THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF PLANT SCIENCES

EXOTIC VEGETATION ASSESMENT (EVA): REMOTE SENSING *PHRAGMITES AUSTRALIS* AT PRESQUE ISLE STATE PARK

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ABSTRACT

Invasions of non-native Common Reed, *Phragmites australis*, alter native wetland communities. To reduce the extent of *Phragmites* invasions, suppression tactics, like herbicide applications, mowing, and burning, are often employed. Monitoring the efficacy of *Phragmites* suppression is a challenging and critical component of *Phragmites* management. Unmanned aircraft systems have successfully been used to map wetland vegetation. This project presents a protocol for collecting aerial imagery using the DJI Phantom 2 Vision+, a commercial remote controlled quad rotor helicopter, and a protocol for classifying land cover classes from aerial imagery. Classified aerial images identified land cover classes with an overall accuracy of 73.62%. Individual *Phragmites* plants could be discerned in the high resolution classified aerial images. Potential applications for imagery collected using unmanned aircraft systems include monitoring the efficacy of *Phragmites* suppression programs, tracking changes in *Phragmites* invasions over time, and detecting new *Phragmites* patches.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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"I bequeath myself to the dirt to grow from the grass I love, if you want me again look for me under your boot-soles."

– Walt Whitman, Song of Myself

Chapter 1

Introduction

Study Species - *Phragmites australis*:

Phragmites australis (Cav.) Trin. ex Steud., hereafter referred to as *Phragmites,* shown in Figure 1, can be found on every continent except Antarctica and is found in all of the continental states in the United States (Marks, Lapin, Randall, 1994; USDA Plants Database). Preferred habitats for *Phragmites* include freshwater, brackish, and alkaline wetlands with slow-moving or stagnant water (Marks, Lapin, Randal1, 1994; Fofonoff et al., 2003). Recently, a Eurasian haplotype of *Phragmites* has begun to proliferate in North American wetlands, as shown in Figure 2, often forming dense monospecific stands in the wetlands it invades (Saltonstall, 2002, 2003).

Figure 1. *Phragmites* monospecific stands.
Image from Michigan Tech University, 2012.

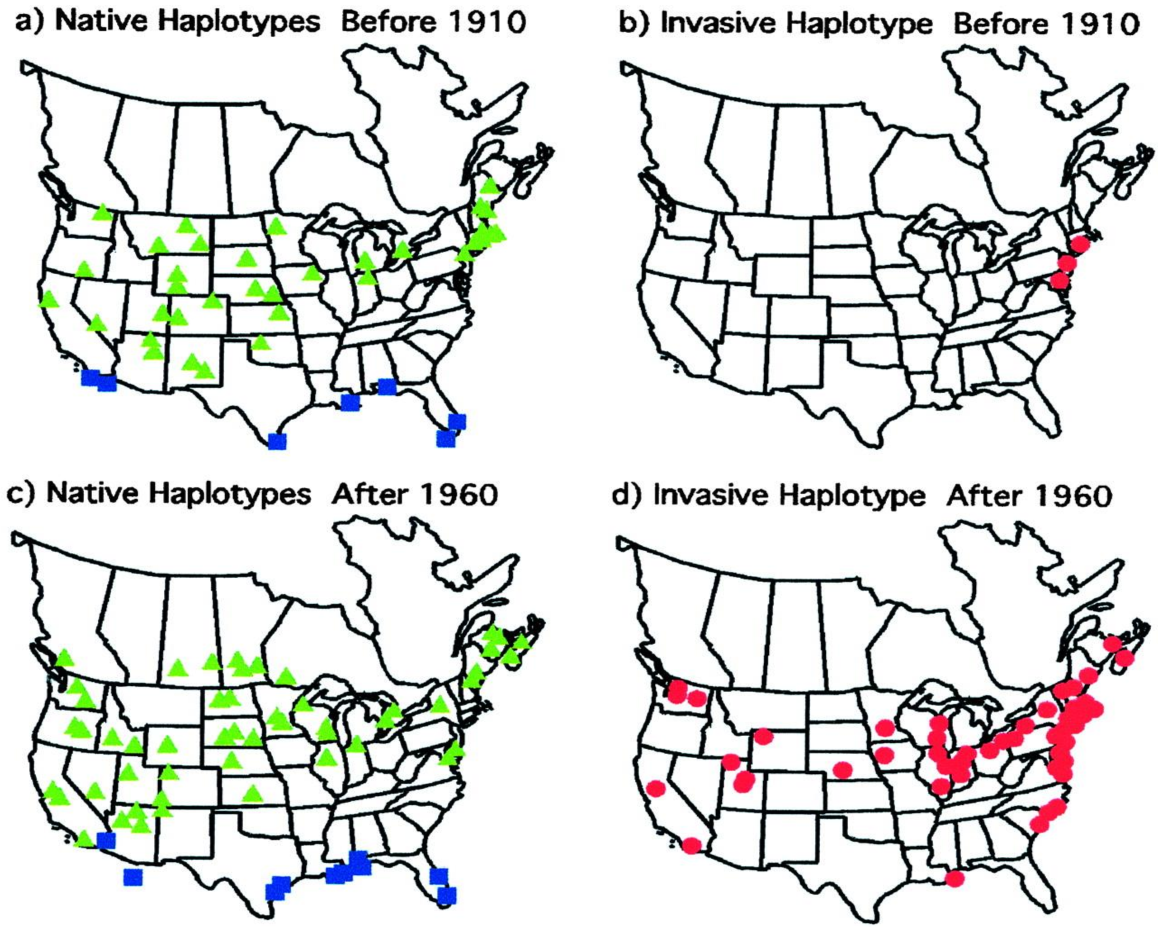

Figure 2. Proliferation of the invasive *Phragmites* haplotype. Image from Saltonstall, 2002.

Phragmites alters the environments it invades and can be classified as a "backseat-driver" of ecosystem change (Mortensen, pers. comm.). "Backseat-drivers" of ecosystem function rely on disturbance to facilitate their initial invasion. Upon establishment, backseat-drivers further alter the ecosystems they invade, resulting in native species declines (Bauer, 2012). On Lake Erie, *Phragmites* invasions have been tied to fluctuations in the lake's depth, climate change, and other anthropogenic ecosystem changes (Whyte et al., 2008; Wilcox et al., 2003). After establishment, *Phragmites* also alters nutrient cycling by sequestering carbon, reducing decomposition, and immobilizing nutrients (Meyerson, 1999). In addition to these impacts, *Phragmites* disrupts marsh food webs (Soulliere, 2007; Gratton & Denno, 2006; Tewksbury, 2002), and reduces plant biodiversity (Chambers et al., 1999). *Phragmites* invasions also have economic implications by reducing property values, impeding recreation, and increasing the risk of fires near large patches of dormant *Phragmites* (Cole, 2010).

Phragmites management typically is achieved using herbicide applications. Between 2005 and 2009, private and public conservation organizations in the United States spent more than $4.6 million per year on *Phragmites* removal, with 94% of organizations relying upon herbicide applications for management (Martin & Blossey, 2013). Two broad spectrum systemic herbicides—glyphosate and imazapyr—are approved for use on *Phragmites* stands. Glyphosate formulations suitable for use in marshes are sold under trade names Rodeo™, GlyPro™ and Aqua Neat™. The imazapyr formulations suitable for use in marshes are sold under trade names including Habitat™, Eagre™ and EcoImazapyr™. Herbicides sprayed in marshes may be mixed with a nonionic surfactant to improve foliar uptake. Herbicides are often applied to *Phragmites* by hand, from a boat using a boom or handgun, or aerially using a helicopter. Mowing and burning are other *Phragmites* removal tactics. *Phragmites* can be controlled mechanically by mowing, cutting, excavating plants, and burning plants and litter. Though, *Phragmites'* response to mowing, cutting, and excavating plants varies (Hazelton et al., 2014); burning alone has been found to stimulate growth (Thompson & Shay, 1985). Short term, high intensity grazing using cattle or goats has shown success in managing *Phragmites*, but, in wetlands, biological control by grazing results in soil compaction and nutrient enrichment from manure (Hazelton et al., 2014). *Phragmites* in North America is also consumed by various invertebrate herbivores; to date, herbivores have not proven effective in controlling the spread of *Phragmites.* Post-control suppression of *Phragmites* should be seen as a restoration ecology challenge. Often, combinations of tactics are more effective at controlling *Phragmites*. For example, herbicide applications followed by mowing or burning have proven effective at exhausting belowground reserves of *Phragmites* (Carlson et al., 2009; Rolletschek et al., 2000). Regardless of the control tactic, management approaches should reflect a restoration ecology approach, as suppression alone is insufficient for the long-term recovery of wetland plant communities. Revegetation of areas where *Phragmites* control tactics have been employed promotes the recovery of wetland plant communities. If *Phragmites* invasions have been in place for some time, accumulated standing litter limits the recruitment of native flora (Minchinton et al., 2006). Revegetation of wetlands with native flora can help competitively exclude *Phragmites*, as wetlands with more intact vegetation are more resistant to invasion (Wang et al., 2006; Kennedy et al., 2002).

