

Quantifying vegetation cover and ecosystem services with hyperspatial UAS imagery in a coastal intermediate marsh



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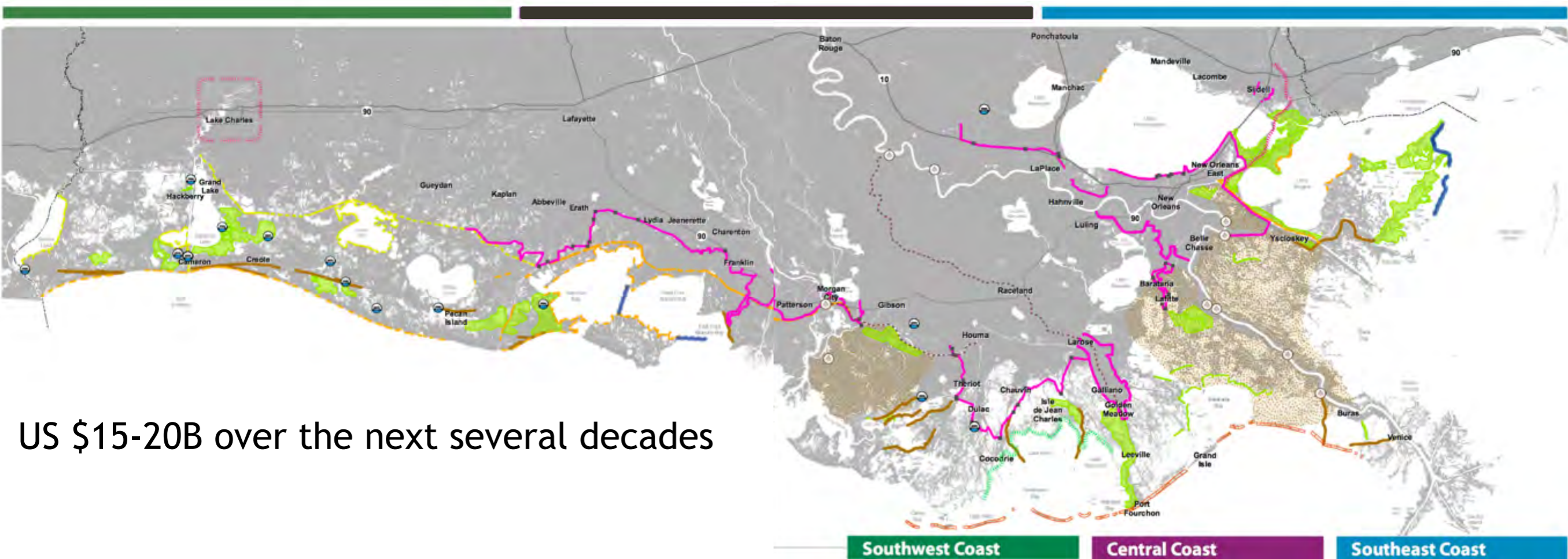
Outline

1. Rationale
2. Current state of the science
3. Here come the drones
4. Remote sensing techniques for vegetation mapping
5. Pilot Project in Terrebonne Parish
 - *Can UAS hyperspatial, multispectral imagery be used to classify species composition and quantify certain ecosystem service metrics, specifically plant height and NDVI, in a *Spartina patens* dominated intermediate coastal marsh?*
 - This information could be used to develop landscape models of aboveground biomass and carbon sequestration.
6. Methods
 - Site location
 - FAA approval, logistics, and flight planning
 - Photogrammetry and Object-Based Image Analysis
7. Results
 - RGB and NIR orthomosaics and Digital Surface Models
 - OBIA classifications and accuracy assessment
 - Comparison with CRMS vegetation surveys



Louisiana's Comprehensive Master Plan for a Sustainable Coast

Monitoring Needs for Restoration



US \$15-20B over the next several decades

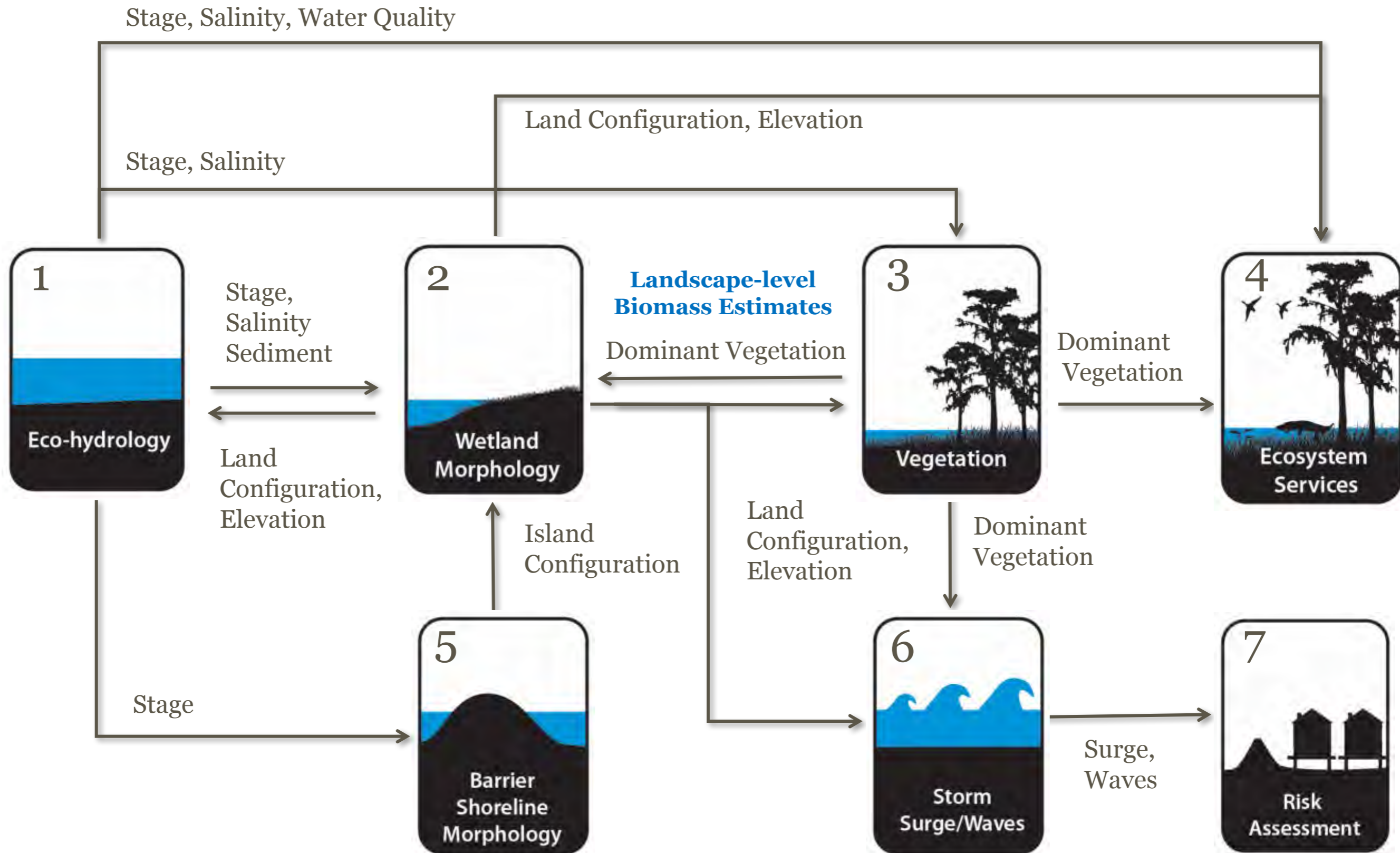
Project Types

- Structural Protection
- Bank Stabilization
- Oyster Barrier Reef
- Ridge Restoration
- Shoreline Protection
- Barrier Island Restoration
- Marsh Creation
- Sediment Diversion
- Hydrologic Restoration

Ecosystem services: Which services are important and applicable for coastal marshes in Louisiana?

- **Habitat quality:** quality and quantity of habitat to support various fish and wildlife (Freeman 1991, Bell 1997).
- **Storm Surge/Wave Attenuation:** Often based on the location and amount of land, type of vegetation, and land elevation (Costanza et al. 2008).
- **Nutrient Uptake:** nitrogen removal in sediments and wetlands (Craft 2007, Craft et al. 2009).
- **Carbon Sequestration:** Carbon storage varies with the type of wetland, the acreage, the annual vertical accretion of soil, and aboveground biomass (Mitch and Gosselink 2008, Barbier et al. 2011)

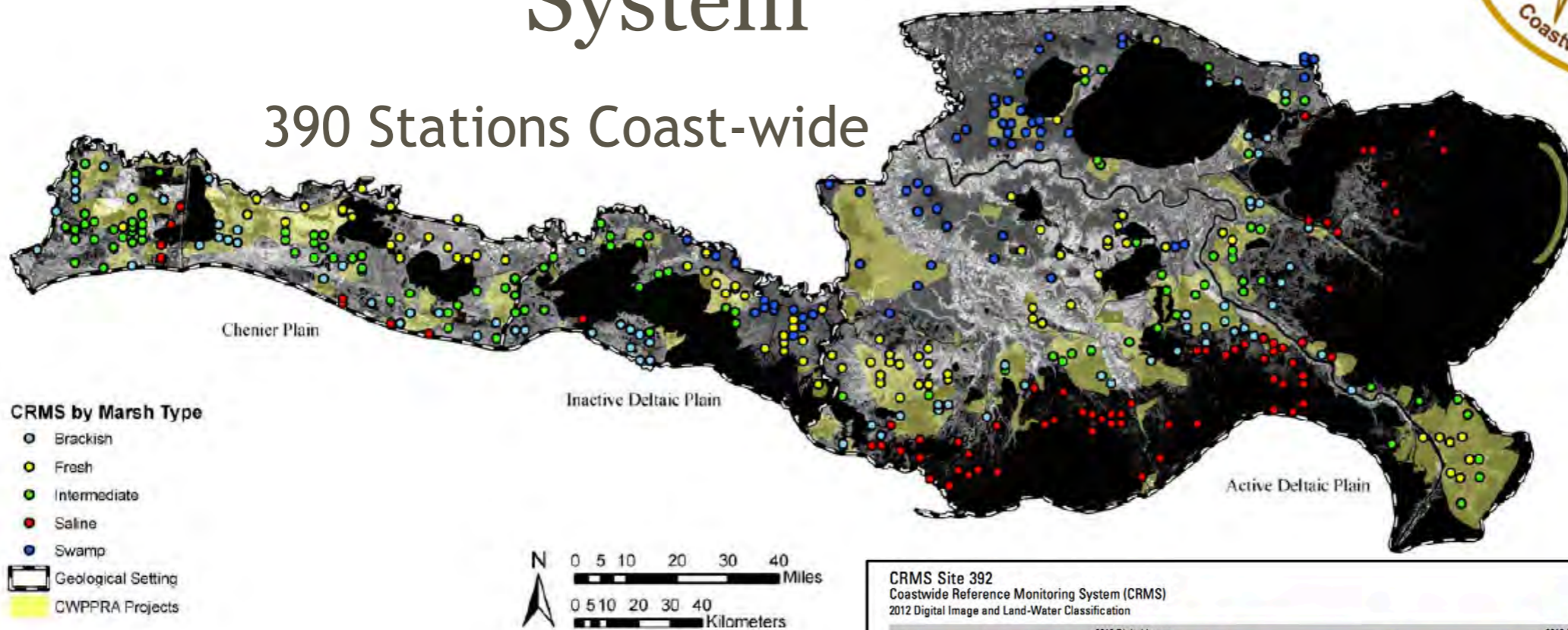
2012 Master Plan Model Suite



Coastwide Reference Monitoring System



390 Stations Coast-wide

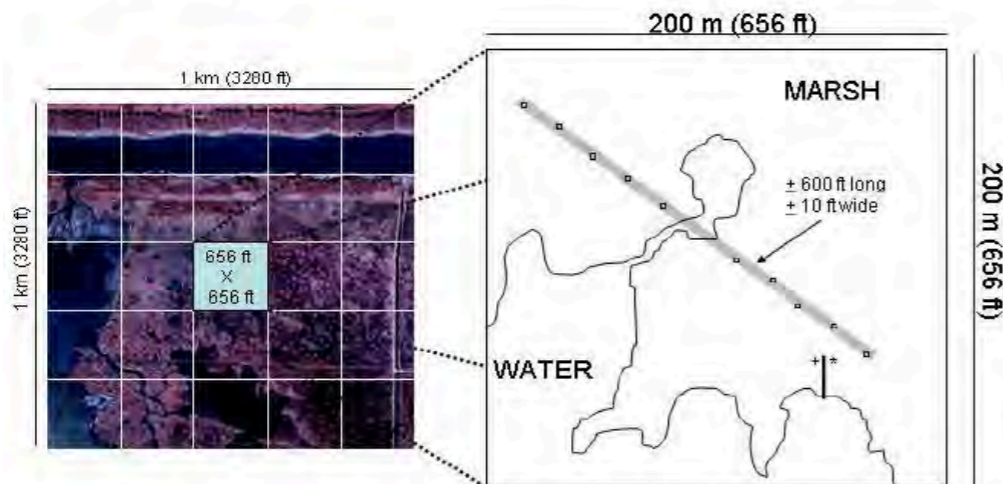


CRMS by Marsh Type

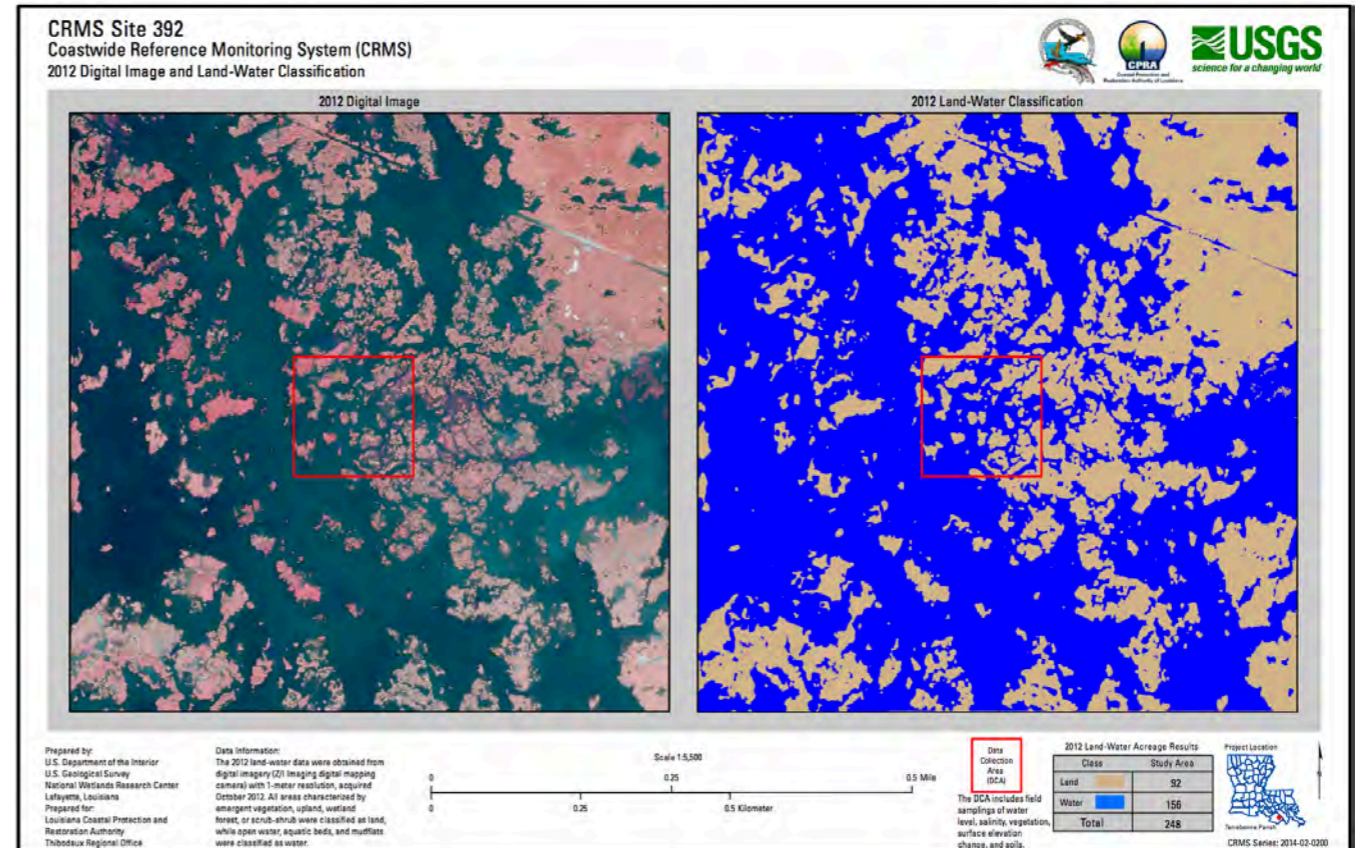
- Brackish
- Fresh
- Intermediate
- Saline
- Swamp
- ▭ Geological Setting
- ▭ CWPBRA Projects

CRMS Sampling Area:
1 km² aerial photo area

CRMS Sampling Area:
200m X 200m data collection area



- ▣ 2m X 2m vegetation station for collecting % cover and species abundance (within 10 ft X 600 ft area)
- * Sediment Elevation Table (SET) for collecting elevation data
- + Data Sonde collecting water level and salinity
- Boardwalk

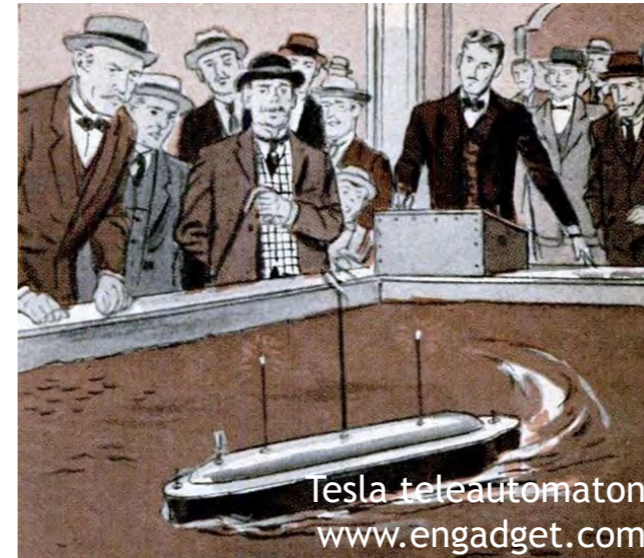


Local field measurements

Landscape spatial analyses

Brief History of Unmanned Aircraft Systems

- 1898: Tesla teleautomaton - First to remotely control a vessel with radio waves
- WWI 1918: Curtiss N-9 floatplane, World's first unmanned aircraft system
- WWII: British "Queen Bee" aircraft designed to be shot down
- Vietnam: UAS reconnaissance
- Desert Storm 1991 & War on Terror: Targeted airstrikes (first wide scale deployment of UAS)
- 2012 - Congress mandates UAS integration into NAS (FAA Modernization and Reform Act of 2012)
- 2016 - FAA 14 CFR Part 107 issued -licensing of "remote pilot airman certificate with a small UAS rating" and UAS operations in NAS



