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
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).


- **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

Stage, Salinity, Water Quality

Stage, Salinity

Land Configuration, Elevation

Land Configuration, Elevation

Dominant Vegetation

Landscape-level Biomass Estimates

Stage, Sediment

Land Configuration, Elevation

Island Configuration

Dominant Vegetation

Vegetation

Storm Surge/Waves

Surge, Waves

Risk Assessment

Barrier Shoreline Morphology

Wetland Morphology

Eco-hydrology

Ecosystem Services
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%

Coastwide Reference Monitoring System

390 Stations Coast-wide

CRMS by Marsh Type
- Marsh
- Fresh
- Intermediate
- Saltine
- Swamp

Geological Setting
- CWPPRA Projects

CRMS Sampling Area:
- 1 km² aerial photo area
- 200m x 200m data collection area

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
Photogrammetry Primer

Image credit: Qassim Abdullah
Photogrammetry Primer

Image credit: JESCO Environmental
Photogrammetry Primer

Image credit: JESCO Environmental
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
Landsat derived DEM - 30m GSD
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
UAS Aerial Photography - 2.5cm GSD

Leaf shape/area
This pilot study collected hyperspatial/multispectral aerial imagery from a UAS in an 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)

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

<table>
<thead>
<tr>
<th>HARDWARE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Fixed wing</td>
</tr>
<tr>
<td>Weight</td>
<td>2.5 kg (5.51 lb)</td>
</tr>
<tr>
<td>Wingspan</td>
<td>1 m (3.28 ft)</td>
</tr>
<tr>
<td>Wing area</td>
<td>34 dm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPERATION</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Endurance¹</td>
<td>50 minutes</td>
</tr>
<tr>
<td>Range¹</td>
<td>60 km (37.28 mi)</td>
</tr>
<tr>
<td>Cruise speed</td>
<td>80 kmh (50 mph)</td>
</tr>
<tr>
<td>Maximum ceiling²</td>
<td>5000 m (16,404 ft)</td>
</tr>
</tbody>
</table>
3 Flight Plans
Sectional Aeronautical Raster Chart with project boundaries shown in red.

FAA Part 107 compliant operations (DO NOT UNDERESTIMATE!)
Flight Plan Software
Ground Control Points
Take Off

Control Station
Chase home

Belly land
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

<table>
<thead>
<tr>
<th>ID</th>
<th>X [cm]</th>
<th>Y [cm]</th>
<th>Z [cm]</th>
<th>Total [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>102</td>
<td>1.04</td>
<td>-0.15</td>
<td>-3.61</td>
<td>3.76</td>
</tr>
<tr>
<td>103</td>
<td>-1.15</td>
<td>0.71</td>
<td>-0.08</td>
<td>1.35</td>
</tr>
<tr>
<td>201</td>
<td>-3.33</td>
<td>-2.49</td>
<td>-1.48</td>
<td>4.41</td>
</tr>
<tr>
<td>202</td>
<td>3.90</td>
<td>0.16</td>
<td>-3.73</td>
<td>5.40</td>
</tr>
<tr>
<td>203</td>
<td>-0.45</td>
<td>1.82</td>
<td>-0.24</td>
<td>1.89</td>
</tr>
<tr>
<td>Maximum</td>
<td>3.90</td>
<td>-2.49</td>
<td>-3.73</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.00</td>
<td>0.01</td>
<td>-1.83</td>
<td></td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>2.69</td>
<td>1.58</td>
<td>1.76</td>
<td></td>
</tr>
<tr>
<td>RMSE (x,y,z)</td>
<td>2.40</td>
<td>1.42</td>
<td>2.42</td>
<td></td>
</tr>
<tr>
<td>RMSEr</td>
<td>2.79</td>
<td>SQRT(RMSEx2 + RMSEy2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACCr (95% Confidence Level)</td>
<td>4.83</td>
<td>RMSEr * 1.7308</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACCz (95% Confidence Level)</td>
<td>4.74</td>
<td>RMSEz * 1.9600</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

Source: Trimble UX5 Aerial Imagery (3cm resolution). Collected August 2016. JESCO Environmental.
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

Explanation
Source data is Purple. Derived data is Green

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
Object Based Image Analysis (multispectral segmentation)
Accuracy Assessment