Remote Sensing *Phragmites*:

For the purpose of this paper, remote sensing can be defined as "the practice of deriving information about the Earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one more regions of the electromagnetic spectrum, reflected or emitted from the Earth's surface" (Cambell & Wynne, 2011). Today, improvements abound in remote sensing platforms, like satellites, airborne imagery platforms, and unmanned aircraft systems. Remote sensing platforms can provide data of varying spatial and temporal resolutions. Spatial resolution, the on-the-ground size of a single image pixel, of remote sensing platforms ranges from multi-kilometer to sub-centimeter pixels. High spatial resolution aerial imagery is more able to discern individual features of the landscape, like scattered weeds (Lamb & Brown, 2001). Temporal resolution, the time between image acquisition events, may range between years, weeks, and days. Satellite remote sensing platforms can provide image resolutions ranging from multiple kilometer pixels to half-meter pixels, with revisit times ranging between weeks and days. Though, clouds may obscure the ground during satellite imagery acquisition, resulting in fewer images useful for remote sensing. This, effectively, reduces the temporal resolution of satellite imagery. Airborne remote sensing platforms, as found aboard specially-designed airplanes, can sometimes provide higher spatial resolution imagery than satellite remote sensing platforms. Yet, tasking imagery from airborne remote sensing platforms is often costly. To save money, aerial imaging may occur yearly or less frequently, effectively reducing the temporal resolution of imagery acquired by airborne remote sensing platforms. Unmanned aircraft systems, commonly referred to as drones, have expanded in popularity amongst enthusiasts and scientists, as they have the potential to routinely acquire affordable, high spatial and temporal resolution aerial imagery. Common unmanned aircraft system models include fixed-wing model aircraft and small remote controlled helicopters. Balloons and kites may also be employed to acquire aerial imagery.

Unmanned aircraft systems have been used in vegetation studies. In the agricultural context, quad rotor helicopters have been used to remotely detect weeds growing amongst crops (Torres-Sánchez et al., 2013). Aerial images collected by a single rotor remote controlled helicopter were used to calculate crop leaf area index and normalized difference vegetation index, a measure of crop health (Sugiara et al., 2005). Additionally, fixed-wing model aircraft have successfully acquired aerial imagery of coffee plantations in Hawaii, providing plantation managers with images showing irrigation discontinuities and weed infestations across the plantation (Herwitz et al., 2004). In rangeland settings, fixed-wing model aircraft and single rotor remote controlled helicopters have been used to acquire aerial imagery for the identification of rangeland species and the detection of weed infestations (Jones, 2007; Laliberte et al., 2009; Rango et al., 2009).

The successes and lessons gleaned from agricultural and rangeland remote sensing using unmanned aircraft systems can be applied to the detection of *Phragmites* using unmanned aircraft systems. Since control of *Phragmites* often spans multiple years and multiple spatial scales, from small individual patches to whole landscapes, regular, long-term monitoring of *Phragmites* control is an essential component of any management plan (Adam et al., 2010). Yet, long-term monitoring of control over large tracts of land is often financially and logistically challenging (Hazelton et al., 2014). Physically traversing wetlands is difficult and typically entails variable water levels, sometimes requiring access by boat, and navigation across unconsolidated terrain and through dense vegetation. The development of high spatial resolution remote sensing tactics can aid in early detection of *Phragmites* invasions (McCormick & Whigham, pers. comm.). Since Ihse and Graneli first determined the relationship between *Phragmites* biomass and infrared/red reflectance ratios in the 1980s, the use of imagery to map

Phragmites has increased (Ozbay et al., 2012). Multispectral satellite imagery from platforms including EO-1 Hyperion, GeoEye, WorldView-2, and Quickbird have been used to remotely sense *Phragmites* (Pengra et al., 2007; Villa et al., 2013; Gilmore et al., 2008). Airborne hyperspectral imagery platforms like the Airborne Imaging Spectrometer for Applications sensor (AISA) and the Multispectral Infrared Visible Imaging Spectrometer (MIVIS) have been used to remotely sense *Phragmites* (Villa et al., 2013). Unmanned aircraft systems have also been used for sensing *Phragmites*. AggieAir™, a fixed-wing aircraft system, has successfully mapped the extent of *Phragmites* invasions At the Bear River Migratory Bird Refuge on the shore of the Great Salt Lake, Utah. In the Watarase wetland of central Japan, imagery acquired using a multi rotor helicopter was successfully used to identify *Phragmites* and *Miscanthus sacchariflorus* at a sub-centimeter resolution (Ishihama et al., 2012). An example of classified imagery generated from the Watarase wetland can be found in Figure 3.

Figure 3. Imagery and classified imagery generated from the Watarase wetland. The image on the left is a magnified image. The image on the left is the magnified image with *Phragmites* and *M. sacchariflorus* classified.

Research Objectives:

This project aims to create a remote sensing protocol for modeling *Phragmites* presence in wetlands where suppression tactics have been implemented. In the longer term, these protocols would be used to remotely assess the efficacy of suppression tactics. The specific objectives of my thesis work are listed below:

1. Develop a flight protocol for acquiring unmanned aircraft system-generated imagery using the DJI Phantom 2 Vision+ quad rotor remote controlled helicopter in *Phragmites* marshes.
2. Create a cover classification protocol for processing imagery from the DJI Phantom 2 Vision+.
3. Measure the accuracy of *Phragmites* estimates from classified imagery from the DJI Phantom 2 Vision+.

Unless otherwise noted, I conducted all methods and analyses necessary to complete the above research objectives.

Study Site:

Presque Isle State Park is an approximately 130 km^2 recurving sand spit located along Pennsylvania's shore of Lake Erie. The park contains seven distinct ecological zones, including: the bay and shoreline, Lake Erie, dunes and ridges, the sand plain and new ponds, the old ponds and marshes, thicket and sub-climax forest, and climax forest. During migration, birds often visit Presque Isle State Park, as it is located along the Atlantic flyway (PADCNR, 2014). Over 339 species of birds have been recorded, including 44 species of concern. A rich floristic community inhabits the park, with over eight hundred plant species listed (Tom Ridge Environmental Center, 2014).

Phragmites became an increasing concern at Presque Isle State Park in the late 1980's and 90's, with recorded suppression programs beginning in 1994. In 2010, the park received a two-year, $500,000 grant from Ducks Unlimited for large-scale *Phragmites* control (Drahos, 2013). An initial aerial application of glyphosate and imazapyr occurred in selected marshes in 2012 (Art Gover, pers. comm.). Since 2012, *Phragmites* management has included yearly sprayer applications and reapplications of herbicides, used in conjunction with mowing (Mike Dzurko, pers. comm.).

For the purpose of this study, site selection at Presque Isle State Park was based upon two factors. First, clear flight paths for the quadcopter were required. Wetlands obscured by trees were avoided, as they pose a risk to the quadcopter and impede visual contact throughout flight. Second, to remotely sense *Phragmites*, sites with *Phragmites* still present after herbicide treatment and mowing were required. Ultimately, a single *Phragmites*-dominated marsh was chosen for image-acquiring quadcopter flights. The marsh selected is marked in red on Figure 4. Prior to imaging, *Phragmites* infestations in the marsh were sprayed with glyphosate and imazapyr and were mowed. The *Phragmites* control history of this marsh is described in Table 1.

