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

Whitney P. Broussard III

Jenneke M. Visser

Robert P. Brooks

Tom Cousté

USGS Wetland and Aquatic Research Center
25 April 2017

UNIVERSITY of LOUISIANA LAFAYETTE

PennState

JESCO ENVIRONMENTAL & Geotechnical Services, Inc.

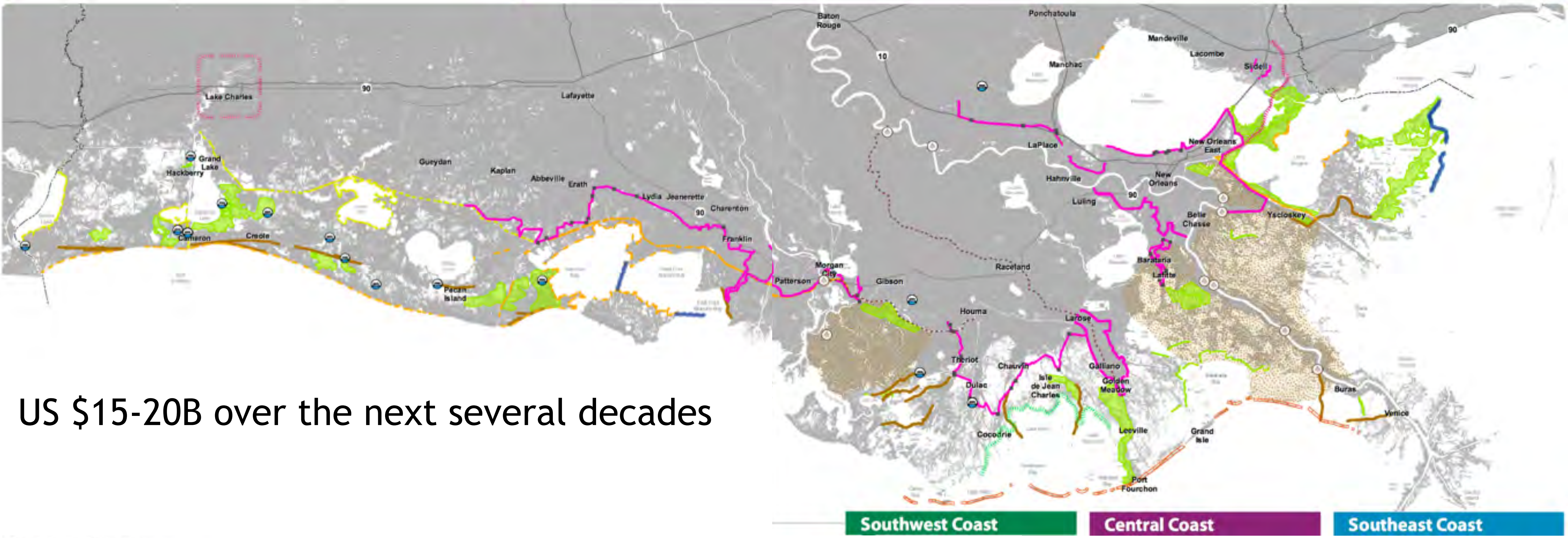
CRMS Wetlands Coastwide Reference Monitoring System

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

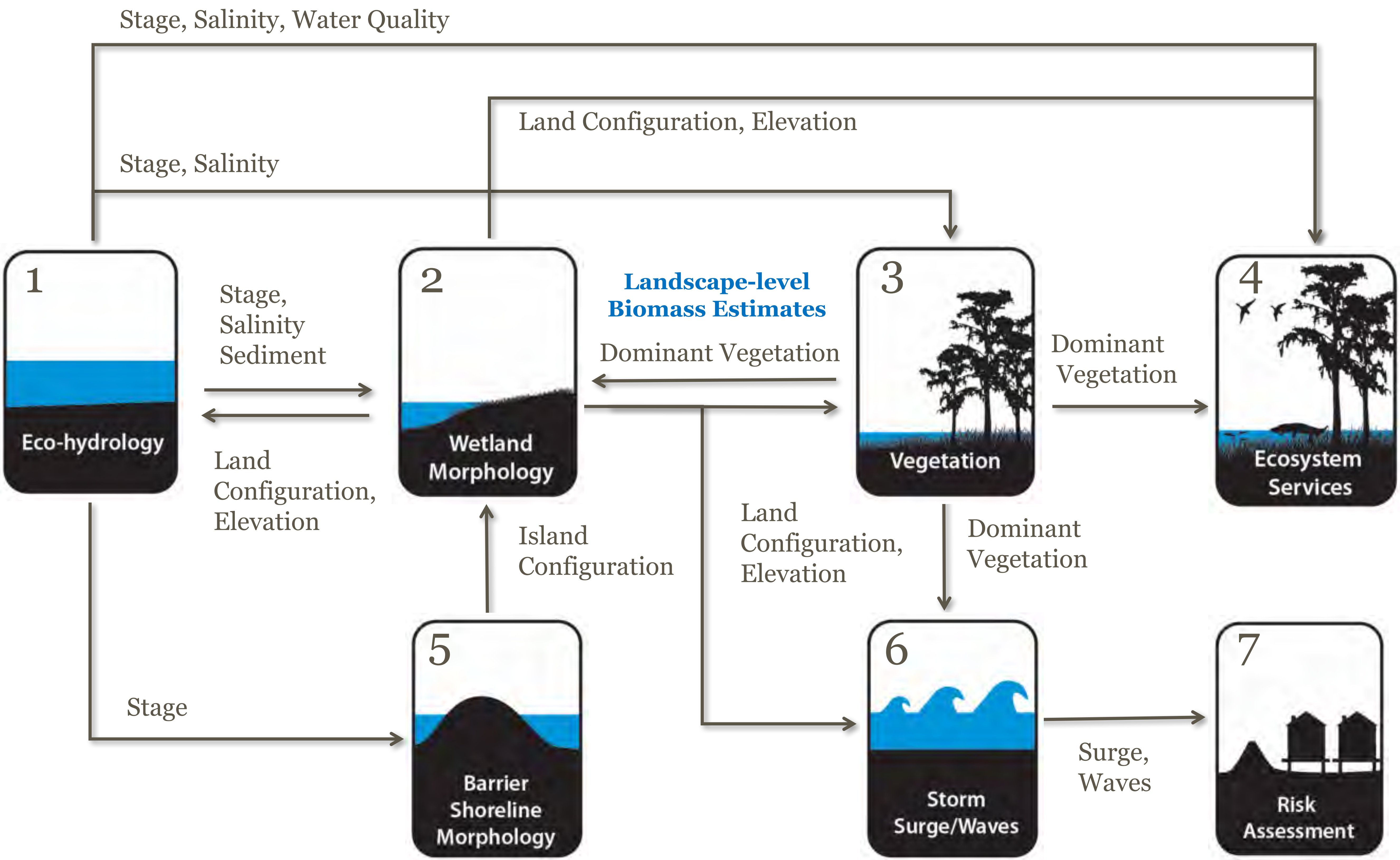


US $15-20B over the next several decades

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



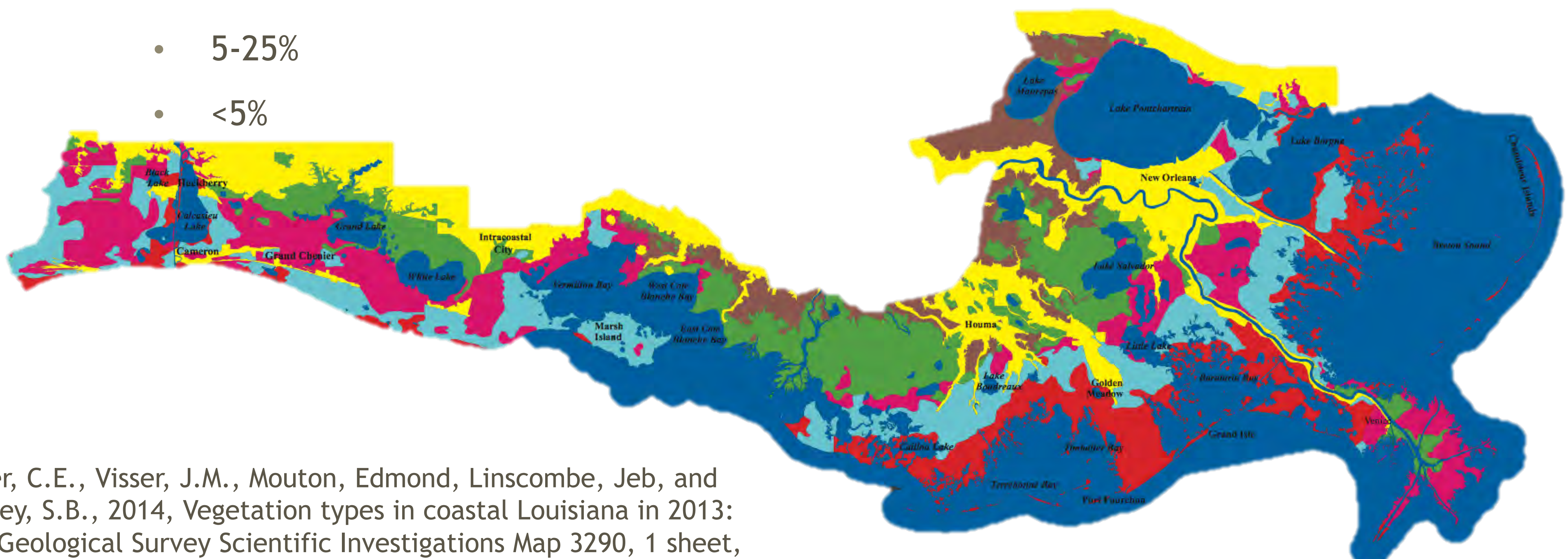
Current Wetland Vegetation Information

Coast-wide Surveys

156 North/South transects spaced 7.5 minutes apart from the Texas state line to the Mississippi state line.

Vegetative data were obtained at predetermined stations spaced 0.5 miles along each transect.

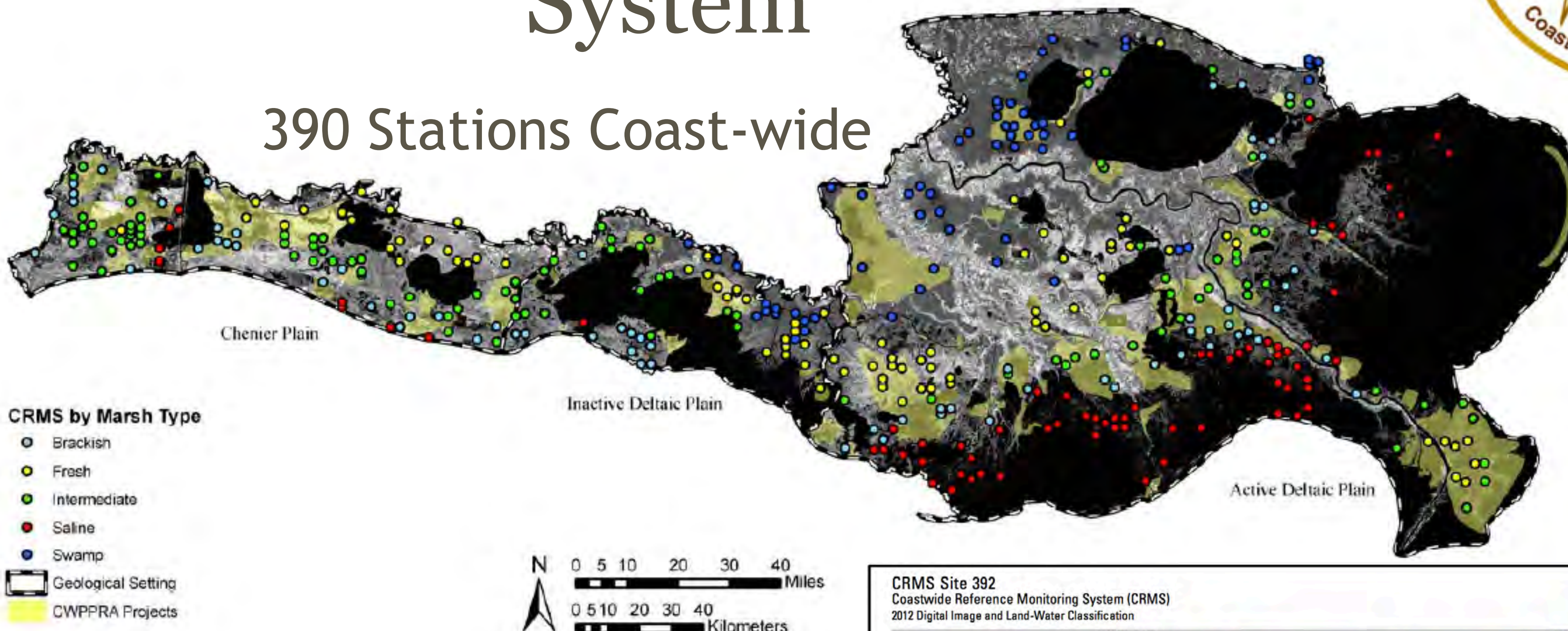
- Species identified
- Five Cover classes (Braun-Blanquet)
  - >75%
  - 50-75%
  - 25-50%
  - 5-25%
  - <5%

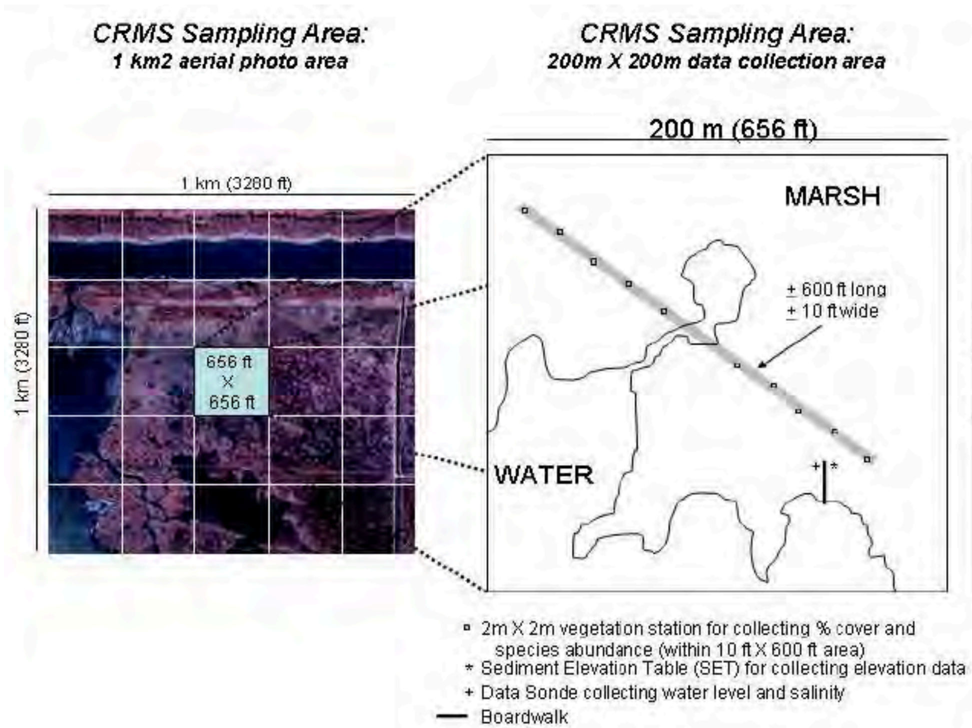


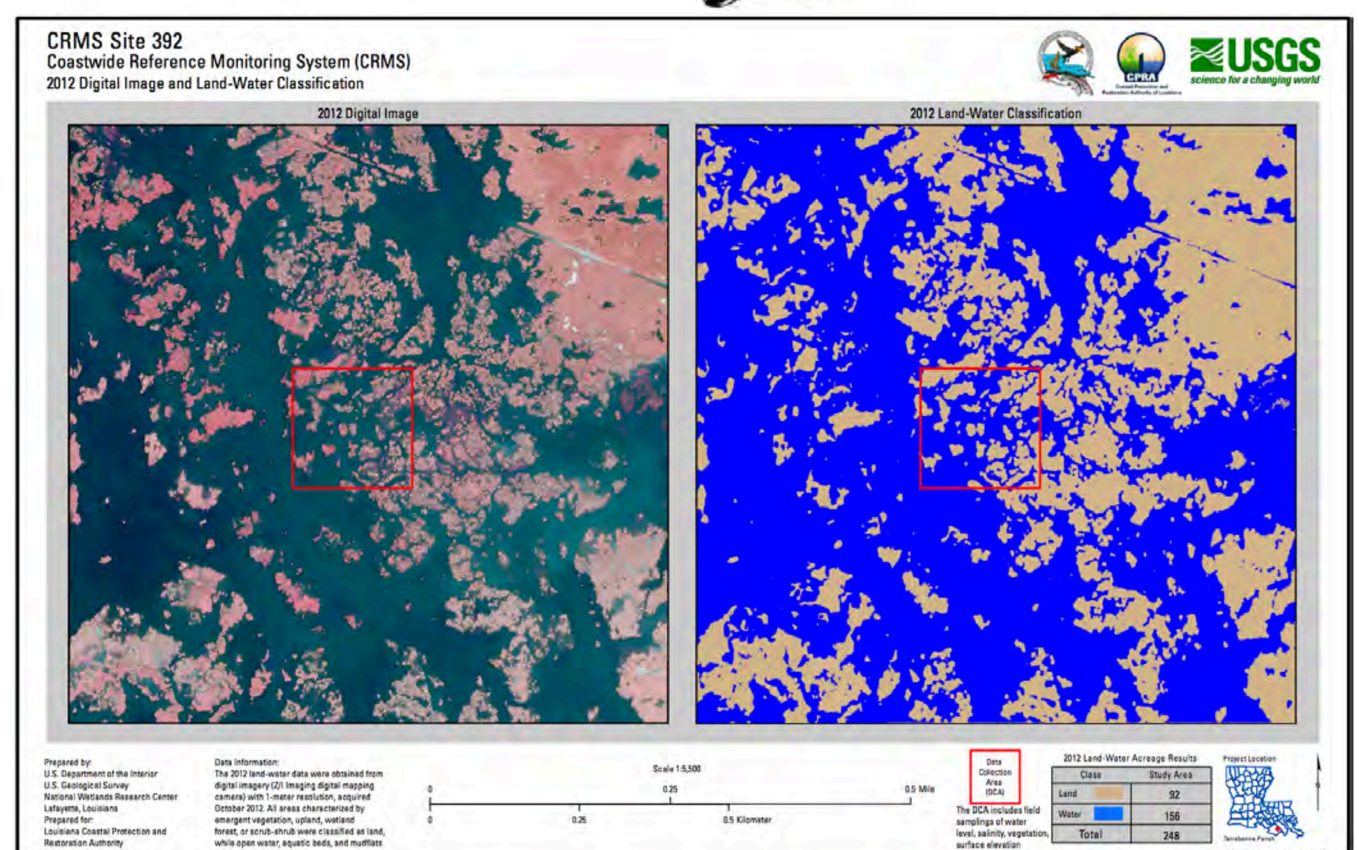
Sasser, C.E., Visser, J.M., Mouton, Edmond, Linscombe, Jeb, and Hartley, S.B., 2014, Vegetation types in coastal Louisiana in 2013: U.S. Geological Survey Scientific Investigations Map 3290, 1 sheet, scale 1:550,000, https://dx.doi.org/10.3133/sim3290.

Coastwide Reference Monitoring System

390 Stations Coast-wide





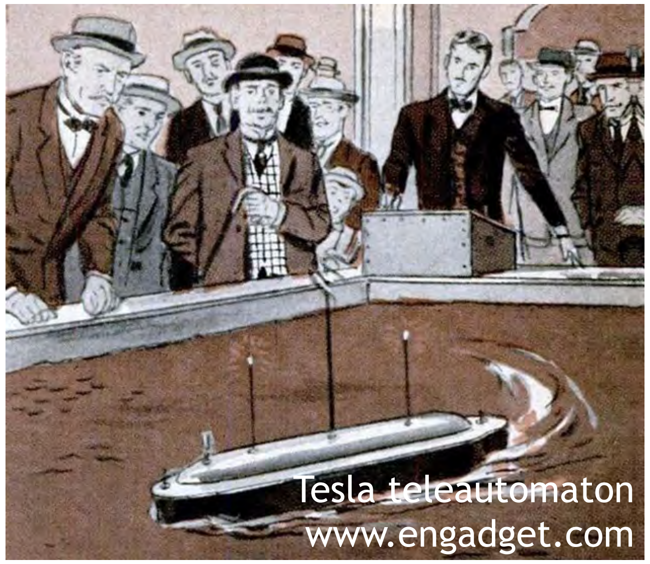


Local field measurements

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 CRF Part 107 issued –licensing of "remote pilot airman certificate with a small UAS rating" and UAS operations in NAS


