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Spatial Analysis of Distributions and Habitat Conditions of Fallopia japonica (Japanese Knotweed) Invasive Species Applying Unmanned Helicopter Remote Sensing

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Abstract:

Fallopia japonica (Japanese knotweed) is a perennial herbaceous plant that is native to East Asia. It is considered as one of the worst invasive species worldwide because of its serious impact on biological diversity and human activities (Lowe et al., 2001). Once established, Japanese knotweed forms dense stands that shade and crowd out native plant species. The objectives of this research were to verify and confirm the distribution of Japanese knotweed as published online by the New York Department of Environmental Conservation (DEC) – iMap and to identify the geographic areas of spreading and the local habitat conditions. In this research, we apply an unmanned helicopter with multiple sensors including digital camera, thermometer and relative humidity sensor to survey the patches of *F.japonica* and its three-dimensional (3D) habitat conditions. The areas of each of the patch surveyed were identified and delineated in polygons applying ERDAS Imagine and ArcGIS software. To identify the local habitat conditions, the shade cover and distance to nearest water body were analyzed by using traditional statistical methods. And the distributions of temperature and relative humidity were analyzed in three-dimensional (3D) method in GIS environment.

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Spatial Analysis of Distributions and Habitat Conditions of *Fallopia japonica* (Japanese Knotweed) Invasive Species Applying Unmanned Helicopter Remote Sensing

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1. Introduction

1.1 Significance of the Study

Fallopia japonica (Japanese knotweed) is a herbaceous perennial plant native to East Asia (Child and Wade, 2000). According to the World Conservation Union (WCU), it is selected as one of the most invasive species worldwide because of its serious impact on biological diversity and human activity (Lowe et al., 2001). Japanese knotweed first caught public attention when it caused serious environmental problems in Europe (Conolly, 1977; Bailey and Conolly, 2000; Bailey, 2005). Recently, *F.japonica* began to invade North America. In comparison to Europe, this invasion is still a relatively new issue in North America (Bailey, 1916; Child and Wade, 2000). However, western New York is one of the many geographic regions that has begun to suffer the invasion of this invasive herbaceous species.

Similar to other successful invaders such as *Rhamnus cathartica* (European buckthorn; Knight et al., 2007) and *Phragmites australis* (Common reed; Chambers et al., 1999), once established in a geographic area, *F.japonica* forms dense stands displacing native flora. Once established, Japanese knotweed is hard to remove (Richards et al., 2012). The bamboo-like stem is hard to break, and its rhizomatous roots spread clonally (Mandujano et al., 1998; De Waal, 2001). Hence, cutting leaves and stems during winter will not stop its growing in the next spring (Richards et al., 2012).

This invasive species will be harmful to the habitat and biodiversity (Mandujano et al., 1998; Young et al., 2002; Aguilera et al., 2012). The extent of damage could even be felt in the regional public infrastructures. Like what I saw during the field investigation, the rhizomatous growth and the shoots grow out during the spring could break the pavement (Figure 1). This makes it necessary for the public to be vigilant towards this invasive species.

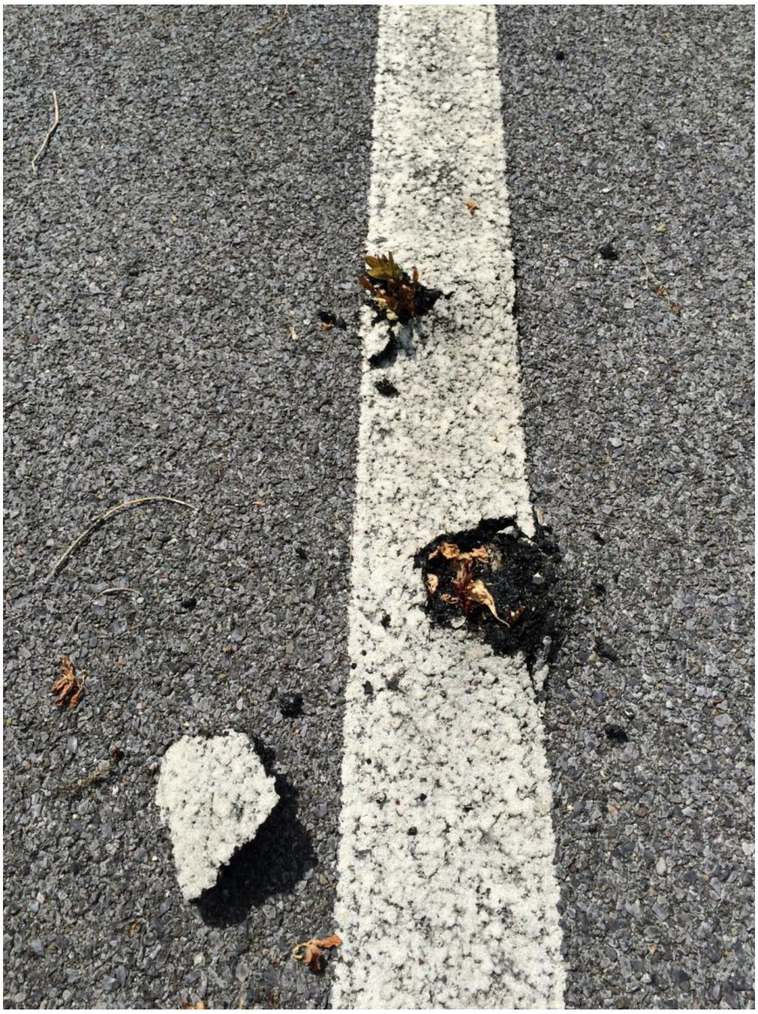

Figure 1 The Japanese knotweed grew under the pathway and broke the road pavement.

1.2 Objectives and Importance of the Study

In this research, we applied an unmanned helicopter with image, temperature and relative humidity sensors to collect data the distributions and habitat conditions of *F.japonica*. Applying the unmanned helicopter as a remote sensing platform is a relatively new method in geography studies. The high-resolution camera attached to the unmanned helicopter can provide us a new angle to inspect the distribution of the *F. japonica*. Also, other sensor instruments such as the hygrothermograph have been added to the unmanned helicopter to help us understand the habitat conditions better.

The objectives of this study are:

a) To locate and verify the major distributions of *F.japonica* in Erie County, New York.

The iMapinvasive website (http://imapinvasives.org/nyimi/map/) was used as a guide to locate the destinations of the field investigations. This website identified the locations of the invasive species by encouraging the public to input their findings during their daily recreational activities such as fishing, hiking, or birdwatching trips. In addition, resource managers could register on that website and upload their study results. As many non-professional investigations and stakeholders are involved in the website, the reported sites may or may not contain the invasive species. Furthermore, information on the website may be out of date. Therefore, field inspections applying unmanned helicopter remote sensing is crucial.

b) To measure the invasion area of *F.japonica*

The iMapinvasive website shows the number of individual patches of each kind of invasive species. For each patch, the description includes the coordinate, investigated date, and sometimes, site photos. One of the problems is that the descriptions do not include patch dimensions or area so that the only thing we can know is there was *F.japonica* in the labeled place. By using the unmanned helicopter, the high-resolution images of *F.japonica* patches can be obtained and from these images patch area may be calculated.

c) To analyze the habitat conditions of *F.japonica* patches

The biotic and abiotic conditions which characterize *F.japonica* patches may be characterized in several ways. In this research, I focus on temperature and relative humidity, the distance from the patch to the nearest water body and the presence or absence of shade associated with tree canopies. Patch area and the presence or absence of shade was recorded by the image sensor; the thermohygrometer attached on the unmanned helicopter recorded the temperature and relative humidity data; combine the images from the field investigating with the base map, the distance from the growing spots to the nearest water body could be detected.

d) To test the concept of using unmanned helicopter to detect the invasive species, in this case, *F.japonica*

Since the spatial and temporal resolution of the satellite and aircraft images is too low for us to study the invasive species, the feasibility of using unmanned helicopter is an interesting idea to test. In this research, I used an unmanned helicopter as the platform of remote sensing to detect the distribution and the habitat condition of the *F.japonica* patches. By using it, I want to find out the advantages and weaknesses of using it to do the environmental researchers. The experience can be provided to the following researchers who are interested in using an unmanned helicopter to do their studies.

2. Literature Review

2.1 Invasive History of *F. japonica* (Japanese Knotweed)

F. japonica is commonly believed to be one of the most efficient invasive alien species against to the local plants in North America and Europe, which significantly lower the species diversity of the local communities (Aguilera et al., 2012). *F.japonica* was first introduced as an ornamental species in the northeast United States in the 1870s (Bailey, 1916; Child and Wade, 2000; Forman and Kesseli, 2003). After it had escaped from cultivation, it invaded widely into disturbed or riparian habitats (Bram and McNair, 2004; Gerber et al., 2010). *F.japonica* also established along traffic corridors, such as railroad, waterway and road rights-of-way (Barney, 2006). Since then, *F. japonica* has spread across the northern tier of the United States (Zika and Jacobson, 2003). The wide geographic distribution of *F.japonica* in North America reflects a broad temperature tolerance. For example, Beerling et al. (1995) did a comparison of climate conditions between Southeast Asia, the native range of *F.japonica*, and the Europe. They found that it grew on the same climatic range in Europe and Southeast Asia and that *F.japonica* tolerates very low minimum temperatures and requires abundant soil moisture.

2.2 Influences of *F. japonica* on Native Species

The invasion of non-native species could impact the ecological system negatively. A good example would be the spreading of *F. japonica* at an impressive speed in Great Britain. As shown in Bailey's study (2005), an exponential increasing of *F. japonica* in Britain is presented during the last century and dramatically lower the diversity of the native species. Tiébré et al. (2007) found that *F. japonica* spread by both extensive sexual reproduction and rhizomatous growth. They indicated that extensive sexual reproduction generates by hybridization could differentiate the genetic of the plants, and the rhizomatous growth will make it hard to be clean and will all accelerate the invasion of the *F. japonica*. Compared with the uninvaded zone (Jiao, 2012), the diversity of species could be reduced by *F. japonica*, which suppressed the regeneration of the forest. The most important factor that is favoring *F.japonica* over native species is its huge amount production of biomass. The biomass it produced could be up to two to six times of that for the local species (Shaw et al., 2009).

The clonal growth refers to the combination growing of mother plants and interconnected ramets (Charpentier and Stuefer, 1999). *F. japonica* tends to spread clonally, which grows rhizomatous to form a monoculture. Clonal growth of many perennial herbs is commonly considered as one of the main approaches to the expansion of population. However, a few studies have been conducted on this phenomenon (Mandujano et al., 1998; Young et al., 2002; Wang et al., 2009). Invasive clonal species may reduce the diversity of native species dramatically (Herben, 2004). The advantage of the clonal plants mostly come from their rhizomatous system. Rhizomes improve the tolerance of the newly emerged ramets that grow underground by protecting them from the dramatically environmental changes that happen above the ground surface (Oborny et al., 2000; Moola and Vasseur, 2009). You et al. (2014) studied the clonal plant *Alternanthera philoxeroides* and found a compensatory response to that biomass losses associated with defoliation. That makes the negative impacts mitigated and improve its invasion ability. Similar to *A. philoxeroides*, since the growth of *F. japonica* is different from the local plants, the former contains rhizomes can penetrate two meters in depth and about 20 meters laterally underground.

2.3 The Effects of Habitat Conditions

Generally speaking, regional climate condition is the main factor that affect the vegetation species and its distribution (Woodward and McKee, 1991). However, on the small scale, non-regional environmental factors decide the distribution pattern of the vegetation (Zhang et al., 2012). For example, in the mountain land vegetation communities, the terrain is the main non-regional factor that control the distribution of vegetation (Parker, 1982; McDonald et al., 1996). It impacts the small scale climate by controlling the spatial distribution of solar radiation and precipitation (Cantón et al., 2004). Given that, the environmental tolerance of a species tends to decline when other limitations such as herbivores, pests, and competition from neighbor plants occur. (Niinemets and Valladares, 2006). This research focuses on the light environment as well as temperature and relative humidity near ground level.

2.3.1 The Effects of Shade (Canopy Cover)

Zhou et al. (2014) collected the shrub height, canopy coverage, single leave area and the root-shoot ratio information from high light (outside of the forest) and low light (inside of the forest) areas to examine shrub adaptations to varying light environments. The three kinds of shrubs were *Salix etosia, Rubus setchuenensis,* and *Hydrangea aspera.* The results show that the different light environments will affect several aspects in shrub growth. For the same kind of shrub, the light environment significantly influenced the root-shoot ratio. Root and branch biomass and morphological plasticity indexes showed a species specific pattern of response to light availability. Similar responses were observed in gap areas of a cypress plantation in central Sichuan Province (Yang et al., 2014). In that study, shrub height, canopy coverage, and litter layer thickness all significantly increased in response to increased light availability (Yang et al., 2014). In fact, the size of the forest gaps determine the habitat conditions such as light environment, temperature, relative humidity and soil content (Long, 2009). That makes the forest gap an important factor shaping plant community succession (Cui et al., 2014). Yang et al. (2014) found that when the gap size was between 90-110 m^2, the Shannon-Wiener index reached to a single peak. Warren et al. (2015) did a research about the urban riparian plant communities and found that the common invasive riparian species such as Japanese knotweed and common reed are likely to distribute in the open tree canopy area.

Xiao et al. (2013) studied the effects of shade condition on the *Acanthopanax trifoliatus.* They found that neither too strong light intensity nor too weak light intensity was conducive to its growth. When the light condition is on the level of 21% of natural sunlight, the *Acanthopanax trifoliatus* could grow the largest. For juveniles growing, the shade tolerance of different species also involves the fertility of soil types. The tolerance range on the basalt soil (nutrient-rich) is wider than it on the rhyolite soil (nutrient-poor) (Sendall et al., 2014). Some other studies also mentioned that the shade tolerance will be reduced by soil infertility and drought (Kobe et al., 1995; Walters and Reich, 1997).

2.3.2 The Effects of Temperature and Relative Humidity

Gaskin et al. (2014) indicated since *F. japonica* is highly related to the rates of growth while nitrogen is limited, reducing nitrogen tends to improve the performance of native species. Furthermore, the nitration and nitrogen mineralization reaction in the soil is affected by many environment factors including temperature and relative humidity (Wang et al., 2000; Tian et al., 2010; Dalias et al., 2002). Also, different kinds of soils will react differently to the change of temperature and relative humidity (Zhou and Ouyang, 2001). This type of phenomenon may be caused by the differences in the physicochemical property and microorganism of the soil in different regions (Wang et al., 2004). For example, in a grassland soil, net nitrification and net mineralization rates under warm conditions depended on soil moisture (Li et al., 2013).

Temperature is also an important factor that influences the photosynthesis of the plants. The model of the temperature dependence of photosynthesis present as a single-peak curve (Berry, 1980). In other words, there are species-specific temperature optima for photosynthesis which influenced by atmospheric CO_2 concentration and relative humidity (Yamori et al., 2010; Hikosaka et al., 2006; Borjigida et al., 2006). Jigedai and Yu (2013) indicated that by studying the leaf area, solar radiation, canopy microclimate, canopy structure and photosynthetic capacity, we can get to know the reaction of the plant community to changes in temperature.

