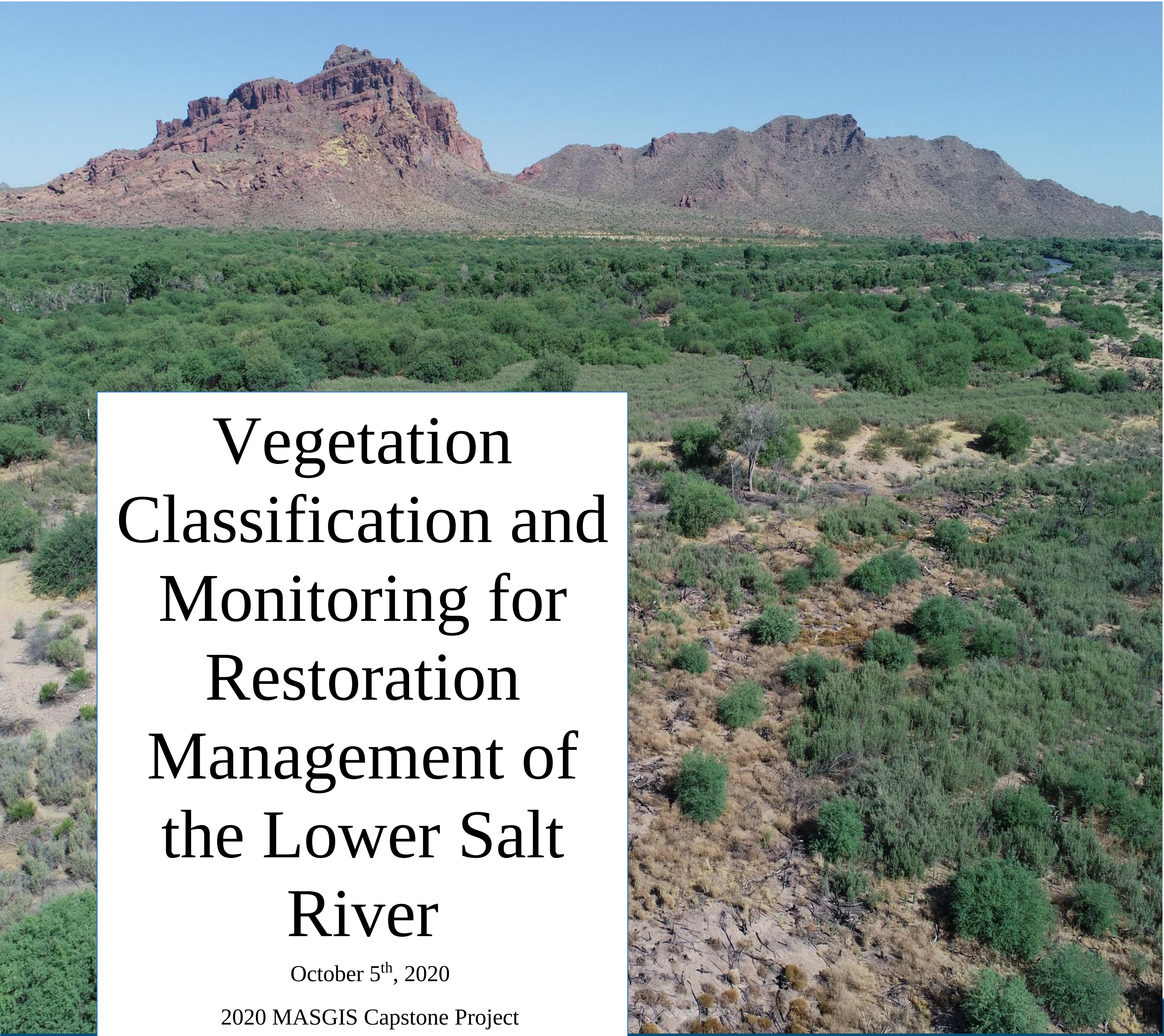

Vegetation Classification and Monitoring for Restoration Management of the Lower Salt River

October 5th, 2020

2020 MASGIS Capstone Project
Technical Report

Group 4

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Introduction

Purpose and Need

The primary purpose of this project was to develop updated monitoring protocols for the Lower Salt River (LSR) using unmanned aerial vehicle (UAV) imagery in collaboration with Green Drone Arizona (GDAZ). Restoration managers have been presented the opportunity to implement advanced remote sensing technologies along the LSR riparian ecosystem. UAVs are becoming an efficient, high resolution method of mapping individual plant species, overall vegetation growth, and treatment against invasive species (Michez et. Al, 2016). Their [UAVs] addition to the ongoing work by the Tonto National Forest and the Lower Salt River Restoration Project (LSRRP) will improve the decisions made for managing the health of the LSR habitat. This capstone project will build upon the existing techniques using geospatial technology for natural resource management with the new inclusion of UAV data.

New aerial imagery collected from UAVs can be analyzed using a geographic information system (GIS). Initial site monitoring and analysis for restorative treatment along the LSR was completed in a 2018 technical report by United States Forest Service (USFS) GIS & Natural Resource Specialist - Justin Eddinger. The purpose of his project was to inventory and map both native and invasive plant populations and propose management protocols for the treatment of key riparian areas within the Lower Salt River Recreation Area, on the Mesa Ranger District, Tonto National Forest. The GIS deliverables within Eddinger's project have shown how successful ecological management can be with the incorporation of geospatial analysis. Project members will be following the procedures proposed in Eddinger's initial restoration plan and expanding the capabilities of GIS analysis using the UAV data. The GIS methods used in this project can be used in future GDAZ workflows for LSR monitoring and community outreach.

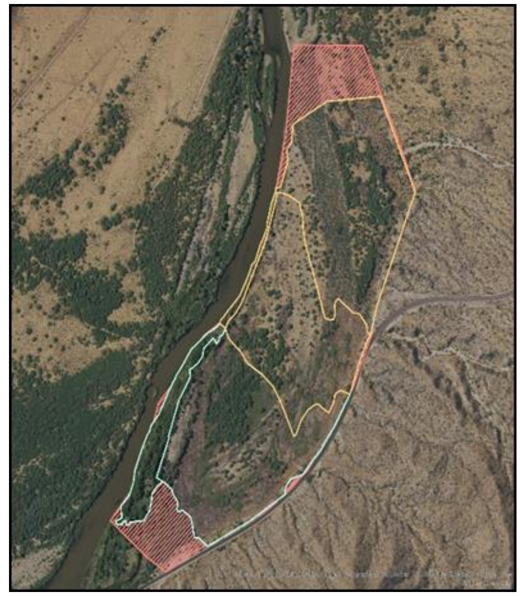
This project has also developed GIS teaching modules for students and teachers to use within future cohorts of GDAZ and their own public curriculum. Accessible education in GIS and how it may be used in ecological restoration is a fundamental goal of the GDAZ team. Geospatial technology was a driving force in the development of monitoring procedures along the LSR which prompted community outreach initiatives across multiple organizations. The GDAZ team understood the importance of public involvement and believes continued project success is achievable by providing educational resources regarding this geospatial technology (i.e. GIS, UAVs). The teaching modules are intended to provide new ArcGIS Online (AGOL) and Collector for ArcGIS users with resources to help understand basic navigation and functions. This will present the next generations of students with the opportunity to immerse themselves in advanced forms of geographic information technology for ecological restoration and other STEM disciplines.

Background

The Lower Salt River Restoration Project

In April of 2017, the Cactus Fire burned over 800-acres of the LSR (InciWeb, 2017). The burn severity and wildfire behavior were not typical of the riparian and Sonoran Desert ecosystems. Salt cedar (*Tamarix spp.)* had formed dense monocultures increasing the fuel load within the riparian area. The naturalization of salt cedar within riparian areas has caused competition among native species and increased fire severity risk (NM Dept of Game and Fish, 2019). Management of invasive species in the burned area was organized into the Lower Salt River Restoration Project (LSRRP) in 2018. With assistance from restoration managers, state agencies, and the volunteering public, the LSRRP has received funding to expand the methods of monitoring, treatment and removal. Large scale removal of invasive plants within the severe burn areas was organized into Phase I & Phase II (Figure 1) in 2018 and 2019 respectively.

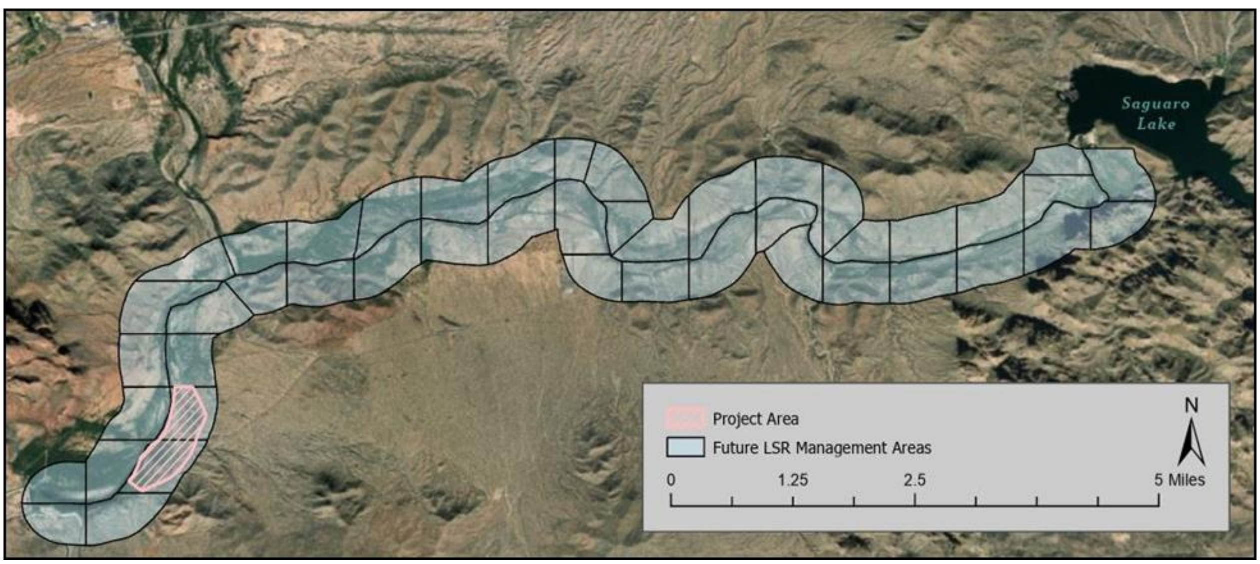
In addition to the removal of invasive plants, LSRRP objectives aim to increase the presence of native vegetation within the project area. The LSRRP has begun to reintroduce native species back into the riparian corridor during the first two phases of treatment by methods of active and passive measures. LSRRP has practiced active methods by using mechanical and chemical treatment to remove invasive species, while replanting native species. Passive methods of site restoration rely on the natural recruitment of native species in the absence of competition from invasive plants removed through treatment. Phase III aims to retreat the 170 acres of invasive species found with Phase I and II and treat an additional 70 acres in the fall of 2020 (Tonto National Forest, 2020).



(Figure 1) Treatment – Phase I (green), Phase II (orange), remaining project area (hatched). NAIP 2017.

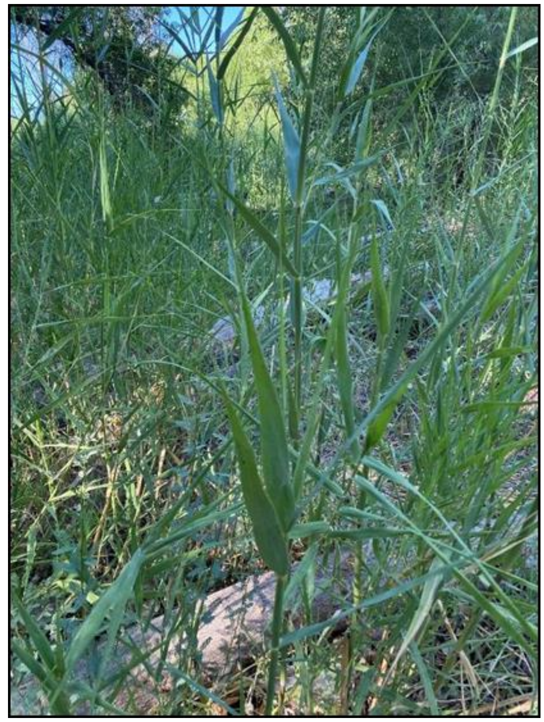
Green Drone Arizona

GDAZ was formed in the fall of 2019 under the umbrella of the LSRRP to innovate vegetation monitoring along the LSR. Natural resource managers are constantly seeking ways to improve the efficiency of vegetation management and the introduction of UAV technology provides highly accurate remote sensing capabilities. GDAZ will then continually develop these protocols throughout the duration of the LSRRP (see Figure 2). This is only possible through a collaborative effort between the Tonto National Forest, Northern Arizona University, Arizona State University, the National Forest Foundation, and the Boeing Company. Boeing has a vested interest in the interdisciplinary use of aerospace technology and believes GDAZ provides an educational example for the growing use of UAVs in ecological research. They have partnered with GDAZ to bolster community outreach regarding this technology and the STEM skills required to address real community environmental challenges (Green Drone AZ, 2020). To do this, GDAZ has partnered with Phoenix area high schools and STEM-led student organizations, such as the Chief Science Officers at the SciTech Institute, to educate students on the use of unmanned aerial vehicles (UAVs) and GIS technologies in natural resource management. In-person and teleconferenced activities, academic lessons, and education modules have been developed to inspire future generations in STEM fields to participate in defining and solving real environmental issues in their community.



(Figure 2) The long-term goal of the LSRRP is to restore 11 miles of the Lower Salt River Recreation Area, form the Granite Reef Recreation Site to Saguaro Lake. This project will focus on the 200 acres in the western portion of the LSR recreation area (ESRI World Imagery).

Invasive Species - Salt Cedar and Giant Reed



(Figure 3) [above] Mature salt cedar along the LSR & [right] Juvenile Giant Reed

Two species have been the predominant focus of treatment and removal since the formation of the LSRRP: salt cedar (*Tamarix spp.)* and giant reed (*Arundo donax*) (Figure 3). Salt cedar, or tamarisk, was intentionally introduced to western North America to control soil erosion but as with many regulated waterways in the southwest, has since naturalized along all eleven miles of the LSR riparian area. Salt cedar forms dense, monotypic stands and secretes salt from pores within its leaves. This causes the soil surrounding the tree to increase in salinity and become too dry for native vegetation to grow and compete for resources (USFS, 2017). This tree has a high resilience to disturbance and is known for its difficulty in removal. The remaining stumps and root systems of salt cedar continue to grow by sending out new shoots within the burn scar. Giant reed is a bamboo-like grass that occupies the banks of the LSR in cluster-like patches; however, giant reed extends up to 300-feet inland within portions of the project site. Giant reed aggressively fills the interspace and understory of native tree communities, outcompeting vegetation in the area. Giant reed is also known to form densely packed patches along waterways, altering hydrological function. The speed at which giant reed consumes resources such as water and sunlight results in rapid growth with the plant exceeding up to 20 feet in height (USFS, 2017). Both species have been treated using mechanical (physical removal) and chemical (herbicide treatment) methods since the Cactus Fire, but their continued pervasive growth requires increased monitoring for sustainable removal along the LSR.

Methodology

Data Collection

Prior to UAV data collection, ground control points (GCPs) were surveyed and monumented throughout the project area. Each GCP contains a defined spatial location, in this case the exact x, y, and z coordinate within the project coordinate system zone. These GCPs assist in georeferencing (the assignment of geo-coordinates to raster pixels) the imagery and are necessary to ensure enhanced spatial accuracy (Hackeloeer et. al, 2014). Placement and collection of GCP coordinate data took place in March of 2020 using a Trimble GNSS Receiver. A total of 28 GCPs were placed in locations throughout the project site that were free of canopy cover and varied in elevation for increased visibility and topographic structure for aerial remote sensing.

UAV data collection took place between March and April of 2020 using the Phantom 4 Pro and Phantom 4 Multispectral quad-copter drones. The P4P drone captured 2,278 images in a single flight plan using the DroneDeploy flight mapping application. The P4M drone completed five flight plans using the Pix4Dcapture mapping platform, capturing 15-17 thousand images across 40 - 50 acres per flight plan. The P4M multispectral drone captures an image for each sensor, resulting in a significantly larger dataset. Each flight plan ensured sensor orientation was perpendicular to the ground surface with extensive overlap to increase the number of viable tie points between images. The parameters for each drone remained consistent throughout all flights (i.e. landing the drone to change the battery and resuming data collection) of their flight plans and are listed below (Table 1).