De Havilland Queen Bee drone, 1941.
Copyright Imperial War Museum



Inspire 2. www.dji.com



eBee. www.sensefly.com



MQ-1 Predator. <http://www.af.mil>

Photogrammetry Primer

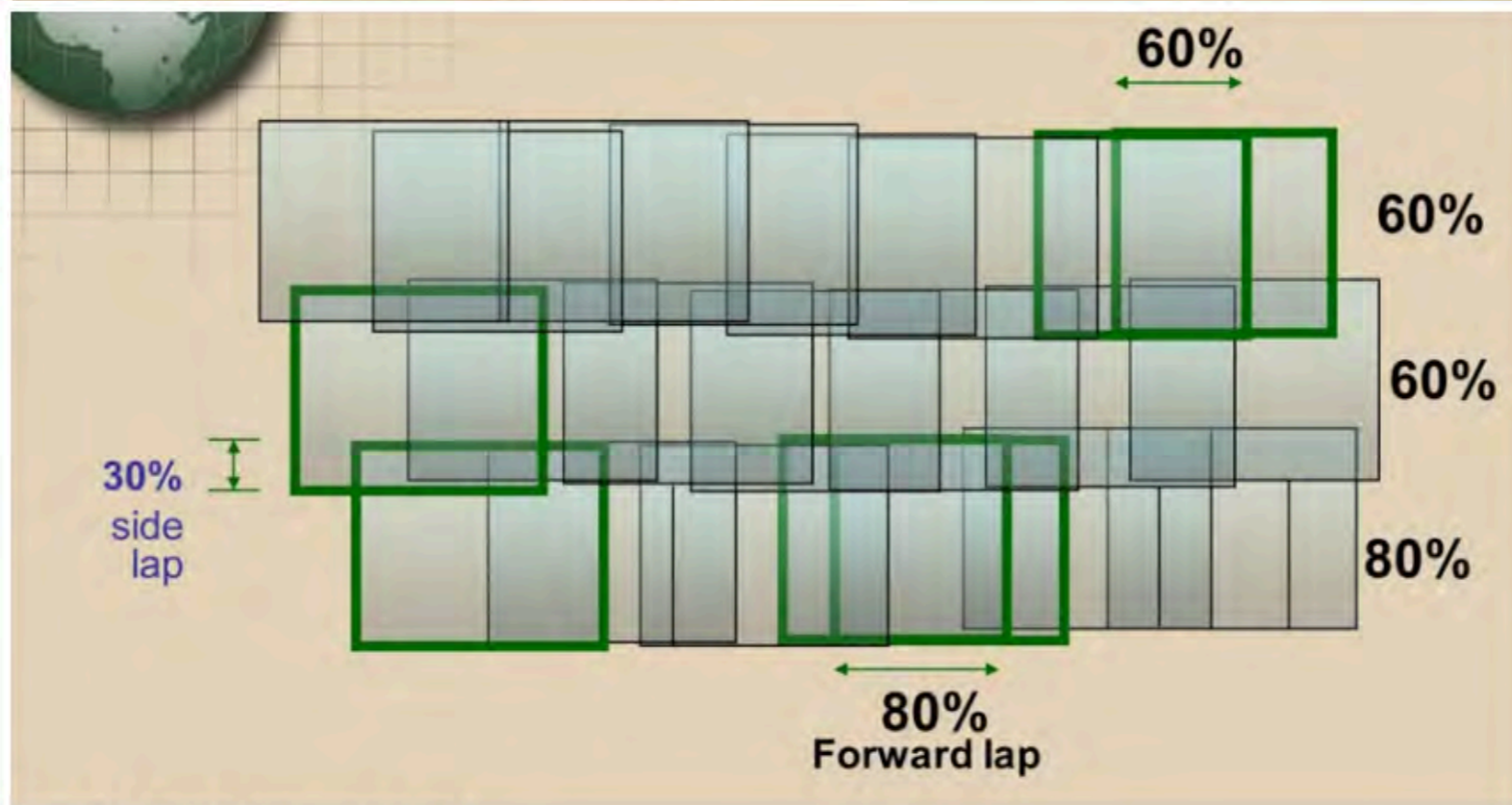
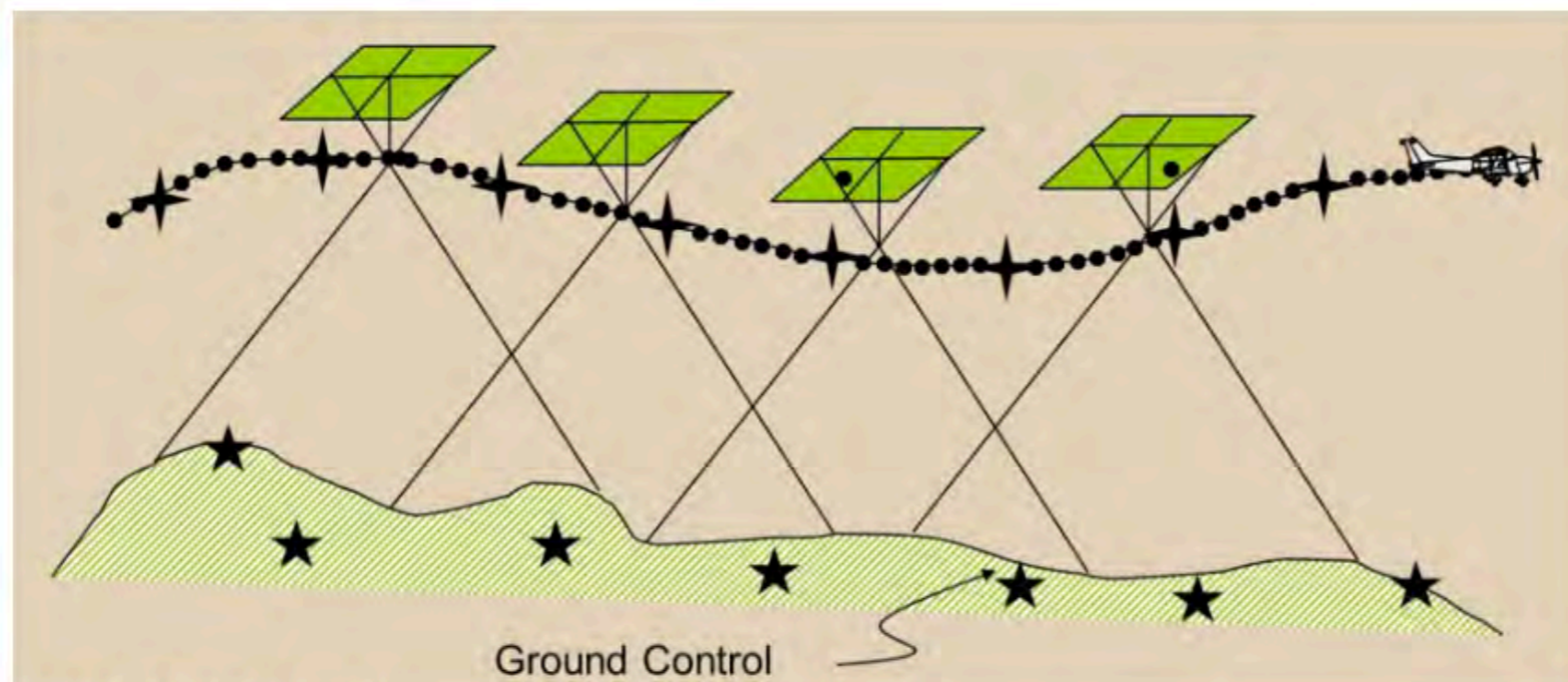
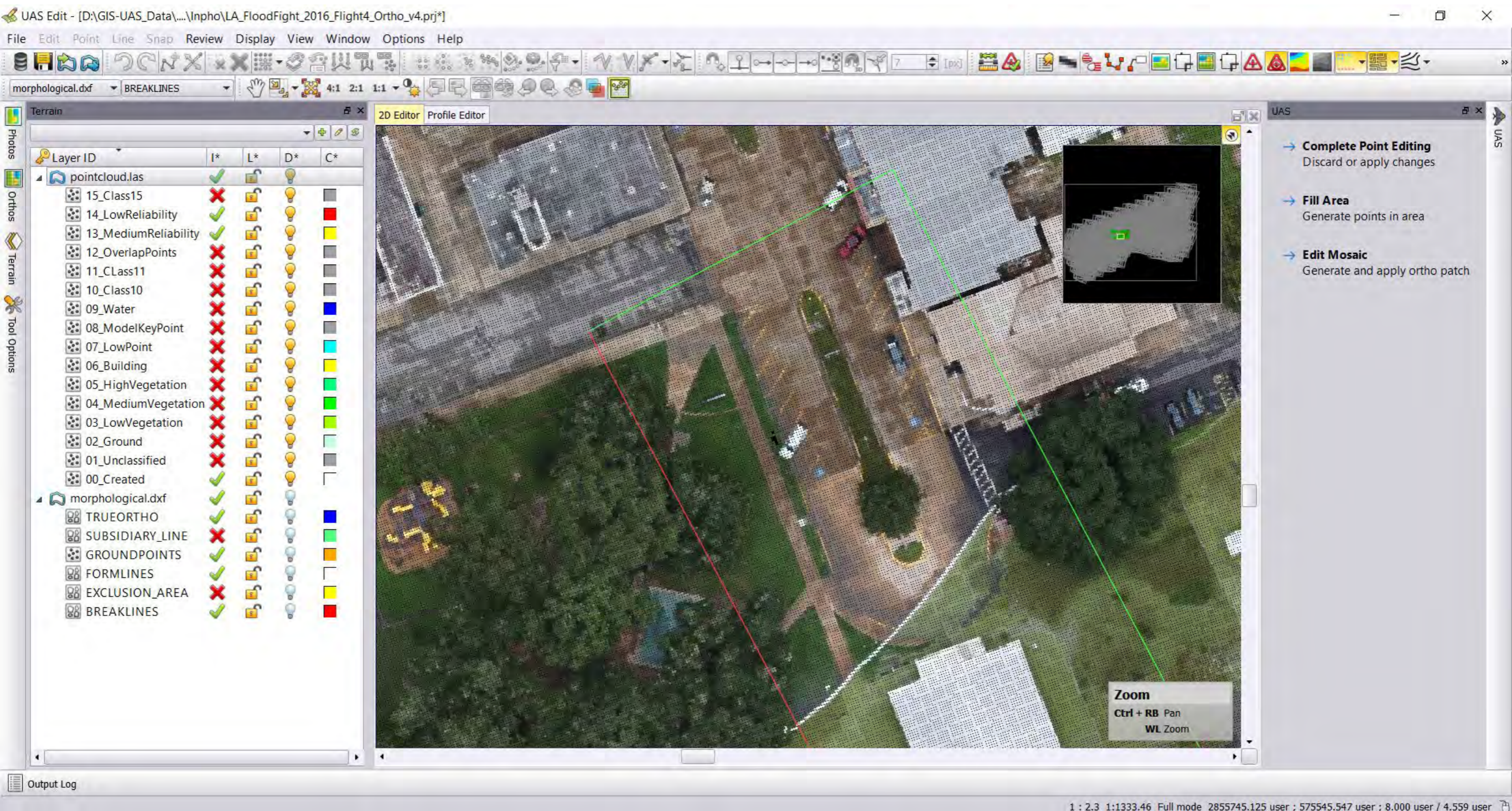
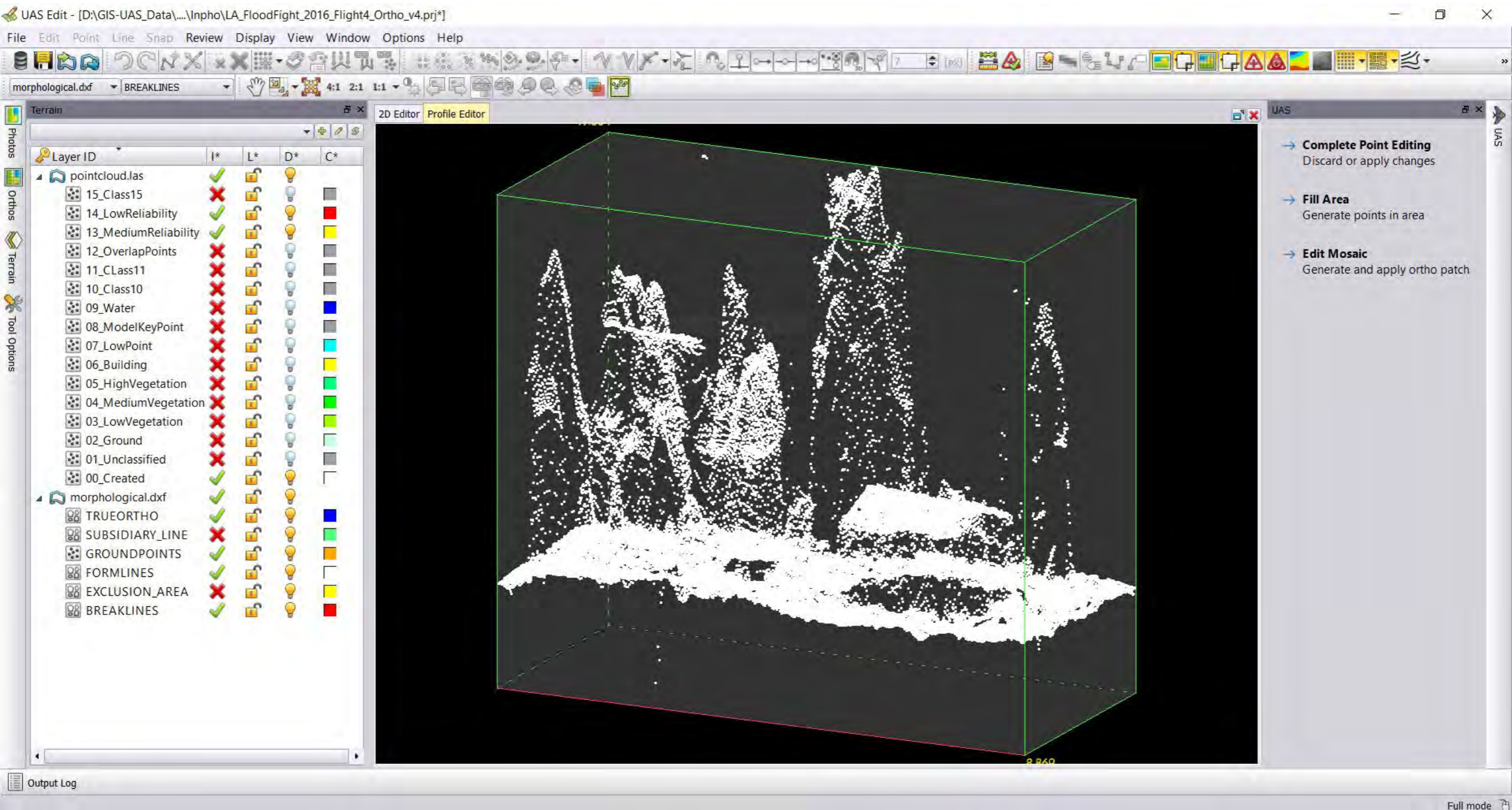


Image credit: Qassim Abdullah

Photogrammetry Primer



Photogrammetry Primer

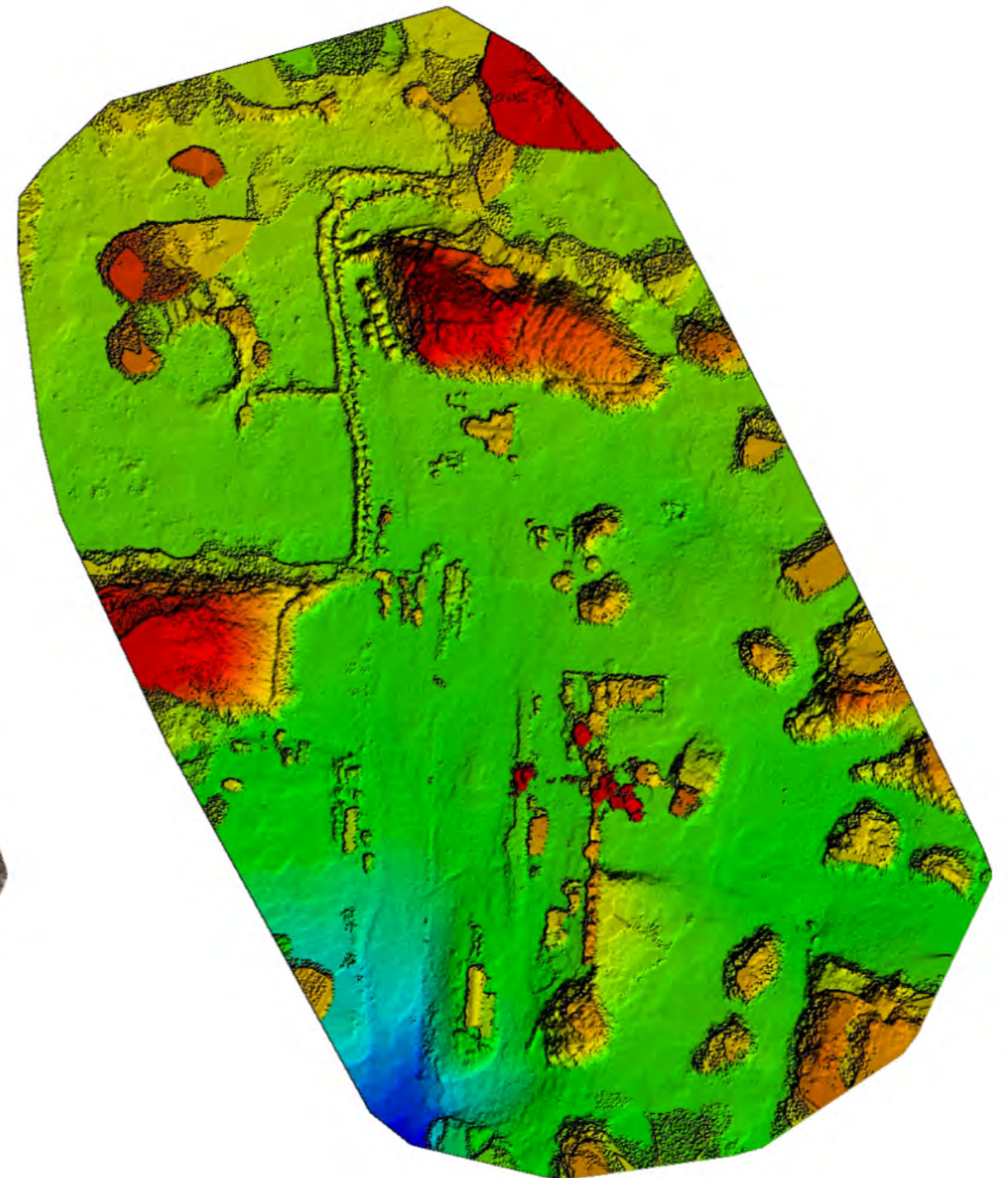


Photogrammetry Primer

Orthomosaic



Digital Surface Model



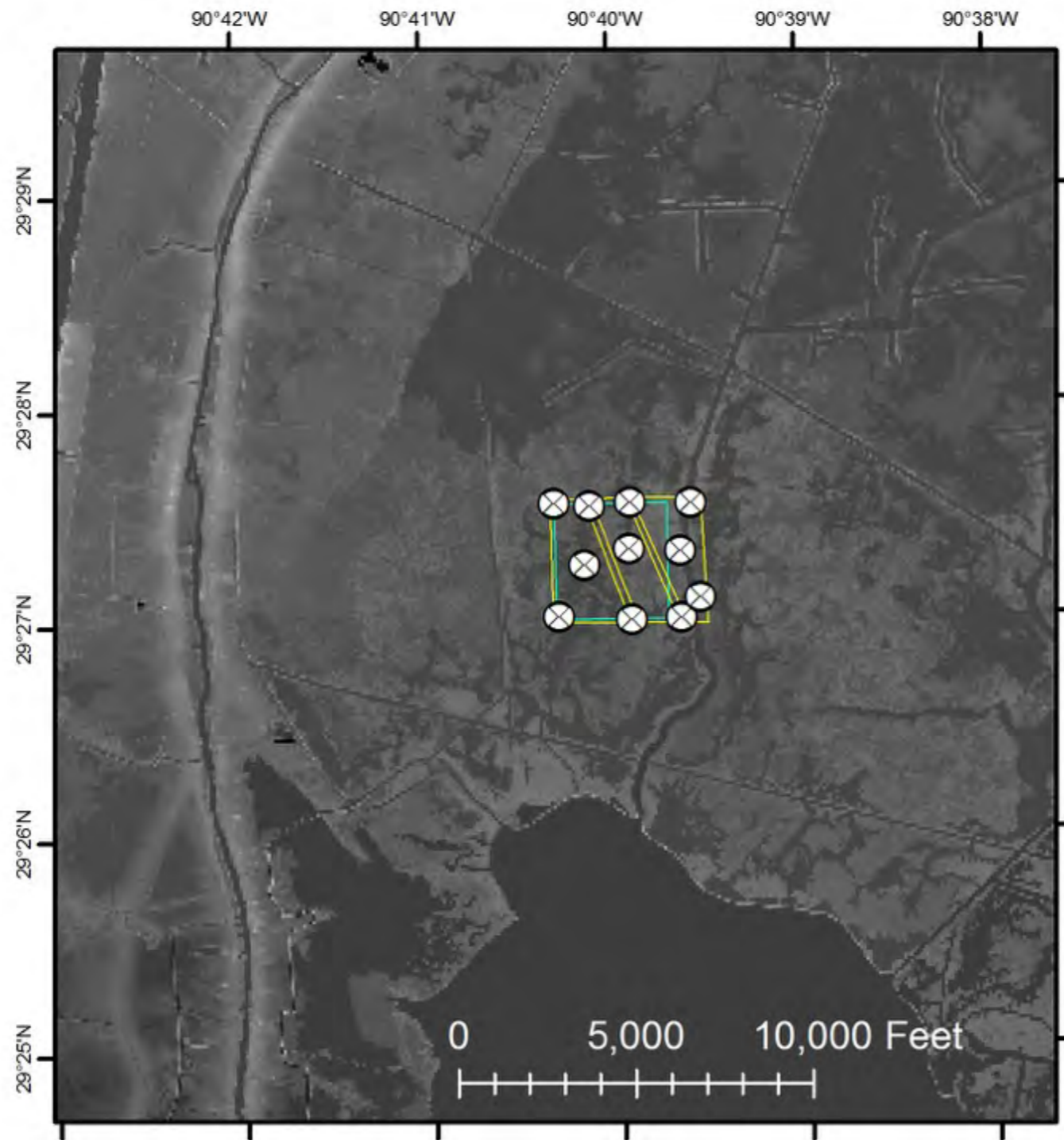
UAS Technology in Coastal Research

- Late 1970s - first use of a fixed wing remotely controlled aircraft in photogrammetry experiments (Przybilla and Wester-Ebbinghaus 1979)
- 1996 - monitoring restoration with multispectral video data (Phin et al. 1996)
- 2004 - first use of a commercial low-cost UAS to create a high-resolution digital terrain model (Eisenbeiss et al. 2005)
- 2007 - High definition video to map local beach erosion (Chong 2007).
- 2007 - High resolution imagery to map channel bathymetry and topography (Lejot et al. 2007)
- 2012 - UAS Hyperspatial data and OBIA to classify upland swamps (Lechner et al. 2012)
- Several other examples of multispectral and hyperspectral imagery used to map wetlands (Chust et al. 2008, Yang and Argtigas 2010, Klemas 2013).
- UAS are now widely used in a host of environmental applications
 - land use mapping, wetlands mapping, LIDAR bathymetry, flood and wildfire surveillance, tracking oil spills, urban studies, and Arctic ice investigations (Klemas 2015).

Comparisons between satellite data, traditional aerial photography, and UAS imagery

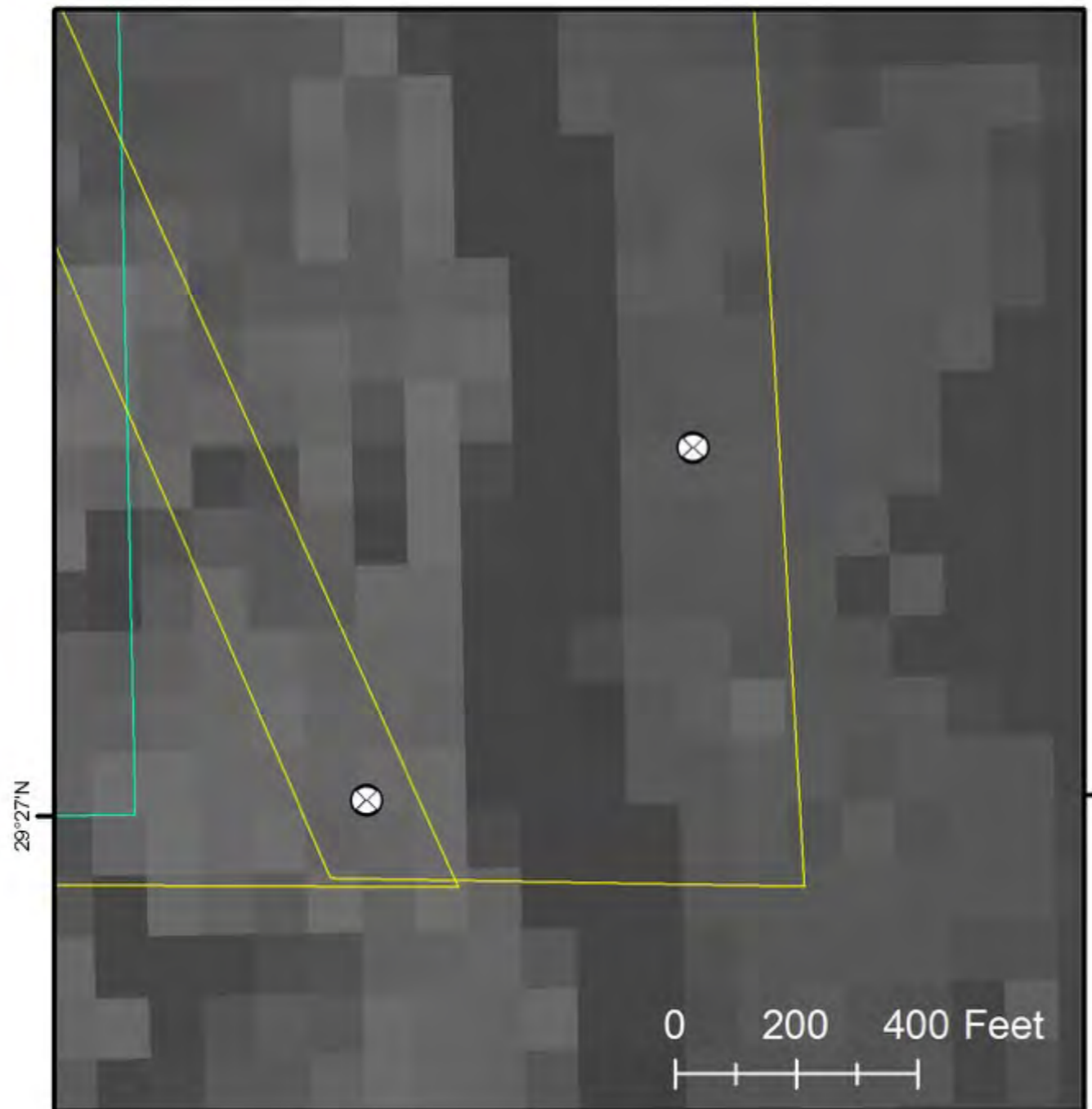
- Flexible deployments - high-temporal and hyperspatial resolution (<1dm) data (Niethammer et al. 2012)
- High resolution, multispectral reflectance will improve vegetation cover estimates and correlations with species richness (Rocchini 2007).
- Photogrammetry techniques can produce point cloud models and provide elevation estimates (for bare earth) and Digital Surface Models (DSM) for vegetation, buildings, towers, and other hard structures.
- Lidar sensors can produce point cloud models, allow for elevation estimates in covered sites, and improve elevation accuracies.

