Vegetation Coverage and Change in Wax Lake Delta

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GIS Project Report

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1. Introduction:

Coastal river deltas are regions of tremendous economic, ecological, and humanitarian importance, which are predicted to be subject to increasingly high risks in the face of global environmental change. Both natural and anthropogenic factors, including sea level rise, subsidence, flooding, and sediment starvation threaten the continued existence of many deltaic systems *[Paola et al., 2011]*. In an effort to mitigate some of these effects, local authorities have begun investing millions of dollars towards engineered mitigation projects. Sediment diversions are one such type of project, in which levees and other flow-control structures are intentionally removed, which allows some of the channel flow to discharge into the sediment-starved fluvial floodplain, deposit sediment, and aggrade land. Sediment diversions have shown tremendous promise in efforts to rebuild lost land in places such as the Louisiana coast *[CPRA, 2012]*. However, the mechanisms by which river deltas build land are complex, and much remains unknown about the interactions between flow, sediment, and vegetation that lead to land growth.

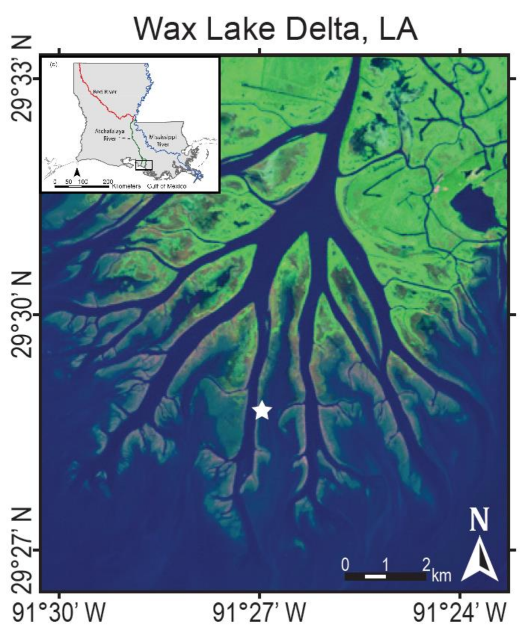

Figure 1

One example of a particularly successful sediment diversion project is the Wax Lake Delta (LA), a naturally prograding delta on the coast of Louisiana, just West of the Atchafalaya delta (Figure 1). The delta is located at the mouth of the Wax Lake Outlet, an artificial diversion of the Atchafalaya River created by the Army Corps of Engineers in 1941 to alleviate flooding problems in Morgan City *[Carle, 2013]*. The WLD has come to be considered a real-world example of the potential land/wetland growth possible via sediment diversion projects. As such, the site has been the subject of a lot of research in the past few decades, the aim of which to determine which factors are important in the process of land building. In recent years, research has shown that flow exchange between the distributary channels and interdistributary islands ("hydrological connectivity") is an important piece of the story, as upwards of 54% of the channel flow is allocated to the islands before being discharged into the bay *[Hiatt & Passalacqua, 2015]*. Modeling work has shown that the amount of vegetation within the deltaic islands is an important control on the degree of that connectivity: more vegetation enhances flow resistance and decreases the hydraulic gradient driving flow into the islands *[Hiatt & Passalacqua, 2017]*. However, to date, most modeling of deltaic environments that include the effects of vegetation assume it to be spatially uniform within the deltaic islands. This is often far from true, as vegetation in deltaic wetlands typically self-organizes into discrete patches of varying size, species, and density *[Carle, 2013]*. Additionally, the percentage of the islands covered by vegetation changes seasonally and yearly *[Olliver & Edmonds, 2017]*. Previous studies have looked at coverage characteristics, but most were done using Landsat imagery, which excludes finer-scale details of the spatial distribution. Thus, in order to better understand the role that vegetation plays in the deltaic processes, it seems important to quantify coverage characteristics. This is the aim of the present study.

2. Methods and Analysis:

2.1 Data Acquisition:

The present analysis quantified vegetation coverage of the WLD using data collected during two high-resolution LIDAR surveys. The first was collected in January 14th 2009 by the NSF's NCALM, and the second February 13th-14th 2013 by the Jackson School of Geosciences at the University of Texas at Austin. The 2009 survey had an areal coverage of 229.87 km^2 surveyed, and an average point density of 1.69 pts/m^2 (4.5 pts/m^2 on land). The 2013 had a lesser areal coverage, at only 30.98 km^2, but a much greater point density, at 14.27 pts/m^2 (12.8 pts/m^2 on land). Each had a reported vertical error of 5.5cm and 3.4cm, respectively. These surveys were used in a previous study by *Wagner et al., 2017*, which extracted ground-truth rasters from the raw point clouds and analyzed locations of elevation change in the WLD. Both datasets were made available via OpenTopography.org (2009: doi:10.5069/G95M63M8; and 2013: doi:10.5069/G9SF2T41).