Model	**Capture Resolution**	**Imagery Sensors**	**Flight Parameters**
DJI Phantom 4 Pro (P4P)	1" Complementary Metal Oxide Semiconductor (CMOS) sensor with 20-megapixel definition	Single RGB sensor for natural imagery	90% frontal & 80% side image overlap with 3.0 second capture interval between images. Drone horizontal speed was approximately 10 mph at 380 ft AGL (height above ground level).
DJI Phantom 4 Multispectral (P4M)	2.9" CMOS sensors with 2.08-megapixel definition	Single RGB sensor with five additional monochrome sensors for multispectral imagery (Blue, Green, Red, Red Edge, Near-InfraRed).	85% frontal & 75% side image overlap with 2.5 second capture interval between images. Drone horizontal speed was approximately 5.5 mph at 200 ft AGL (height above ground level).

(Table 1) Drone Information and Flight Parameters

Additional project data was collected during ground-truthing - on site collection of data to supplement the use of UAV aerial imagery. Project staff utilized ESRI Collector for ArcGIS and captured geotagged photographs using an iPhone 11. This device was chosen for its built-in GPS/GNSS location service, 12-megapixel camera, and ability to house ArcGIS applications. Average accuracy for point data within the Collector application and each geotagged image was kept below three meters (10 feet). Collector was primarily used for on-the-ground reference when group members physically visited the project site. For example, after GCPs had been established, members used the approximate locations as waypoints when traversing through on-site vegetation. Polygons of the classified burn areas were also uploaded into the Collector app to be used as a reference while examining species' growth in severely burned boundaries.

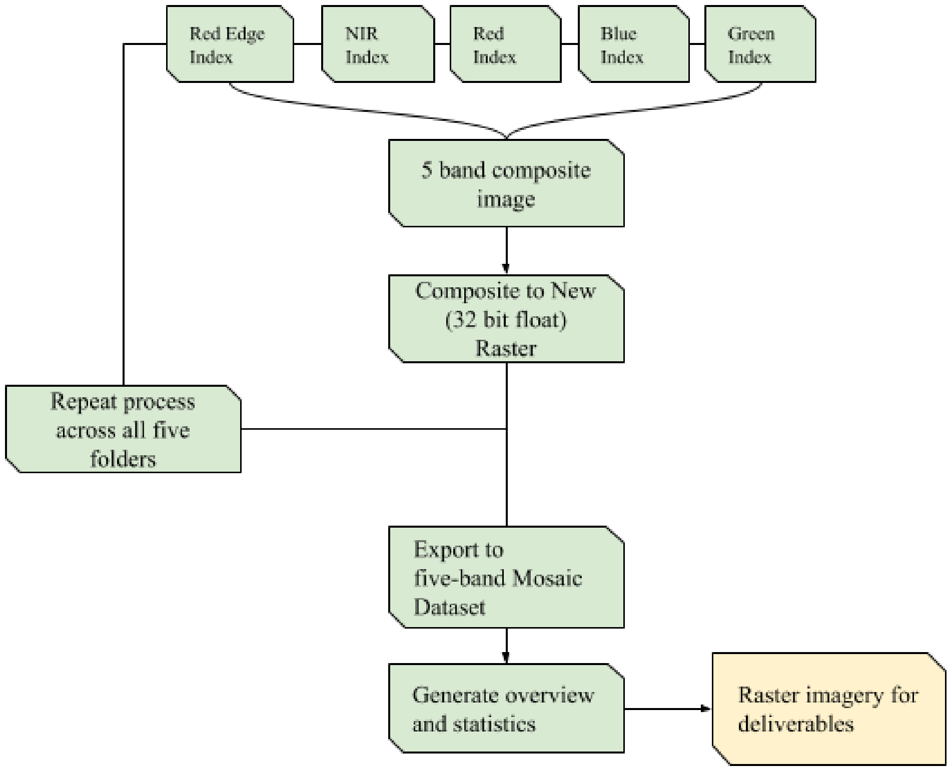
Along with creation of polygon features, recording point data on site is beneficial towards determining existing vegetation locations during initial data collection. Ground-truthing was reserved for post-digitization analysis, used to determine boundaries, spatial locations, and ecological varieties of plants where remote sensing images could not provide adequate information. However, geotagged photos were the preferred method to assist in plant identification ground-truthing throughout project analysis. Each point feature's GPS coordinates were extracted from the geotagged images and referenced with the datasets collected after the UAV flight plans. Along with an attached photograph of the vegetation, each geotagged image provided a degree of direction representing ordinal direction placements. The ordinal direction of the image allows analysts to properly identify species that may be indistinguishable in the aerial imagery, reducing the point-coordinate error of the GNSS receiver.

Data Processing

Once images were captured with the P4M, photogrammetry processing was completed in Pix4Dmapper 4.5.6. Photogrammetry is making measurements of three-dimensional features from photographs (Aber et al., 2019). All output data were assigned to the NAD83 UTM Zone 12N coordinate system and the EGM96 Geoid vertical coordinate system. After completing initial processing, which establishes image matching through key points between images, GCPs were georeferenced to ensure the acceptable accuracy of raster datasets. The known coordinates of each GCP is essential for creating a more accurate representation of the project site within the collected imagery and the physical surface of the LSR. Afterwards, point clouds, point mesh, digital elevation models (DEM), orthomosaics, and camera bands indices were created. For efficient processing, index maps were processed individually and later combined using the composite raster function in ArcGIS Pro.

All processed P4M raster datasets were compiled, composited, and created into a mosaic dataset, similar to the orthomosaic produced during Pix4D processing. Each monochrome sensor index .tif file was joined using the Composite Raster function. These composited sections of the project area were then clipped and exported as new Raster Mosaics. The composite raster function allowed for multispectral band assignments similar to practices found in widely used aerial imagery, such as National Agriculture Imagery Program (NAIP) or USGS LandSat8 data. Proper assignment of these bands will provide future GDAZ staff members with ease of analysis when examining reflectance combinations, such as the ones used in this project (Figure 4).

The primary purpose of this project was to provide UAV collected data to project managers, ecological researchers, and other GIS specialists throughout the lifespan of the LSRRP. Previous iterations of data management within the LSRRP demonstrated acceptable accuracy when utilizing remote sensing data, notably with NAIP aerial imagery. These new datasets represent highly accurate UAV imagery, increasing the spatial accuracy from one-meter ground sample distance (GSD) to under four centimeters GSD. Once imagery data was collected and processed, ArcGIS Pro 2.4 was used to perform analysis due to its available raster geoprocessing tools and ease of geodatabase creation.



(Figure 4) Processing of individual spectral bands into a complete mosaic dataset.

Data Analysis

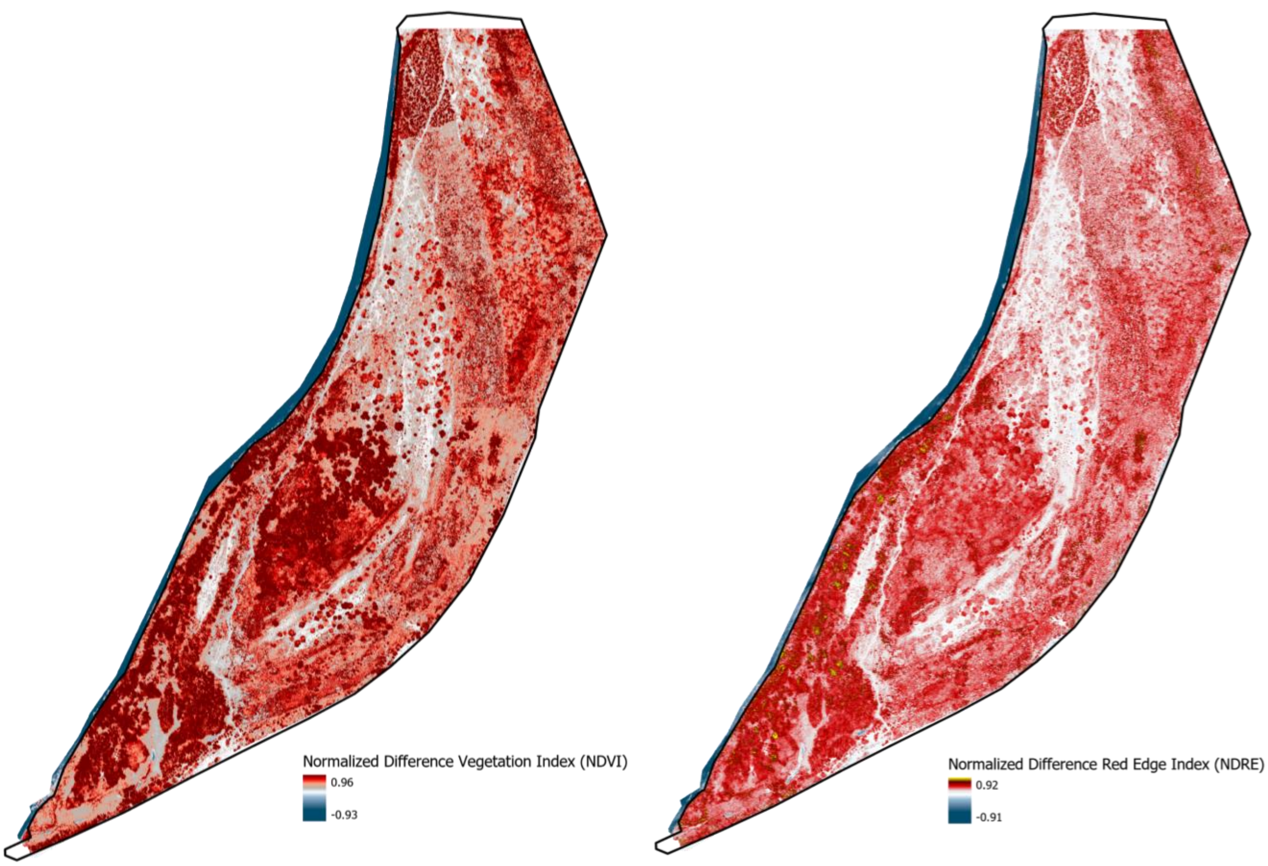
The manipulated raster datasets and the resulting analysis aim to demonstrate quantitative use of the collected data to expand ecological understanding of the LSR. Six separate raster layers have been created and stored within the final file geodatabase. Each raster dataset has been utilized towards these project's deliverables of an updated plant inventory, use in vegetation classification, image interpretation examples, and vegetation index analysis. These datasets have been compiled into a single mosaic dataset, with overview capabilities and statistics catered to displaying each raster image for species identification. All figures of interest within this report were developed using these raster datasets—with supplemental vector datasets—that can be found within the final project geodatabase. Below is the list of rasters contained within the geodatabase with corresponding spectral combinations of indices (Table 2).

Raster File	**Light Spectrum Combinations**
RGB Orthomosaic	Red / Green / Blue
Multispectral - Natural Color	Red / Green / Blue
Multispectral - False Color	NIR / Red / Green
Normalized Difference Vegetation Index (NDVI)	$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$
Normalized Difference Vegetation Index Red Edge (NDRE)	$NDRE = \frac{(NIR - RE)}{(NIR + RE)}$

(Table 2) Multispectral Combinations used in project site analysis

Vegetation Indices Analysis

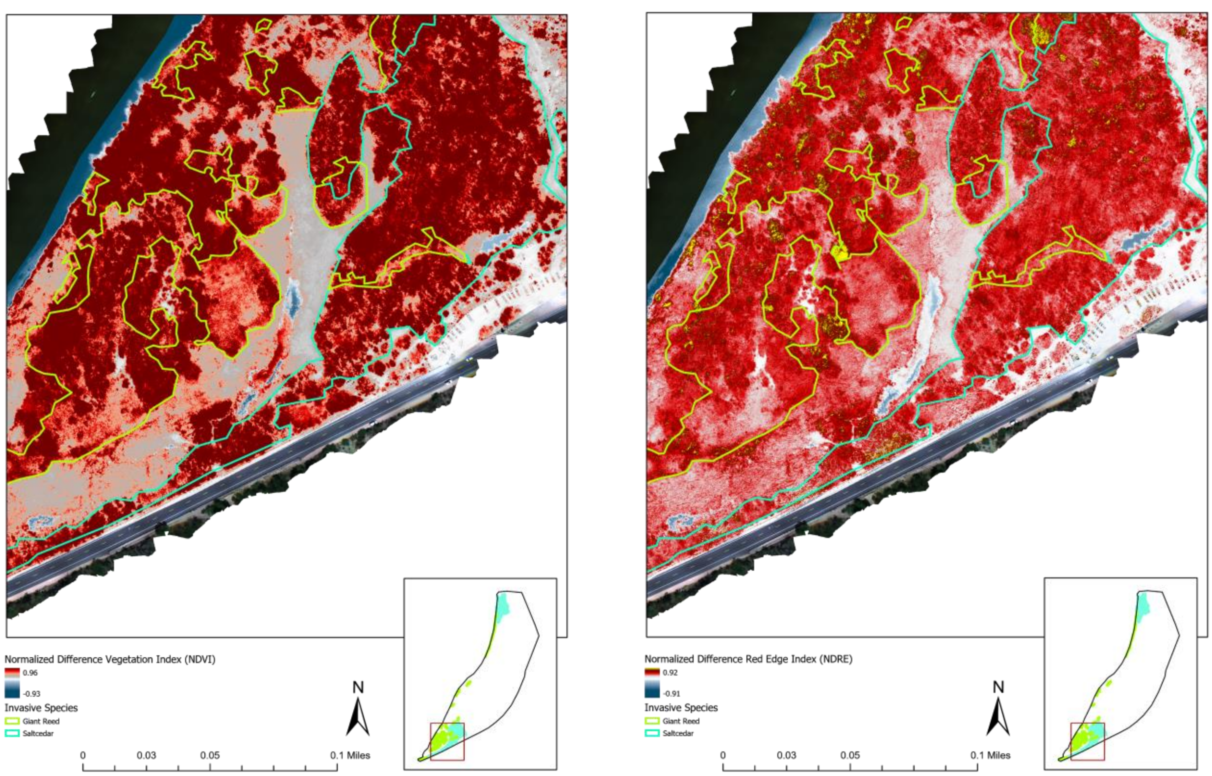
The Normalized Difference Vegetation Index (NDVI) is calculated from near-infrared (NIR) and red bands of multispectral sensors. The health of vegetation can be measured between NDVI values of -1 to 1 in the form of greenness maps (EOS 2019, ESRI 2000). Using this index, a species of interest returns unique values across this greenness scale and can be used for advanced spatial identification (Leduc & Knudby). The red edge multispectral sensor has been observed to improve the estimation of canopy greenness when combined with the NIR imagery (Xie et. Al, 2018; Evangelides & Nobajas, 2019). The Normalized Difference Red Edge (NDRE) index reflectance penetrates top canopies of vegetation, returning chlorophyll content values of differing species that may be too clustered to differentiate by NDVI alone (Sharma, et. Al, 2015). For the purpose of analysis within the LSR, the datasets that were produced directly from the mosaic dataset of reflectance composites were customized. First, both indices produced normal distribution of values, so a standard deviation of 3σ was used for symbology. Negative values within both indices indicate areas without active vegetation and their symbology is reflective of non-essential values that can be ignored. In addition, both indices contain a neutral symbology for values for 0 to 1σ, as these lower values correspond to ground values, or non-reflective areas of vegetation such as dead vegetation (Figure 5).



(Figure 5) Mean values for both vegetation indices have been set to 0 with a 3σ stretch layer symbology for analysis. NDVI σ = 2.0 to represent deviations of vegetation health from barren, to low-lying shrubs and weeds, and finally healthy foliage. NDRE σ = .08. It has been observed to follow this distinction of return values, though the majority of NDRE values are placed within the 1σ to 3σ deviation range.