Landsat derived DEM - 30m GSD



Aerial Imagery: Landsat DEM

Landsat derived DEM - 30m GSD



Aerial Imagery: Landsat DEM

Aerial Photography - 1m GSD



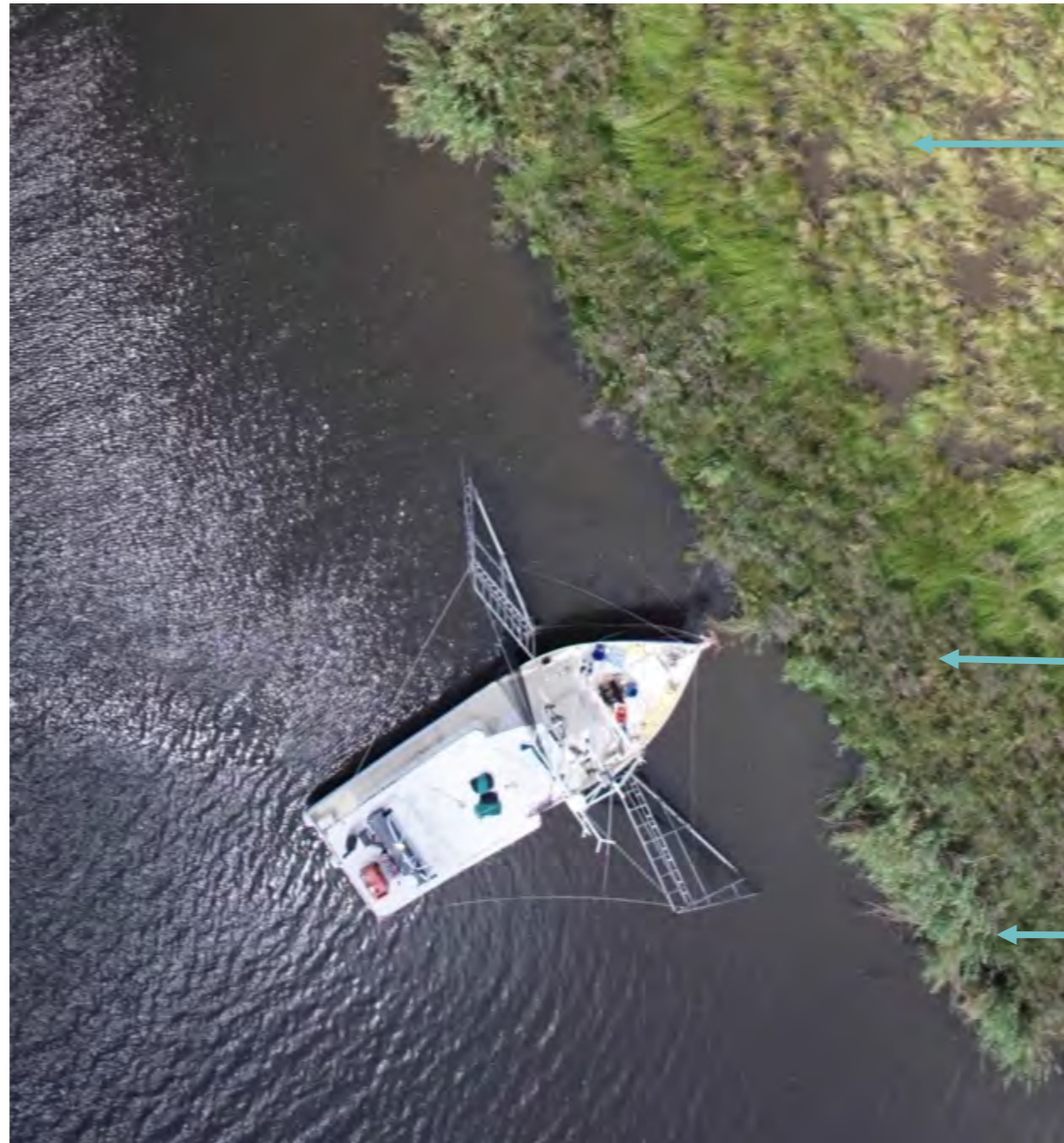
Aerial Imagery: Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA), 2008

Aerial Photography - 1m GSD



Aerial Imagery: Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA), 2008

UAS Aerial Photography - 2.5cm GSD



Spartina patens

Iva frutescens
Baccharis halimifolia

Phragmites australis

UAS Aerial Photography - 2.5cm GSD



Individual

UAS Aerial Photography - 2.5cm GSD

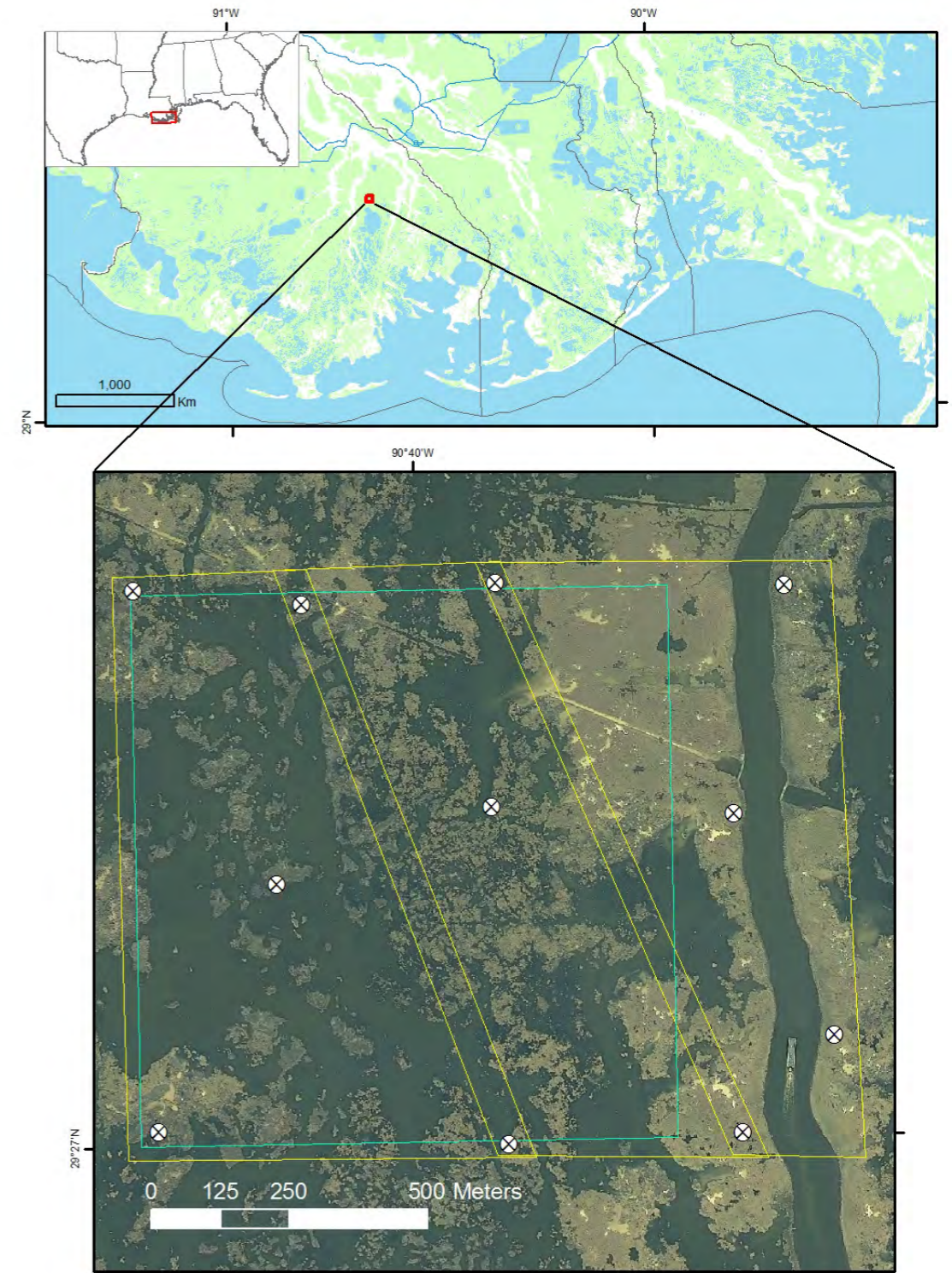


Leaf shape/area

PROJECT GOALS AND OBJECTIVES

This pilot study collected hyperspatial/multispectral aerial imagery from a UAS in a intermediate marsh environment in coastal Louisiana to determine the feasibility of the technology for vegetation mapping and landscape analyses of ecosystem service metrics.

1. Collect 2 cm GSD RGB and NIR imagery of a 1 km² area.
2. Create georeferenced orthomosaic and DSM raster datasets
3. Object-Based Image Analysis
 - Species composition and ecosystem service metrics
 - Land-water interface
 - Dominant species classification
 - Plant height
 - Productivity (NDVI)



Aerial Imagery: Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA), 2008

Project location in Terrebonne Parish, Louisiana. Coastwide Reference Monitoring System (CRMS) site in Cyan, Flight Blocks in yellow, GCPs are white crosses.

Fieldwork

Trimble UX5 Aerial Imaging Rover



Sony 1α-5100 with RGB sensor



Sony NEX-5r with NIR sensor



HARDWARE

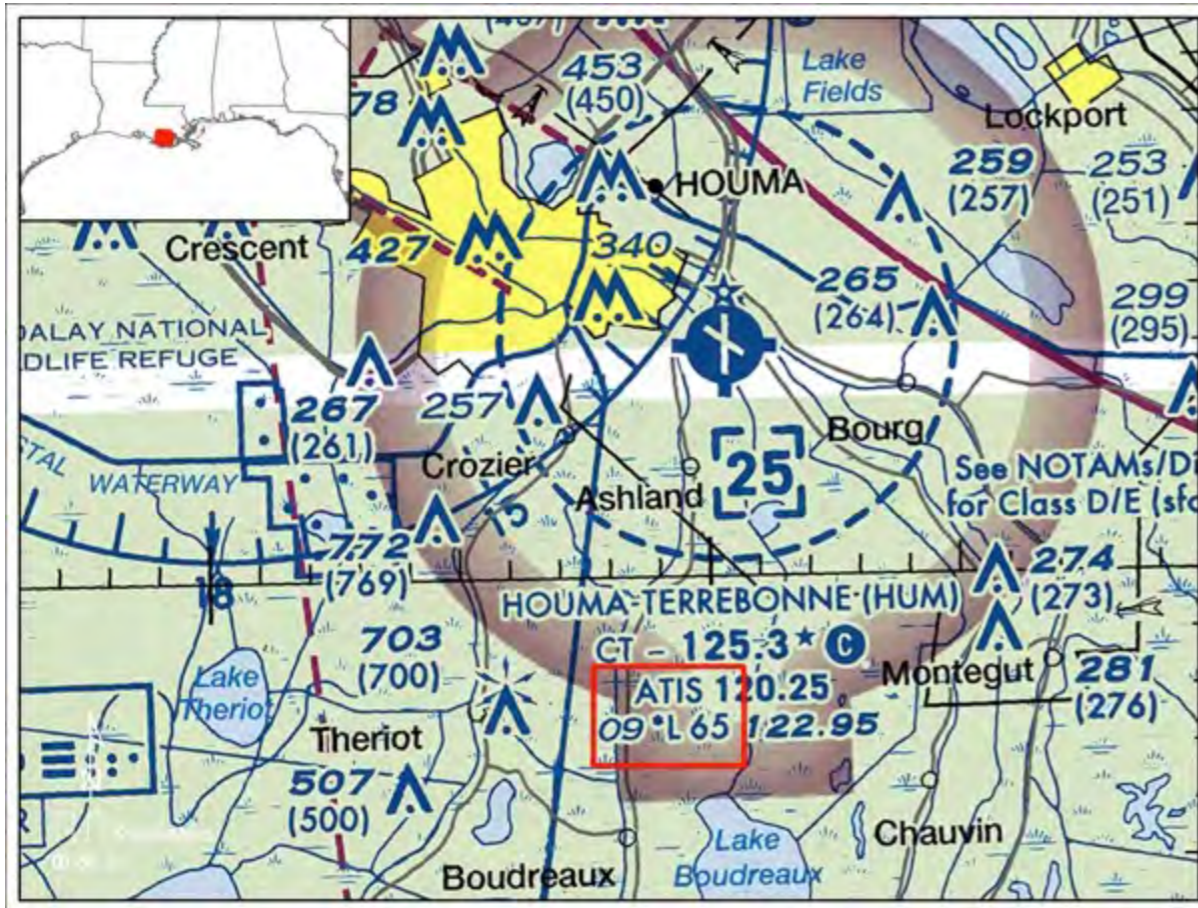
Type	Fixed wing
Weight	2.5 kg (5.51 lb)
Wingspan	1 m (3.28 ft)
Wing area	34 dm

OPERATION

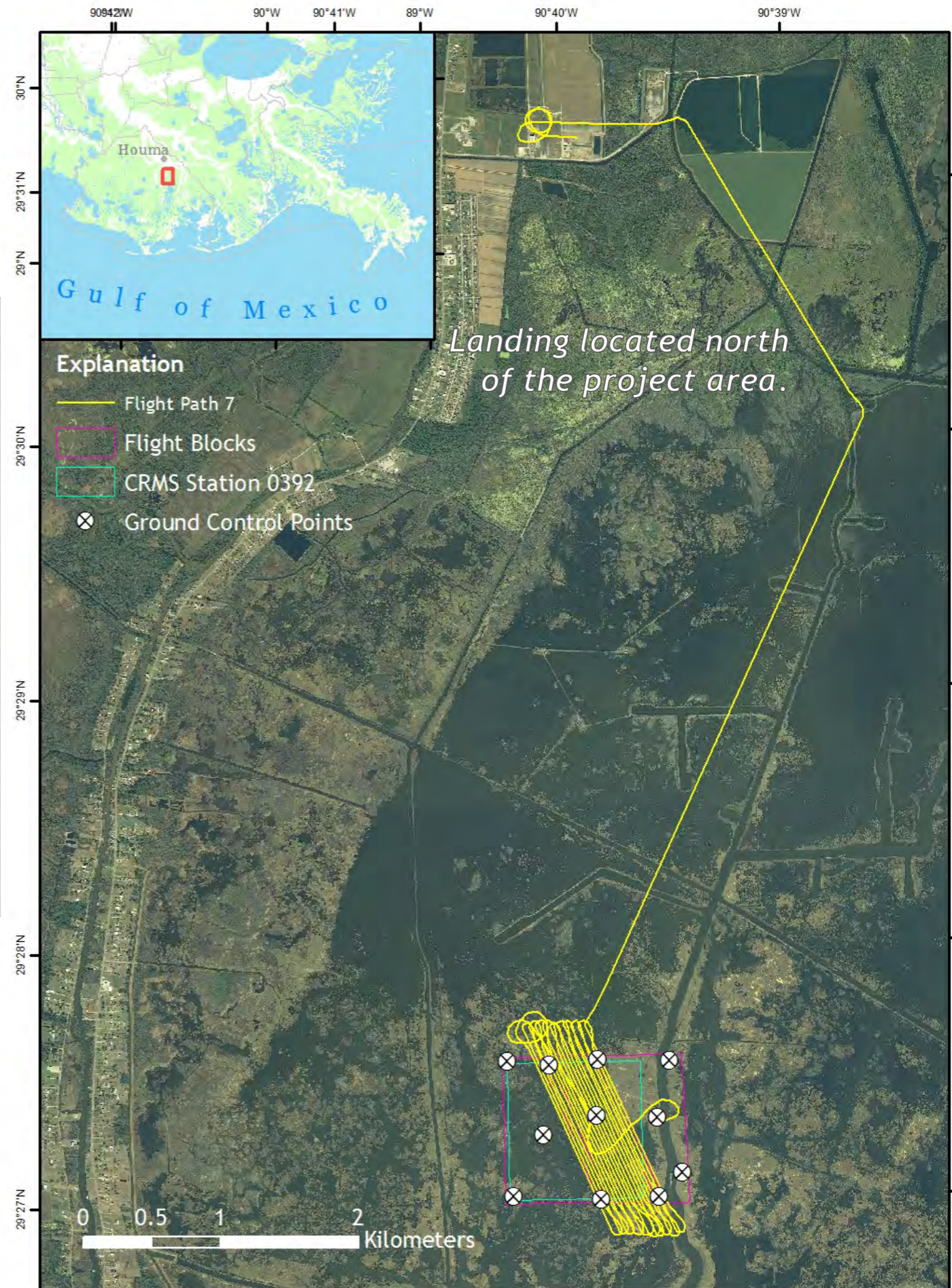
Endurance ¹	50 minutes
Range ¹	60 km (37.28 mi)
Cruise speed	80 kmh (50 mph)
Maximum ceiling ²	5000 m (16,404 ft)

3 Flight Plans

Sectional Aeronautical Raster Chart with project boundaries shown in red.



FAA Part 107
compliant operations
(DO NOT UNDERESTIMATE!)




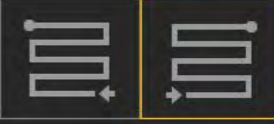
Flight Plan Software

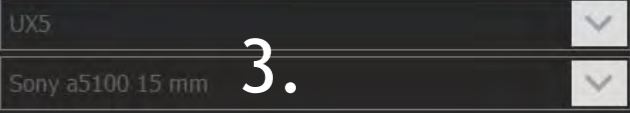
Aerial Imaging V2.2.05.0003

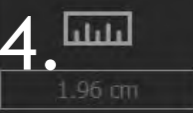
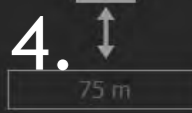
Trimble Access Aerial Imaging - V2.2.05.0003



TPCG Veg Mapping - CRMS*



1. 

2. 

3. 

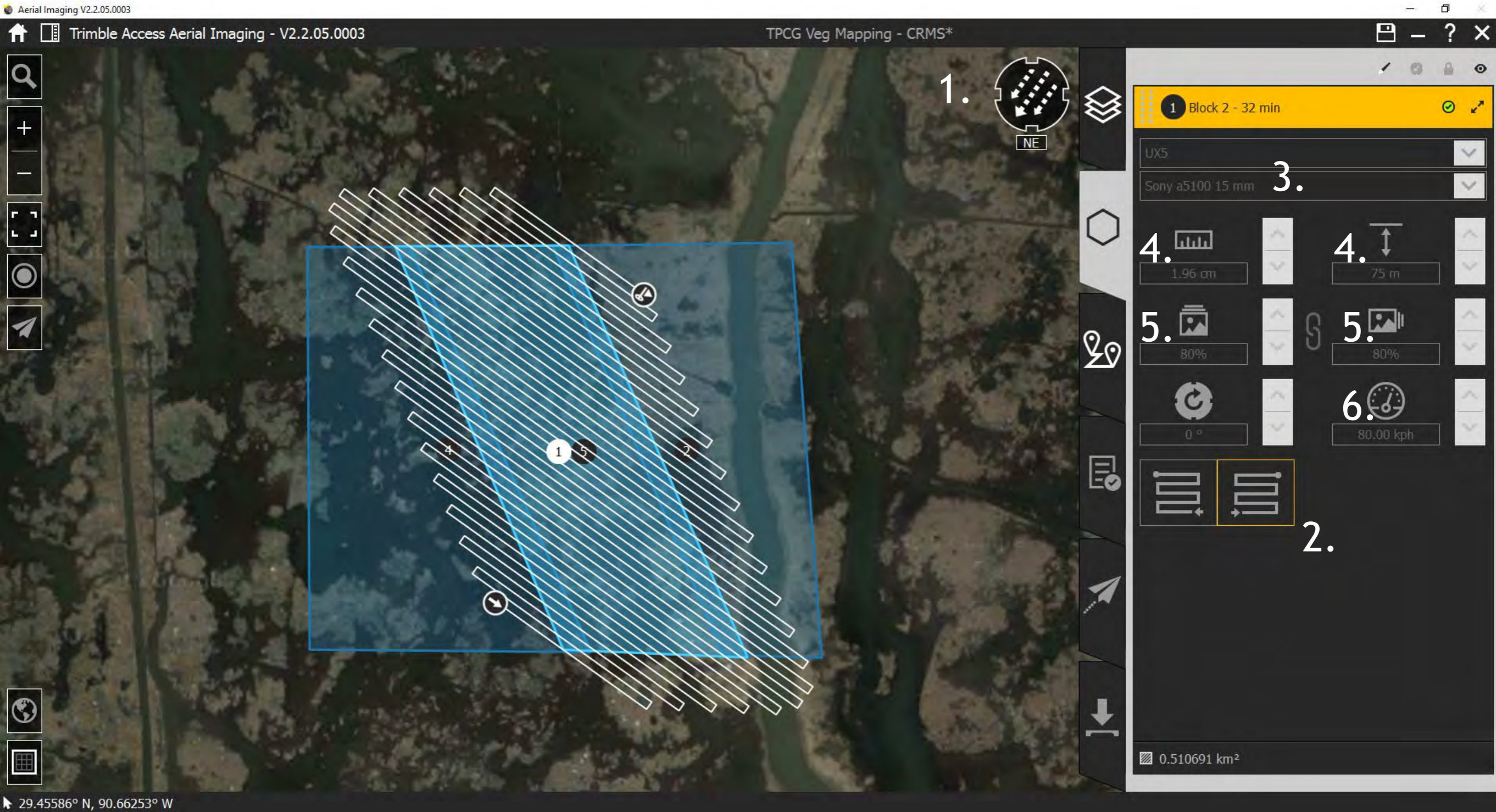
4.  1.96 cm  75 m

5.  80%  80%

6.  0°  80.00 kph

0.510691 km²

29.45586° N, 90.66253° W



The screenshot displays the Trimble Access Aerial Imaging software interface. The main window shows an aerial map with a blue flight plan overlay consisting of parallel lines. A central point is marked with a '1'. The right-hand control panel is organized into sections: a yellow header for 'Block 2 - 32 min', a camera selection section (labeled '3.') showing 'UX5' and 'Sony a5100 15 mm', and a flight parameters section (labeled '2.') with six adjustable settings: 1.96 cm (labeled '4.'), 75 m (labeled '4.'), 80% (labeled '5.'), 80% (labeled '5.'), 0°, and 80.00 kph (labeled '6.'). A mission list icon (labeled '2.') is also visible. The bottom status bar shows a total area of 0.510691 km² and coordinates 29.45586° N, 90.66253° W.



Aerial Imagery: Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA), 2008

Ground Control Points





Take Off

Control Station

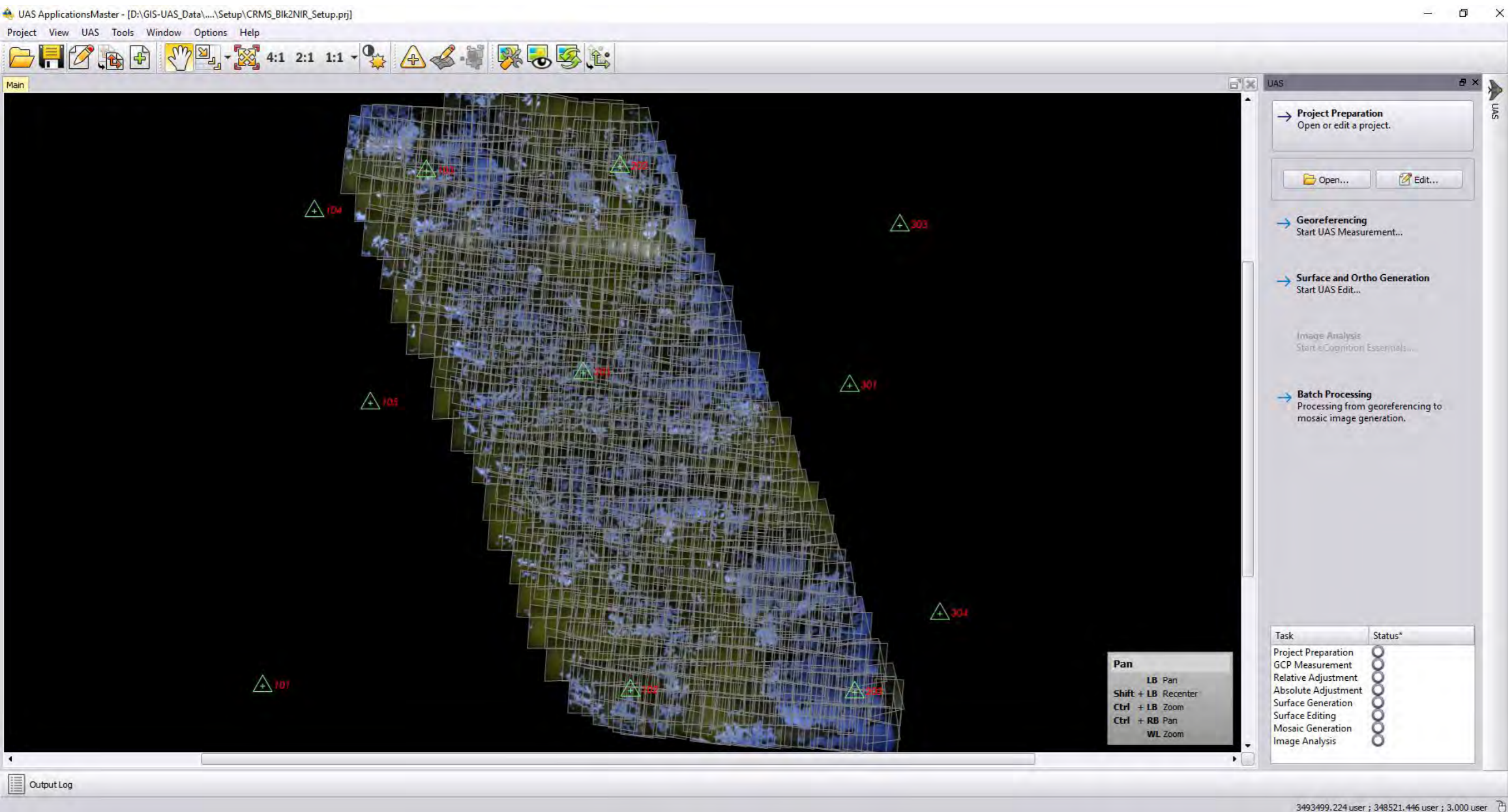


Chase home



Belly land

Post-Processing: Trimble UAS Master



*A screenshot of the Photogrammetry software Trimble UAS Master showing the wireframes of the raw NIR imagery, Ground Control Points, and orthomosaic overview.
Over 1000 images per flight!*

Post-Processing: Trimble UAS Master

The screenshot displays the Trimble UAS Master software interface. The main window shows a multi-aerial view of a landscape with a central image labeled 'Image 7112'. A blue diamond-shaped region is overlaid on the image, indicating the location of a ground control point (GCP) 301. The interface includes a menu bar (File, Edit, View, Window, Options, Help), a toolbar, and several panels:

- Points Panel:** Contains a 'Point List' table and 'Point Details' for GCP 301.
- Block MultiAerial Panel:** Shows a sequence of images (6968, 7020, 7021, 7022, 7054, 7055, 7056, 7112, 7113, 7114, 7139, 7140, 7141) and a 'Mode' dropdown set to 'Retain current image election'.
- UAS Panel:** Contains a list of tasks and their status.
- Point Image Points Table:** A table listing image points for GCP 301 across various images.

ID	Type	Predictions	Links	StripRefs
puDL1C0	TP	15	7 (0) 2	
304	HV	18	6 (0) 4	
303	HV	14	8 (0) 3	
301	HV	13	6 (1) 3	
203	HV	20	10 (0) 5	
202	HV	10	8 (0) 4	
201	HV	0	0 (0) 0	
105	HV	0	0 (0) 0	
104	HV	0	0 (0) 0	
103	HV	0	0 (0) 0	

General	Value
Identification	301
Type	HV
Activation	<input checked="" type="checkbox"/> True
Description	GCP - NAD83 - US State Plane 1983 - Louisiana South 1702 - ...
Deviations	[Standard, Standard]
Position	[user]
Coordinates	[3494856.025, 347974.461, -46.163]
Residuals	[0, 0, 0]
StdDevs	[0, 0, 0]
Measurements	
Predicted	13
Measured	6

ID Photo	x [mm]	y [mm]	vrx [um]	Mode	Block	Elim
<input type="checkbox"/> 7113	-3.31768	-2.22596	0.00000	LSM	*	-
<input checked="" type="checkbox"/> 7112	1.27699	-3.44772	0.00000	LSM	*	-
<input checked="" type="checkbox"/> 7055	0.05752	-0.38760	0.00000	LSM	*	-
<input checked="" type="checkbox"/> 7054	5.69307	1.28131	0.00000	LSM	*	-
<input checked="" type="checkbox"/> 7022	-0.53442	7.49281	0.00000	LSM	*	-
<input checked="" type="checkbox"/> 7021	3.11702	5.23702	0.00000	LSM	*	-

Task	Status*
Project Preparation	<input checked="" type="checkbox"/>
GCP Measurement	<input checked="" type="checkbox"/>
Relative Adjustment	<input type="checkbox"/>
Absolute Adjustment	<input type="checkbox"/>
Surface Generation	<input type="checkbox"/>
Surface Editing	<input type="checkbox"/>
Mosaic Generation	<input type="checkbox"/>
Image Analysis	<input type="checkbox"/>

A screenshot of the Georeferencing Editor and the GCP/Manual Tie Point Table showing the location of a ground control point 301 in image 7112.