Tesla teleautomaton
www.engadget.com


Sperry Aerial Torpedo, 1918
http://www.cradleofaviation.org


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


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


Inspire 2. www.dji.com


eBee. www.sensefly.com

Photogrammetry Primer

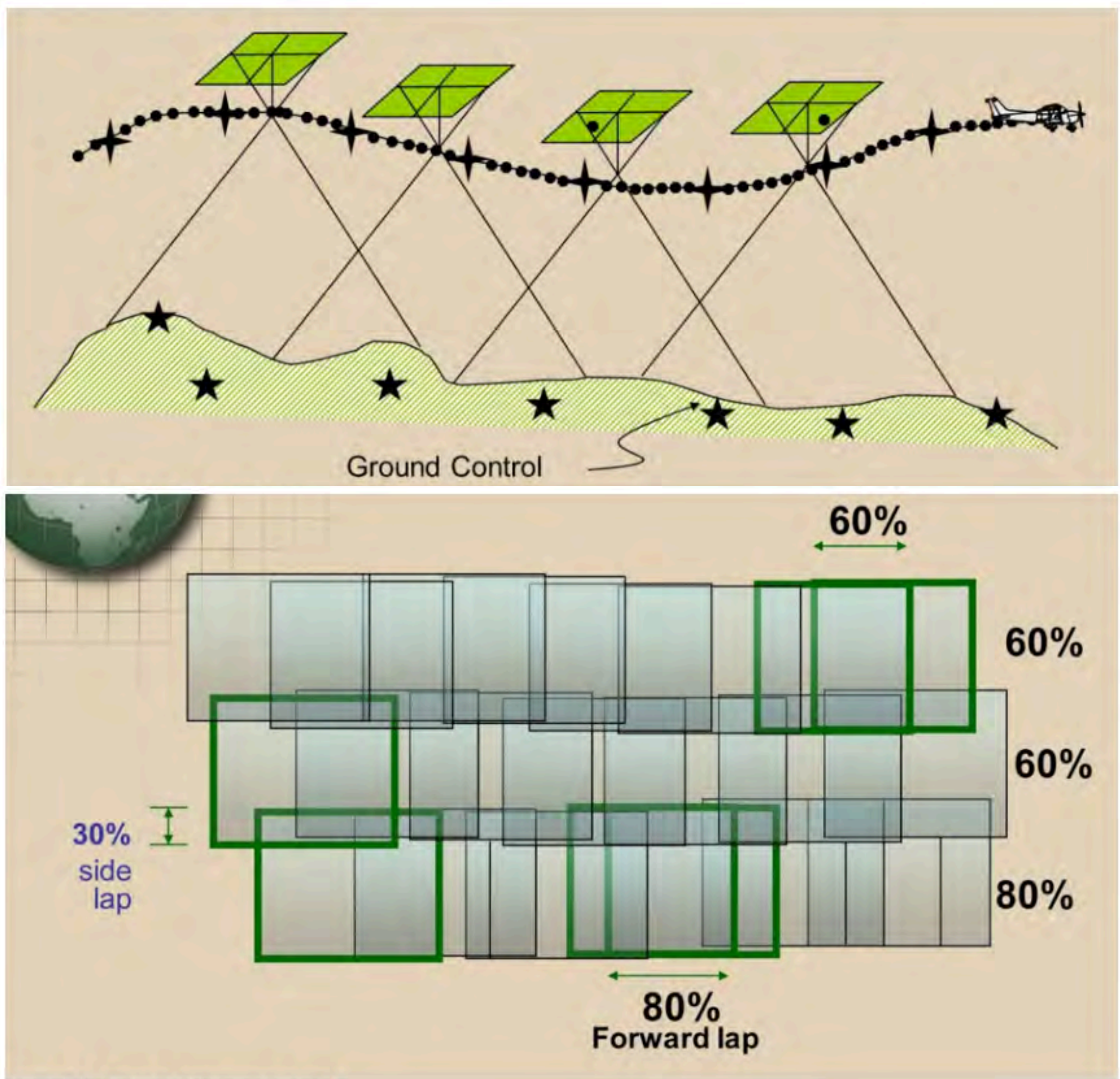


Image credit: Qassim Abdullah

Photogrammetry Primer

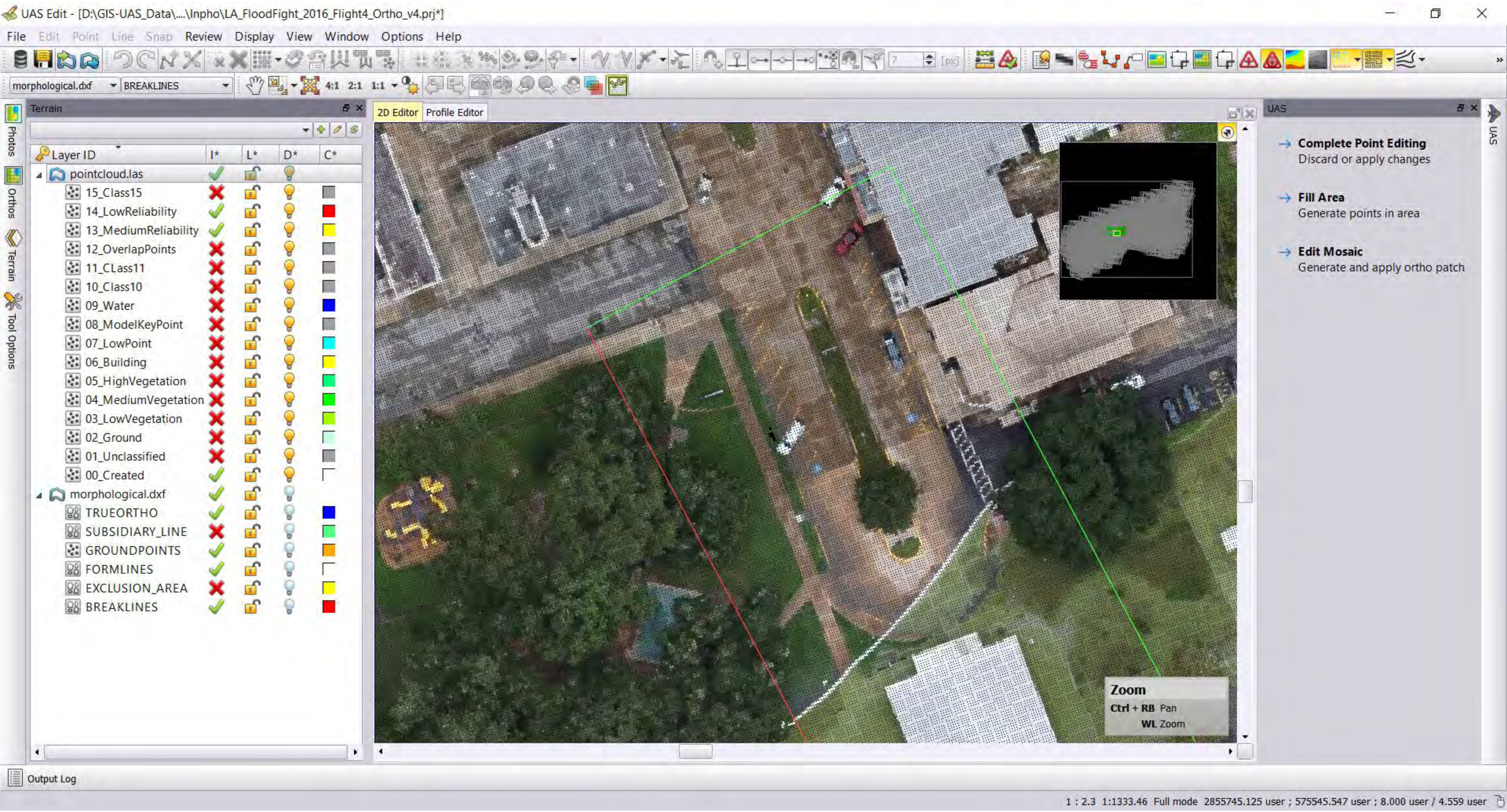


Image credit: JESCO Environmental

Photogrammetry Primer

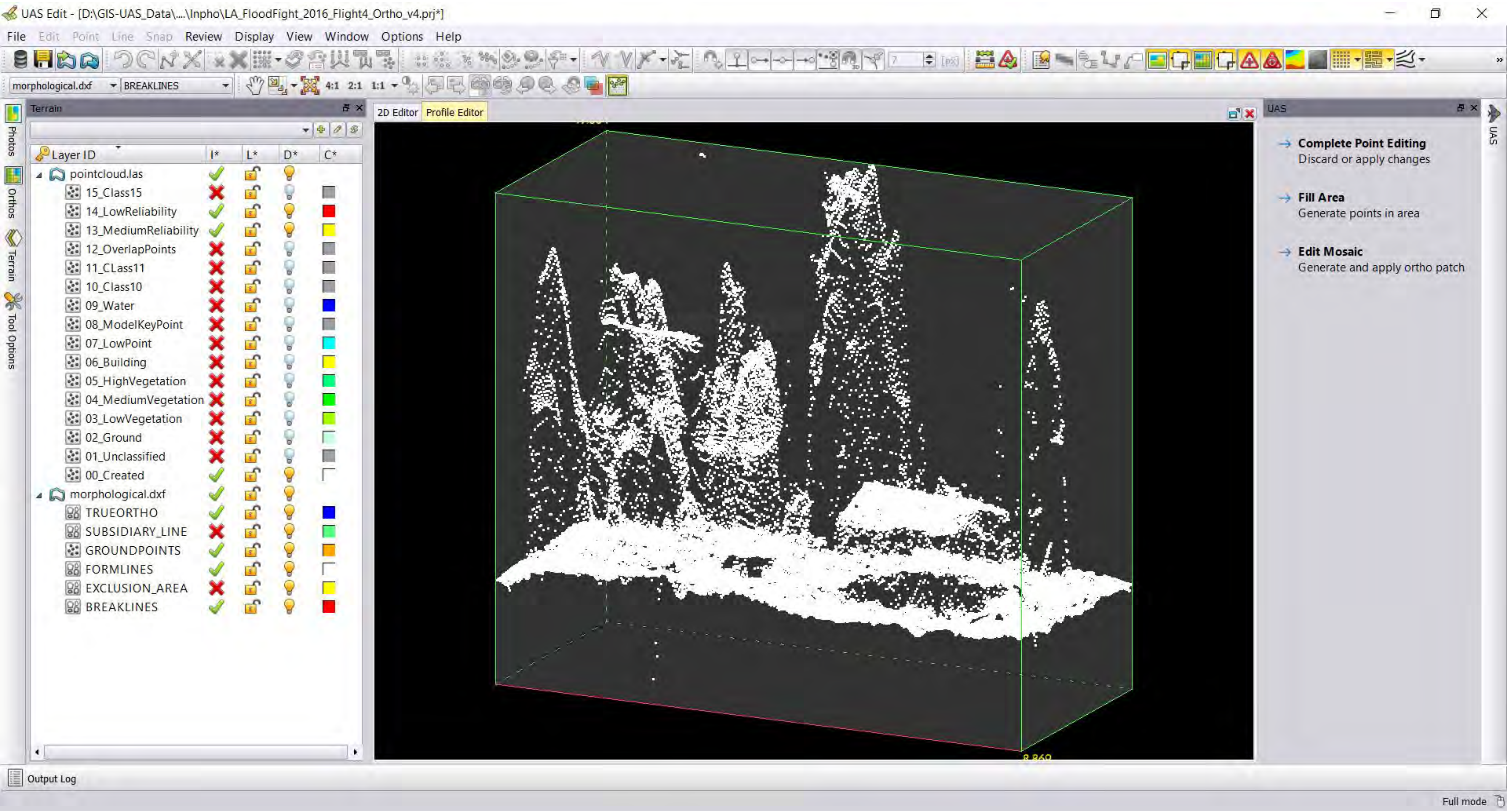


Image credit: JESCO Environmental

Photogrammetry Primer

Orthomosaic

Digital Surface Model

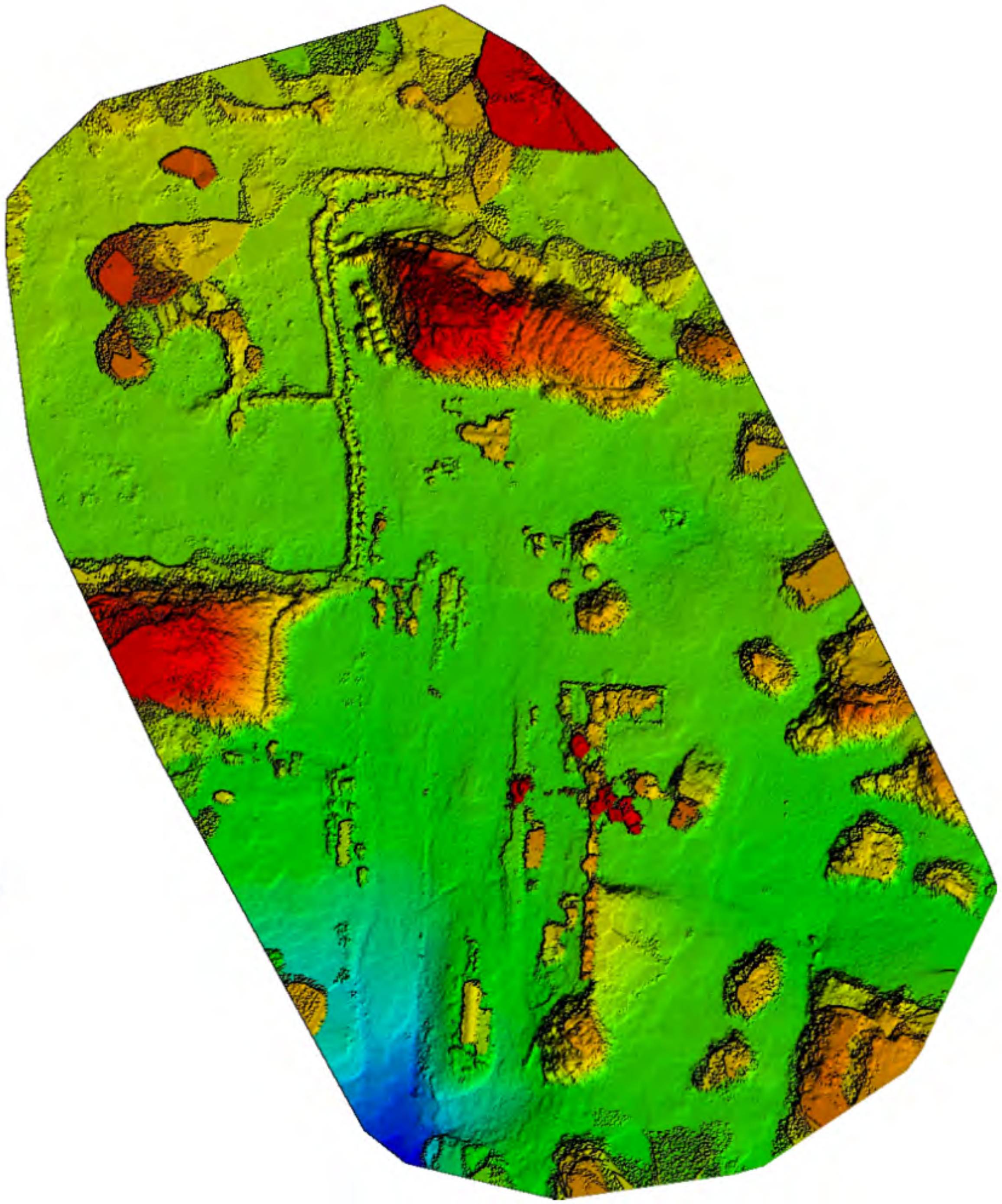


Image credits: PIX4D

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 multispectal 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

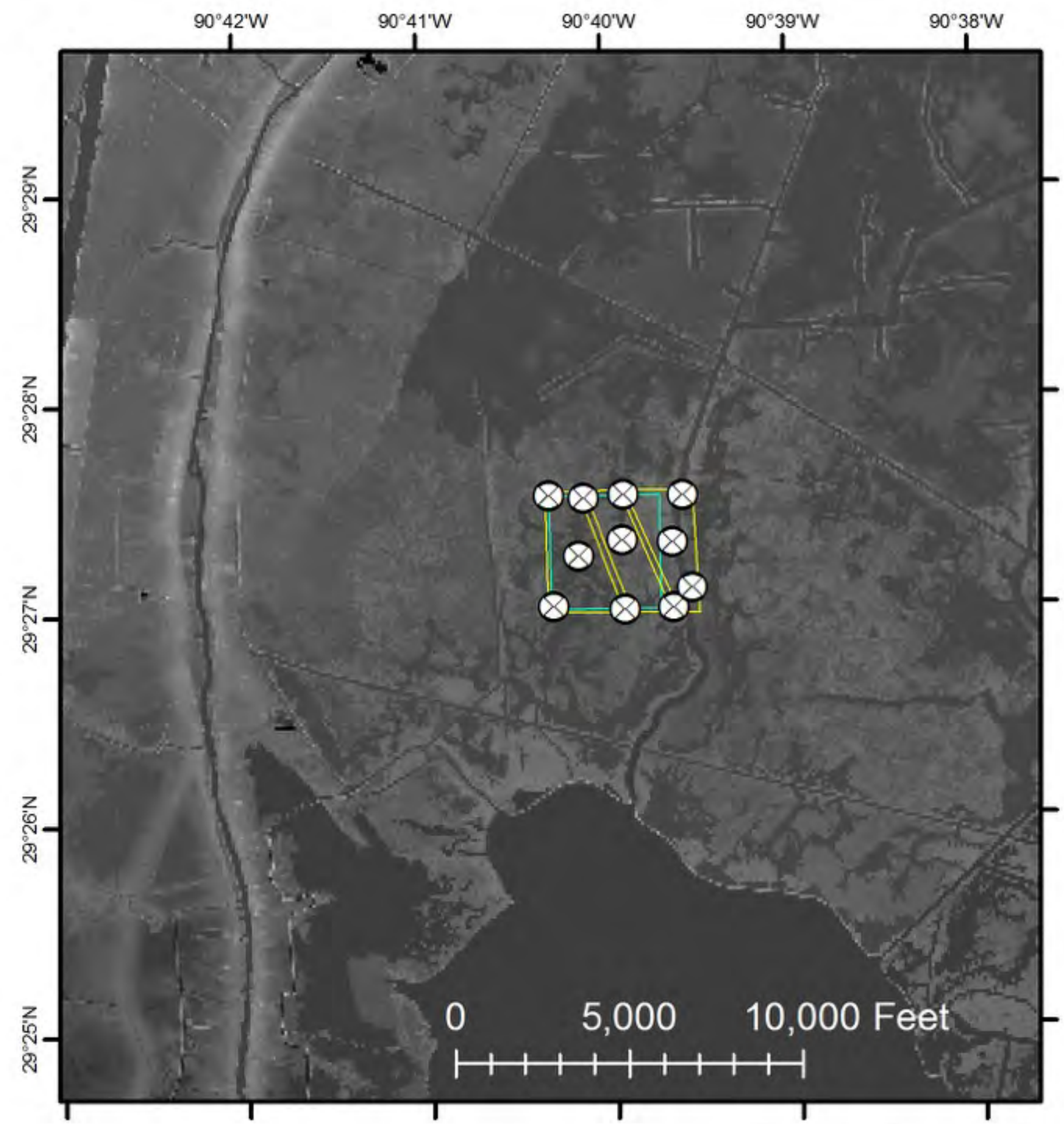
- Flexible deployments - high-temporal and hyperspatial resolution (<1dm) data (Niethammer et al. 2012)

- 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.

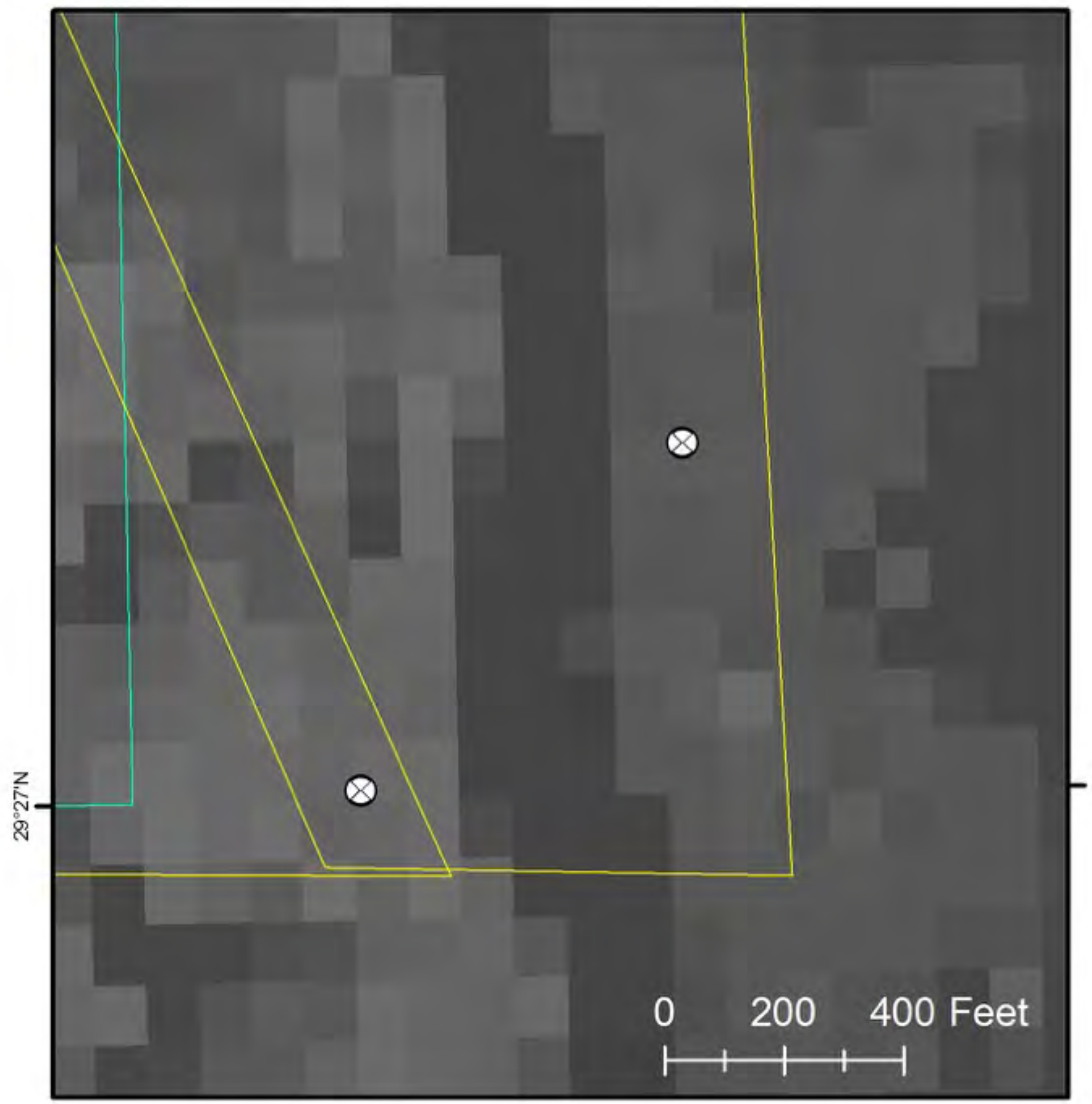
- Lidar sensors can produce point cloud models, allow for elevation estimates in covered sites, and improve elevation accuracies.

Landsat derived DEM – 30m GSD



Aerial Imagery: Landsat DEM

Landsat derived DEM – 30m GSD



Aerial Imagery: Landsat DEM

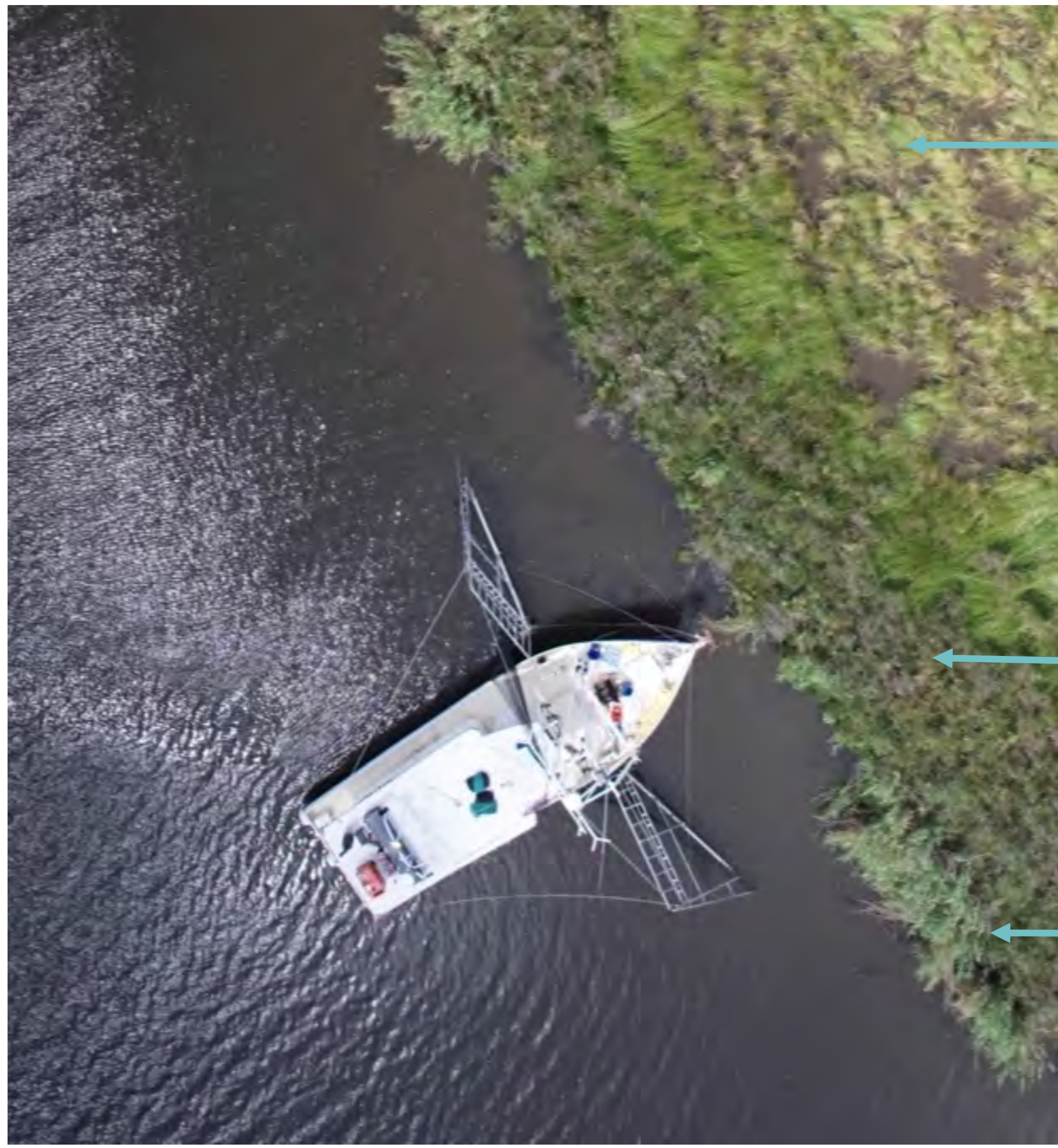
Aerial Photography – 1m GSD

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



UAS Aerial Photography – 2.5cm GSD

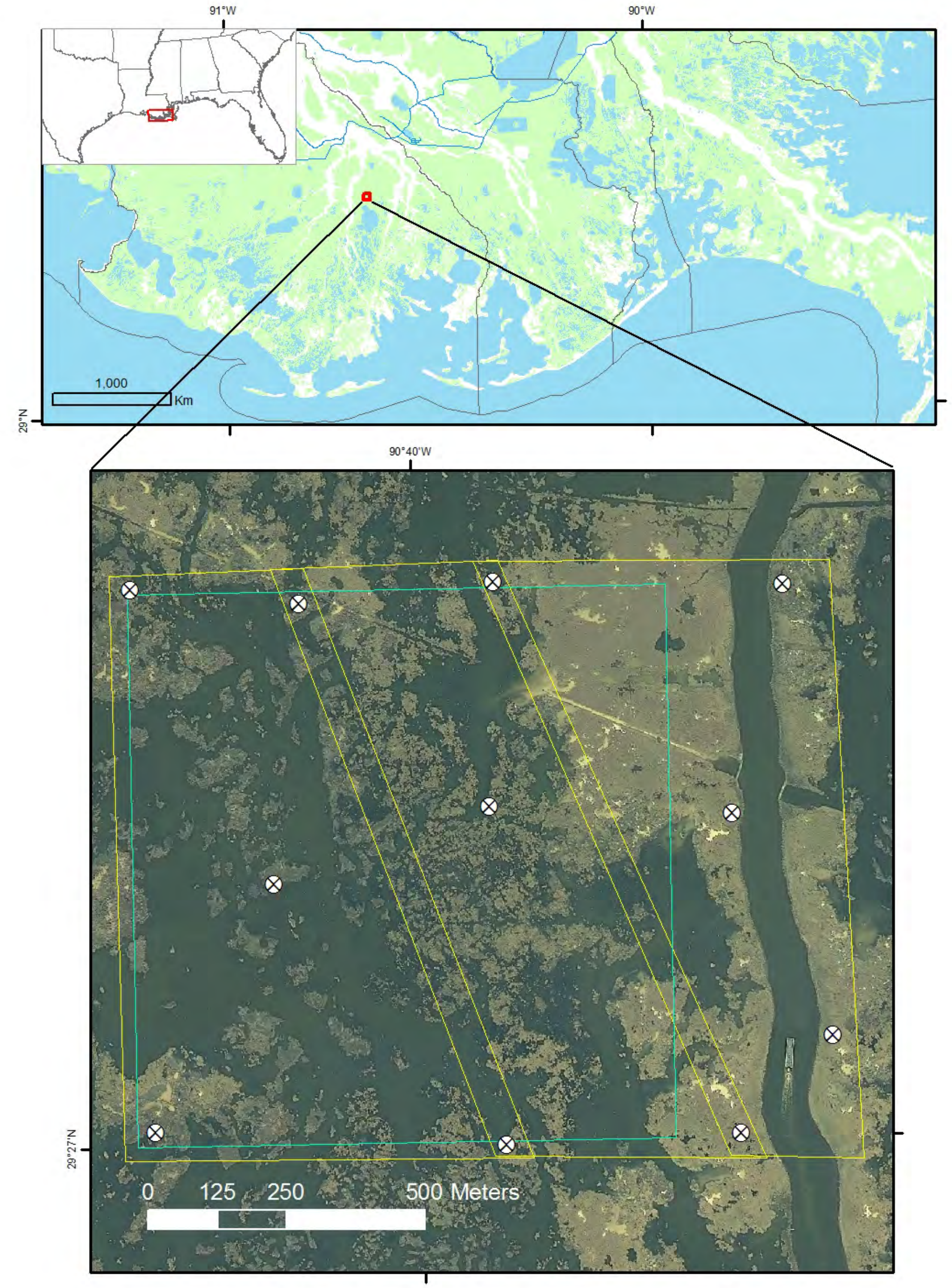
UAS Aerial Photography – 2.5cm GSD

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 km^2 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