Project Site Example 1: Future Treatment Areas

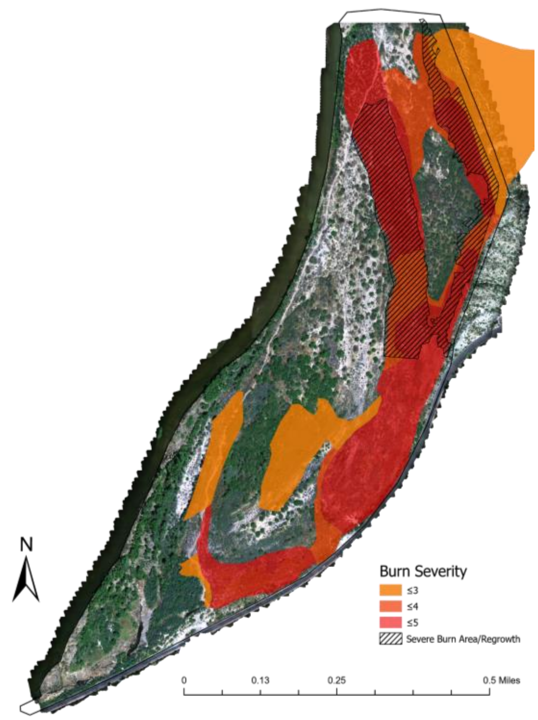
Both indices give useful information about vegetation health within the project site. However, as Sharma et al. explains, the sole use of an NDVI raster may not provide enough variation between the large amount of values represented by project site vegetation. More comprehensive analysis of vegetation health can be achieved when both indices are under examination. In the fall of 2020, the LSRRP will commence retreatment efforts of the southwestern portion of the project site, where the presence of both salt cedar and giant reed suffered low burn severity. Both indices reflect +2σ values of each species within this area, particularly a large congestion of salt cedar. Removal and treatment of healthy salt cedar will provide distinct challenges from previous treatment opportunities where the salt cedar was already damaged following the Cactus Fire (see Figure 6).



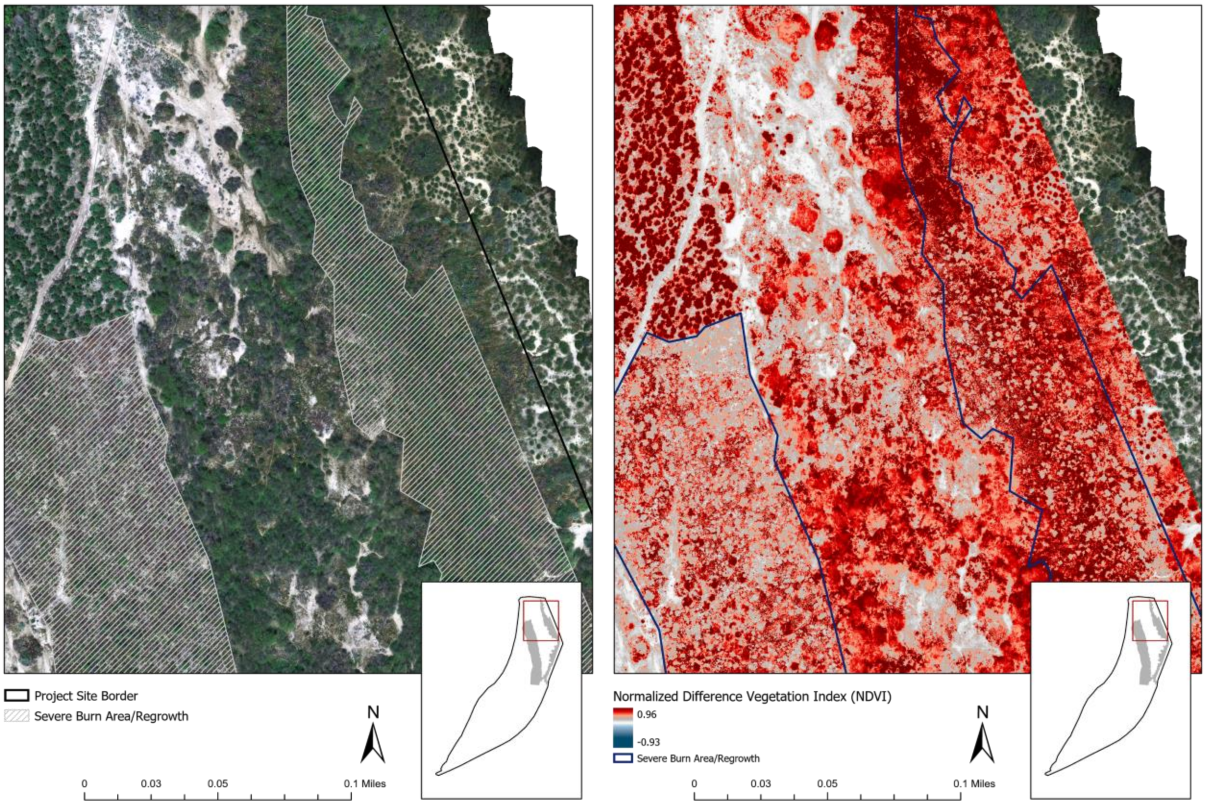
(Figure 6) NDVI [left] & NDRE [right] observation of southern portion of the project site.

Project Site Example 2: Severe Burn Area & Regrowth Monitoring

A more compelling example examined by these indices is through the monitoring of regrowth in sections of the project site that have experienced the highest burn severity after the Cactus Fire (Figure 7). During the process of digitization, species within the northern portion of the project site could not reliably be identified by aerial imagery alone. However, examination of both vegetation indices after development of the multispectral mosaic dataset prompted a closer examination of the severely burned area because of the high concentrations of healthy reflectance from the vegetation present in the imagery.

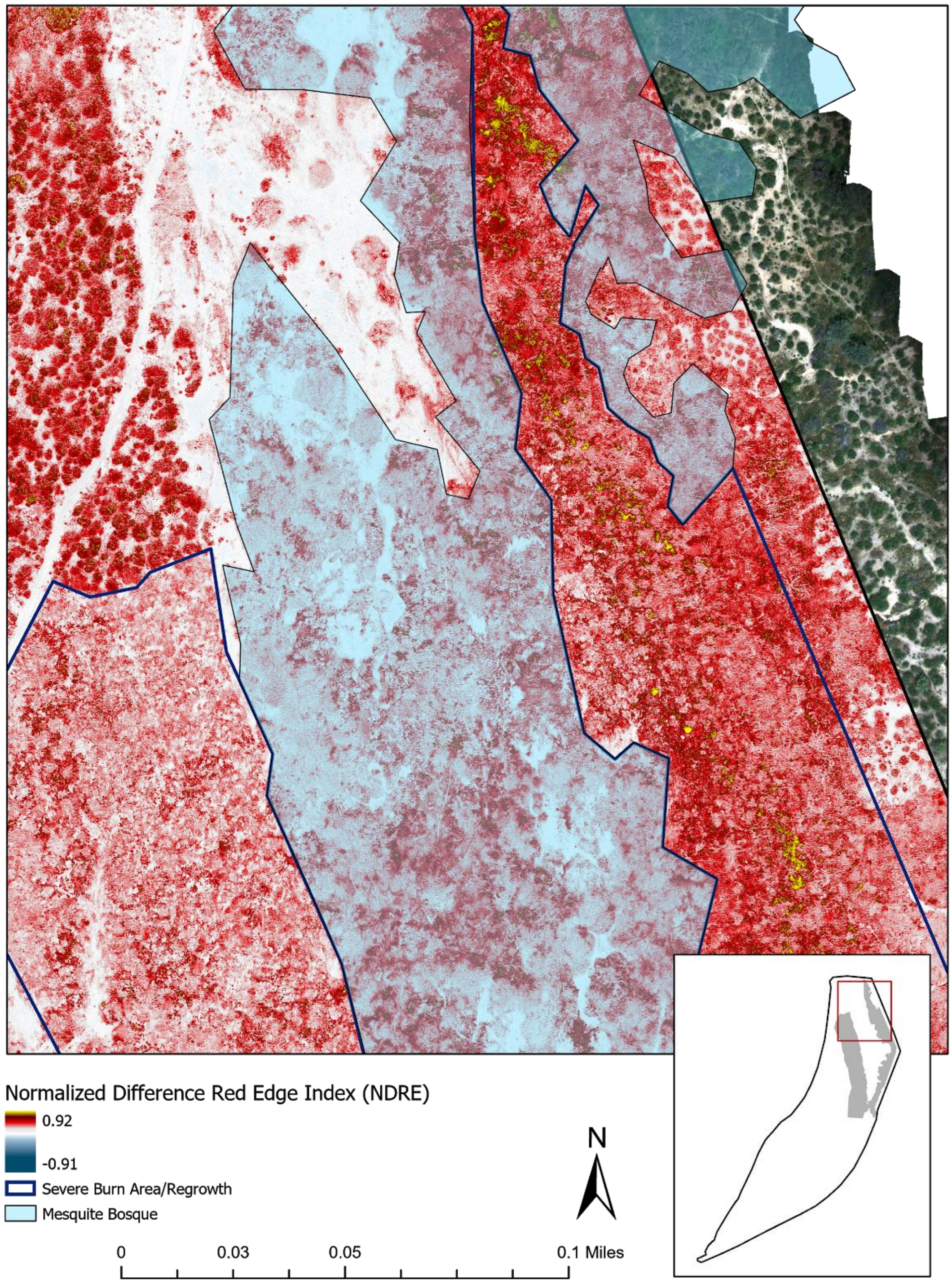


(Figure 7) High burn severity areas of the Cactus Fire throughout the project site



(Figure 8) Section of the severe burned area [left] and NDVI [right] observation in the northern portion of the project site.

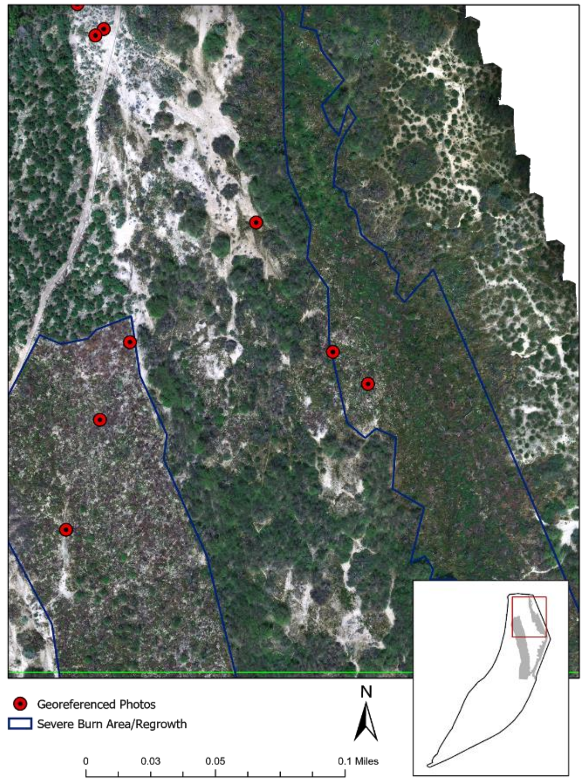
The NDVI reflectance does give analysts base conclusions regarding the health of vegetation within this section of the project site (Figure 8). The high concentration of values over 0.6 (3σ) indicates there is healthy and actively growing vegetation in the area. However, the NDRE index allows for a more salient representation of vegetation reemergence (Figure 9). Given digitization and monitoring of the project site was a primary purpose of this project, this led to ground-truth in the area in question.



(Figure 9) Mean values for both vegetation indices have been set to 0 with a 3σ stretch layer symbology for analysis. NDVI σ = 2.0 to represent deviations of vegetation health from barren, to low-lying shrubs and weeds, and finally healthy foliage. NDRE σ = .08. It has been observed to follow this distinction of return values, though the majority of NDRE values are placed within the 1σ to 3σ deviation range.

Ground-truthing Verification

Two observations were made from site visits and resulting geotagged imagery within this area viewed above (see Figure 9). The first is that high return values of the vegetation indices are produced by a variety of smaller plant species found in the footprint of the severe burn area. Much like globe chamomile and Sahara mustard, mostly found in large concentrations on the southeastern portion of the project site—these invasive plants spread and crowd the available ground (Figure 11). Both globe chamomile and Sahara mustard are seen spreading northward along Bush Highway, and their presence requires additional treatment to reduce populations.



(Figure 10) Locations of geotagged images within the burn area

(Figure 11) Invasive forbs (Sahara Mustard) in the burn scar

Salt cedar is fire adaptive and while the Cactus Fire reduced the age class of existing trees on the project site, there is a noticeable resurgence in growth, particularly in the burn footprint (USFS, 2017). Phase II chemical treatments of salt cedar within this area are not to be disregarded by these observations. As previously mentioned, this severe burned area contains growing salt cedar, but not at both the growing extent or densities that are seen in the south and eastern portions of the project site (see Figure(s) 10 – 12). However, the use of the red edge vegetation index is what prompted the on-ground examination of this section of the project site, whereas the concentrations of +3σ values from the NDVI alone can be lost by how common those values are reflected. The recorded photographs and point data were taken to provide temporal monitoring that may prompt further management strategies within this area in the near future.

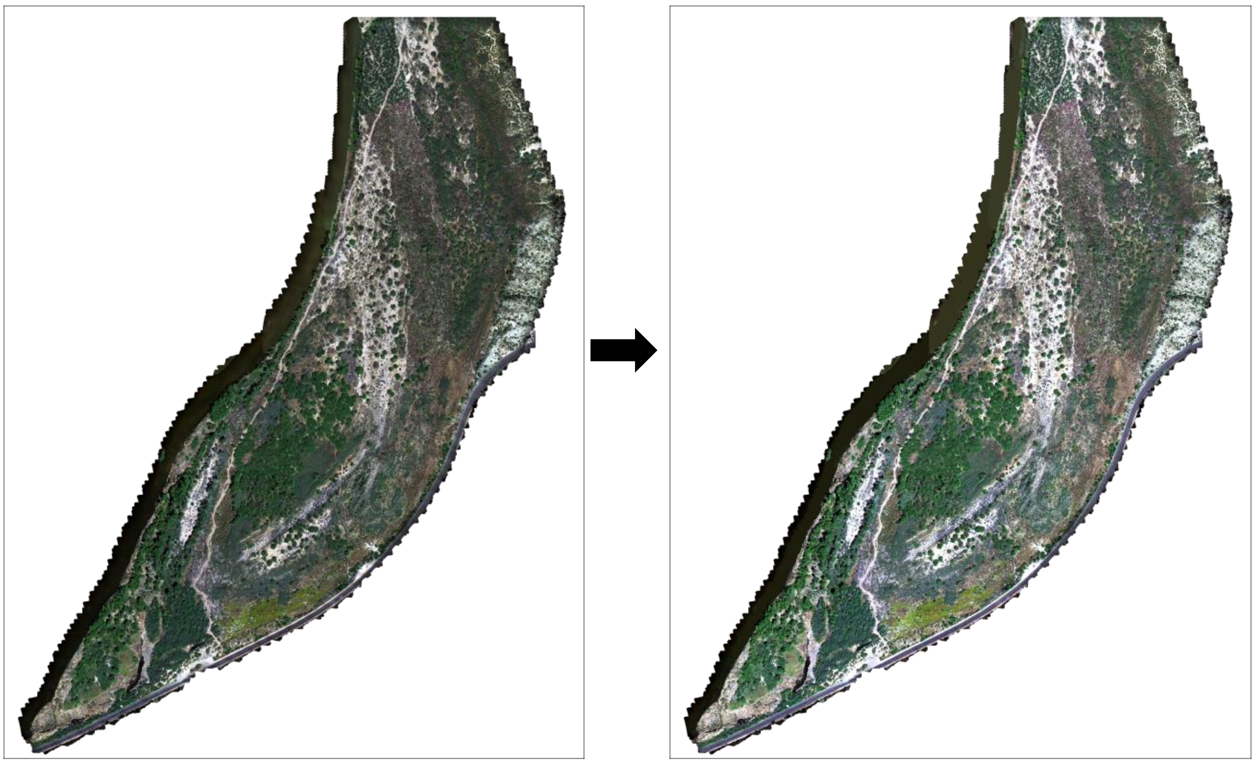
(Figure 12) Regrowth of Salt cedar within the severe burn footprint

Deliverables

Vegetation Analysis & Classification

Multiband mosaic datasets using the P4M multispectral data will be continually produced and analyzed throughout the project life of the LSRRP. The remote sensing capabilities of UAV data and GIS analysis can be used for monitoring the LSR's land cover. One form of land cover analysis using the mosaic dataset is a supervised image classification. The focus of this project's classification is determining distinct pixel values that represent vegetation species within the project site of the LSR. We have selected eight species (arrow weed, cattail, cottonwood, giant reed, globe chamomile, mesquite, Sahara mustard, tamarisk) and three geographic features (Ground, Water, Infrastructure) for our image classification.