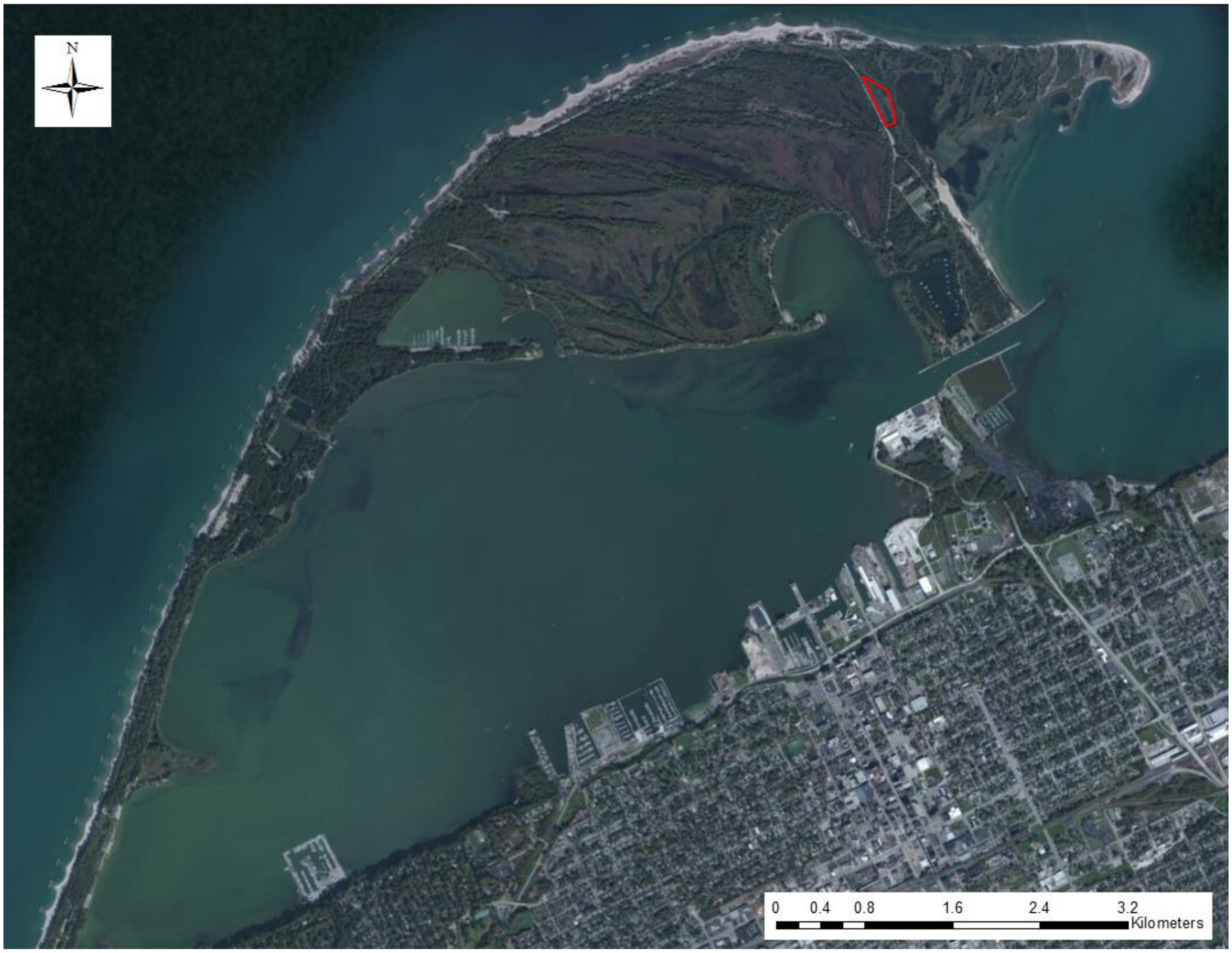

Figure 4. Satellite image of Presque Isle State Park with study site outlined in red.

Table 1. *Phragmites* management tactics used at the study site on Presque Isle State Park. Information from Mike Dzurko, pers. comm.

Year	***Management Tactics***
2013	Application of glyphosate at 3.4 kg ae/ha + imazapyr at 1.1 kg ae/ha
2014	Applications of glyphosate at 3.4 kg ae/ha and imazapyr at 1.a kg ae/ha in July, August, and October. Dead *Phragmites* stems were mowed down.

Chapter 2

Materials and Methods

Project Permissions:

Prior to conducting field work, it was necessary to secure permissions to collect data from Presque Isle State Park. This entailed working with park staff at Presque Isle State Park to fill out a collection permit. The approved permit can be found in Appendix A. Additionally, the Federal Aviation Administration (FAA) Safety Team Program Director at the Allegheny Flight Safety District Office of the FAA was contacted to ensure that flying a quadcopter for research would not violate the FAA's unmanned aircraft system policies. Since no monetary compensation was involved in this work, quadcopter flights fell under the jurisdiction of the FAA's Model Aircraft Operating Standards Advisory Circular 91-57 (FAA, 1981; Henrik Vejlstrup, pers. comm.). Standards followed for research flights, as well as other training flights, included:

- Selecting unpopulated flight areas
- Minimizing flight in front of spectators until the quadcopter was proven flight-worthy
- Flying below 400 feet at all times
- Notifying air traffic control towers at local airports of planned flights occurring within 5 km of an airport
- Maintaining line-of-sight with the UAS at all times

Presque Isle State Park is within 5 km of Erie International Airport. Thus, it was necessary to contact air traffic controllers at Erie International Airport before and after each flight at Presque Isle State Park.

Grant Writing:

A Penn State College of Agricultural Sciences Undergraduate Research Grant proposal was written in collaboration with Dave Mortensen to fund my project. Art Gover and Doug Miller, respectively, provided input on *Phragmites* invasions at Presque Isle State Park and remote sensing tactics useful for vegetation identification. The Plant Sciences Department of the College of Agricultural Sciences at Penn State, awarded $2,000 to this project, providing funds for purchasing supplies. The grant proposal to Penn State can be found in Appendix B.

Flight Altitude Test:

In order to determine the best altitude for imagery acquisition at Presque Isle State Park, an initial set of aerial images were collected using the DJI Phantom 2 Vision+. An ideal altitude for image acquisition is 70 m, as that altitude ensures sufficient image overlap for mosaicking. Presque Isle State Park's proximity to Erie International Airport necessitated a lower flight path. Thus, images were taken above one white rectangular target at 5 m, 10 m, 15 m, and 20 m. A single image of *Phragmites* and native vegetation was collected at each altitude. Image resolution was visually assessed using a laptop in the field. Later, a lens correction specific to the DJI Phantom 2 Vision+ was applied to all images in Photoshop CS6, effectively removing lens distortion. The resulting images can be found in Figures 6 through 8. Image resolution decreased with altitude, and the field of view increased with altitude. In-field assessments of imagery resolution indicated that image collection altitudes of 5 m, 10 m, 15 m, and 20 m would all provide sufficient detail for remote sensing individual plants. Since it is often challenging to acquire adequate image overlap for photo mosaicking at low altitudes, a flight altitude of 20 m was selected for this study.

Figure 5. Image of *Phragmites* and native vegetation acquired at an altitude of 5 m.

Figure 6. Image of *Phragmites* and other vegetation acquired at an altitude of 10 m.

Figure 7. Image of *Phragmites* and other vegetation acquired at an altitude of 15 m.

Figure 8. Image of *Phragmites* and other vegetation acquired at an altitude of 20 m.

Imagery Acquisition and Pre-Processing:

The Phantom 2 Vision+ (DJI; Shenzhen, China), as shown in Figure 9, is a relatively new ready-to-fly remote controlled quad rotor helicopter, hereafter referred to as a quadcopter. It is equipped with a built-in combination HD video and 14 megapixel still photograph camera. The camera has a focal length of 5 mm and a 35 mm focal equivalent of 30 mm, with a field of view ranging between 85^{o} and 110^{o}. The camera is mounted on a three-axis brushless motorized gimbal, with a controllable pitch ranging from 0^{o} to -90^{o}. This allows it to take vertical aerial photographs for photogrammetry use. Images are collected across multiple spectral bands, corresponding to three color channels: red, green, and blue.

Figure 9. DJI Phantom 2 Vision+ quadcopter. Image from quadcopters.co.uk.

The dataset for this project consisted of quadcopter-generated aerial images. Aerial images were collected using the DJI Phantom 2 Vision + on November 7, 2014 under full cloud cover conditions.

Transects were flown as shown in Figure 10 at an altitude of approximately 20 m over a 50 m by 120 m area. Images were taken every 3 seconds, generating a total of 469 images with over 60% overlap. Image overlap is a critical element in image mosaicking, as overlapping features serve as key points used in photo stitching algorithms. In Photoshop CS6, a lens correction specific to the DJI Phantom 2 Vision+'s camera was applied to all images, effectively removing lens distortion, as shown in Figure 11. Images were then mosaicked together using Microsoft Image Composite Editor's Planar Motion 2 setting. The resulting image mosaic was cropped to remove uneven edges and residual edge distortions, as shown in Figure 12.

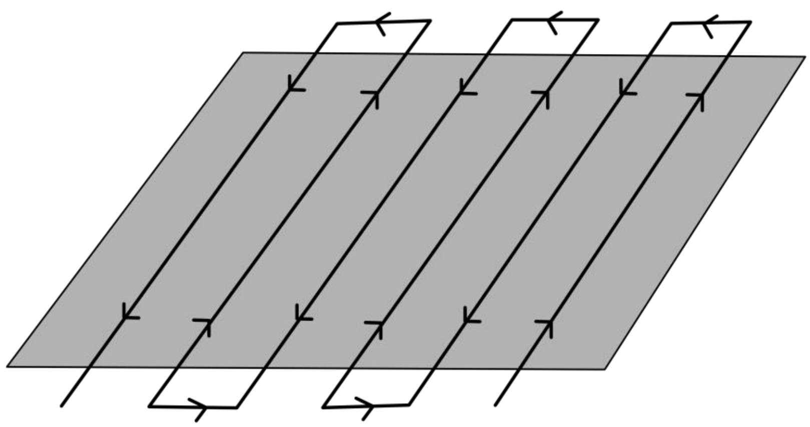

Figure 10. Flight path flown at Presque Isle State Park.