Each LIDAR survey was downloaded from OpenTopography in several forms: (1) the ground-truth (DEM) rasters developed in *Wagner et al., 2017*, (2) the raw point cloud, (3) a digital surface model (DSM) developed from the raw point cloud (by OpenTopography), which was locally-gridded to the maximum point return within each 1m x 1m cell. Other products, such as the locally-gridded minimum and mean elevation rasters, were also produced, but were not used in the present analysis. The ground-truth DEMs and the DSM were imported into ArcGIS Pro 2.0 for analysis. The raw DEM (as obtained from OpenTopography) for 2009 and 2013 is shown in Figure 2.

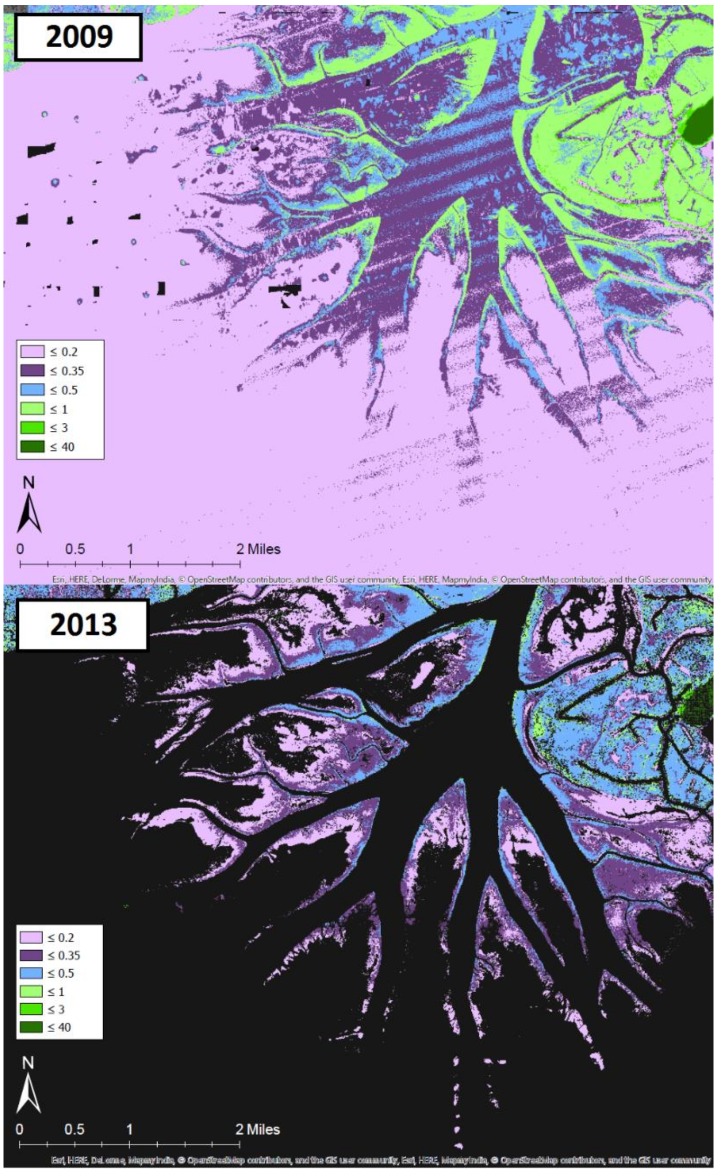

Figure 2 – The DEM rasters for WLD in 2009 and 2013

2.2 Data Preparation:

In order to do any analysis on the LIDAR rasters, some processing was required to clean them up and get rid of extraneous information. As is clear from Figure 2, the raw 2009 DEM registered much of the water features along with the land, all of which needed to be removed. This was done by creating a raster mask which filtered out any cell that was not present in both LIDAR surveys. Due to the nature of the data, this primarily meant that the 2013 DEM acted as a filter on the 2009 DEM. This removed the vast majority of the water features, and made the DEM look as expected. While it is possible that this masking process removed some of the land cells in the 2009 survey that should have been included, visual inspection showed that the differences in channel locations between 2009 and 2013 was minimal (less than 5m), and a more complex filtering process was deemed unnecessary for the level of analysis being done.