2.4 GIS-based Spatial Analysis of Invasive Species

GIS is considered a powerful technology to analyze the invasion of species

(Masocha and Skidmore, 2011). In particularly, it is powerful in the investigation of new invasion since the distribution of species highly depends on the characteristics of the environment. Among various statistical models, the Geographically Weighted Regression (GWR) analysis can be used to analyze spatial data and make predictions (Fotheringham et al., 1999, 2002; Brunsdon et al., 2007). Compared to the traditional statistical analytical methods, the GWR method can model explicit relationships between dependent and explanatory variables and estimate correlation coefficients spatially. Thus, a two-dimensional map that shows the relationship between variables can be made (Fotheringham et al., 2002). To use this method, it would be better if there are over 150 valid data (Guo et al., 2008).

Blanco-moreno et al. (2008) studied the relationship between crop biomass and weed density using GWR method. They compared the GWR method with the linear least squares (NLS) in some situation and found the GWR can significantly improve the fitting result because the GWR model provides a way to show the relationship of spatial heterogeneity, which otherwise would be ignored in non-linear regression models (Blanco-moreno et al., 2008). GWR has also been applied to spatial modeling of traffic accidents (Erdogan, 2009) and hotel room pricing (Zhang et al., 2011). These research applications demonstrate that the GWR method is accepted globally and can fit different situations.

2.5 The Applications of Unmanned Helicopter Remote Sensing Technology

Since the beginning of the 21^{st} century, the Unmanned Aerial Vehicle (UAV) has been used as a platform of remote sensing. Compared with the traditional remote sensing platforms like piloted aircraft and satellites, UAVs are less costly and more flexible (Laliberte et al., 2010). These characteristics make UAVs capable of producing high spatial and temporal resolution images. An early application of UAVs for remote sensing was in regional agriculture resource monitoring (Herwitz et al., 2004). In Japan, Sugiura et al. (2005) used the unmanned helicopter to generate high resolution maps of crop status. After that, the UAVs started to have an extended Kalman filter (EKF) based navigation system that can lower the cost of using it (Xiang and Tian, 2011). UAVs are also used in places that are difficult or too dangerous for manned aircraft such as volcanoes (Kaneko et al., 2011). For the area of the environmental science, the unmanned helicopter was used to detect the canopy shadow fraction (CSF) by taking images from multiple view zenith angles (VZA) for the same target canopy (Sharma et al., 2013). They developed an algorithm to extract the CSF automatically and help mapping the distribution of the trees.

3. Methodology

3.1 Study Area

Erie County is located in the western part of the New York state (N 42.4369 ~ N 43.0962, W 78.4645 ~ W 79.1388). The county borders the eastern shore of Lake

Erie and has many rivers and creeks in it. This region falls in the snow zone that Lake Erie generates in the winter time. Erie County contains many abandoned and deconstructed industrial areas near water bodies which provide suitable conditions for the growth of riparian invasive species such as *F.japonica* (eFloras, 2008). In addition, some shoreline disturbance in public waterfront parks and recreation areas has created suitable habitat for riparian invasive species.

According to the iMapinvasive website, almost every area that is labeled growing *F. japonica* is located in public parks or nature preserves that were once the abandoned industrial sites. This research investigated most of the areas and collected the images of *F. japonica* distribution and the temperature and relative humidity (RH) data of its growing habitat. The following areas were investigated for invasive sites: Greenway near Buffalo Outer Harbor; Greenway near the Buffalo West Side Rowing Club; La Salle Park; Reinstein Woods Nature Preserve; Seneca Bluffs; Tifft Nature Preserve; Times Beach Nature Preserve; and Wilkenson Pointe.

iMapInvasives (http://imapinvasives.org/nyimi/map/) is an online database system for the location of the invasive species. Users of the website can report the presence of common invasive species wherever they are observed. It is very useful as an internet tool for scientific researchers to identify the scale and locations of an invasive species. To date, according to their website, ten states including New York State have already participated in this internet-based reporting system.

Owing to the operational mode of this website, most of the data came from ordinary citizens, as they may find some invasive species during weekend leisure trips and report their findings. This leads to popular locations, such as public park and nature preserves, being reported by the citizens and generate the sampling bias in the iMap database. Some of invasive species sites are located in the backyards of private houses. There could be the inaccuracy of data because the reporters are mostly amateurs. Also, after years of data collection, there may be some changes in the identified areas. For instance, managers at Tifft Nature Preserve conducted a project of physically removing *F. japonica* in last few years (Spiering, 2009). In contrast, some of the places that already have established *F. japonica* might not be shown on the website. During the field investigation, some of the new established *F. japonica* were be found. They are included in this study. *F.japonica* concentration areas are mainly along the Lake Erie shoreline, rivers, and creeks in suburban settings (Figure 2). There are fewer reported sites in the urban core or in rural areas. Part of the reason may be that these places are the most anthropogenic disturbed areas which create opportunities for *F.japonica* to establish.

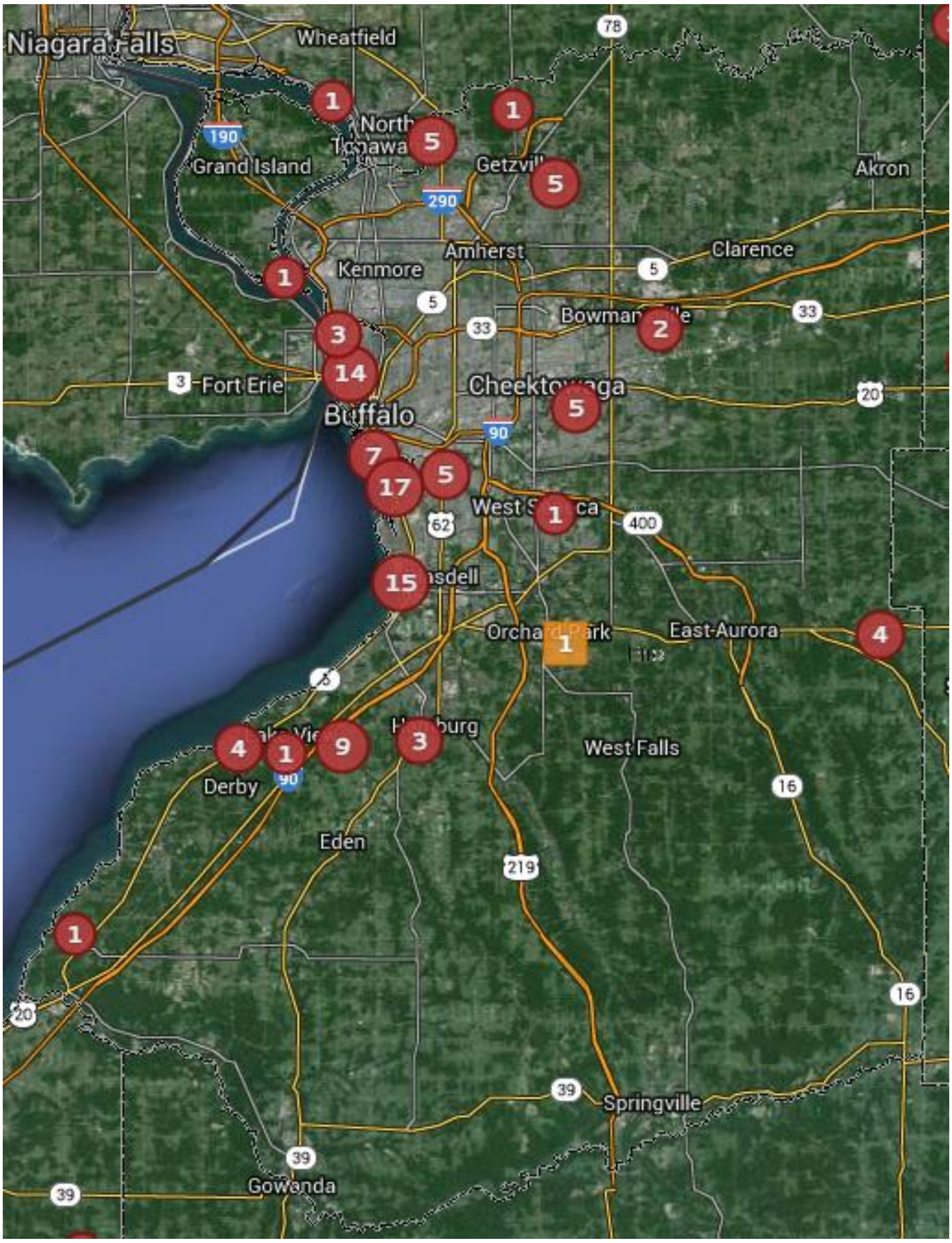

Figure 2 The distribution of *F. japonica* according to iMapInvasive. The red circles on the map show the position and amount of the *F. japonica* that have been observed. The orange square shows the uncertain spots of *F. japonica* invasion.

3.2 Applying UAV Remote Sensing

The Phantom 2-Plus UAV was used as an image collection platform. Phantom 2-Plus is a light weight unmanned helicopter equipped with a 3-axis gimbal stable camera (Da-Jiang Innovations Science and Technology Co., Ltd. Shenzhen, Guangzhou, China).

Figure 3 The unmanned helicopter DJI Phantom 2 vision+.

Using the DJI VISION mobile application (App) for this aerial camera (sensor), we can observe the images that the camera is catching through a smartphone. In addition, the action of recording images can also be accomplished through the App. The camera is stabilized by a 3-axis gimbal to ensure the image quality and records images at a resolution of 4384×3288 pixels.

Digital images were taken from an altitude of 25 meters high, vertically to the ground surface. Using these remote sensing images, we can get information, such as the surrounding geographic objects and shadow cover. Also, the invaded area could be differentiated from native vegetation covers, such as surrounding grassland, and wetland based on the different colors of the pixels by using the remote sensing image analysis technology.

3.3 Collection of Temperature and Relative Humidity Data

The HOBO Temperature/Relative Humidity Data Logger, model U12-011, was attached to the unmanned helicopter. It was manufactured by the Onset Computer Corporation (Bourne, MA, US). The temperature range of this device is -20℃ to 70℃, and the relative humidity range is from 5% to 95%. The temperature and relative humidity were recorded while the drone is flying in the sky. In that way, a three-dimensional microscale and boundary layer meteorological data of *F.japonica* growing could be obtained.

Because of the battery of the unmanned helicopter can only support it flying for approximately 15 minutes, the maximum range that the data can be collected is from the ground to the altitude of 14 meters at each surveying site. So that the vertical temperature and relative humidity data were taken from the ground to the height of about 14 meters. The layer from the ground to 14 meters altitude has been divided into 8 levels, every 2 meters for one level. The detector records data every second. However, the equipment does not react quickly enough to the surrounding habitat environment. To obtain the correct data from the field investigations, the equipment must be given some time for it to acclimate to the temperature and relative humidity in surrounding area.

We designed and executed the flying plans to keep the unmanned helicopter stay at each level for two minutes. The time period of flying at a particular altitude was gauged by an alarm on the smart cell phone. In that condition, a uniform two-minute data would be captured for each level, which means 120 measurements will be taken at each sampling altitude.

The HOBO data logger records the temperature and relative humidity data with time stamps. By contracting the height displayed at the bottom of the screen with the time recorded during the field investigations, the temperature, and relative humidity data could be matched with elevations.

3.4 Areal Digital Image Analysis in ERDAS Imagine Remote Sensing Software Environment

In this research, ERDAS Imagine is used to extract the *F.japonica* patches and the shaded area from the original image that the unmanned helicopter obtained from the field investigations.

For example, we can clearly see from Figure 4 that the color of *F.japonica* is a little bit lighter than other plants. Based on that, we extracted the patch of *F. japonica* out from all other ground objects. So that the polygon of the patch can be generated, and the area could be measured.

In ERDAS Imagine image processing and analyzing software, there are several methods to classify the geographic objects on the images. Unsupervised classification and supervised classification were used to analyze the images in this research. Within the supervised classification, three methods were used to test the ideal situation: maximum likelihood, minimum distance, and Mahalanobis distance.

Maximum likelihood is a method that calculates the probability of every image pixels to every class and put the pixel in the class that its likelihood is the highest. It is one of the most used supervised classification methods (Lillesand and Kiefer, 2000).

Minimum distance is a method that classifies the image pixels based on the distance in the brightness value (BV) or digital number (DN). Every class will have an average value. The pixel is cataloged into the class which has the minimum distance between its mean value and the value of the pixel. This method is simple and inaccurate, but it is convenient in most situations (Lillesand and Kiefer, 2000).

Mahalanobis distance has some commonalities with the Maximum distance method, but it assumes that the covariance of every class is all the same (Lillesand and Kiefer, 2000).

Figure 4 The original image was taken near the parking lot of the Buffalo West Side Rowing Club.

Before the work begins, the question of which method should be used needs to be answered. To find which one is the most suitable method to extract the *F. japonica* from other ground objects, all these imagery processing methods need to be tested.

First, the unsupervised classification is used to classify this image (Figure 5).

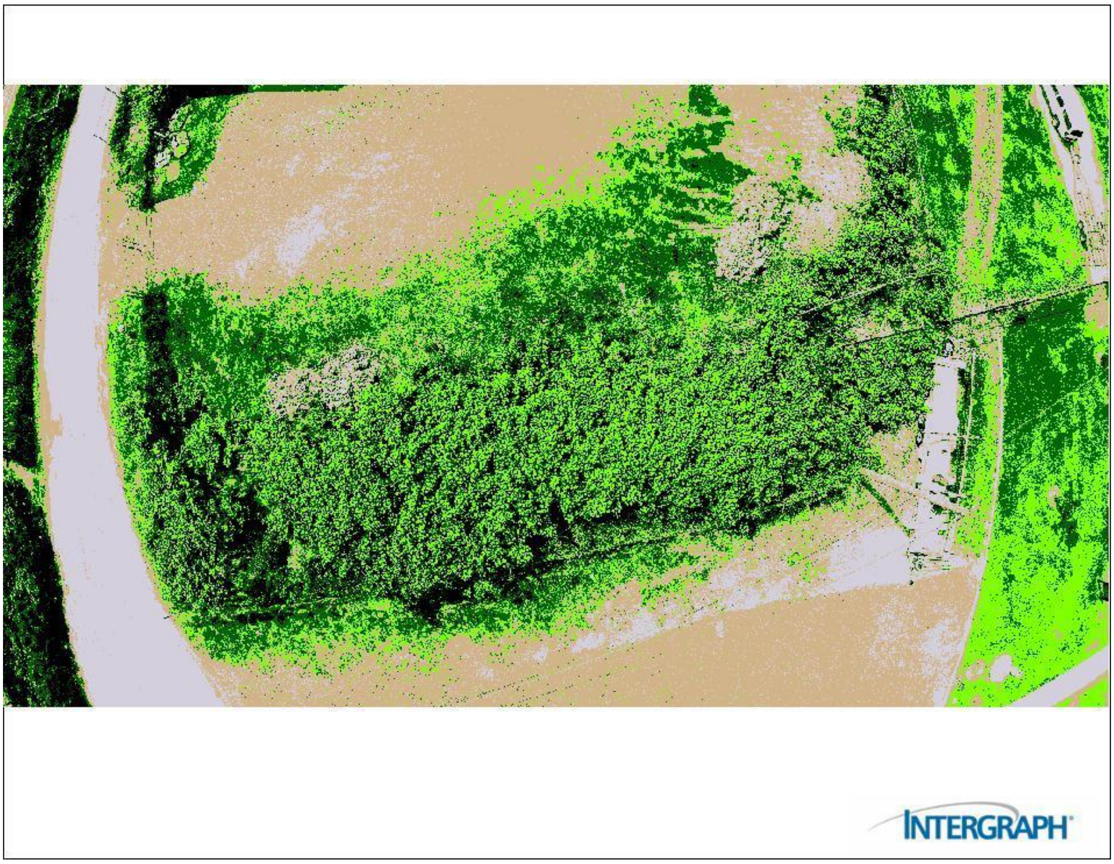

Figure 5 Unsupervised classification for the image taken near the parking lot of the Buffalo West Side Rowing Club.