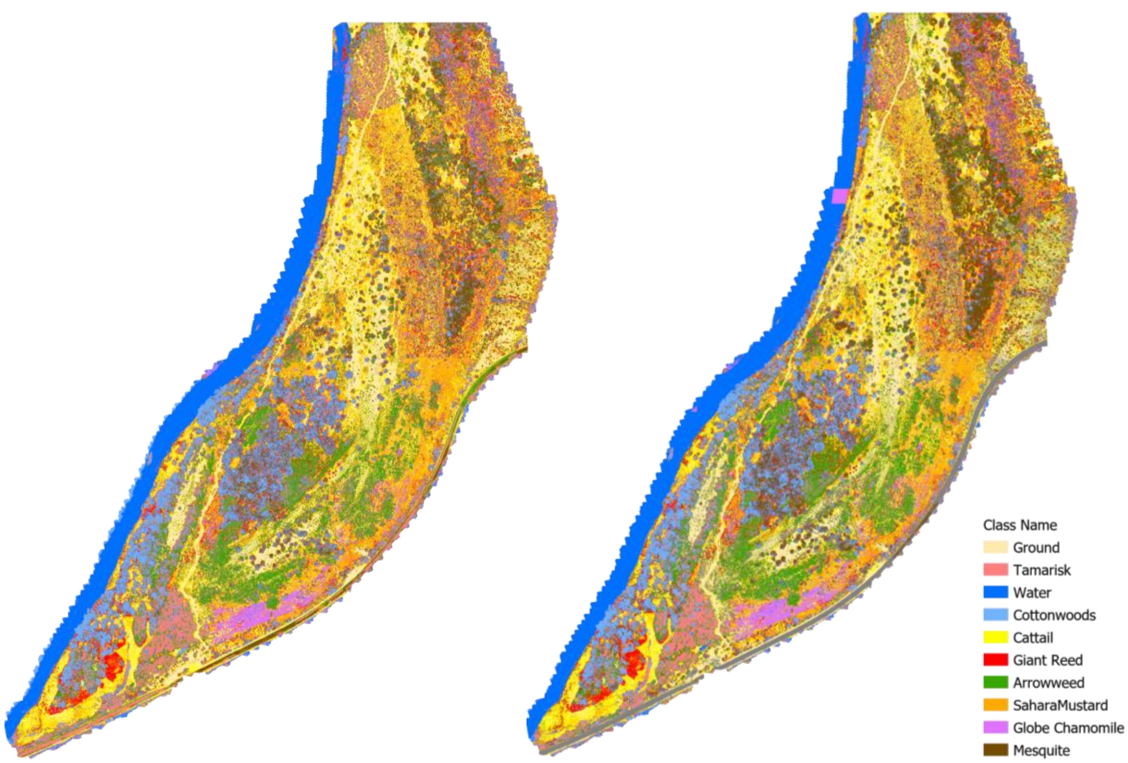
The pixel size of the mosaic dataset in use is $3.47cm^2$ and in order to begin a supervised classification, the imagery must be segmented - extracting similar pixels to be grouped into small objects. The original imagery contains too many records for classification to distinguish between object-oriented pixels otherwise. The segmentation of this imagery reduces the natural 5-band, 32-bit mosaic to a 3-band, 8-bit raster.



(Figure 13) [left] RGB mosaic dataset of the entire project site with [right] image segmentation used for image classification.

Following segmentation, a training sample shapefile was produced. Isolating the specific groupings of the vegetation species within the segmented image trains the classification models used later to identify like pixel groups, even if they are not directly put into this shapefile. This is the basis of the supervised classification and goal of GDAZ. The training samples within this workflow will be delivered and utilized for identifying species returning similar values in new areas during future phases of GDAZ (Figure 13).

Two different classification methods were chosen to test the capabilities of classifying the mosaic dataset and both contained segment attributes based upon active chromaticity color, the mean digital number of their attributes, and the compactness of the pixels. The first was a Random Trees classifier, which uses multiple decision trees and selects a variable at random to classify frequency of appearance. Our model used a maximum of 50 trees with a tree depth of 30. The results of the Random Trees classification obtained an accuracy assessment of 0.54 using a stratified Random Sampling Strategy. The second method was using the Support Vector Machine classifier. This classifier uses machine learning to take labelled points within an image and constructs an optimized hyperplane to assign values to the points themselves. The support vector took significantly longer to process but produced a higher accuracy assessment of 0.66 using a stratified Random Sampling Strategy.



(Figure 14) The product datasets for both classification methods, Random Trees [left] and Support Vector Model [right]. Random Trees classifier contained a .56 accuracy assessment while the SVM produced an accuracy assessment of .65. Both accuracy assessments utilized 2000 random stratified points.

Future Considerations for Classification

Overall classification of the species in this project did not produce statistically significant accuracy assessments using either methods. This is mainly due to two reasons. The first is because of similarities multiple species have using the RGB multispectral imagery. The crowns of mesquites and cottonwoods, specifically, reflect similar values when under segmentation and when processed through both classifiers. Overlap between the eleven separate values occurs throughout the project site. However, it is important to note the success when classifying large numbers of vegetation stands that were placed outside of the training samples. Notable examples of this process are the identification of the large tamarisk stand within the southwest portion of the project site and the inclusion of singular mesquite stands within the central portion of the area. Instances such as these can be observed throughout the project site. These identifications of individual stands can be used for future digitization to assist in plant inventories, the primary goal of using classification methods (Figure 14). While not significant at identifying attributes of the entire project site, it may pave the way for further examination and use in future flights across the LSR.

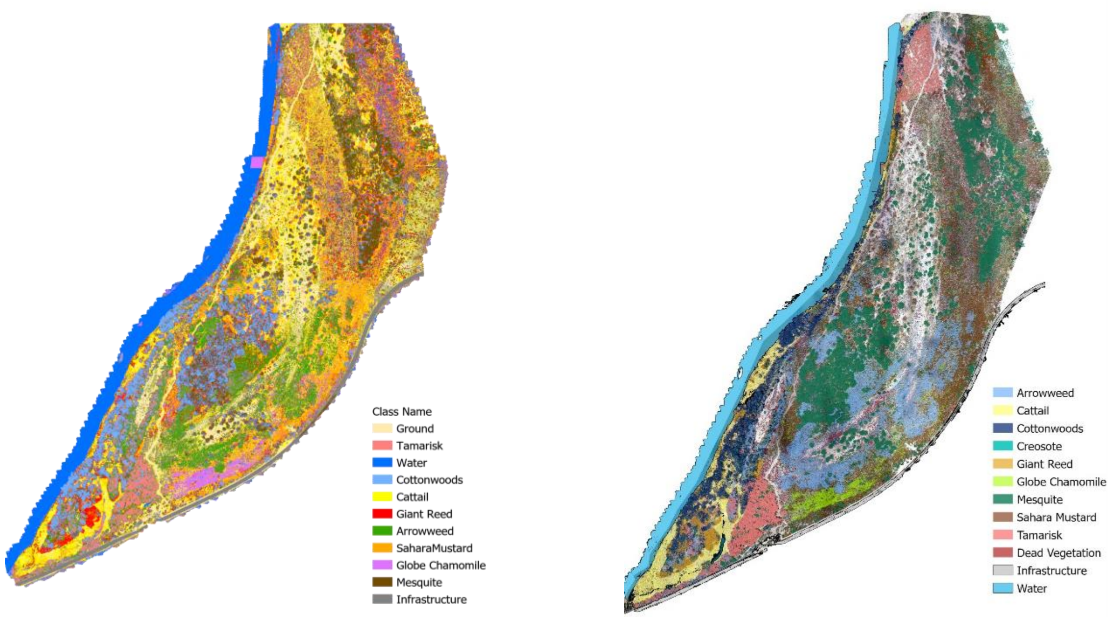
There are three possible considerations that will maintain and increase the accuracy of each classification method. The first is to increase the number of training samples for all classes that are integrated to each classifier method. Within the current workflow, over twenty unique samples have been assigned to each class under examination. For future iterations of this workflow, increasing the training samples to extend the entire project site would benefit classification of areas where new monitoring is taking place, such as Phase III locations.

The second consideration is to expand the class structure that is to be analyzed. This can be in generalizing the classes into categories such as “vegetation” instead of individual species, “types” of vegetation such as shrubs, weeds, grasses, and trees, or by using a false color raster dataset to distinguish between vegetation and no vegetation classes. These regressions of individual stand identification would favor increasing the accuracies of the classes while sacrificing the nuance of specific species monitoring.

The final consideration is the maintenance of flight parameters and the development of routine flight schedules for continuity of data collection. The reflected values of vegetation stands are dependent on consistency of UAV flight times. Scheduled monitoring over the LSR is suspected to take place biannually and proper monitoring of vegetation should consider the sunlight placement that produces reflectance of each multispectral band. This final consideration would allow for vegetation analysis and the resulting management strategies to maintain temporal data integrity.

Updated Plant Inventory

Recognizing these strategies, an updated inventory feature class has been developed using a reclassified raster dataset from the Support Vector Model (SVM). P4M and P4P raster aerial imagery was used to reclassify the model to represent each class more accurately, and a subsequent accuracy assessment using the same training sample post-reclassification raised the dataset's assessment results from 0.66 to 0.80. This dataset was then geoprocessed into vector polygon features segregated among the eleven class names used in the classification scheme. Two additional classes were created within this vector dataset, one representing dead vegetation found among the project site that was originally classified as infrastructure and one for creosote vegetation originally classified as mesquites (Figure 15).



(Figure 15) Reclassified raster dataset of 11 classes with a 0.80 accuracy assessment (left) with final feature class containing 12 classes and P4P orthomosaic as a base map (right).

New classes were not the only form of feature editing needed to make the vector dataset more functional. The geoprocessed classes produced upwards of two million polygons representing the features of the project site. There were numerous instances where classes were misrepresented and needed to be field calculated into another class identification or removed from the project site altogether. Referencing the P4P and P4M mosaic datasets, these polygons were merged, split, and exploded into smaller polygons feature counts using ArcGIS Pro editing tools. The original two million polygons were processed into approximately 5,000 polygons among the thirteen classes (Table 3).

Class Name	**Approximate Acreage on Project Site**	**Polygon features**
Arrow weed	16.810	82
Cattail	6.671	5
Cottonwoods	9.002	1362
Creosote	0.224	125
Giant Reed	4.099	529
Globe Chamomile	2.688	22
Mesquite	32.317	1765
Sahara Mustard	26.721	30
Tamarisk	8.019	845
Dead Vegetation	5.435	106
Infrastructure	4.561	35
Water	21.657	16
Ground	51.95	1

(Table 3) The project site inventory feature class attributes of native and invasive vegetation and surrounding geographic features.

The conversion from SVM raster to vector polygon feature class allows project contributors to extend or retract the boundaries following analysis of future flight plans. The number of species under treatment and removal observation have a higher number of polygons that represent smaller vegetation stands or individual plants. Each attribute contains an approximate calculation of the geometry's shape area from square meters to acres, following the practice of previous feature class inventories. This is included in the project file geodatabase's domain structure, along with the common name and scientific name of vegetation on the project site. An editable vector dataset from the first flight plans during GDAZ provides a temporal and spatial reference to be consulted in comparison to newly captured data in Phase III.

Image Interpretation Key

The imagery in this project is the first captured UAV data of the GDAZ workflow. With monitoring flights continuing throughout the lifespan of the LSRRP, this project will assist future workers in GDAZ through the creation of an image interpretation key. Image interpretation guides are developed to aid the users of imagery datasets for classification and the high-resolution dataset allows for more robust monitoring of the riparian ecosystem (Gini, et. al., 2018 & USFS, n.d.). This key uses the P4P and P4M RGB image mosaics for all vegetation examples and overview scales, ranging from 1:25 - 1:2500. Texture, size, location within the project site, and identifying features have been recorded for each vegetation species in question, along with two image examples. The primary goal is that these keys will be continually referenced during subsequent classification of the vegetation within this project site and the rest of the LSRRP. Image interpretation guides for salt cedar, giant reed, globe chamomile, Fremont cottonwood, and mesquites are in Appendix 1.

ArcGIS Training Modules

In addition to the implementation of drone monitoring on the LSRRP, GDAZ aims to engage and educate students interested in STEM careers in the use of technologies such as GIS and UAV in natural resource management. For the continued use of UAV technology on the LSRRP, GDAZ has developed educational modules for teachers and high school-level students in the Phoenix Metropolitan Area. These modules include introductions to GIS as well as tutorials on the use of ArcGIS Online and Collector for ArcGIS. An ESRI story map was developed for future use by the GDAZ staff members to help with teaching new users how to use ArcGIS Online and Collector for ArcGIS, as well as some basic GIS information. It is a step-by-step tutorial to help with basic AGOL commands, like adding data to a map, changing symbology and looking at the attribute table. It also has a step-by-step tutorial on how to create a map to use in Collector.

Future Implications

Continued support and education for ecological restoration

This project, along with GDAZ, could not be possible without the support of multiple organizations that value the use of advanced monitoring systems and ecological restoration. Mentors from Boeing, the National Forest Foundation, Northern Arizona University, and the Tonto National Forest have all collaborated and assisted in this project's workflow. A greater goal of GDAZ is to use the deliverables as an example for continued support from existing partners, and new partners with the goal for accessible restoration of the LSR. In addition, these partners understand the importance of community outreach and education. Deliverables produced from this project are to be presented to GDAZ sponsors as well as a STEM student cohort, Chief Science Officers, to demonstrate the effectiveness of UAVs and GIS within this project. It is a long-term goal of GDAZ to continue educating teachers, professionals and students about these innovative technologies and how this project has assisted in the beginning of this goal.

The use of GIS with UAV remote sensing

The extracted data within this project provided an increased examination of plant phenology within the LSR. Two components regarding the use of UAV are to be considered throughout the continuation of GDAZ:

1. Temporal advantages and considerations: GDAZ coordinators intend to monitor the LSR project site twice annually. The first iteration within this project was during the months of March - April of 2020. Future flights for data collection will be taken in the fall of this year, with Phase 3 of the LSRRP project goals. Future flights should fall within the growth patterns of the species under examination. For example, salt cedar's visual identification for analysis is made easier during the spring when it's branches and leaves are visibly distinct (see plant inventory *tamarisk spp.*). Fall flights should note site conditions following the anticipated wet season at the end of the summer, ending in September (Tonto National Forest, 2020). The growth of vegetation within the project site can be examined during this time, as annual monsoons will alter stand and individual plant spatial characteristics.
2. Consistent flight parameters and use of UAV models: currently, the P4M and P4P drones are to be used throughout the project lifespan. Until an alternative provides attributes of data collection that can be significantly improved upon (i.e. spatial resolution, flight time, battery life, multispectral sensors), protocol revolves around the use of these drones. To maintain integrity of topography over the entirety of the LSRRP, the flight parameters

noted here should remain consistent. This includes respective considerations of: AGL, horizontal speeds, time of day of image capture, and image overlap.

Conclusion

The experience working with new forms of monitoring technologies within GDAZ has been eye-opening. The use of UAVs in ecological restoration solely within this project opens the door for advanced forms of analysis and development of updated management protocols. The ability to cover large areas of the riparian habitat and minimize on-the-ground monitoring to only specific areas of interest is projected to reduce man-hours, cost of treatment and removal, and provides for a better understanding of the LSR ecosystem. It is imperative to showcase the capabilities of GIS analysis in conjunction with the use of UAV collected data. The attention surrounding the restoration of the LSR has only gained traction with the formation of GDAZ. GDAZ's goal for educational outreach will ensure continued interest surrounding this riparian area and the use of geospatial technology for its restoration.