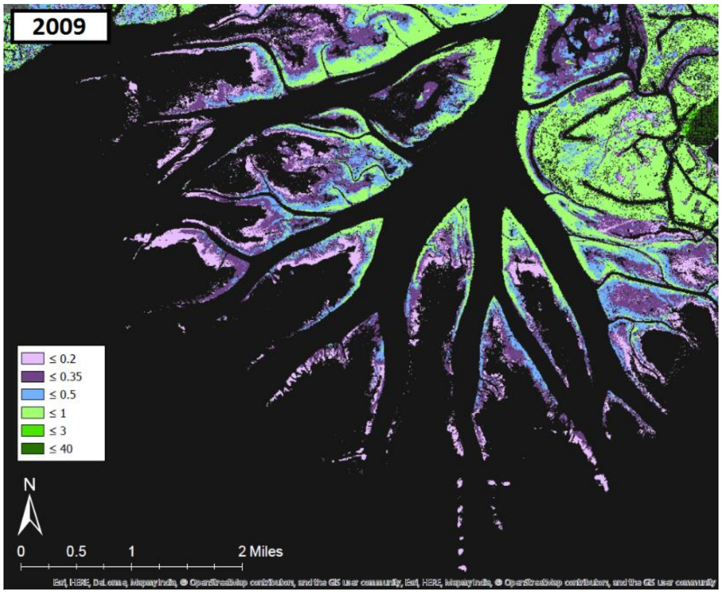

Figure 3 – Filtered 2009 DEM

The properties of each DEM listed the same geographic coordinate system (GCS WGS 1984) and was referenced to the same vertical datum (NAVD88). However, the DEM for 2009 appeared to have higher elevations than 2013 in much of the delta, which was contrary to the finding suggested in *Wagner et al., 2017*. Thus, to ensure that the data was indeed referenced properly with respect to each other, the elevation change analysis in that study was repeated and the results compared to theirs (Figure 3). While there are a few visible differences, in most areas the recreated image is very similar to the original. This finding suggested that the DEM as acquired was already processed to the extent necessary to use in the present analysis.

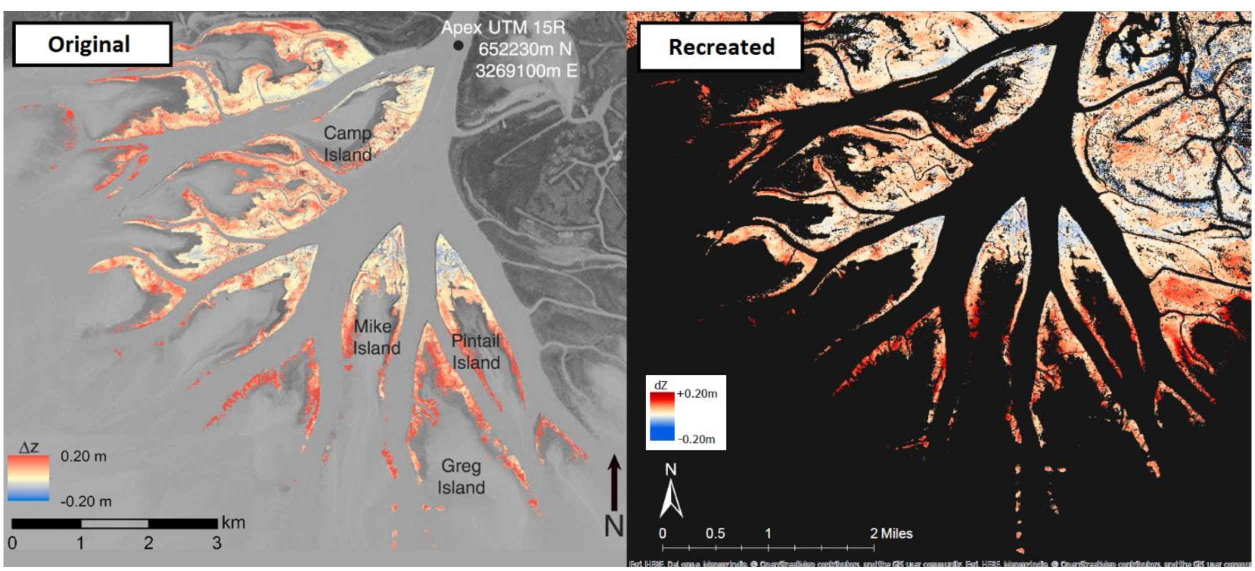

Figure 4 - Elevation change from Wagner et al., 2017 (left) and the present study (right)

To extract vegetation from the DSM, a difference map needed to be created that removed the elevation of the ground, which would leave only the information that was removed in the creation of the DEM. This can be done simply with the ArcGIS Pro raster calculations. However, there was one problem: the DEM had been processed to a 2m x 2m grid resolution. In order to retain the 1m resolution of the vegetation map, each DEM was first resampled to a 1m resolution, using the ArcGIS resample tool using the "nearest" setting for each grid value. This setting retained the values of the original raster, and did not create any additional NoData values, which was the result when several other methods (e.g. bilinear) were attempted. After resampling, the difference maps between the DSM and DEM were created, using the same mask as the filtering process, and the result for each is shown in Figure 5.