The pixels in Figure 4 were classified into five classes in Figure 5. The road was shown in gray, sandy parking lots are in cinnamon color, and the vegetation is shown in dark and light green colors. The difference is clear between the road the vegetation, but the *F.japonica* and other plants are difficult to differentiate from this method of image classification.

The unsupervised classification was mainly used for the areas that were not known well. When it is hard for us to identify the ground features from the satellite images, the unsupervised classification tool can catalogue the pixels automatically based on the similarity among them. In this case, the similarity depends on the red, green and blue (RGB) colors of the ground features. This process does not need human interventions. Hence, the image pixels that have little differences will not be identified clearly, and classified accurately.

The result of unsupervised classification of images in this research showed this type of characteristics as well. All of the vegetation classified does not show specific difference based on its species. In fact, the dark green should represent the lawn, and the light green should represent the *F.japonica*. However, in the unsupervised classification, the dark and light green was all mixed. It is hard to identify which color represents which kind of plant species. Therefore, the unsupervised classification is not suitable for this situation (Figure 5).

Next, the supervised classification methods were tested (Figure 6, 7, 8). The first step of the supervised classification is to make the signature files of the different geographic objects. I chose five areas of each class as the samples for classification. The lighter green represents the growing area of *F.japonica*; dark green shows the patches of other plants like grass; reddish brown areas are roads and parking lots. After the training of ERDAS Imagine software using the identified object signature files, we got a template to classify the pixels.

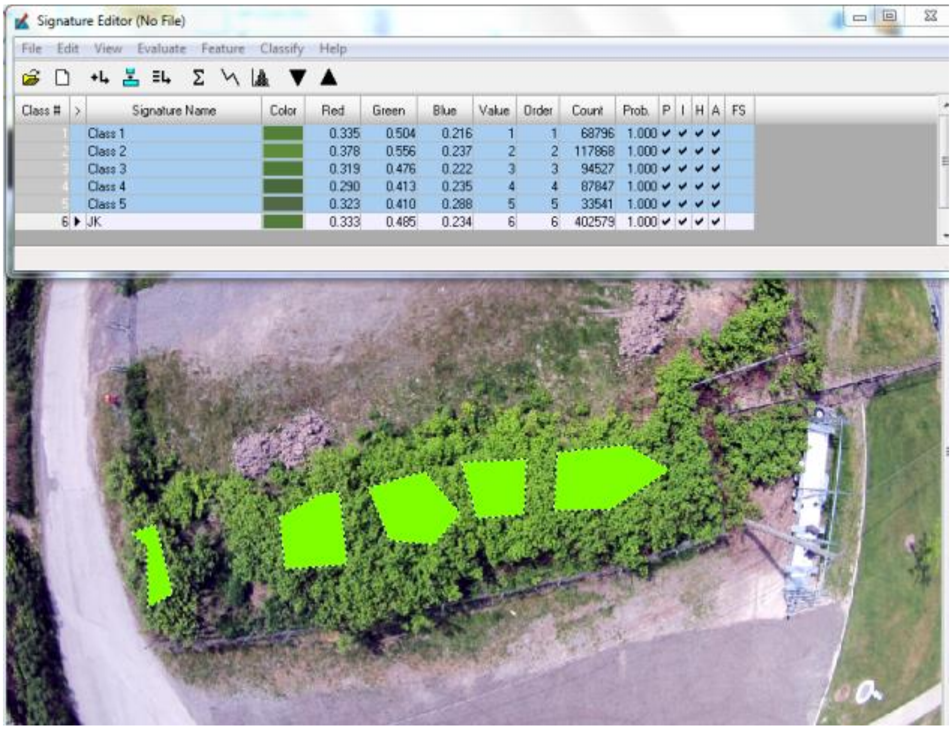

Figure 6 Training area of *F. japonica.*

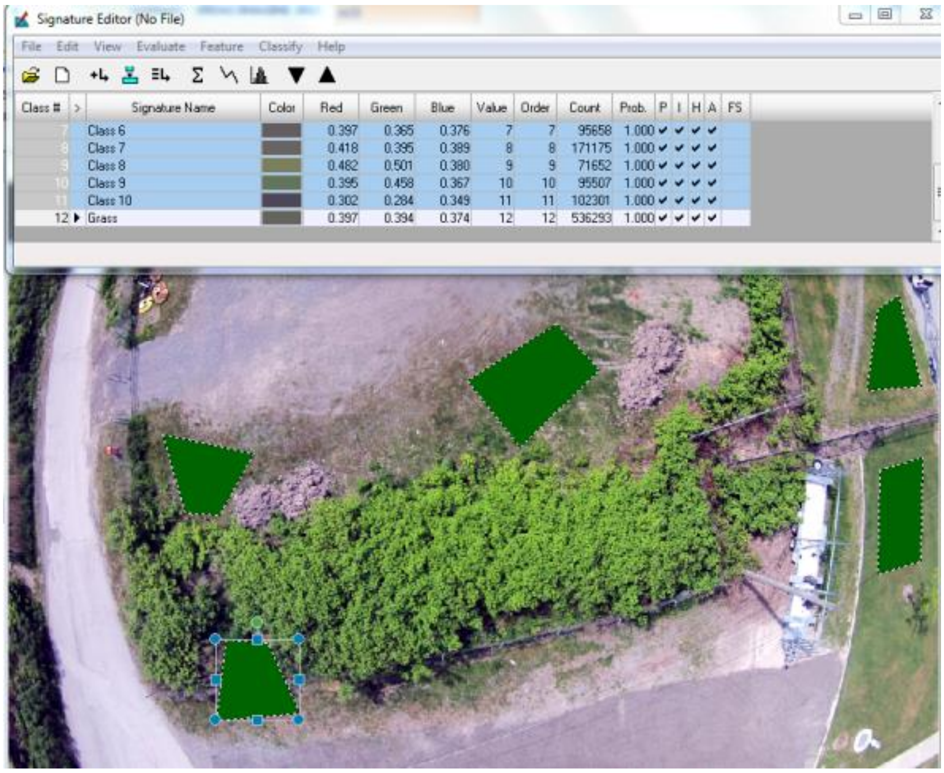

Figure 7 Training area of grass.

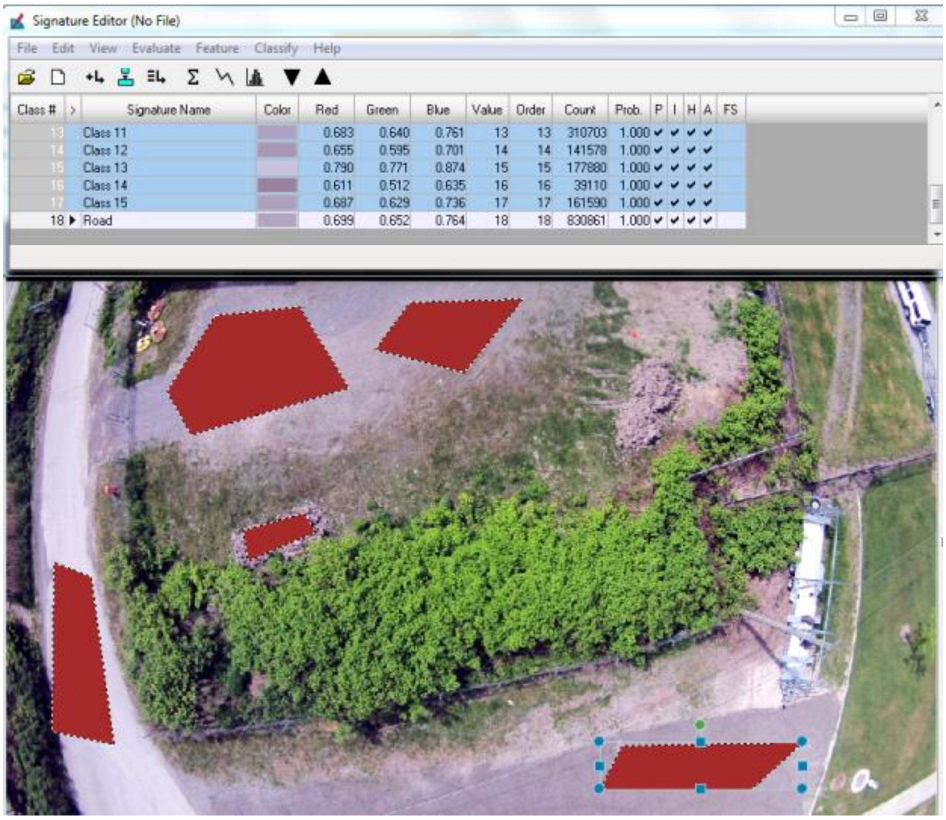

Figure 8 Training area of the road and parking lots.

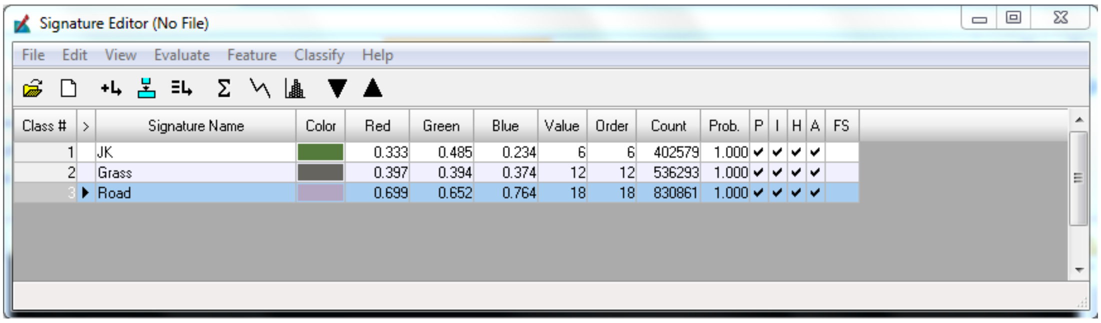

Figure 9 The final classify template.

The next step is to utilize the signature files to conduct different types of supervised classifications to test which one generates the complete classification for this research.

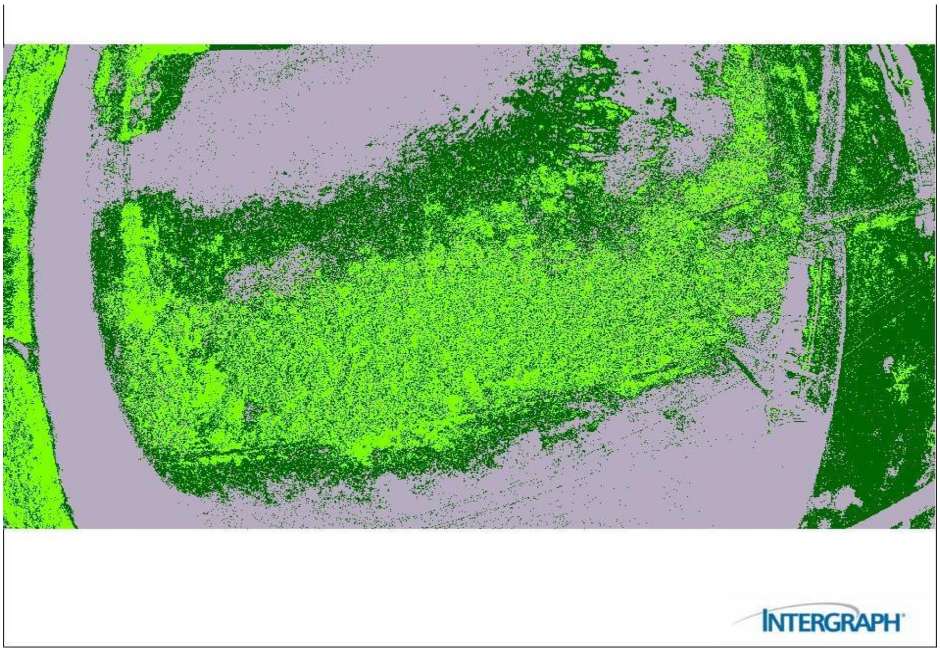

Figure 10 Result of supervised classification, minimum distance.

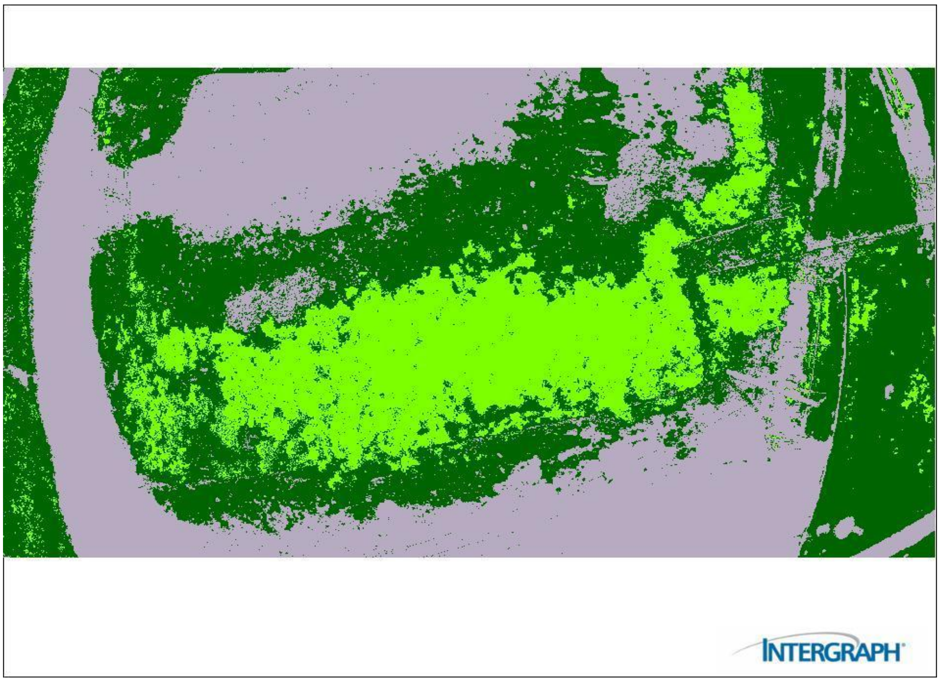

Figure 11 Result of supervised classification, maximum likelihood.