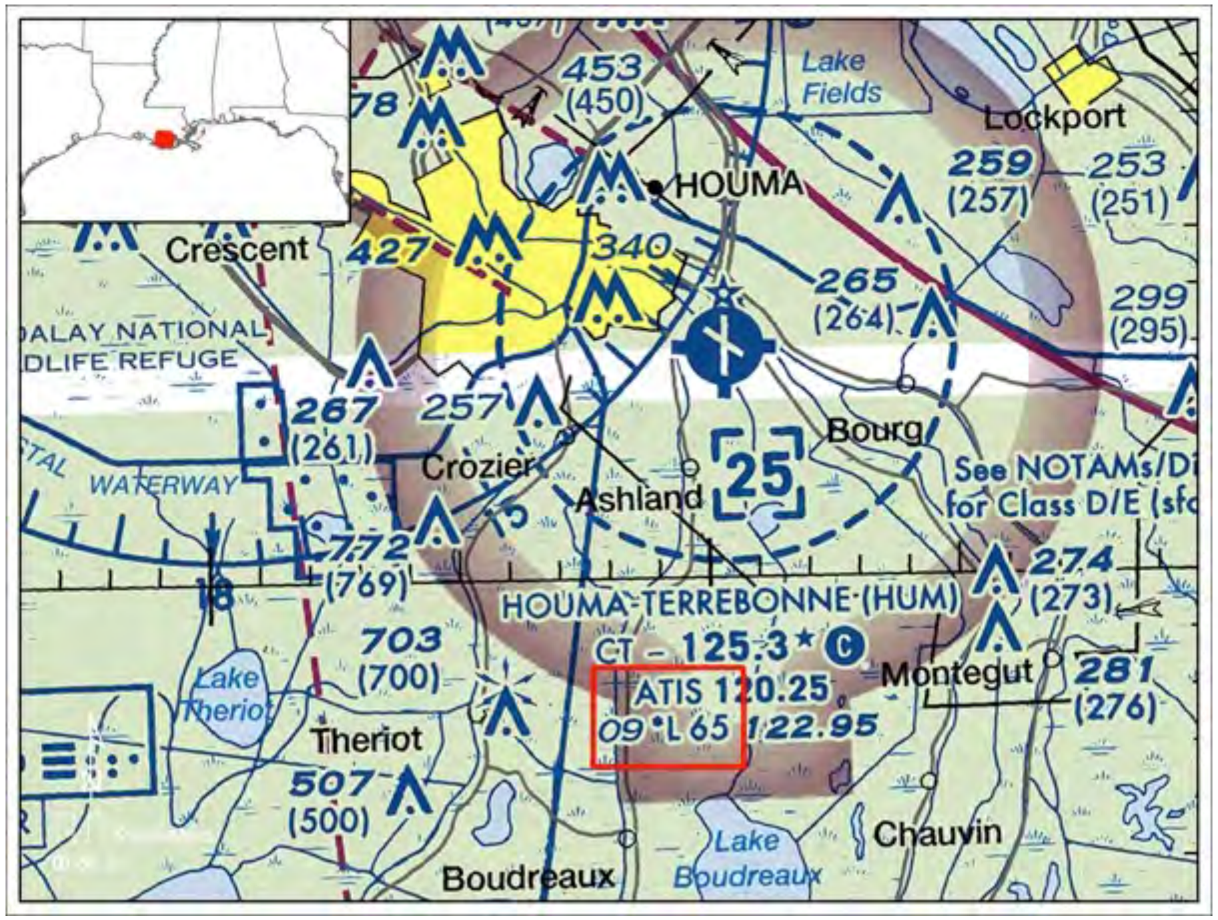
HARDWARE	
Type	Fixed wing
Weight	2.5 kg (5.51 lb)
Wingspan	1 m (3.28 ft)
Wing area	34 dm

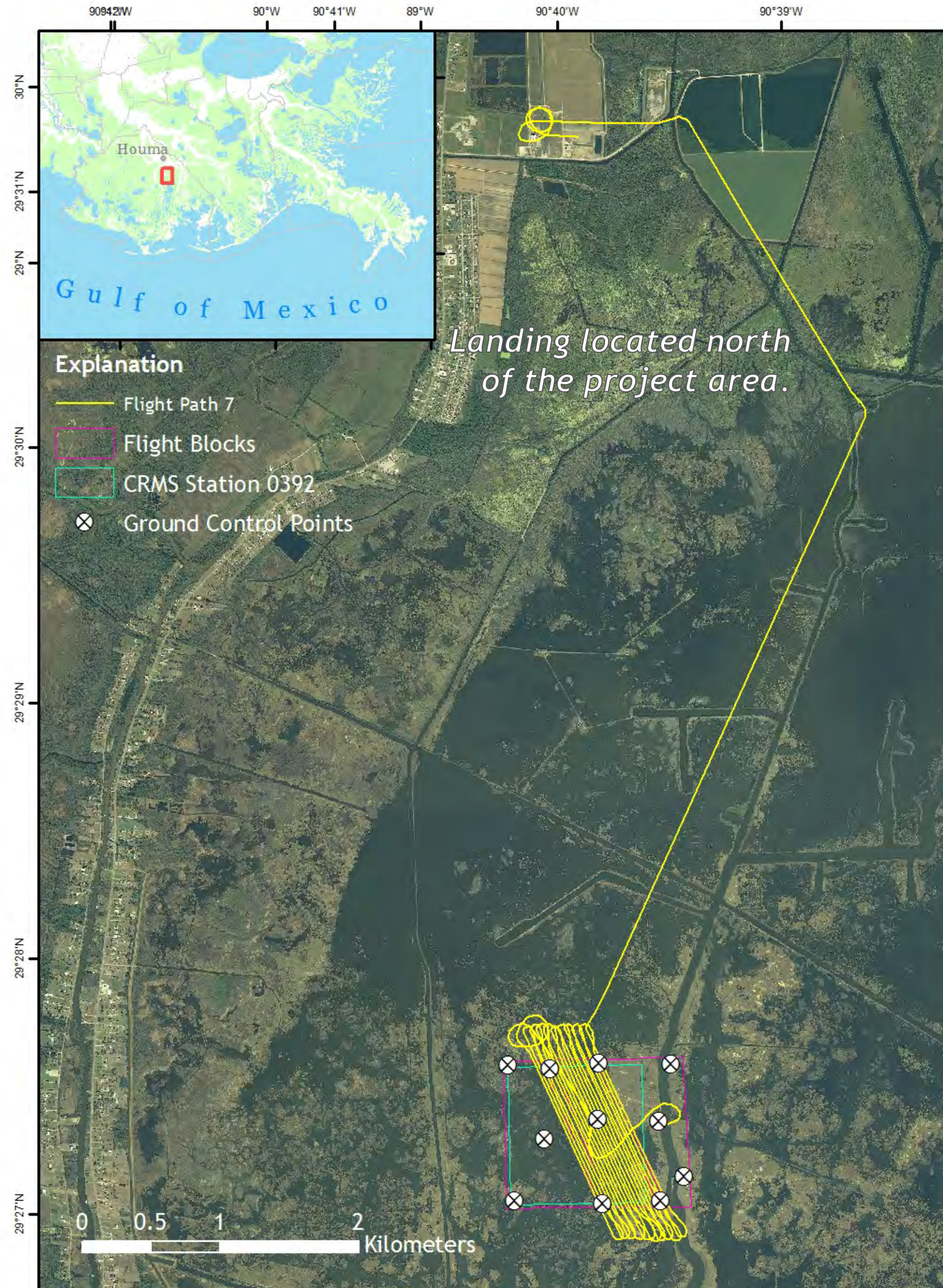
OPERATION	
Endurance[1]	50 minutes
Range[1]	60 km (37.28 mi)
Cruise speed	80 kmh (50 mph)
Maximum ceiling[2]	5000 m (16,404 ft)

Image credits: Trimble Navigation Limited

3 Flight Plans

Sectional Aeronautical Raster Chart with project boundaries shown in red.

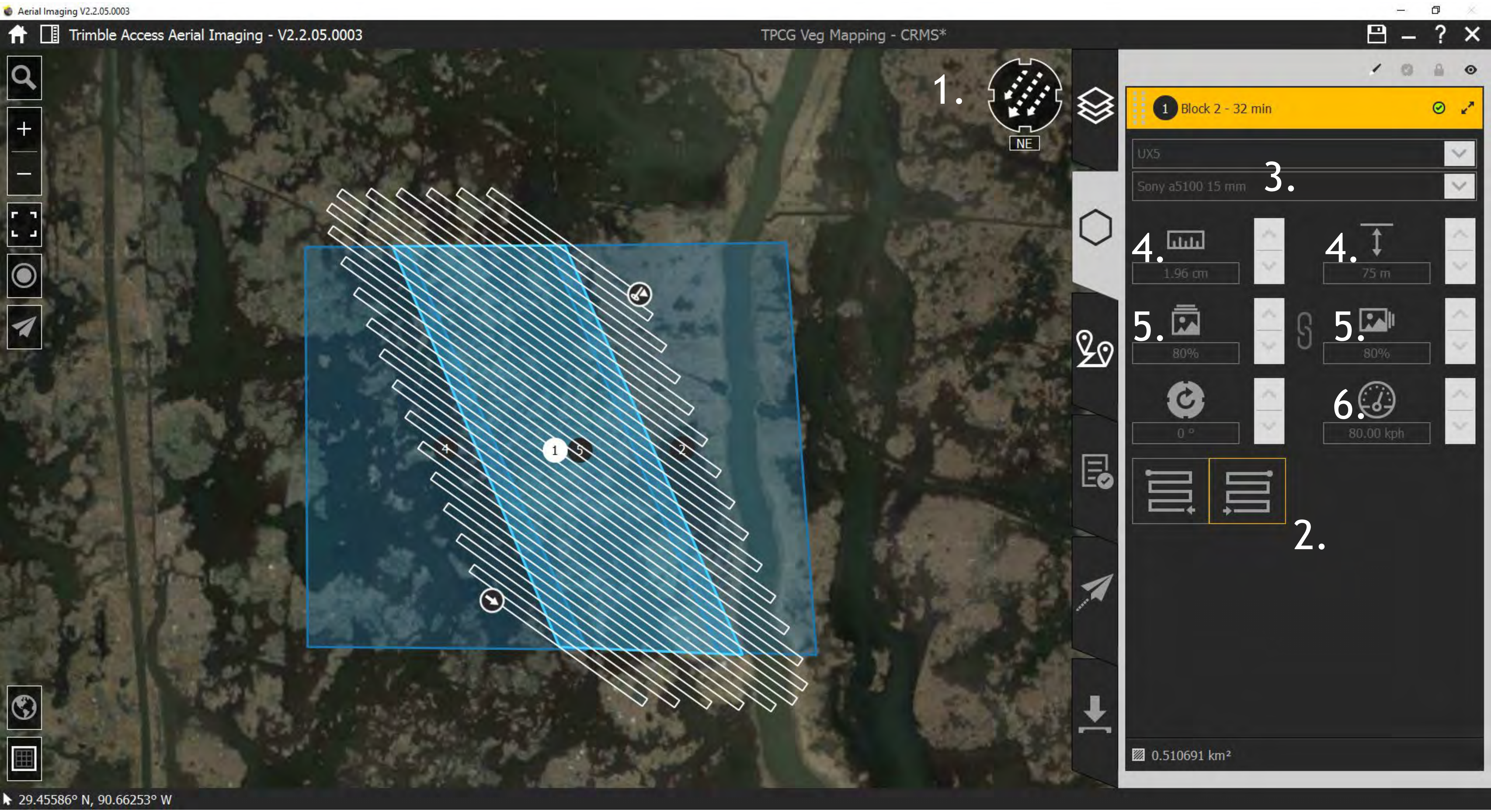


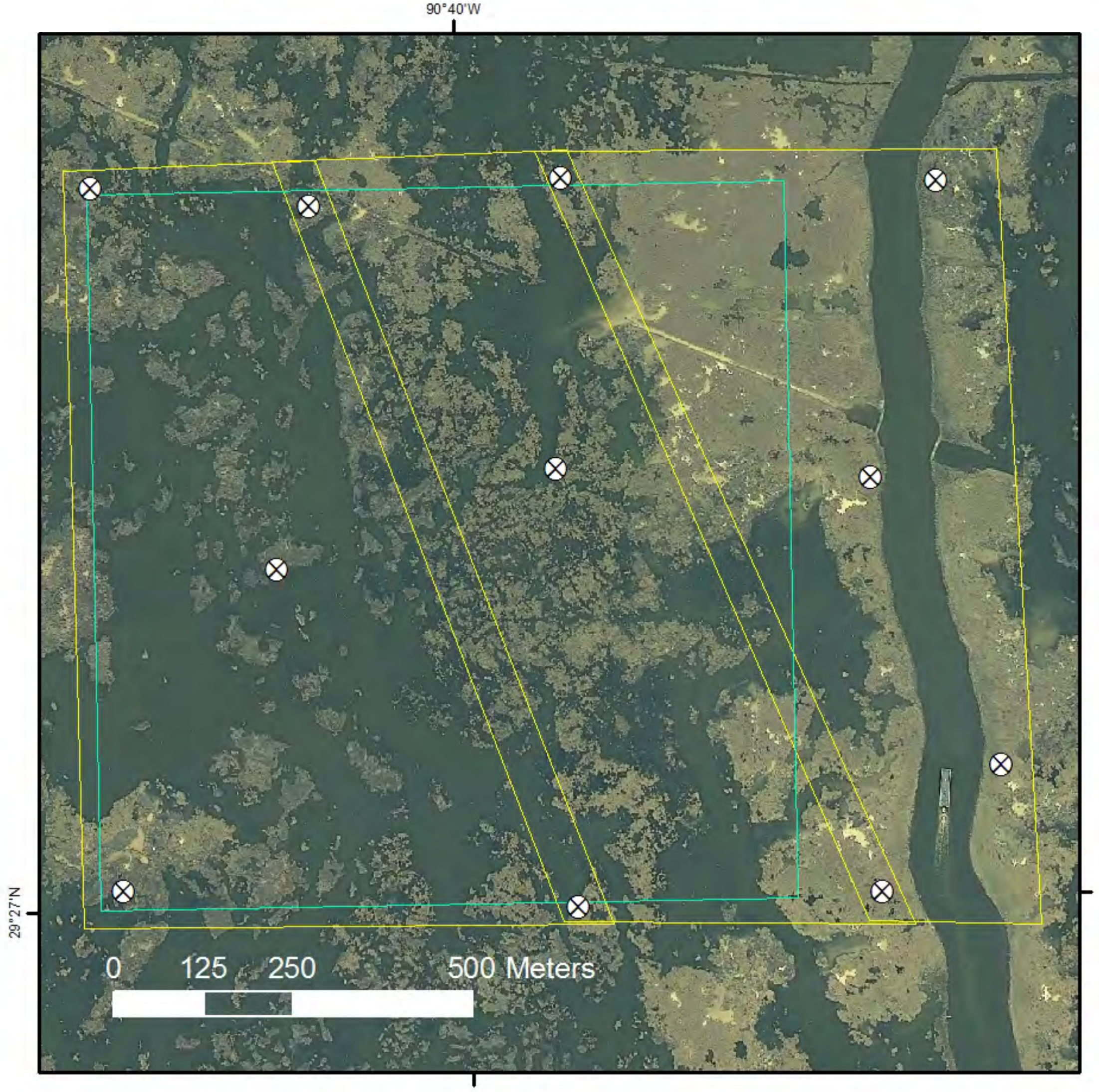


Aerial Imagery: Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA), 2008

FAA Part 107 compliant operations (DO NOT UNDERESTIMATE!)

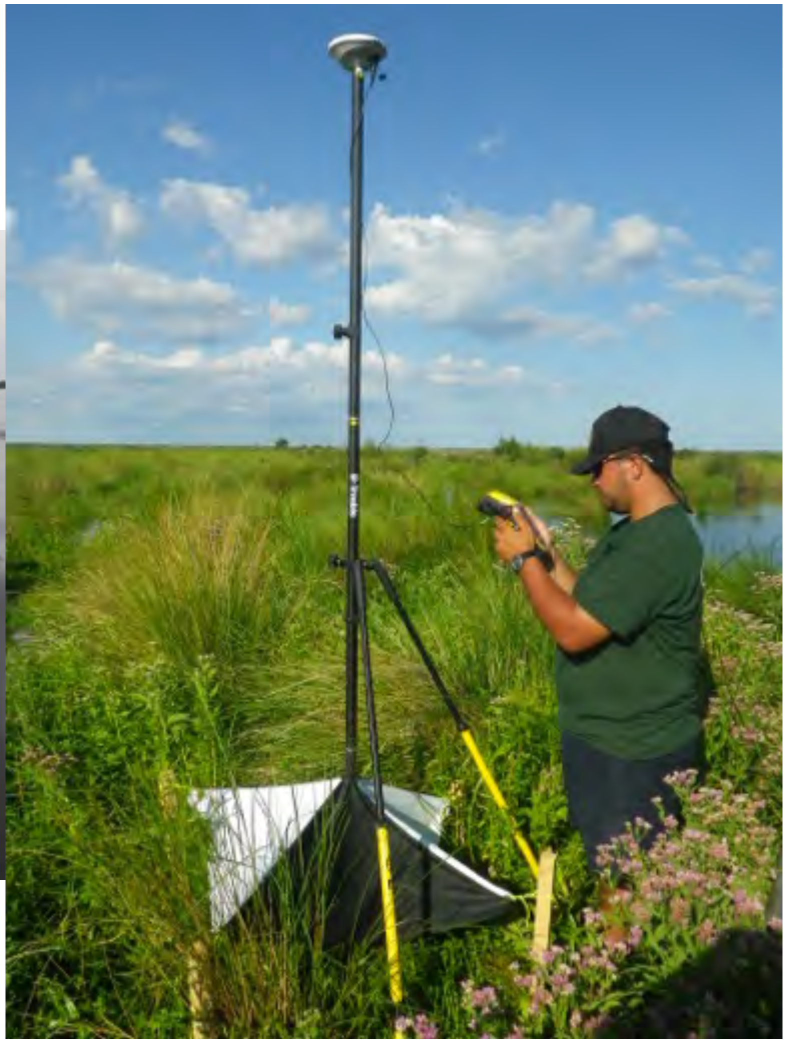
Flight Plan Software





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

Ground Control Points



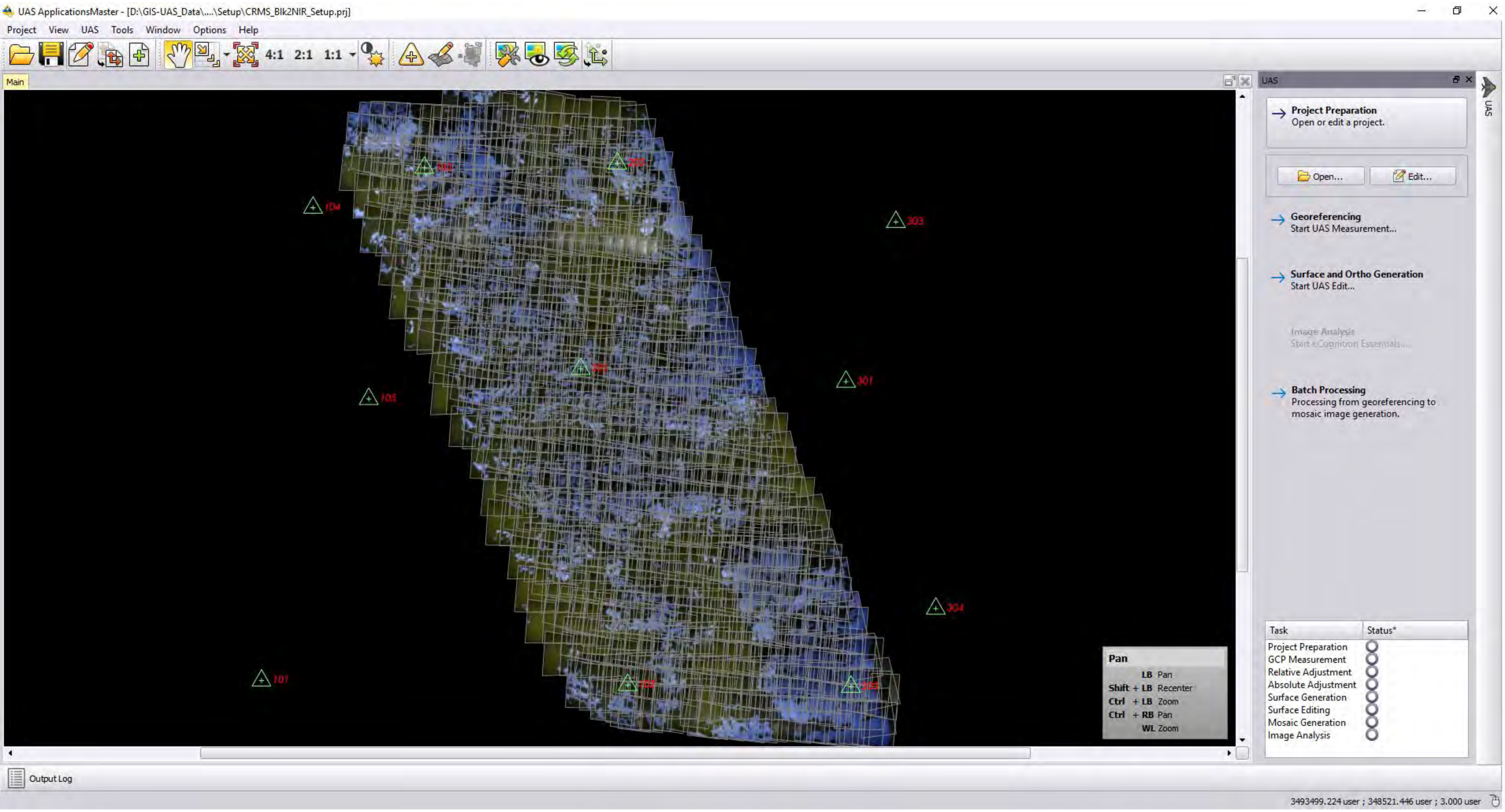
Take Off

Control Station

Chase home

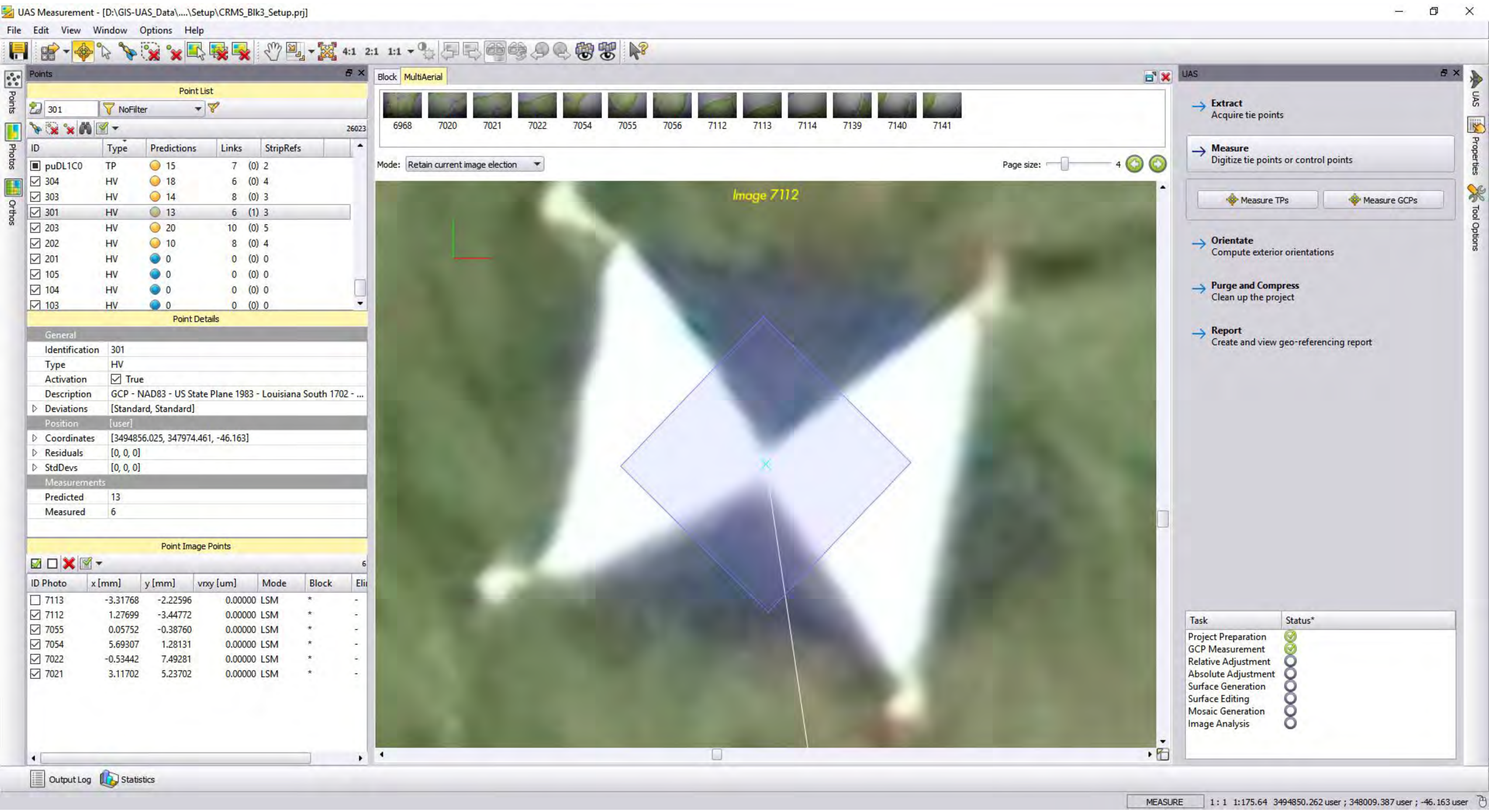
Belly land

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



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.