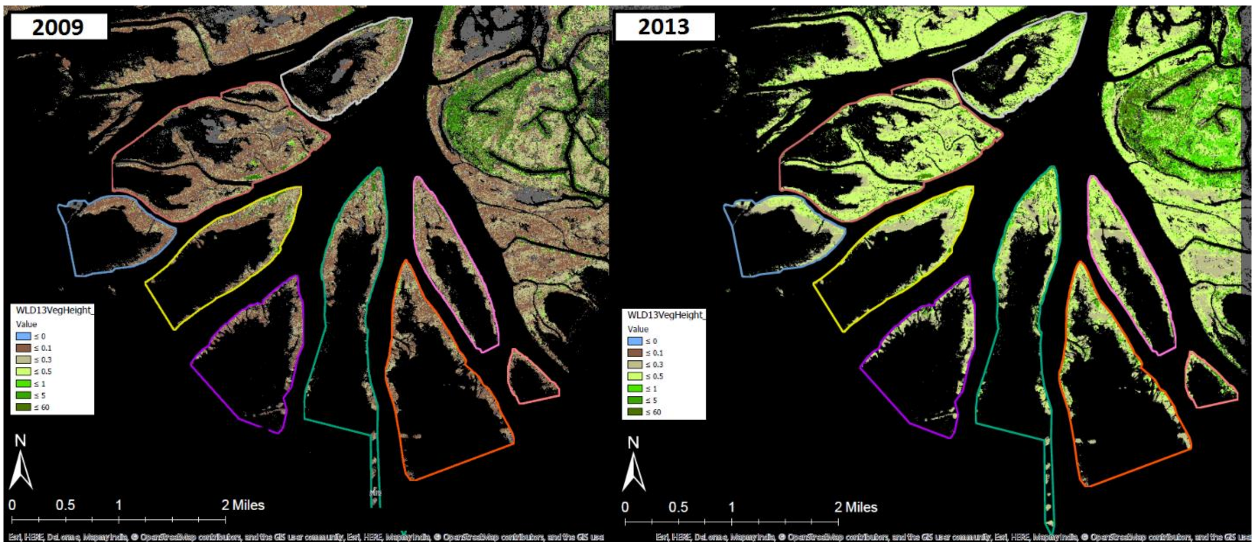

Figure 5 - Extracted vegetation heights in 2009 and 2013

From these maps, it certainly seems as though 2013 was a much more vegetated period than 2009. It is worthy of note that both LIDAR surveys were flown near each year's vegetation minimum, due to the fact that extracting the ground, not vegetation, was their goal. However, the survey in 2013 was flown closer to 2013's reported vegetation minimum (Feb 16^{th}) than was the 2009 survey (Mar 1^{st}), so it seemed counterintuitive that more vegetation would be present in the 2013 survey *[Olliver & Edmonds, 2017]*. However, 2008 was a year of large vegetation losses in WLD *[Olliver & Edmonds, 2017]*, likely due to a large storm, so the trend seen here is likely due to the fact that vegetation in 2009 was still rebounding to its unperturbed state.

2.3 Extraction of Individual Islands

Also shown in Figure 5 are outlines of each major island. These features were drawn manually, so that vegetation in each island could be analyzed independently of its neighbors. The intention was to extract the vegetation data for each island using the feature class as a mask, which could then be analyzed in Matlab – however, there were a number of errors that arose in this process. The vegetation data for a given island could be isolated, but the exporting process would create NoData values surrounding the island of interest, to fill the full extent of the .tif file. This is by design, and is necessary to retain only the data within the island. However, because all of the water features within the island area registered as NoData, these first needed to be converted to some real value, so as to differentiate them from the cells outside of the island perimeter. In addition, the redesignation of water to real values needed to be done before island extraction. Thus, a model was constructed in the ArcGIS Pro ModelBuilder to automate this task. The full model is shown in Figure 6.