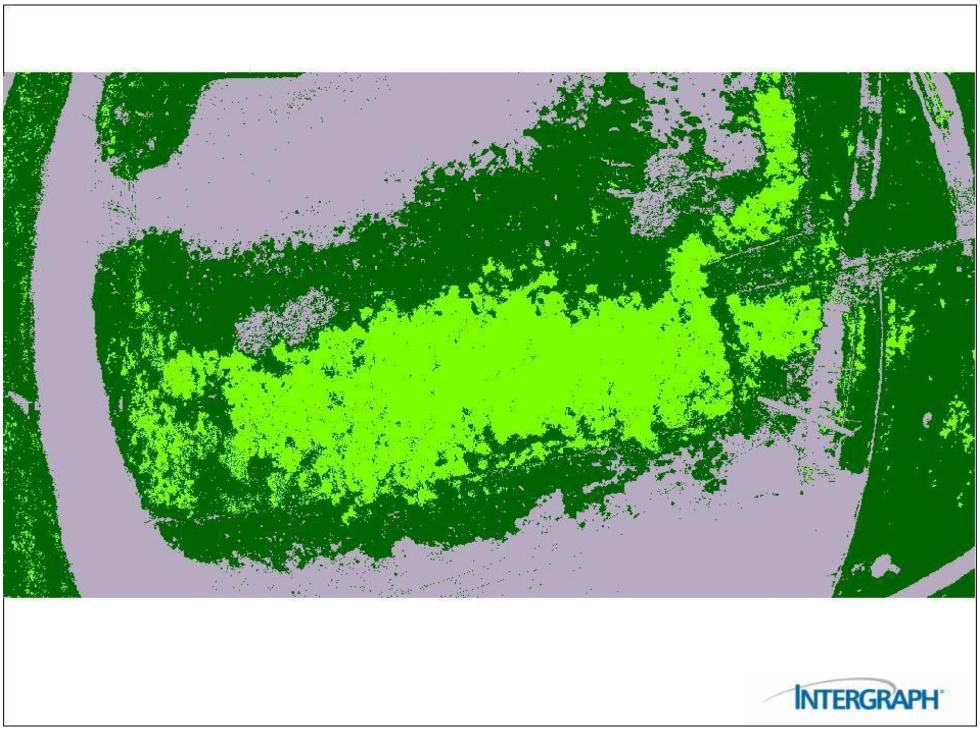

Figure 12 Result of supervised classification,Mahalanobis distance.

The software was calibrated prior to the classification. A template displays the RGB color signature of different objects was set up to complete this job. This template was used in all these three different methods to see which methods can generate the most accurate results.

On the result images, the roads and parking places are shown in gray, the vegetation other than the *F.japonica* is shown in dark green, and the *F.japonica* was shown in light green.

The result of minimum distance methods (Figure 10) shows *F.japonica* distribution better than that of the unsupervised classification. However, the *F.japonica* growing area is still mixed by both dark and light green. In comparison, the maximum likelihood (Figure 11) and Mahalanobis distance (Figure 12) methods are more accurate. The light green and dark green colored pixels separate the species, *F.japonica,* and the grass clearly. The difference between maximum likelihood method and Mahalanobis distance method is small. The result of Mahalanobis distance method shows more dark green part than the method of maximum likelihood does.

To test if the different classification methods generate similar results at different study areas, another site was used for this experiment as well (Figure 13).

Figure 13 The original image of the site near the Peace Bridge.

Similar to the previous experiment process, the *F.japonica* also shows in lighter green in comparison with other kinds of species nearby (Figure 14). The black hole in the middle of the bush was caused by the leaves there were not begin to grow yet in the early spring. There were only stems in that relatively small area but it still adequate to identify the *F.japonica* species.

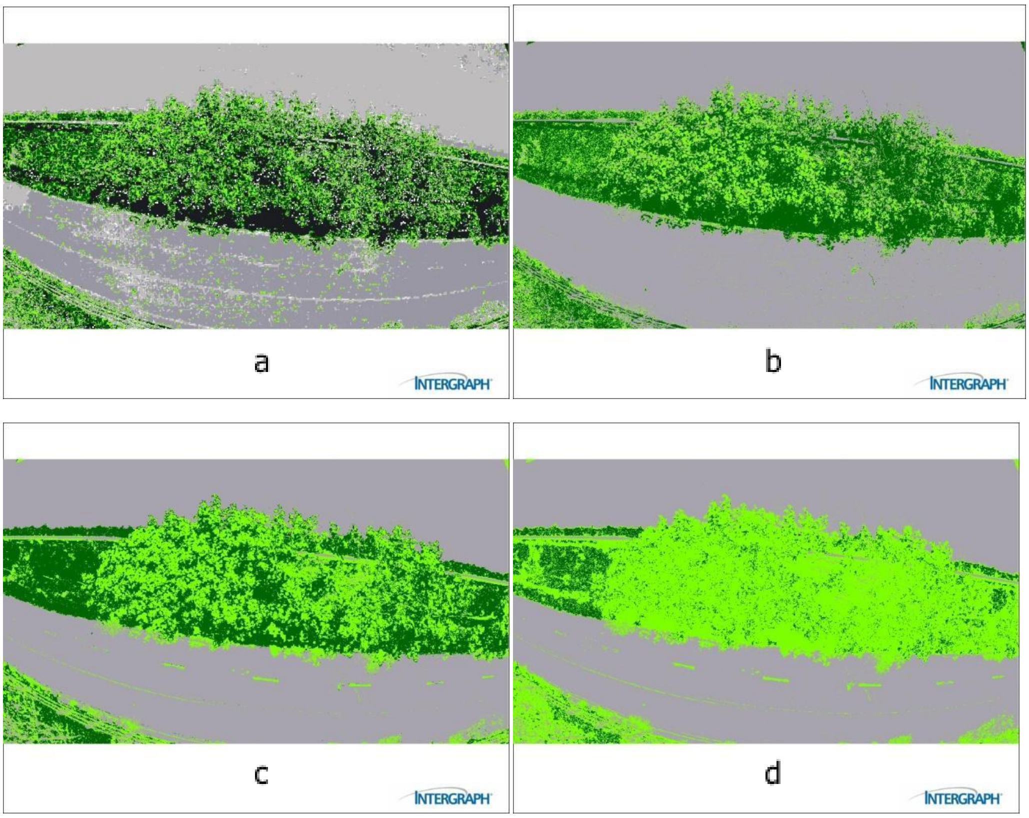

Figure 14 a) unsupervised classification
b) supervised classification -- minimum distance
c) supervised classification -- the maximum likelihood
d) supervised classification -- Mahalanobis distance

In comparison with other methods, the Mahalanobis distance method classifies more light green pixels. That means some plants are classified as *F.japonica* incorrectly, for instance, the lower left corner of the image.

Composite this example and the example of Buffalo West Side Rowing Club, I decided to use maximum likelihood method of supervised classification to process and analyze the original images.

Also, the shadow cover situation can be seen directly after classification. Figure 15 is the original picture shows the *F.japonica* patch in an area of shade. In fact, whether there is shade for overstory trees or not in this area is already clearly displayed in the original image, but it is still necessary to use classification method to quantify the area.

Figure 15 *F. japonica* patch in the Tifft Preserve. Light green shows the invaded area of *F. japonica*. Grey green shows the tree canopy. The black shows the shaded area. (Latitude: 42° 50′ 38″, Longitude: 78° 51′ 9″, took at 2015/5/28, 10:30 a.m.)

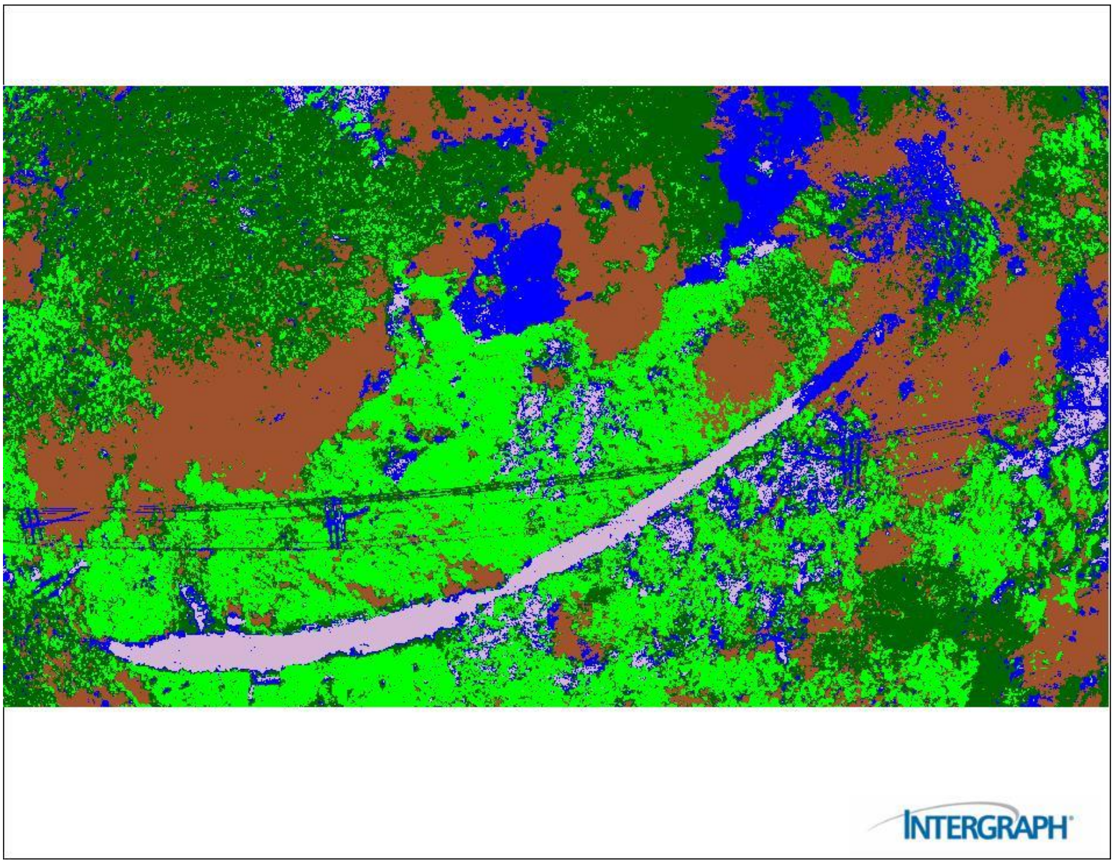

Figure 16 Maximum likelihood classification of the canopy covered area. The light green shows the *F.japonica* patch. The dark green shows the tree canopy. The brown color shows the shaded area. The blue color shows the water body.

In the next step management, the area of these parts will be merged into the *F.japonica* patches to get the total number of the areas that we need.

3.5 Spatial Analysis in ArcGIS Environment

The results of image classifications in ERDAS imagine can be imported into ArcGIS for the next step in the analysis. First, the raster image needs to be adjusted to the right place on the larger scale maps. The georeferencing tool is suitable for this purpose. By connecting the identical significant points with the satellite image, the raster images obtained from the field investigation can be georeferenced in their exact locations that the *F.japonica* grows.

To complete the geo-reference, several points should be picked up as control points (Figure 17). One point from raster layer and one point from the satellite image could be grouped as a pair. These two points should be identical on the same ground feature as control points. Then, the adjustment tool can 'drag' the raster layer to the right place on the satellite image.

Figure 17 Georeferencing for the raster layer. Control points are indicated with numbered crosses. Red crosses are labeled on the base map. Green crosses are labeled on the classified image.

The raster images were vectorized into vector layer in the ArcGIS then. This processes can be done by using the vectorization tool. It generates the polygons based on the colors of the pixels (Figure 18).

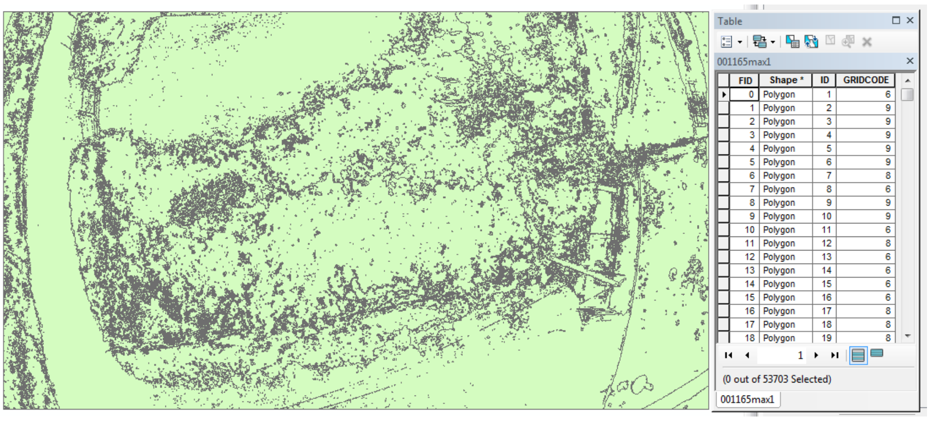

Figure 18　The process of vectorization.

Each polygon has a grid code that represent its color. The polygons that have the same color are coded in the same value. The next step is to dissolve all the polygons with the same value into one polygon, and thematically map them by different colors (Figure 19).

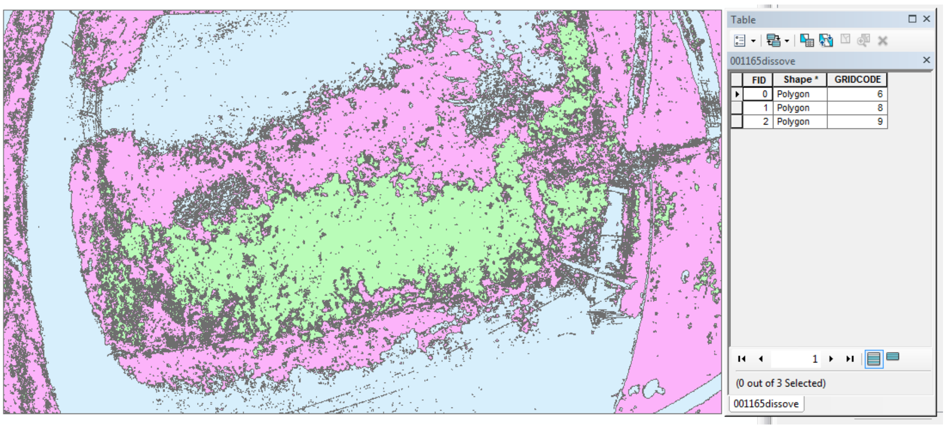

Figure 19　Dissolve polygons with the same code into on.

The only needed polygon in this research is the polygon that shows the area of *F.japonica* species. In addition, the outlines of the water bodies that are near the field of interest were drawn as another vector layer (Figure 20).

Figure 20 The vector image of the Peace Bridge area.

From this image (Figure 20), the distribution of *F.japonica* is presented to be clear and intuitive. Those vector layers can help to estimate the area of the invasive species patches and the distance from the invaded area to the nearest water body. *F.japonica* has been determined as one of the riparian invasive species (Beerling et al., 1995; Gerber et al., 2010). It is necessary to test if there is a significant correlation between its patches area and the distance to the water body. The relationship between these two factors can be discussed and tested by using statistic methods.

Temperature and relative humidity data can be also analyzed by using ArcGIS to obtain the habitat conditions that suitable for the *F. japonica* to thrive. To use Geographic Weighted Regression (GWR; Charlton and Fotheringham, 2009), a dependent variable and one or more explanatory variable should be given. In this case, I used polygon area of *F. japonica* patches as the dependent variable and assigned temperature/RH difference between each height and the ground temperature/RH as the explanatory variable. Also, the slopes of the temperature/RH show their changing rate as the altitude rises. Therefore, the slopes should also be considered if it is relative to the polygon area. After this geoprocessing, we can have a point map layer that shows all the considered statistical values, like coefficient value and local R^2 of each point.

Since the data were collected at different heights during the field investigations, the climate conditions of each site can be expressed in one layer to see the differences between the various sites. Spatial interpolation tools were used to analyze these data and transfer the point layer into explanation surface.

To analyze the local R^2 of each point and try to find out if the differences are related to the growing situation of the *F.japonica*, and how close they are linked, the Kriging method was adopted.