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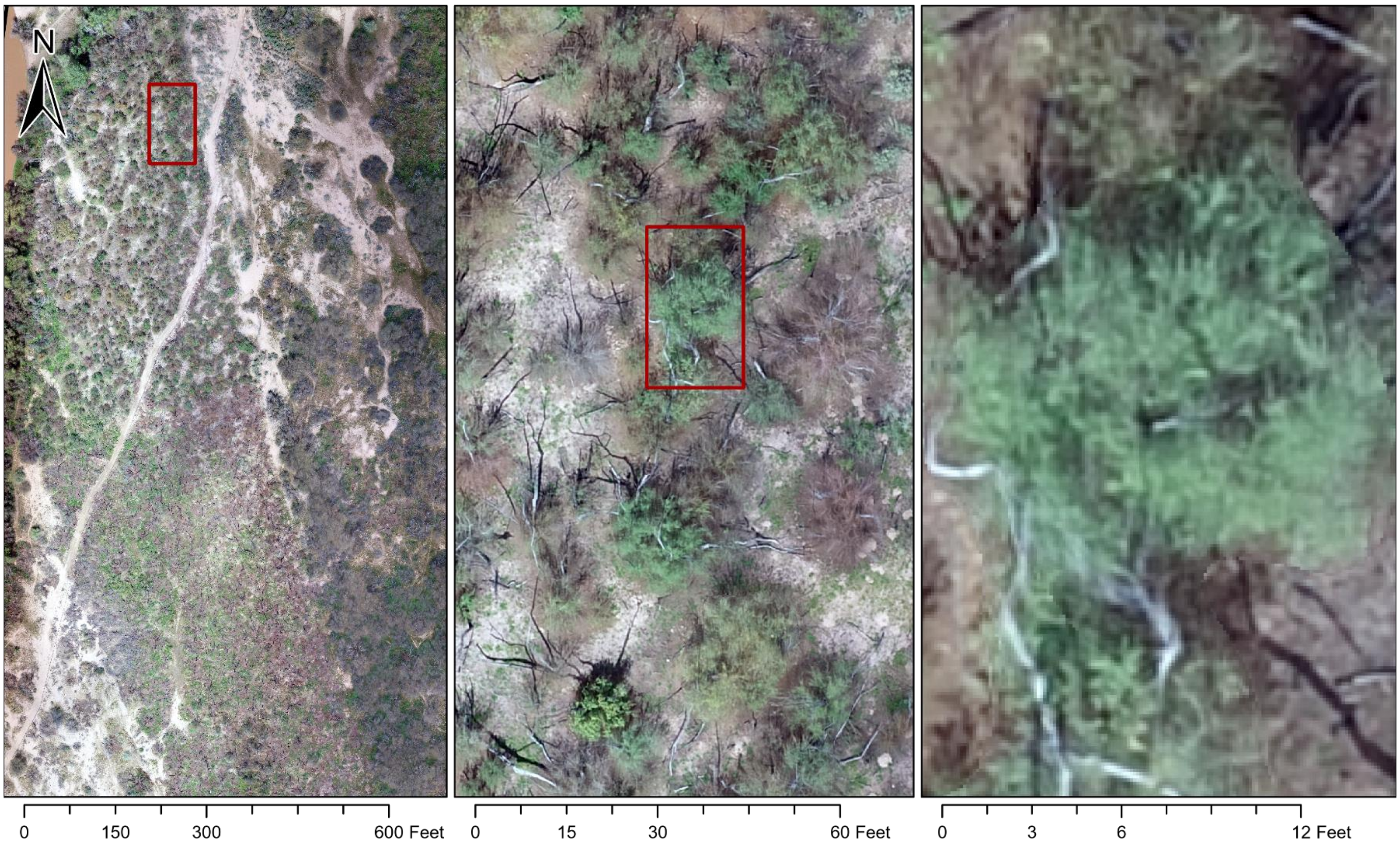
Appendix 1 – Image Interpretation Keys

Common Name	Scientific Name	Stand Texture	Growth Characteristics	ID for Imagery	Location Description
Salt cedar	*Tamarix chinensis*	Northern Stand: Coarse texture of mature trees that contain discrete ground values in between individual trees. Southern Stand: Medium texture of dense stand with trees intertwining together.	• Red, thin branches with pronged stamen, containing its seeds. • Shrub-like growth into a deciduous tree, growing perennially and close to waterways. • Ability to grow over 7 meters, with averages heights around 4 meters. Most trees found in the project area are within the average range, with larger individuals found outside of the previous burned area.	As it begins to seed during the spring and summer, overhead imagery captures the tree's flat leaves, pepper-like seeds, and neutral colored flowers.	Forms part of the overstory canopy close to the bank of the river. Dense stands of tamarisk are found here, though treated individuals are found throughout the project site.



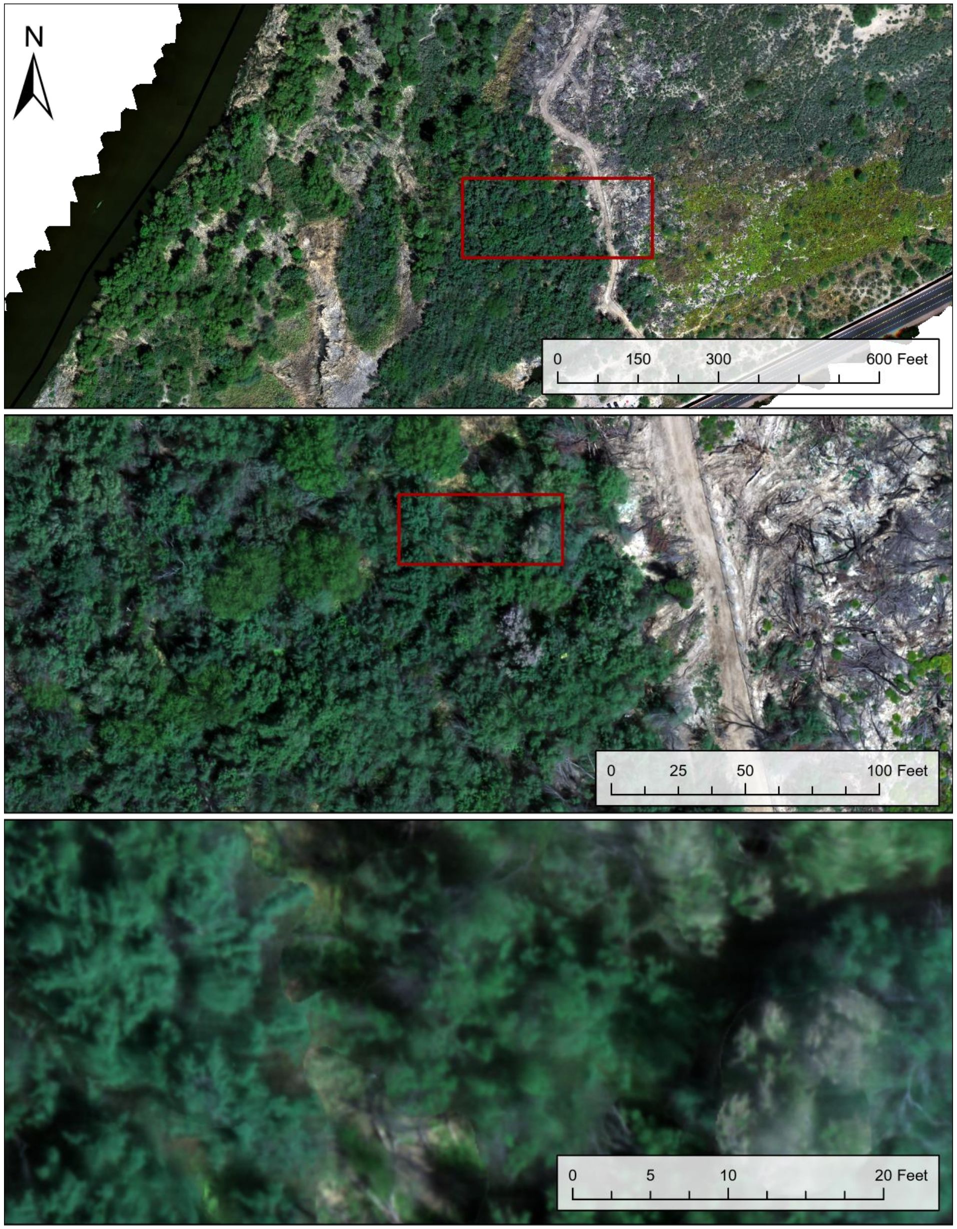
(Left)

North stand of Salt Cedar. Area has been left untreated due to protected species within stand.

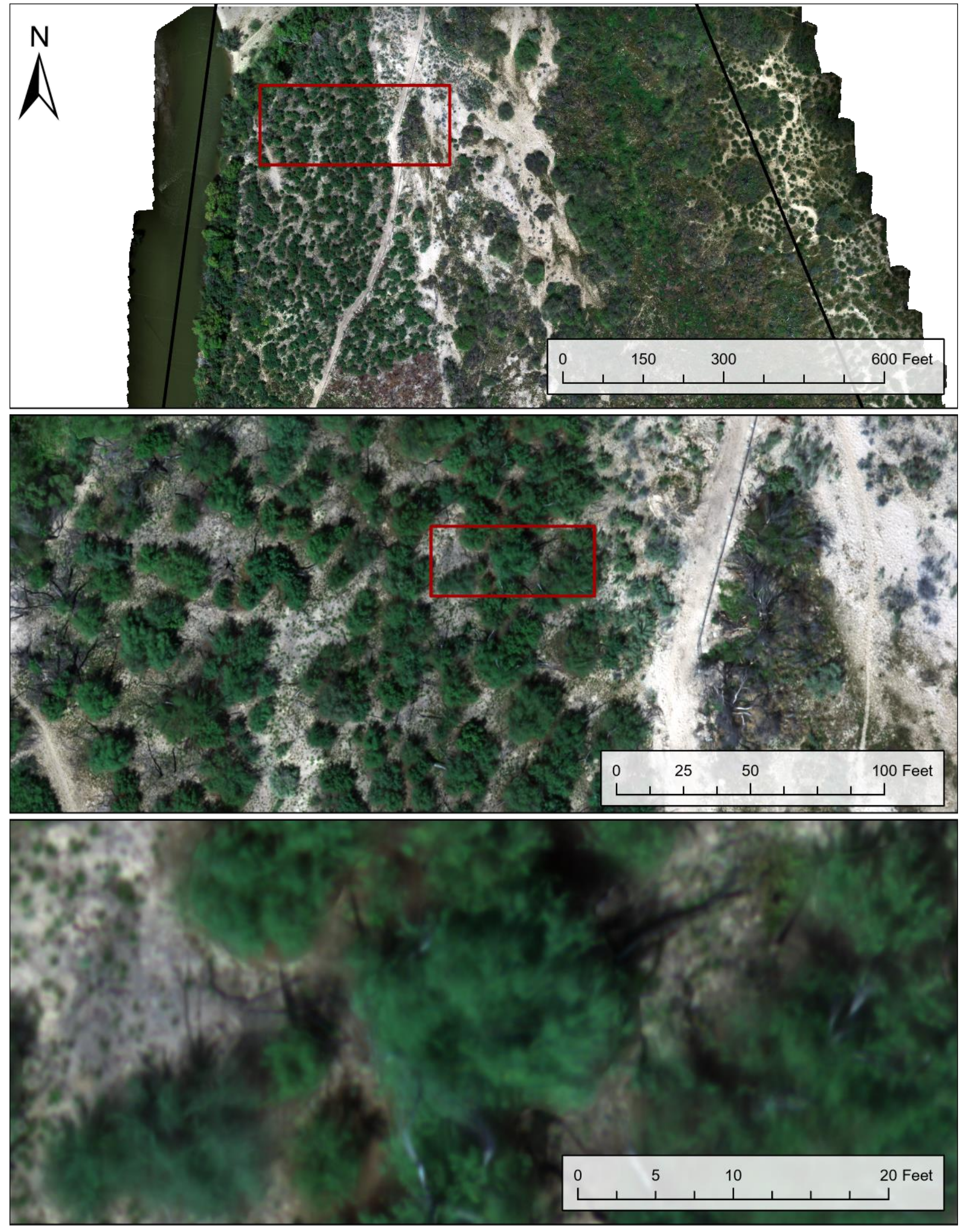
L-R: 2500:1, 250:1, and 25:1 image scale using P4P RGB Orthomosaic.

Approximate coordinates of sample: 111.6693°W 33.5308°N

(Below) South monoculture stand of Salt Cedar. L-R: 2500:1, 250:1, and 25:1 image scale using P4P RGB Orthomosaic. Approximate coordinates of sample: 111.6743°W 33.5184°N

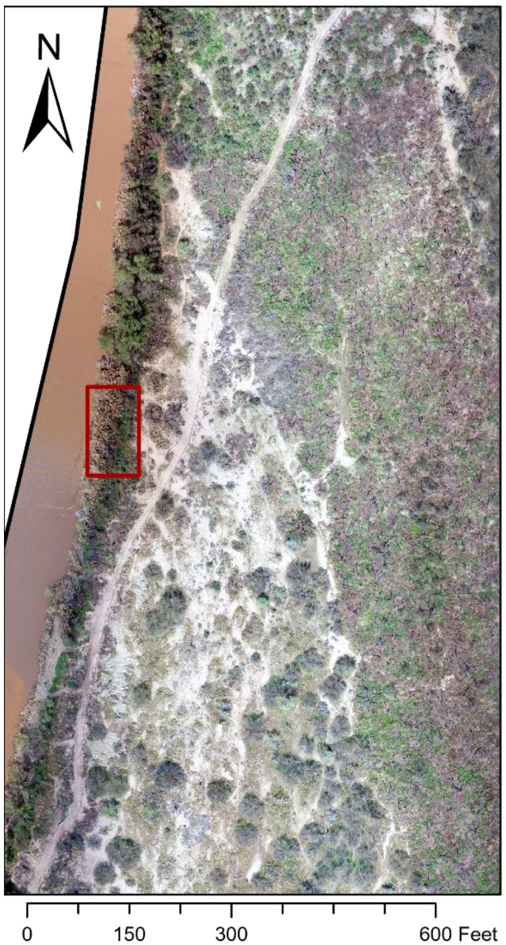


(Above) South monoculture stand of Salt Cedar. Top to Bottom: 2500:1, 500:1, and 80:1 image scale using P4P RGB Mosaic Dataset. Approximate coordinates of sample: 111.6743°W 33.5184°N



(Above) Northern stand of Salt Cedar. Area has been left untreated due to protected species within stand. Top to bottom: 2500:1, 500:1, and 80:1 image scale using P4M RGB Mosaic Dataset. Approximate coordinates of sample: 111.6693°W 33.5308°N

Common Name	Scientific Name	Stand Texture	Growth Characteristics	ID for Imagery	Location Description
Giant Reed	*Arundo donax L.*	Dense, fine texture at all scales and growth cycles	• Perennial grass can grow to be roughly 20-30 feet. • Stems are roughly 2 inches in diameter. • Flowers between June and November but can vary depending on the location. • Giant reed aggressively fills interspaced soils between native tree communities, outcompeting vegetation in the area	Typically found along the banks of waterways, they are difficult to identify when found outside of clusters. This is due to their ability to grow underneath crowns of larger native canopies such as cottonwoods but also between growths of salt cedar found on the banks of the Lower Salt River.	Occupies the subcanopy along the banks of the river. Concentrated close to the water channel before the riparian terrace.



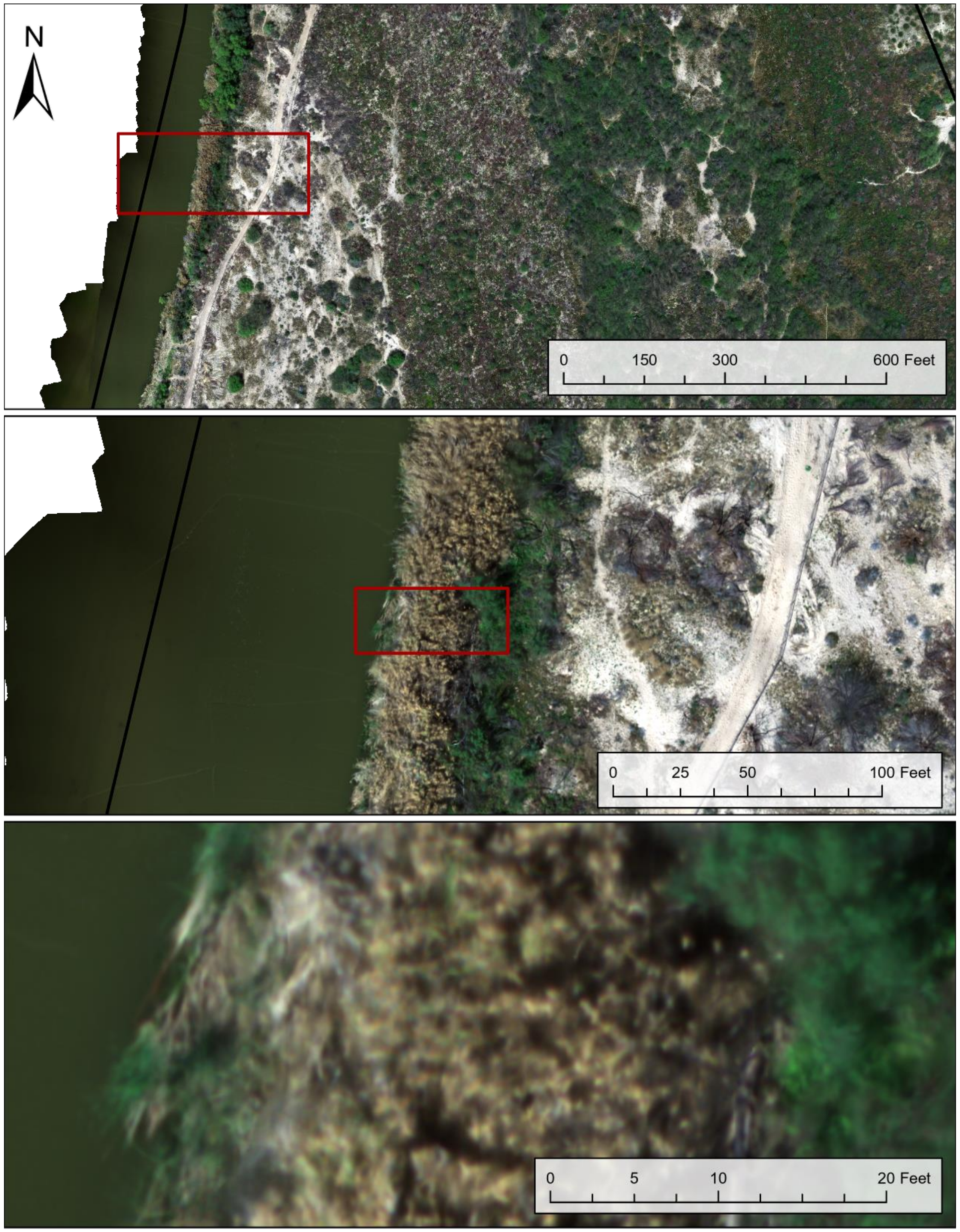
(Left)

Stand of Giant Reed along the banks of the Lower Salt River. Located in the western portion of the project site.