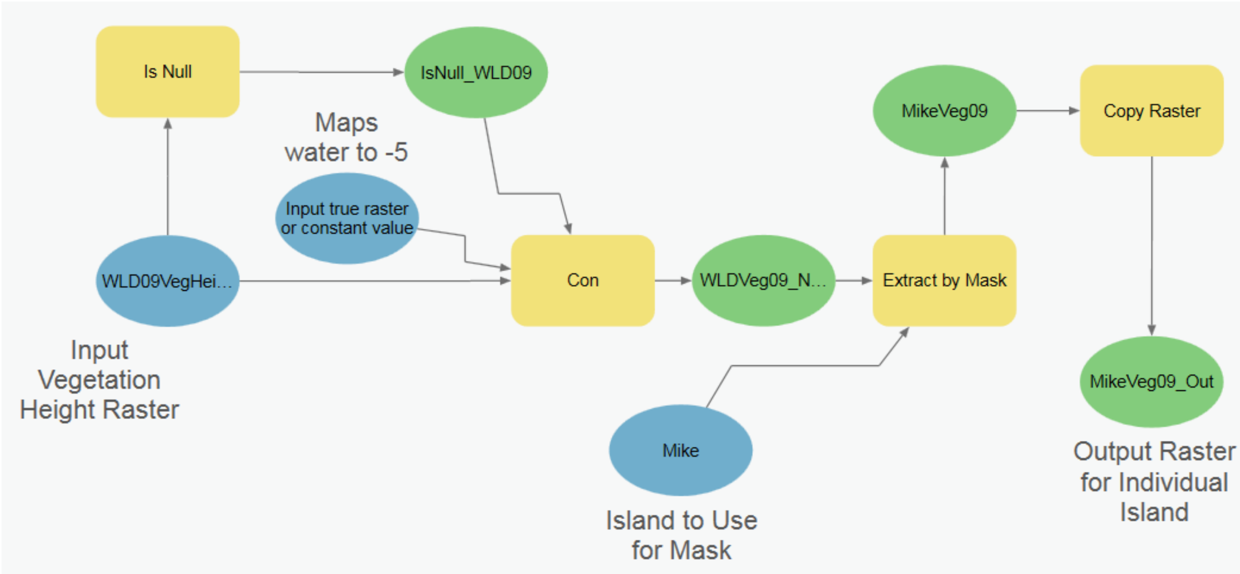

Figure 6 - Model used to isolate vegetation height data for each individual island

The functional flow of the model works as follows:

1. A raster of vegetation height values (i.e. those shown in Figure 5) is selected
2. The Is Null function is used to create a logical array, which notes whether each cell in the input file is a NoData cell, or a cell that contains data.
3. The Con function is used on the output of the Is Null function, which operates based on two conditions:
    a. If a given cell was registered as Null, the Con function gives that cell a constant value (-5 was selected)
    b. If a given cell was not registered as Null, the Con function fills that cell with the value of the original vegetation height raster
4. From the output of Con, a raster of the full delta extent is created in which all "water" features (or otherwise excluded data) register as a constant -5.
5. An island feature is selected to act as a mask on the vegetation data (island names include Mike, Tim, Chester, Pintail, Sherman, Greg, Bob, and Camp)
6. The Extract by Mask function extracts the vegetation data within a given island
7. The Copy Raster function is used to export a copy of the island-extracted raster as a .tif file that can be analyzed in other programs.

After steps 1-4 were completed on the 2009 and 2013 rasters, the model was simplified to only include the latter steps, as the previous products of the model could be reused to reduce computational time. After the data from each island was extracted, the majority of the analysis was conducted in Matlab and Excel. While some of these functions could have simply been done within ArcGIS Pro, it was generally less work and less computationally intensive to perform these simple actions in other programs.

2.4 Island Coverage Characteristics

Several scripts were created to determine some noteworthy characteristics of the vegetation on the deltaic islands. First, one would expect there to be multiple classes of vegetation sorted approximately by height. This likely includes *Salix nigra* (black willow) at the highest heights, *Colocasia esculenta* (elephant ear) at intermediate heights, and *Polygonum punctatum* (dotted smartweed) at lower heights *[Carle, 2013]*. The latter two can grow to around 2.5m and 1m, respectively, with willow trees growing upwards of 10m. The lowest elevations in the islands are typically occupied grasses on land, and by emergent or floating vegetation in the water, such as Nelumbo lutea (American lotus). However, most of these species are perennial, so we shouldn't expect to see their signature in the survey data. To determine which of these species is likely to be present in the data, histograms were developed for each island that counted the number of cells at a given vegetation height for each vegetation height observed. Several of these are shown in Figure 7. All axes are identical, except (A). Height units in meters.

