Invasive Species Detection and Mapping Using Unmanned Aerial Systems (UAS)

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INVASIVE SPECIES MANAGEMENT ADIRONDACKS

The Nature Conservancy

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UAS aerial image of a common reed grass *(Phragmites australis)* infestation.

Contents

Introduction

What are UAS?

Unmanned aerial vehicles (UAVs) – often referred to as drones – are aircraft without a human pilot on board. The combination of a UAV and its ground control station comprise an unmanned aerial system (UAS). Most UAS used by civilian operators are small, defined by the Federal Aviation Administration (FAA) as being over 0.55 pounds and less than 55 pounds. Multiple aircraft types are available (Figure 1), but multi-rotor aircraft are the most commonly utilized, particularity by novice operators, due to their relatively low cost and ease of operation. Multirotor aircraft have at least two lift generating motors. They are easy to operate but have limited flight time. Fixed wing aircraft use a horizontal wing to provide lift. They have one or more motors that provide forward propulsion. Fixed wing aircraft can survey larger areas but are difficult to operate and require larger areas for taking off and landing. Hybrid fixed wing aircraft combine attributes of multirotor and fixed wing aircraft. They are capable of vertical takeoff and landing, but transition to forward flight for increased flight time.

There are numerous manufacturers to choose from in the commercial UAS market. DJI is one of the most common suppliers of consumer aircraft, capturing approximately 54% of the commercial UAS market (Drone Analyst, 2021). Their popular platforms include the Phantom, Mavic, and Matrice series.

	MULTIROTOR	FIXED WING	HYBRID FIXED WING
COST	● ○ ○	● ● ●	● ● ●
FLIGHT TIME	● ○ ○	● ● ●	● ● ○
EASE OF USE	● ● ●	● ○ ○	● ○ ○

Figure 1. Common UAS platform types and their characteristics.

Benefits of UAS

Like any remote sensing data collection platform (ex: manned aircraft, satellites, etc.), there are benefits and drawbacks associated with the use of UAS. Before considering the use of UAS for a project, it’s best to consider data needs in terms of spatial, spectral, and temporal resolution.

Spatial Resolution

Spatial resolution can be defined as “a measure of the smallest object that can be resolved by the sensor or the linear dimension on the ground represented by each pixel” (Liang & Wang, 2020). In other words, it describes how much detail is present in an image. The higher the spatial resolution, the more detail is present.

Spatial resolution is influenced by a variety of factors including sensor specifications and the altitude at which data is collected (distance to target). Collections from lower altitudes generally have a higher spatial resolution than high altitude collections. Because UAS are most often operated at 400 feet above ground level (AGL) or less, the resulting data typically has a very high spatial resolution. For example, UAS orthomosaics may reach spatial resolutions of 2cm/pixel, where common satellite data sources such as Landsat and Sentinel have resolutions of 30m and 10m, respectively (Figure 2).

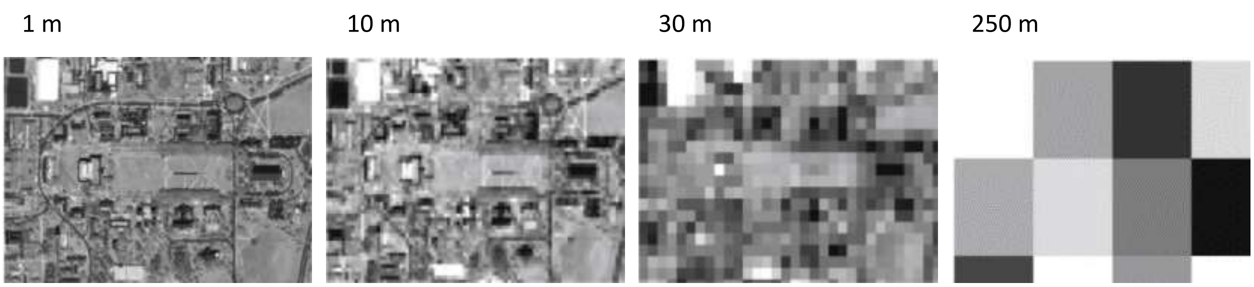

Figure 2. Example of varying spatial resolutions. Adapted from Liang & Wang, 2020.

The incredibly high resolution offered by UAS can facilitate detailed analysis or be used to identify small features; however, this high resolution comes at the cost of coverage. Manned aircraft and satellites generally provide the broadest coverage, while UAS acquisitions are usually restricted to a few hundred acres due to the constraints of the aircraft.

Spectral Resolution

Spectral resolution describes “the number and width of spectral bands captured by a sensor” (Liang & Wang, 2020). The greater the number of bands, the greater the spectral resolution. Most consumer-grade UAS capture true-color imagery comprised of three bands (red, green, blue). Some enterprise UAS platforms have the capacity to accept more advanced sensors with additional spectral bands, but that technology comes at a high monetary cost.

True color imagery is sufficient to create high resolution orthomosaic maps, but additional spectral bands, such as near-infrared, are required to perform advanced analysis like calculating normalized difference vegetation index (NDVI). Many satellite platforms offer multispectral data but provide only low to moderate spatial resolution.

Temporal Resolution

Temporal resolution is “a measure of the repeat cycle or frequency with which a sensor revisits the same part of the Earth's surface” (Liang & Wang, 2020). In other words, temporal resolution describes how often the data are collected. The more often data are collected, the higher the temporal resolution. UAS data can be collected on an “as needed” basis, capturing data specific to the needs of a project, whereas satellite data collects information at fixed repeat intervals (Table 1).