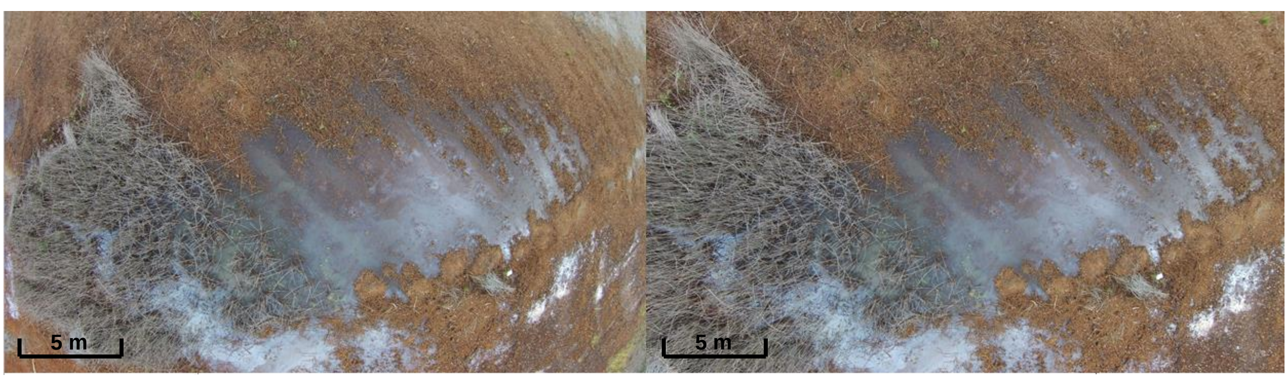

Figure 11. Lens distortion removal in Photoshop CS6. This figure shows one photograph capturing a portion of the study site. The image on the left has not had its lens distortion removed in Photshop CS6. The image on the right has had its lens distortion removed in Photoshop CS6.

Figure 12. Mosaicked image generated by Microsoft Image Composite Editor. This figure shows the composite image of the study site using the 469 images generated on November 7, 2014.

Imagery Classification:

Classification of the remotely sensed images distinguishes between cover types present in the image. Classification of cover types in image data can be divided into two methods, unsupervised and supervised classification. Unsupervised classification uses the image processing software to divide pixels with similar spectral values into groups without input from the map producer. To determine what these pixel groupings represent, map producers must ground-truth the data in the field or use data within the image to assign cover classes to each grouping. Supervised classification uses the map producer's expertise to select training areas, collections of pixels in the image which represent the cover classes of interest, which help the image processing software create a library of spectral values associated with each cover class. The image processing software then uses these spectral libraries of cover classes to classify and group the pixels in the image into the various cover classes (Prather & Lass, 2006).

This study used a supervised classification to determine *Phragmites* cover. In ArcGIS 10.2 (ESRI, Redlands, California, USA), the Image Classification toolbar was used to create a total of 40 training areas with a roughly equal number of pixels allocated to each of seven cover classes present in the image. The seven cover classes include *Phragmites* (defined as "Phragmites" in all output maps), standing *Phragmites* litter (defined as “Litter_1” in all output maps), sediment-covered *Phragmites* litter (defined as “Litter_2” in all output maps), two classes of native vegetation (defined as “Native_1” and “Native_2” in all output maps), bare ground (defined as “Bare Ground” in all output maps), and water (defined as “Water” in all output maps). Spectral libraries of each cover class were stored as spectral signature documents. A maximum likelihood classification was conducted using the spectral signature documents to define the cover class of each pixel present in the image. Detail of the classified mosaic can be found in Figure 13.

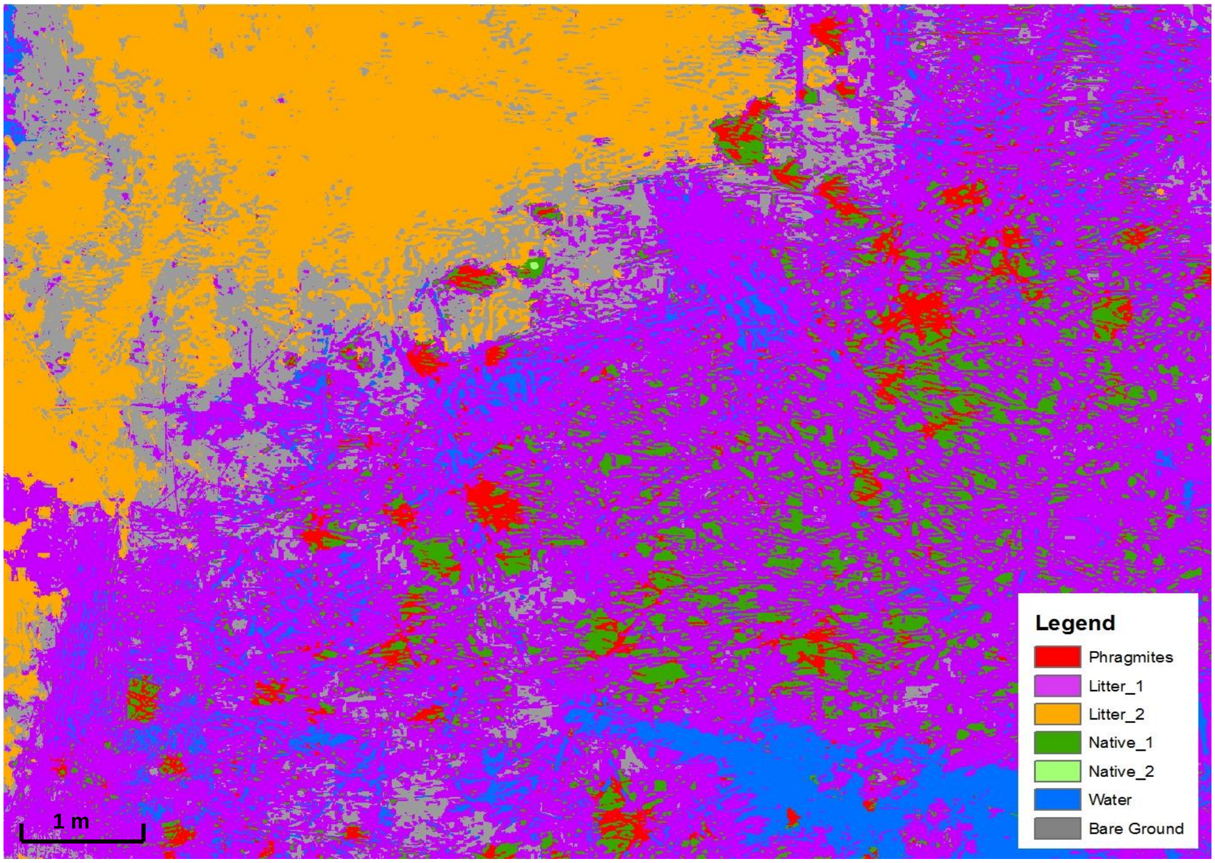

Figure 13. Detail of the classified image mosaic. The small isolated pixels are noise in the classification.

Post-Processing Imagery:

Post-processing output classified images helps to remove noise in the classification and smooth edges of pixel grouping. Post-processing of the output raster document from the maximum likelihood classification was conducted in ArcGIS 10.2. Noise present in the output raster was reduced using the Majority Filter tool at default settings. Ragged class boundaries on the output raster were smoothed using the Boundary Clean tool using an ascending sorting technique. Small isolated regions of pixels were reclassified to nearby classes using the Region Group, Set Null, and Nibble tools. A null value of 250 pixels was selected through my visual assessment of details lost in the output raster after reclassification. This null value balanced accuracy with ease of interpretation.

Accuracy Assessment:

Accuracy assessment is a critical step in successfully quantifying the efficacy of a classification scheme. Error is present in all classifications and can originate from poorly identified training samples, poorly created spectral libraries, over generalization, and registration errors. To account for error, studies often utilize a large number of ground-truthed data points to determine the accuracy of image classification (Campbell & Wynne, 2011). In general, 50 samples per *n* cover classes can be used to calculate the accuracy of an image classification using ground-truthed data (Congalton, 1991). In this study, a stratified random sampling of the seven coverage classes was conducted with approximately fifty points randomly generated for each coverage class, for a total of 350 points. Random points were created with the Create Random Points tool in ArcGIS 10.2. Since the classified imagery data had such a high resolution, a highly accurate GPS unit with sub-centimeter accuracy was required for navigation to individual ground-truth points. Due to technological constraints, the 350 points generated in ArcMap 10.2 were visually checked, instead of ground-truthed, for cover class accuracy in the aerial image and the classified image. The overall accuracy, the kappa coefficient, producer accuracy, and user accuracy were calculated using a confusion matrix. Confusion matrices identify overall classification accuracy for each cover class, as well as misclassifications in each class. Overall accuracy is a measure of total points correctly classified divided by the total number of points checked for accuracy. The kappa coefficient is a measure of the difference between observed map agreement and agreement which may be attained by chance (Cambell & Wynne, 2011). The equation is as follows:

$$\kappa = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}\left(x_{i+} \times x_{+i}\right)}{N^2 - \sum_{i=1}^{r}\left(x_{i+} \times x_{+i}\right)}$$

Where *N* denotes the total sites in the matrix, *r* denotes the number of rows in the matrix, x_{ii} is the number in row *i* and column *i*, x_{+i} row *i*'s total , and x_{i+} is the total for column *I* (Jensen 1996). Producer accuracy is a measure of the classified image's accuracy from the map producer's viewpoint and is based upon the errors of omission, instances when the classified image does not represent a cover class, even though it is present on the ground. In this case, an error of omission was when the image processing software failed to indicate the presence of *Phragmites* when *Phragmites* was actually present in the image and on the ground. Consumer accuracy is a measure of the classified image's accuracy from the map user's viewpoint and is based upon errors of commission, instances when the classified image represents a cover class when it is not present on the ground (Campell & Wynne, 2011). In this case, an error of commission was when the image processing software indicated the presence of *Phragmites* when *Phragmites* was not actually present in the image and on the ground.

