QUANTIFICATION OF MICRO-SCALE BIOMASS, NECROMASS, ROOT ARCHITECTURE, PORE STRUCTURE, AND SEDIMENT DENSITY IN WETLAND SOILS USING X-RAY COMPUTED TOMOGRAPHY

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Abstract: Wetlands are examples of nature-based sustainable and resilient coastal protection solutions. However, there is a need to quantify the capacity of the marsh platform to withstand hurricane disturbance through a better understanding of the root structure architecture and strength (RSAS). Therefore, the purpose of this study is to investigate the marsh platform stability as a function of wetland root structure. This study is synergistic towards the X-ray computed tomography (XCT) Nikon XTH 320/225 system at the Environmental Molecular Sciences Laboratory (EMSL) for nondestructive studying of root-system architecture in coastal wetland vegetation. The testbeds for this study are the Atchafalaya (natural active delta) and Terrebonne (continued river abandonment) Basins to forecast how long-term vulnerability to hurricanes, coastline erosion, and sea level rise (SLR) will impact these distinct basins.

Introduction

To achieve sustainable and resilient coastal protection, nature-based solutions such as wetlands creation/rehabilitation are being promulgated by federal and local stakeholders (Bridges et al., 2014). However, their capacity to withstand disturbance during a hurricane is largely dependent on how well wetland vegetation root structure can stabilize the intertidal platform during storm surge (Howes et al., 2010; Jafari et al., 2019). This exploratory research is to investigate the intertidal platform stability as a function of wetland root structure using an integrated multi-scale experimental program, leveraging field testing in the Mississippi River Delta Plain (MRDP) and XCT scanning at EMSL.

XCT imaging was used to quantify the micro-scale live biomass, necromass, root architecture, macro pore structure, and sediment density in cores collected from the Atchafalaya and Terrebonne Basins across a salinity gradient of fresh to saline marsh (Fig. 1). The application of XCT to quantify roots, rhizomes, and peat is relatively new and promising as an accurate alternative to the traditional hand-sieving methods that are time-consuming and can be prone to high variability. The XCT scans analysis involves with image segmentation performed using Fiji, supplemented with Matlab and Python. In addition to the classical image processing, scans were segmented using machine learning unsupervised and supervised models.

Fig. 1. Field sites in Atchafalaya and Terrebonne basins.

Field Campaign

Fieldwork included sampling and conducting cone penetration testing (CPTu). Samples were collected using a biomass core sampler (15 cm diameter). Afterwards, soil cores were extruded into HDPE pipe with a diameter of 15 cm and length of 35 cm (Fig. 2). Samples were shipped to the EMSL at the Pacific Northwest National Laboratory (PNNL) in Richland, Washington for scanning.

Fig. 2. Biomass sampler and field measurements during sampling.

Image Processing

XCT slices analysis included three steps: normalization, segmentation and quantification. Image normalization ensures optimal comparisons across data acquisition methods and texture instances. The normalization of pixel values (intensity) is recommended for imaging modalities that do not correspond to absolute physical quantities (Depeursinge et al., 2017). In this work, a linear correction was performed to ensure a constant pixel intensity along the core for the two reference materials; (HDPE and air). Afterwards, scans were masked to create a new image for a specific region of interest. Image segmentation in digital image processing is used for dividing the image into different segments and discrete regions (Nadipally, 2019). Image segmentation is a challenging, complex task that is affected by numerous aspects, including noise, low contrast, illumination, and irregularity of the object boundaries (Guo et al., 2019). The outcome of image segmentation is a group of segments that jointly enclose the whole image or a collection of contours taken out from the image. In this work, an unsupervised machine learning algorithm was used to cluster data based on the Expectation Maximization. Gaussian mixture models (GMM) assumes all the data points are generated from a mixture of a finite number of Gaussian distributions with unknown parameters. The GMM was applied using the python open-source library scikit-learn (Pedregosa et al., 2011).) to segment a number of 2D scans along the core. Afterwards, the GMM output (labeled image) was used to train a random forest model using the same library (scikit-learn) along with various features (e.g., canny edge, gaussian s7, median s3, gabor) to segment the 3D volume. Figure 3 illustrates the image processing workflow as well as an example of the original and segmented scan. This scan represents depth (10-15 cm) for site 421, Terrebonne. Segmented scans will be used in the quantification step and for studying the live biomass structure architecture.