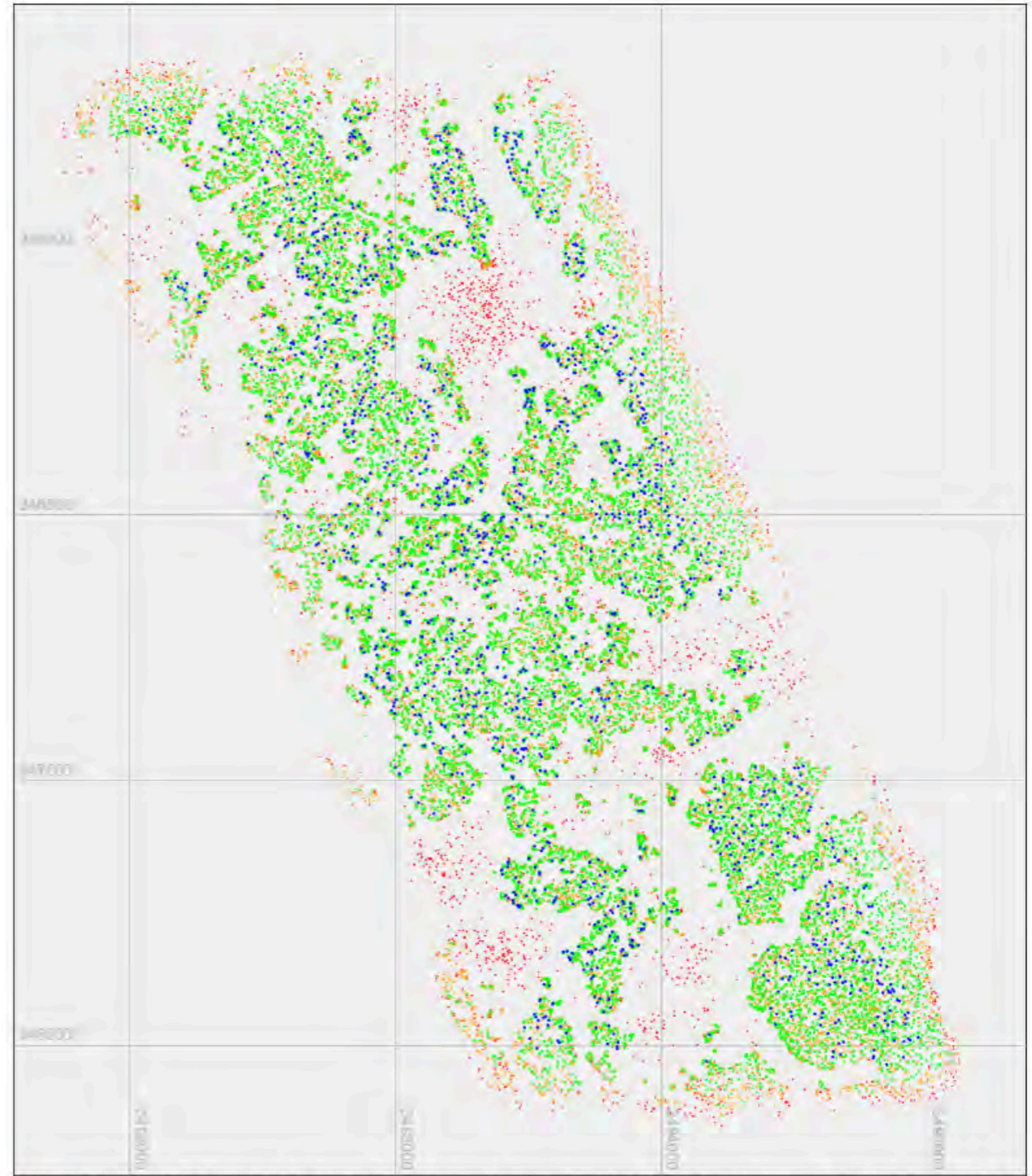
Each GCP is measured (located) within each available picture to orientate the orthomosaics and georeference them to a datum.

Post-Processing: Trimble UAS Master

Ground Control Point Accuracy

ID	X [cm]	Y [cm]	Z [cm]	Total [cm]
102	1.04	-0.15	-3.61	3.76
103	-1.15	0.71	-0.08	1.35
201	-3.33	-2.49	-1.48	4.41
202	3.90	0.16	-3.73	5.40
203	-0.45	1.82	-0.24	1.89
Maximum	3.90	-2.49	-3.73	
Mean	0.00	0.01	-1.83	
Std. Dev.	2.69	1.58	1.76	
RMSE (x,y,z)	2.40	1.42	2.42	
RMSEr	2.79	SQRT(RMSEx ² + RMSEy ²)		
ACCr (95% Confidence Level)	4.83	RMSEr * 1.7308		
ACCz (95% Confidence Level)	4.74	RMSEz * 1.9600		

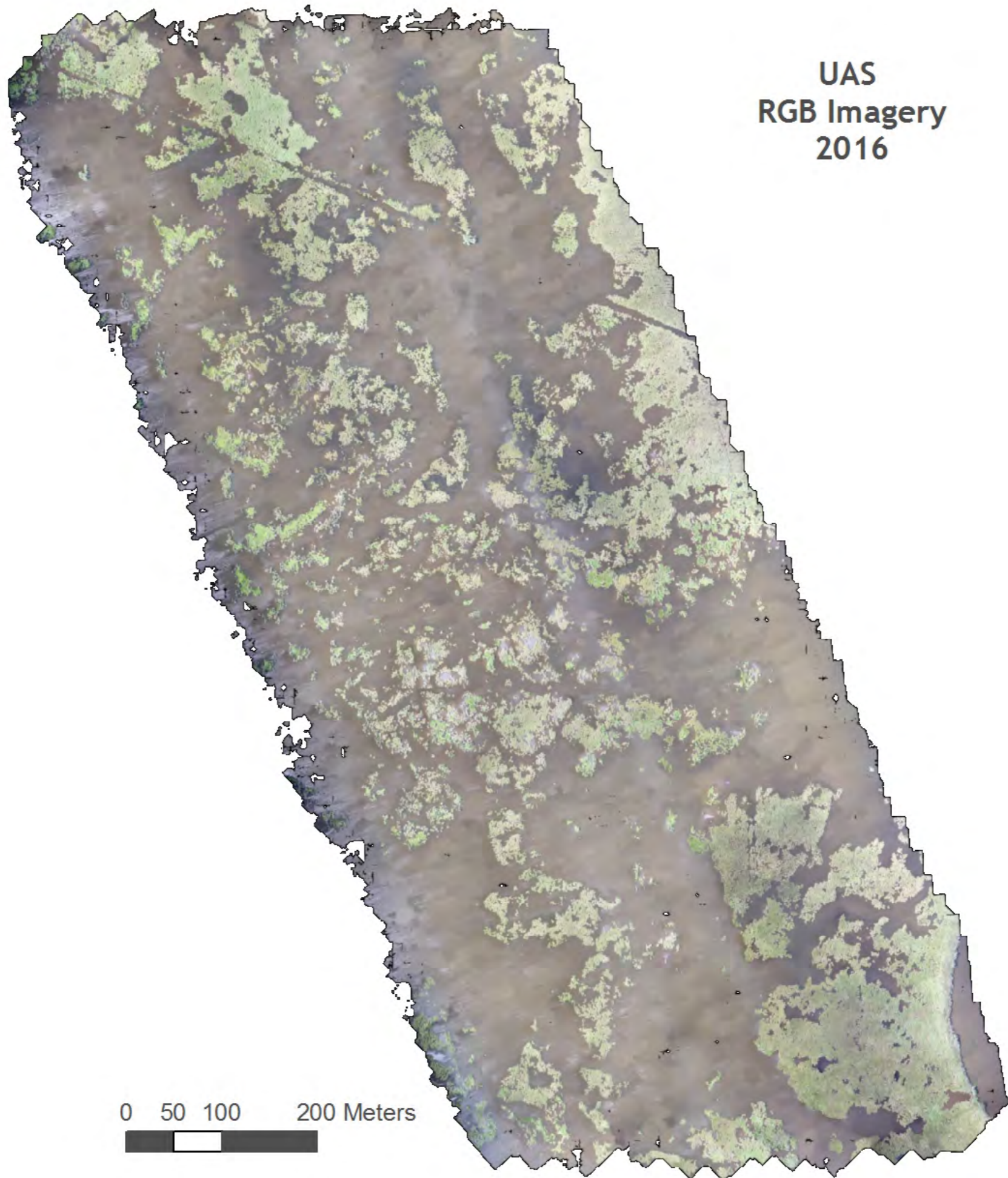
Tie point distribution



Tie point distribution of 37896 points in the project. The point size and colour reflects the number of images containing the point. The area has a planimetric extent of about: 3742 x 4413 [user] and a height range of about: -21 - 23 [user].

- : Point found in (0-2) images.
- : Point found in (3-4) images.
- : Point found in (5-10) images.
- : Point found in (>10) images.

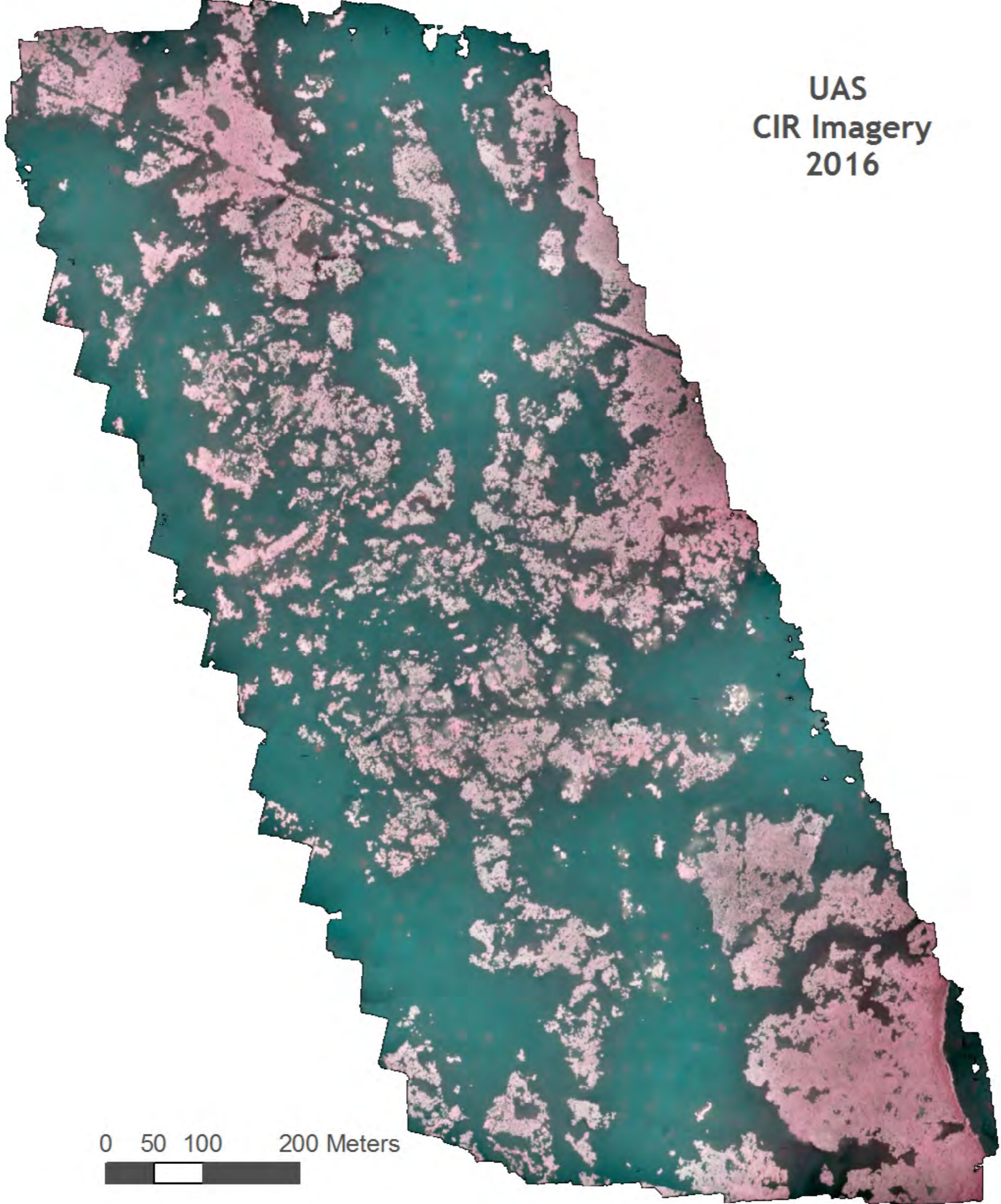
UAS
RGB Imagery
2016




0 50 100 200 Meters



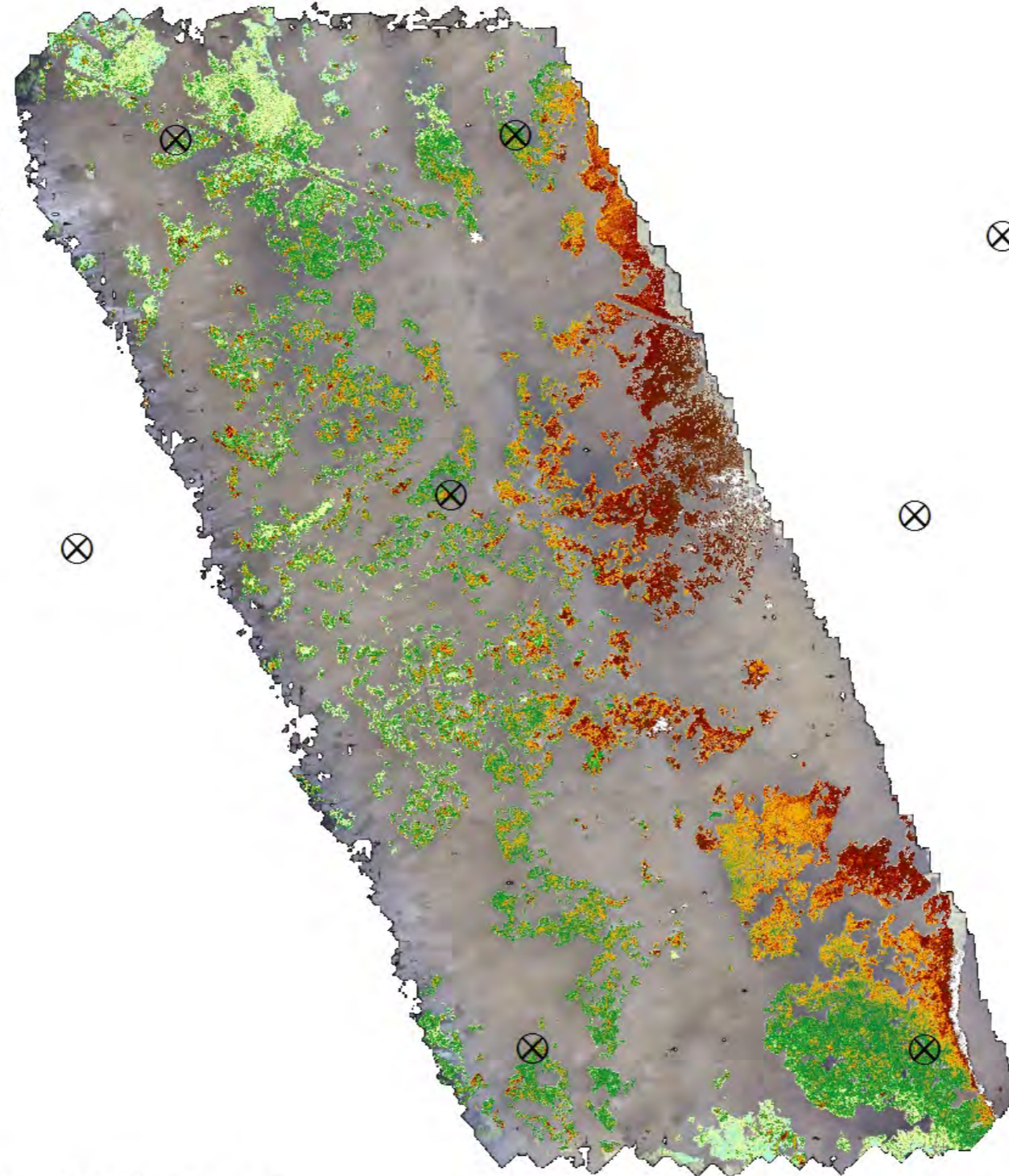
UAS
CIR Imagery
2016



0 50 100 200 Meters

A scale bar is located at the bottom left of the image. It consists of a horizontal line with four segments. The first segment is the longest and is labeled '0'. The second segment is shorter and labeled '50'. The third segment is the same length as the second and labeled '100'. The fourth segment is the longest of the four and labeled '200 Meters'.

Predicted
Digital Surface Model
2016



Marsh grasses
show promise.
Open water is a
challenge.