Table 1. Repeat interval and spatial resolution of common no-cost satellite remote sensing platforms.

Sensor	Repeat Interval (days)	Spatial Resolution (m)
Landsat 8 & 9	16	30
Sentinel 2	10	10
MODIS	2	250

APIPP’s FireFly6 Pro, hybrid fixed wing aircraft ready for takeoff.

UAS Data Collection Process

Many UAVs transmit real-time video to their ground control station. This bird's-eye view video can be monitored by the pilot to search for features of interest; however, a major benefit of UAS is their ability to generate high resolution orthomosaic maps using automated flight software (Table 2). An overview of the automated mapping process is provided below:

Table 2. Capabilities of common UAS flight software.

	Flight Planning	Processing
Pix4D	X	X
DroneDeploy	X	X
Drone2Map		X
Site Scan	X	X
Site Scan LE	X	
Map Pilot Pro	X	

Mission Planning

Using a flight planning application, pilots define a survey area and can input basic flight settings such as:

- Flight altitude
- Aircraft speed
- Image front overlap
- Image side overlap

Depending on the planning application used, survey areas may be defined as a polygon (with parallel or crosshatched flight paths), linear/corridor, or vertical surface. Based on user defined parameters, the software creates a series of flight paths and uploads the flight plan to the aircraft.

The flight plan is then verified by the aircraft. When ready to begin the mission, the UAS pilot issues a command for the aircraft to launch. The UAV follows its defined course, collecting a network of overlapping images.

After the mission is complete, images are uploaded to post-processing software, where they are stitched into a composite map. A variety of end products can be generated depending on the sensor and post-processing software used. Common outputs include true color orthomosaics, digital surface models, and digital terrain models.

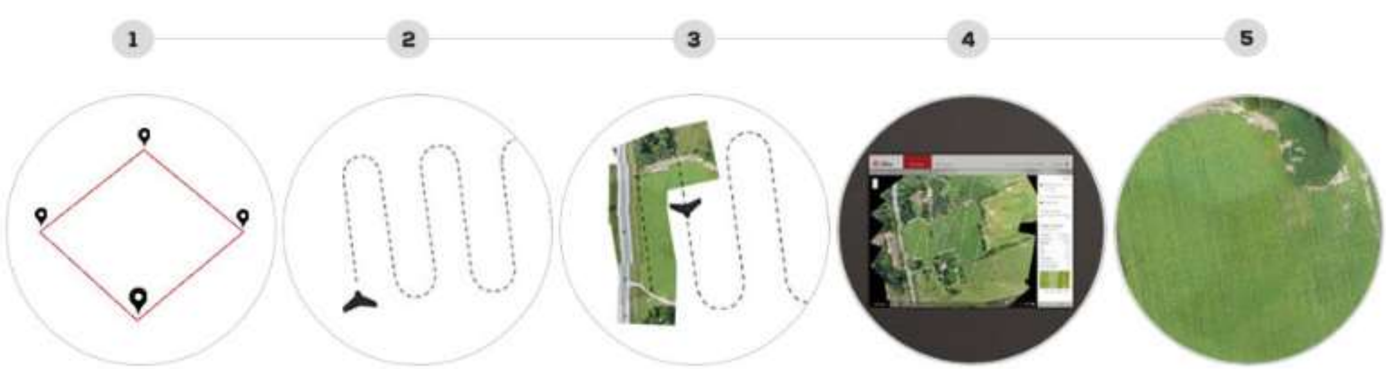

Figure 3. UAS data collection process workflow (Figure Credit: Landpoint Aerial Services)

UAS Applications in Conservation

UAS are becoming a common tool for conservation work. Numerous studies have demonstrated the utility of UAS remote sensing for natural resource applications such as species counts, invasive species control, prescribed fire management, vegetative community classification, and more. Select examples of UAS applications are provided below:

Wildfire
Researchers from the University of Nebraska developed a custom UAS to ignite prescribed fire by remotely dropping specially designed incendiary balls. The device was used to perform tasks dangerous to firefighters and costly to perform from manned aircraft (Beachly et al. 2017). UAS are also used in wildfire management to detect hotspots via thermal imaging.


Photo Credit: James Junda/McGill University

Wildlife
UAS can be used to count, study, and protect wildlife from harm. They have been used to estimate population sizes, monitor/detect poaching of protected species, and even to deliver anesthetic darts.

Invasive Species
UAS have been widely used in a variety of invasive species management efforts ranging from simple tasks like vegetation surveys to advanced applications such as depositing pesticide baits for invasive mammal/insect control and aerial herbicide spraying.

Adirondack PRISM Invasive Species Case Study

The Nature Conservancy's Adirondack Park Invasive Plant Program (APIPP) conducted a two-part case study to evaluate the use of true-color UAS imagery for the detection of common reed grass (*Phragmites australis)* in the Adirondacks*.* The target species was selected based on its distribution in the region, propensity to grow in open wetlands where UAS flights are logistically feasible, and its conspicuous morphology that lends to aerial detection. Although this case study evaluates UAS for detection of a single species in a specific geography, the lessons learned are more broadly applicable to the general use of UAS for detection of invasive species.

To evaluate the use of true-color UAS imagery for invasive species detection, APIPP conducted two assessments:

1. **Evaluating flight parameters for optimal detection of *Phragmites australis***
   Repeat UAS flights were conducted at various altitudes and across multiple months throughout the growing season. All flights occurred over wetlands with known *P. australis* infestations in order to assess the effect of flight altitude and seasonal timing on detection/mapping accuracy.