4. Results

I collected aerial images with the UAV at 20 sites. The three-dimensional temperature and relative humidity data were collected at fourteen of the aerial imaging sites. Two categories of approaches were mainly used for analyzing and integrating these datasets.

4.1 Results of Spatial Distribution

Here is the table of the *F. japonica* distribution and the contrast with the information from the iMapinvasive website (Table 1). The observation information from the website includes its ID, County, location, observed date, watershed, and sometimes, photos.

Table 1 The result of verifying *F. japonica* patches that labeled on iMapinvasives site

ID (website)	Latitude (°)	Longitude (°)	Observed date	watershed	Appearances in field investigation	Area (m^2)
NY-321254U	43.05298	-78.77005	May 14, 2014	Tonawanda Creek	No	NA
NY-330332U	43.01586	-78.73879	Aug. 13, 2014	Tonawanda Creek	Yes	61.864
NY-330153U	43.01561	-78.73810	Aug. 13, 2014	Tonawanda Creek		
NY-330146U	43.01495	-78.73812	Aug. 13, 2014	Tonawanda Creek		
NY-328010U	42.89240	-78.71712	June 10, 2014	Buffalo River	Yes, burgeon	NA
NY-313476U	42.88907	-78.72793	May 11, 2011	Buffalo River	No	NA
NY-321629U	42.93154	-78.89361	June 4, 2014	Tonawanda Creek	Yes	124.63
NY-321534U	42.90403	-78.90150	May 29, 2014	Buffalo River	Yes	2505.8
NY-321549U	42.90268	-78.90146	May 29, 2014	Buffalo River	Yes	4076.57
NY-321565U	42.90066	-78.90068	May 29, 2014	Buffalo River	Yes	134.11
NA	42.90048	-78.90094	NA	Buffalo River	Yes	148.37

<table>
<tr><td>NY-319838U</td><td>42.88866</td><td>-78.88994</td><td>Aug. 9, 2013</td><td>Buffalo River</td><td>Yes</td><td>482.69</td></tr>
<tr><td>NY-319835U</td><td>42.89082</td><td>-78.89089</td><td>Aug. 9, 2013</td><td>Buffalo River</td><td>Yes</td><td>95.766</td></tr>
<tr><td>NY-319836U</td><td>42.89040</td><td>-78.89046</td><td>Aug. 9, 2013</td><td>Buffalo River</td><td>Yes</td><td>51.242</td></tr>
<tr><td>NY-319837U</td><td>42.89005</td><td>-78.89013</td><td>Aug. 9, 2013</td><td>Buffalo River</td><td>Yes</td><td>102.2</td></tr>
<tr><td>NY-319838U</td><td>42.88866</td><td>-78.88994</td><td>Aug. 9, 2013</td><td>Buffalo River</td><td>No</td><td>NA</td></tr>
<tr><td>NY-319849U</td><td>42.87547</td><td>-78.88820</td><td>Aug. 15, 2013</td><td>Buffalo River</td><td>Yes</td><td>389.78</td></tr>
<tr><td>NY-319977U</td><td>42.87137</td><td>-78.88558</td><td>Aug. 15, 2013</td><td>Buffalo River</td><td rowspan="2">Yes</td><td rowspan="2">460.76</td></tr>
<tr><td>NY-319840U</td><td>42.87132</td><td>-78.88556</td><td>Aug. 14, 2013</td><td>Buffalo River</td></tr>
<tr><td>NA</td><td>42.87054</td><td>-78.87963</td><td>NA</td><td>Buffalo River</td><td>Yes</td><td rowspan="3">1007.5</td></tr>
<tr><td>NA</td><td>42.86453</td><td>-78.87617</td><td>NA</td><td>Buffalo River</td><td>Yes</td></tr>
<tr><td>NA</td><td>42.85936</td><td>-78.87088</td><td>NA</td><td>Buffalo River</td><td>Yes</td></tr>
<tr><td>NY-20696</td><td>42.85251</td><td>-78.85880</td><td>July 17, 2008</td><td>Buffalo River</td><td>Yes</td><td>803.93</td></tr>
<tr><td>NY-20660</td><td>42.84725</td><td>-78.85693</td><td>July 17, 2008</td><td>Buffalo River</td><td>Yes</td><td>321.32</td></tr>
<tr><td>NY-20644</td><td>42.84433</td><td>-78.85355</td><td>July 17,</td><td>Buffalo River</td><td>Yes</td><td>2099.8</td></tr>
</table>

			2008			
NY-20664	42.84394	-78.85305	July 17, 2008	Buffalo River		
NY-20663	42.84373	-78.85223	July 17, 2008	Buffalo River		
NY-23158U	42.86539	-78.81967	April 27, 2010	Buffalo River	Yes	348.32
NY-23159U	42.86539	-78.81967	April 27, 2010	Buffalo River		
NY-23135U	42.86434	-78.81957	April 27, 2010	Buffalo River		
NY-328255U	42.78912	-78.85234	June 18, 2014	Buffalo River	Yes	3626.86
NY-12462	42.78912	-78.85222	May 16, 2008	Buffalo River		
NY-328219U	42.79031	-78.85141	June 18, 2014	Buffalo River		
NY-328237U	42.79184	-78.85256	June 18, 2014	Buffalo River		
NY-328871U	42.69926	-78.90593	July 21, 2014	Buffalo River	Yes	Near airport should not fly
NY-328870U	42.69974.	-78.90351	July 21, 2014	Buffalo River		
NY-328864U	42.69933	-78.90479	July 21, 2014	Buffalo River		
NY-328835U	42.70590	-78.89982	July 21, 2014	Buffalo River		

NY-328833U	42.70450	-78.89963	July 21, 2014	Buffalo River		
NY-328832U	42.70549	-78.89985	July 21, 2014	Buffalo River		

Based on the coordinate information in Table 1, the location of the *F. japonica* growing sites is labeled on a map of western New York (Figure 21). Most of the sites where *F. japonica* has been identified are located within 200 meters of the Lake Erie shore. Only four out of 20 invaded sites were located more than 1,000 meters from Lake Erie.

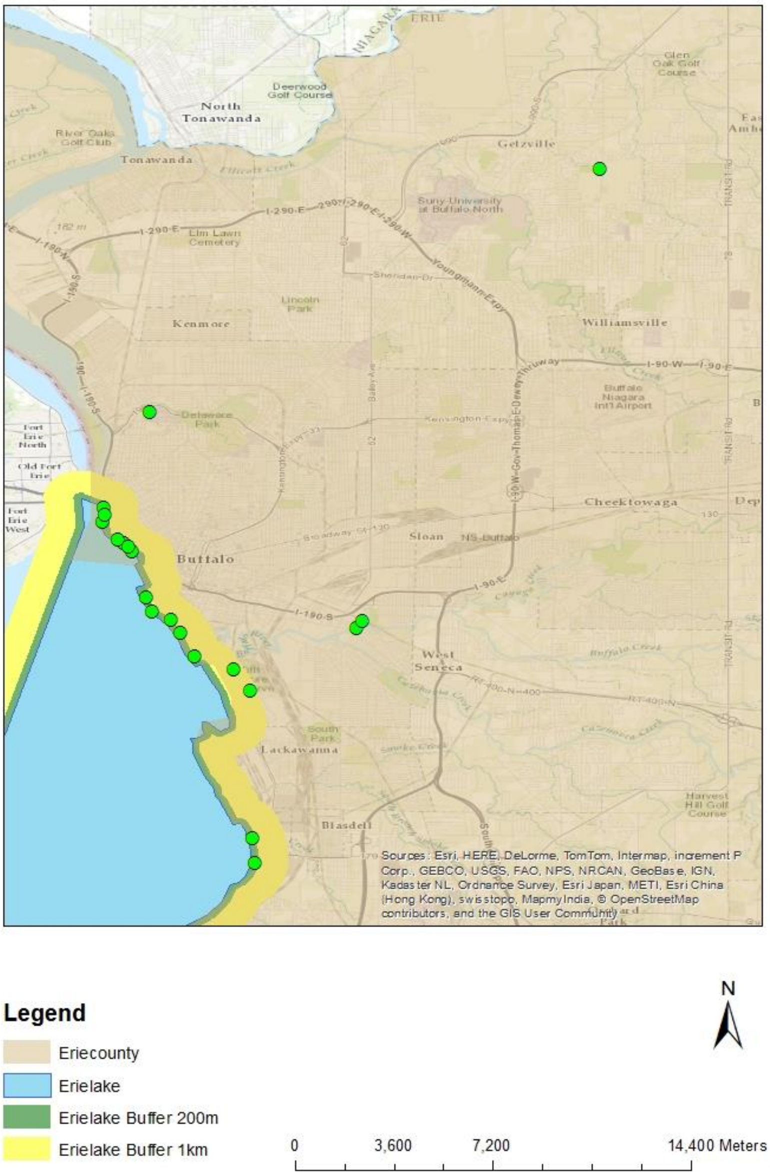

Figure 21 The distribution of sampling points.

Lake Erie modifies regional temperatures and precipitation (Mortsch and Quinn, 1996). Especially during the early winter, the wind blows across the relatively warm lake, and it takes the moisture to the shoreline area. That increases the precipitation of the downwind shore area (Niziol, 1987). After the winter, the snow that accumulated during the past a few months would melt and provide a significant amount of humidity and fulfill the shallow groundwater to the formerly snow-covered areas. According to the Flora of China (eFlora, 2008), the *F. japonica* is likely to grow in moist places. That moisture could refer to the air humidity; and also, could refer to the soil humidity. The results of this research partially explained the distribution of the *F. japonica* shown in Figure 21. But to determine which one is the major impact factor, further work should be done in the future.

4.2 Result of the Habitat Condition

In a combination of UAV image interpretations, ERDAS Imagine, and ArcGIS analysis, Table 2 shows the invaded areas and the distances to the nearest water body. The shaded situation is also listed in this table.

Table 2 Spatial distribution results

Site ID	Area(m^2)	Minimum Distance (m)	Maximum Distance (m)	shade	Mean Distance (m)
lassalle01	95.766	192.17	198.64	0	195.405
lassalle02	51.242	192.79	196.36	0	194.575
lassalle03	102.2	189.28	194.53	0	191.905
lassalle04	135.53	185.89	191.58	0	188.735
margaret01	61.864	210.38	235.5	1	222.94
peace01	2505.8	20.76	50.27	0	35.515
peace02	4076.57	0	31.06	0	15.53
peace03	134.11	16.01	22.54	1	19.275
peace04	148.37	96.02	108.84	0	102.43
peace05	482.69	55.69	98.2	0	76.945
tifft01	803.93	0	11.38	0	5.69
tifft02	321.32	0	13.95	1	6.975
tifft03	2099.8	25.85	76.63	0	51.24

timesbeach01	389.78	0	9.46	0	4.73
timesbeach02	460.76	0	15.09	0	7.545
timesbeach03	1007.5	23.49	71	0	47.245
timesbeach04	830.58	149.30	184.93	0	167.115
senecabluff01	348.32	36.80	82.84	0	59.82
bs01	124.63	41.82	54.64	0	48.23
Woodlawnb01	3626.86	35.04	142.50	0	88.77

Based on the distance to the nearest water body and the polygon area results, the analysis of next step will concentrate on the correlations between them. It will also be used in testing if the study sites being shadowed or not correlated with the size of growing area.

Since the weather of each sample day varied, temperature and relative humidity at different altitudes were subtracted from the ground surface temperature to calculate the difference between them. In this case, standard values are used instead of using absolute value (Tables 3 and 4; Figure 22 and 23).

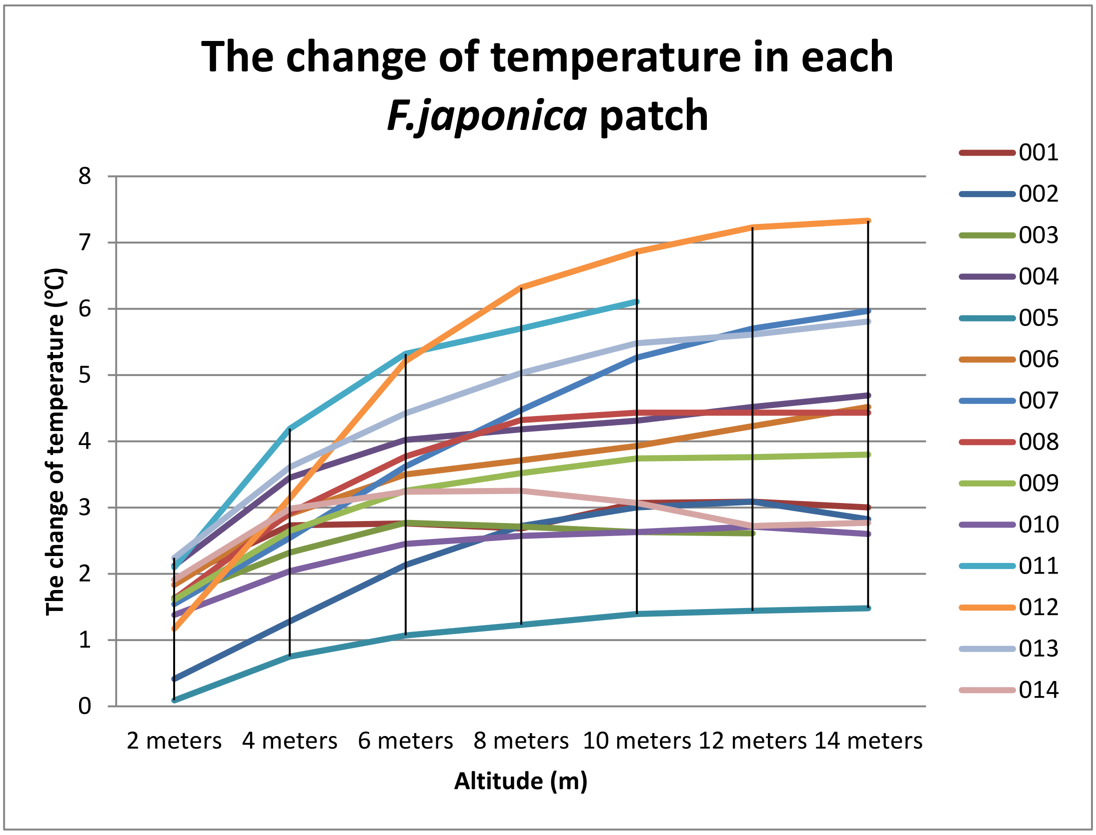

Figure 22 The change of temperature in each *F.japonica* patch.