0 100 200 Meters



Ground Control Points

Elevation (ft) above Geoid 12A

High : 30.462

Low : -1.886

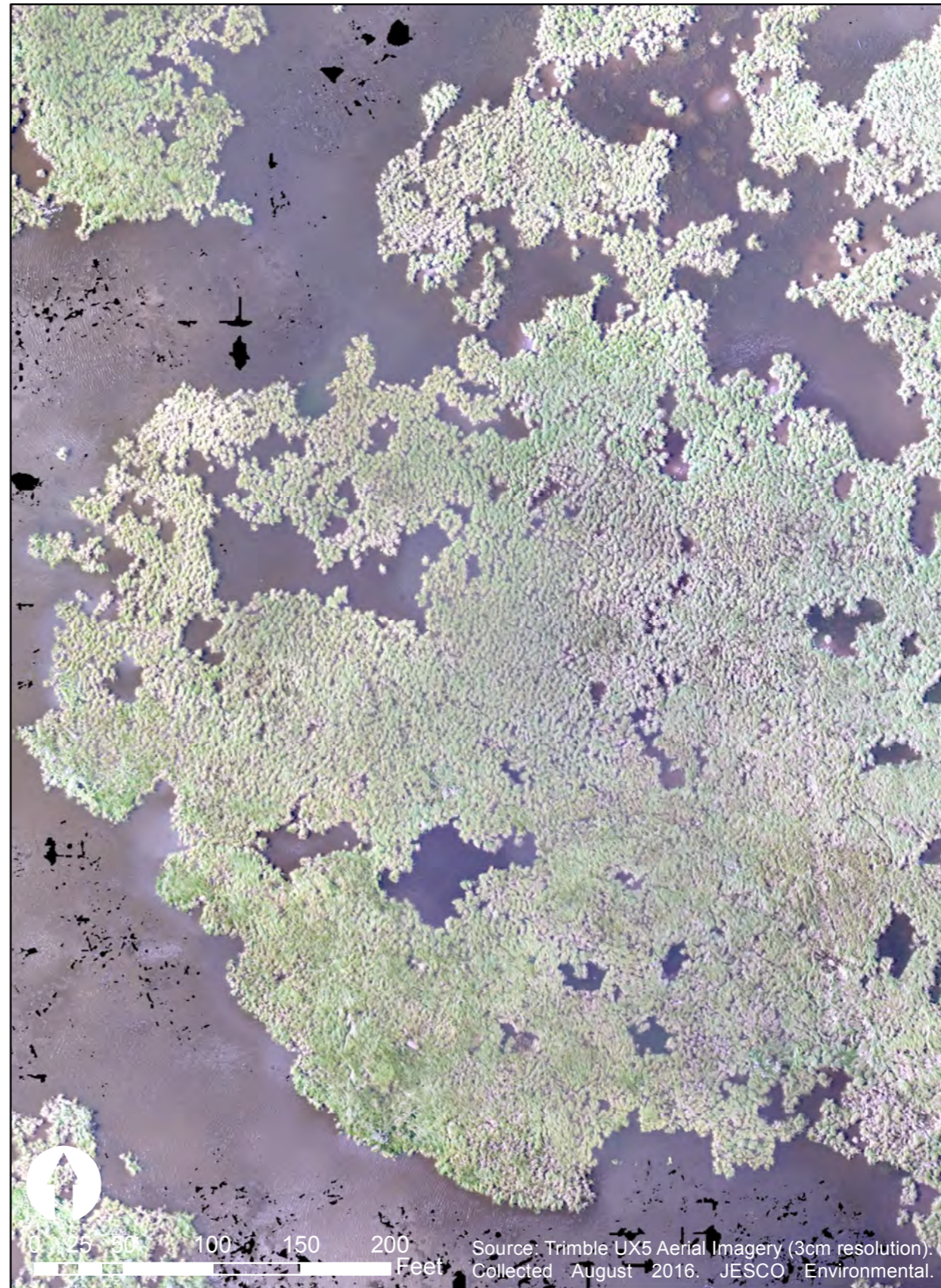
Orthomosaic

Horizontal accuracy
(95% Confidence)
4.83cm

Vertical accuracy
(95% Confidence)
4.74cm



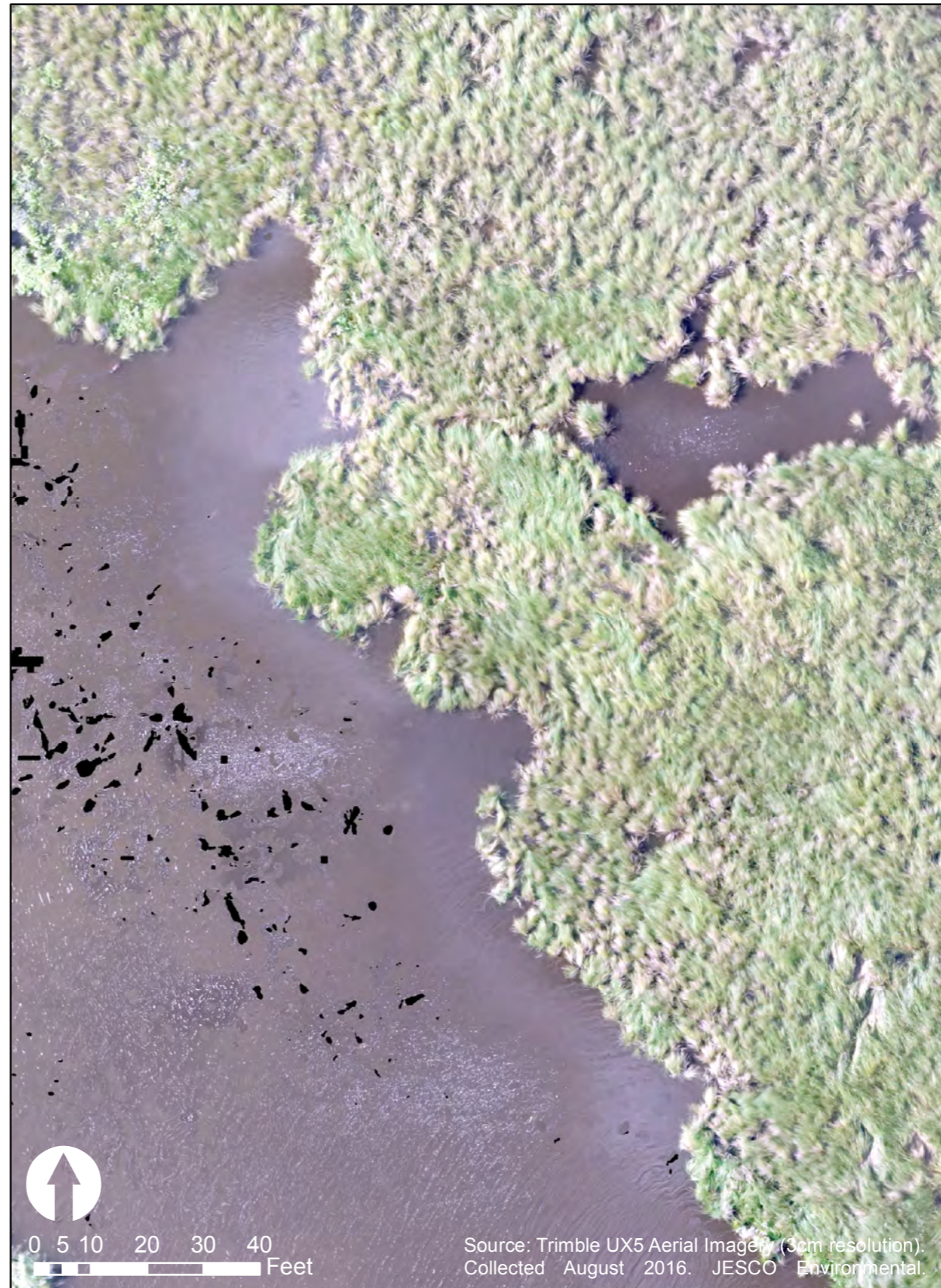
Orthomosaic



Orthomosaic



Orthomosaic



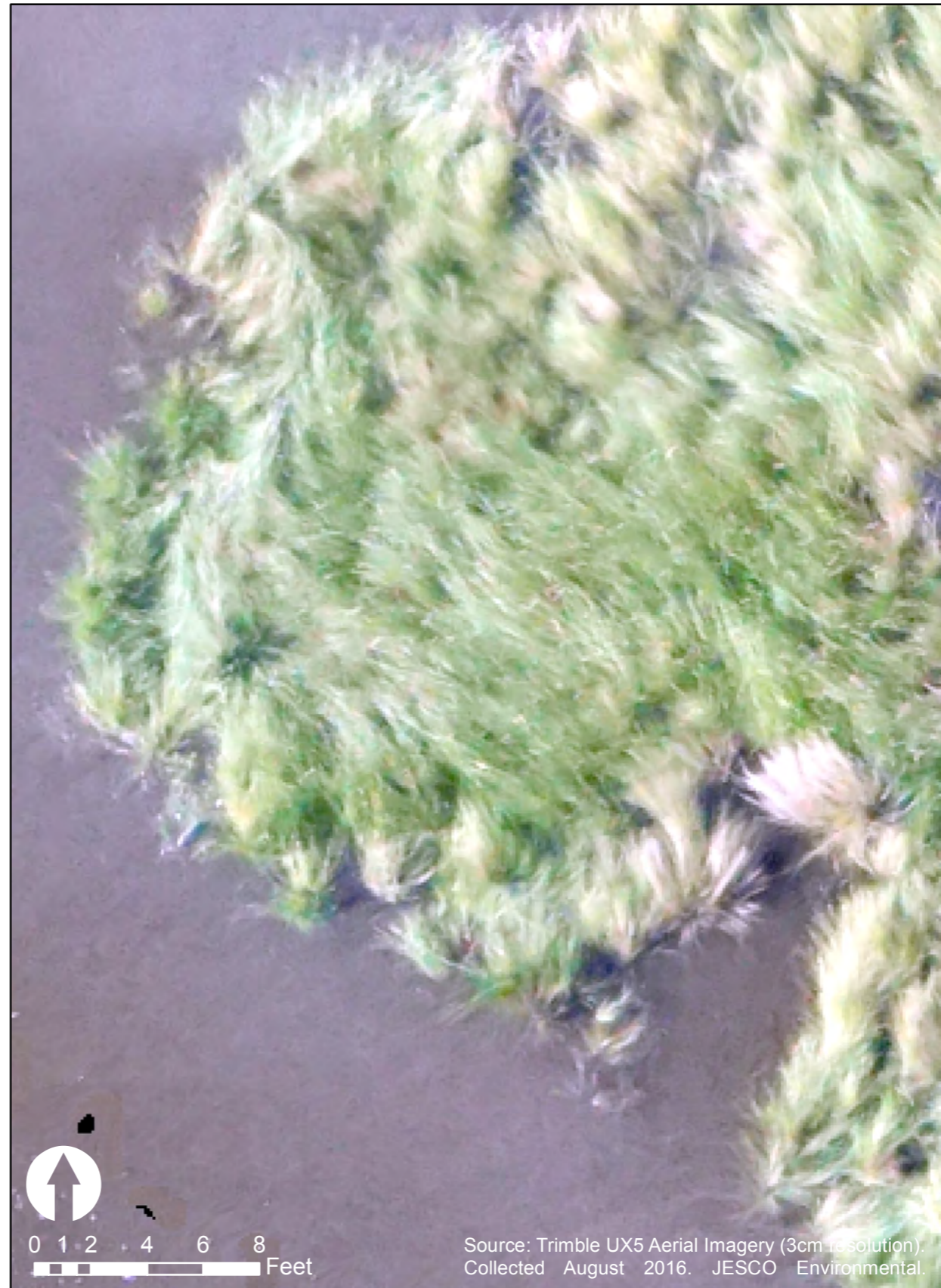
Orthomosaic



0 1 2 4 6 8 Feet

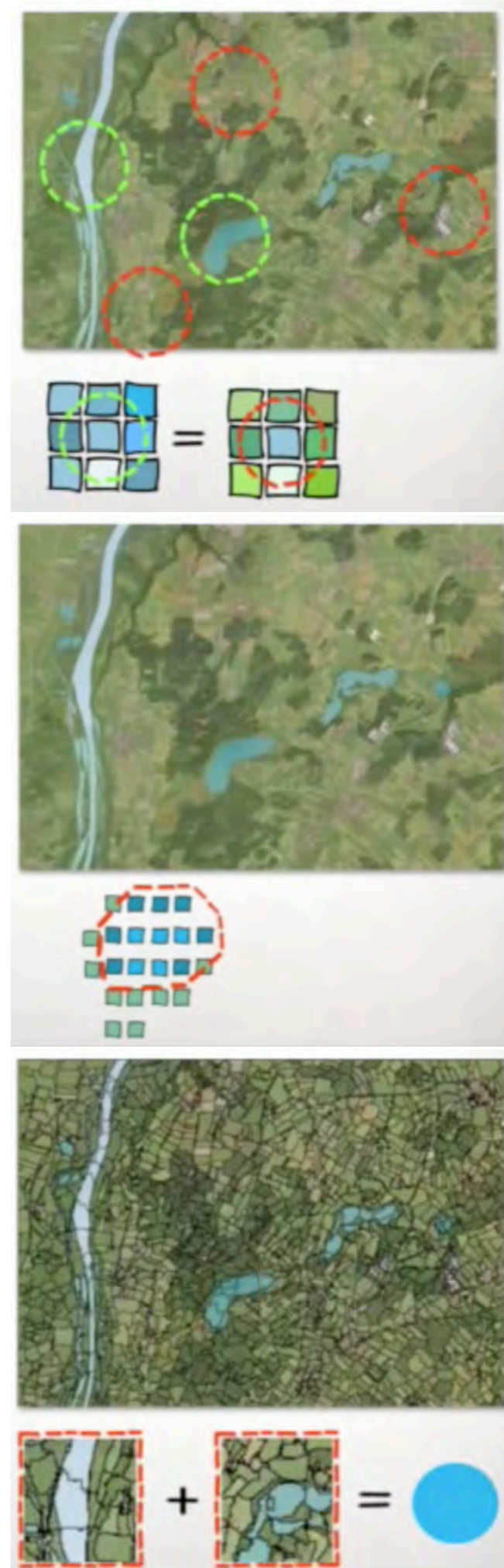
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Orthomosaic

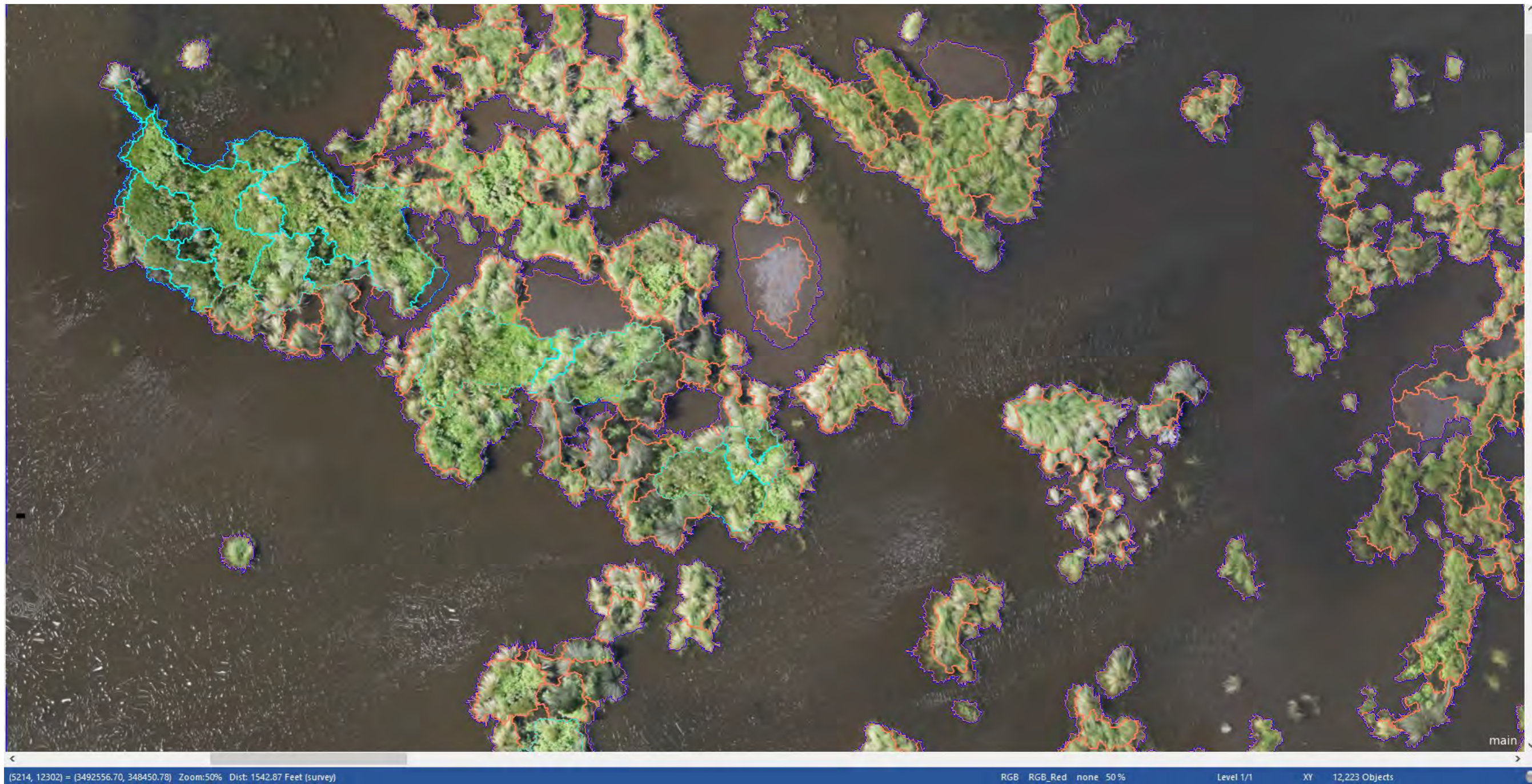


Object Based Image Analysis

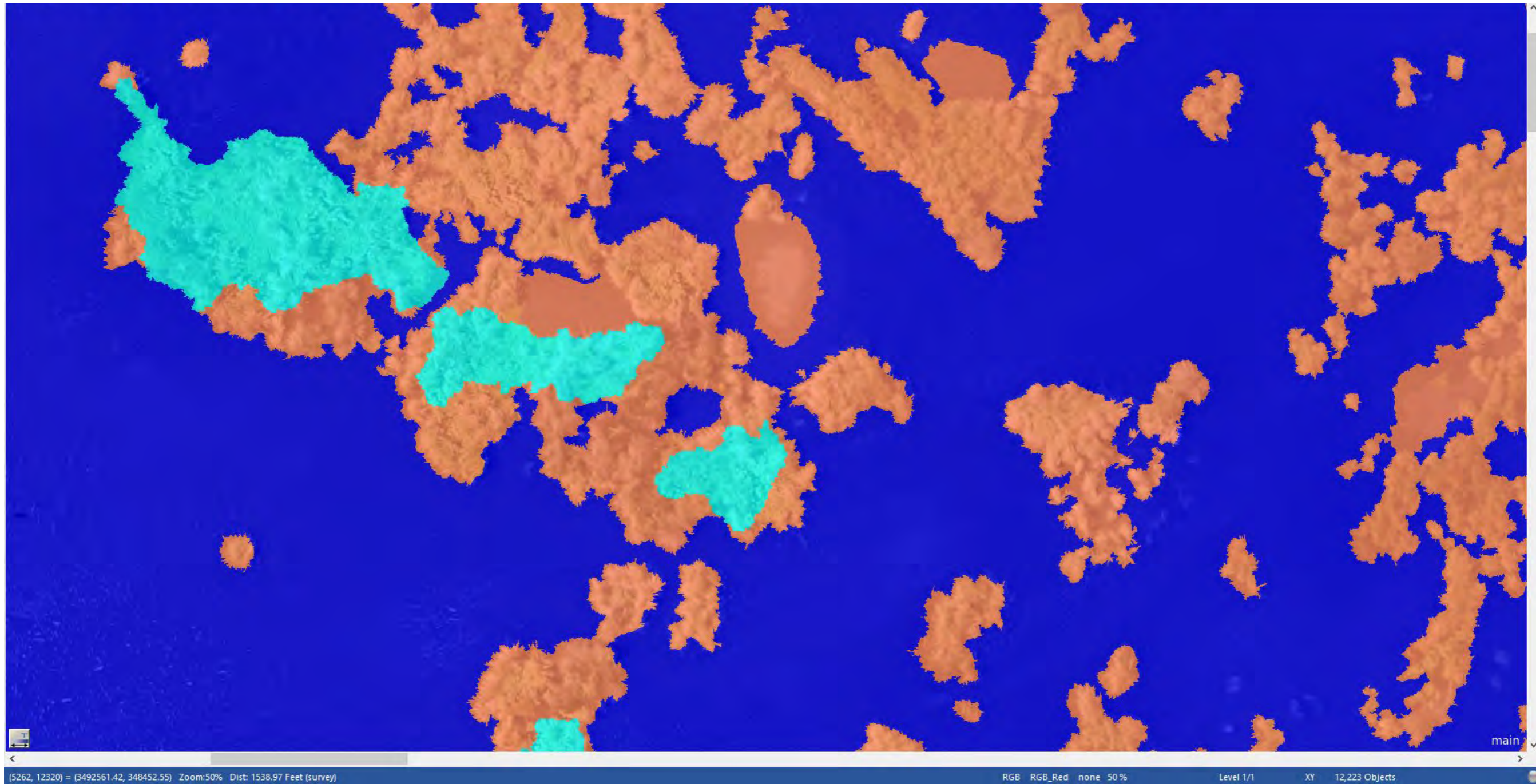
- High resolution datasets - spectral variance increases within target classes
- Spectral separation between the classes is more difficult to specify and classify (Marceau and Hay 1999, Blaschke 2010).
- Similar to human interpretation, OBIA methods address these scaling issues by segmenting or grouping the finer pixels into image objects that are made up of multiple neighboring pixels sharing similar attributes such as spectral signature, texture, shape, and context to other objects (Blaschke, 2009)
- This makes classification easier because we're now working with average values by object (100's to 1000's of pixels) rather than individual 2-3cm pixels
- UAS imagery is commonly analyzed using OBIA classification methods (e.g. Laliberte and Rango 2009, Laliberte and Rango 2011).



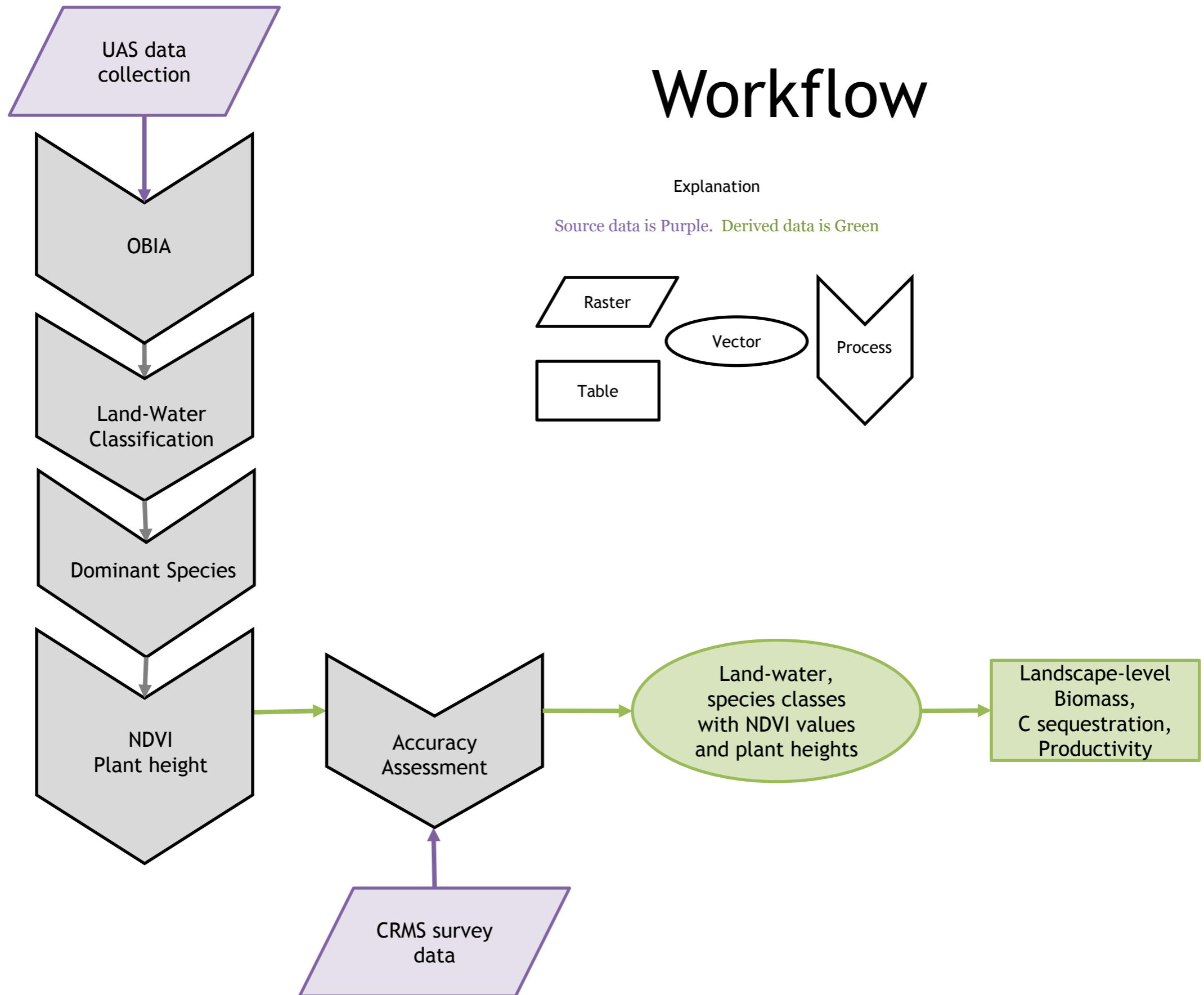
Object Based Image Analysis (multispectral segmentation)



Object Based Image Analysis (multispectral segmentation)



Workflow



Object Based Image Analysis (multispectral segmentation)

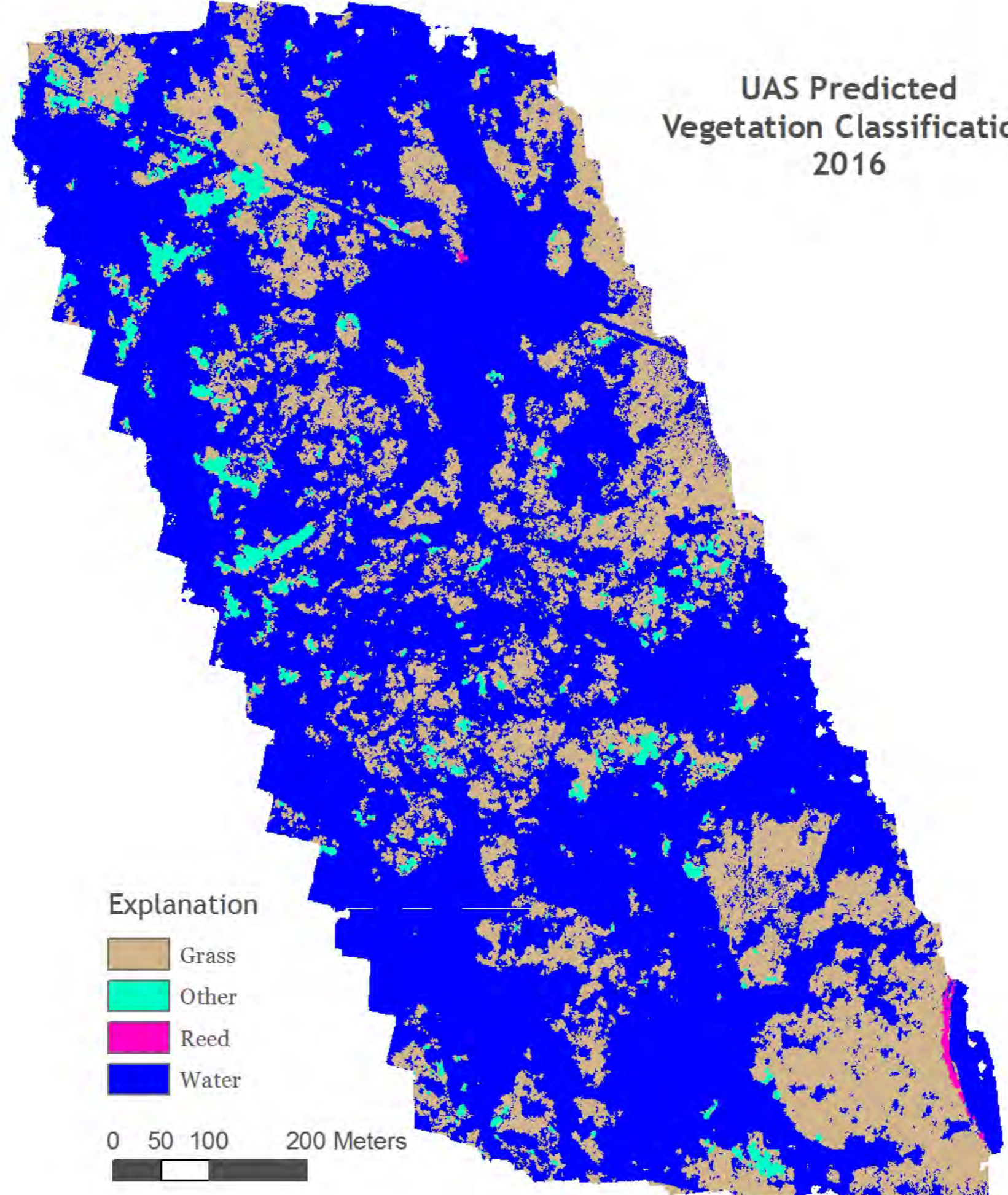
The screenshot displays the CRMS_UAS_Developer software interface. The main window shows a map view of a segmented image with a color-coded classification scheme: blue for water, orange for land, cyan for reeds, and yellow for other vegetation. The map is titled 'main' in the bottom right corner.

The 'Process Tree' panel on the right details the classification workflow:





- CRMS UAS Vegetation Classification**
 - Delete Level
 - delete 'Level 1'
 - Classify Water
 - Segmentation
 - 100 [shape:0.1 compct.:0.5] creating 'Level 1'
 - unclassified with Mean NIR_NIR < 1 at Level 1: No_Data
 - unclassified with Mean NIR_NIR < 90 at Level 1: Water
 - Water at Level 1: merge region
 - Water with Area < 2222 Pxl at Level 1: unclassified
 - unclassified with Rel. border to Water = 1 at Level 1: Water
 - Resegment for Processing
 - Water at Level 1: 250 [shape:0.2 compct.:0.5]
 - Classify Land
 - Blank Slate - Land
 - unclassified at Level 1: merge region
 - Segmentation
 - unclassified at Level 1: 125 [shape:0.5 compct.:0.9]
 - Classify Land
 - Blank Slate - Land
 - unclassified at Level 1: merge region
 - Segmentation
 - unclassified at Level 1: 125 [shape:0.5 compct.:0.9]
 - unclassified at Level 1: spectral difference 8
 - Classify Reeds
 - unclassified with Mean DSM > 5 at Level 1: Potential_Reed
 - Potential_Reed with Imagery Brightness > 90 at Level 1: unclassified
 - [unclassified with Mean diff. to neighbors DSM (0) > 0.5 at Level 1: Potential_Reed]
 - [Potential_Reed with Mean diff. to neighbors DSM (0) > 2 at Level 1: unclassified]
 - Potential_Reed with GLCM Dissimilarity NIR_NIR (all dir.) < 10 at Level 1: unclassified
 - Potential_Reed with GLCM Contrast NIR_NIR (all dir.) < 225 at Level 1: unclassified
 - unclassified with Rel. border to Potential_Reed > 0.4 and (Rel. border to Water > 0.4) at Level 1: Potential_Reed
 - unclassified with Rel. border to Potential_Reed > 0.6 at Level 1: Potential_Reed
 - Potential_Reed with Rel. border to unclassified = 1 at Level 1: unclassified
 - Potential_Reed at Level 1: Reed
 - Classify Other
 - [unclassified at Level 1: spectral difference 8]
 - unclassified with NGRDI > 0.055 at Level 1: Potential_Other
 - Potential_Other with GLCM Dissimilarity NIR_NIR (all dir.) < 15 and GLCM Contrast NIR_NIR (all dir.) < 420 at Level 1: unclassified
 - [Potential_Other with GLCM Contrast NIR_NIR (all dir.) < 450 at Level 1: unclassified]
 - Potential_Other, unclassified with Rel. border to Potential_Other > 0.4 and (Rel. border to Water > 0.4) at Level 1: Potential_Other
 - Potential_Other, unclassified with Rel. border to Potential_Other > 0.5 at Level 1: Potential_Other
 - Potential_Other with Rel. border to unclassified = 1 at Level 1: unclassified
 - [Potential_Other at Level 1: merge region]
 - [Potential_Other with GLCM Homogeneity NIR_NIR (all dir.) < 0.08 at Level 1: unclassified]
 - [Potential_Other with GLCM Dissimilarity NIR_NIR (all dir.) < 11 at Level 1: unclassified]
 - Potential_Other at Level 1: Other
 - Classify Grasses
 - unclassified at Level 1: Grass

The bottom status bar shows the current view is 'Main' with a zoom of 8%. The bottom right corner indicates 'Level 1/1', 'XY' coordinates, and '12,223 Objects'.