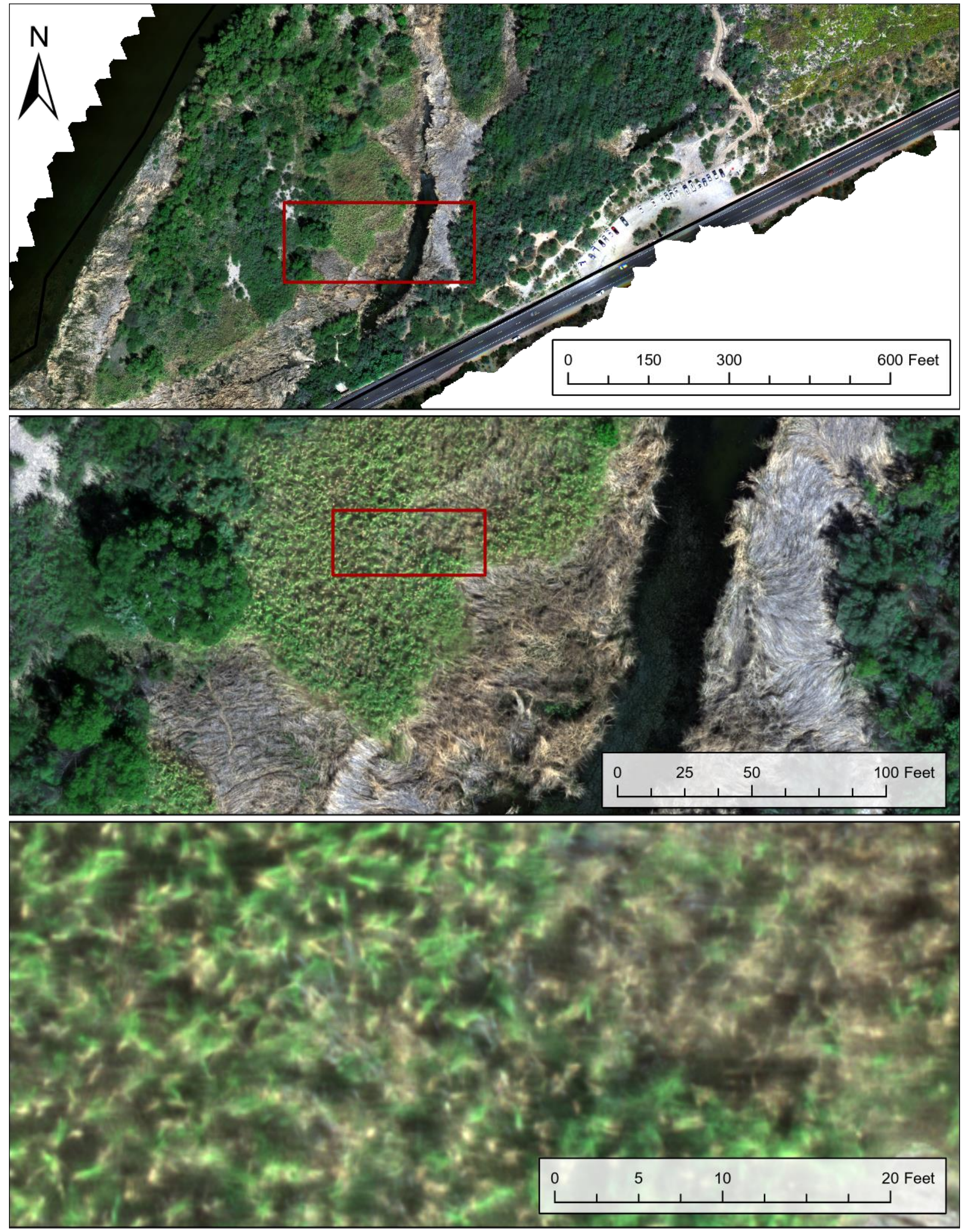
L-R: 2500:1, 250:1, and 25:1 image scale using P4P RGB Orthomosaic.

Approximate coordinates of sample: 111.6705°W 33.5281°N

(Below). Giant Reed stand found in the southern portion of the project site. This stand is intertwined with native cottonwoods and cattails. L-R: 2500:1, 250:1, and 25:1 image scale using P4P RGB Orthomosaic. Approximate coordinates of sample: 111.6761°W 33.5175°N

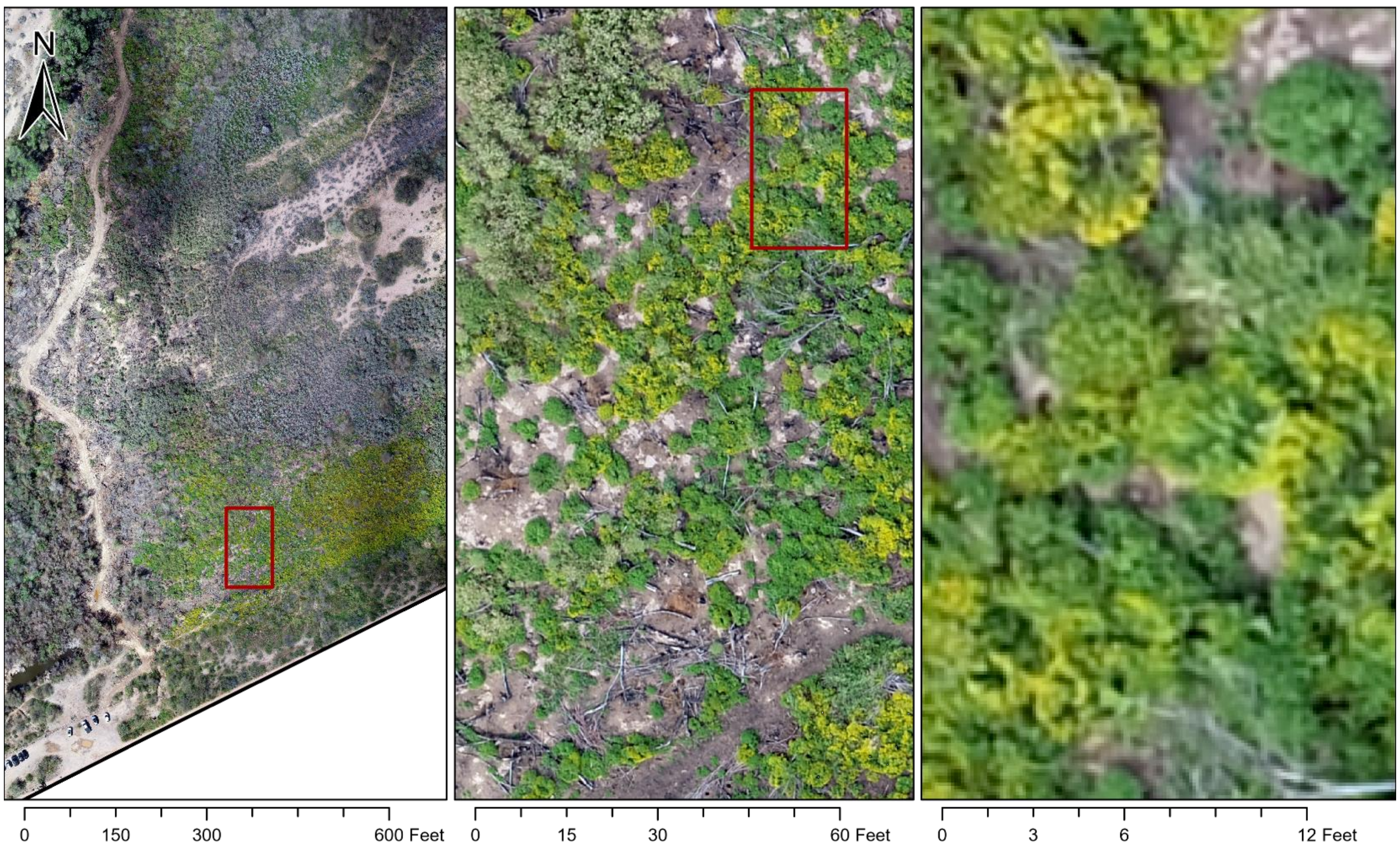


(Above) Stand of Giant Reed along the banks of the Lower Salt River. Located in the western portion of the project site. Top to bottom: 2500:1, 500:1, and 80:1 image scale using P4M RGB Mosaic Dataset. Approximate coordinates of sample: 111.6705°W 33.5281°N



(Above) Giant Reed stand found in the southern portion of the project site. This stand is intertwined with native cottonwoods and cattails. Top to bottom: 2500:1, 500:1, and 80:1 image scale using P4M RGB Mosaic Dataset. Approximate coordinates of sample: 111.6761°W 33.5175°N

Common Name	Scientific Name	Stand Texture	Growth Characteristics	ID for Imagery	Location Description
Globe Chamomile	*Oncosiphon piluliferum*	Fine textured when observed in larger scales (25:1). Smooth textured with distinct coloring and boundaries at smaller scales (2500:1)	• Herb vegetation that grows to roughly two feet in height. • Unpleasant odor. • Overlapping growth between individual plants, creating monoculture. • Rapid and pervasive spread, with seed dispersion to be expected in the early fall.	Easily identifiable by yellow lobes at the ends of stems, flowering in the spring. An annual standing forb, filling the disturbed grounds of the severe burn scar.	Subcanopy, located within the riparian terrace between riverbank canopy and upland.



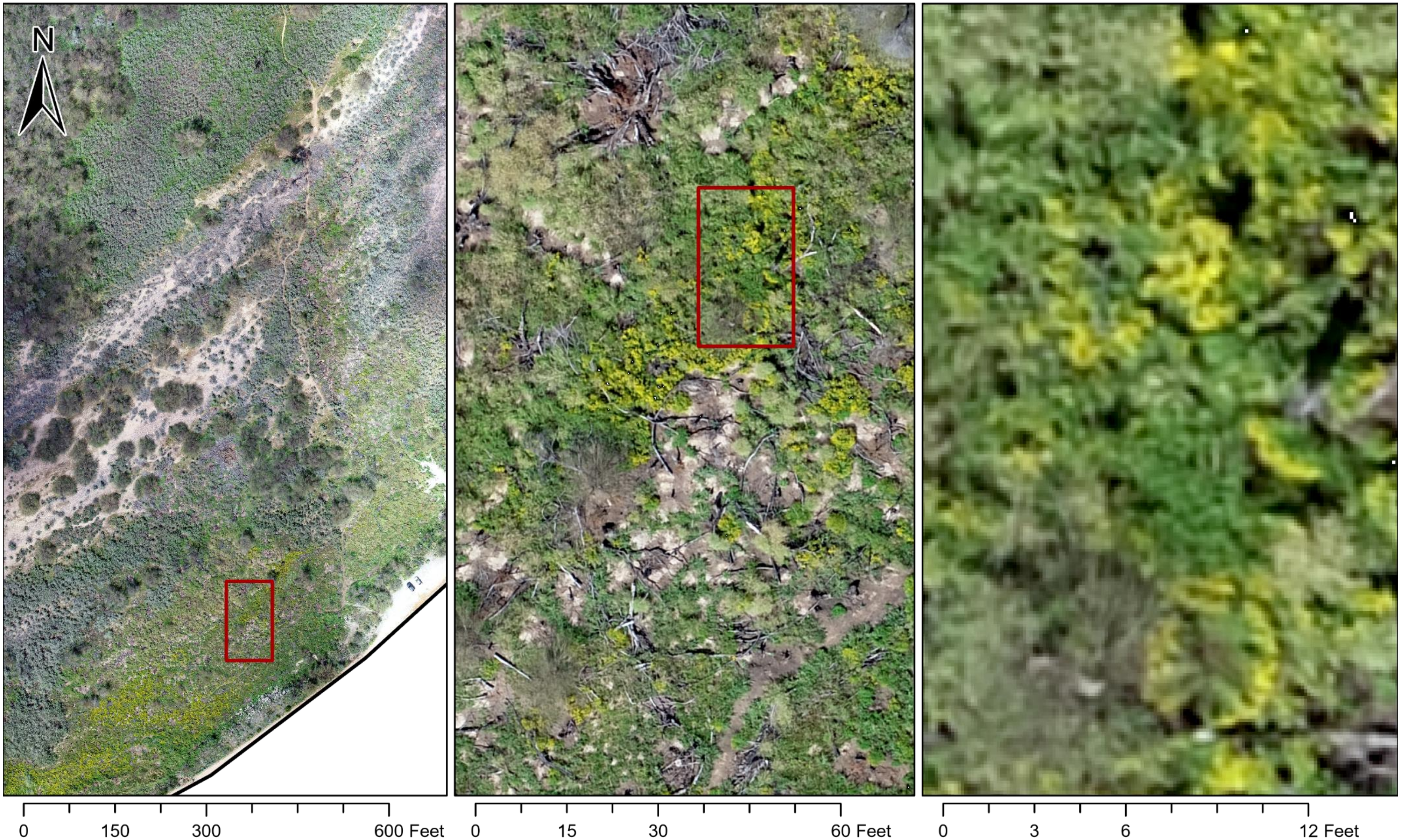
(Left)

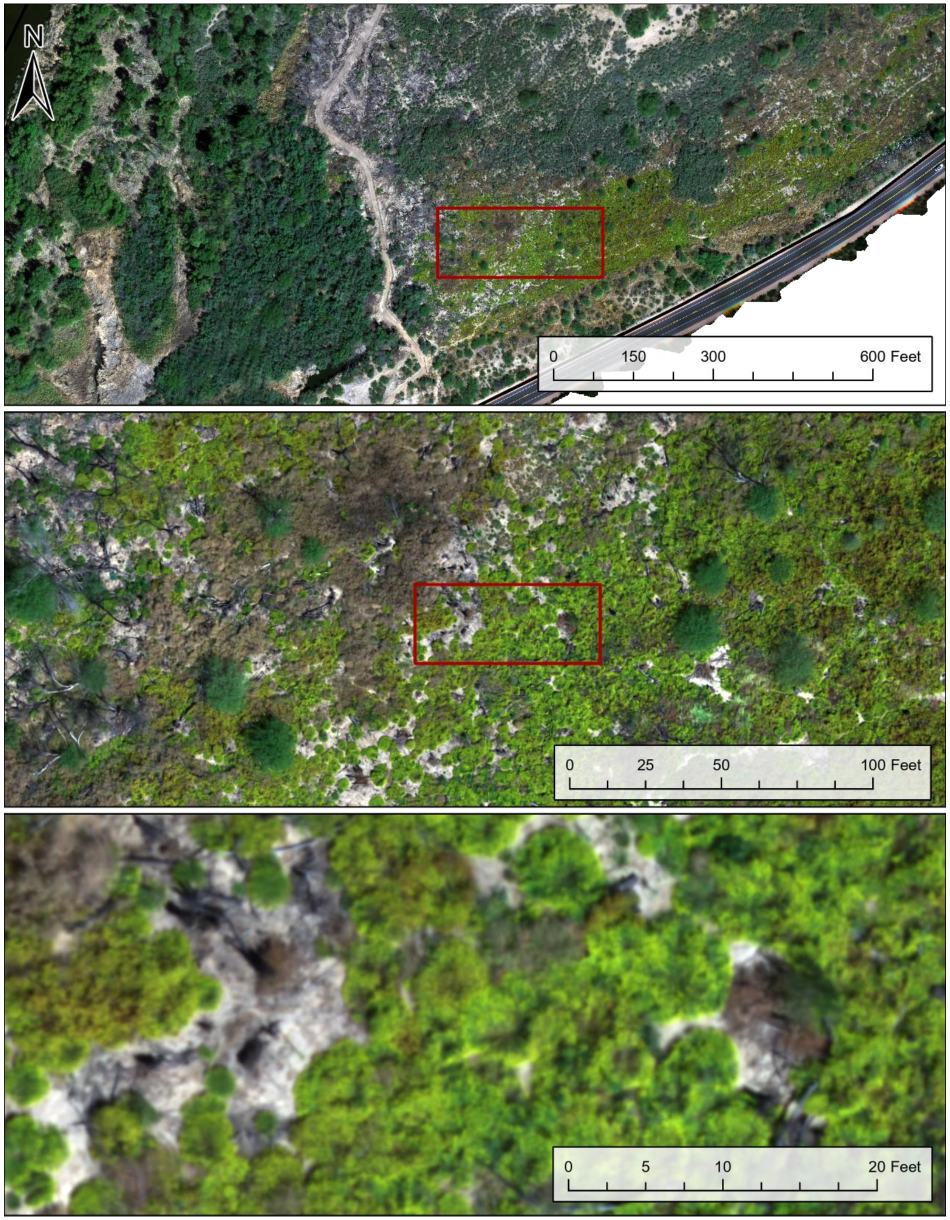
Emerging growth of Globe Chamomile in the southeast of the project site, along the Bush Hwy.