Chapter 3

Results

Classified Imagery:

The classified quadcopter-generated mosaic can be found in Figure 14. Visual interpretation indicates a high fidelity between the classified image and the quadcopter-generated mosaic. Further detail of the classified quadcopter-generated mosaic can be found in Figure 15.

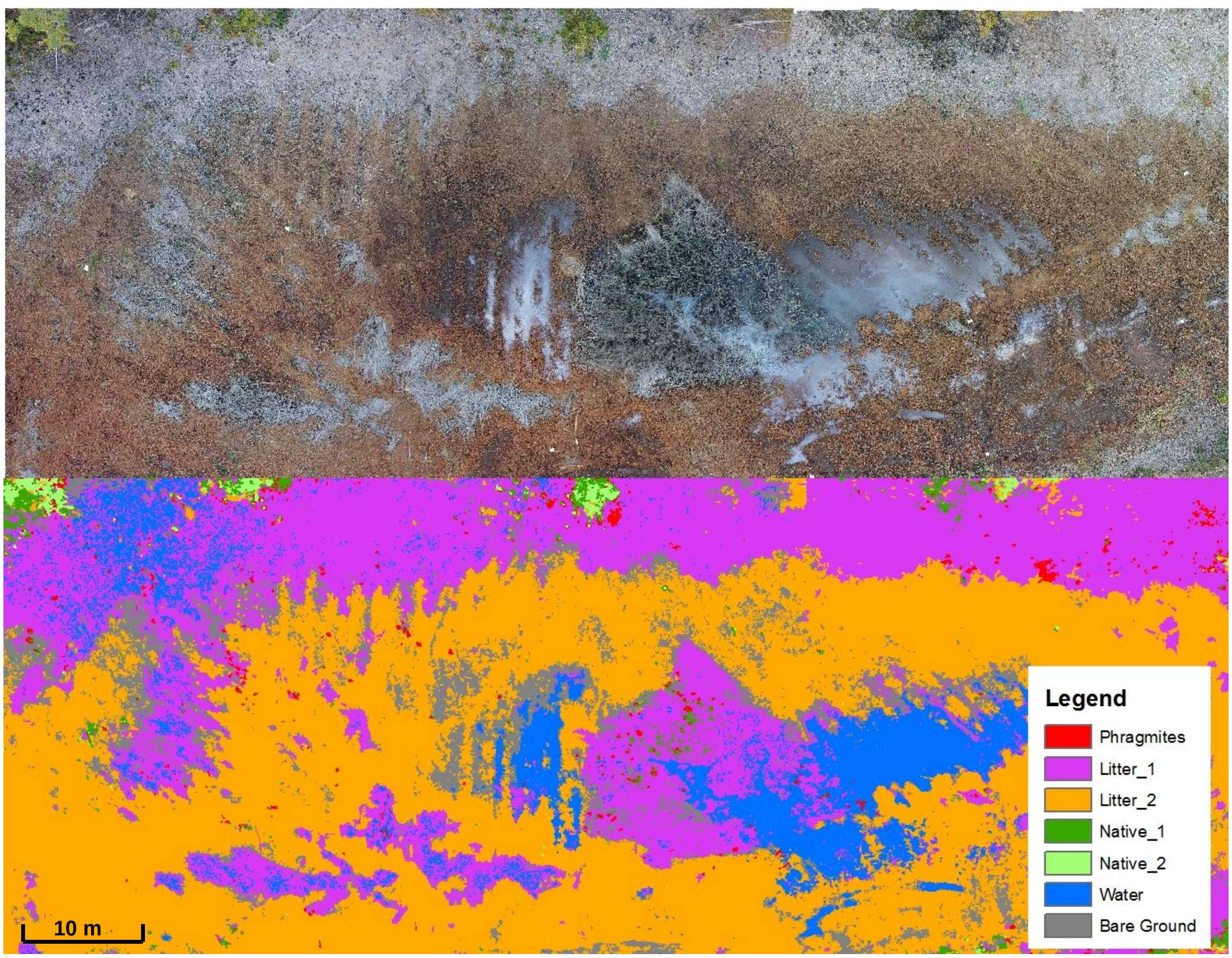

Figure 14. Classified quadcopter-generated mosaic and input image mosaic. Seven cover classes are present in this classification, *Phragmites*, standing *Phragmites* litter (denoted as Litter_1), sediment-covered *Phragmites* litter (denoted as Litter_2), two native vegetation classes (denoted Native_1 and Native_2), water, and bare ground.

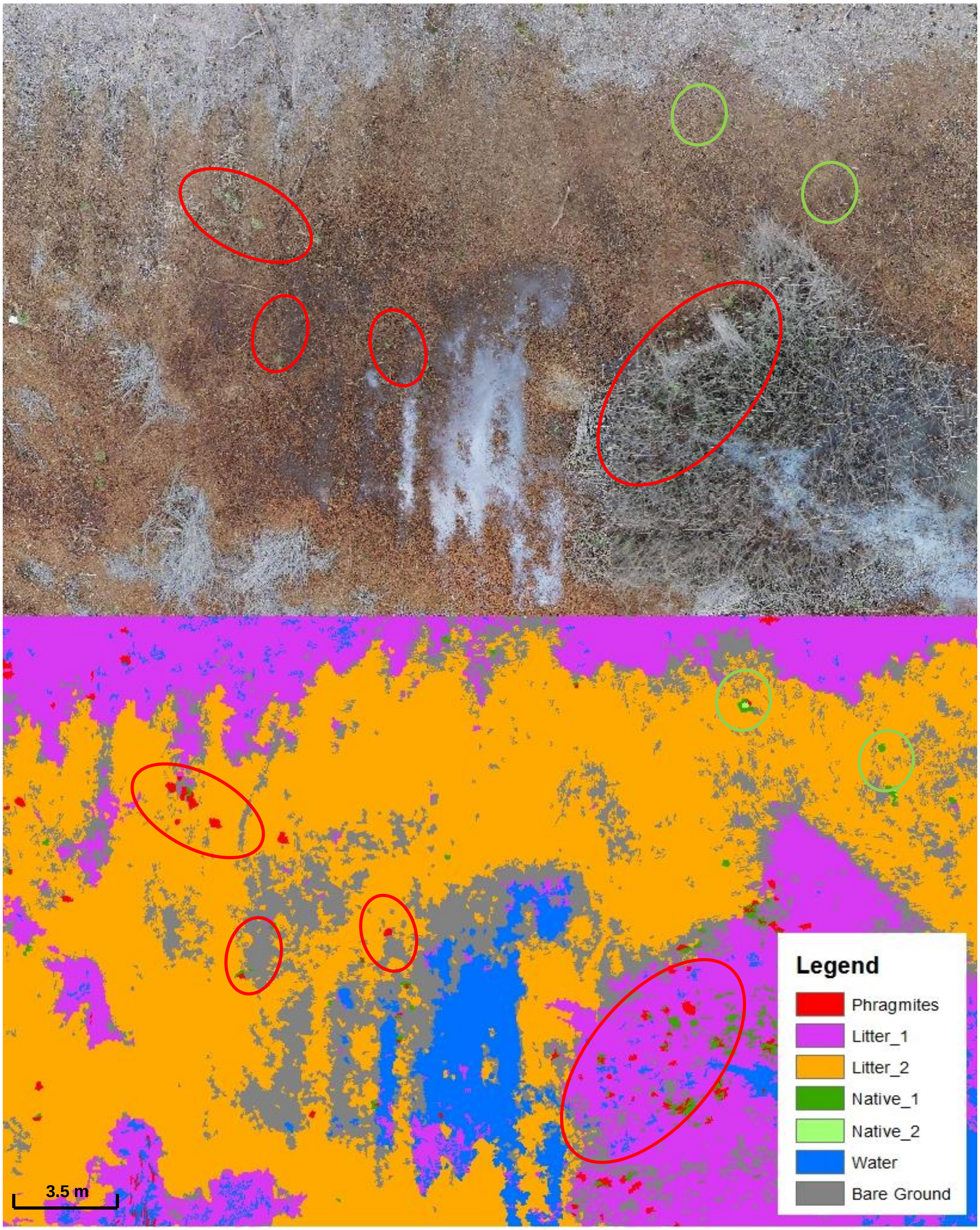

Figure 15. Detail of classified quadcopter-generated mosaic and input image mosaic. Individual *Phragmites* plants are circled in red on the input image mosaic. Native vegetation is circled in green on the input image mosaic.