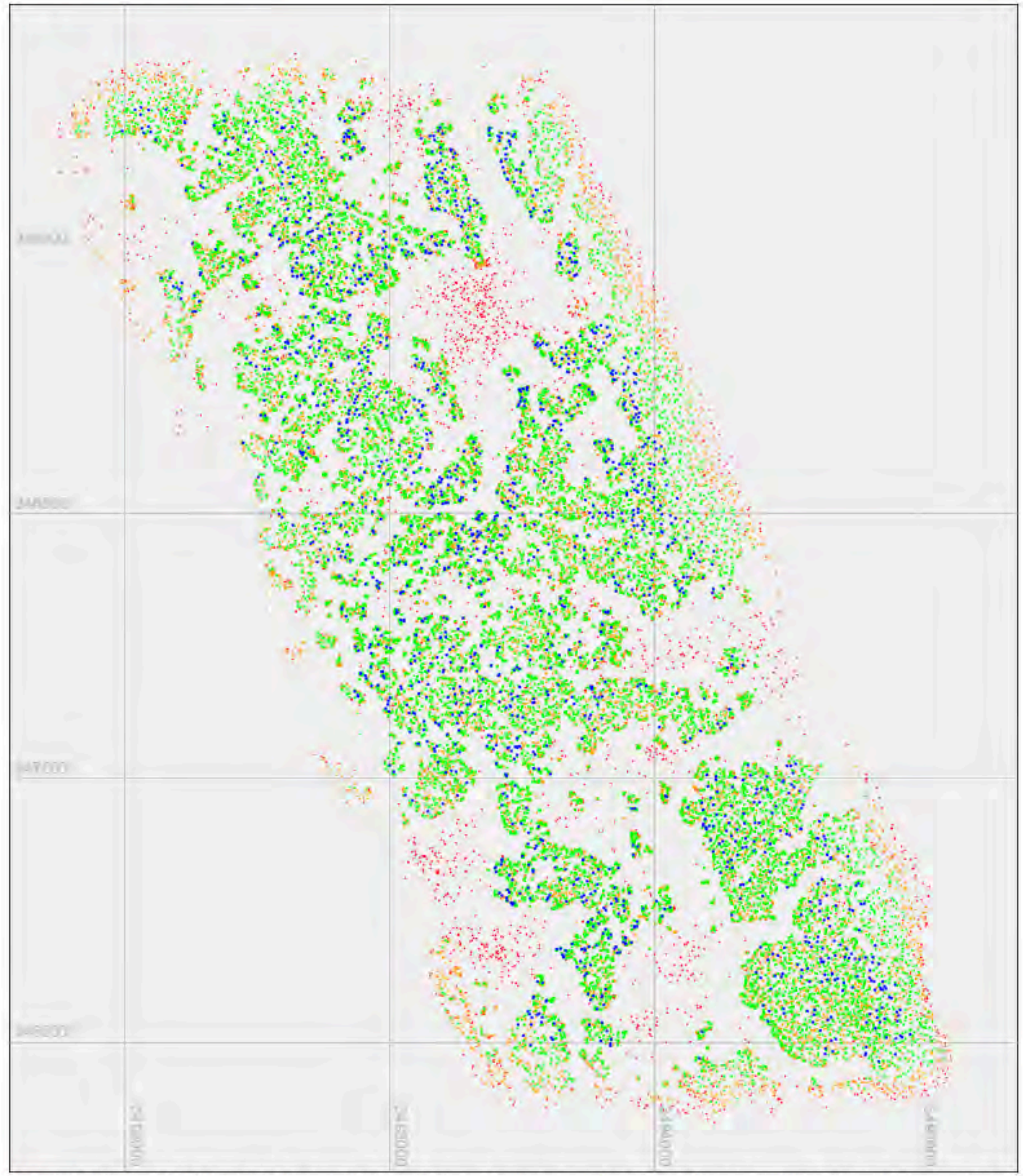
Post-Processing: Trimble UAS Master

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(RMSEx2 + RMSEy2)		
ACCr (95% Confidence Level)	4.83	RMSEr * 1.7308		
ACCz (95% Confidence Level)	4.74	RMSEz * 1.9600		

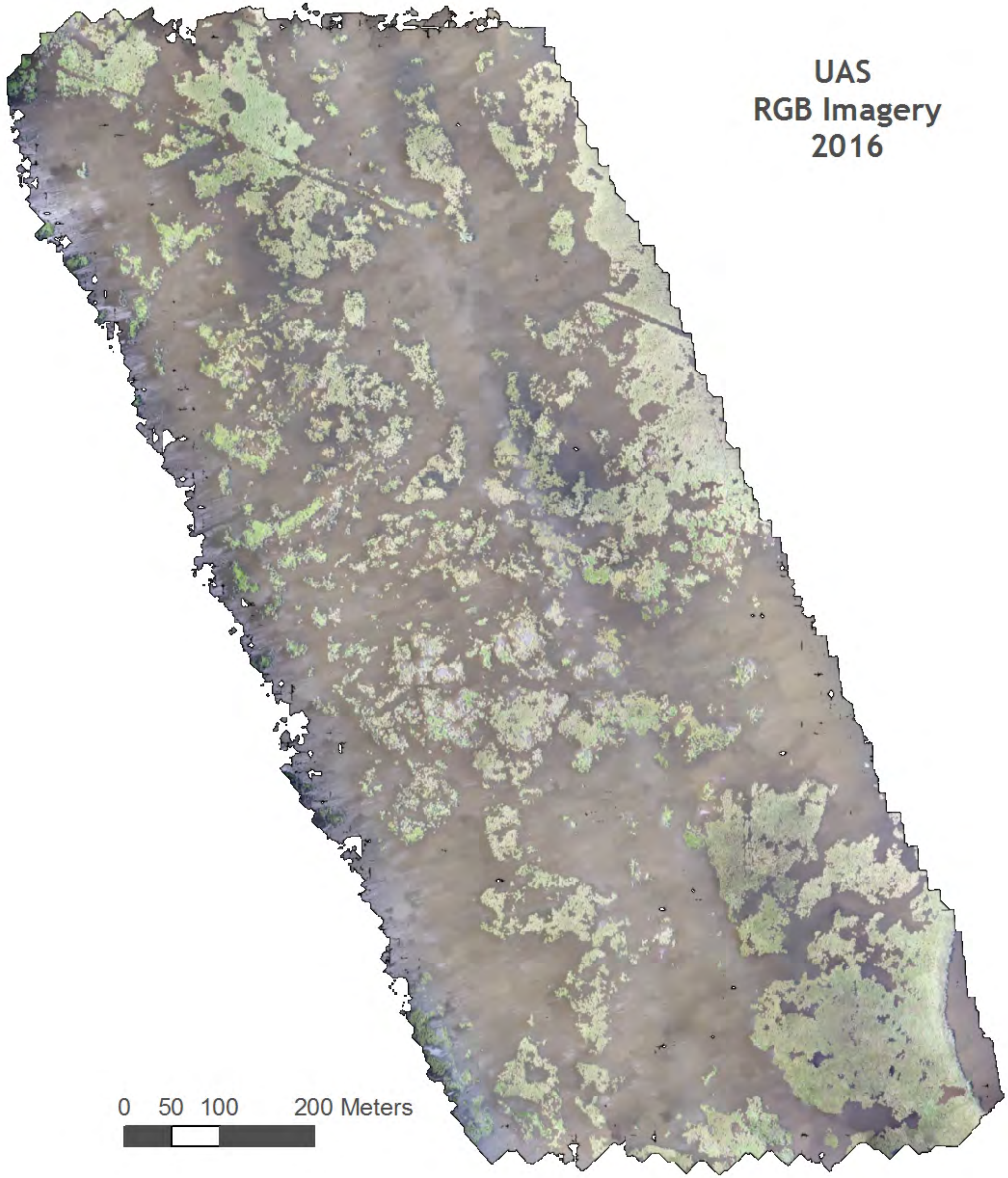
Trimble UAS

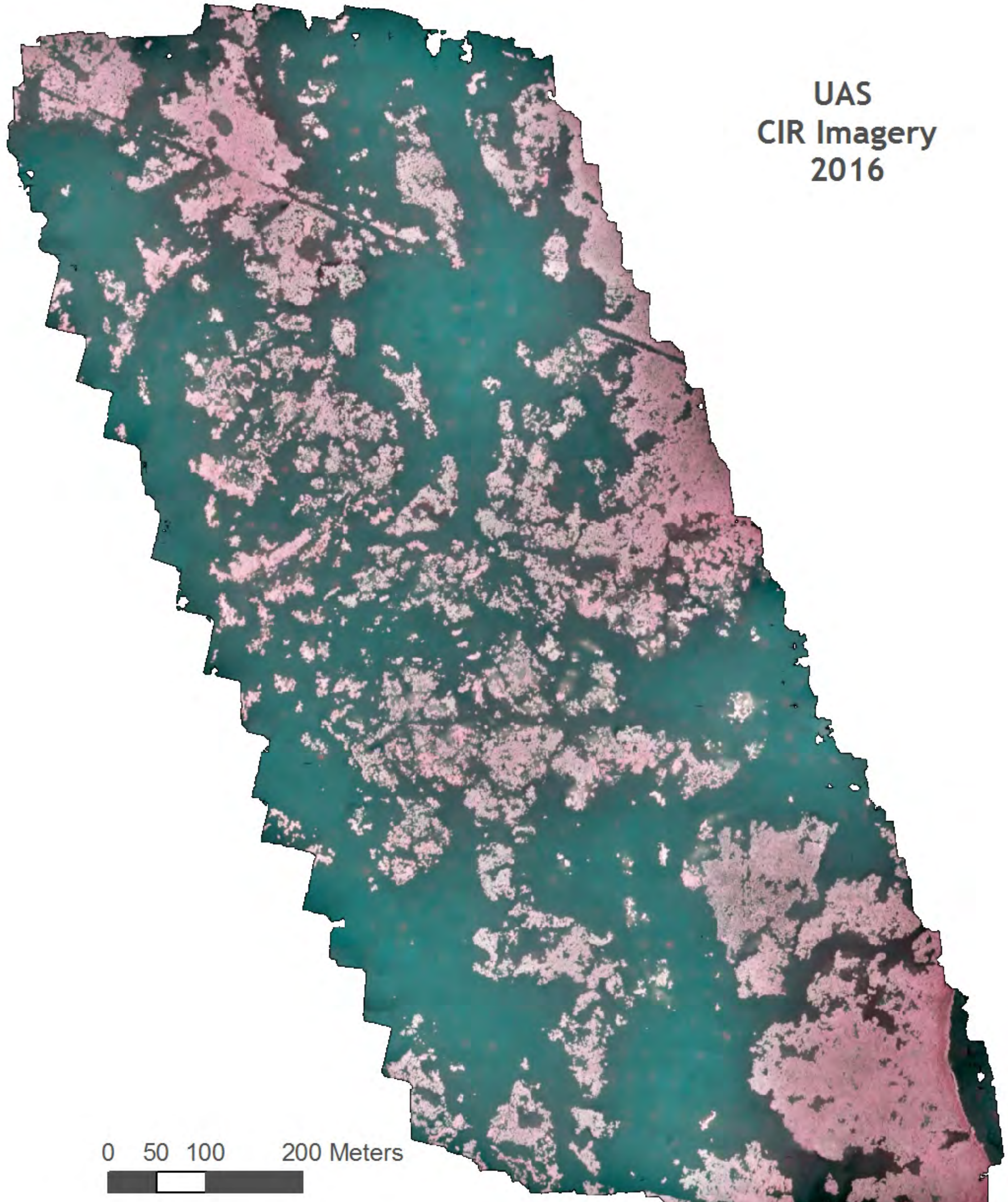
Tie point distribution

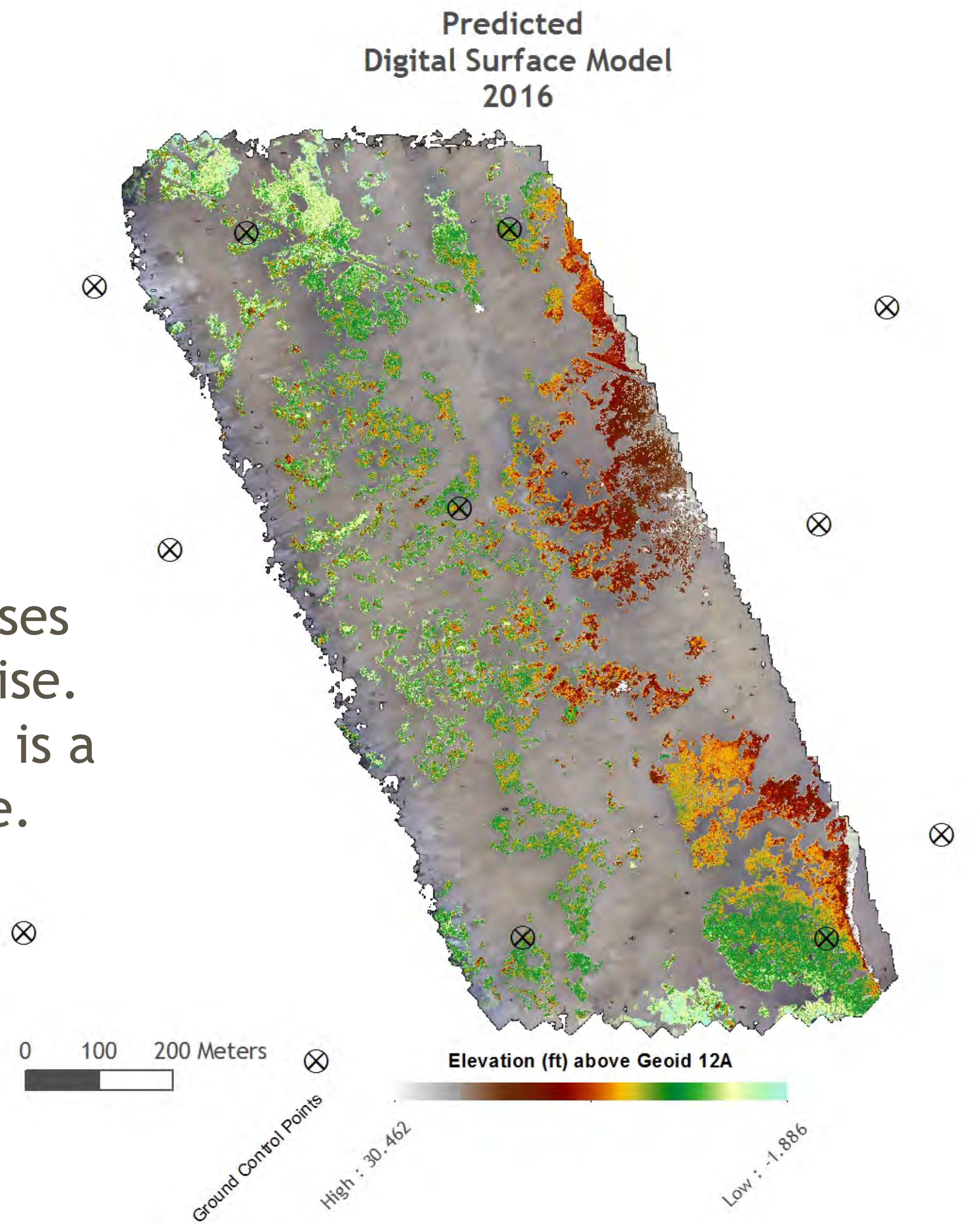


Tie point distribution of 37896 points in the project. The point size and colour reflects the number of images containing the point. The area has a planimetric extent of about: 3742 x 4413 [user] and a height range of about: -21 - 23 [user].

- : 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



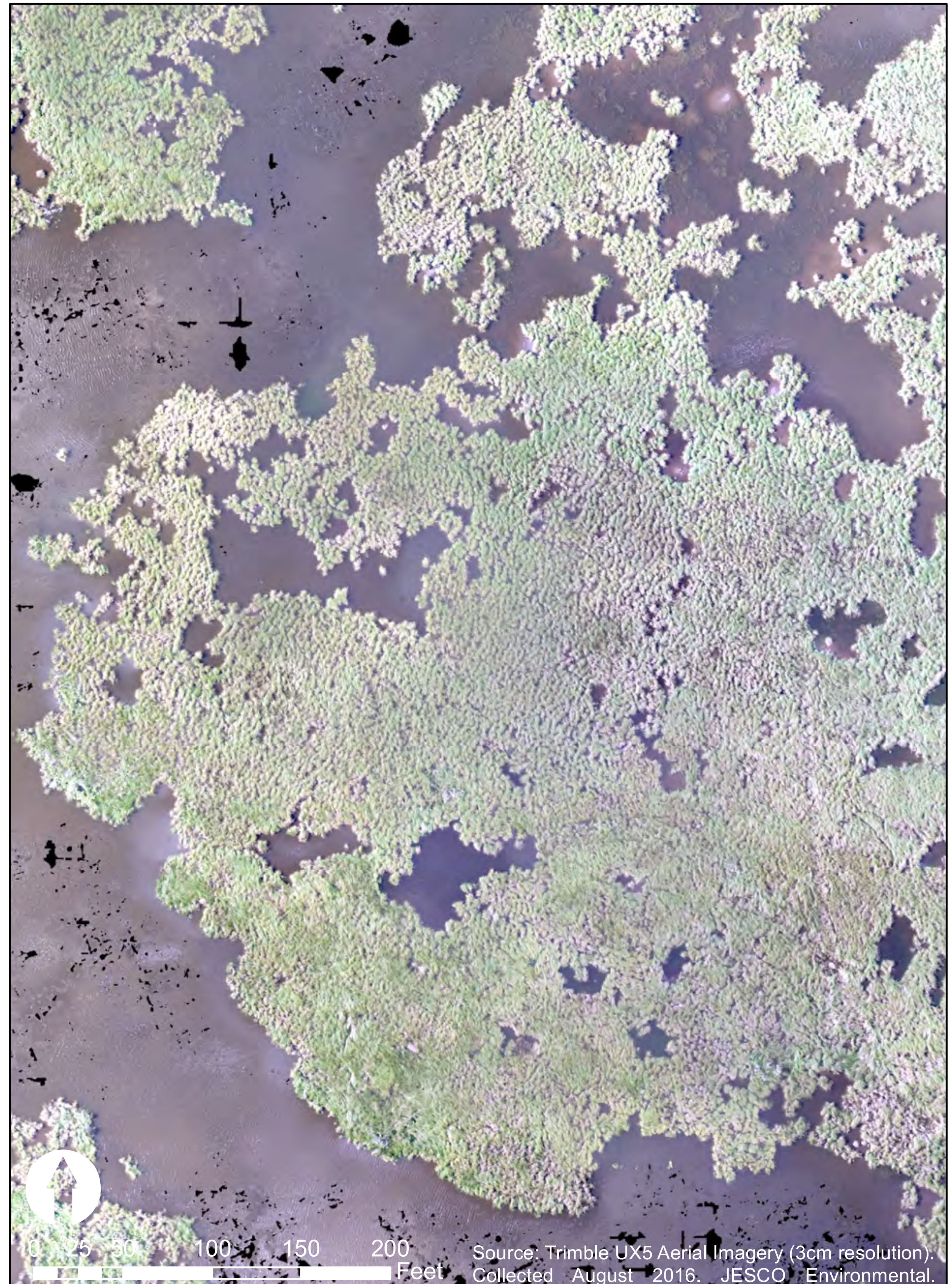
Marsh grasses show promise. Open water is a challenge.