L-R: 2500:1, 250:1, and 25:1 image scale using P4P RGB Orthomosaic.

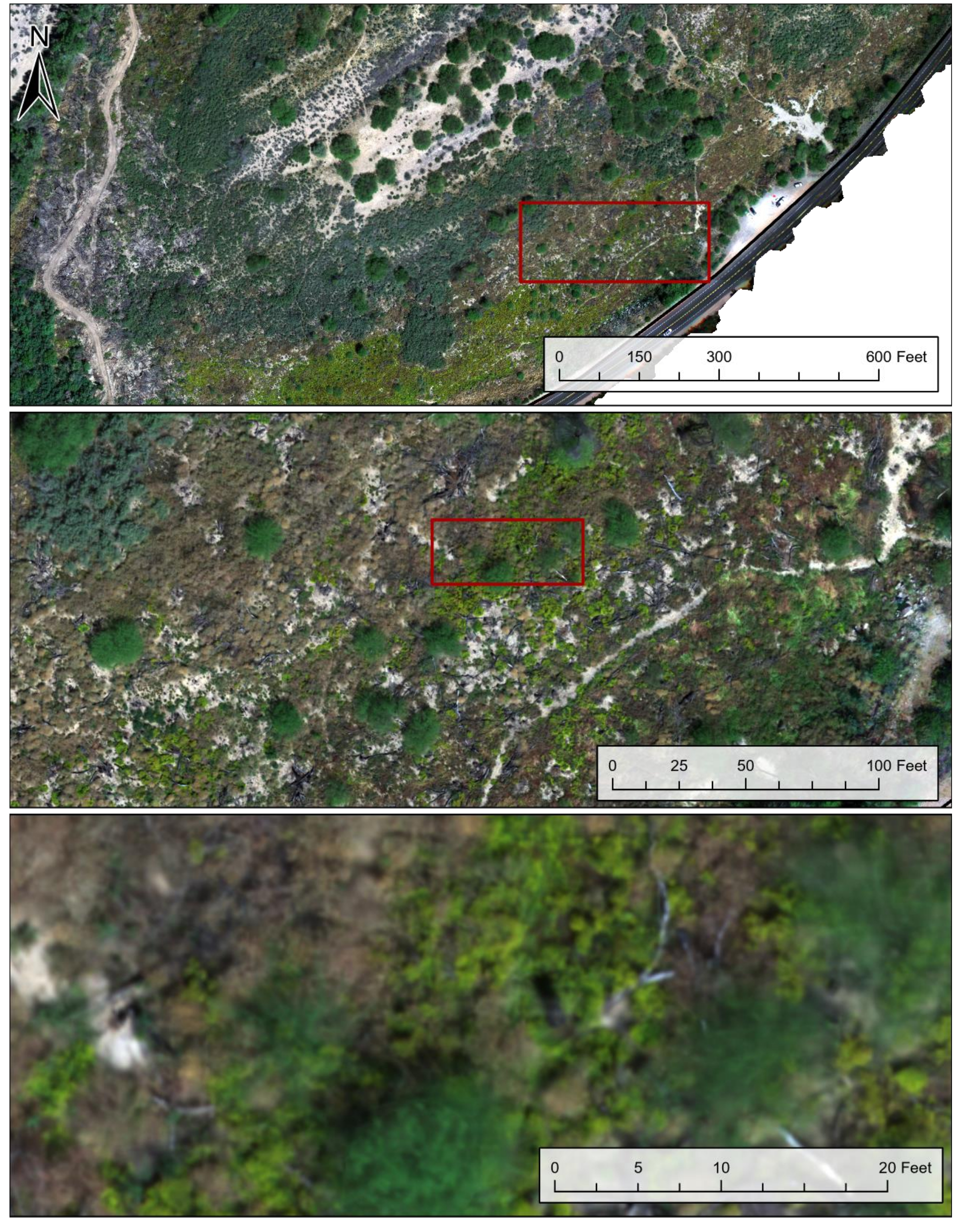
Approximate coordinates of sample: 111.673°W 33.518°N

(Below) Growth of Globe Chamomile due northeast of first sample, continuing along the Bush Hwy. L-R: 2500:1, 250:1, and 25:1 image scale using P4P RGB Orthomosaic. Approximate coordinates of sample: 111.671°W 33.519°N.



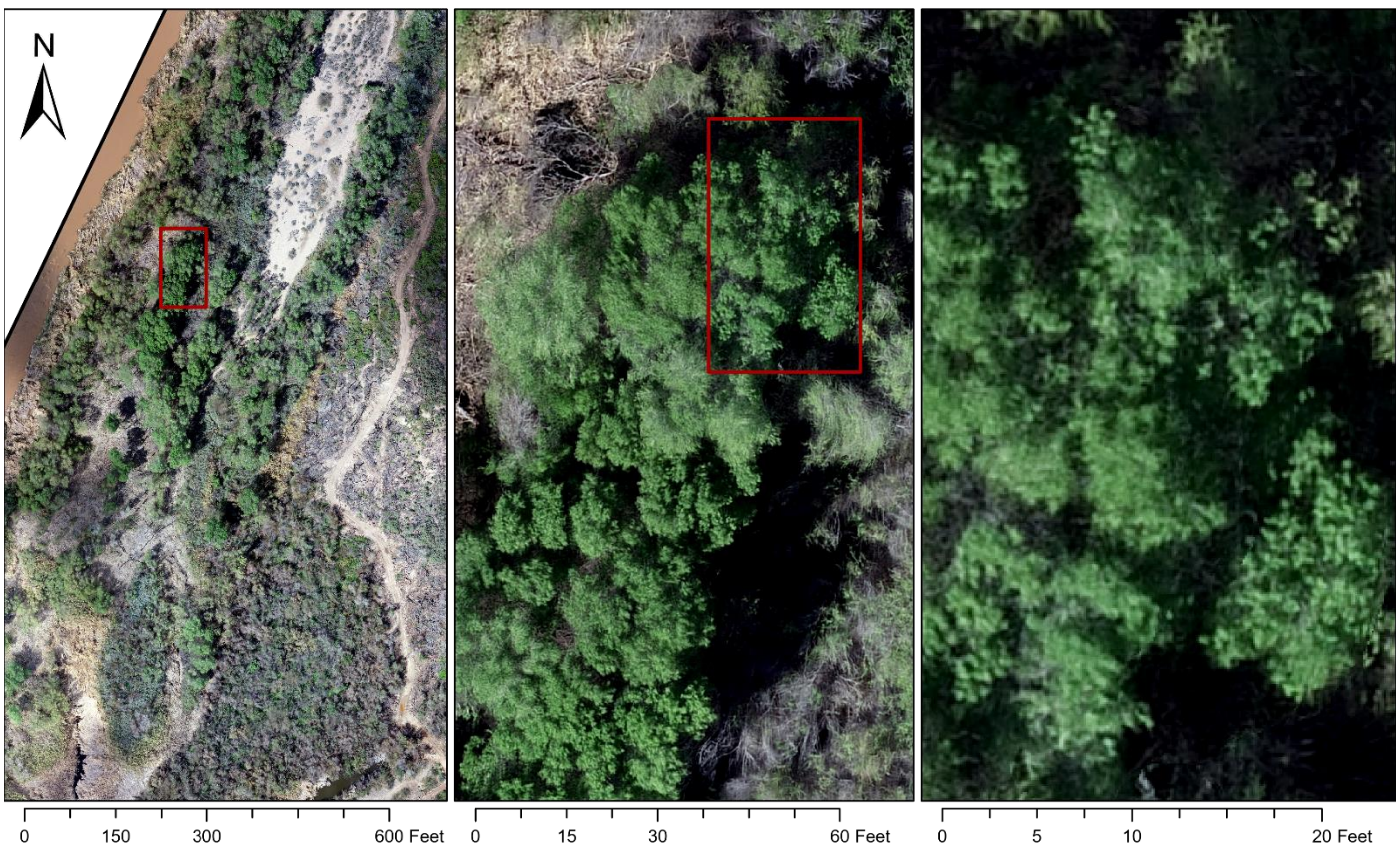


(Above) Emerging growth of Globe Chamomile in the southeast of the project site, along the Bush Hwy. Top to bottom: 2500:1, 500:1, and 80:1 image scale using P4M RGB Mosaic Dataset. Approximate coordinates of sample: 111.673°W 33.518°N



(Above) Growth of Globe Chamomile due northeast of first sample, continuing along the Bush Hwy. Top to bottom: 2500:1, 500:1, and 80:1 image scale using P4M RGB Mosaic Dataset. Approximate coordinates of sample: 111.671°W 33.519°N

Common Name	Scientific Name	Stand Texture	Growth Characteristics	ID for Imagery	Location Description
Fremont cottonwood	*Populus fremontii*	Discrete, rough crowns with rounded outlines.	• Perennial tree growing up to 30 meters tall. • Broad-leafed with tannish brown branches. Canopies sprout vertically with long branchlets congregating at the top of the trunk • Flowers between March and June. • Forms galleries parallel to the waterways	The cottonwood's branches move vertically, with crown's made up of multiple clusters of leaves. Contains discrete sections of the canopies that are from the same tree trunk but composed of segmented branches and leaves. What is left are circular sections with gaps where leaves do not interlace, creating the appearance of empty spaced borders.	Major component of the riparian overstory canopy. Found along the floodplain and river channel before leading into the riparian terrace.



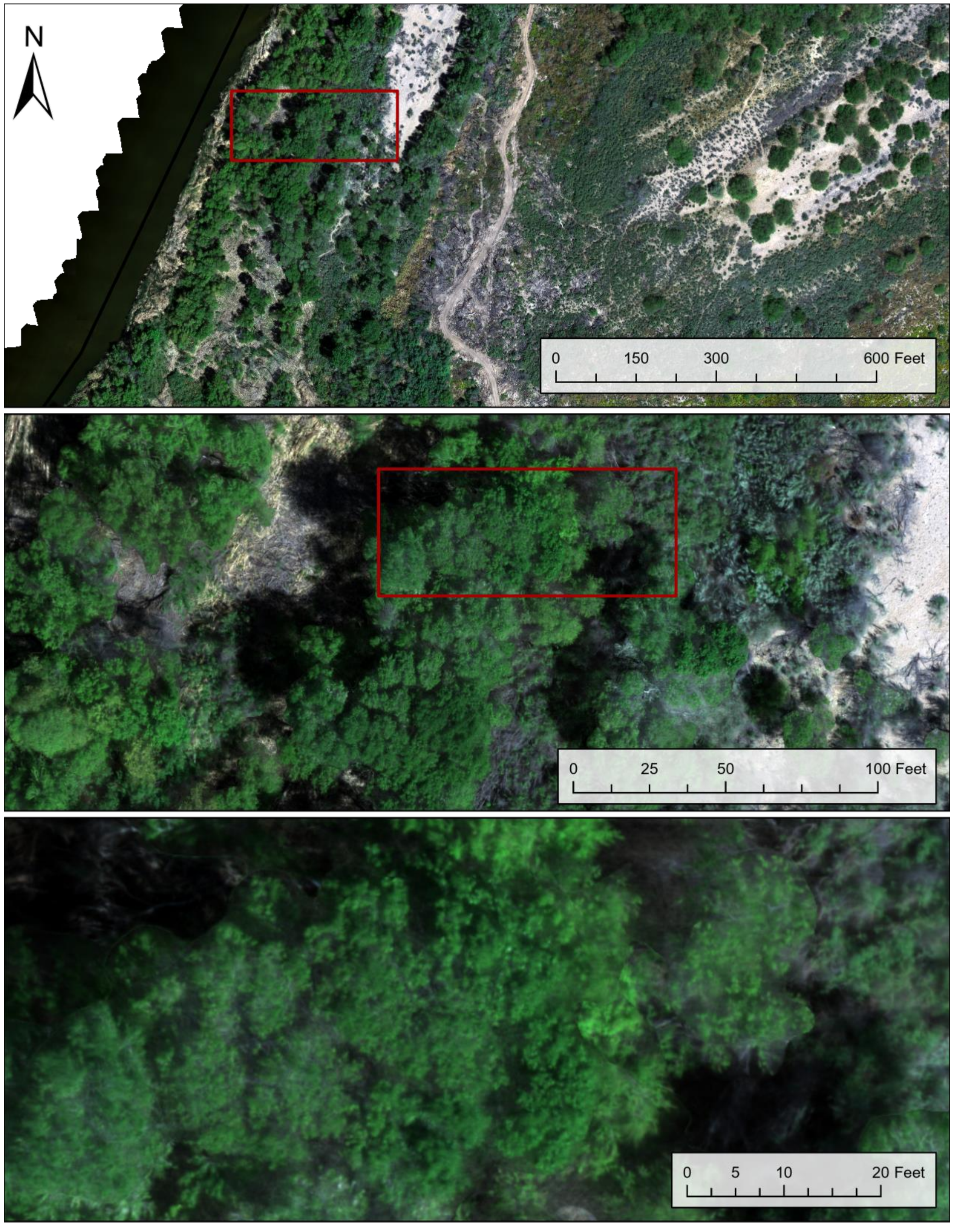
(Left)

Mature cottonwood community in the west of the project site.