2. **Early detection of *Phragmites australis* infestations using true-color imagery**
   To test the efficacy of UAS as an early detection tool for *P. australis,* we selected previously unsurveyed wetlands with suitable habitat for the target species and compared the accuracy and efficiency of UAS vs. a ground-based observer.

   For this assessment, UAS performance is evaluated by detection rate, mapping accuracy, and efficiency as defined below:

   Detection Rate: the ability to identify an infestation using UAS; binary measurement (detected or not-detected)

   Mapping Accuracy: the difference between a UAS derived measurement of infestation extent vs. ground-based GPS (control)

   Efficiency: comparison of time to survey and collect data; UAS vs. ground-based observer

Evaluating Flight Parameters for Optimal Detection of *Phragmites australis*

Methods

To evaluate the effect of seasonal timing and flight altitude on UAS detection and mapping accuracy of *P. australis,* we selected three wetlands containing 3-11 known infestations of the species (Table 3) and conducted monthly flights at each site from the time of emergence to senescence, approximately June to October. September flights were not completed due to logistical constraints. To the greatest extent possible, each monthly flight was performed during periods of similar weather and sunlight to minimize confounding variables. During each visit, flights were repeated at 150, 300, and 400 feet above ground level (AGL). All flights were completed using a DJI Phantom 3 Professional and an autonomous mapping software to maintain a consistent data collection extent and flight parameters for all samples. During each monthly visit, we collected ground-based GPS measurements of each *P. australis* infestation for comparison against UAS derived measurements.

Table 3. Summary of study sites for evaluation of altitude and seasonal timing.

	Webb Royce Swamp	Matty's Mountain	Berry Pond
Number of Infestations	8	11	3
Average *P. australis* Extent (ground GPS acres)	0.153	0.289	0.111
Average *P. australis* Cover	65	51	28

All UAS data was processed using Environmental Systems Research Institute (Esri) Drone2Map software. True color orthomosaics were imported to ArcMap for assessment and all visual *P. australis* infestations were manually digitized and delineated. To determine the effect of flight parameters, we compared UAS derived data vs. ground-based GPS to evaluate:

(1) the number of infestations correctly identified by UAS; and
(2) the accuracy of UAS derived extent measurements vs. ground-based GPS.

When evaluating mapping accuracy, no differentiation was made for errors of commission vs. omission. Total mapping error was reported as absolute difference. Accuracy analysis was performed only for infestations that were successfully detected with UAS.

Results

Four missions were completed at each study site between June and August and in October for a total of 36 flights. The average flight time of each mission was 11.3 mins. (range 3.38-46.25 mins.), and each mission collected an average of 129 photos (range 15-490 photos) for orthomosaic generation. Flight altitude had the greatest impact on image processing efficiently and completeness. As flight altitude increased, both the number of images collected and spatial resolution of the map decreased (Figure 4a). However, changes in average spatial resolution between altitudes were not statistically significant.