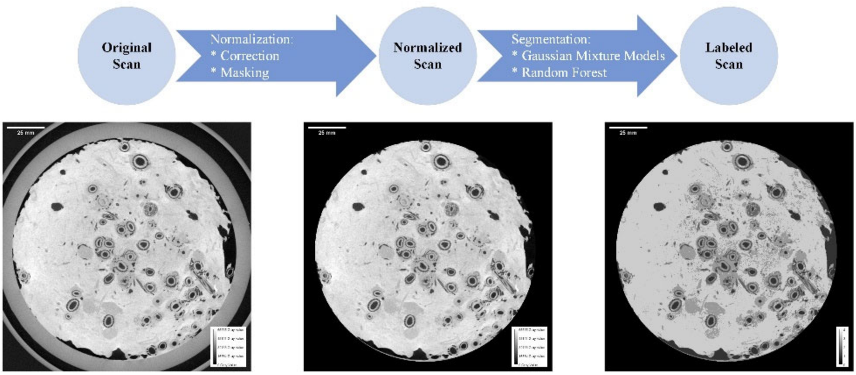

Fig. 3. Image processing workflow with an example.

Quantify the micro-scale biomass, necromass, root architecture, macro-pores, and sediment density using XCT scans is the key to understand the capacity of the intertidal platform to withstand hurricane disturbance and the role of root structure architecture and strength (RSAS) to the ecosystem design of more resilient natural features. In this work, the area occupied by each label was calculated for each scan along the entire core. Figure 4 demonstrates the preliminary quantification results of the biomass, necromass, macro-pores, and sediment volume with depth for site 421, Terrebonne.

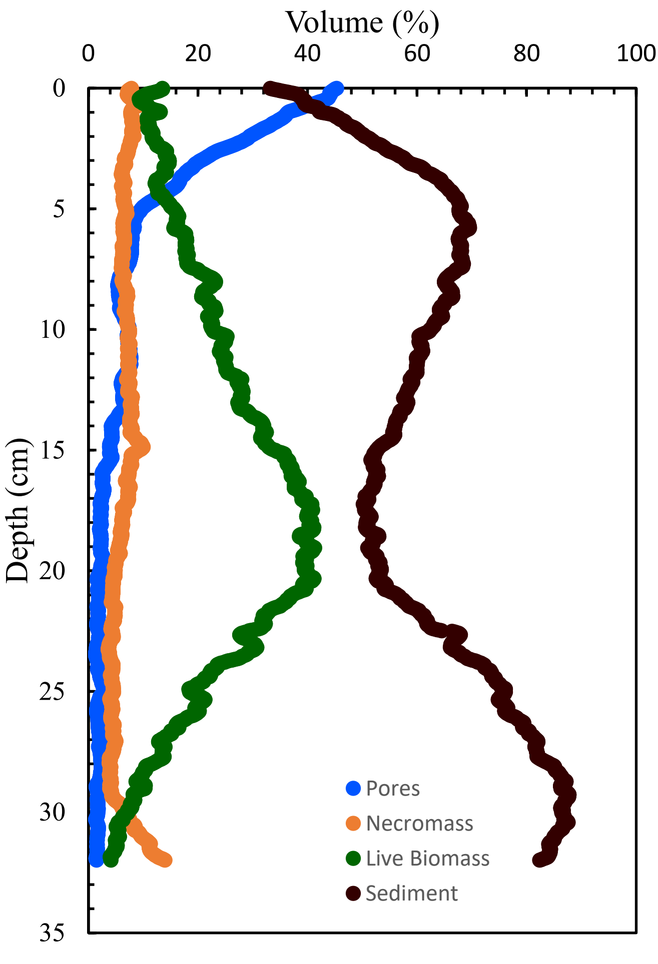

Fig. 4. Quantification result for site 421, Terrebonne.

Verification and next steps

X-Ray CT quantification results will be verified with the hand-sieving results for the samples and the cone penetration testing logs. In addition to that, this study will include a comprehensive verification plan that will include direct shear testing, tensile strength testing, scanning electronic microscope (SEM) and micro XCT for individual live biomass and necromass. Therefore, it would be possible to achieve this study objectives which are:

1- Quantify the micro-scale biomass, necromass, root architecture, pore structure, and sediment density using XCT scans.

2- Measure the macro-scale field strength of root systems using cone penetrometer tests (CPTs).

3- Develop a mechanistic understanding that captures the design functions of coastal ecogeomorphology and RSAS that can be incorporated into future landscape models.

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