Stratified Random Sampling by predicted class

50 Water
50 Grass
20 Other
10 Reed
## Error Matrix

<table>
<thead>
<tr>
<th>Reference Class</th>
<th>Predicted Class</th>
<th>1) Water</th>
<th>2) Grass</th>
<th>3) Other</th>
<th>4) Reed</th>
<th>Count</th>
<th>Producer's Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Water</td>
<td>1) Water</td>
<td>49</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>49</td>
<td>100%</td>
</tr>
<tr>
<td>2) Grass</td>
<td>2) Grass</td>
<td>7</td>
<td>35</td>
<td>6</td>
<td>0</td>
<td>48</td>
<td>73%</td>
</tr>
<tr>
<td>3) Other</td>
<td>3) Other</td>
<td>2</td>
<td>2</td>
<td>16</td>
<td>0</td>
<td>20</td>
<td>80%</td>
</tr>
<tr>
<td>4) Reed</td>
<td>4) Reed</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>8</td>
<td>10</td>
<td>80%</td>
</tr>
<tr>
<td>Count</td>
<td></td>
<td>58</td>
<td>37</td>
<td>24</td>
<td>8</td>
<td>127</td>
<td></td>
</tr>
<tr>
<td>User's Accuracy</td>
<td></td>
<td>84%</td>
<td>95%</td>
<td>67%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 Spatial Data – Land/Water Analysis

<table>
<thead>
<tr>
<th></th>
<th>CRMS</th>
<th>UAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (sq. km)</td>
<td>0.2</td>
<td>0.12</td>
</tr>
<tr>
<td>Percent</td>
<td>42%</td>
<td>26%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>CRMS</th>
<th>UAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (sq. km)</td>
<td>0.27</td>
<td>0.35</td>
</tr>
<tr>
<td>Percent</td>
<td>58%</td>
<td>74%</td>
</tr>
</tbody>
</table>

CRMS Predicted Classification 2012

UAS Predicted Classification 2016
Predicted Plant Height
2016

Plant Height (ft) above marsh elevation

Ground Control Points
High : 29.2737
Low : 3.0511

0 100 200 Meters
Comparison with 2012 CRMS Vegetation Survey
Comparison with 2012 CRMS Vegetation Survey

<table>
<thead>
<tr>
<th>Marsh Elevation</th>
<th>CRMS</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>V03</td>
<td>0.229</td>
<td>0.52</td>
</tr>
<tr>
<td>V09</td>
<td>0.229</td>
<td>0.77</td>
</tr>
<tr>
<td>V61</td>
<td>0.229</td>
<td>0.55</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum Plant Height (ft)</th>
<th>Predicted (diff. <strong>modeled</strong> marsh elev.)</th>
<th>Predicted (diff. <strong>measured</strong> marsh elev.)</th>
<th>Fit</th>
<th>Fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRMS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V03</td>
<td>4.84</td>
<td>3.97</td>
<td>82%</td>
<td>4.26</td>
</tr>
<tr>
<td>V09</td>
<td>3.91</td>
<td>0.86</td>
<td>22%</td>
<td>1.406</td>
</tr>
<tr>
<td>V61</td>
<td>1.6</td>
<td>1.19</td>
<td>74%</td>
<td>1.504</td>
</tr>
</tbody>
</table>
Comparison with 2012 CRMS Vegetation Survey

<table>
<thead>
<tr>
<th>CRMS</th>
<th>Predicted</th>
<th>Fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>V03</td>
<td>5%</td>
<td>94%</td>
</tr>
<tr>
<td>V09</td>
<td>1%</td>
<td>8%</td>
</tr>
<tr>
<td>V61</td>
<td>100%</td>
<td>94%</td>
</tr>
</tbody>
</table>

Vegetation Classification

<table>
<thead>
<tr>
<th>CRMS</th>
<th>Predicted</th>
<th>Fit</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>V03</td>
<td>Grass</td>
<td>100%</td>
<td>Amaranthus, Patens, Cyperus mix</td>
</tr>
<tr>
<td>V09</td>
<td>Grass</td>
<td>100%</td>
<td>Patens clump</td>
</tr>
<tr>
<td>V61</td>
<td>Other</td>
<td>100%</td>
<td>Bacopa, Eleocharis, Pluchea, mix</td>
</tr>
</tbody>
</table>
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.
Acknowledgements

• UL Lafayette Institute for Coastal and Water Research
  • Jenneke Visser and Grant Kleiner

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THANK YOU!

For more information

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