Classification Accuracy:

The overall accuracy of the maximum likelihood classification was 73.62%, with a kappa coefficient of 0.692. At high resolution, maximum likelihood classifications confuse living *Phragmites* with standing dead *Phragmites* litter, water with standing dead litter, and bare ground with sediment-covered *Phragmites* litter. Producer's accuracy for the "*Phragmites*" class was 66% and user's accuracy was 84.62%, with 33 of the 50 reference points correctly assigned. 8 of the 80 reference points were classified to the "Litter_1" class, indicating that the "*Phragmites*" class can be confused with standing dead litter. The confusion between *Phragmites* and standing dead *Phragmites* can be explained by the photo mosaicking process in Microsoft Image Composite Editor. During mosaicking, photo edges sometimes became distorted, as shown in Figure 16.

Figure 16. Blurred photo edge from the mosaicking process.

In areas where standing dead *Phragmites* was the dominant cover, the distortion and blurring appeared similar in color to living *Phragmites*. For the “Litter_1” class, producer’s accuracy was 88.22% and user’s accuracy was 53.62%, with 37 of 45 reference points correctly assigned. For the “Litter_2” class, the maximum likelihood classification yielded a producer’s accuracy of 73.68% and a user’s accuracy of 70%, with 42 of 60 reference points correctly assigned. For the “Native_1” class, the producer’s accuracy was 66.67% and the user’s accuracy was 91.43%, with 32 of 35 reference points correctly assigned. The producer’s accuracy of the “Native_2” class was 95.83% and the user’s accuracy was 80.7%, with 46 of 57 reference points correctly assigned. For the “Water” class, the producer’s accuracy was 70.83% and the user’s accuracy was 79.07%, with 34 of 43 reference points correctly assigned. For the “Water” class, 14 of the 48 reference points were assigned to the “Litter_1” class, indicating that the image classification often confused water with standing dead litter. The confusion between water with standing dead *Phragmites* litter can be explained by the standing water reflecting the clouds and appearing grey in the image. The grey color of the water appears similar in color to the grey color of standing dead *Phragmites* litter, explaining the confusion between the two cover classes. The producer’s accuracy of the “Bare Ground” class was 61.22% and the user’s accuracy was 71.43%, with 30 of 42 reference points correctly assigned. For the “Bare Ground” class, 12 of the 49 reference points were assigned to the “Litter_2” class, indicating that bare ground was often confused with sediment-covered *Phragmites* litter. The confusion between bare ground with sediment-covered *Phragmites* litter can be explained by the similar colors of bare ground and sediment-covered *Phragmites* litter. Table 2 indicates the above results, and the supervised random classification sampling scheme used for this analysis can be found in Figure 17.

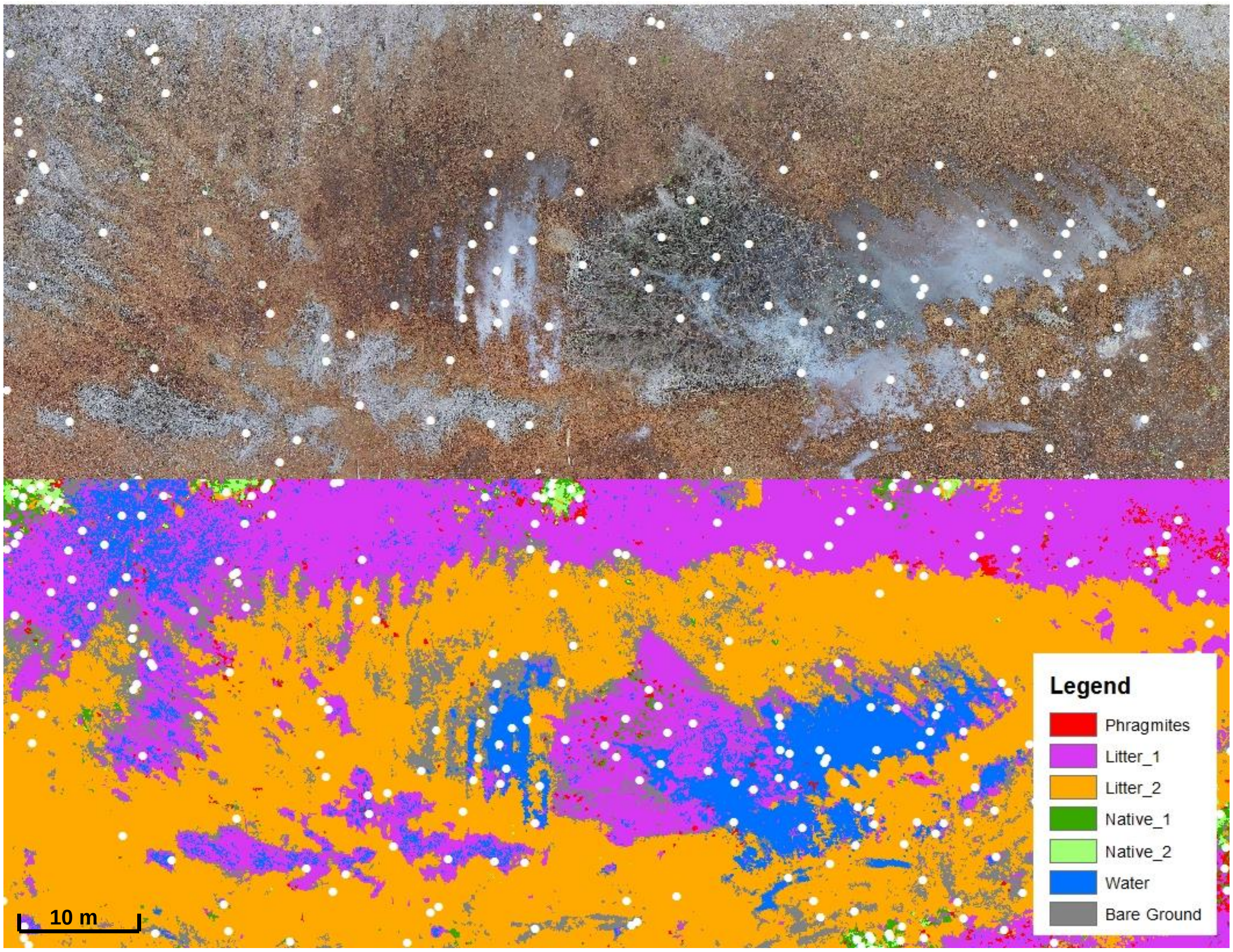

Figure 17. Supervised random classification sampling scheme. White points indicate individual reference points used for accuracy assessment.

Table 2. Error matrix of maximum likelihood image classification.

		Reference Classification								
		Phragmites	***Litter_1***	***Native_1***	***Native_2***	***Litter_2***	***Water***	***Bare Ground***	***Classification Overall***	***Producer Accuracy***
Maximum Likelihood Classification	***Phragmites***	33	8	2	4	3	0	0	50	66%
	Litter_1	1	37	0	1	3	0	3	45	88.22%
	Native_1	5	4	32	6	0	0	1	48	66.67%
	Native_2	0	0	1	46	0	0	1	48	95.83%
	Litter_2	0	2	0	0	42	6	7	57	73.68%
	Water	0	14	0	0	0	34	0	48	70.83%
	Bare Ground	0	4	0	0	12	3	30	49	61.22%
	Truth Overall	39	69	35	57	60	43	42	345	
	User Accuracy	84.62%	53.62%	91.43%	80.7%	70%	79.07%	71.43%		

Chapter 4

Discussion

My thesis project successfully created a protocol for aerial imagery acquisition and classification of quadcopter-generated images. The classification scheme was able to discern individual clumps of native vegetation and *Phragmites* plants from their surroundings with a relatively high level of accuracy, indicating that commercial, ready to fly, quadcopters, like the DJI Phantom 2 Vision+, have the potential to greatly assist land managers. Images generated from such quadcopters can be used to monitor the efficacy of *Phragmites* suppression, to map the extent of *Phragmites* invasions over time, and to identify nascent *Phragmites* invasions. After *Phragmites* suppression, classified images from the DJI Phantom 2 Vision+ can help land managers determine the extent of *Phragmites* control by providing quantified estimates of post-suppression *Phragmites* regeneration. Often, the success of *Phragmites* suppression is assessed visually by land managers. Suppression tactics are deemed successful when treated areas are largely devoid of *Phragmites*. Areas with *Phragmites* regeneration are not considered successful and often necessitate further suppression. Quantified measurements of *Phragmites* extent, like percent cover, can help land managers target *Phragmites* suppression efforts. In the future, quadcopters, like the DJI Phantom 2 Vision+, and other unmanned aircraft systems could help park staff at Presque Isle State Park rapidly quantify park-wide *Phragmites* control, allowing access to secluded *Phragmites* patches which can only be reached by boat. Such measurements of landscape-wide *Phragmites* extent could also be used to map and measure *Phragmites* patches over time, indicating instances when patches merge together and when patches are broken apart. In areas where *Phragmites* have not proliferated, low-altitude aerial imagery can assist in identifying the emergence of individual plants, allowing for targeted suppression.