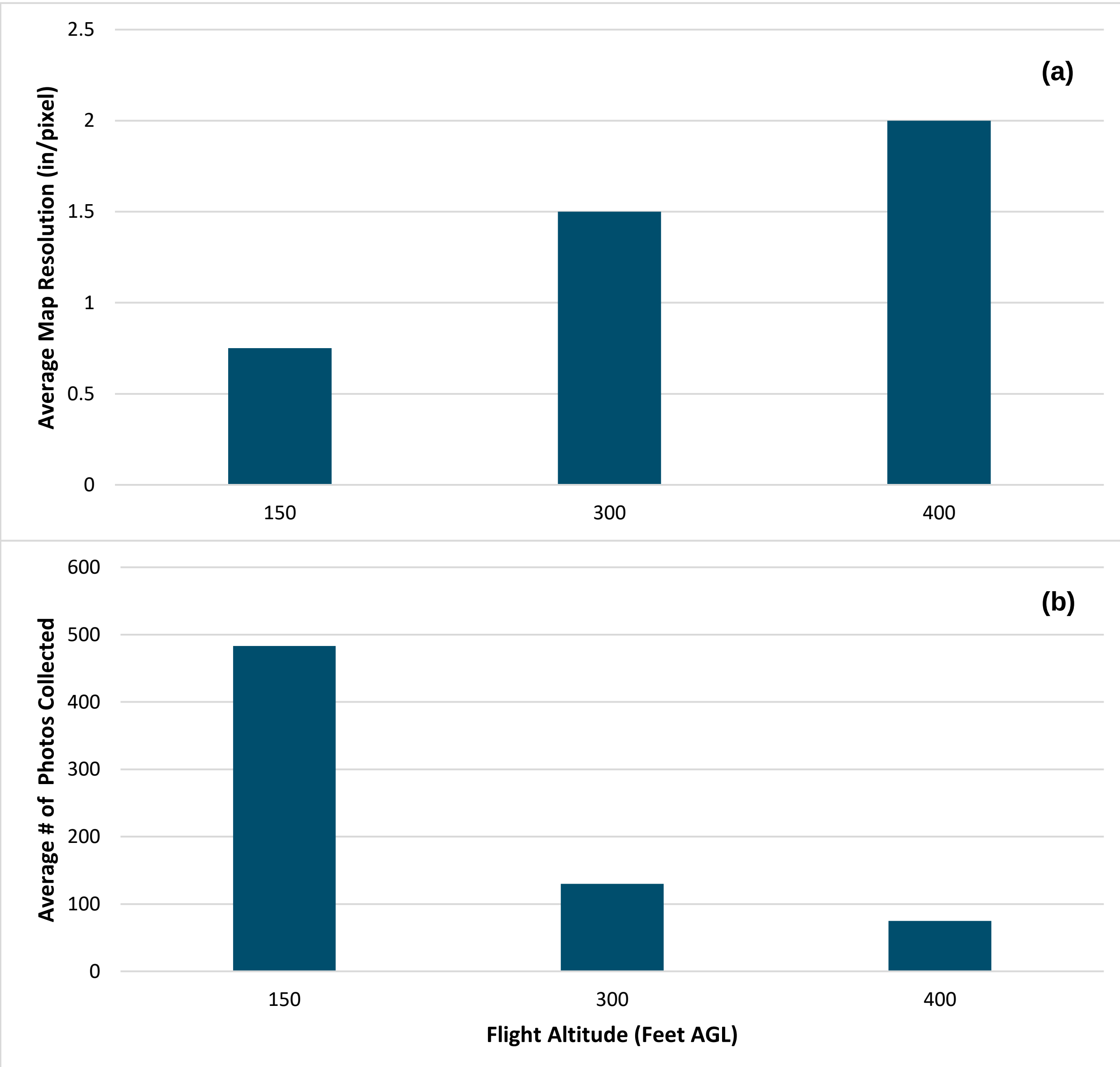

Figure 4. (a) Map resolution (inches/pixel) and (b) average number of photos collected per mission at various flight altitudes.

Patch Detection

Average patch detection rate, measured as the percentage of known infestations detected, across all months and altitudes was 52% (range 0.25 – 0.72). The highest accuracy was achieved in August for flights performed at 300 and 400 ft when 72% of known infestations were detected. Averaged across all altitudes, the greatest detection was achieved in August (62%), corresponding with peak growth and tassel of *P. australis.* Averaged across all months, detection was greatest for flights performed at 300 ft (57%) but followed closely by 400 ft (56%) (Figure 5). In general, detection ability increased as a function of increasing flight altitude.

Infestations that were successfully detected averaged 0.276 acres in extent and 67% invasive species cover, while undetected patches averaged 0.136 acres and 34% cover.

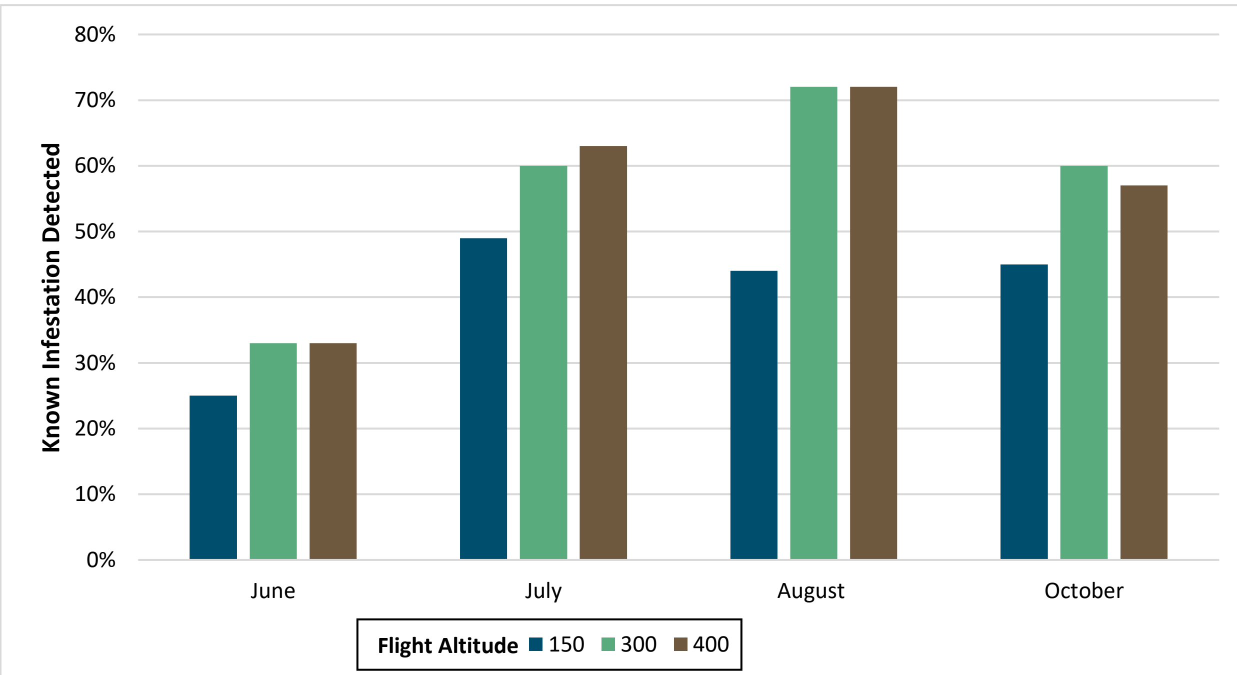

Figure 5. Percent of known *P. australis* patches detected by month and flight altitude.

Mapping Accuracy

On average, drone derived measurements of extent deviated 0.067 acres from GPS measurements (range 0.002 to 0.942 acres). For the 149 infestations detected by UAS, there was not a statistically significant difference (p=0.25) between UAS and GPS derived extent measurements.

