve as permanent ground control points within each study area. Before each UAS flight, white bucket lids (31.45 cm in diameter) were placed within the flight study areas and marked with GPS as temporary ground control points. GCPs were scattered throughout the flight study areas, capturing edges, interior, and center of

<table>
<tr><td></td><td></td><td colspan="2">Class from training set</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Dalmatian toadflax</td><td>Not Dalmatian toadflax</td><td>Class classification error</td><td>Overall error</td><td>Flight altitude</td><td>Data collection date</td></tr>
<tr><td rowspan="6">Class assigned by imagery classification</td><td>Dalmatian toadflax</td><td>47</td><td>5</td><td>0.096</td><td rowspan="2">0.095</td><td rowspan="2">30m</td><td rowspan="2">May</td></tr>
<tr><td>Not Dalmatian toadflax</td><td>5</td><td>48</td><td>0.094</td></tr>
<tr><td>Dalmatian toadflax</td><td>184</td><td>16</td><td>0.075*</td><td rowspan="2">0.064*</td><td rowspan="2">30m</td><td rowspan="2">July</td></tr>
<tr><td>Not Dalmatian toadflax</td><td>12</td><td>220</td><td>0.047</td></tr>
<tr><td>Dalmatian toadflax</td><td>46</td><td>5</td><td>0.098</td><td rowspan="2">0.088</td><td rowspan="2">30m</td><td rowspan="2">August</td></tr>
<tr><td>Not Dalmatian toadflax</td><td>4</td><td>47</td><td>0.078</td></tr>
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Table 2. Combined confusion matrices for binary Dalmatian toadflax random forest classification of JK Ranch site for July sampling dates at 30m, 50m, and 70m flight altitudes. Bold cells indicate correct classification of training data, and * represent best accuracy rates for Dalmatian toadflax identification and overall classification accuracy.

imagery.

GPS units and protocol

Two Emlid Reach RS+ GPS units (Emlid, Hong Kong, Hong Kong) were used for marking GCPs and mapping Dalmatian toadflax presence, with one as the stationary base on a tripod in the center of the study area. The base unit records position, then transmits LoRa corrections to the moving rover on a surveying pole, placed over targets to hold for 15 seconds while position is recorded using fixed solutions, resolving inaccuracies and making real time kinematic corrections, resulting in centimeter level horizontal accuracy. Targets were marked and labelled with a point on Emlid ReachView app on smartphone or tablet for each study site.

Sensor calibration

The Parrot Sequoia sensor was calibrated with a MicaSense calibration panel (MicaSense Inc., Seattle, WA, USA) before and after flights and image capture, to account for changes in illumination and compare reflectance. These images were stored and later used for imagery calibration.

Ground mapping (Ishawooa Site only)

Dalmatian toadflax locations were marked at the Ishawooa site only, following our GPS protocol for about half of the sparsely infested Ishawooa site. For every square meter covered by Dalmatian toadflax, a point was marked, resulting in 1,090 Dalmatian toadflax presence points.

Data processing

Imagery calibration

After data collection, UAS imagery was calibrated in Pix4Dmapper (Pix4D S.A., Lucerne, Switzerland) using calibration panel images taken in the field, incoming illumination information from the sunshine sensor, and Parrot Sequoia reflectance factors for each band of light (Parrot, 2017).

		Class from training set					
		Dalmatian toadflax	Not Dalmatian toadflax	Class classification error	Overall error	Flight altitude	Data collection date
Class assigned by imagery classification	Dalmatian toadflax	**184**	16	0.075	0.064*	30m	July
	Not Dalmatian toadflax	12	**228**	0.047			
	Dalmatian toadflax	**51**	2	0.038*	0.067	50m	July
	Not Dalmatian toadflax	5	**47**	0.096			
	Dalmatian toadflax	**49**	4	0.075	0.067	70m	July
	Not Dalmatian toadflax	4	**47**	0.078			

Table 3. Combined confusion matrices for binary Dalmatian toadflax random forest classification of JK Ranch site for May, July, and August sampling dates at 30m flight altitudes. Bold cells indicate correct classification of training data, and * represent best accuracy rates for Dalmatian toadflax identification and overall classification accuracy.

Imagery mosaicking

Images collected from each flight are separated in multispectral and RGB projects in Pix4Dmapper, one for a multispectral imagery stack and the other for RGB orthoimagery. Flight images were uploaded, optimized, matched, and georeferenced, then key points were identified (features that are recognizable in multiple images), densified, and combined into a three dimensional point cloud, from which images were mosaiced (Becker et al., 2017; Kaamin et al., 2020). Imagery was then exported as reflectance for each band. Since imagery is kept in two separate projects and collected in a different part of the sensor, bands must be georeferenced to align spatially. Locations of permanent and temporary ground control points are visible in flight imagery and were linked by location in imagery sets to match extent and alignment of bands in ArcMap Version 10.5.1 (ESRI Inc, 2016).

Digitizing training polygons

For classification, training polygons were digitized by user identification of land cover classes in ArcMap 10.5. For the basic classification, Dalmatian toadflax and objects other than Dalmatian toadflax were digitized and used for training classification. For an expanded classification, Dalmatian toadflax, road, rocks, sagebrush, cheatgrass, and perennial grasses were digitized, used for training, and classified in the resulting imagery classification. For all imagery digitized polygons, area was also calculated. Additionally, vegetation polygons were digitized from ground-level imagery set and reflectance was extracted for Dalmatian toadflax and co-occurring vegetation species.