Orthomosaic

Horizontal accuracy
(95% Confidence)
4.83cm

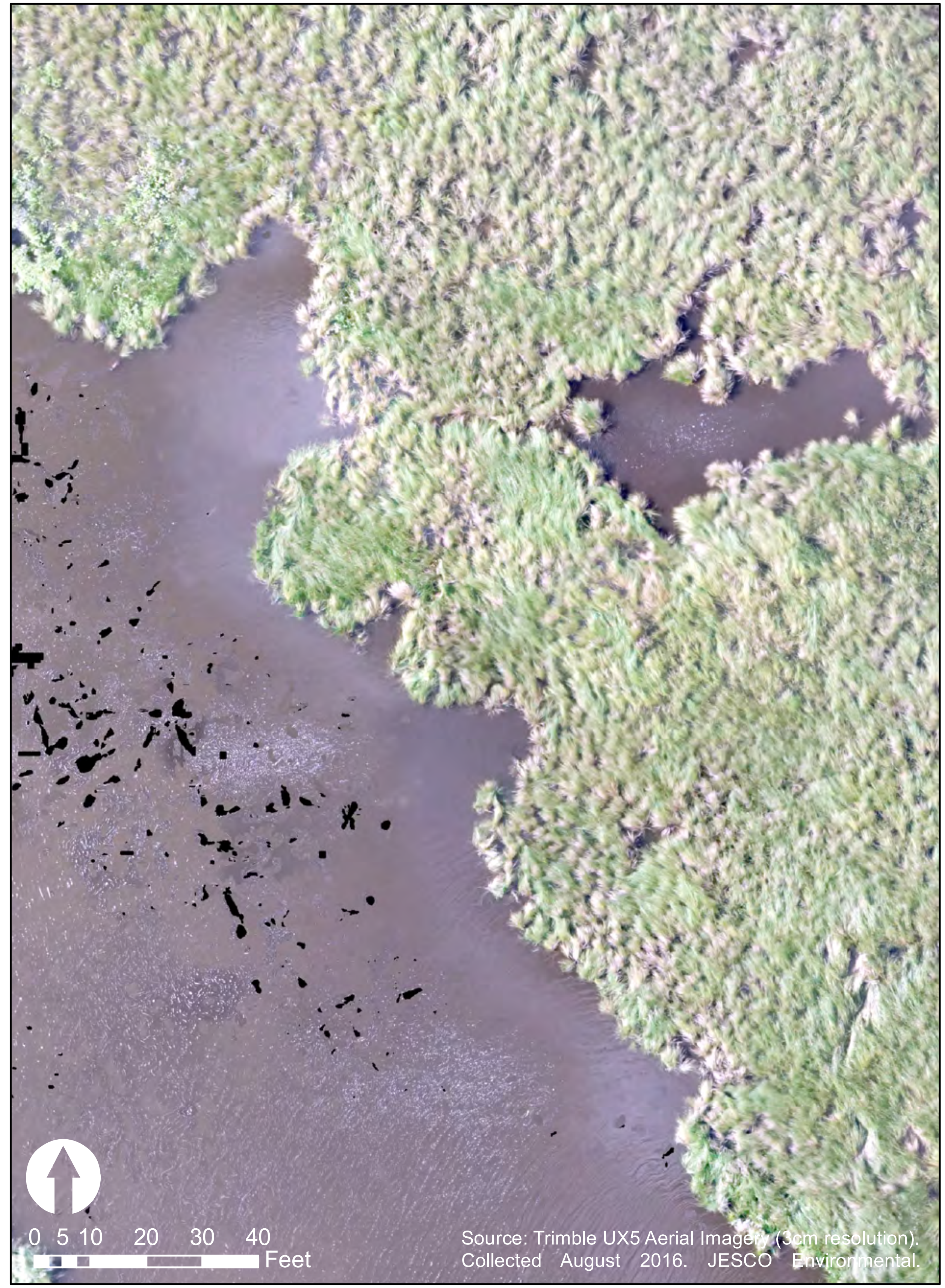
Vertical accuracy
(95% Confidence)
4.74cm

Orthomosaic



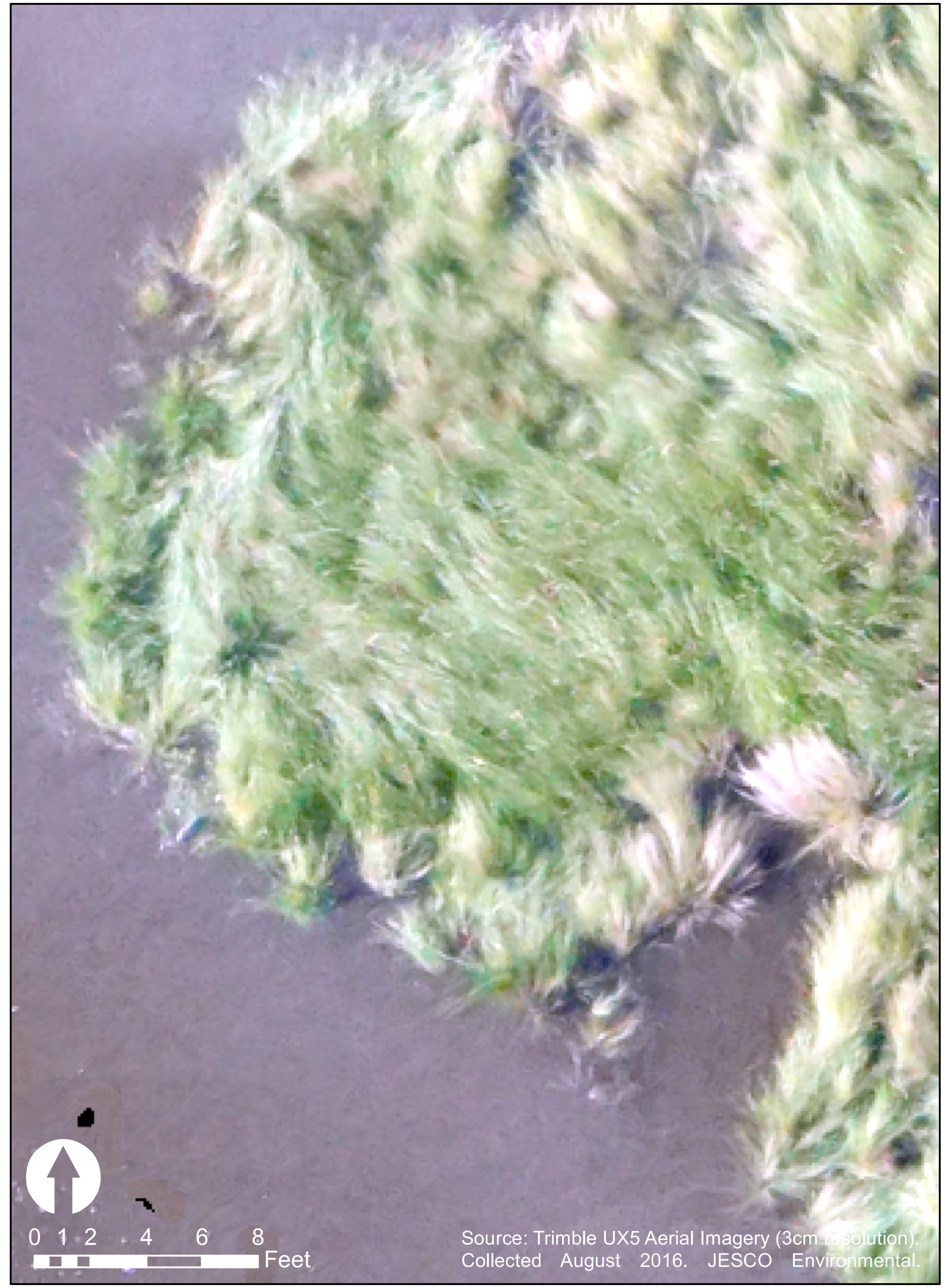
Orthomosaic

Orthomosaic



Orthomosaic

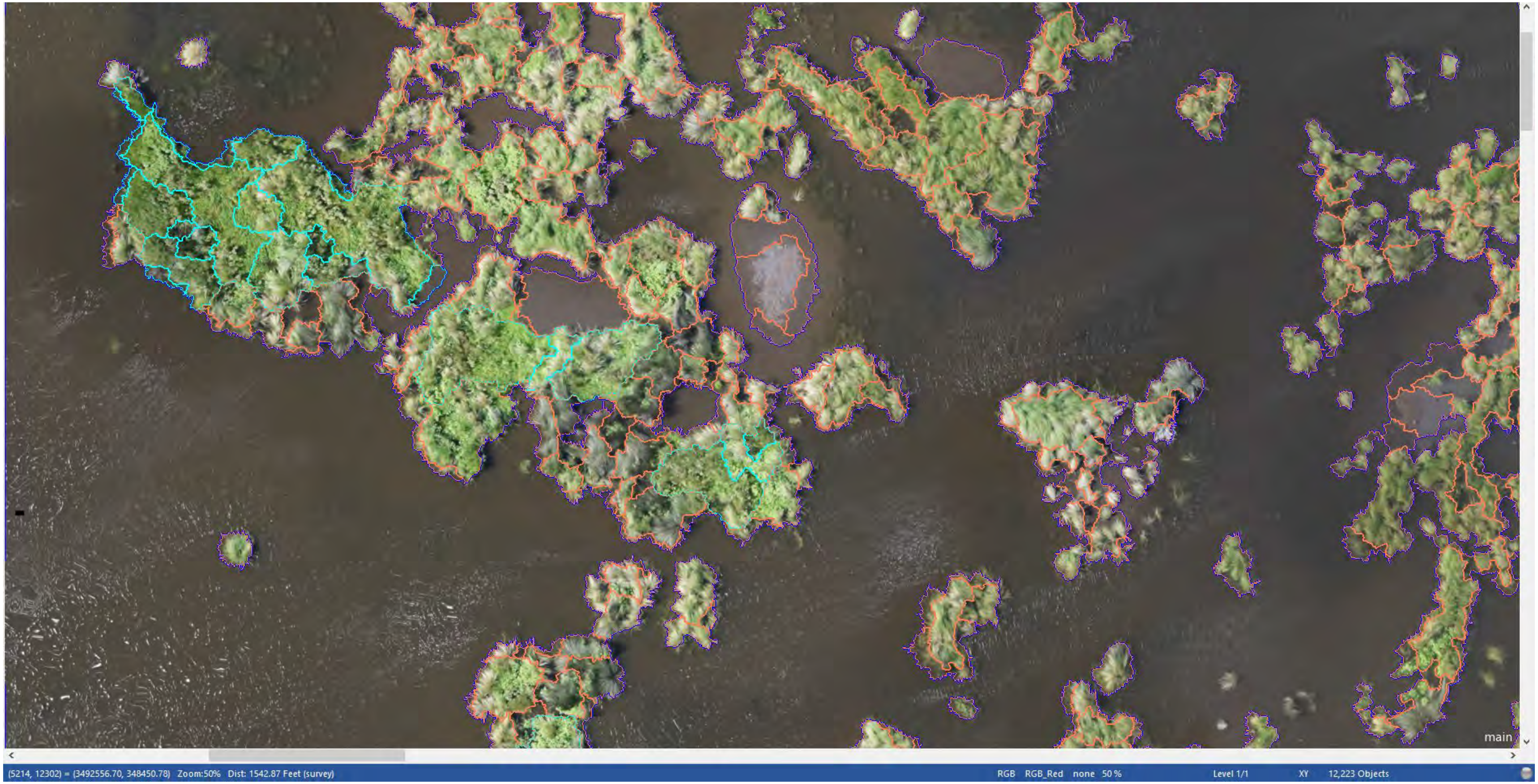
Orthomosaic



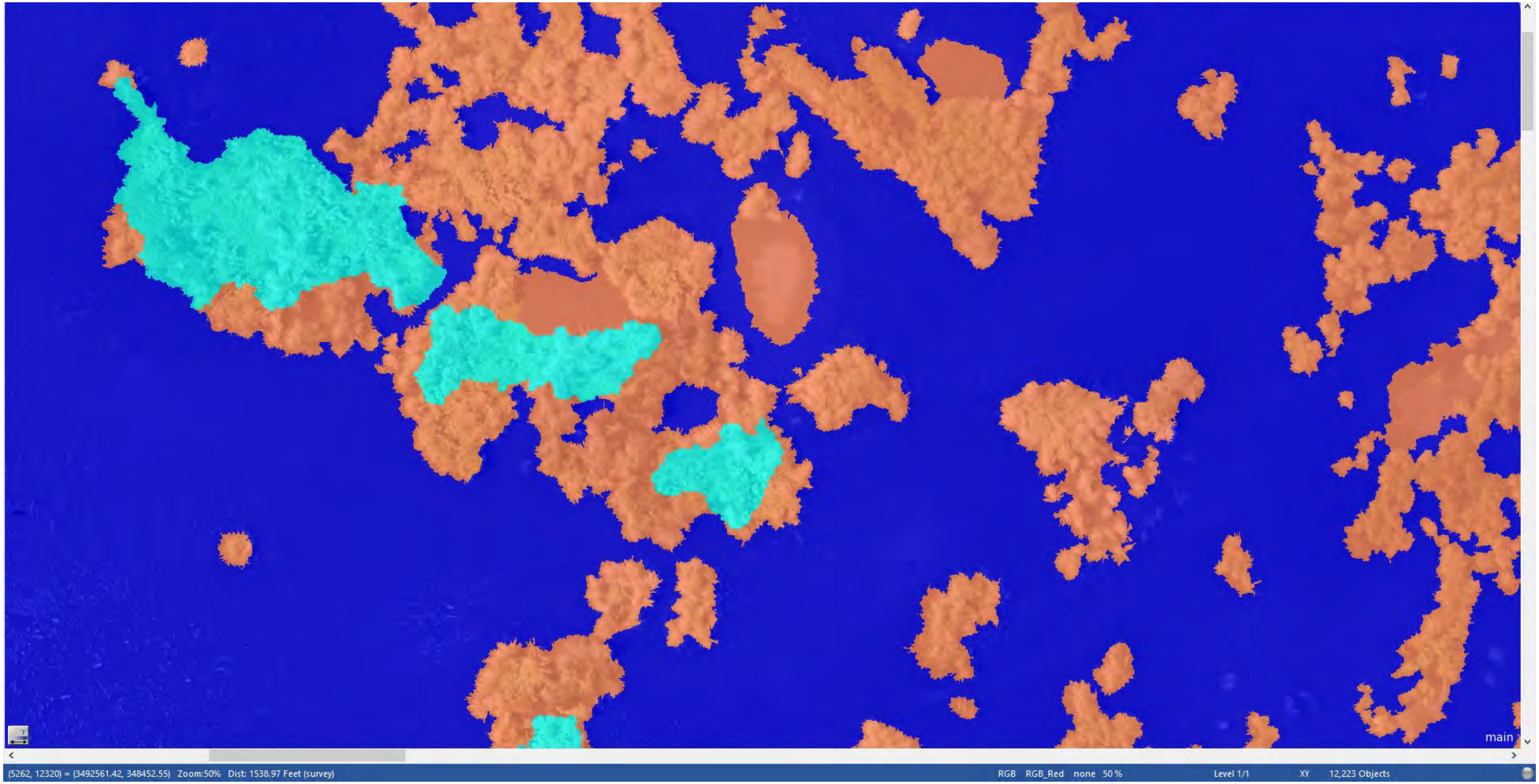
Object Based Image Analysis

- 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).

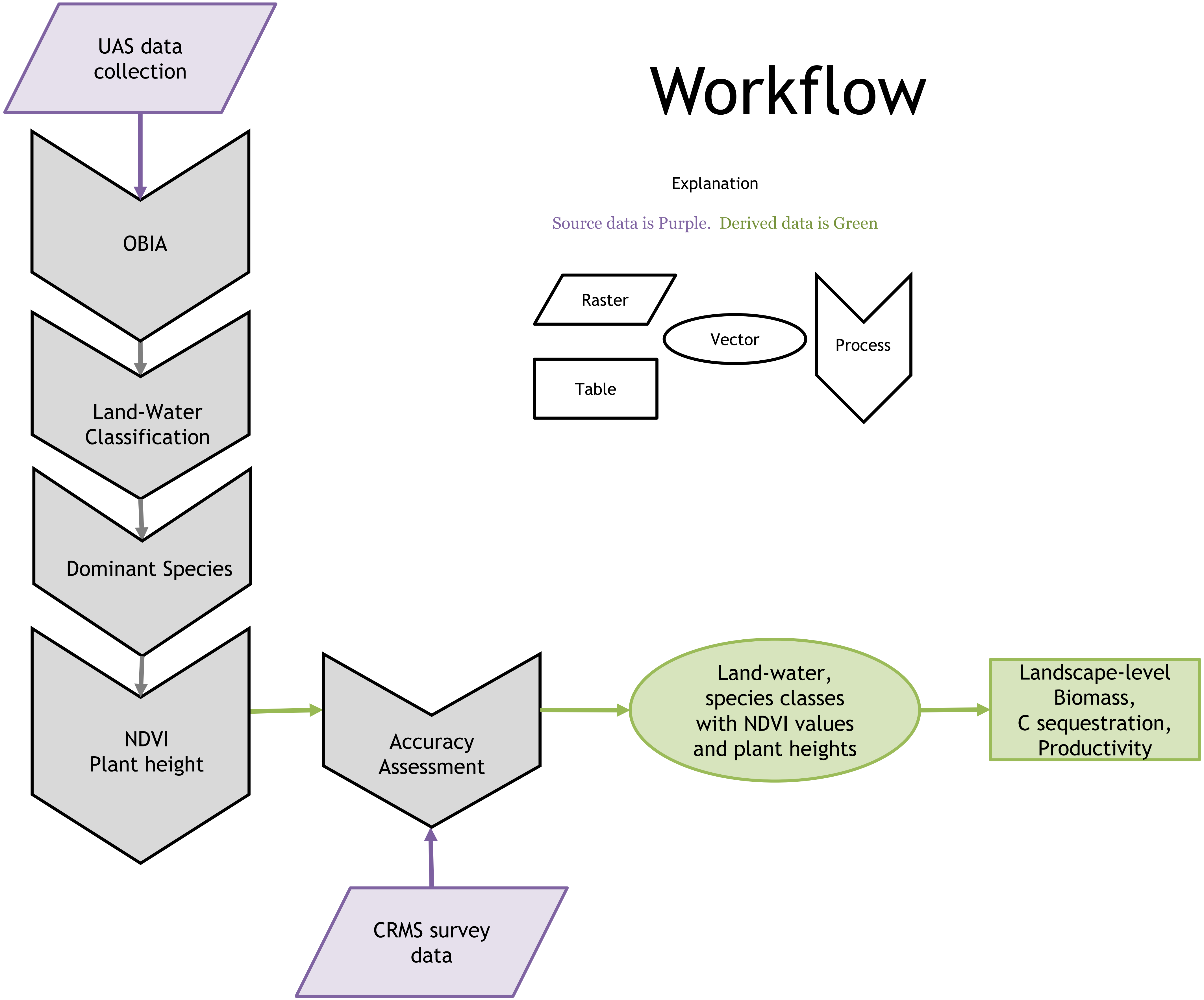
Object Based Image Analysis (multispectral segmentation)



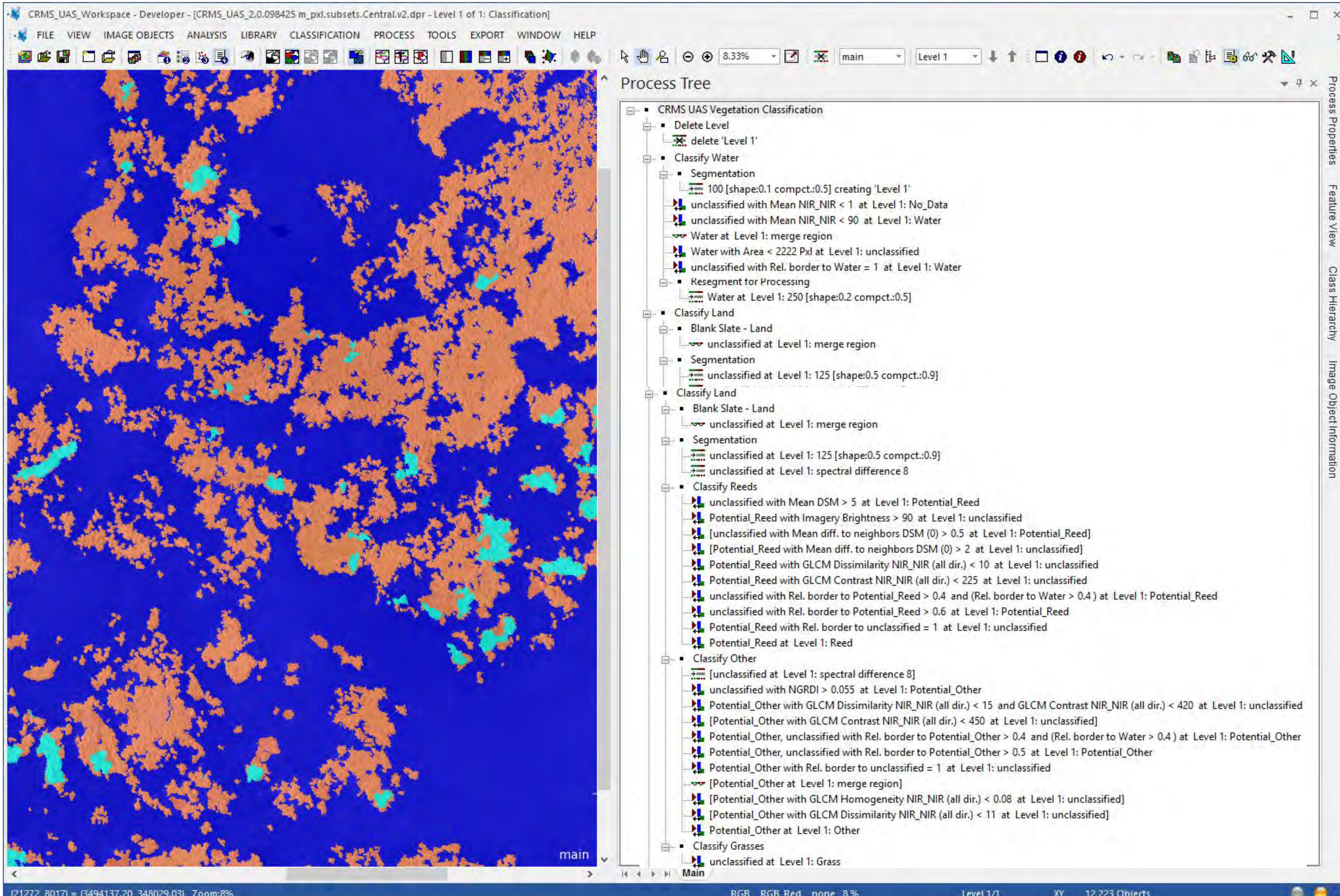
Object Based Image Analysis (multispectral segmentation)

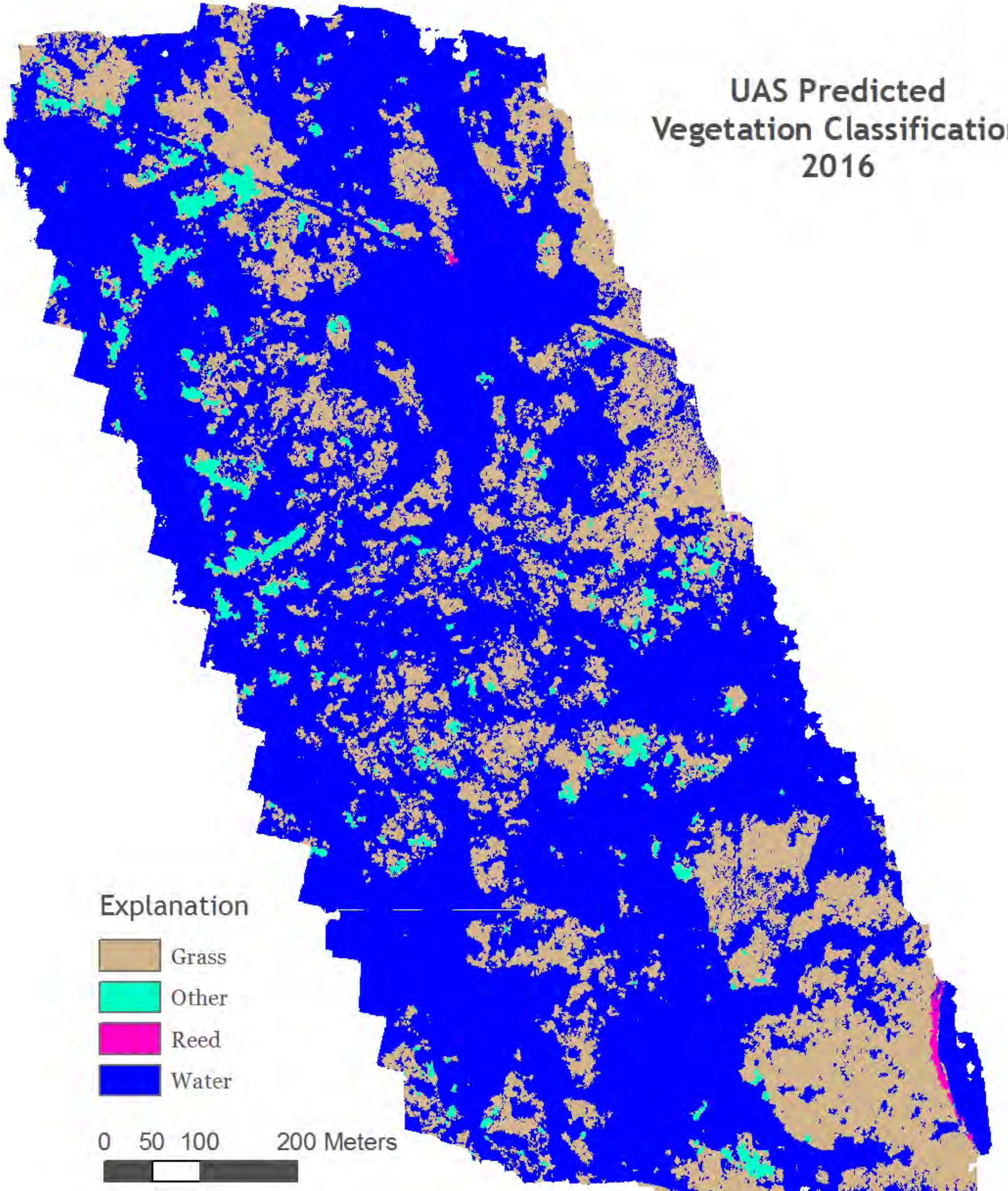


Workflow


UAS data collection
OBIA
Land-Water Classification
Dominant Species
NDVI
Plant height
Accuracy Assessment
CRMS survey data
Land-water, species classes with NDVI values and plant heights
Landscape-level Biomass, C sequestration, Productivity
Explanation
Source data is Purple. Derived data is Green
Raster
Vector
Process
Table

Object Based Image Analysis (multispectral segmentation)