Error was lowest for flights preformed in August at 300ft AGL where UAS measurements were within 0.04 acres of GPS controls. Averaged for all sites and altitudes, the greatest mapping accuracy was achieved in July (avg. error 0.05 acres) (Figure 6). Across all months, mapping accuracy was greatest for flights performed at 400 ft (avg. error 0.05 acres). In general, mapping accuracy increased as a function of increasing flight altitude.

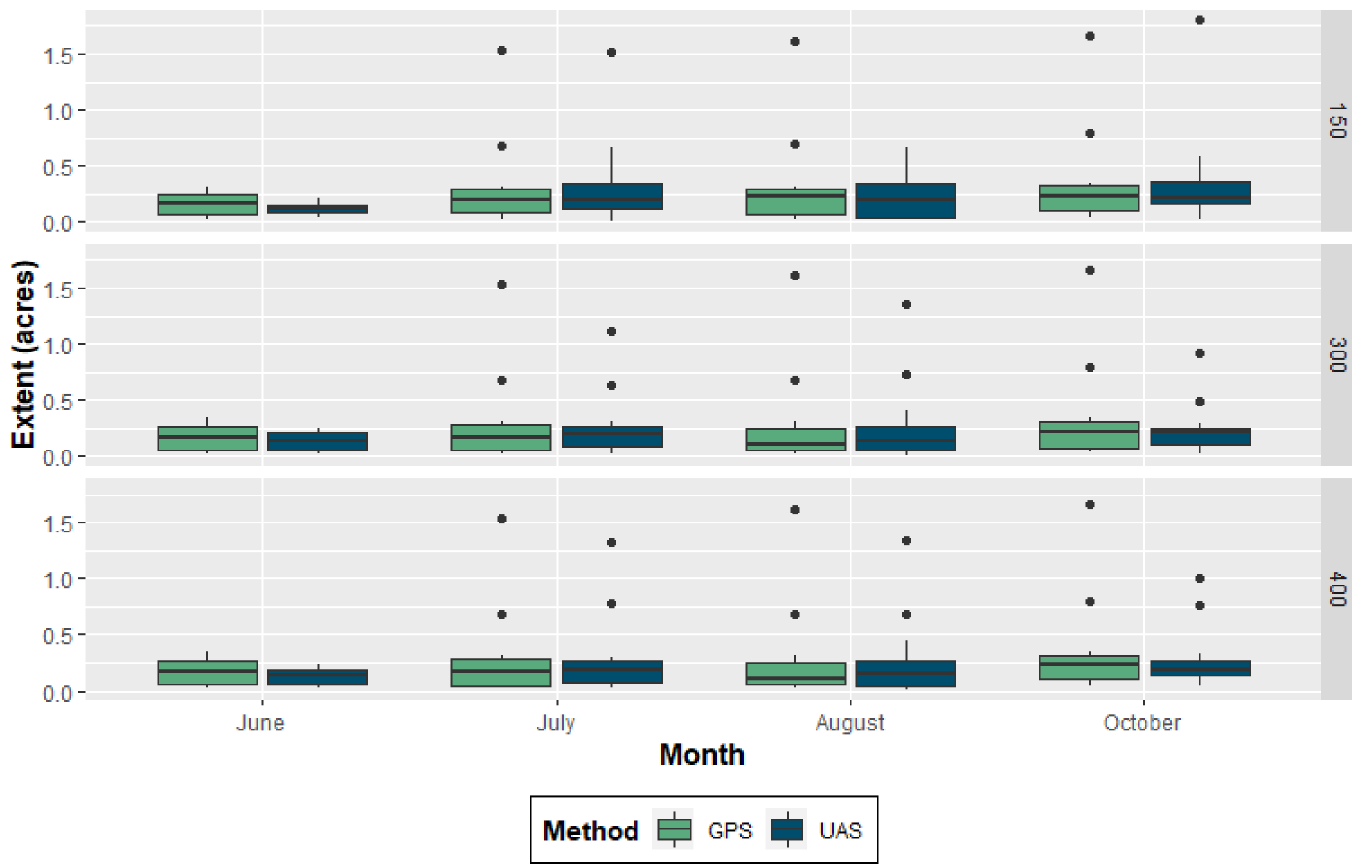

Figure 6. Comparison of UAS and GPS extent measurements for varying flight altitude and months.

Conclusions
Detection of *P. australis* was best during August, which corresponded with the peak growth period of the target species. Detecting and delineating infestations from true-color UAS imagery was most effective when *P. australis* increased in size and became more distinguishable from surrounding vegetation. In addition, the tassel-like inflorescence of *P. australis,* which developed in late summer, presented a unique texture that aided detection and mapping accuracy.

Contrary to expectations, detection and mapping accuracy improved as the altitude of flights increased. While lower altitude flights produced maps with greater spatial resolution (more detail), this presented challenges for map processing. Images collected during low altitude flights have a small footprint and, as a result, little heterogeneity. The similar vegetation/landcover in the small footprint of each image resulted in map processing errors that excluded portions of the study site(s) from final maps. Conducting flights at a higher altitude not only increased detection and mapping accuracy, it also required fewer images, which minimized computing requirements and facilitated faster processing time.

Key Takeaways:

- **Synchronize flights with the target species peak phenology.** Best results were achieved when the target species was at full growth and most distinguishable from surrounding vegetation. Conducting flights while conspicuous diagnostic features (ex: fruits, flowers) are present can also improve performance.

- **Higher altitude flights improved results and efficiency.** The difference in spatial resolution between flights performed the maximum legal altitude (400 ft AGL) and low altitude was negligible. Higher altitude photos had larger footprints with greater heterogeneity that improved processing/stitching during orthomosaic map generation. In addition, higher altitude flights could be completed faster and with fewer batteries and required fewer photos, which improved overall processing efficiency.