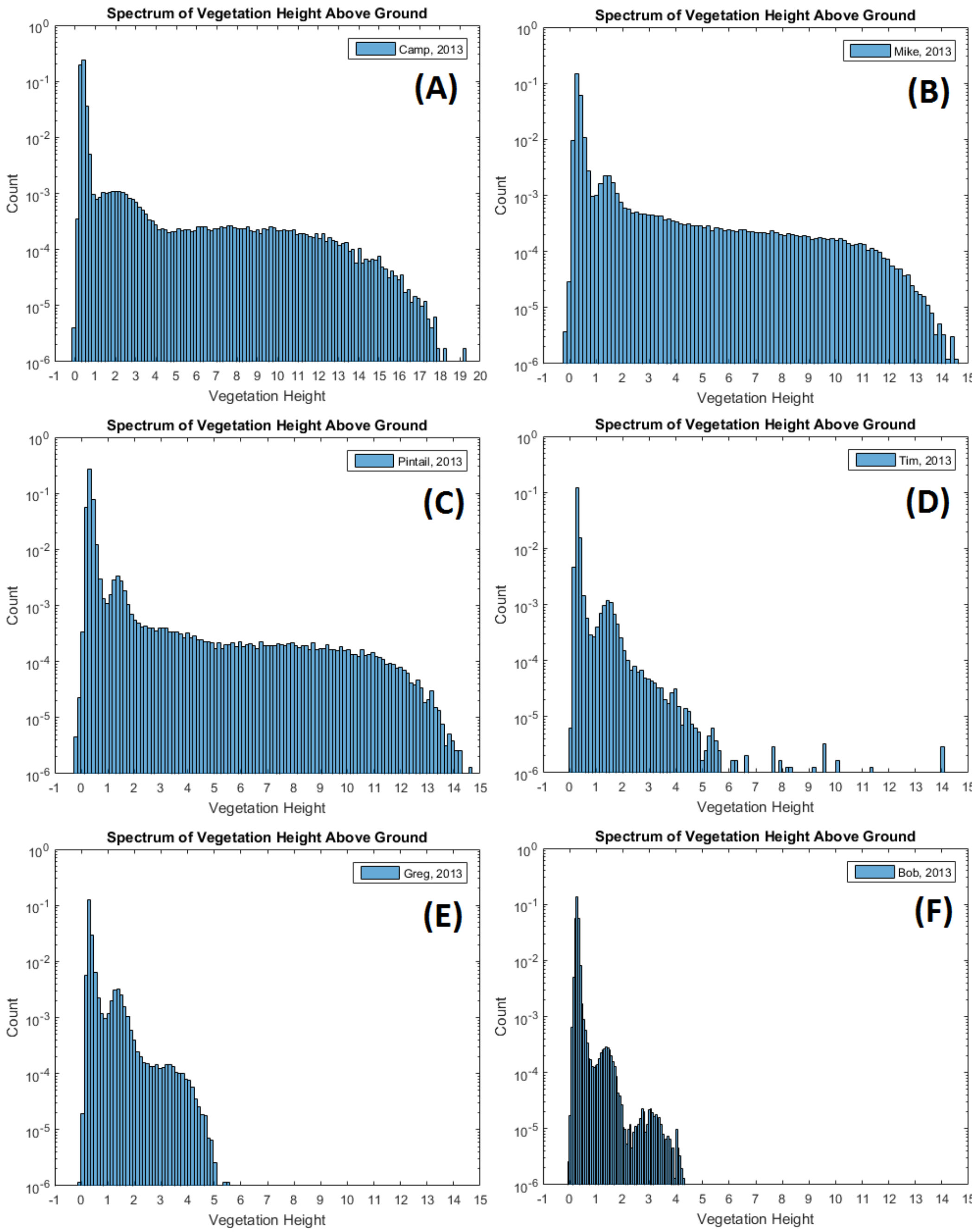

Figure 7 - Histograms of vegetation height for islands at increasing distances from the delta apex

As can be seen in Figure 7, these histograms reveal an interesting structure. There are several noticeable modes in the data: near 0.3m, 1.4m, 3.1m, and between 5-12m. Each mode is not present in the histogram of each island, but many are visible in multiple. The largest mode, at about 0.3m, most likely includes much of the noise from LIDAR returns of bare earth. The letters are ordered approximately corresponding to the distance of each island from the delta apex; (A, Camp) is the most proximal island, and (F, Bob) the most distal. It is clearly visible that at increasing distances from the delta apex, vegetation heights decrease. We hypothesize that one key difference in the pdf of the proximal and distal islands is the lack of willow trees in the more distal islands. The pdf for Greg and Bob islands, which lack abundant willow trees, reveal the small mode near 3.1m, which could correspond to a species not present in the proximal islands, but more likely was simply washed out by noise associated with the willow trees.

A comparison of the pdfs of the same islands at different times reveals that the differences in vegetation corresponded to a lack of the low-lying species in 2009 (Figure 8). The histograms on the right correspond to the same islands as those on the left: Camp (A,B), Mike (C,D), and Greg (E,F).