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

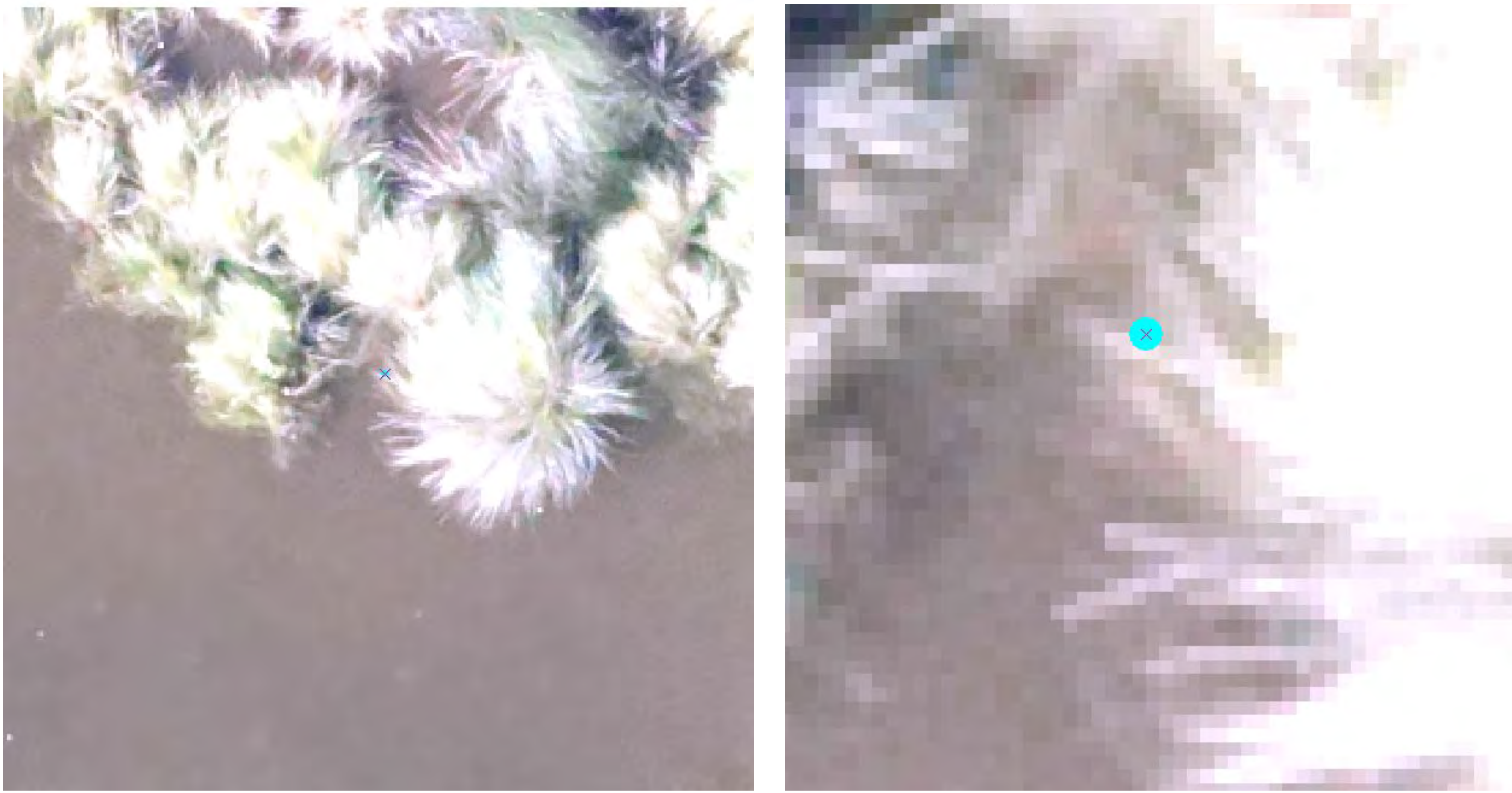
Reference Class

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%		

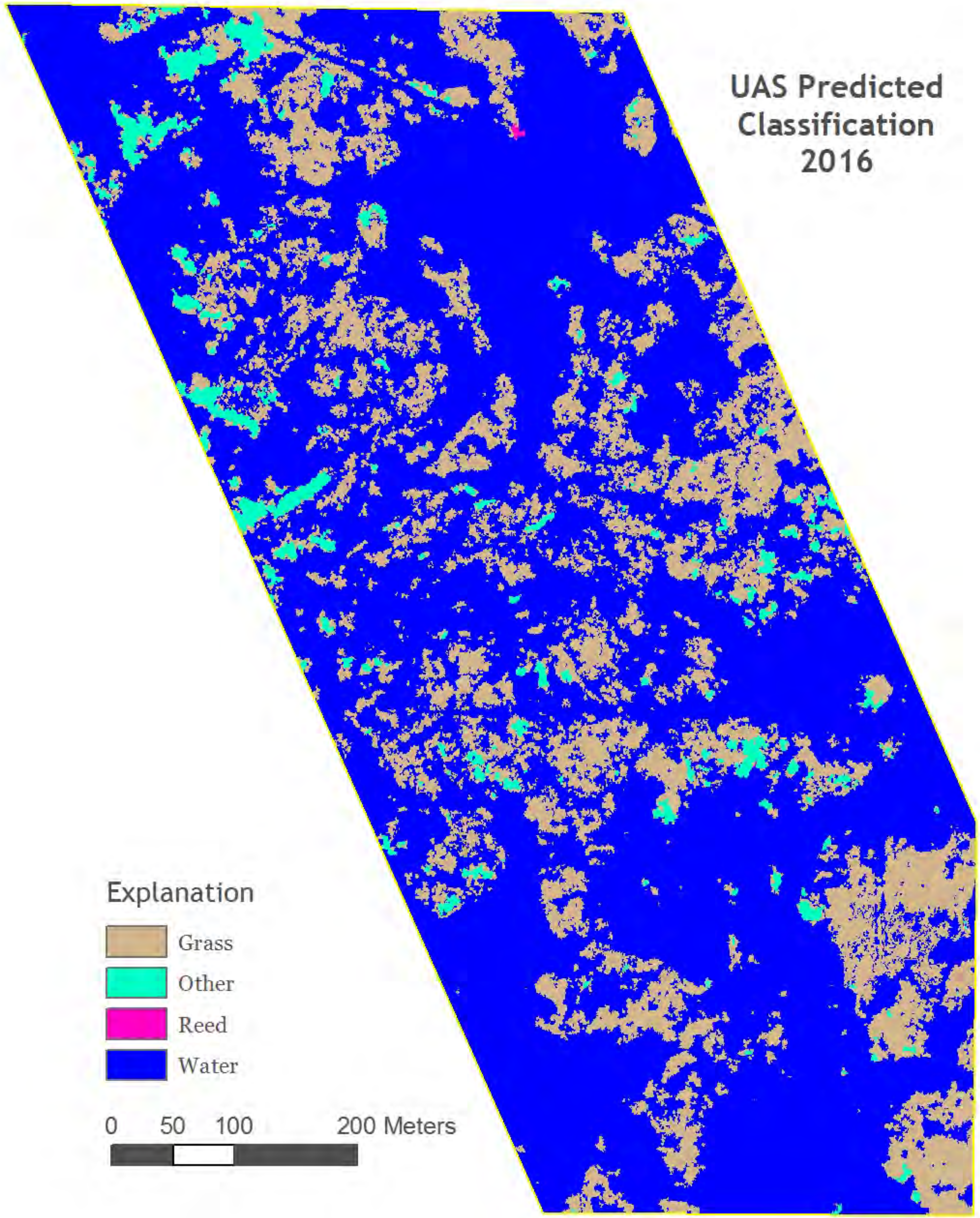
Overall Accuracy: 85%
Kappa Coefficient: 0.78

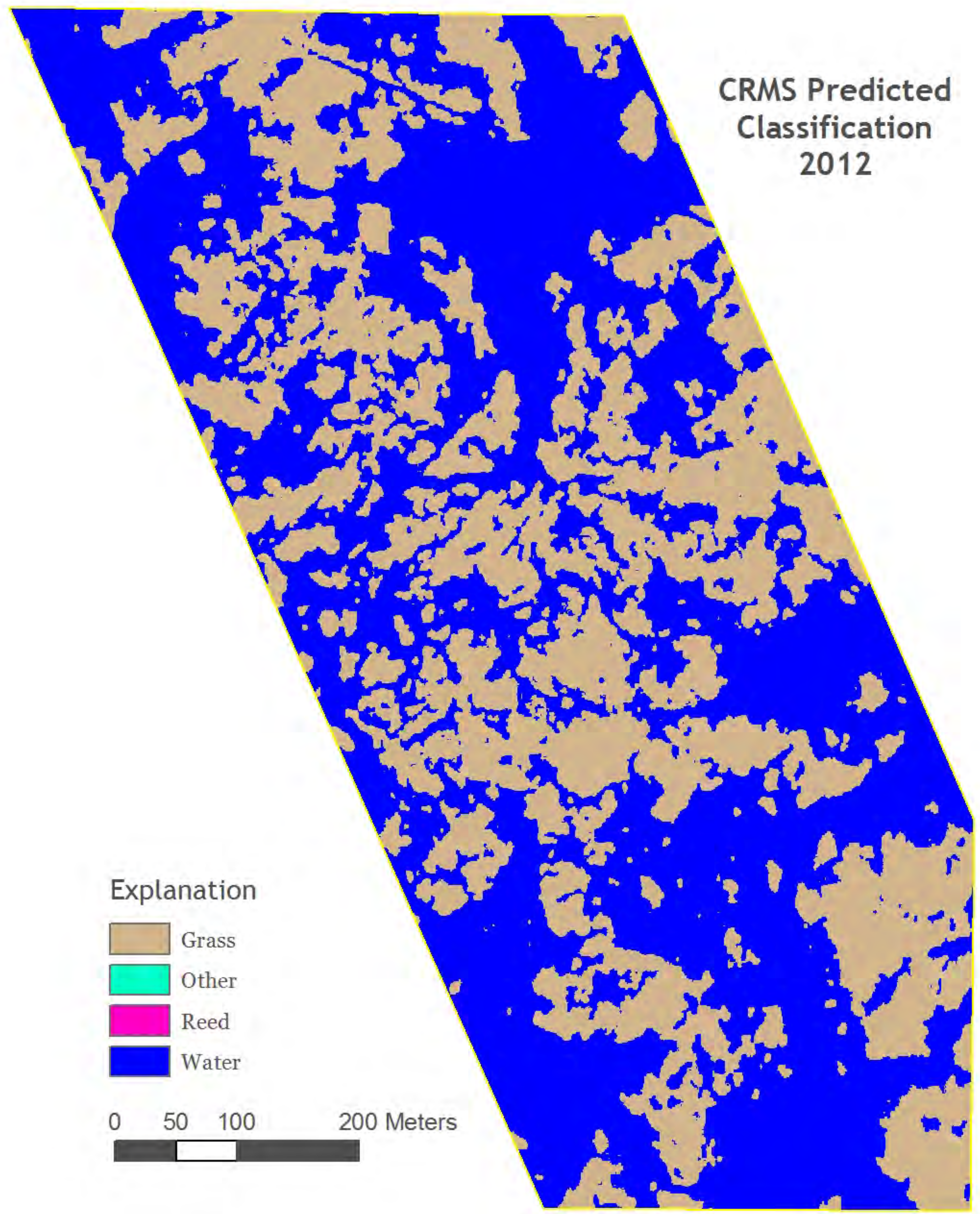
Challenges with land-water interface and high resolution imagery

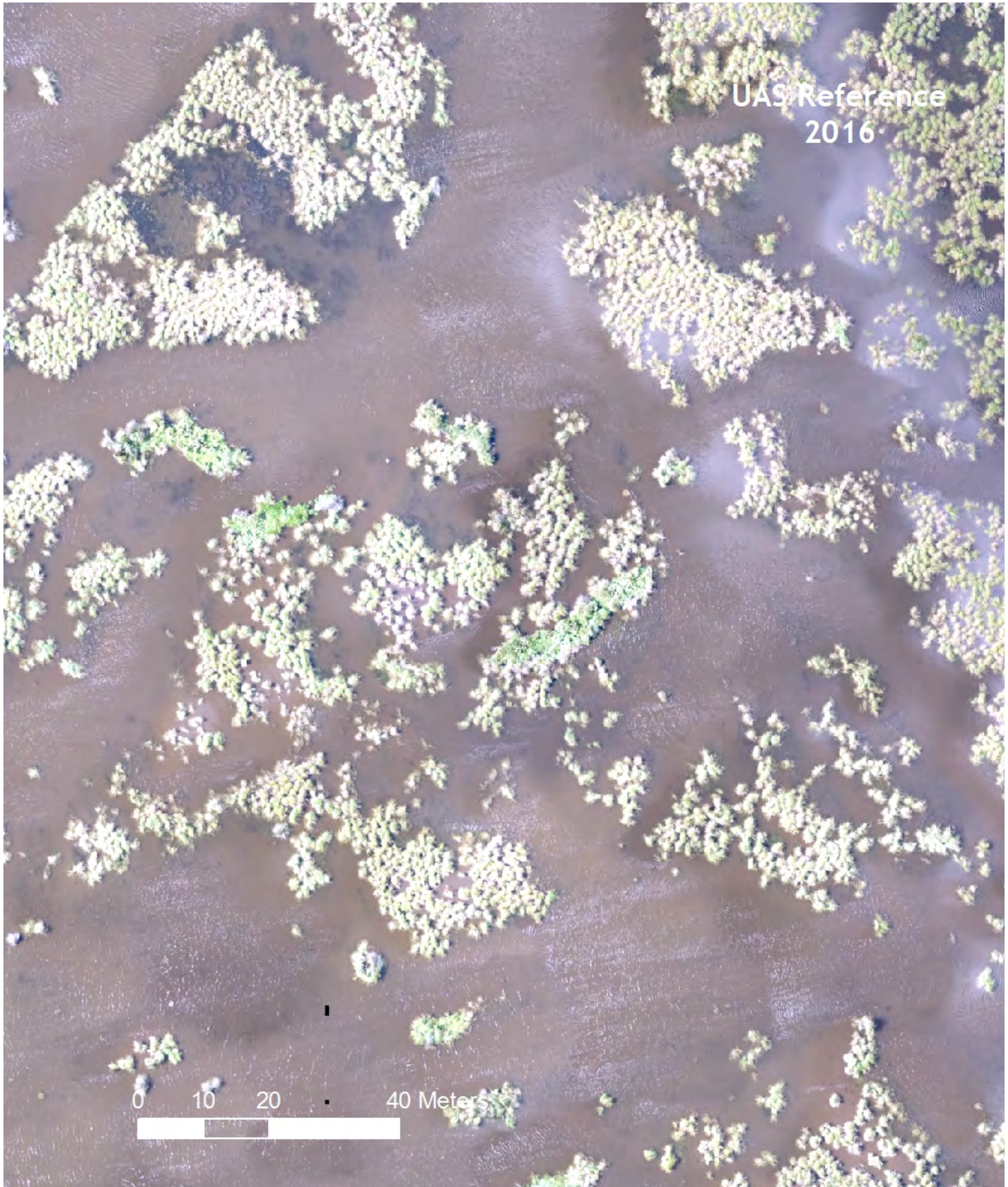


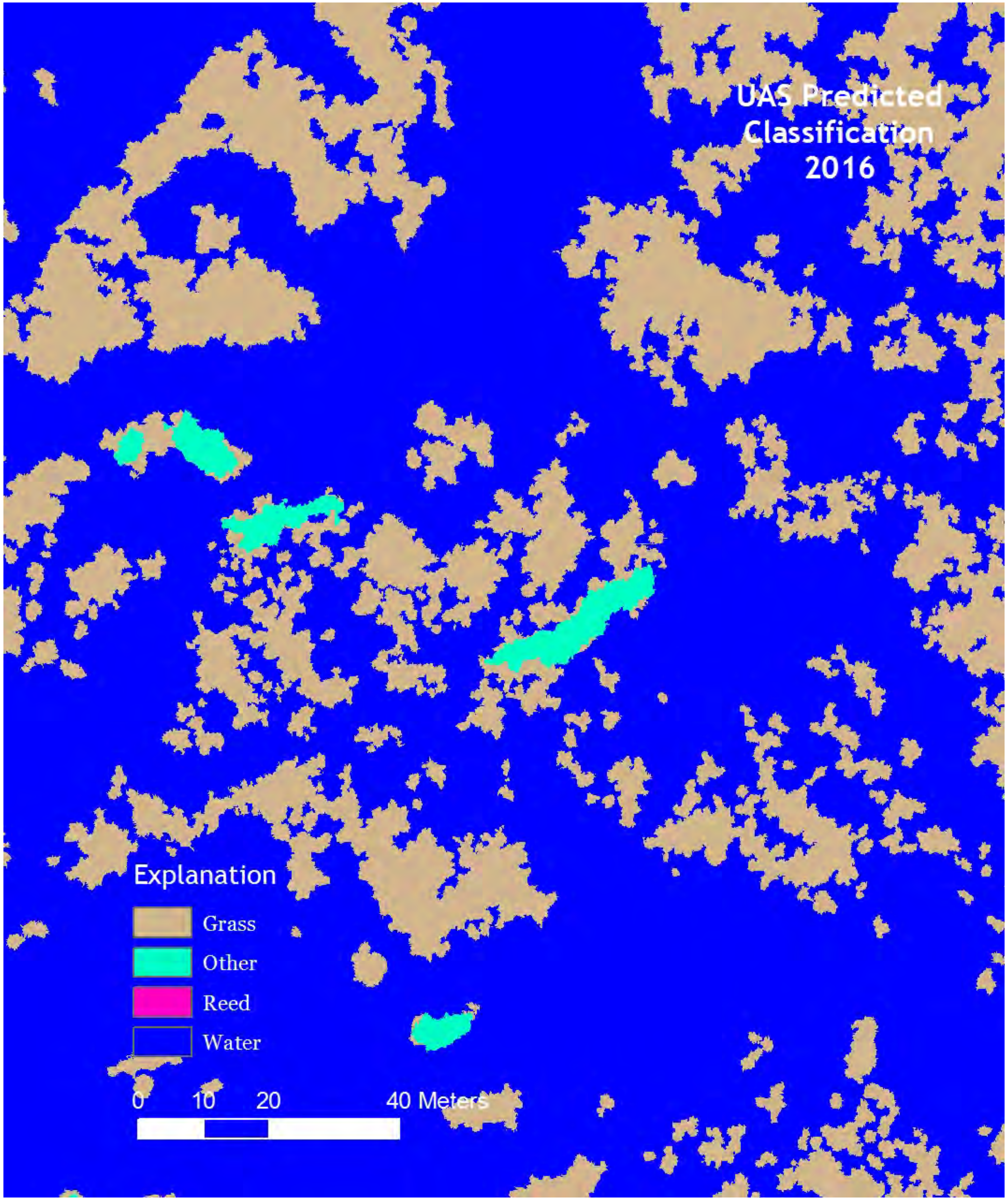
OBIA classified this point as land, but high res imagery shows vegetation extending over water

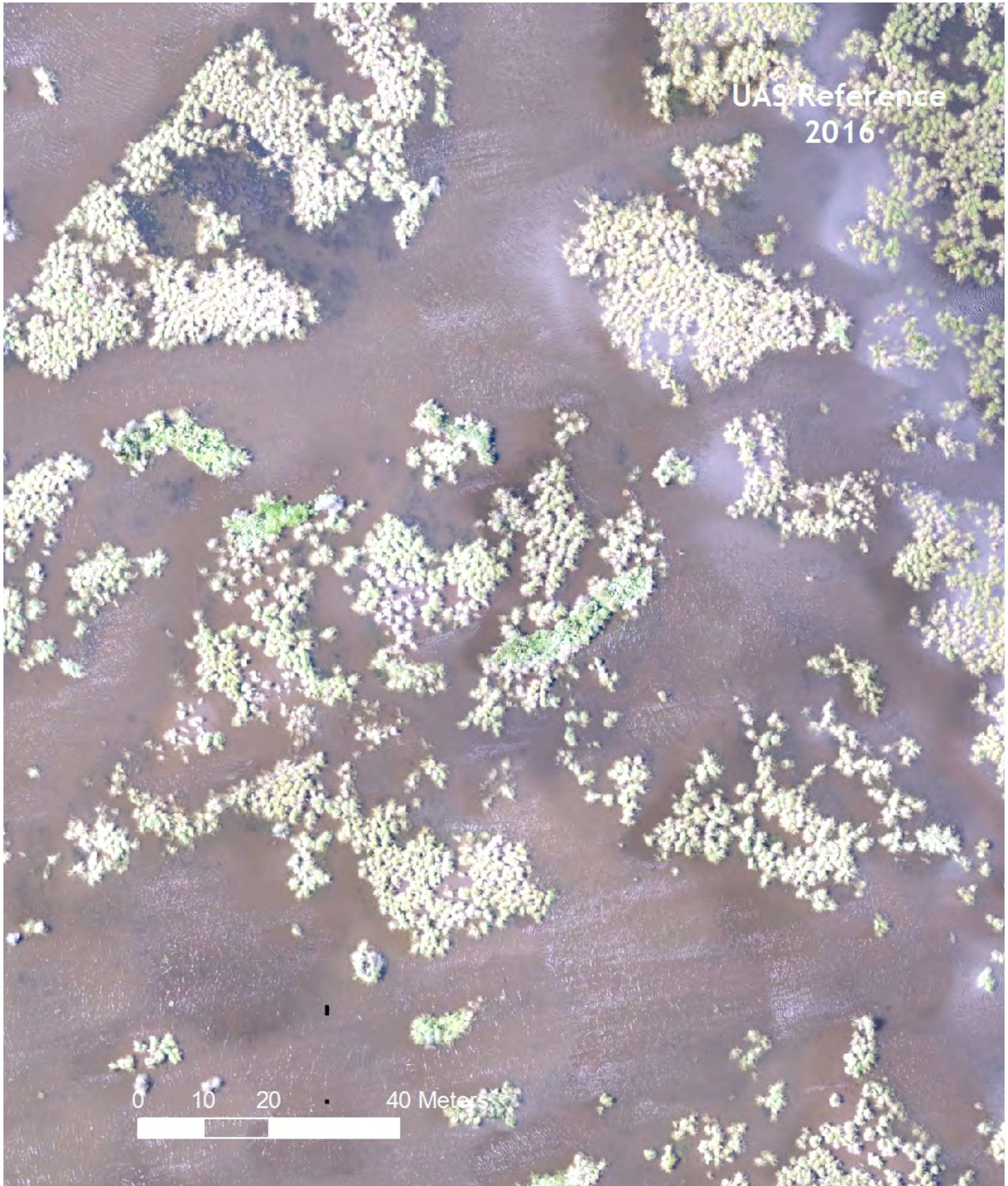
Comparisons with CRMS Data



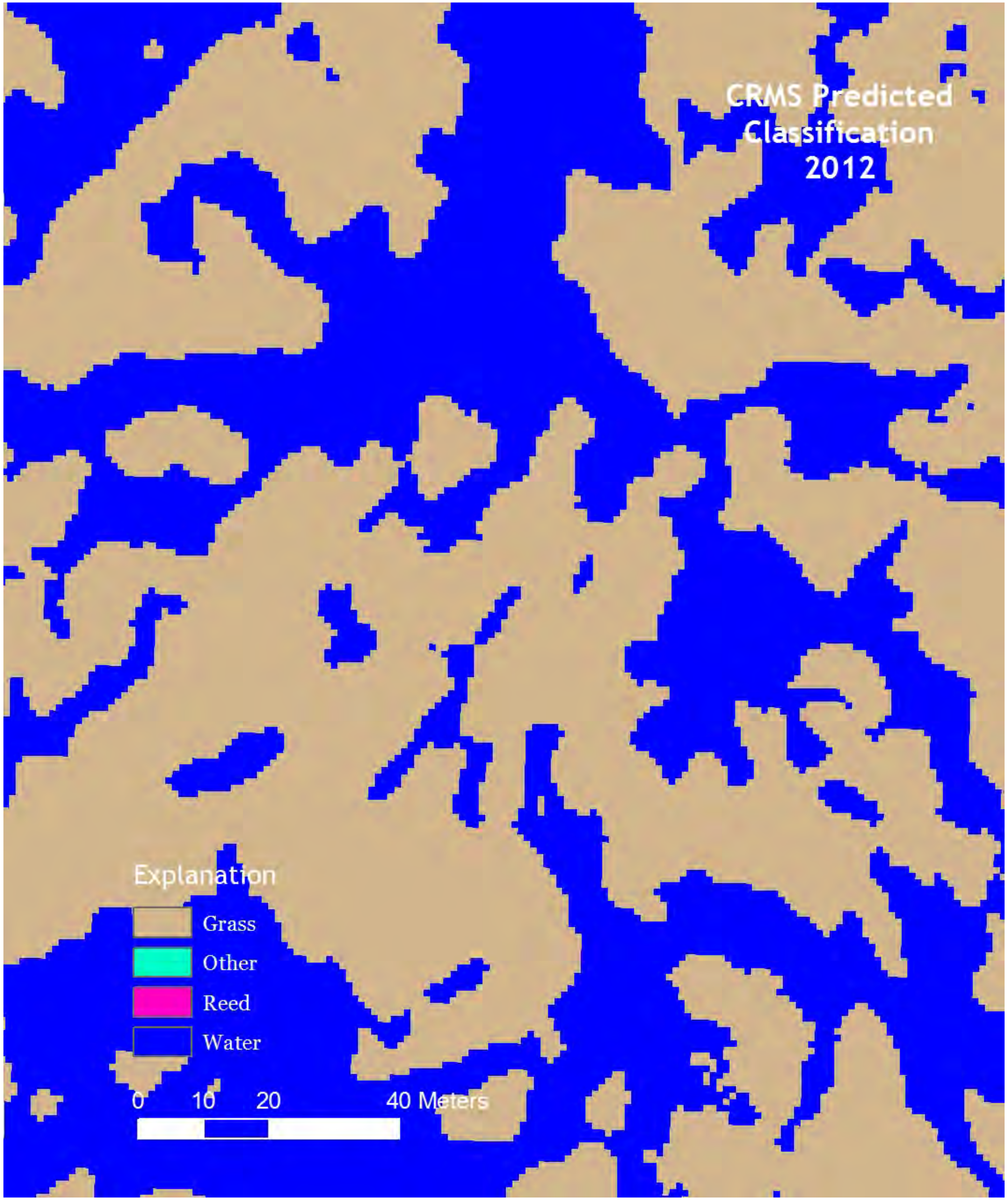

CRMS Predicted
Classification
2012
Explanation
Grass
Other
Reed
Water
0
50
100
200 Meters