Early detection of *Phragmites australis* infestations using true-color imagery

Methods

To test the efficacy of UAS as an early detection tool for *P. australis* we selected 39 previously unsurveyed wetlands with suitable habitat for the target species. We intentionally selected survey sites in close proximity of roads to increase the likelihood for *P. australis* presence. Prior to each field survey, we delineated an intended survey area using desktop geographic information systems (GIS) and freely available satellite data. Survey areas ranged from 5.79 to 236.56 acres and typically encompassed the entirety of an emergent wetland complex.

We performed paired surveys at each site using UAS and a ground-based GPS data recorder. The ground and UAS surveys were performed by separate data recorders to minimize bias and ensure the UAS pilot would not have a priori knowledge of whether the wetland was invaded. To complete ground surveys, a field crew member was provided the survey area polygon on a GPS enabled mobile device. The surveyor was instructed to walk transects through the survey area until they could confirm with a high degree of certainty whether *P. australis* was present or absent. If *P. australis* was detected, the surveyor delineated the infestation using the GPS enabled mobile device. Field crew members recorded total survey time for each study site, beginning when they entered the wetland and ending when they returned to their point of origin.

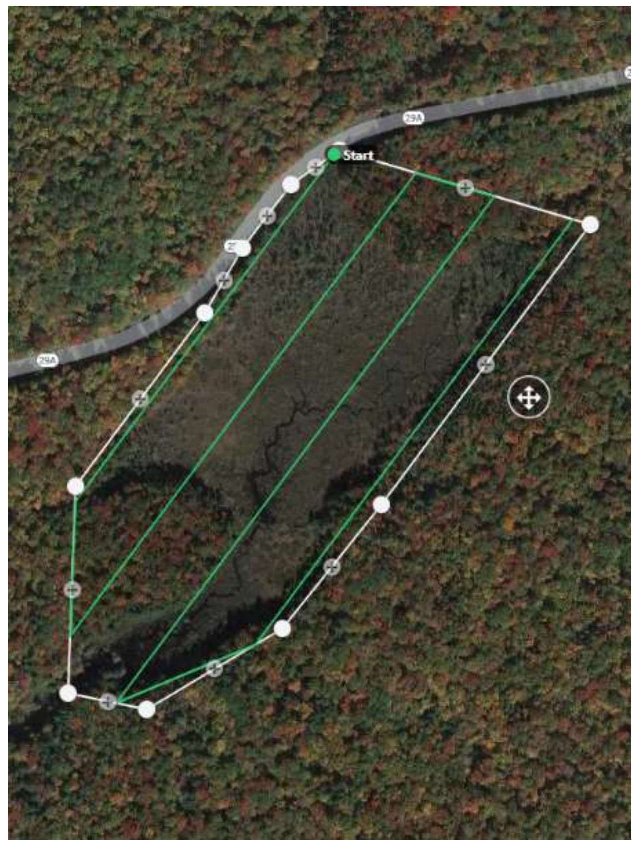

Figure 7. Example of UAS flight plan for a 25+ acre wetland.

For UAS surveys, we used the intended survey area polygon to create an autonomous UAS mission (Figure 7). The UAS pilot executed the autonomous mission, collecting a series of overlapping nadir images. Each mission was processed using Esri's Drone2Map software to create a single orthomosaic map of the site. The processed orthomosaic was imported to desktop GIS, where it was manually reviewed to determine presence or absence of *P. australis*. To facilitate manual review, a fishnet of 1.5-acre grids was overlayed on the map. Each grid was visually examined to assess *P. australis* presence/absence. If infestations were detected, they were manually digitized. As part of the UAS data collection, we recorded the total time required to complete the drone flight (acquisition), process the imagery, and complete manual review. We calculated total survey time as a sum of these three measurements and active survey time as the sum of data acquisition plus manual review.
To evaluate the efficacy of UAS for *P. australis* early detection, we compared UAS derived data vs. ground-based GPS surveys to evaluate:

(1) the number of infestations correctly detected by UAS; and
(2) the accuracy of UAS derived extent measurements vs. ground-based GPS

When evaluating mapping accuracy, we did not differentiate errors of commission and omission. Total error was reported as absolute difference. We performed this analysis only for infestations that were successfully detected with UAS.

Finally, we evaluated the efficiency of UAS as a survey tool by comparing the total time required to complete UAS vs. ground-based surveys. We considered total UAS time (flight + processing + review) and active UAS time (flight plus review) where human input was required.

Example of processed orthomosaic map for the approximately 25-acre Swede Brook Wetland. Two infestations of *P. australis* were detected using UAS.

Results
A total of 39 wetlands were surveyed, ranging in size from 5.79 to 236.56 acres ($\bar{x}$ = 64.18). All flights were performed at 400 feet AGL near the peak growth period of *P. australis*.

Patch Detection

Ground based surveyors detected 18 infestations of *P. australis* at 13 survey sites. Five sites contained two infestations and the remaining eight locations each contained one infestation. The average extent of infestations measured by GPS was 0.19 acres (range 0.001 – 0.78) and average percent cover was 33% (range 5-75).

Using UAS orthomosaic maps, we successfully detected 5 of 18 (28%) known *P. australis* infestations. UAS analysis resulted in two false positives at one wetland with no *P. australis* present. We successfully confirmed *P. australis* absence at 26 survey sites.