Table 3 The data of temperature

Research site ID	TEMP02M	TEMP04M	TEMP06M	TEMP08M	TEMP10M	TEMP12M	TEMP14M
001	1.91	2.73	2.76	2.68	3.07	3.09	3.00
002	0.41	1.28	2.13	2.72	3.00	3.09	2.82
003	1.64	2.32	2.77	2.71	2.63	2.61	NA
004	2.12	3.45	4.02	4.18	4.31	4.52	4.69
005	0.09	0.75	1.07	1.23	1.39	1.44	1.48
006	1.83	2.90	3.50	3.71	3.93	4.23	4.52
007	1.54	2.54	3.62	4.47	5.26	5.70	5.97
008	1.62	2.92	3.77	4.32	4.43	4.43	4.43
009	1.61	2.65	3.25	3.52	3.74	3.76	3.80
010	1.38	2.04	2.45	2.57	2.63	2.71	2.60
011	2.10	4.19	5.32	5.70	6.11	NA	NA
012	1.17	3.14	5.21	6.32	6.86	7.23	7.33
013	2.24	3.61	4.42	5.03	5.48	5.61	5.81
014	1.91	2.98	3.24	3.25	3.07	2.72	2.77

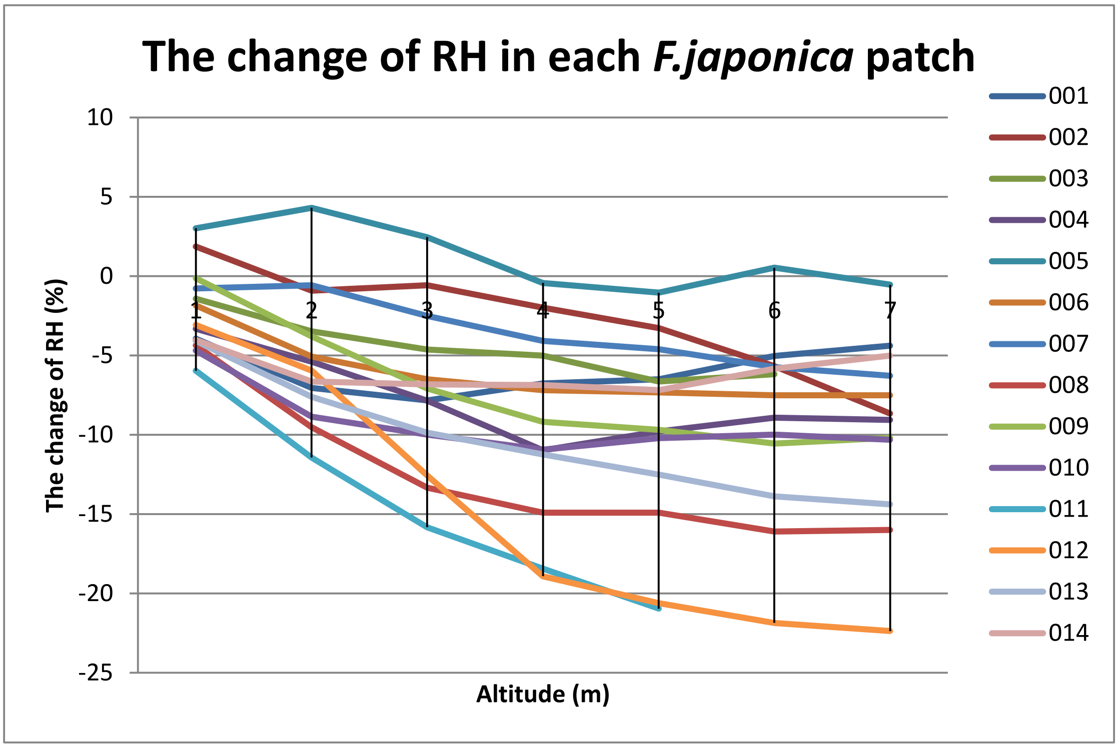

Figure 23 The change of RH in each *F.japonica* patch.

Table 4 The data of relative humidity

Research site ID	RH02M	RH04M	RH06M	RH08M	RH10M	RH12M	RH14M
001	-3.95	-7.05	-7.84	-6.77	-6.50	-5.04	-4.38
002	1.86	-0.91	-0.57	-1.99	-3.27	-5.68	-8.66
003	-1.42	-3.48	-4.63	-5.01	-6.64	-6.17	NA
004	-3.32	-5.39	-7.85	-10.97	-9.78	-8.92	-9.07
005	3.02	4.31	2.45	-0.43	-1.04	0.53	-0.54
006	-1.85	-5.07	-6.50	-7.19	-7.32	-7.51	-7.52
007	-0.78	-0.58	-2.51	-4.08	-4.60	-5.73	-6.29
008	-4.36	-9.52	-13.34	-14.90	-14.90	-16.09	-16.00
009	-0.14	-3.80	-7.09	-9.19	-9.68	-10.55	-10.20
010	-4.69	-8.87	-9.98	-10.93	-10.21	-9.99	-10.32
011	-5.96	-11.44	-15.83	-18.44	-20.96	NA	NA
012	-3.07	-5.95	-12.58	-18.92	-20.61	-21.86	-22.37
013	-4.09	-7.61	-9.87	-11.23	-12.51	-13.88	-14.38
014	-4.02	-6.64	-6.83	-6.87	-7.18	-5.84	-5.01

4.2.1 The Relative Position to the Nearest Water Bodies

In the progress of field investigation, I found that all the places that have been invaded by the *F.japonica* are near water bodies which are consistent with the other descriptions of *F.japonica's* preferred habitat conditions (eFlora, 2008; Beerling, 1991; Schnitzler and Muller, 1998; Conolly, 1977). So I made a prediction that the growth of the *F.japonica* could be relevant to the water body. I hypothesized that proximity to water would positively influence the patch size of *F.japonica*. To test my hypothesis, the regression analysis was applied to find out whether there is a specific pattern for it.

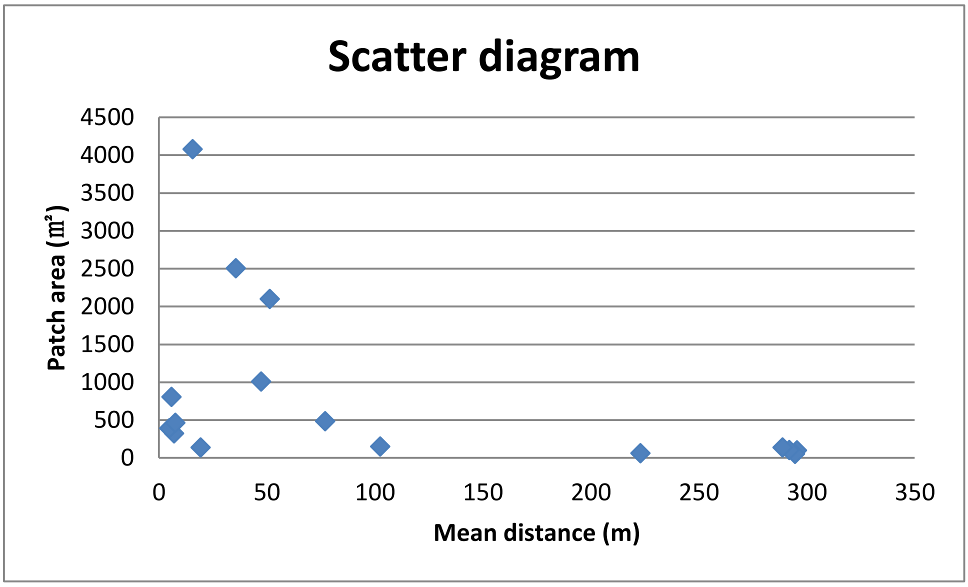

Figure 24 Scatter diagram of mean distance and growing area.

From the scatter diagram (Figure 24), we can see that the distribution of the points shows several extreme values, and that will make the data difficult to be analyzed. Therefore, I did a log transform to the patch area, and the scatter diagram express the data much better (Figure 25).

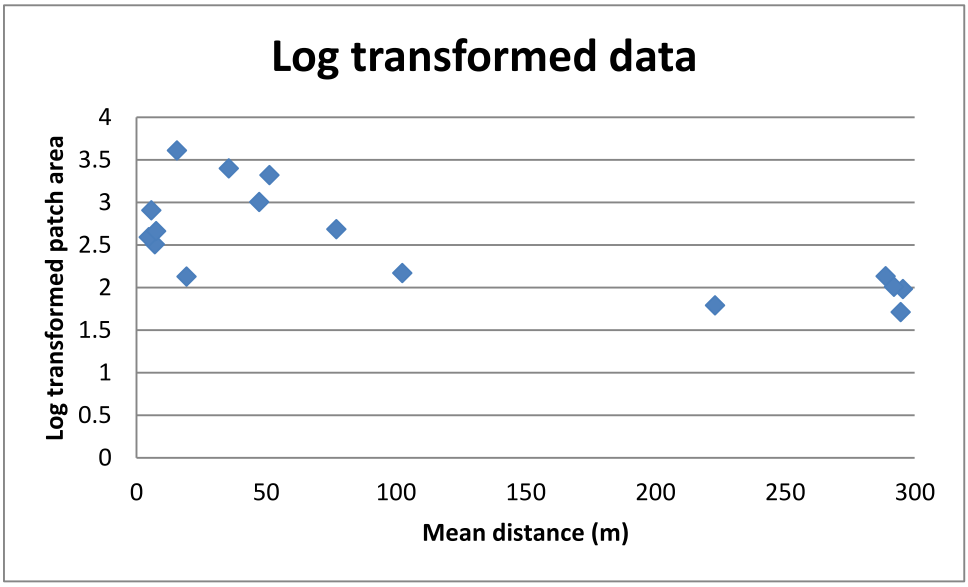

Figure 25 Scatter diagram of log-transformed data

Based on that, the relationship between the mean distance from the *F.japonica* patches to the nearest water bodies and the patches' area could be tested by doing a linear regression (Figure 26).

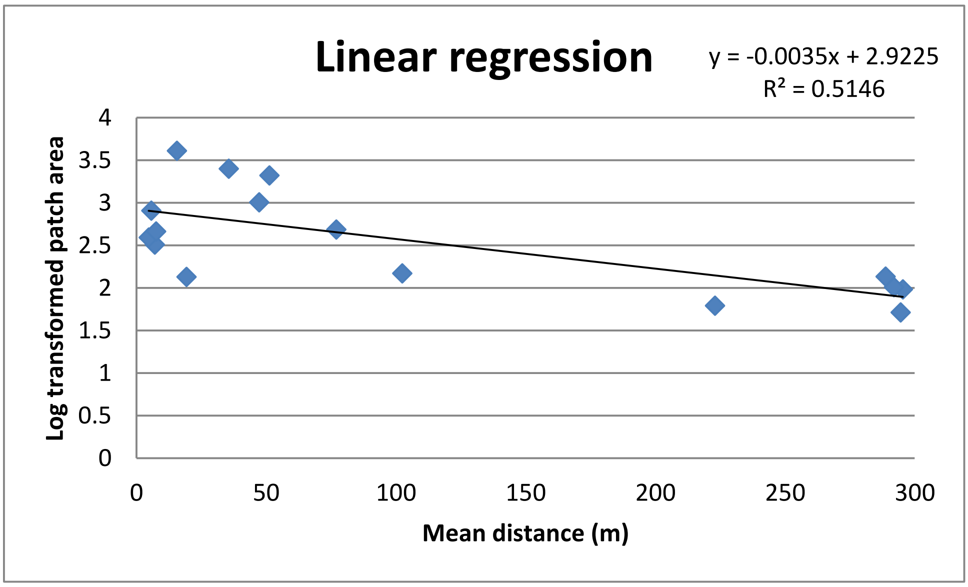

Figure 26 Linear regression of the log-transformed data

We can see that the regression line fits the points distribution well. That indicate the distance between the *F. japonica* growing patch and the nearest water body decreases, the area of the will increase. And the pattern fits a linear regression.

4.2.2 Shade Cover Analysis

Only 3 out of 20 *F.japonica* sites were shaded by surrounding trees. This is consistent with the widely made observation that *F.japonica* is shade intolerant (Zhou et al., 2014; Yang et al., 2014; Long, 2009; Cui et al., 2014; Xiao et al., 2013; Sendall et al., 2014). Based on these observations, I hypothesized that unshaded patches of *F.japonica* can grow better than those that were shaded by nearby trees. To test this hypothesis, I use R to do the two tail t-test for these two groups.

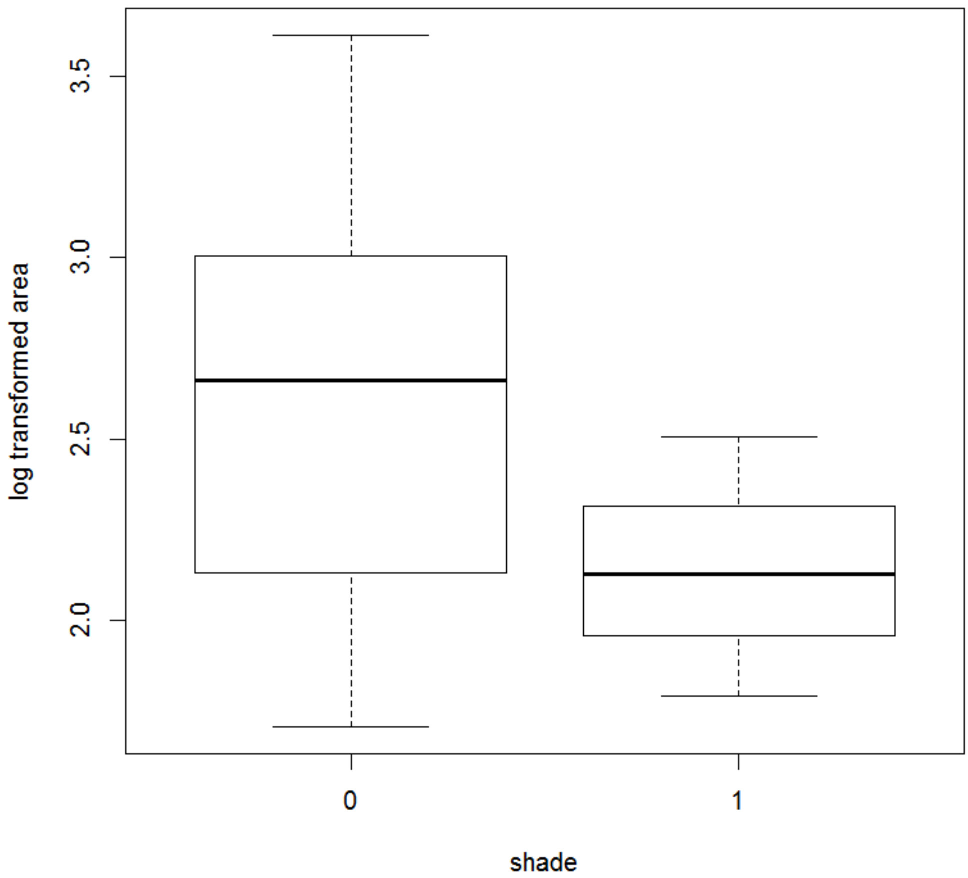

Figure 27 Plot of shadow t-test Zero (0) indicates that there was no shadow cover in the growing area, and one (1) indicates that there was shadow cover.

Consistent with my hypothesis, shaded *F. japonica* patches are significantly smaller than unshaded patches (P = 0.125; Figure 27).