UAS Predicted Vegetation Classification 2016



Explanation

-  Grass
-  Other
-  Reed
-  Water

0 50 100 200 Meters



Accuracy Assessment

Stratified Random
Sampling by
predicted class

50 Water
50 Grass
20 Other
10 Reed



Error Matrix

Reference Class

Predicted Class

	1) Water	2) Grass	3) Other	4) Reed	Count	Producer's Accuracy
1) Water	49	0	0	0	49	100%
2) Grass	7	35	6	0	48	73%
3) Other	2	2	16	0	20	80%
4) Reed	0	0	2	8	10	80%
Count	58	37	24	8	127	
User's Accuracy	84%	95%	67%	100%		

Overall Accuracy: 85%
Kappa Coefficient: 0.78

Challenges with land-water interface and high resolution imagery



OBIA classified this point as land, but high res imagery shows vegetation extending over water

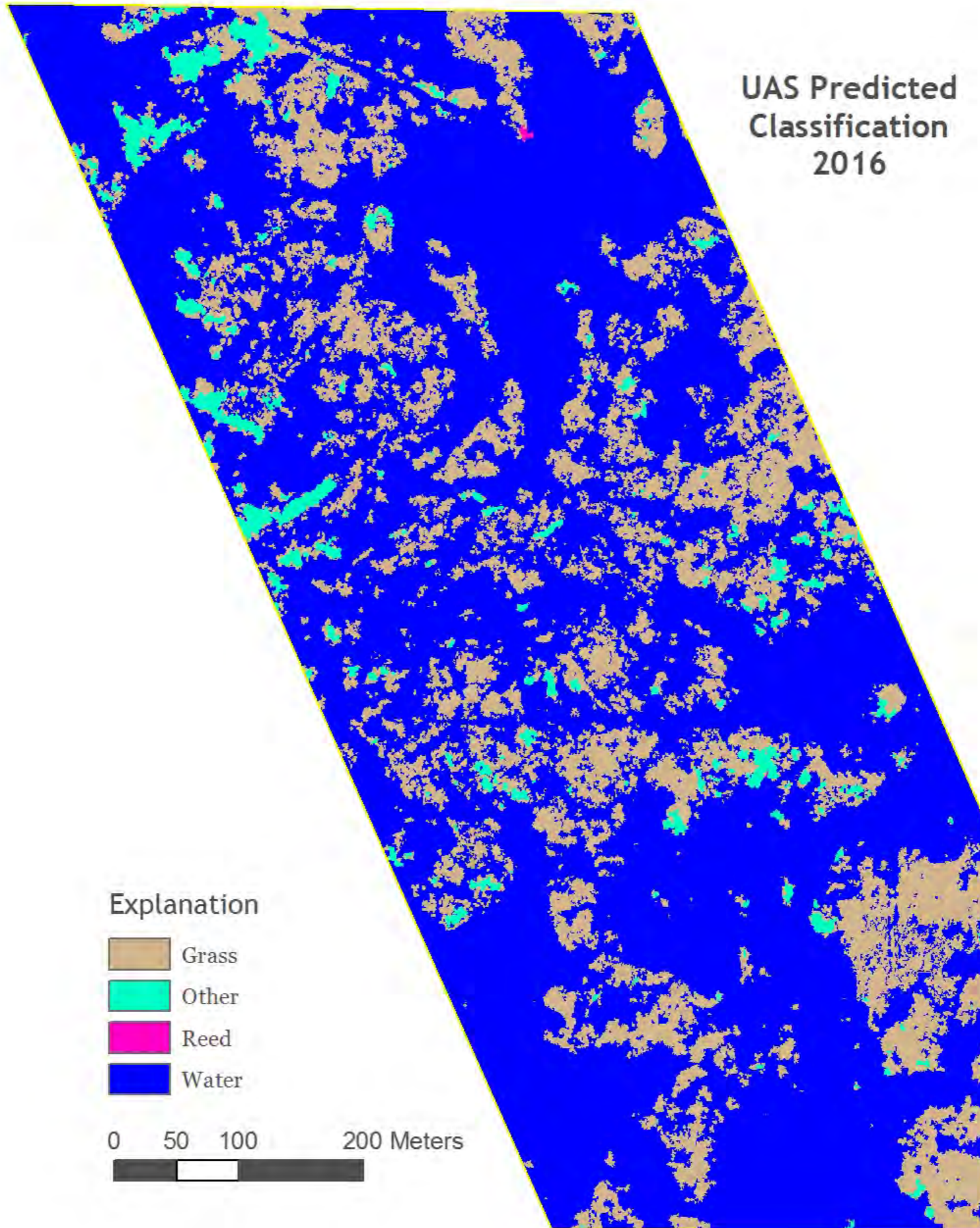
Comparisons
with
CRMS
Data

UAS Predicted
Classification
2016

Explanation

- Grass
- Other
- Reed
- Water

0 50 100 200 Meters

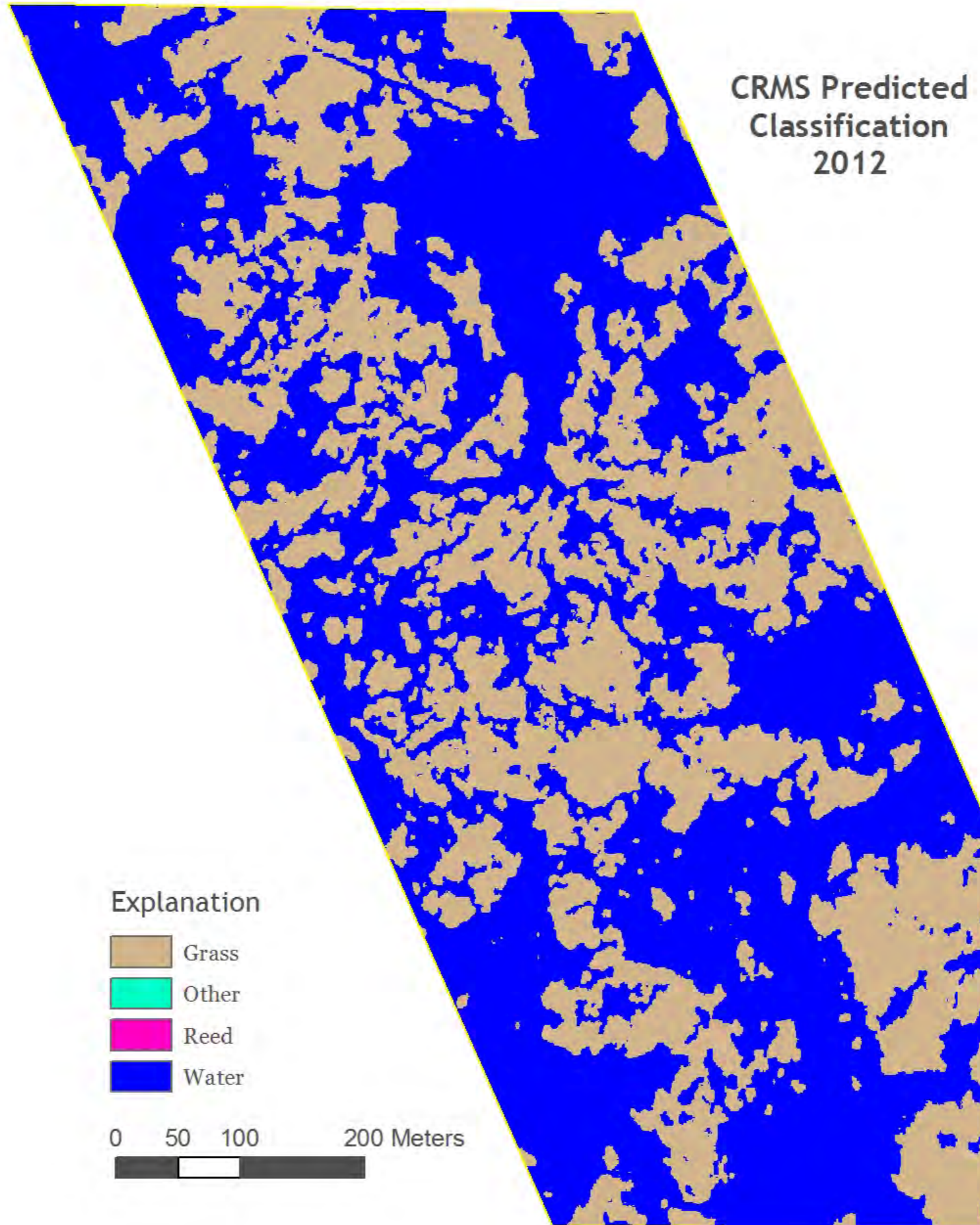


CRMS Predicted
Classification
2012

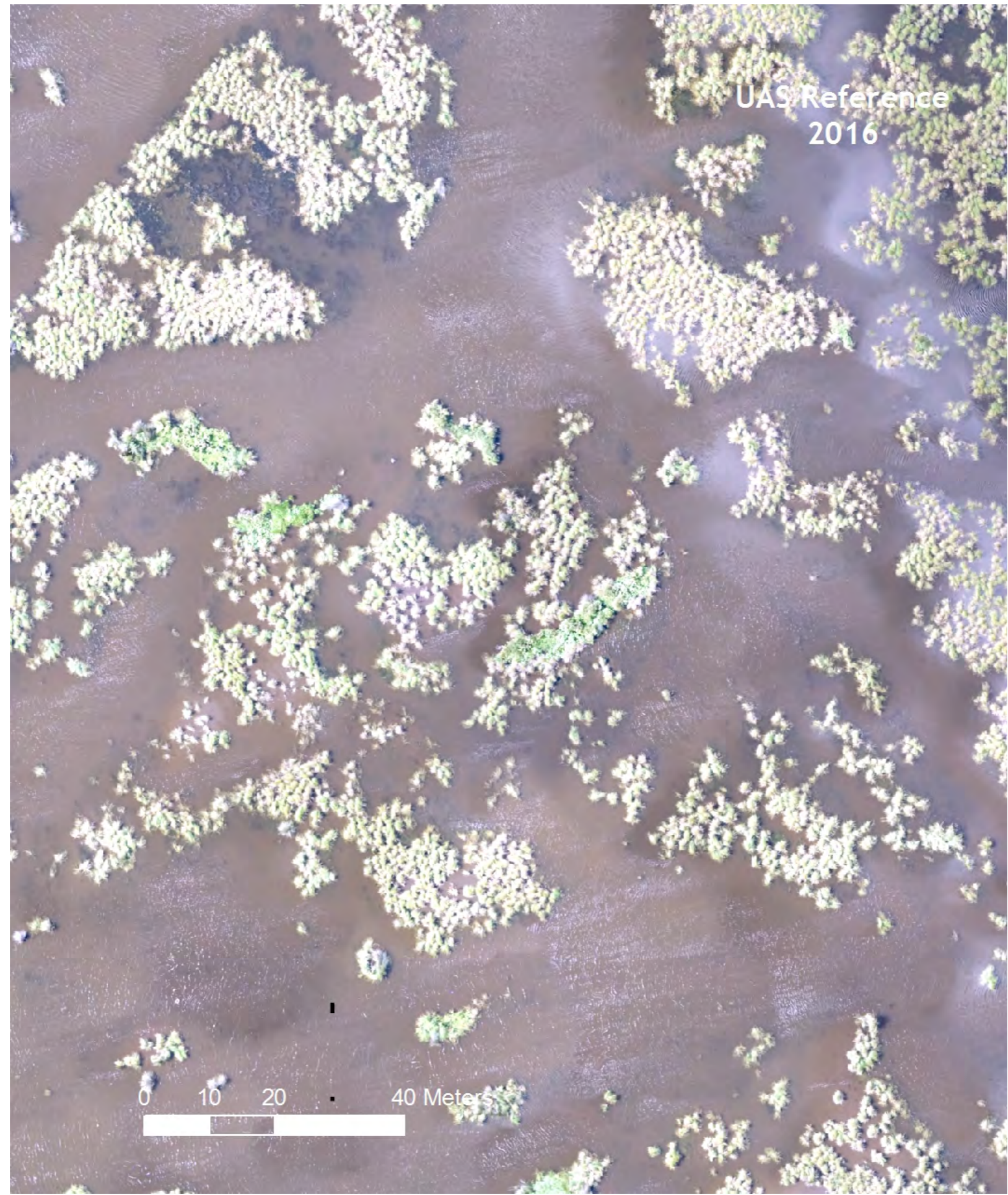
Explanation

- Grass
- Other
- Reed