There were notable differences in *P. australis* extent and cover for infestations that were detected vs. not-detected by UAS. In general, patches that were detected by UAS had a higher percent cover of *P. australis* and were larger in extent (Figure 8, Table 4).

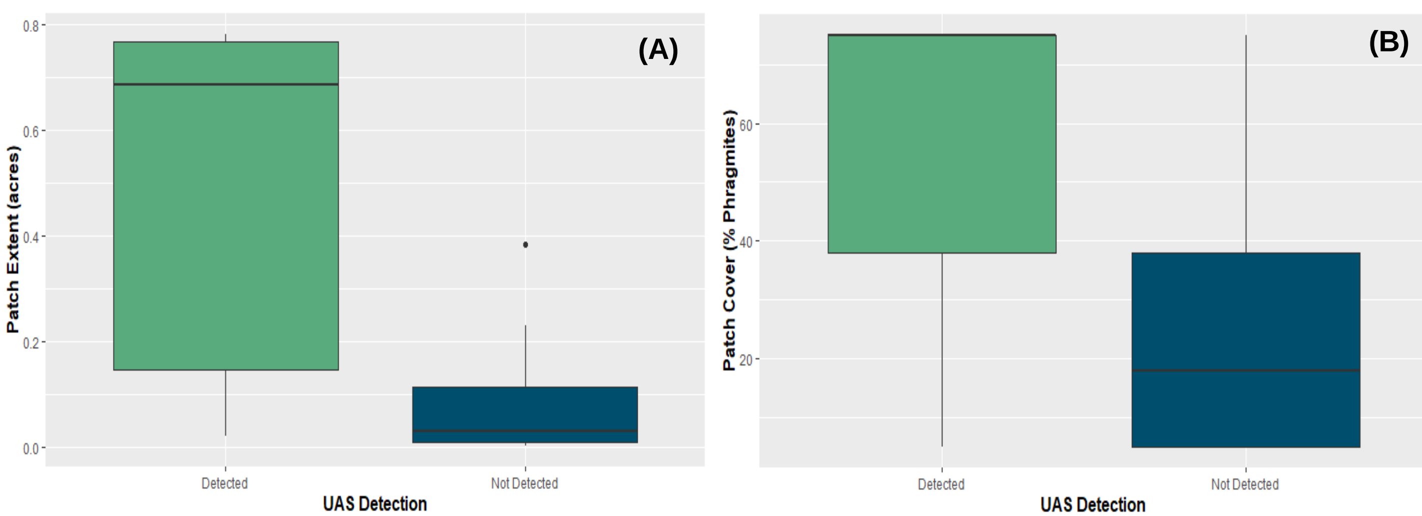

Figure 8. Difference in average extent (A) and cover (B) of *P. australis* infestations that were successfully detected vs. not-detected with UAS.

Table 4. Average extent and percent cover of *P. australis* infestations detected by detection ability.

	Detected	**Not Detected**
Average Extent (acres)	0.48	0.08
Average *Phragmites* Cover (%)	54	26

Mapping Accuracy

We successfully detected 28% of known *P. australis* infestations (n=5). For these sites, we compared the accuracy of UAS derived extent measurements vs. ground-based GPS. There was no statistically significant difference (p=0.16) in extent measurements between patches mapped with UAS and GPS. In general, UAS measurements slightly underrepresented the extent of infestations. The average error for all infestations was 0.1 acres (Figure 9).

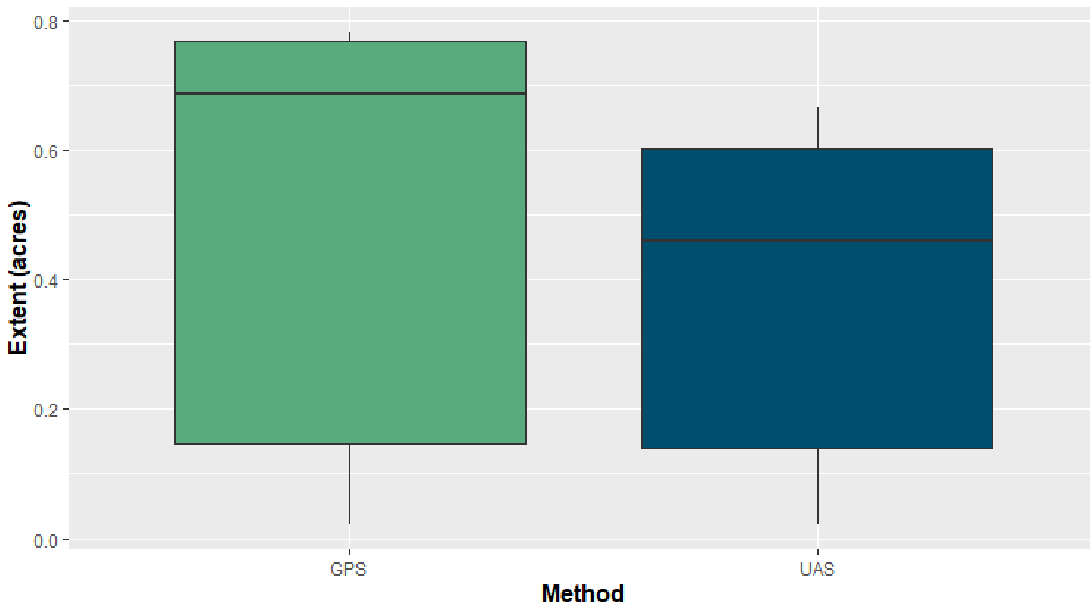

Figure 9. Comparison of UAS and GPS derived measurements of extent (acres) for infestations successfully detected by UAS,

Efficiency

Survey time was evaluated only for study sites with 100% detection accuracy including confirmed presence and absence (n=29). Total UAS survey time per site ranged from 16.63 to 457.93 minutes ($\bar{x}$=130.27 min). On average, map processing accounted for 81% of the total UAS survey time ($\bar{x}$=111.93 minutes). UAS data acquisition and visual review was a much smaller component of total time, requiring an average of 18.35 mins/site. GPS survey time ranged from 14.95 to 352.62 minutes ($\bar{x}$=108.83) per site. Both UAS and GPS survey time had a strong positive correlation to survey area (Figure 10).