UAS Reference
2016
0 10 20 40 Meters


UAS Predicted Classification 2016
Explanation
Grass
Other
Reed
Water
0 10 20 40 Meters

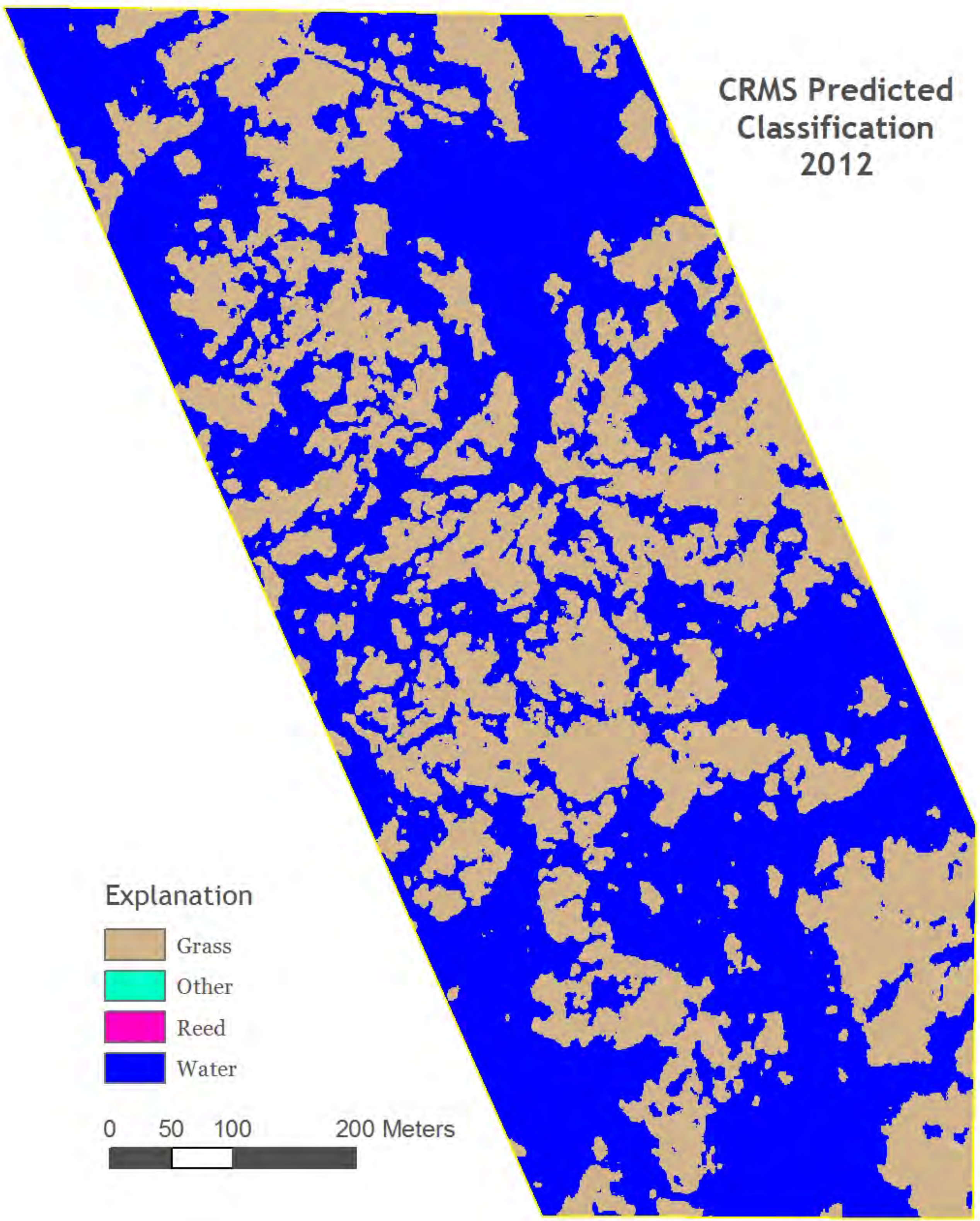


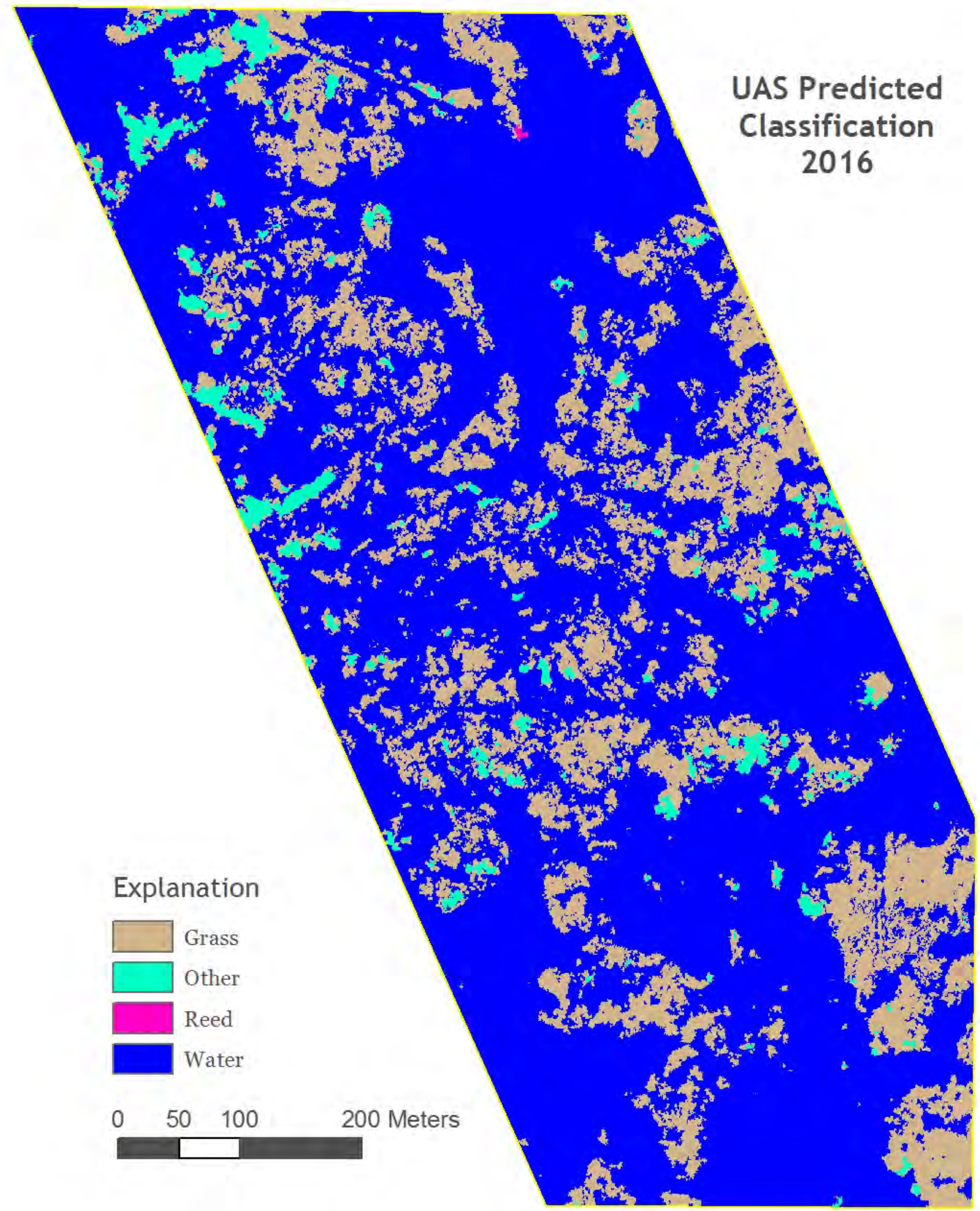
UAS Reference
2016
0
10
20
40 Meters


CRMS Predicted
Classification
2012
Explanation
Grass
Other
Reed
Water
0
10
20
40 Meters

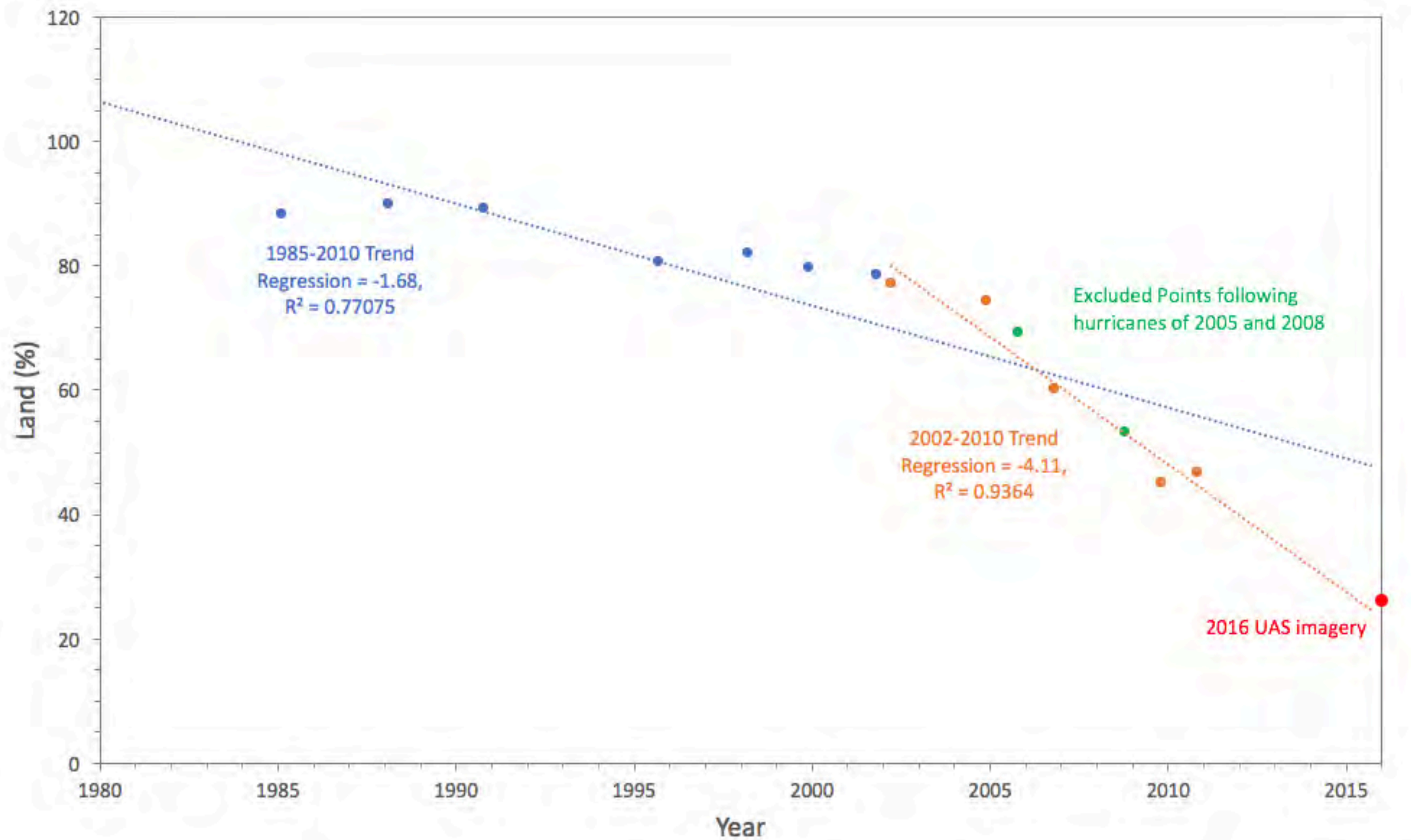
CRMS Spatial Data – Land/Water Analysis

	Land		Water	
	CRMS	UAS	CRMS	UAS
Area (sq. km)	0.2	0.12	0.27	0.35
Percent	42%	26%	58%	74%



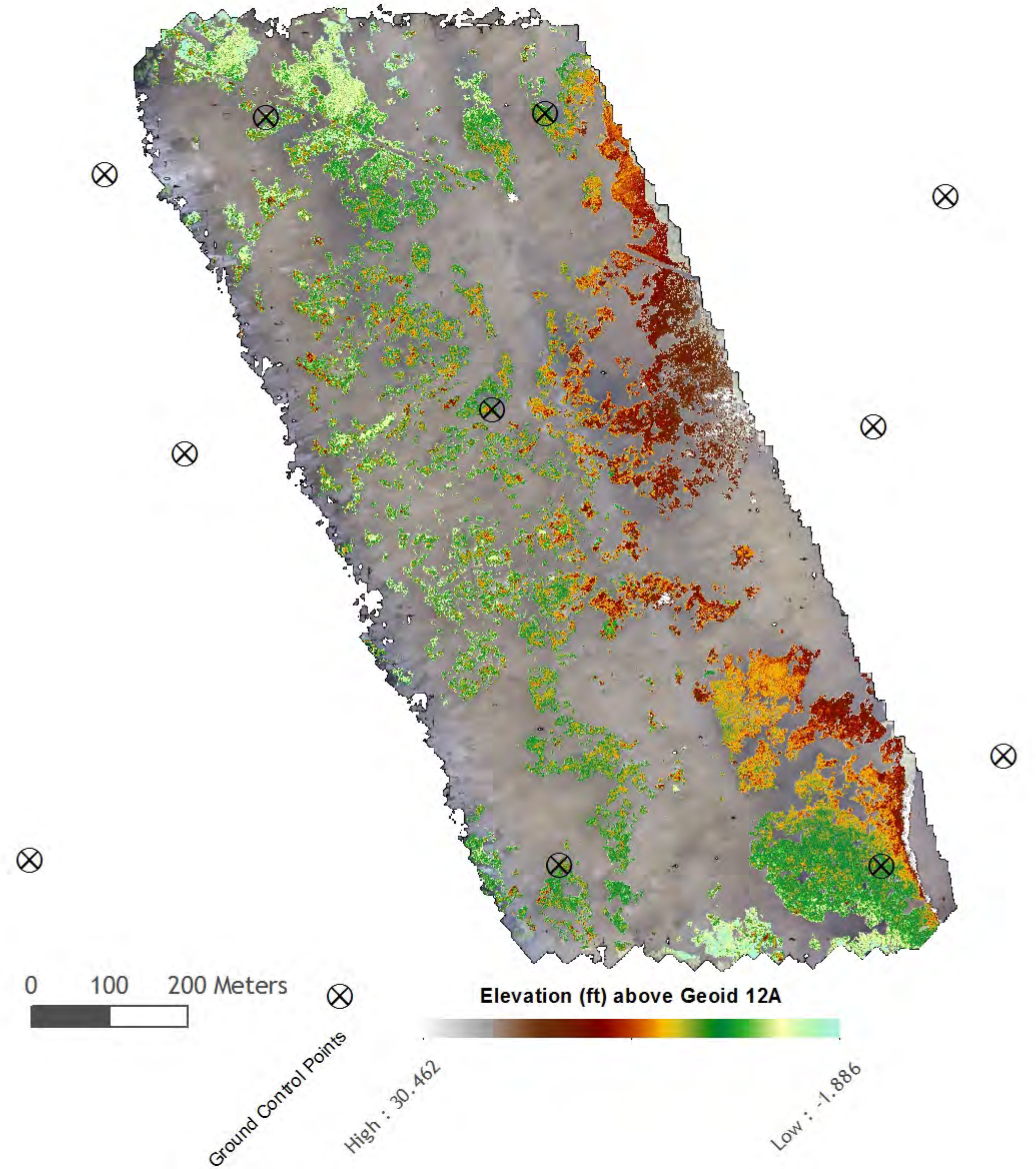


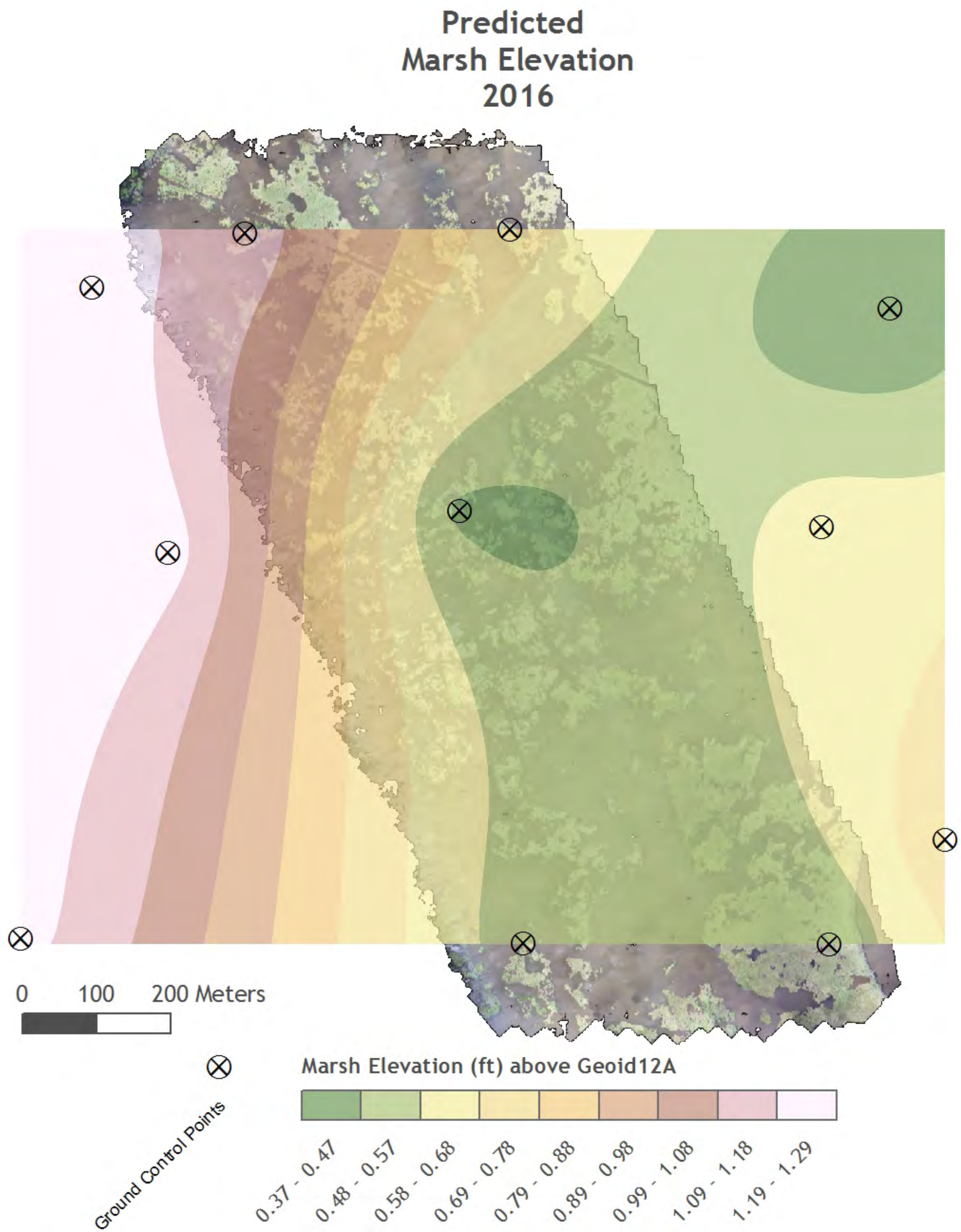
CRMS0392 – 1985 through 2010



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.

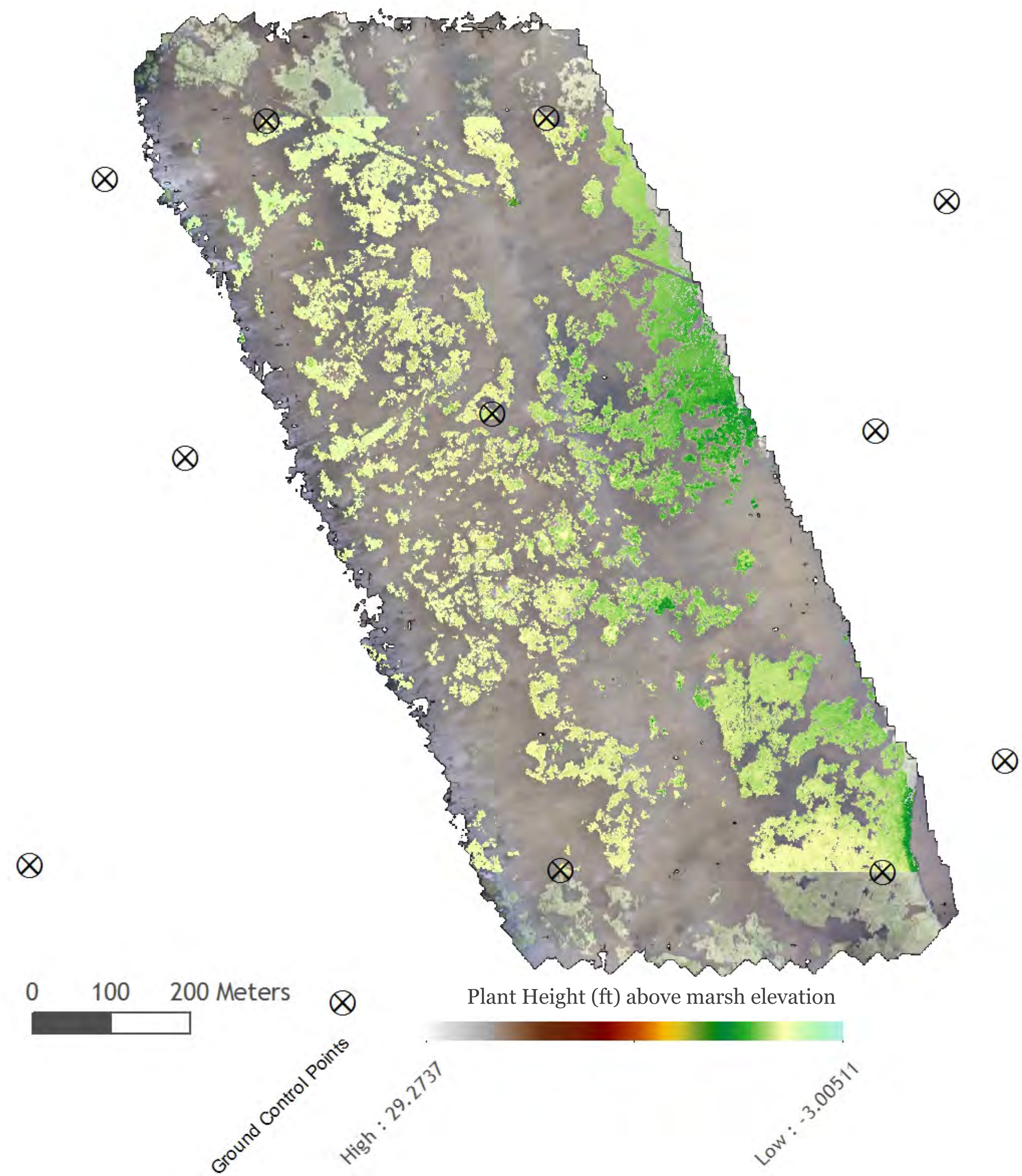
Predicted
Digital Surface Model
2016



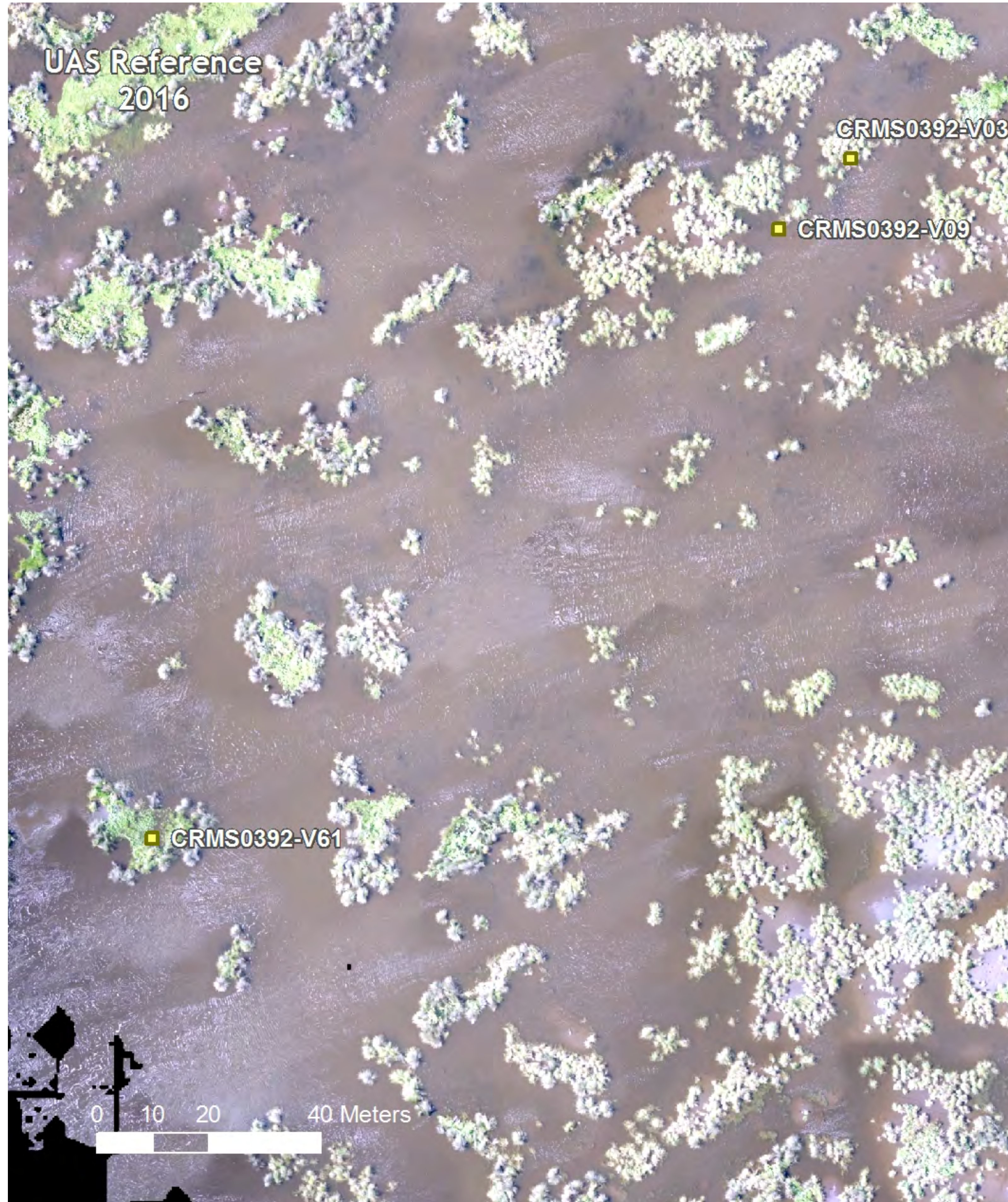


Predicted
Marsh Elevation
2016
0
100
200 Meters
Ground Control Points
Marsh Elevation (ft) above Geoid12A
0.37 - 0.47
0.48 - 0.57
0.58 - 0.68
0.69 - 0.78
0.79 - 0.88
0.89 - 0.98
0.99 - 1.08
1.09 - 1.18
1.19 - 1.29