4.2.3 Relative Humidity Analysis

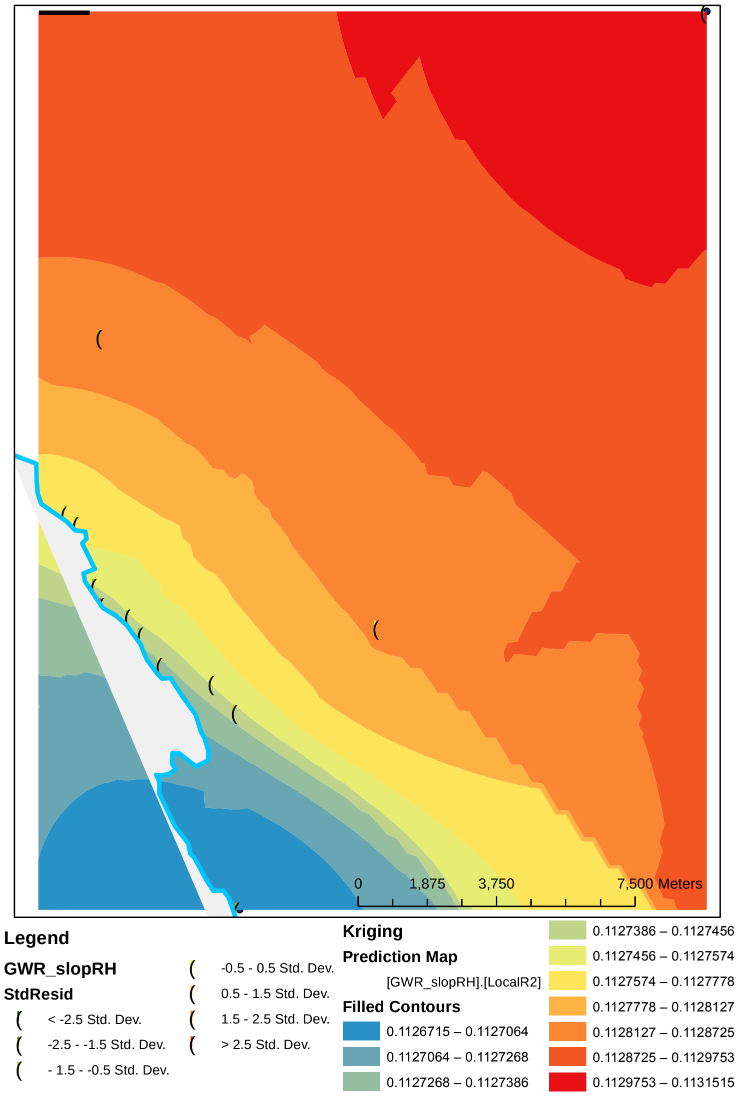

Figure 28 Relative humidity slope analyze. The color of the background indicates the regional prediction of the local R^2 in this area. The colors of the points show the standard deviation of each point. Lake Erie located on the bottom left corner of the figure. The light blue line indicates the shoreline of it.

Relative humidity can not be considered to a relative with the growing situation of the *F.japonica* (Figure 28). The reason of this may because the change of relative humidity is highly related to the weather of the day that the data was collected, and the relative humidity differences between heights can be variable. Sometimes the relative humidity increased as altitude increased higher, but sometimes relative humidity decreased, which made it hard to obtain the pattern of the relationship with the growing situation. Even if the variable at the different locations have been normalized by using the differences between the ground and on different elevations. If long-term data could be collected, this problem may be solved.

4.2.4 Temperature Analysis

Comparing with the relative humidity, the temperature has a more obvious pattern as the altitude changes. As we know, the temperature should decrease 0.64 ℃ as the altitude increase 100m (Jacobson, 2005). But on a small scale, in the boundary layer, how would it change? It will also decrease, but the slope and the detail changes will be a variable.

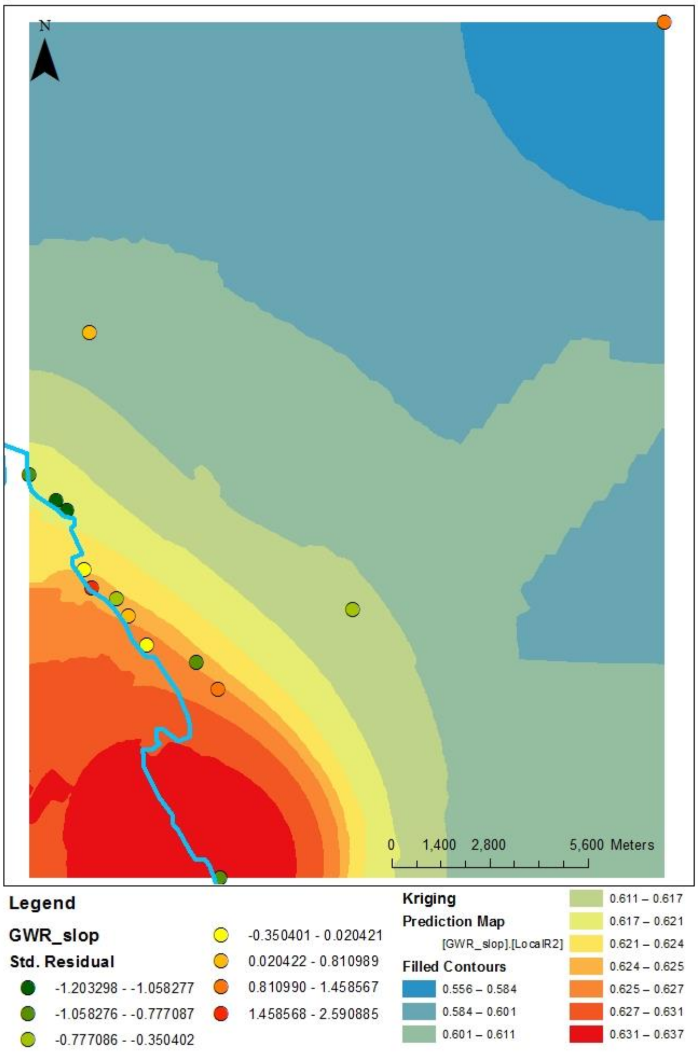

Figure 29 The slope analysis of temperature in studying area. The color of the background indicates the regional prediction of the local R^2 in this area. The colors of the points show the standard deviation of each point. Lake Erie located on the bottom left corner of the figure. The light blue line indicates the shoreline of it.

The relationship between temperature slope and catch area fit the GWR well and from the lakeshore to inland, the coefficient decreased obviously (Figure 29). The color of the points shows that most of the points have a relatively small standard deviation, which means that just a few values of sampling points are not fit the pattern between the dependent and explanatory variable.

The details of the small-scale temperature changes are shown in Figure 30-36.

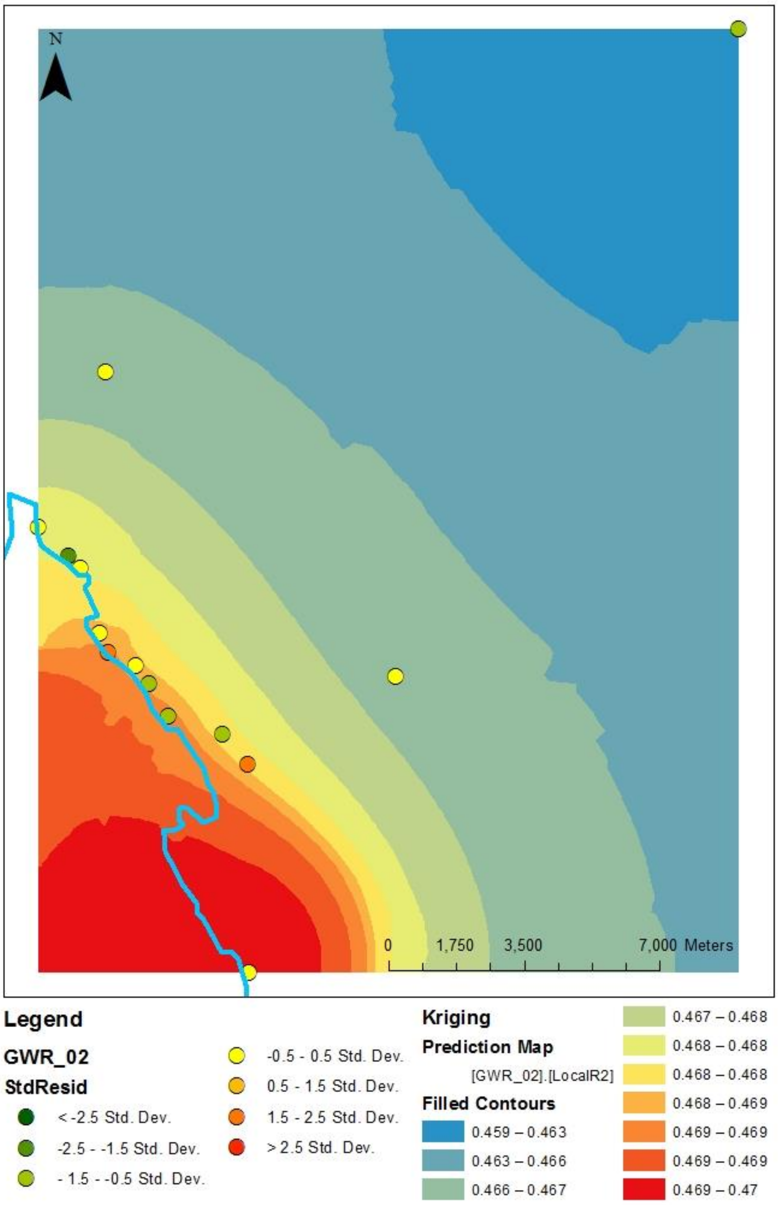

Figure 30 The results of temperature analysis in 2m altitude.

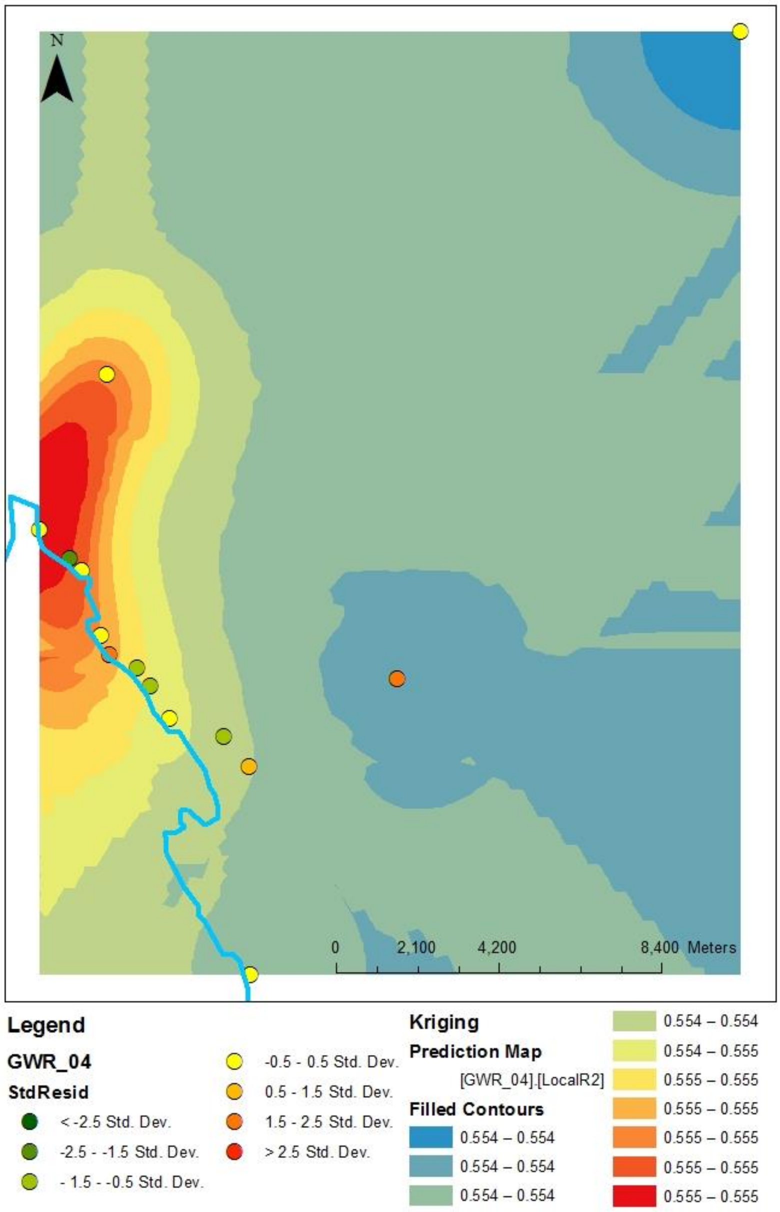

Figure 31 The results of temperature analysis in 4m altitude.