Data analysis

Imagery classification method(s)

All pixels in all imagery sets were classified using a random forest classification, which uses machine learning method to grow many decision trees, with

		Dalmatian toadflax	Road	Rocks	Cheatgrass	Mountain mahogany	Sage	Class classification error	Overall error
Class assigned by imagery classification	Dalmatian toadflax	**191**	0	2	4	0	3	0.045	0.0795
	Road	0	**49**	0	0	0	2	0.039	
	Rocks	2	0	**50**	0	0	0	0.038	
	Cheatgrass	3	0	0	**48**	0	0	0.059	
	Mountain mahogany	1	0	0	0	**34**	0	0.029	
	Sage	10	3	4	0	1	**33**	0.353	

Table 4. Confusion matrix for expanded classification of JK Ranch site for July sampling date at 30m flight altitude. All imagery pixels were classified into Dalmatian toadflax, road, rocks, cheatgrass, mountain mahogany, and sagebrush cover classes. Bold cells indicate correct classification of training data.

branches separating pixels into classes based on digitized training data. This classification was done in the RandomForest Package in Program R (Liaw and Wiener, 2002). For each random forest model run, 351 trees were grown with one band of light tested at each branch of each classification tree. Pixels were assigned classes based on a majority vote from all 351 trees. Classification results were evaluated using reserved training samples for validation and classification, resulting in confusion matrices with overall and class accuracies. Finally, classification prediction maps were generated and exported.

Preliminary results

Dalmatian toadflax training samples were identified correctly 77% of the time or more in classifications performed across all sites, dates, and flight altitudes of imagery. July imagery that captured Dalmatian toadflax in peak bloom resulted in the lowest overall error and highest Dalmatian toadflax classification rates (Table 2). July Dalmatian toadflax was identified with 96% and 93% accuracy for 50m and 30m flight altitudes respectively, although overall accuracy rate was higher for the 30m imagery (94%) (Table 3). The classification with additional land cover classes (Dalmatian toadflax, road, rocks, cheatgrass, mountain mahogany, and sage) did not improve overall classification rate, but did improve Dalmatian toadflax detection accuracy. Dalmatian toadflax was misclassified as rocks, cheatgrass, and sagebrush (Table 4). Finally, when comparing the two sites, dense Dalmatian toadflax at the JK Ranch was identified with 93% accuracy while the sparse Dalmatian toadflax at the Ishawooa site was identified correctly 77% of the time (Table 5).

Conclusions

Overall, unmanned aerial system multispectral remote sensing appears to be an effective tool for identifying Dalmatian toadflax in the mixed vegetative community of the Shoshone National Forest. Limitations of this application include relatively short flight times of UAS, challenges of automating flights in steep terrain, and potentially missing small, sparse infestations of Dalmatian toadflax. More work must be conducted, potentially with fixed wing UAS or manned aerial systems, to cover the fully area of interest for Dalmatian toadflax management in the Shoshone National Forest.

Future work

Training polygons will be compared to imagery classification results, and polygons will be grouped into correctly and incorrectly classified toadflax presence and absence in ArcMap 10.5. These classes will be true positives (true Dalmatian toadflax presence), false negatives (missed Dalmatian toadflax), true nega-

		Class from training set							
		Dalmatian toadflax	Not Dalmatian toadflax	Class classification error	Overall error	Site	Toadflax abundance	Flight altitude	Data collection date
Class assigned by imagery classification	Dalmatian toadflax	**184**	16	0.075*	0.064*	JK Ranch	Dense	30m	July
	Not Dalmatian toadflax	12	**228**	0.047					
	Dalmatian toadflax	**69**	21	0.233	0.127	Ishawooa	Sparse	30m	July
	Not Dalmatian toadflax	14	**171**	0.076					

Table 5. Combined confusion matrices for binary Dalmatian toadflax random forest classification of JK Ranch site and Ishawooa site for July sampling dates at 30m flight altitudes. Bold cells indicate correct classification of training data, and * represent best accuracy rates for Dalmatian toadflax identification and overall classification accuracy.

tives (Dalmatian toadflax absence), and false positives (other landcover class misclassified as Dalmatian toadflax). Reflectance for all bands will be extracted for these polygons, and reflectance values for correctly and incorrectly classified training polygons will be compared using a two-way ANOVA for each band. Post-hoc mean separation will be conducted using Tukey's Honest Significant Difference to compare reflectance between true and false positives and negatives in Program R.

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References

Becker, C., N. Häni, E. Rosinskaya, E. d'Angelo, and C. Strecha. 2017. Classification of aerial photogrammetric 3D point clouds. arXiv preprint arXiv:1705.08374 .

Blumenthal, D., D. T. Booth, S. E. Cox, and C. E. Ferrier. 2007. Large-scale aerial images capture details of invasive plant populations. Rangeland Ecology & Management **60**:523–528.

Huang, C.-y., and G. P. Asner. 2009. Applications of remote sensing to alien invasive plant studies. Sensors **9**:4869–4889.

Jacobs, J., and S. Sing. 2006. Ecology and management of Dalmatian toadflax (Linaria dalmatica (L.) Mill.). Invasive Species Technical Note No. MT-3. Bozeman, MT: US Department of Agriculture, Natural Resources Conservation Service. 9 p. .

Kaamin, M., A. Sarif, N. Husin, K. Supar, S. Razali, S. Sahat, and M. Mokhtar, 2020. Advanced Techniques in As-Built Survey by using UAV Technology. Page 032110 *in* Journal of Physics: Conference Series, volume 1529. IOP Publishing.

Liaw, A., and M. Wiener. 2002. Classification and Regression by randomForest. R News **2**:18–22. https://CRAN.R-project.org/doc/Rnews/.

Sing, S. E., R. De Clerck-Floate, R. W. Hansen, H. Pearce, C. B. Randall, I. Tosevski, and S. M. Ward. 2016. Biology and biological control of Dalmatian and yellow toadflax. FHTET-2016-01. Morgantown, WV: US Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team. 141 p. .