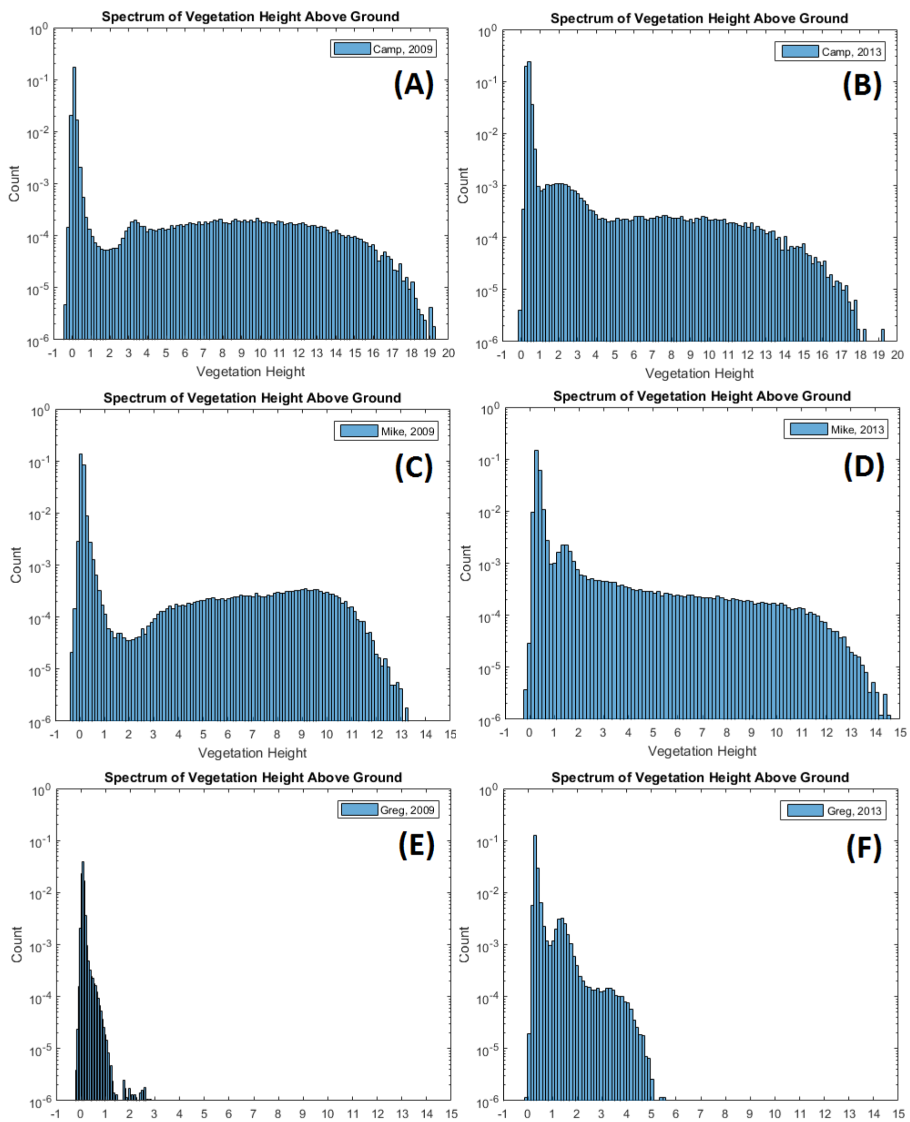

Figure 8 - Histograms for the same three islands in 2009 and again in 2013. The difference clearly indicates a loss of low-lying vegetation

In addition to the decreasing heights at increasing distance from the delta apex, we should expect decreasing heights at increasing distance from the apex of each individual island. A scatterplot of vegetation heights vs distance of that height from the apex of Mike Island was developed for 2009 and 2013. The results of each are shown in Figure 9. Note: water cells have been mapped to the height value of -1. It is clearly visible that the delta apex is dominated by willow trees, as well as a number of other low-lying species focused around 1m and 3m. Some of this low-lying vegetation is also visible near the center of the island, at least in 2013. At the far end, several discrete patches are visible, which are likely a mix of bare earth noise and sub-meter grasses.

Figure 9 also makes apparent one aspect of the of the LIDAR survey: many of the returns, corresponding to the local maxima in the point cloud, correspond to the middle of the underlying vegetation. Most of the points near the apex above 4m but below 10 are almost certainly correspond to somewhere in the middle of a willow tree. The higher-point-density survey in 2013 seems to have done a better job of penetrating the uppermost vegetation, which is to be expected.