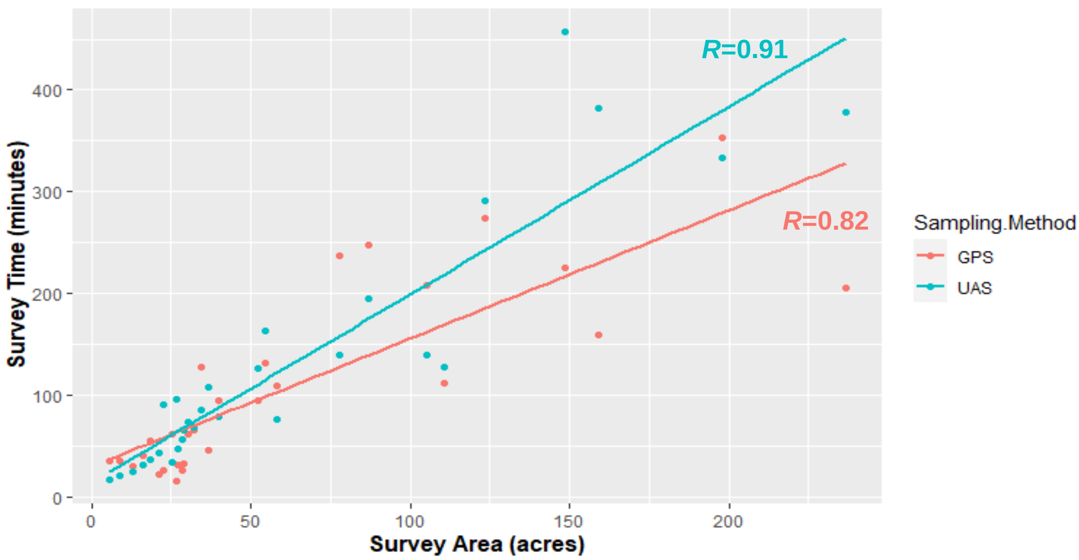

Figure 10. Relationship of UAS and GPS survey time (min) to survey area (acres).

There was not a statistically significant difference between GPS time and total UAS time ($p=0.14$). However, a statistically significant difference was observed when comparing GPS time to active UAS time ($p<0.001$). A summary of survey times aggregated by detection status is provided in Table 5.

Table 5. Comparison of UAS and GPS survey time (minutes) by site type.

UAS Detection Status	Number of Sites	Average GPS Time §	Average UAS Total Time † (active time ††)
Successfully Confirmed Absence	26	110.54	136.24 (17.65)
Successfully Confirmed Presence	3	93.99	78.55 (24.36)
Failed to Confirm Presence	10	112.81	104.07 (18.92)

§ GPS time calculated as total person time to account for multiple surveyors per site.
† Total UAS time includes data acquisition (flight), processing, and visual review/delineation.
†† Active UAS time only includes tasks where active user input is needed (acquisition and visual review)

Conclusions
Of the 39 wetlands surveyed, UAS successfully confirmed presence or absence at 29 sites for an overall accuracy of 74%. However, for wetlands with *P. australis* present, the use of true-color UAS imagery for early detection of incipient infestations produced mixed results.

Sample size was limited due to the low distribution and abundance *P. australis* in wetlands suitable for UAS flights. When *P. australis* was present, infestations were small, averaging 0.26 acres, and often had low percent cover. Only 28% of infestations were detected; however, infestations that were identified could be delineated with a high level of accuracy. Two undetected infestations were located under tree canopy, which precluded aerial detection. Anecdotally, infestations were more likely to be detected when *P. australis* cover was high, regardless of extent. Even large infestations with low percent cover were difficult to detect, especially when interspersed with native vegetation such as cattails (*Typha spp.)*.

The difference between total UAS survey time vs. ground-based GPS was not statistically significant, indicating UAS is not an inherently faster survey technique. However, when UAS map processing time is excluded, there is a significant time difference between the techniques. Processing maps does not require active user input, allowing the data recorder/practitioner to complete other tasks.

Additionally, there are advantages to the use of UAS besides time savings. For example, field crews do not have to walk through thick vegetation, deep mud, or deal with hazardous conditions to access sites on the ground. Aerial surveys can have less direct impact to vegetation than ground surveys.

Key Takeaways:

- **UAS are a complement, but not a replacement, for boots on the ground surveys.** UAS can be used to confirm invasive species absence or detect the presence of large and/or dense infestations of conspicuous species. However, early detection of small, sparse patches may not be possible with true-color imagery alone. The use of machine learning or advanced data (multispectral, elevations models, etc.) may improve detection rates.

- **UAS surveys are significantly faster than ground surveys** when map-processing time is excluded. However, map processing accounts for approximately 80% of total UAS survey time. Although user input is not required during this process, it does impact the timeliness of results.

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