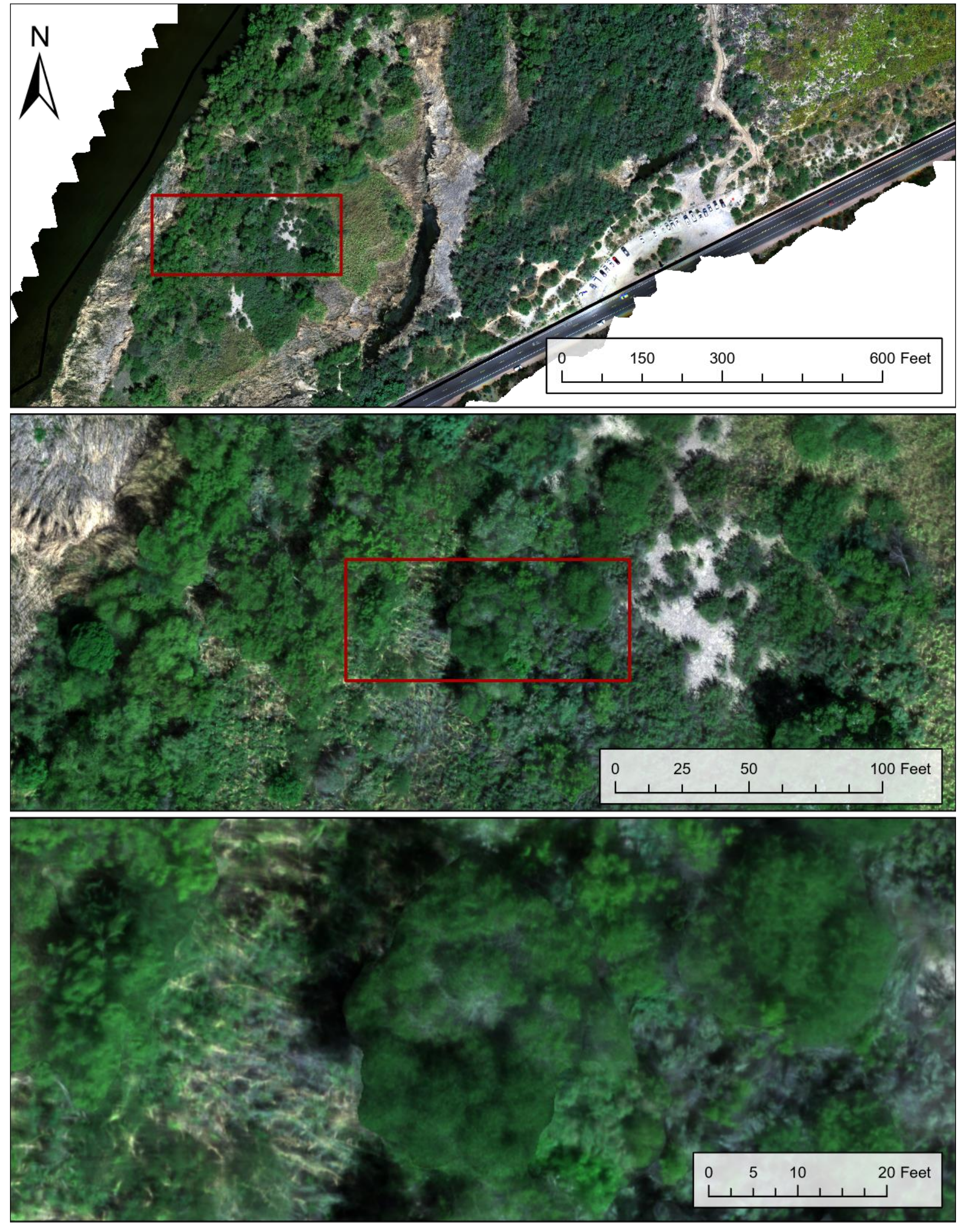
L-R: 2500:1, 250:1, and 80:1 image scale using P4P RGB Orthomosaic.

Approximate coordinates of sample: 111.6752°W 33.5200°N

(Below) Interspaced Cottonwood trees within a dense stand Giant Reed. L-R: 2500:1, 250:1, and 80:1 image scale using P4P RGB Orthomosaic. Approximate coordinates of sample: 111.6769°W 33.5172°N

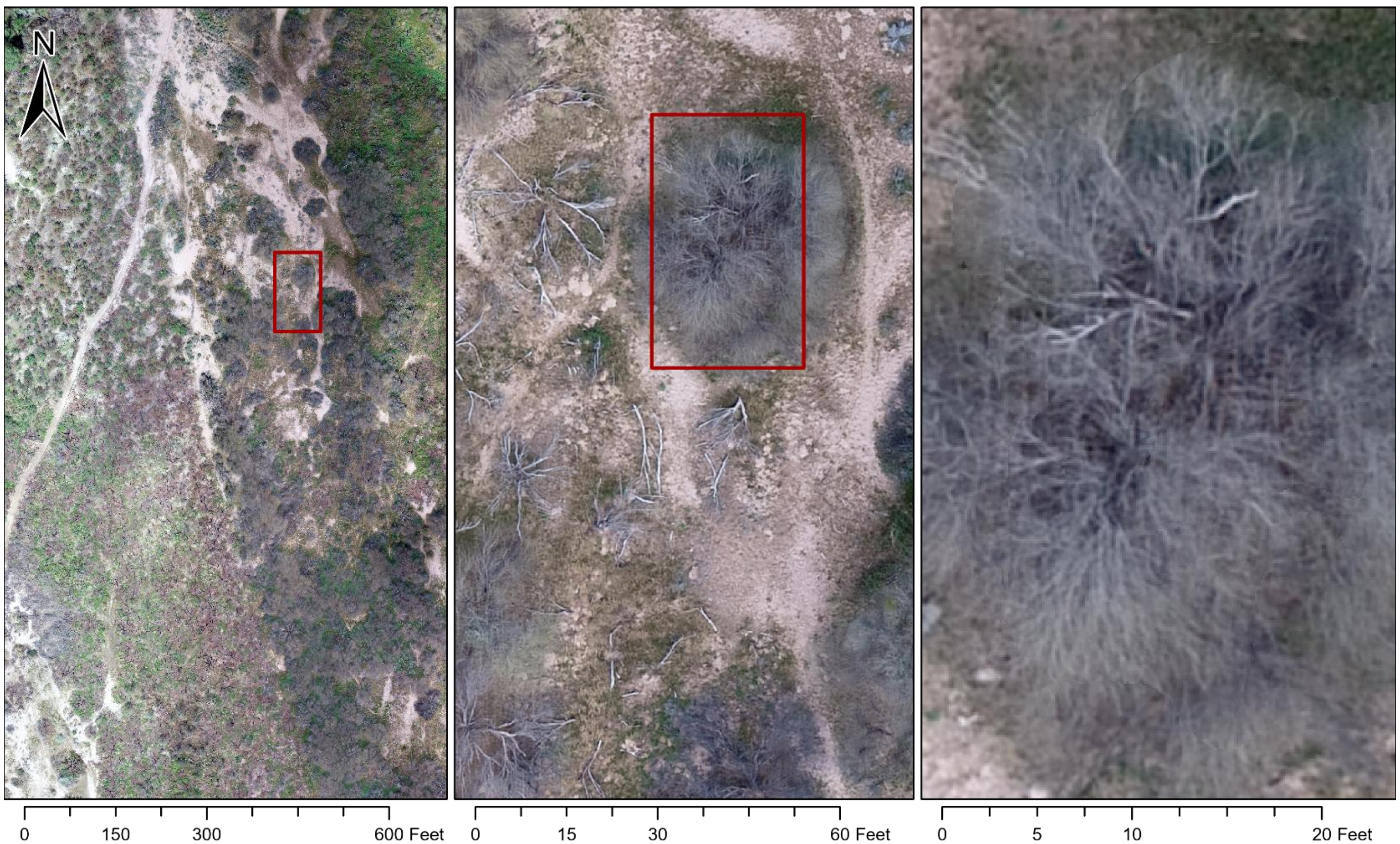


(Above) Mature cottonwood community in the west of the project site. Top to Bottom: 2500:1, 500:1, and 150:1 image scale using P4M RGB Mosaic Dataset. Approximate coordinates of sample: 111.6752°W 33.5200°N



(Above) Interspaced Cottonwood trees within a dense stand of treated Giant Reed. Top to Bottom: 2500:1, 500:1, and 150:1 image scale using P4M RGB Mosaic Dataset. Approximate coordinates of sample: 111.6769°W 33.5172°N

Common Name	Scientific Name	Stand Texture	Growth Characteristics	ID for Imagery	Location Description
Mesquite	***Prosopis spp.***	Coarse texture of branches before flowering in the summer.	• Perennial tree • Can grow between 25-35 feet tall • Low branches, with dark bark • Grows asymmetrically, with multiple trunks • Flowers between in late spring, followed by yellow-green seed pods during the summer	RGB aerial imagery of certain mesquite bosques may be limited to the multiple branches without visible leaves. The growth of their canopies extends into summer and was absent during the initial P4P recorded data. However, the wide stemming branches are visible as the grow into multiple shorter branch segments.	Both large mesquite bosques make up the overstory of the riparian terrace. Singular trees are dispersed throughout the terrace into the upland areas.



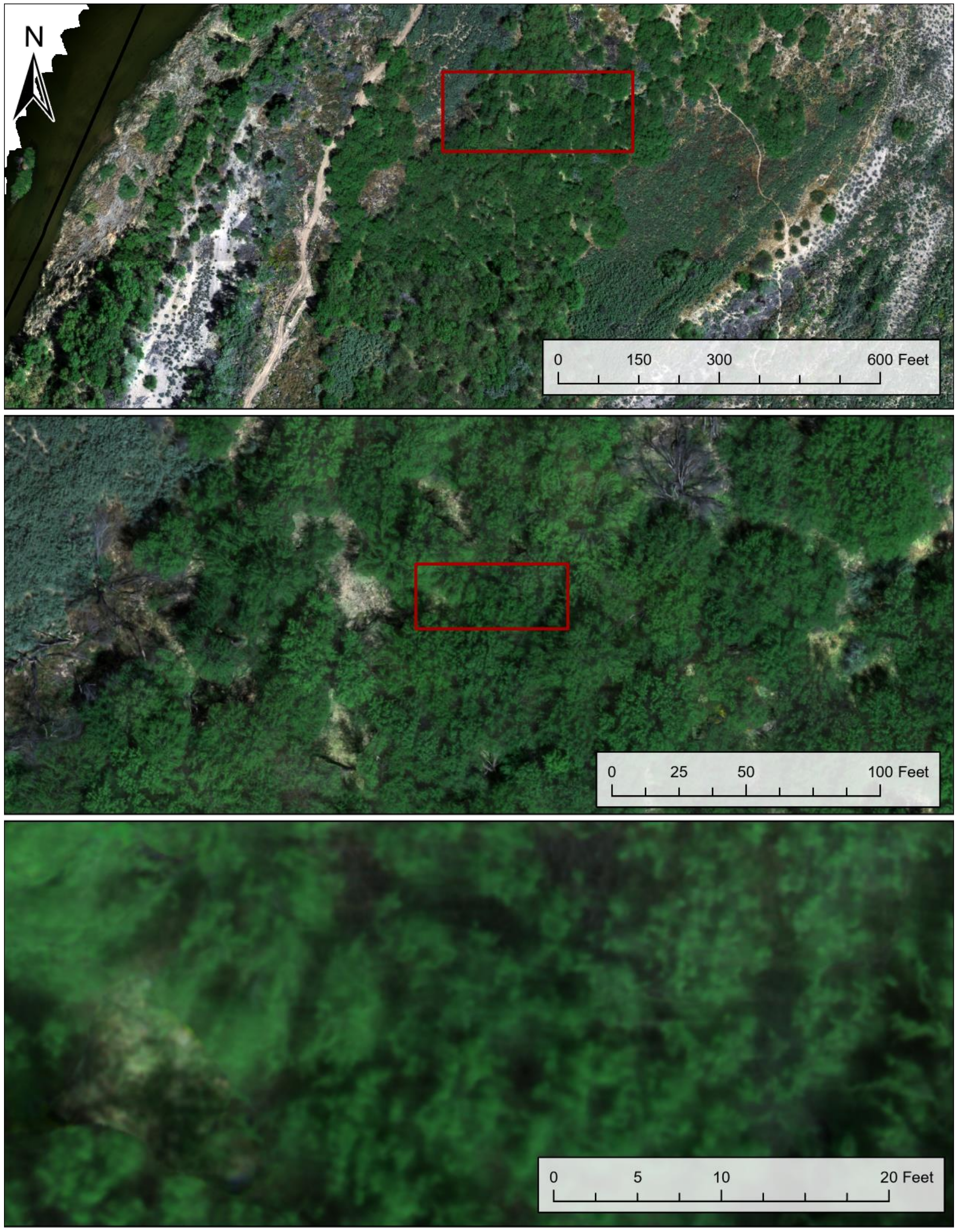
(Left)

Mesquite tree in the northern section of the project site, part of a larger mesquite bosque.

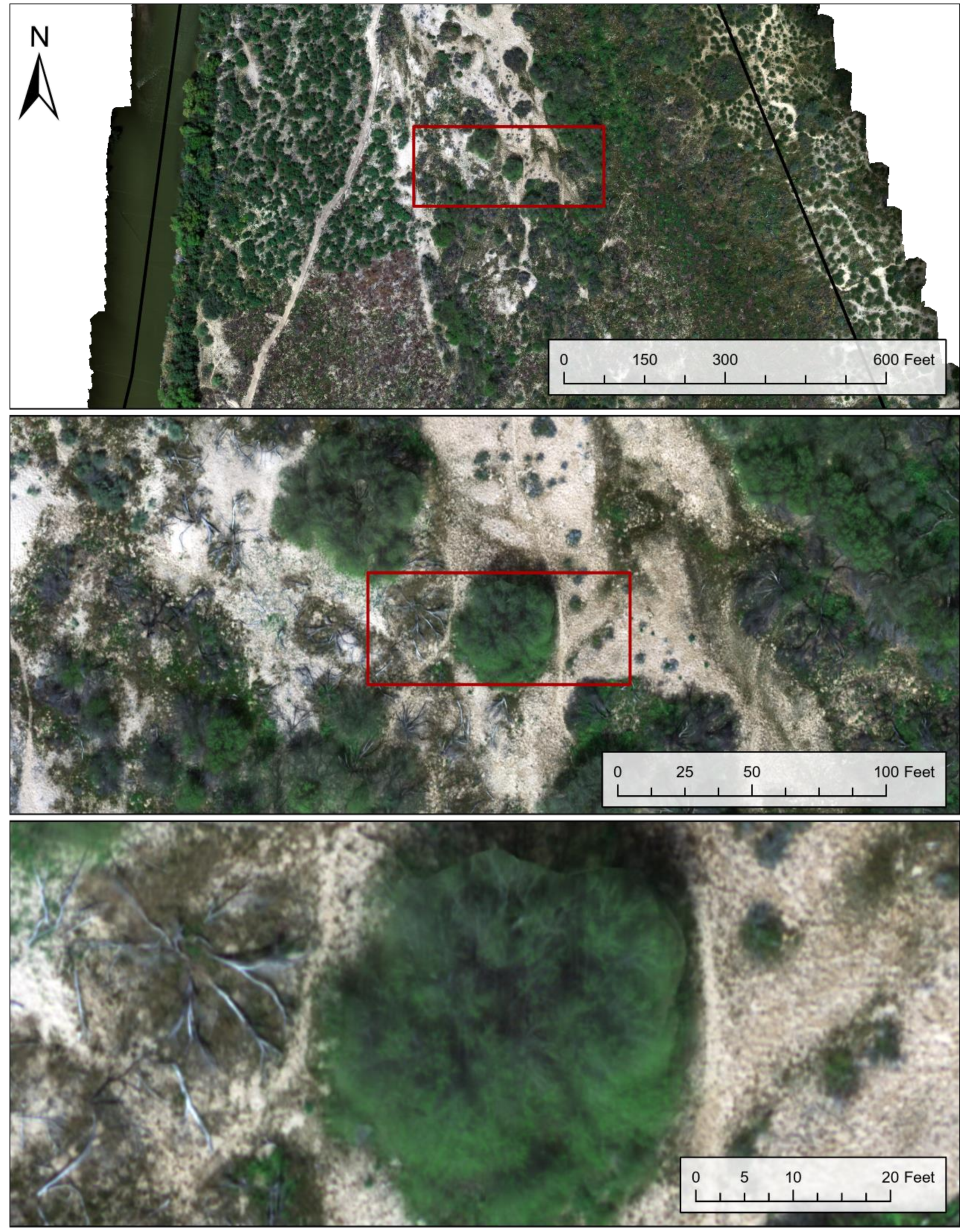
L-R: 2500:1, 250:1, and 80:1 image scale using P4P RGB Orthomosaic.

Approximate coordinates of sample: 111.6683°W 33.5300°N

(Below) Large mesquite bosque in the middle of the project terrain. L-R: 2500:1, 250:1, and 80:1 image scale using P4P RGB Orthomosaic. Approximate coordinates of sample: 111.6769°W 33.5172°N



(Above) Large mesquite bosque in the middle of the project terrain. Top to bottom: 2500:1, 500:1, and 80:1 image scale using P4M RGB Mosaic Dataset. Approximate coordinates of sample: 111.6769°W 33.5172°N



(Above) Mesquite tree in the northern section of the project site, part of a larger mesquite bosque. Top to bottom: 2500:1, 500:1, and 80:1 image scale using P4M RGB Mosaic Dataset. Approximate coordinates of sample: 111.6683°W 33.5300°N