While my thesis project was successful in creating a protocol for classifying *Phragmites* plants and other cover classes using imagery from the DJI Phantom 2 Vision+, additional efforts to fine-tune the classification process are necessary. Three recommendations to improve the classification process are outlined, as follows. First, classified images generated using the protocol described are not georeferenced to highly accurate ground control points. Thus, classified images discerning *Phragmites* plants and other coverage classes cannot be used as accurate maps to navigate to individual plants or coverage classes. Though, with adequate knowledge of a study site, an average user could navigate to large coverage classes. In the future, this workflow will be updated to include a georeferencing step using a differential GPS unit, allowing users of the classified images to effectively navigate to individual *Phragmites* plants and cover classes. Second, further efforts are needed to refine the mosaicking process. As previously noted, image mosaicking in Microsoft Image Composite Editor results in distortion and blurring of image edges which are then stitched together. New structure from motion (SFM) technology has been used to mosaic large datasets of aerial imagery. SFM technology relies on the use of matching key points from each image, like Microsoft Image Composite Editor, as well as camera geometry and geographic information stored with each image, to create a dense 3D-point cloud and a mosaicked image. This dense 3D-point cloud can be used to correct for geometric distortions present in the mosaicked image, resulting in an orthophoto suitable for photogrammetric measurements. Prior to mosaicking images in Microsoft Image Composite Editor, multiple attempts were made to use various SFM programs to stitch the images together. Ultimately, I decided against using SFM technology for this project because the computing power available to me was not sufficient. Third, further efforts are needed to refine the image classification process. ArcMap 10.2's Image Classification toolbar provides maximum likelihood classification capabilities. Other programs, like ERDAS Imagine (Leica Geosystems, Atlanta, Georgia, USA) and ENVI (Exelis Visual Information Solutions, Boulder, Colorado, USA), provide additional classification options, allowing for higher classification fidelity.

Given my success in remotely sensing *Phragmites* plants using the DJI Phantom 2 Vision+, I plan to use the protocol I developed to map *Phragmites* in subestuaries of the Chesapeake Bay. I will compare quadcopter-produced maps of current *Phragmites* extent to historical measurements of *Phragmites* extent to identify new patches and to track changes in patch size. Additionally, I plan to use low altitude aerial images to identify and quantify new invasions of *Phragmites*. The images collected from these projects will be used to study the spatial and temporal dynamics of *Phragmites* invasions, specifically how the extent of *Phragmites* patches has changed over time and how nearby land use and land cover affects the proliferation of *Phragmites*. The data from this larger project will also help land owners and managers implement informed *Phragmites* control programs.

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Appendix A

Commonwealth of Pennsylvania
Department of Conservation and Natural Resources
Bureau of State Parks
Permit for Research and/or Collection of State Park Resources

Complete Application/Permit; submit one copy to the Resources Management and Planning Division, Bureau of State Parks, PO Box 8551, Harrisburg, PA 17105-8551; or, email: fkearns@state.pa.us, or telephone (717) 787-6674.

Section 1 – Contact Information (To be completed by all applicants):

Name of Applicant
Hope Brooks
Street
424 ASI Building
City/State/ZIP
University Park, PA 16802
Phone/FAX
443-510-0312
Email
hzb5048@gmail.com

Project Title
Invasive Plant Remote Sensing
Park Intended for Study
Presque Isle State Park
If Student, Name of Advisor
David A. Mortensen
University/Affiliation
The Pennsylvania State University
Funding Source (If Any)
College of Agriculture at the Pennsylvania State University

Section 2 – Collection Information (To be completed by all applicants when applicable):

Species to be Collected
Images of *Phragmites australis* and *Typha latifolia*
Method of Collection/Capture
Quadcopter taking aerial photos over marsh

Total Number to be Collected
Over 1,000 images per collection
Number of Collections
One, potentially two, 2014 collection events from patches of invasive species across the park

Section 3 – Terms and conditions:

- **Upon approval by bureau staff, this document serves as a permit for collection, study and monitoring activities in PA State Parks. It is required that this permit be carried at all times while conducting research activity on state park land.**
- **Collection and monitoring shall occur in areas inconspicuous to park visitors.**
- **The park manager must approve all marking, tagging and other materials used upon state park land. The permittee is responsible for removal of all such objects upon the completion of the study.**
- **The Bureau of State Parks reserves the right to withdrawal this permit should it determine that the interests of the Commonwealth or the Bureau of State Parks are no longer being served.**
- **Whenever possible, flora and fauna shall be observed and studied in the field without collection. All collections shall comply with existing laws and regulations set forth by the Pennsylvania Department of Conservation and Natural Resources, the Pennsylvania Game Commission, the Pennsylvania Fish and Boat Commission, and the U.S. Fish and Wildlife Service. If fish or other Herpetofauna are collected, a fishing license Type 1 Scientific Collectors Permit (issued by the Pennsylvania Fish and Boat Commission) must accompany this permit. All vertebrates approved for collection shall be returned to original collection area. Many types of mammalian and ornithological research require a Special Use permit (issued by the Pennsylvania Game Commission). If such a permit is required, the PGC Permit number must be submitted with this application. Disposition of preserved specimens shall be coordinated with the Bureau of State Parks at the conclusion of the study.**
- Copies of field data and reports will be supplied to the Director, both in hard copy and electronically, within 60 days of the termination date of this permit, or at the end of each year's work. Failure to do so will result in future application permits being denied.
- **Additional permit requirements and conditions (State Parks-Resources Management use only)**
- Researcher will notify the Park, in advance, what date(s) they would like to collect/study.
- Researcher will check in at Park Office prior to collection/study activities
- At Presque Isle State Park, established procedures and protocol for collection of specimens must be followed. Contact Curatorial Coordinator, Dr. Edwin Masteller (e11@psu.edu), before commencement of collection process.

Section 4 – For Bureau of State Parks Use Only:

Reviewed by Resources Management Section- [signature] 9/29/2014
Signature Date

Permit Approval- [signature] 9/24/2014
Director Date

Permit Number: 2014-64 **Issue Date:** 09/25/2014 **Termination Date:** 12/31/2014

cc: File
Email: Park Region(s): 2, Presque Isle

DCNR

Commonwealth of Pennsylvania
Department of Conservation and Natural Resources
Bureau of State Parks

Application/Permit
For
Research and/or Collection of State Park Resources

Name of Applicant Hope Brooks	***Project Title*** Invasive Plant Remote Sensing
Collection Permit Number **2014-64**	

FOR ALL CONDUCTING RESEARCH AT PRESQUE ISLE STATE PARK: The Bureau of State Parks strongly encourages you to report your findings at the annual Regional Science Consortium Research Symposium at the Tom Ridge Environmental Center. The Symposium is the first Thursday and Friday of November. Please contact Jeanette Schnars, Executive Director for details (Jeanette@RegSciConsort.com).

Section 5 – Project Description/Proposal **(To be completed by all applicants):**

Include: List of park(s) for collection/study, start and end dates, collection/study methods, species to be collected/studied, and time(s) of collection/study. Attach additional pages as needed.
Park for Collection/Study: Presque Isle
Start End Dates: October 6 – 10, 2014
Species for Collection/Study: *Phragmites australis* and *Typha latifolia*
Times of Collection/Study: Between 8 am and 5 pm
Necessary Checks: Called Erie Coast Guard station and Erie Airport to determine permissions to fly a quadcopter over marshes. Erie Airport forwarded questions to the Allegheny Flight Safety District Office. Erie Coast Guard Station and Allegheny Flight Safety District Office found no issues with flying a quadcopter over marshes for research purposes. All flights must stay under 500 feet height and should not occur over people.
Objectives of Research:
- Create a protocol to analyze existing aerial imagery of Presque Isle for *Phragmites australis* and *Typha latifolia* cover accessing high resolution imagery that predates suppression programs initiated in 2013 and imagery of treated areas since the summer of 2013.
- Acquire an autonomous drone or UAV to obtain higher resolution imagery of *Phragmites* and *Typha* patches at Presque Isle pre- and post-herbicide treatment (where additional areas will be treated in 2014). Ground-truth the aerial imagery by walking Phragmites patches and and outlining them with a global positioning system while at the same time estimating herbicide treatment efficacy. I will then develop a second protocol to analyze *Phragmites* and *Typha* cover from UAV-generated imagery.
- Test the ability to detect Phragmites patches and assess their suppression by comparing the ground-truthed data against satellite (coarse) resolution data and higher spatial resolution UAV-collected data.

Appendix B

Introduction and Background Information:

Since its initial introduction from Europe, the Common Reed (*Phragmites australis*) has spread across the Cheseapeake Bay and other estuaries out-competing native vegetation in the marshes it invades. Today, there is a large effort to control its spread in local ecosystems where herbicides, often used in conjunction with mechanical mowing, are seen as the most tractable approach to management. However, since these infestations cover large areas and to fully assess the performance of the suppression tactics the sites must be revisited over several years a large-scale method for assessing the efficacy of suppression tactics. My project aims to estimate the efficacy of such suppression programs for *Phragmites* at Presque Isle on Lake Eerie through the development of GIS models of *Phragmites* cover using old aerial imagery and aerial imagery from unmanned aerial vehicles (UAV).