Predicted Plant Height 2016



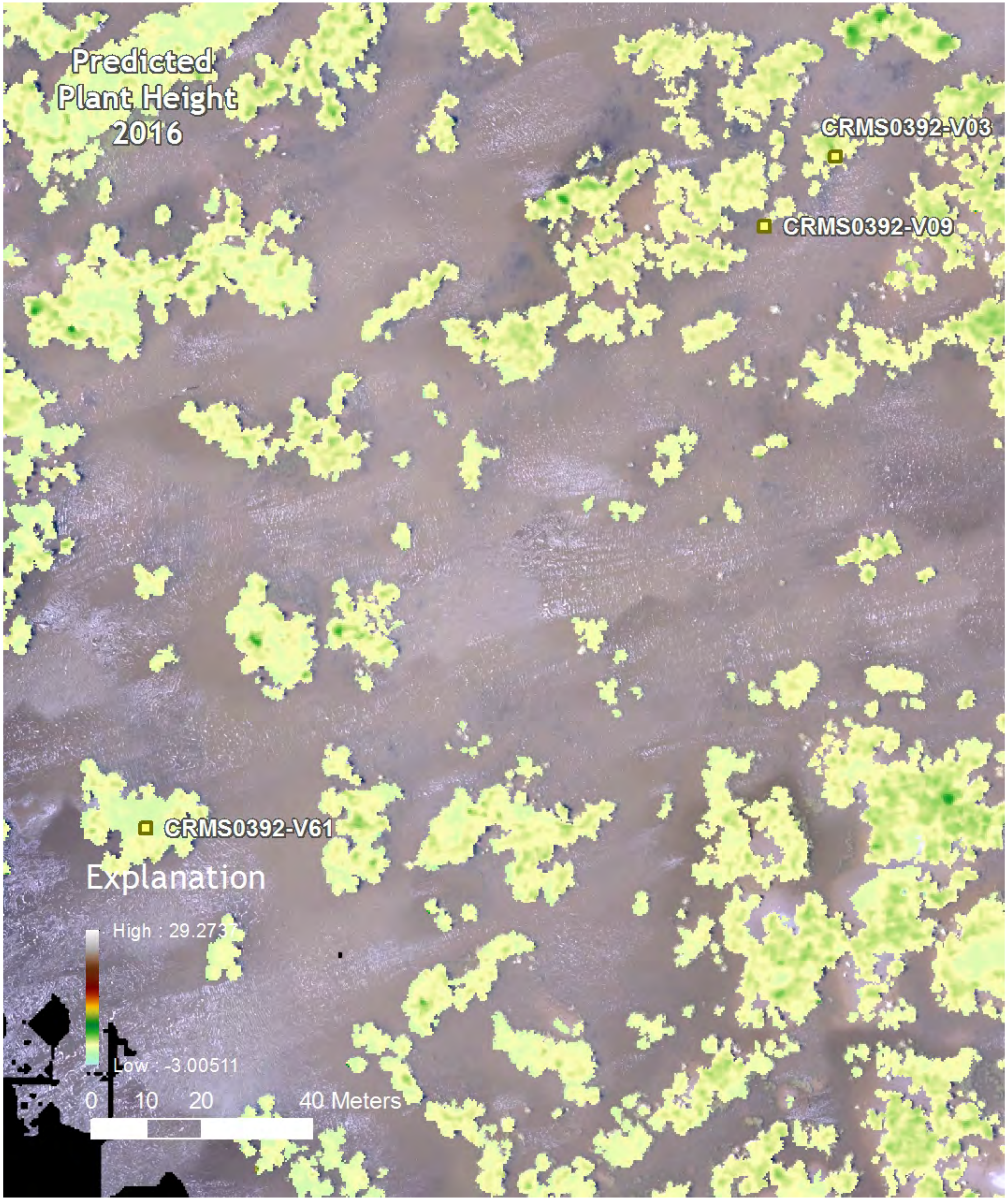
Comparison with 2012 CRMS Vegetation Survey



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

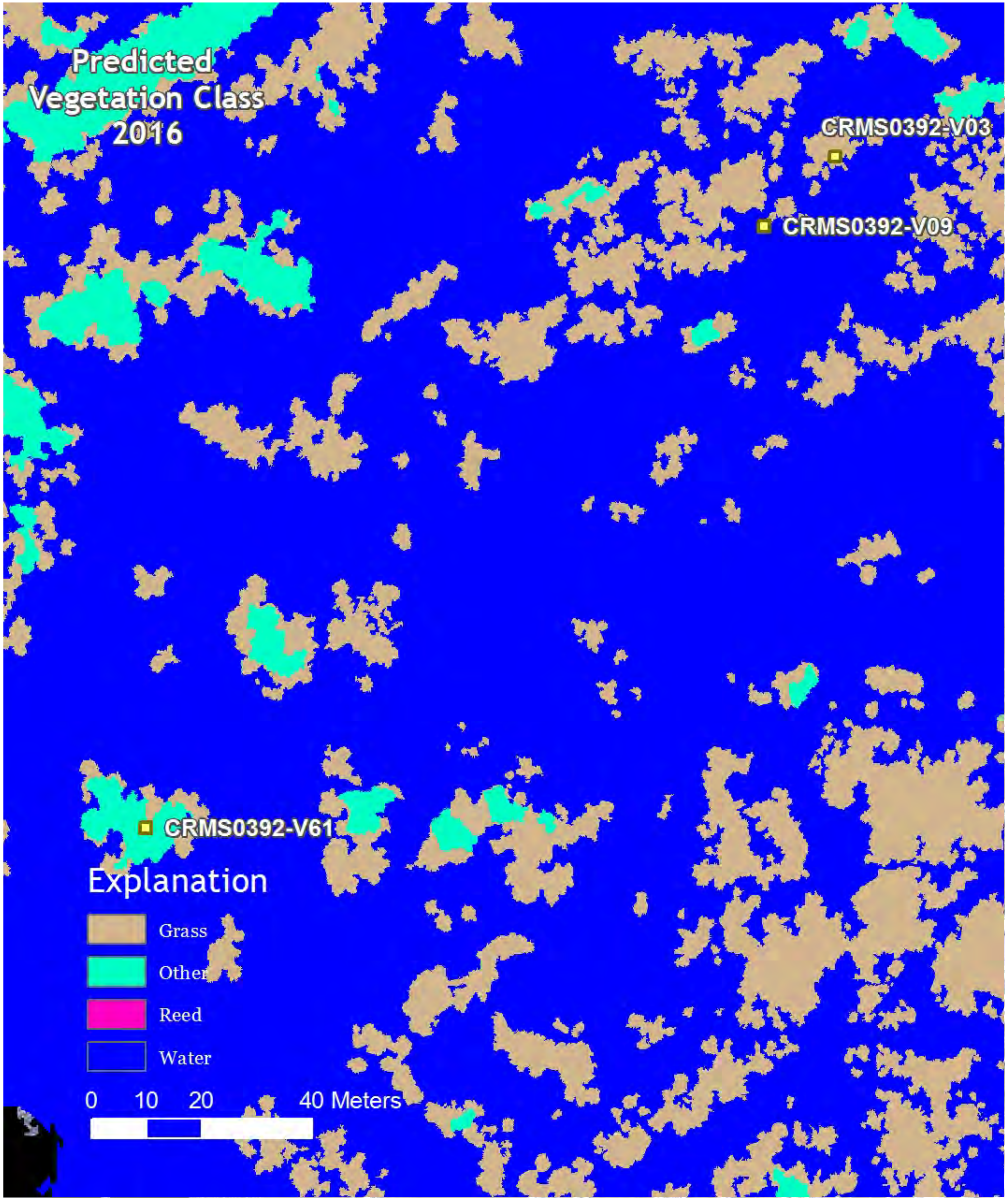
	Maximum Plant Height (ft)				
	CRMS	Predicted (diff. **modeled** marsh elev.)	Fit	Predicted (diff. **measured** marsh elev.)	Fit
V03	4.84	3.97	82%	4.26	88%
V09	3.91	0.86	22%	1.406	36%
V61	1.6	1.19	74%	1.504	94%



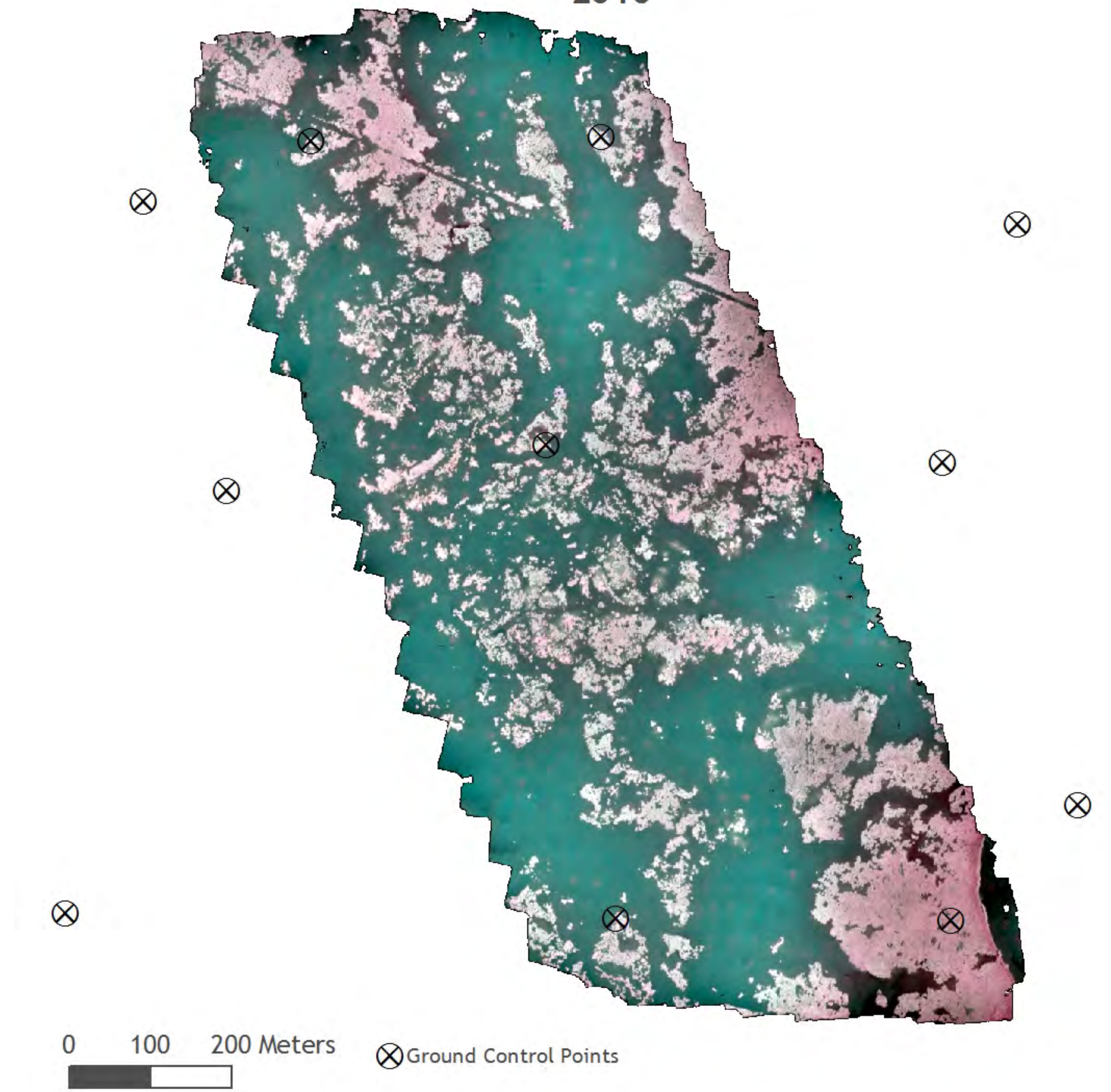
Comparison with 2012 CRMS Vegetation Survey

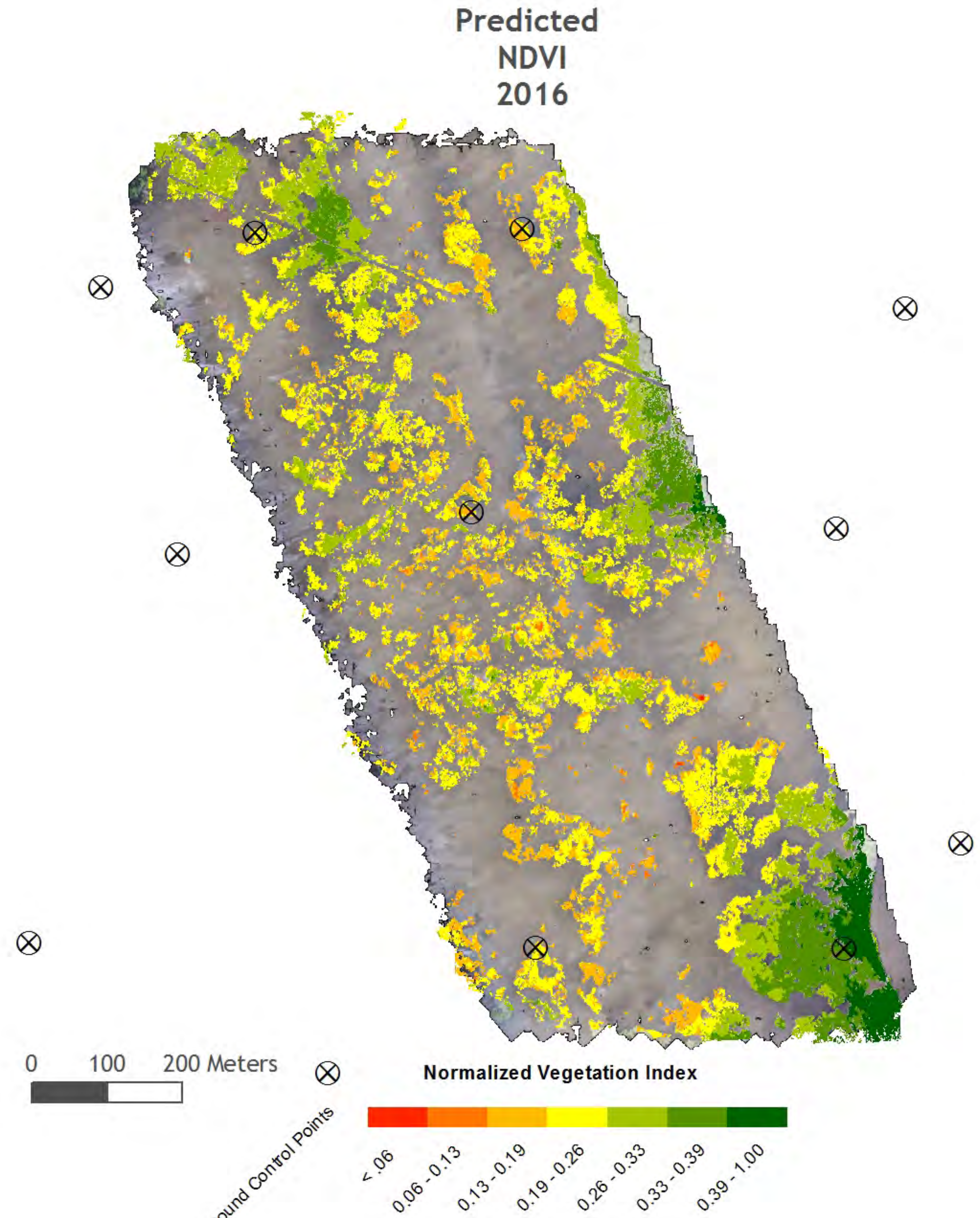
	% Land		
	CRMS	Predicted	Fit
V03	5%	94%	+89%
V09	1%	8%	+7%
V61	100%	94%	-6%

	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





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

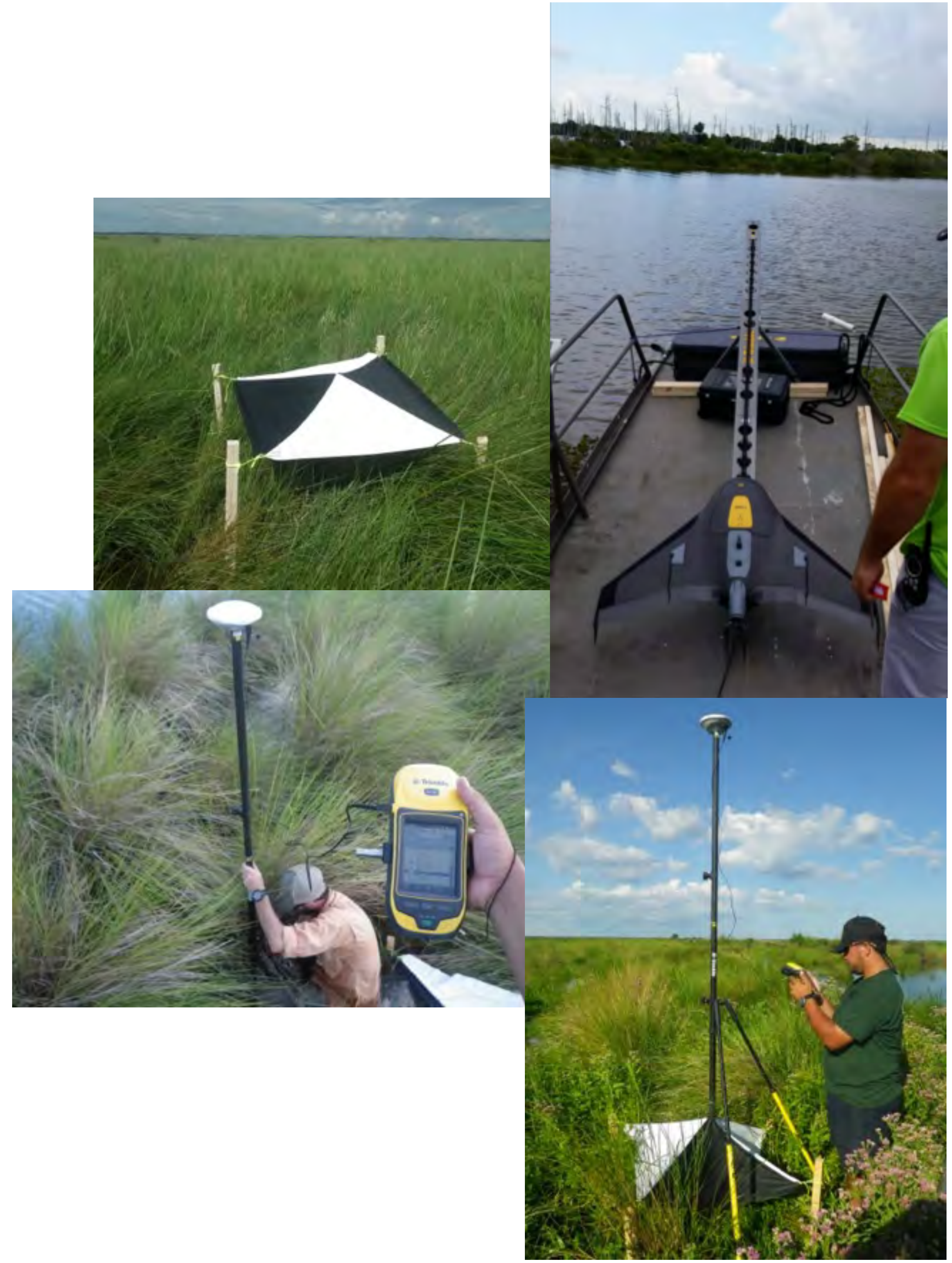
Expected UAS Challenges

- 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

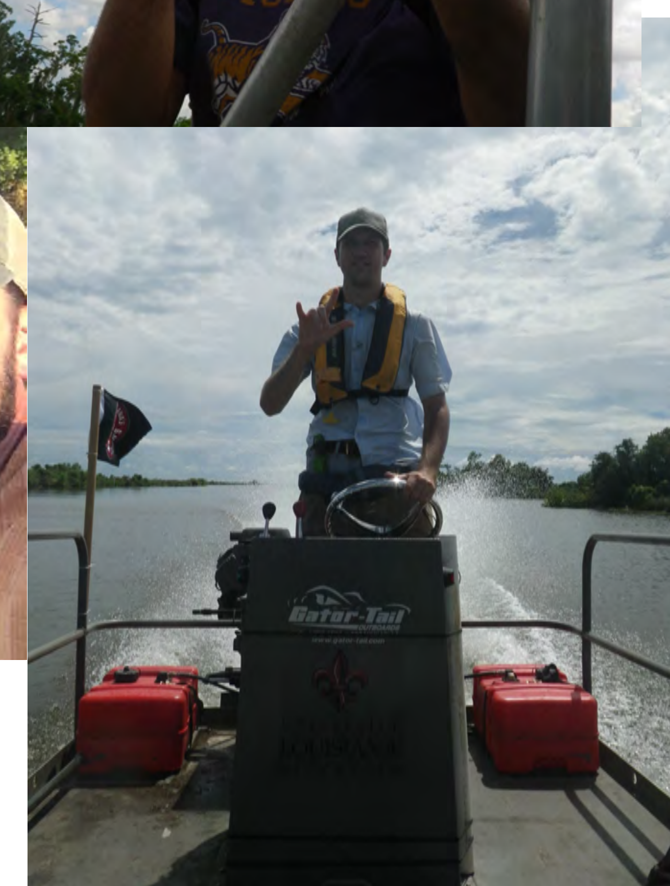
Expected UAS Benefits

- 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, $4m^2$ 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.



Acknowledgements

- UL Lafayette Institute for Coastal and Water Research
  - Jenneke Visser and Grant Kleiner
- JESCO Environmental and Geotechnical Services UAS team
  - Tom Cousté, Alvinette Teal, Shayne Teal, and Ben Landry
- Penn State Department of Geography
  - Rob Brooks and Jarlath O'Neil-Dunne
- CPRA and USGS CRMS monitoring team
  - Leigh Anne Sharp and Sarai Piazza



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, I-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!

For more information

wbroussard@louisiana.edu