- Water

0 50 100 200 Meters



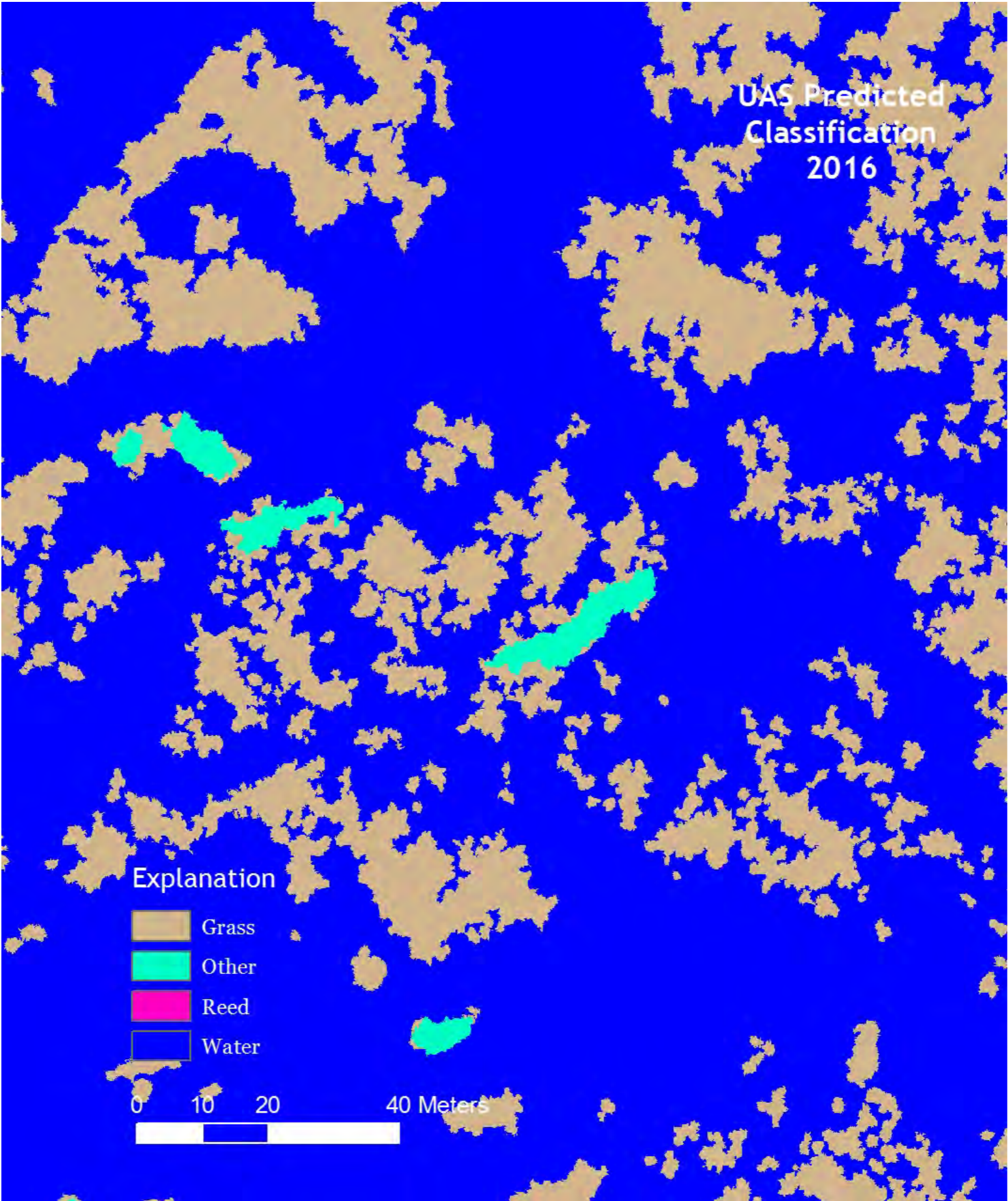
UAS Reference
2016



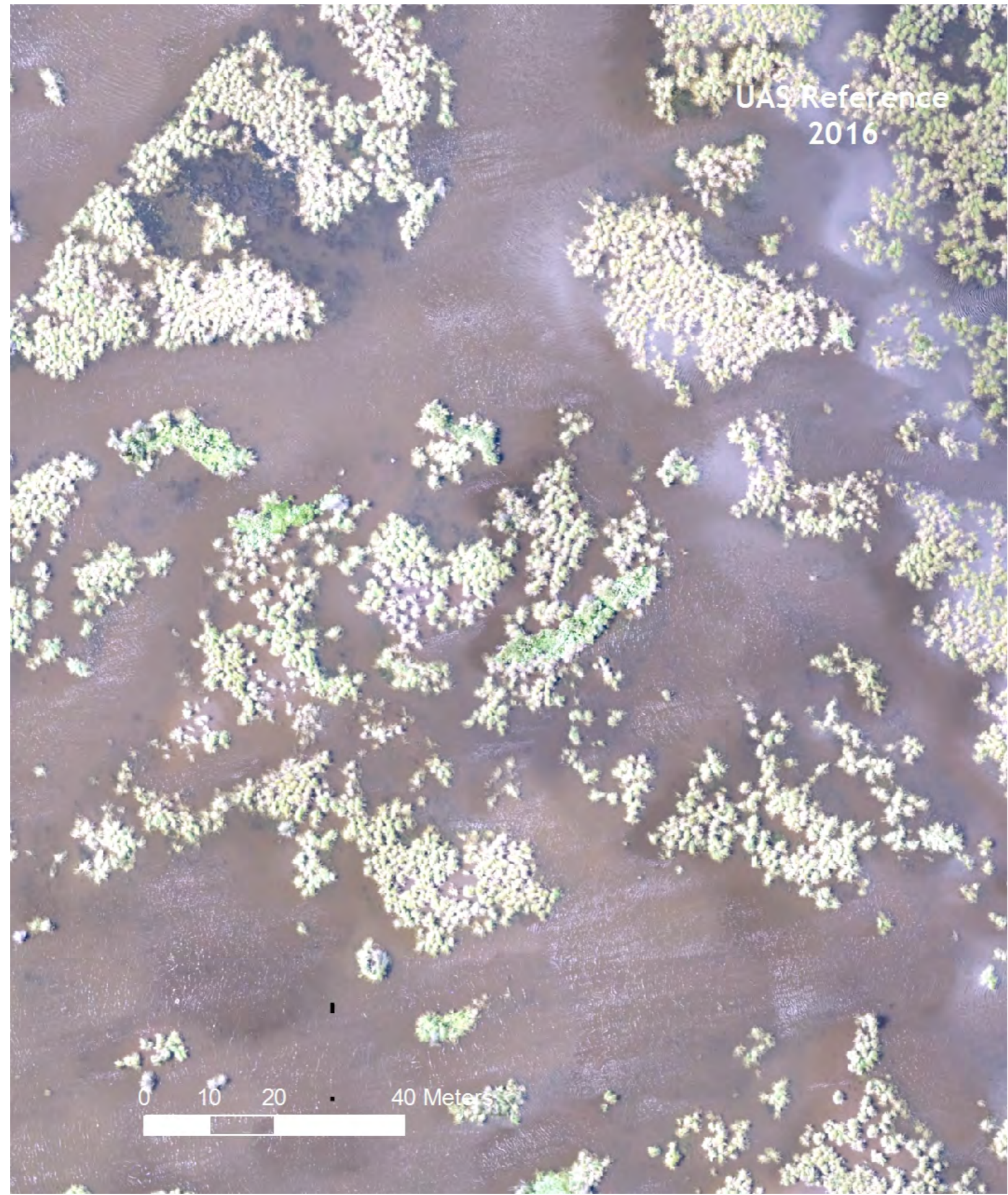
UAS Predicted
Classification
2016

Explanation

- Grass
- Other
- Reed
- Water



UAS Reference
2016

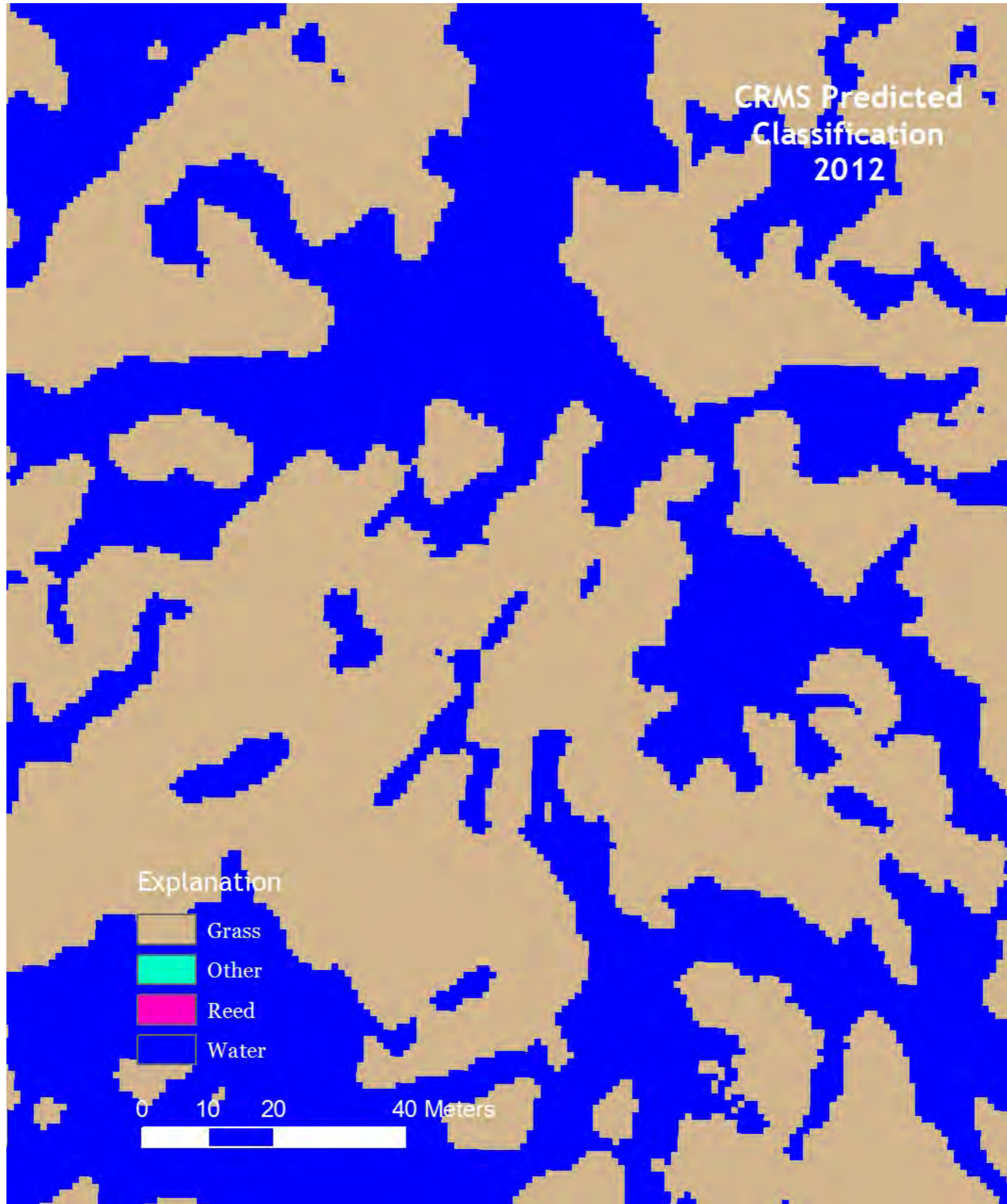


CRMS Predicted
Classification
2012

Explanation

- Grass
- Other
- Reed
- Water

0 10 20 40 Meters



CRMS SPATIAL DATA –

LAND/WATER

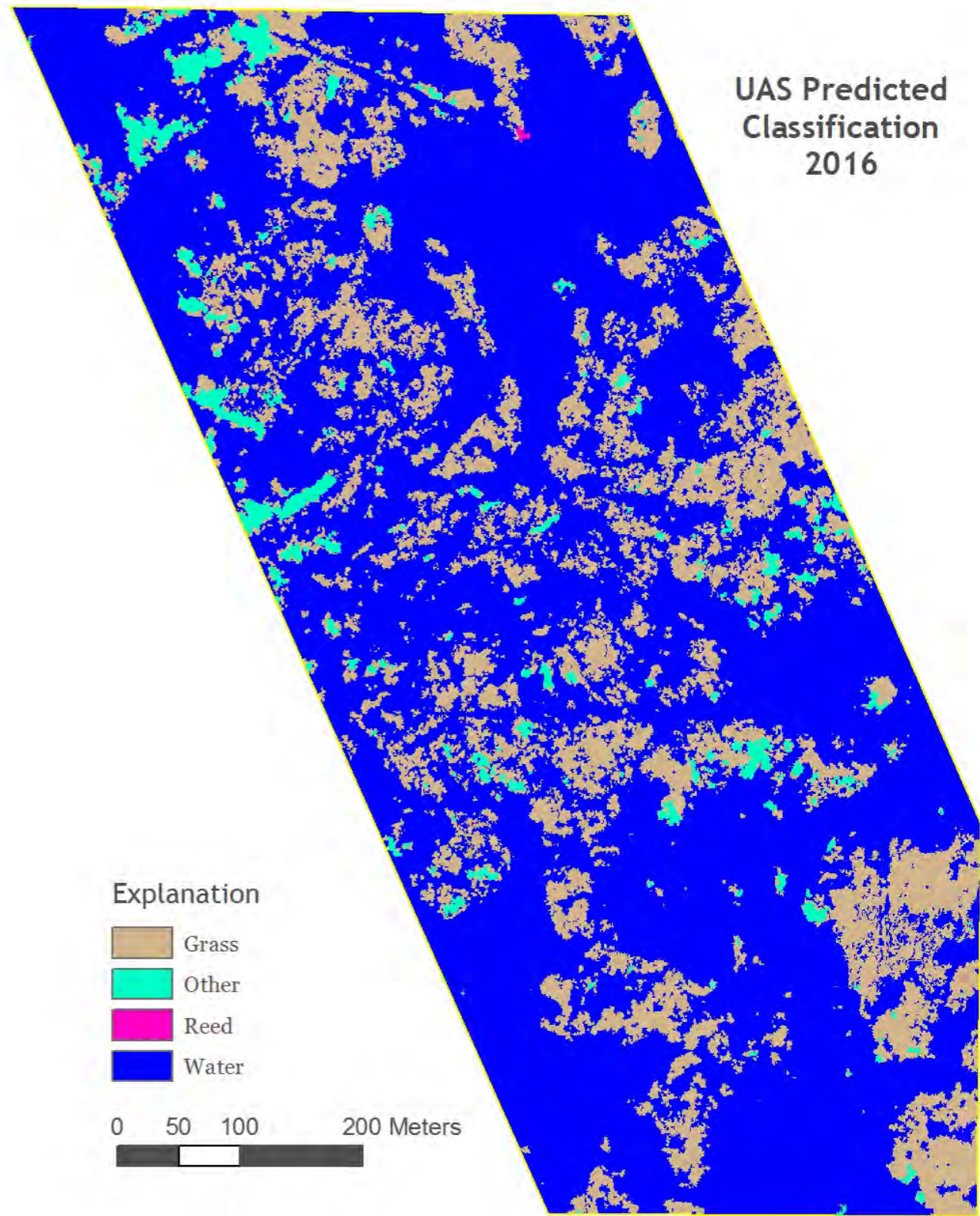
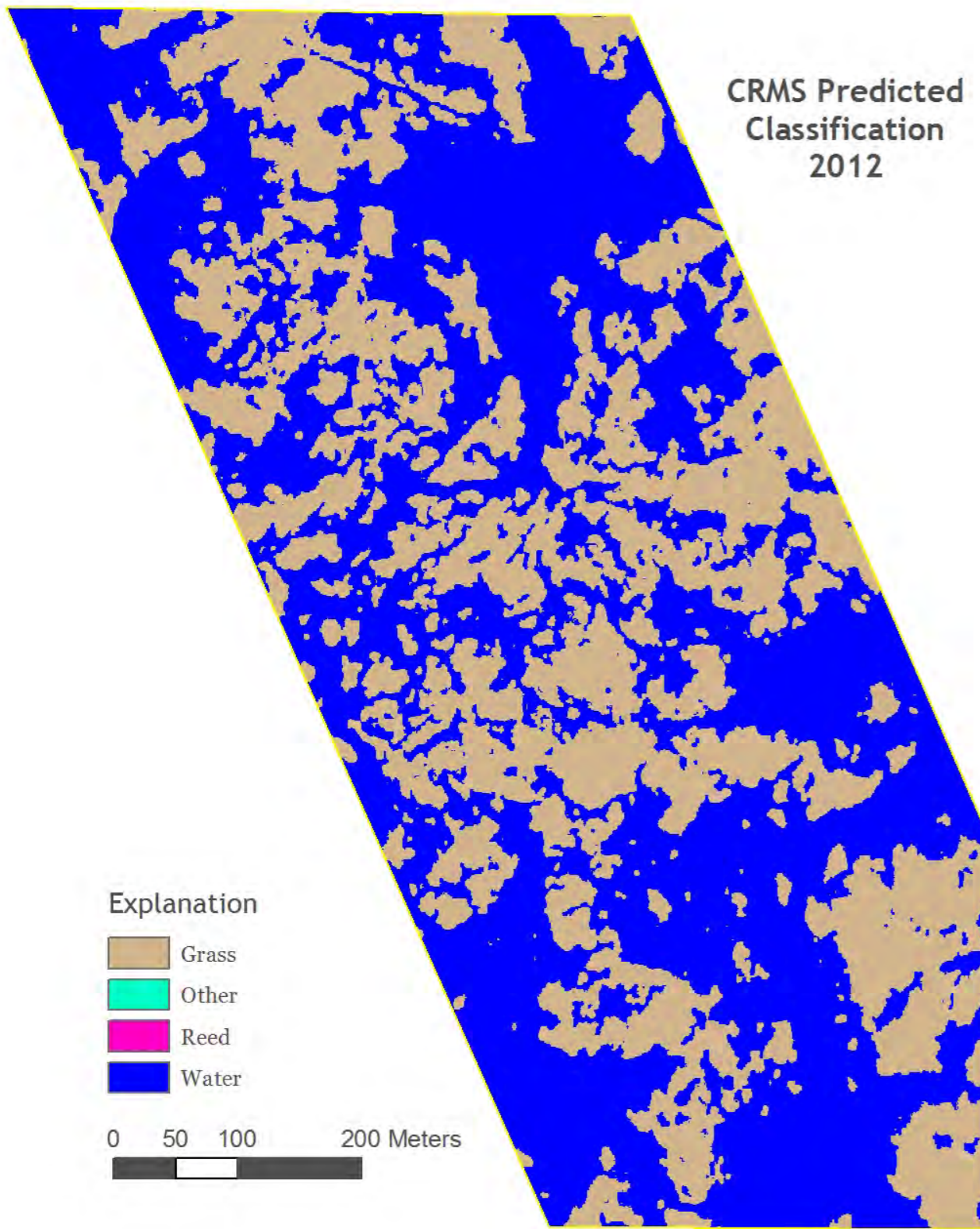
ANALYSIS

Area (sq. km)
Percent

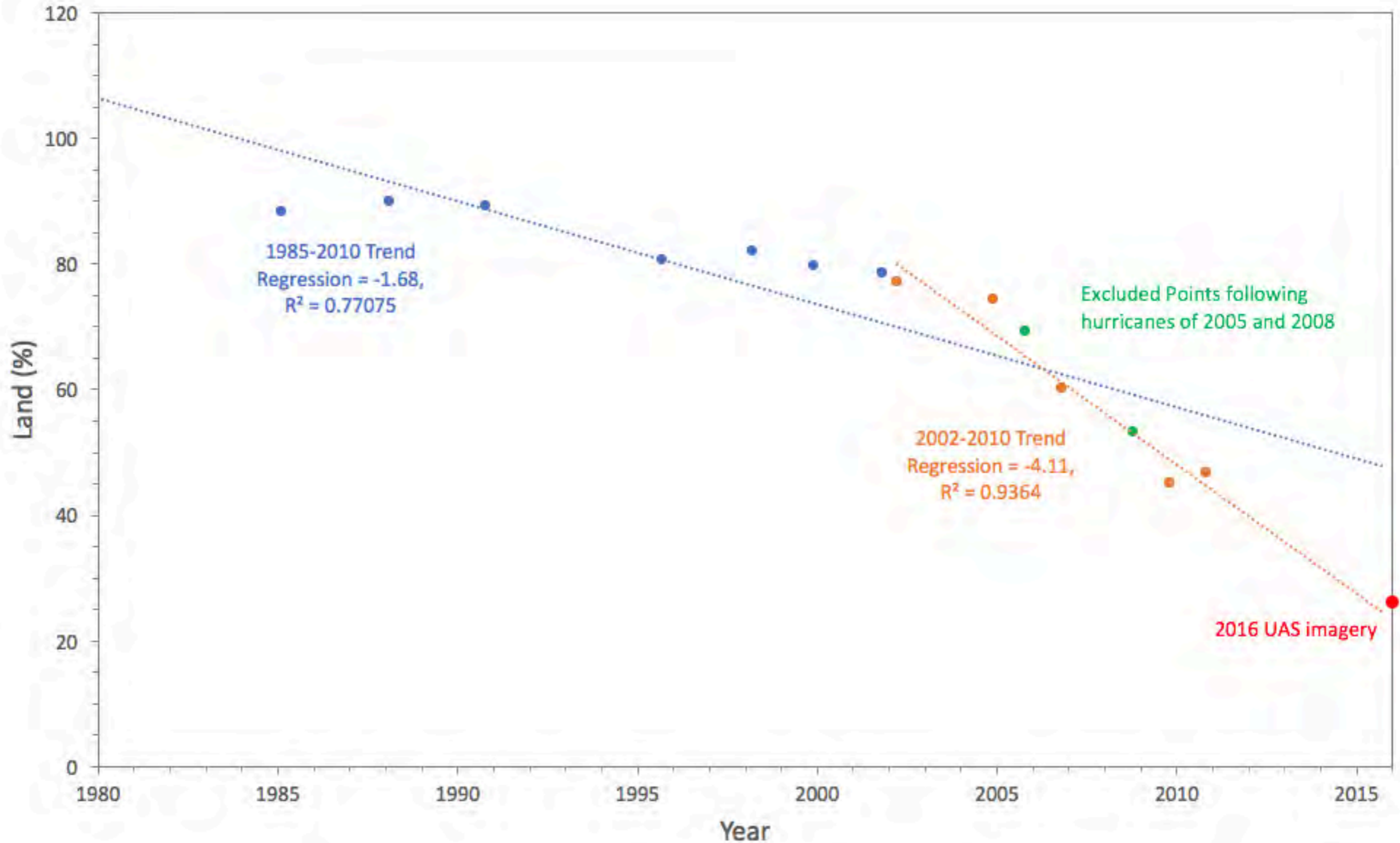
Land

Water

CRMS	UAS	CRMS	UAS
0.2	0.12	0.27	0.35
42%	26%	58%	74%

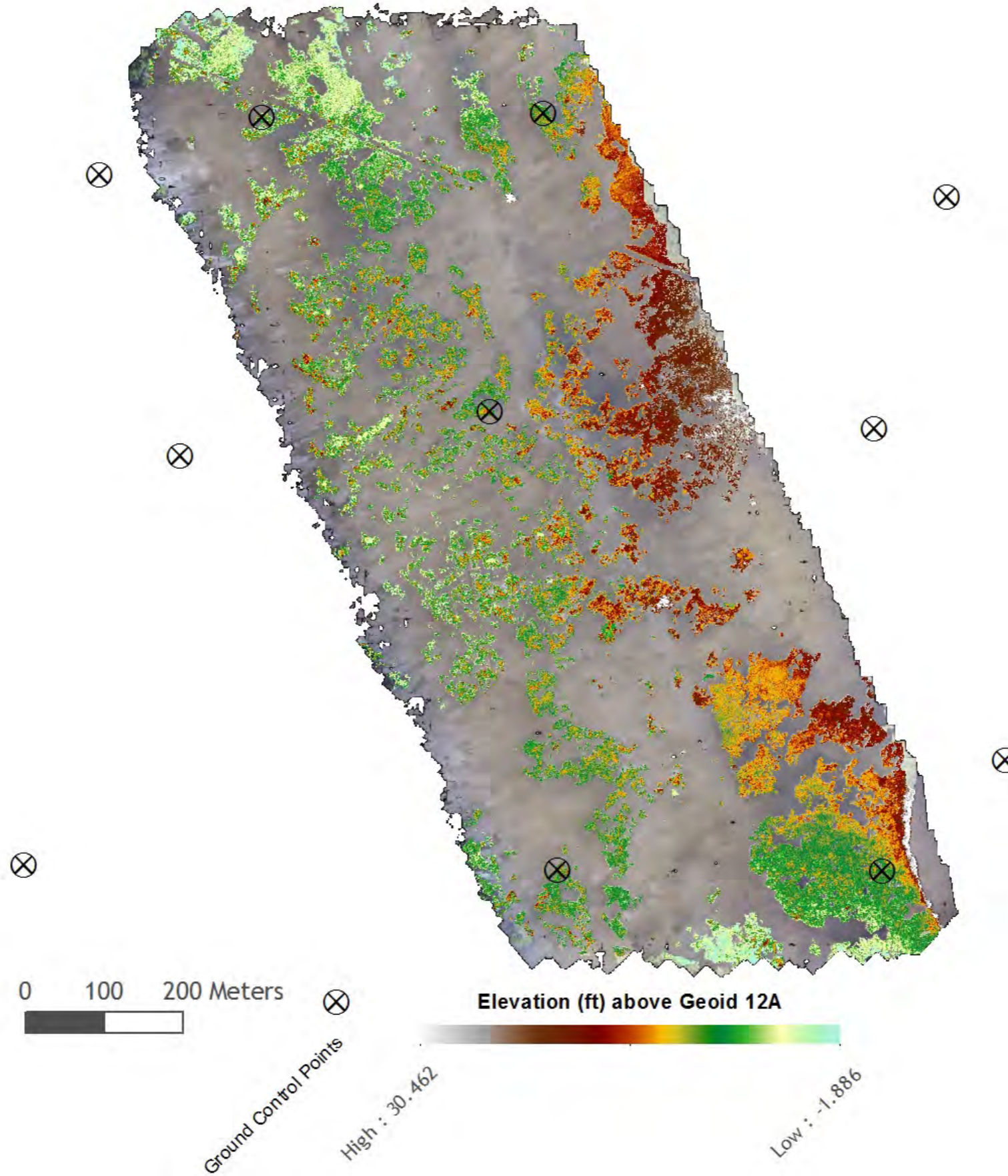


CRMS0392 - 1985 through 2010

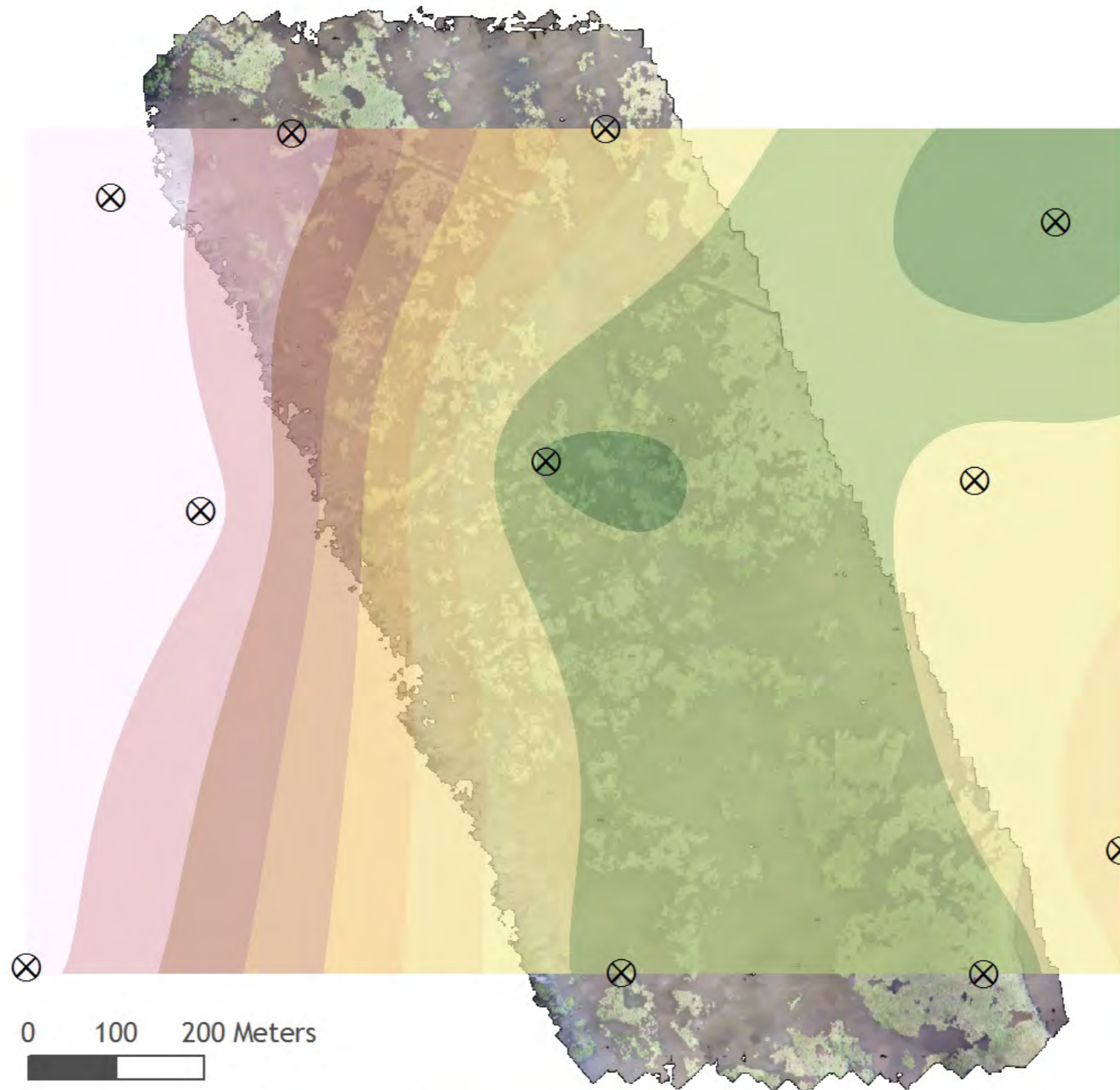


Data Source: Coastal Protection and Restoration Authority (CPRA) of Louisiana. 2017. Coastwide Reference Monitoring System-Wetlands Monitoring Data. Retrieved from Coastal Information Management System (CIMS) database. <http://cims.coastal.louisiana.gov>. Accessed 24 April 2017.