Project Objectives:

1. Create a protocol to analyze existing aerial imagery of Presque Isle for *Phragmites* cover accessing high resolution imagery that predates suppression programs initiated in 2013 and imagery of treated areas since the summer of 2013.
2. Acquire an autonomous drone or UAV to obtain higher resolution imagery of *Phragmites* patches at Presque Isle pre- and post-herbicide treatment (where additional areas will be treated in 2014). Ground-truth the aerial imagery by walking *Phragmites* patches and outlining them with a global positioning system while at the same time estimating herbicide treatment efficacy. I will then develop a second protocol to analyze *Phragmites* cover from UAV-generated imagery.
3. I will test the ability to detect *Phragmites* patches and assess their suppression by comparing the ground-truthed data against satellite (coarse) resolution data (outlined in 1) and higher spatial resolution UAV collected data (outlined in 2).

Significance of the Project:

Overall, my project will contribute two protocols for remotely assessing *Phragmites* suppression. I have been working closely with the Penn State Invasive Plant Management Group in developing this project and through this collaboration know such a method enhancement would increase their ability to manage invasive plants on state lands across Pennsylvania (Dave Mortensen and Art Gover, personal communication). Future land managers out of Presque Isle and elsewhere will only have to fly a UAV over their watershed before their herbicide treatment, treat the *Phragmites*, and then fly the UAV again after treatment. Using my model, the land managers will have a tool to compare the area covered by *Phragmites* before and after treatment from far away, saving labor costs and time.

My Role in the Research:

I have already visited the study site at Presque Isle to assess the scope of the *Phragmites* invasion. Later, I will work to arrange UAV flights over Presque Isle before and after seasonal herbicide spraying, generating two sets of high resolution imagery. I will collaborate with researchers from Penn State including Art Gover, Dave Mortensen, Katy Barlow, and Doug Miller, as well as colleagues from the Smithsonian Environmental Research Center in Maryland, and Utah State University. I will use ArcGIS 10.2 and other tools to analyze existing imagery and UAV-generated imagery of Presque Isle, visually estimating initial *Phragmites* cover as well as pre- and post-herbicide application cover. Then, I will draft protocols describing my analysis methods for future use at Presque Isle.

Materials and Methods:

First, I will compare 2013 helicopter spray-block polygons used at Presque Isle with 2009 High Resolution Orthoimagery and other existing imagery of Presque Isle (I have access to other imagery obtained by specially arranged low-altitude flyovers at the site). Using color differences between *Phragmites* and other plant species and consultations with land managers, I will manually delineate *Phragmites* patch polygons in the 2009 imagery in ArcGIS 10.2 as described by Maheu-Giroux and Blois (2005).

Second, I will work with Doug Miller and David Mortensen to acquire a UAV for taking multi-spectral images of *Phragmites* patches at Presque Isle pre- and post-herbicide treatment. Both Miller and Mortensen are working collaboratively to obtain a UAV for this and other work, so I am confident I will be able to obtain this imagery during the course of this research. Pre-herbicide treatment, I will outline *Phragmites* patches using a handheld GPS then fly the UAV collecting multi-spectral images of the patches. The multi-spectral images will be used to estimate *Phragmites* cover. Following the herbicide treatment, I will return to the field and randomly sample areas within the *Phragmites* patches, noting the herbicide treatment's efficacy. I will also fly the UAV again to collect a second set of multi-spectral images to be analyzed like the first set of images.

Finally, I will compare the estimated initial *Phragmites* cover from 2009 imagery to UAV-estimated cover and the pre-treatment polygons. This will be used to determine the accuracy of existing imagery for estimating *Phragmites* cover. Next, I will compare the pre-treatment percent cover of *Phragmites* estimated using multi-spectral images and the pre-treatment polygons. This will be used to determine the accuracy of UAV-generated *Phragmites* polygons. Lastly, I will compare *Phragmites* cover before and after herbicide treatment to determine the treatment's efficacy. I have been working closely with Dave Mortensen, Doug Miller and Art Gover in developing this project and have their enthusiastic support as I conduct the important research outlined in this proposal.

How Data Will Be Analyzed and Used:

I will create polygons of *Phragmites* patches from 2009 High Resolution Orthoimagery of Presque Isle, helicopter spray blocks, and other existing imagery using ArcGIS 10.2. Drone-generated imagery from Presque Isle will be orthorectified and mosaicked. Using the *Phragmites* polygons generated in the field, a supervised classification of the drone-generated imagery will be conducted to estimate *Phragmites* cover pre- and post-herbicide treatment as described by Long et al (2012). The accuracy of the pre-treatment UAV imagery will be determined by comparing estimated *Phragmites* cover polygons from the field. I will use this data to track herbicide treatment efficacy and improve my protocol. Lastly, I will communicate the results of my study with the Invasive Plant Management team and other researchers at Penn State.

Literature Cited:

Long, A.L., C.M.U. Neale, and K.M. Kettenring. 2012. Determining the current extent of Phragmites australis in Great Salt Lake wetlands using multi-spectral remote sensing techniques. Final report to the Utah Department of Natural Resources, Division of Forestry, Fire & State Lands.15 pp.

Maheu-Giroux, Matthieu, and Sylvie De Blois. "Mapping the Invasive Species Phragmites Australis in Linear Wetland Corridors." *Aquatic Botany* 83 (2005): 310-20. Web. 3 Dec. 2013.

Hope Brooks

Education:

Bachelor of Science: Plant Science – Focus on Wetland Science and GIS

The Pennsylvania State University: Schreyer Honors College (2014), University Park, PA

Experience:

Smithsonian Environmental Research Center – *Intern (May 2014- Present), Edgewater, MD*

- Assisted in monitoring populations of two federally listed species, the Small Whorled Pogonia (*Isotria medeoloides*) and Swamp Pink (*Helonias bullata*), at U.S. Army Fort A.P. Hill and one National Park.
- Studied the effects of canopy thinning efforts and symbiotic mycorrhizal fungi on I. medeoloides population health, and researched the impacts of controlled burning on soil nutrient regimes and forest canopy closure in H. bullata populations.

Honors Thesis – Weed Ecology Lab – *Lab Technician (Nov. 2013 – Present), University Park, PA*

- Monitoring the spread and control of the invasive Common Reed (*Phragmites australis*) at Presque Isle on Lake Eerie using unmanned aerial vehicles and existing aerial imagery.
- Establishing a set of written protocol for use to determine the efficacy of *Phragmites* control.

Smithsonian Environmental Research Center – *Intern (June 2013 – August 2013), Edgewater, MD*

- Studied the spread of *Phragmites australis* through watersheds to identify hybrid plants and determine the extent of gene flow through pollen and seed using nuclear and chloroplast DNA.
- Conducted inventories of the endangered *Isotria medeoloides*, performed marsh vegetation inventories, and performed field work across Maryland and Virginia.

Penn State University – *Lab Technician (Fall 2011 – Present), University Park, PA*

- Researched the effects of agricultural production practices on biological control of insect pests, weed control, and soil health.
- Documented lifecycle of *Cenococcum geophillium* from 12 years of minirhizotron images collected at the Duke Forest FACE site to understand its production, lifecycle, and vitality in temperate deciduous forest ecosystems

USDA APHIS PPQ-ER – *Lab Technician (Spring 2012 – Summer 2012), University Park, PA*

- Collaborated on projects including the control and identification of *Phytophthora ramorum Puccinia horiana*, Citrus Greening Virus, and Plum Pox Virus.
- Identified plant diseases using DNA extractions and qPCR, inoculated diseases, and performed general lab duties

Certifications:

- **U.S. Fish and Wildlife Service Approve Surveyor for Small Whorled Pogonia** *(Fall 2014)*

Awards and Academic Honors:

- **John n. Adam, Jr. Scholarship for Excellence in Agriculture** *(Fall 2014)*
- **Swartley Scholarship in Plant Sciences** *(Fall 2014)*
- **Honor Society of Phi Kappa Phi Pennsylvania State University Chapter** *(Spring 2013)*
- **Penn State Alumni Annapolis Chapter Scholarship** *(2013 – 2014)*
- **Oswald Scholarship** *(2013 – 2014)*
- **Huber Lawrence Memorial Scholarship** *(2012 – 2013)*
- **Thevaos Honors Scholarship** *(2012 – 2013)*
- **Rumbaugh Family Award and Rumbaugh Agricultural Leadership Award** *(2011 – 2012)*
- **Wolfe Scholarship** *(2011 – 2013)*
- **Girl Scout Gold Award** *(2009 – 2011)*

Extracurricular Activities:

- **Student Liaison for the Society of Wetland Scientists Conference at Penn State** (*Spring 2014)*
- **Nittany Grotto Caving Club President** *(Spring 2013 – present)*
- **Nittany Grotto Inc. Secretary-Treasurer** *(Summer 2013 – present)*
- **Elected Mid-Appalachian Region National Speleological Society Secretary** *(Fall 2012 – present)*