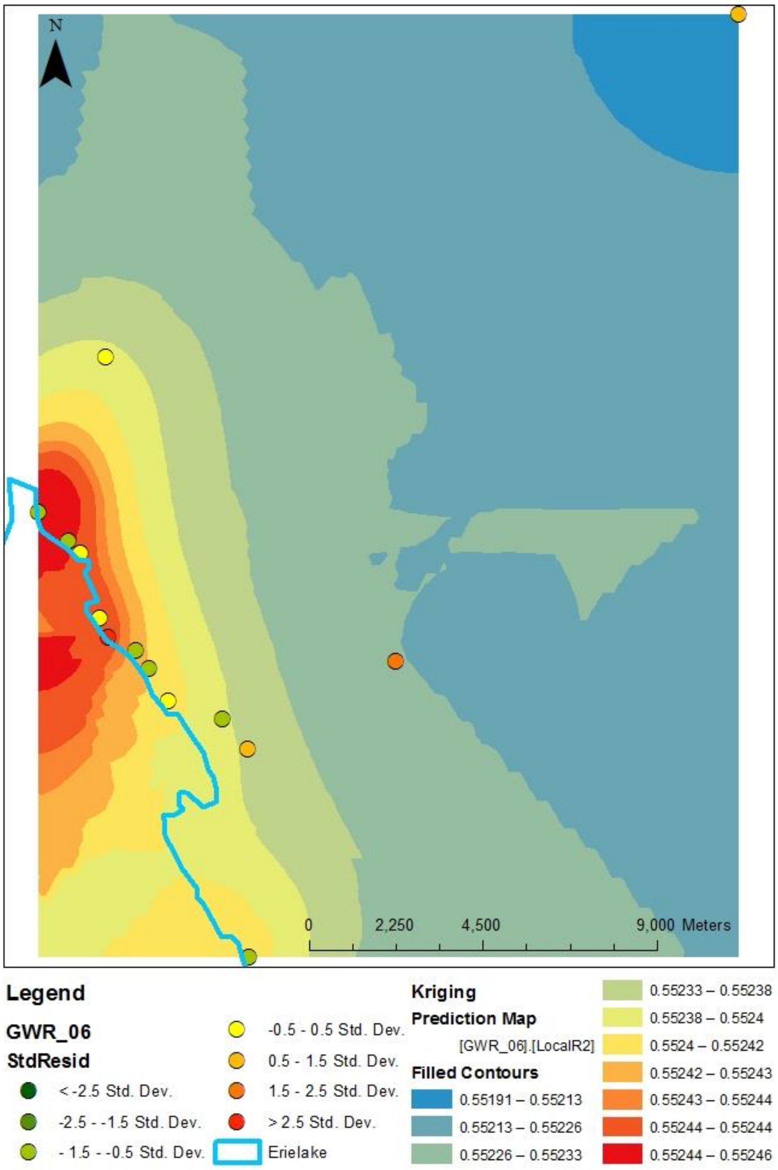

Figure 32 The results of temperature analysis in 6m altitude

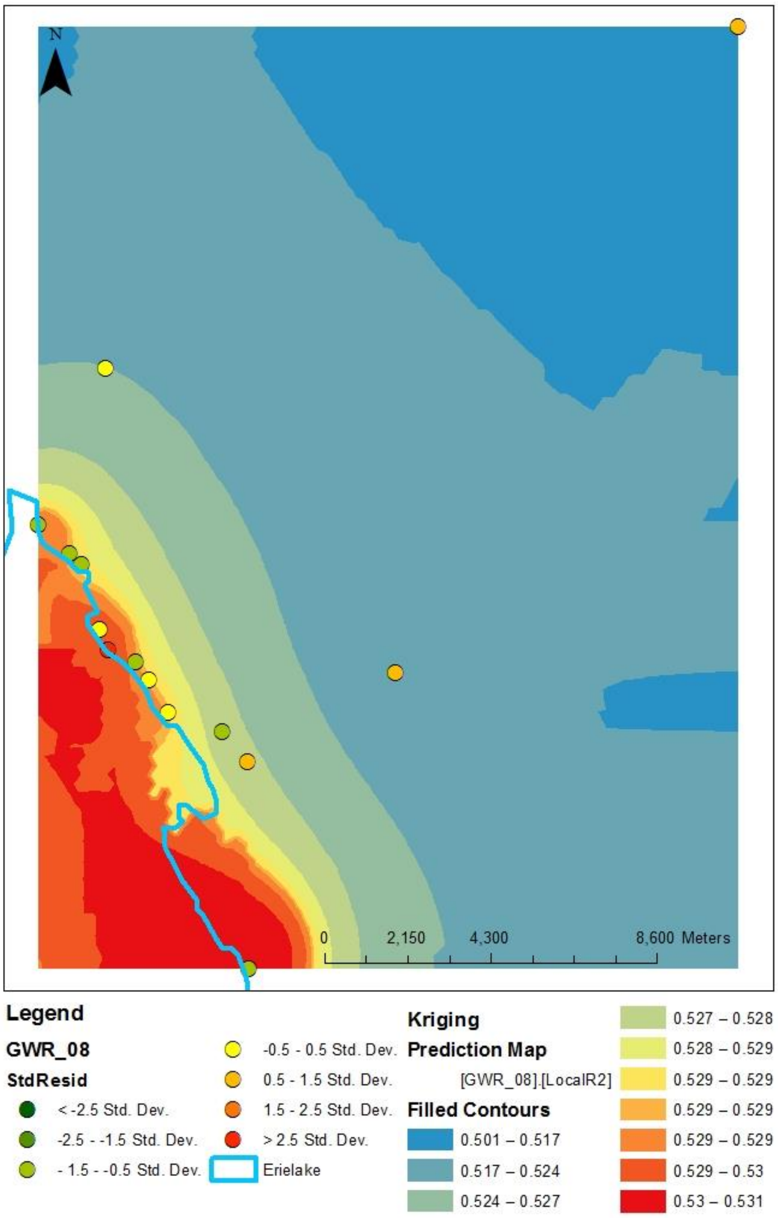

Figure 33 The results of temperature analysis in 8m altitude.

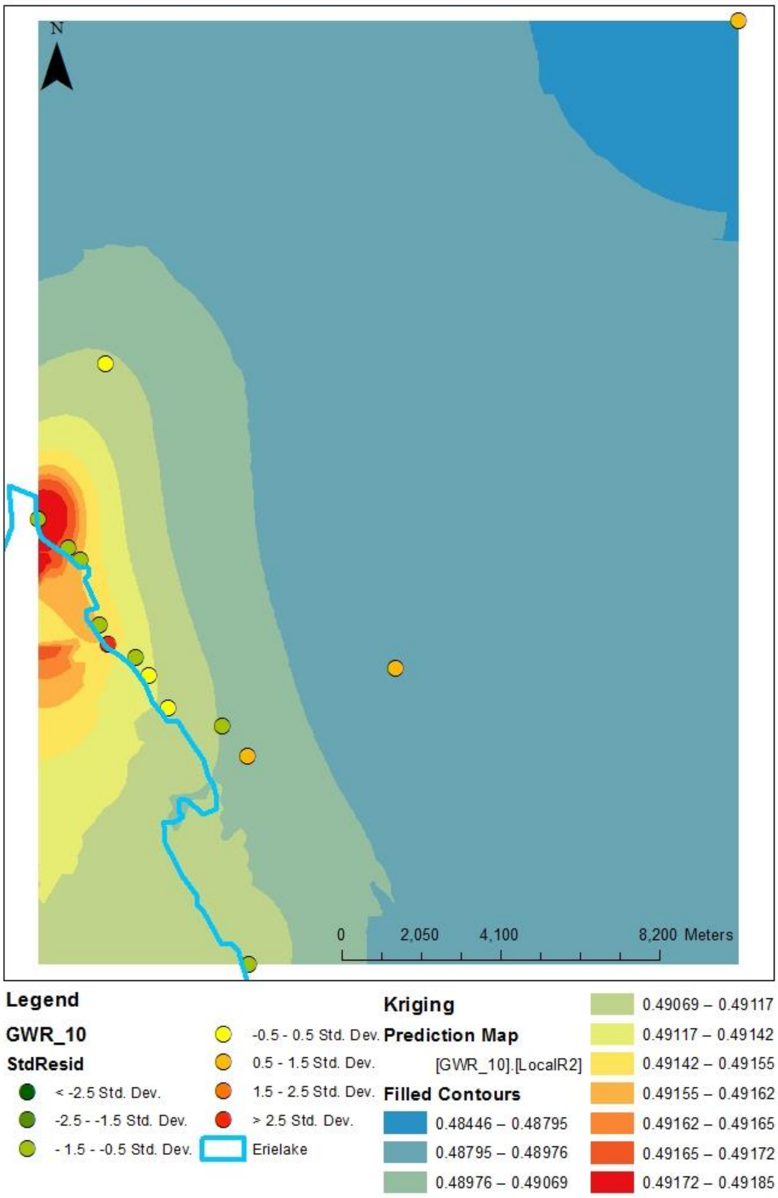

Figure 34 The results of temperature analysis in 10m altitude.

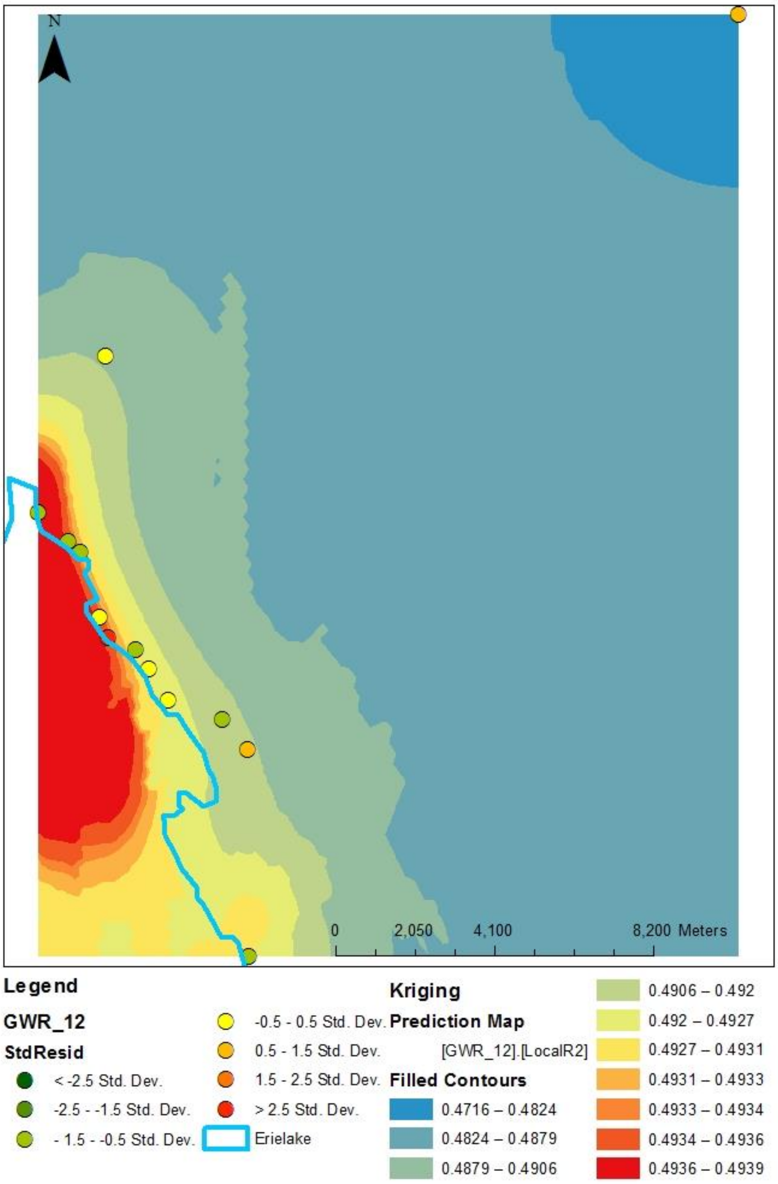

Figure 35 The results of temperature analysis in 12m altitude (one point has no data).

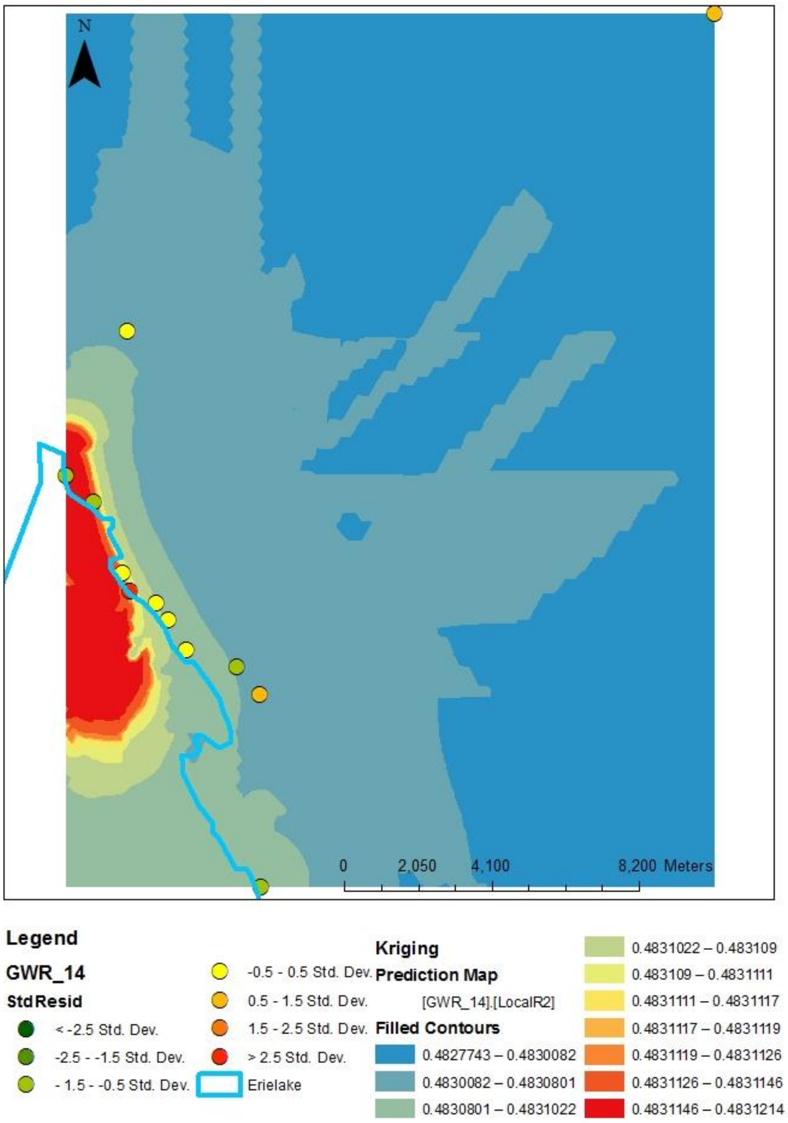

Figure 36 The results of temperature analysis in 14m altitude (two points have no data).

Across a range of altitudes, local R^2 declines with increasing distance from the lakeshore (Figure 30-36).

The results of temperature at the 2m altitude (Figure 30) are the most similar one to the outcome of the temperature slope. But the local R^2 is the smallest ones among the regressions of temperatures at the different altitudes. The local R^2 at 4m level is the largest, and after that, it decreases as the altitude increases. That means the temperature difference between the 4m altitude and the ground and the *F.japonica* growing situation have the most significant correlations. That may be because that is the height for the species to grow (eFlora, 2008).

Also, the same as the result of changing slope of the temperature, those points that have large standard deviation still shows in red in Figure 30-36. It means those points have a remarkable difference from other points in each detecting altitudes. That may because the extreme weather the day the data were collected. If there is a large database, this problem may be solved.

5. Conclusion

5.1 Major Distributions of *F. japonica*

Most of the *F.japonica* sites identified on the iMapinvasives website were located in public parks. Some of these locations were subject to *F.japonica* control by the parks managers. In addition, I identified several new sites which help illustrate the rapid spread of this emerging invasive species (Table 1). Generally speaking, in Erie County *F.japonica* patches are mainly distributed near the lakeshore or adjacent to creeks or other smaller bodies of water.

5.2 The Impact of Shade on *F. japonica* Patch Size

The statistical test indicated that the shading situation of *F.japonica's* growing area does have a correlation with the growing area of *F.japonica*. The places without the shadow or canopy cover by another plant can provide a better condition for the *F.japonica* to grow. In contrast, the total number of the shadowed places that are growing *F.japonica* is tiny. The average area of those growing places is significantly lower than the places with plenty of sunshine. Based on that, the managers should pay more attention to the surrounding area of *F.japonica* patches that do not have much shadow cover. Comparing to the shady area, these places have a higher risk to be invaded by *F.japonica.* Furthermore, managers can reduce the suitable potentially invade area by plant trees to generate larger canopies coverage area.

5.3 The distance from *F.japonica* patches to the nearest water bodies

The result of linear regression showed that the distance from *F.japonica* patches to the nearest water bodies and the area of the patches have significant correlation. That means even in the urban area, the impact of the water body is still effective to the growth of *F.japonica.* This conclusion may lead the managers to pay more attention to the river banks and lakeshore area. Especially the shoreline area without any shadow cover.

5.4 Small Scale 3-Dimentional Habitat in Growing Area

The result of the spatial analysis indicated that the relative humidity changes in the boundary layer do not show significant impacts to the growing conditions of plants. The temperature changes, by contrast, show a significant coefficient with the growing situation on both temperatures slope changing and the specific temperature changes at each elevation level. Among all the levels, the changes between 4m height and the ground are the most significant according to GWR test. It may need further research to get more scientific explanations. The limitation of this research is the size of the dataset. The analysis could be more precise if there are more data because the GWR model works much more accurate with a large dataset.

5.5 The feasibility of using UAV to detect the invasive species

Comparing to the satellites and airborne, using UAV as a platform to do the remote sensing can be much cheaper and more flexible. This research proved that the UAV is a very effective equipment to detect the distribution and the habitat condition of the invasive species. It can take high resolution images and with proper attached sensors, the temperature and relative humidity in different altitude level could be recorded. With the improvement of the UAVs, we can do more things such as set a frequently used way for the UAV to fly along so that it could detect a certain area many times through a data collecting season. In the future, more sensors like infrared cameras could be attached onto the UAVs and that will provide us more aspects to study the environment.

In contrast, there are several things that we should pay attention to during the field investigation. The first thing is the usage of UAV is largely limited by the weather condition. It could not be used in the windy or raining weather. The other thing should be considered is the limitation of the battery storage. In my research, the batteries can only last for 15 minutes. That means I need to prepare several batteries for one field trip and the data collection process should be designed based on it.

With the improvement of the equipment, to monitor the invasive species in a certain area by using the UAV will be possible soon.

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