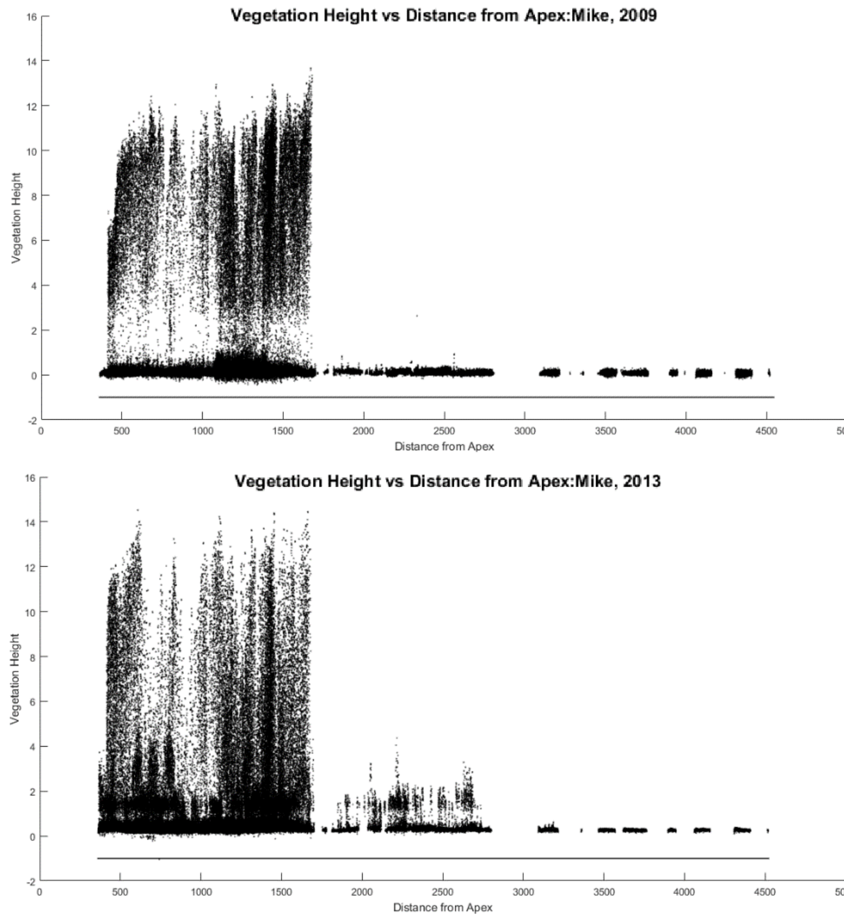

Figure 9 - Vegetation height as a function of the distance from the apex of Mike island in 2009 and 2013

One vegetation quantity of primary importance is the percentage of the island occupied by vegetation. While estimates based on these LIDAR surveys likely are not perfect, due to the fact that gaps in the ground DEM correlated with regions of dense vegetation, it is still an important quantity that can be compared to estimates derived by other measures *[*e.g. *Olliver & Edmonds, 2017]*. In order to try to exclude noise associated with the bare earth, "vegetation cover" was classified using a threshold of 0.1m, which was the threshold used by *Wagner et al., 2017* to eliminate vegetation. The results of this are given in Table 1. For every island, vegetation coverage in 2013 is higher than in 2009. The weighted average of this vegetated fraction for all islands increases from 12.8% in 2009 to 32.9% in 2013. Generally, the fractional coverage is higher in the proximal islands than in the distal islands. Both of these findings match what is to be expected from previous studies, as well as what seems to be true by visual inspection of the LIDAR rasters. The islands included in this analysis represent approximately 21 km^2, of which about 6.4 km^2 is emergent land. This analysis cannot measure land change between the two surveys, due to the method by which the rasters were filtered.

Table 1 – Island Characteristics for 2009 and 2013

Island	Year	Area (m2)	Land Fraction	Water Fraction	Vegetated Fraction
Camp	2009	1742661	0.4407	0.5593	0.1922
	2013		0.5091	0.4909	0.5091
Mike	2009	3300192	0.2566	0.7434	0.1228
	2013		0.2590	0.7410	0.2589
Sherman	2009	4196036	0.5029	0.4971	0.1906
	2013		0.5435	0.4565	0.5435
Pintail	2009	1555634	0.4496	0.5504	0.2186
	2013		0.4503	0.5497	0.4499
Chester	2009	2308997	0.2811	0.7189	0.1237
	2013		0.2841	0.7159	0.2840
Tim	2009	2441085	0.1489	0.8511	0.0497
	2013		0.1474	0.8526	0.1474
Greg	2009	3531415	0.1911	0.8089	0.0750
	2013		0.1895	0.8195	0.1895
Pintail Bar	2009	394764	0.2126	0.7874	0.0795
	2013		0.2124	0.7876	0.2124
Bob	2009	1527214	0.2561	0.7436	0.0672
	2013		0.2675	0.7325	0.2673
All Islands	2009	20997998	0.3137	0.6863	0.1279
	2013		0.3286	0.6714	0.3285

3. Conclusions

The present analysis used data collected from two high-resolution LIDAR surveys of the Wax Lake Delta to quantify vegetation coverage and change within 9 deltaic islands. Raster differencing between the DSM and processed ground-truth DEM allowed for the extraction of vegetation, which was then extracted on a per-island basis. Vegetation height was found to correlate with the distance from the apex of the delta, as well as from the distance from the apex of individual islands. Histograms of the vegetation heights revealed several modes, which should correspond to different species of vegetation common within the Wax Lake Delta. The same distributions were also used to show that the difference in vegetation coverage between 2009 and 2013 corresponded with a loss of the low-lying vegetation (i.e. average heights 1.4 and 3m) between the two surveys. This information could potentially be of use for those studying the role that vegetation plays in land growth and hydrological connectivity in river deltas, and the models and codes developed herein could serve as a proof of concept to analyze future LIDAR campaigns.

4. References:

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