Predicted Digital Surface Model 2016



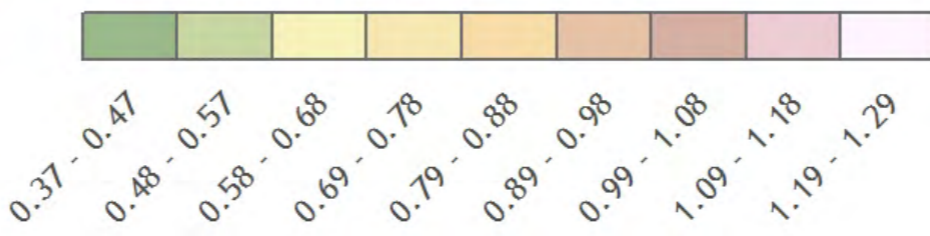
Predicted Marsh Elevation 2016



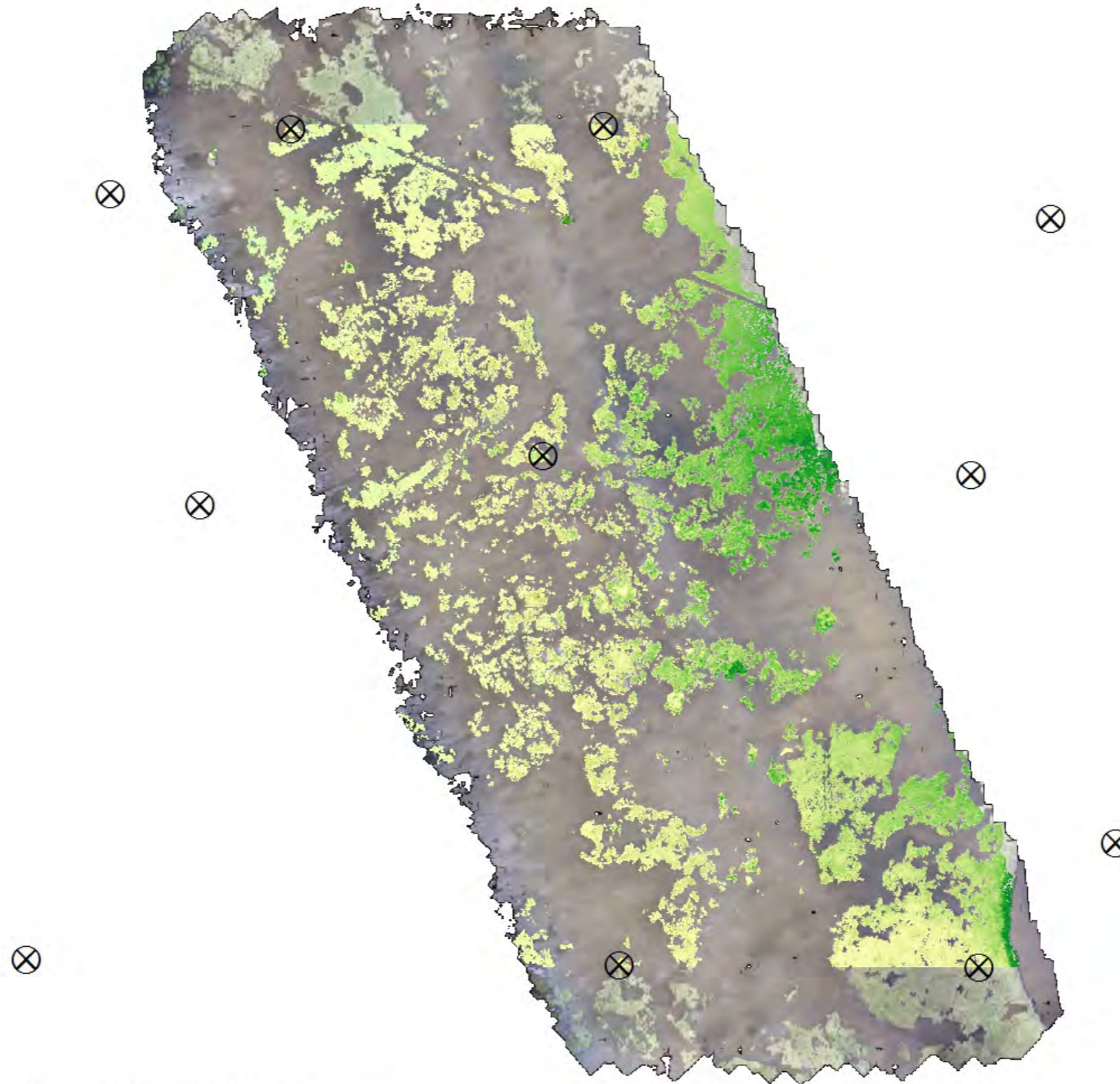
0 100 200 Meters

⊗
Ground Control Points

Marsh Elevation (ft) above Geoid12A



Predicted Plant Height 2016



0 100 200 Meters



Ground Control Points

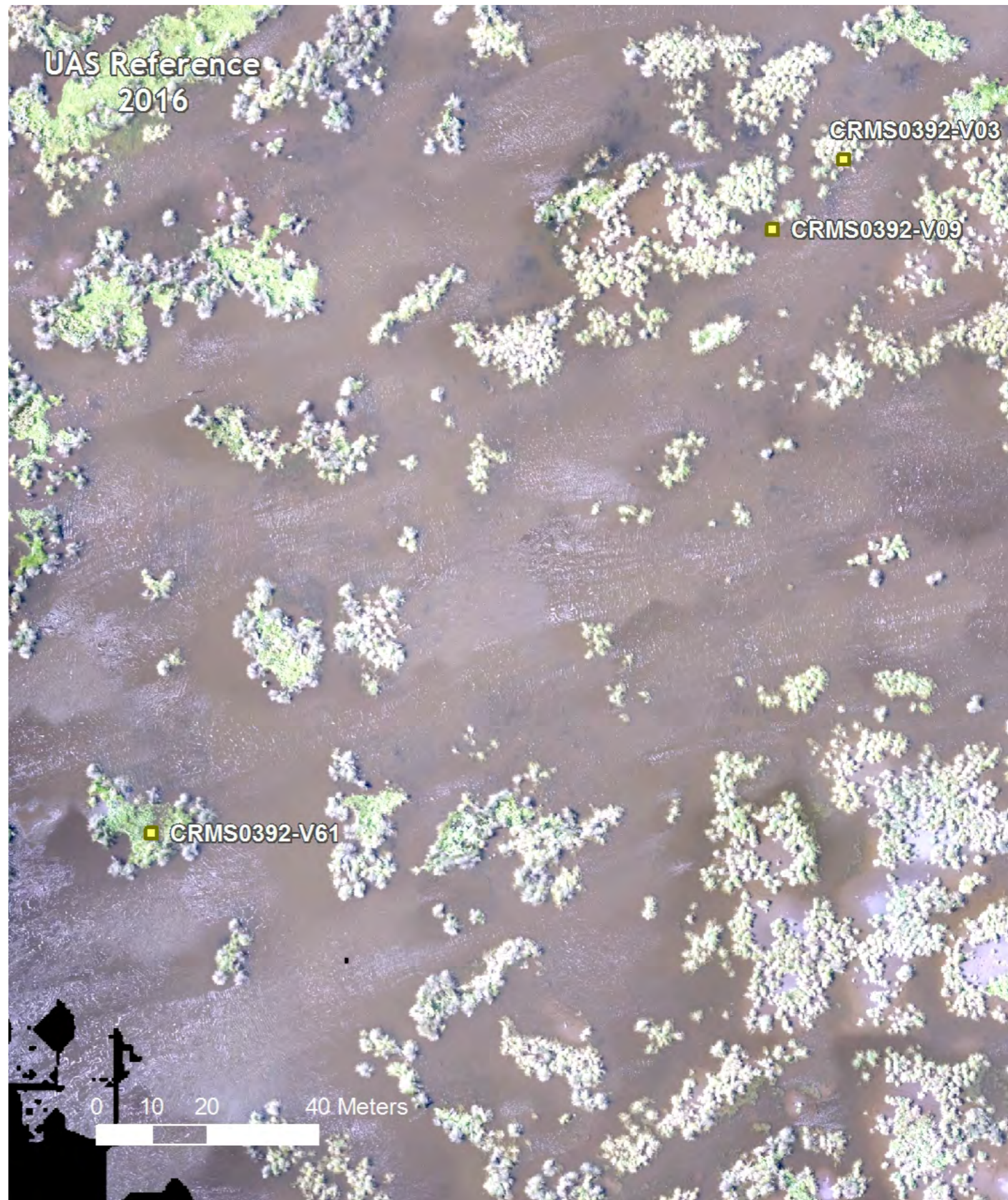
Plant Height (ft) above marsh elevation



High : 29.2737

Low : -3.00511

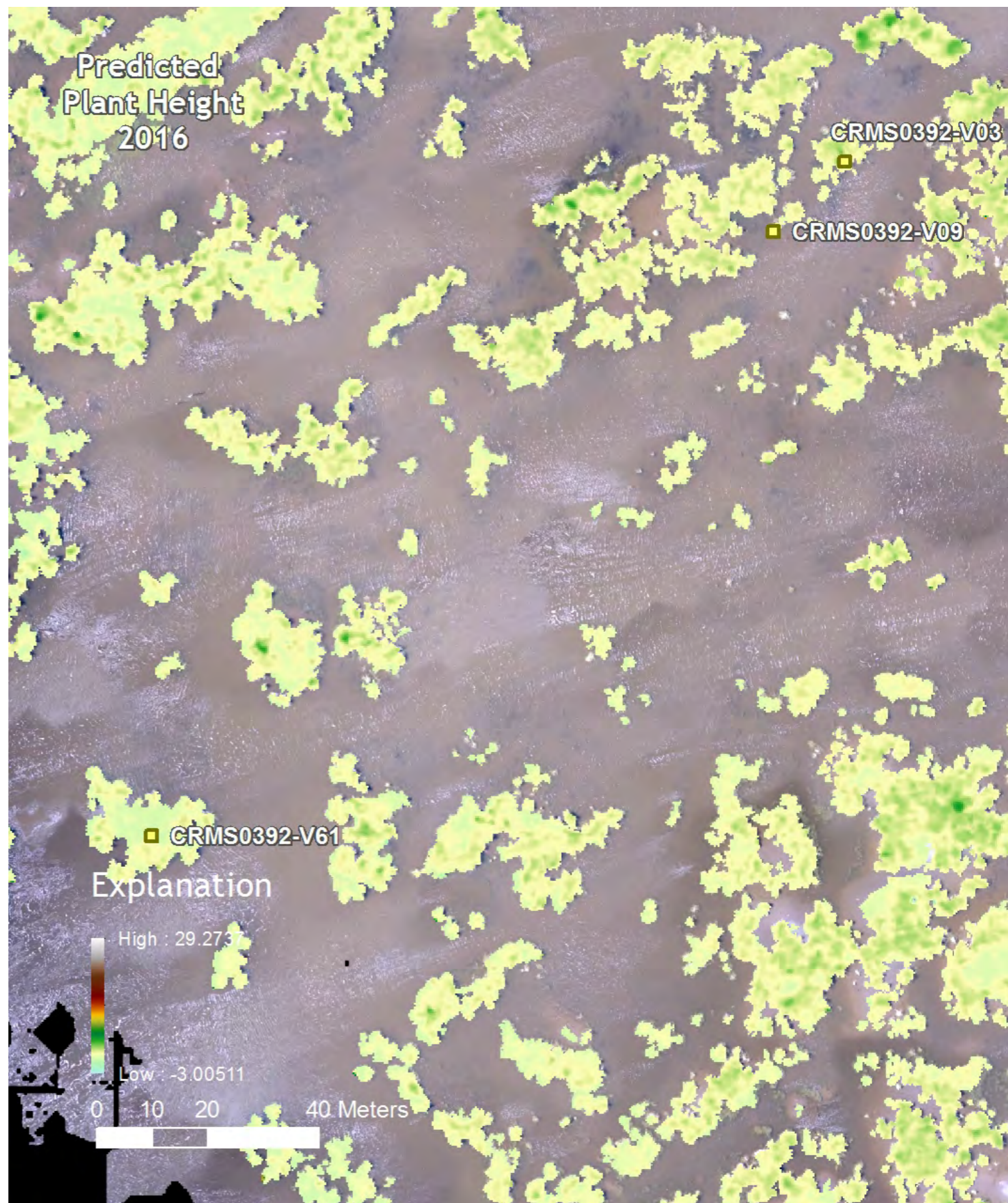
Comparison with 2012 CRMS Vegetation Survey



Comparison with 2012 CRMS Vegetation Survey

	Marsh Elevation	
	CRMS	Predicted
V03	0.229	0.52
V09	0.229	0.77
V61	0.229	0.55

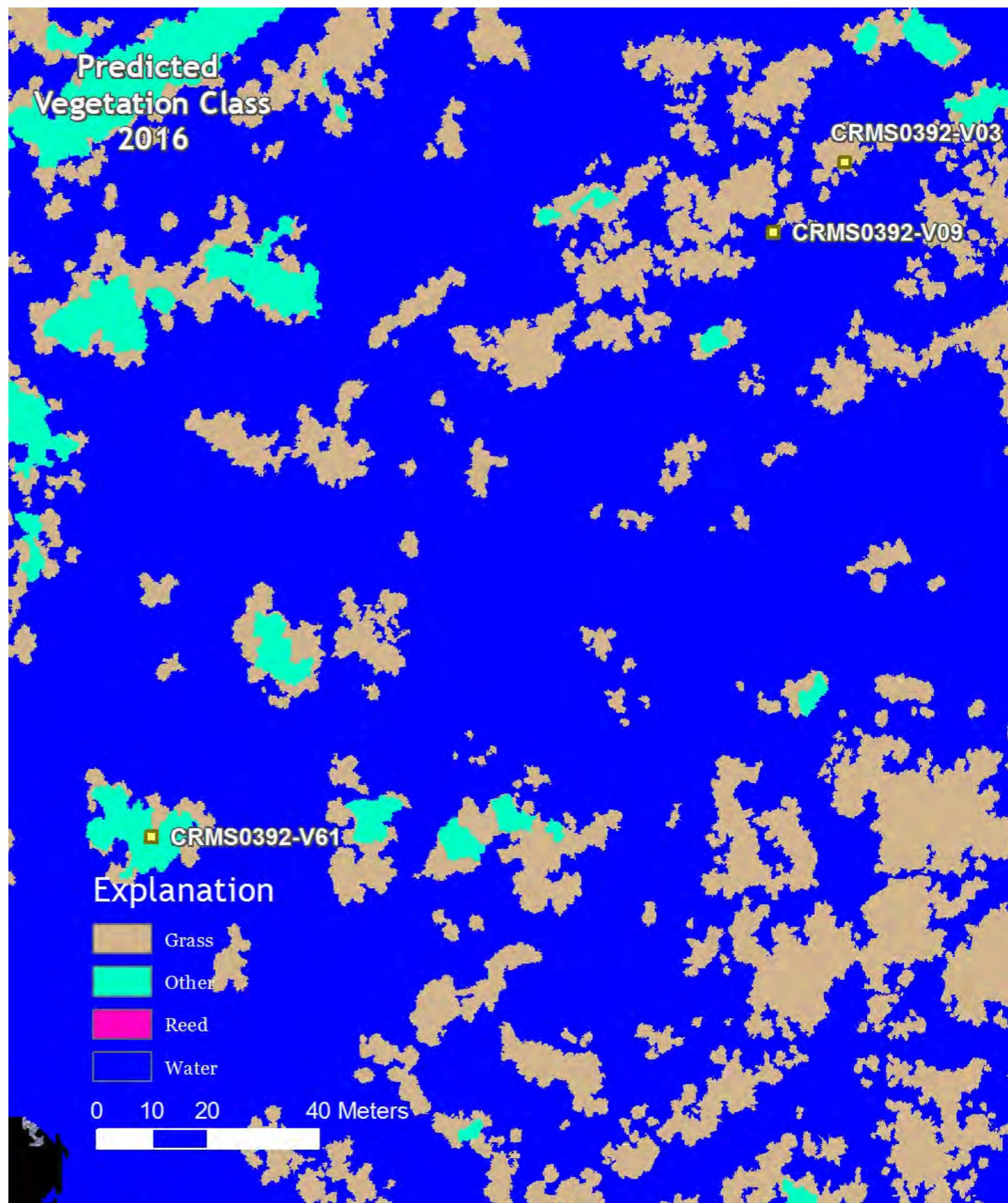
	Maximum Plant Height (ft)				
	CRMS	Predicted (diff. modeled marsh elev.)	Fit	Predicted (diff. measured marsh elev.)	Fit
V03	4.84	3.97	82%	4.26	88%
V09	3.91	0.86	22%	1.406	36%
V61	1.6	1.19	74%	1.504	94%



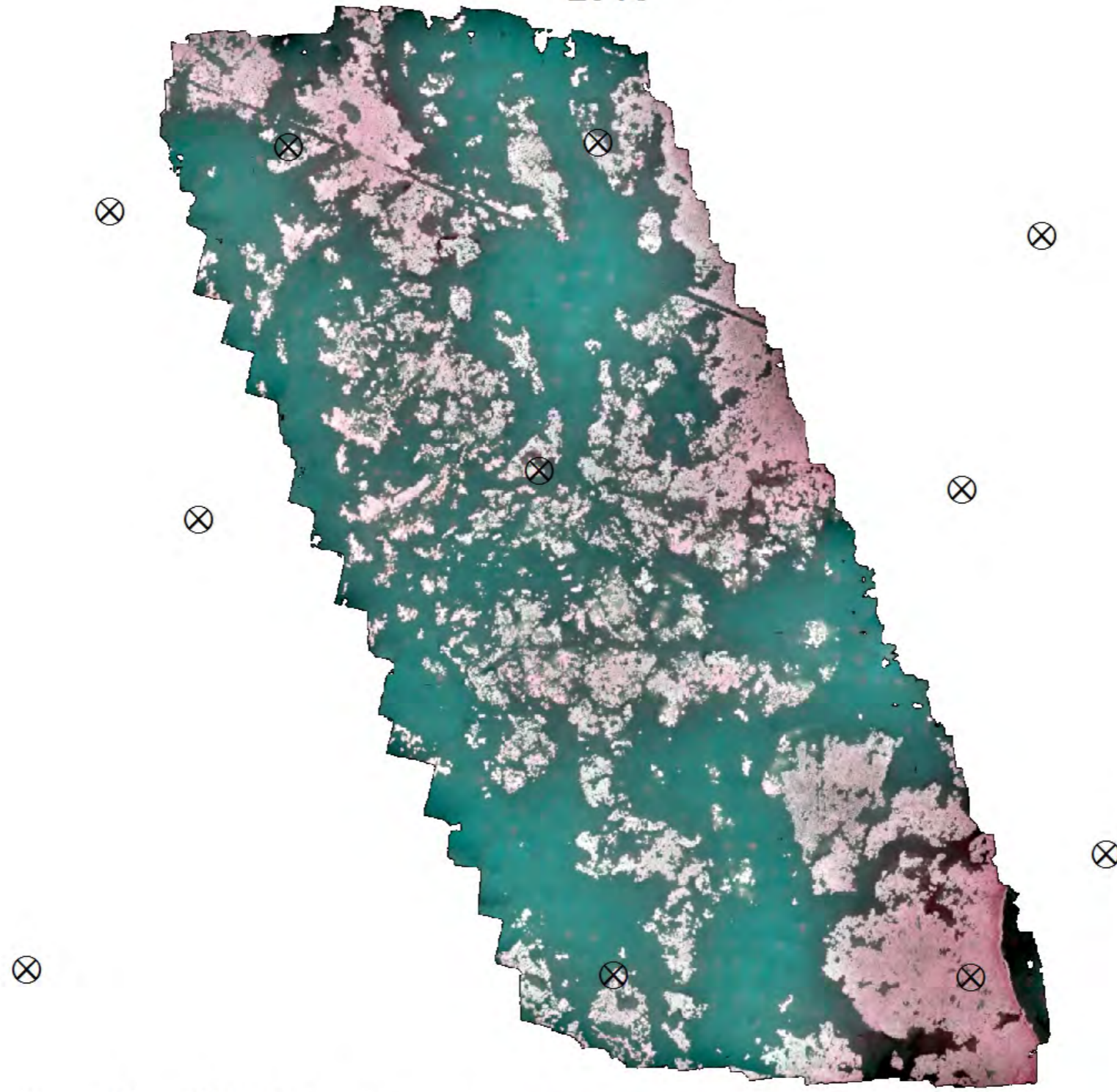
Comparison with 2012 CRMS Vegetation Survey

	% Land		
	CRMS	Predicted	Fit
V03	5%	94%	+89%
V09	1%	8%	+7%
V61	100%	94%	-6%

	Vegetation Classification			Notes
	CRMS	Predicted	Fit	
V03	Grass	Grass	100%	Amaranthus, Patens, Cyperus mix
V09	Grass	Grass	100%	Patens clump
V61	Other	Other	100%	Bacopa, Eleocharis, Pluchea mix



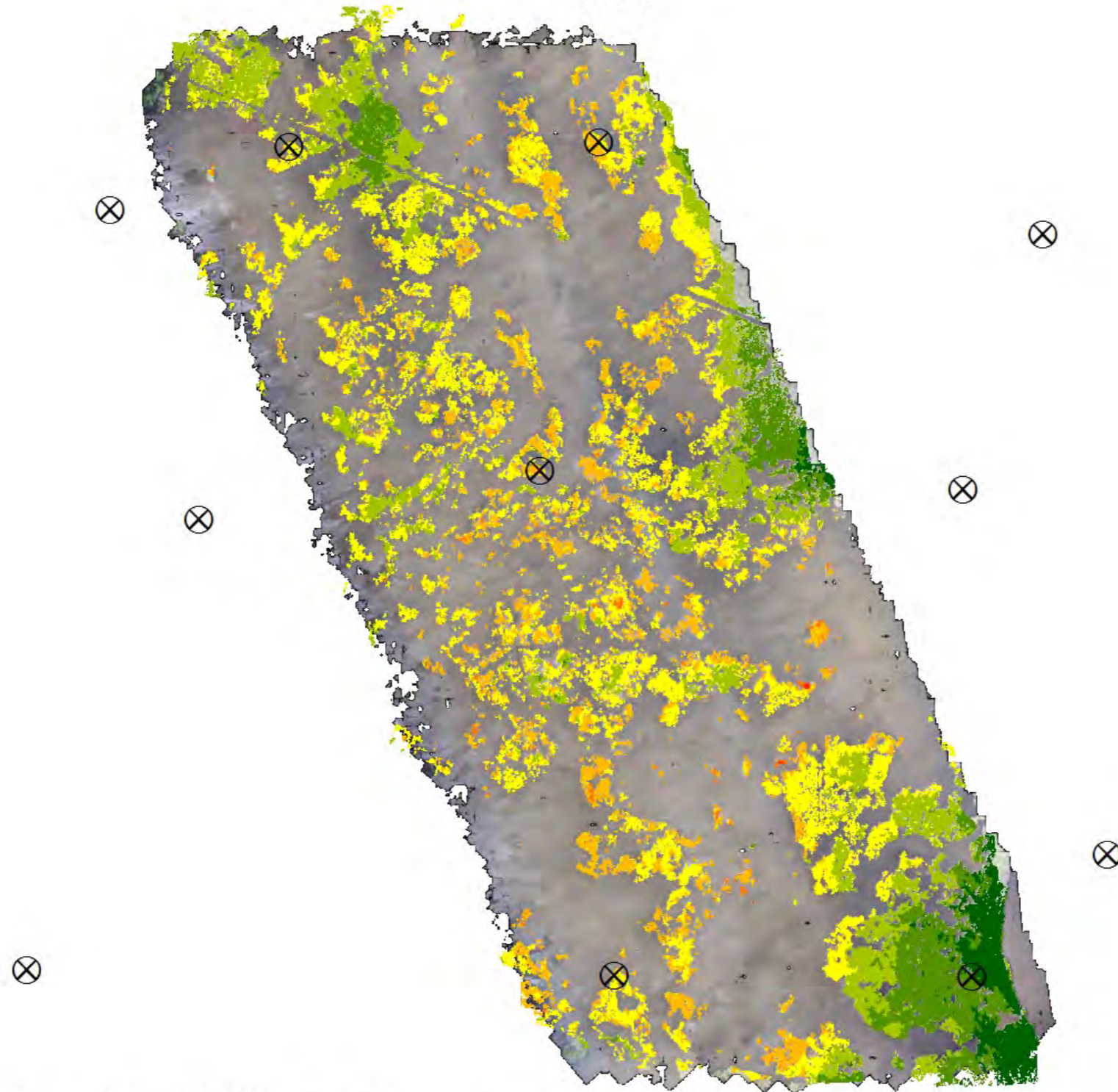
UAS
Color Infrared Imagery
2016



0 100 200 Meters

X Ground Control Points

Predicted NDVI 2016



0 100 200 Meters

⊗
Ground Control Points

Normalized Vegetation Index



< .06
0.06 - 0.13
0.13 - 0.19
0.19 - 0.26
0.26 - 0.33
0.33 - 0.39
0.39 - 1.00

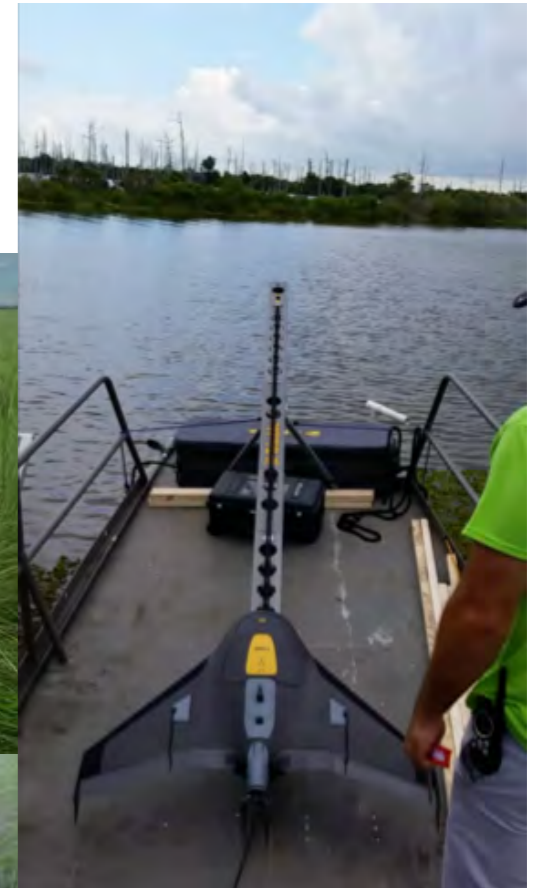
Expected UAS Challenges

- Flight time - Battery life
- Beyond Line of Site operations
- Privacy Issues and permissions
- Take Off - Landing Zones
- Standardizing segmentation algorithms
- Radiometric concerns for large scale assessments



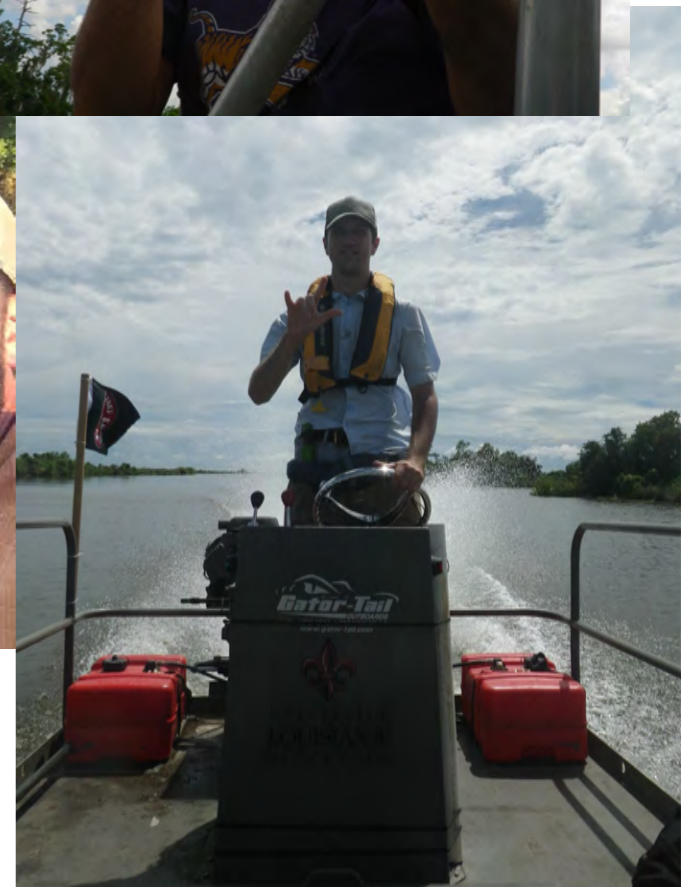
Expected UAS Benefits

- Save time and money
- Increased efficiency for vegetation and elevation surveys
- Fewer personnel requirements and ability to overcome site accessibility issues
- More frequent monitoring events
- Develop high resolution 3D structural models, multispectral orthomosaic images of entire projects, surface elevation models, and volumetric measurements
- Multiple habitat types
- Project operations (marsh creation compaction) and long-term monitoring (settling along shorelines barriers and vegetation expansion)
- high resolution maps of the land-water interface, land loss, and habitat fragmentation metrics
- Ability to scale up from the 200 m site (really 10, 4m² plots) to a 1km² to capture site variability (easy to do in one day).
- Another method to link on-the-ground field measurements with landscape-level remotely sensed data.



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- UL Lafayette Institute for Coastal and Water Research
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References

- Blaschke, T. (2010). Object based image analysis for remote sensing. *ISPRS Journal of Photogrammetry and Remote Sensing*, 65(1), 2-16.
- Chong, A.K. (2007) HD aerial video for coastal zone ecological mapping. The 19th Annual Colloquium of the Spatial Information Research Centre.
- Chust, G., et al. (2008). Coastal and estuarine habitat mapping, using LIDAR height and intensity and multi-spectral imagery. *Estuarine, Coastal and Shelf Science*, 78(4), 633-643.
- Eisenbeiss, H., Lambers, K., & Sauerbier, M. (2005). Photogrammetric recording of the archaeological site of Pinchango Alto (Palpa, Peru) using a mini helicopter (UAV). Annual Conference on Computer Applications and Quantitative Methods in Archaeology CAA, (March 2005), 21-24.
- Klemas, V. (2013). Airborne Remote Sensing of Coastal Features and Processes: An Overview. *Journal of Coastal Research*, 29(2), 239-255.
- Klemas, V. (2015). Coastal and Environmental Remote Sensing from Unmanned Aerial Vehicles: An Overview. *Journal of Coastal Research*, 315(5), 1260-1267.
- Laliberte, A. S., & Rango, A. (2009). Texture and scale in object-based analysis of subdecimeter resolution unmanned aerial vehicle (UAV) imagery. *IEEE Transactions on Geoscience and Remote Sensing*, 47(3), 1-10.
- Laliberte, A. S., & Rango, A. (2011). Image Processing and Classification Procedures for Analysis of Sub-decimeter Imagery Acquired with an Unmanned Aircraft over Arid Rangelands. *GIScience & Remote Sensing*, 48(1), 4-23.
- Laliberte, A. S., et al.. (2011). Multispectral remote sensing from unmanned aircraft: Image processing workflows and applications for rangeland environments. *Remote Sensing*, 3(11), 2529-2551.
- Lechner, A. M., et al. (2012). Characterising Upland Swamps Using Object-Based Classification Methods and Hyper-Spatial Resolution Imagery Derived From an Unmanned Aerial Vehicle. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 1-4(September), 101-106.
- Marceau, D., and Hay, G. J (1999). Contributions of remote sensing to the scale issue. *Canadian Journal of Remote Sensing*, 25(4), 357-366.
- Niethammer, U., et al. (2012). UAV-based remote sensing of the Super-Sauze landslide: Evaluation and results. *Engineering Geology*, 128, 2-11.
- Phinn, S. R., et al. (1996). Monitoring Wetland Habitat Restoration in Southern California Using Airborne Multi spectral Video Data. *Restoration Ecology*, 4(4), 412-422.
- Przybilla, H.-J., & Wester-Ebbinghaus, W. (1979). Bildflug mit ferngelenktem Kleinflug- zeug. *Bildmessung Und Luftbildwesen Zeitschrift Fuer Photogrammetrie Ferner- Kundung*, 47(5), 137-142.
- Rocchini, D. (2007). Effects of spatial and spectral resolution in estimating ecosystem diversity by satellite imagery. *Remote Sensing of Environment*, 111(4), 423-434.
- Yang J., Artigas F. J., (2010) Mapping salt marsh vegetation by integrating hyperspectral and LiDAR remote sensing. In: Wang, J. (ed.). *Remote Sensing of Coastal Environments*. Boca Raton, FL: CRC, pp. 173-190.

THANK YOU!

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