Project Narrative

1.1. Rationale and Rationale

1.1.1. Water Qualities in Louisiana: Navigating Multi-Stressors

Understanding phytoplankton taxonomy composition (PTC) is pivotal in Louisiana estuaries, particularly in the face of deteriorating water quality issues like eutrophication and harmful algal blooms (HABs), and the overarching challenges posed by climate change. Estuarine-coatal system in Louisiana, exemplifies how riverine nutrients cause eutrophication, HABs, and hypoxia. Moreover, Louisiana is facing the nation's most rapid rate of wetlands loss, is witnessing an increase in shallow open water areas. This situation is expected to worsen with predicted rises in sea level, precipitation and storm intensity, further amplifying nutrient inflow into Louisiana's shallow waters. the Louisiana coast is implementing coastal restoration initiatives, for example, in 2017 Coastal Master Plan, $5.1 billion is allocated for river sediment diversions, diverting sediment and fresh water from the Mississippi and Atchafalaya Rivers into adjacent basins during high river flows, which could significantly alter phytoplankton dynamics and water quality (Bargu et al., 2019; Jaeqqe et al., 2022; Jung et al., 2023). These diverse array of stressors underscores the increasing need to enhance monitoring techniques and advance forecasting capabilities of PTC in the MARS to guide natural resource management and restoration practices. Satellite-derived phytoplankton taxonomy data at a regional scale is instrumental in evaluating water quality and habitat suitability for various species (e.g., fish and shellfish) (Lefebvre et al., 2022). Furthermore, accurately distinguishing phytoplankton species is critical in monitoring HABs for timely warnings and mitigating potential losses. Our proposed study, therefore, is not just scientifically significant but also essential for Louisiana’s Coastal Master Plan in point of sediment.

1.1.2. The Advantages of Hyperspectral Measurements

Recent advancements in ocean color algorithm development have allowed space-based instruments reach beyond Chl a (O’Reilly et al., 1998) to quantify certain aspects of phytoplankton community composition (Bracher et al., 2017). However, the limited number of spectral bands available in current multispectral satellite sensors are inadequate for the diverse phytoplankton species in aquatic ecosystems, yielding relatively low taxonomic resolution. Also limited taxonomic data and a gap in understanding hyperspectral optical properties of various phytoplankton species impede the effective evaluation of phytoplankton diversity in the Louisiana waters. Unlike multi-spectral sensors with discrete and broad wavebands, hyperspectral spectroscopy typically operates in a spectral range of visible, near-infrared (NIR), and shortwave infrared (SWIR) segments of the electromagnetic spectrum (400-2500 nm) with narrow band features (e.g., 5 and 10 nm). Hyperspectral imaging can be performed on different platforms, including but not limited to airborne platforms (e.g., AVIRIS), International Space Station (ISS) (e.g., HICO and DESIS) as well as satellites. Up to now, some, but not too many satellite-based hyperspectral instruments have been launched (e.g., PRISMA in 2019) with additional missions are in planning, including PACE (launch planned January 2024), SBG and GLIMR. Acquiring hyperspectral images allows for greater details in studying phytoplankton assemblages (e.g., mixture algal blooms) because narrow spectral bands are in positions that focus on key bio-optical properties of aquatic constituents. For example, the absorption properties (Fig. 1c) of 17 phytoplankton groups (Lain et al., 2023) plotted at DESIS wavelengths highlights the strength of hyperspectral measurements in capturing the absorption of multiple pigments (Fig. 1c), offering significantly greater spectral detail for characterizing phytoplankton community when compared to multispectral satellites, such as, Sentinel 3-OLCI and MODIS.

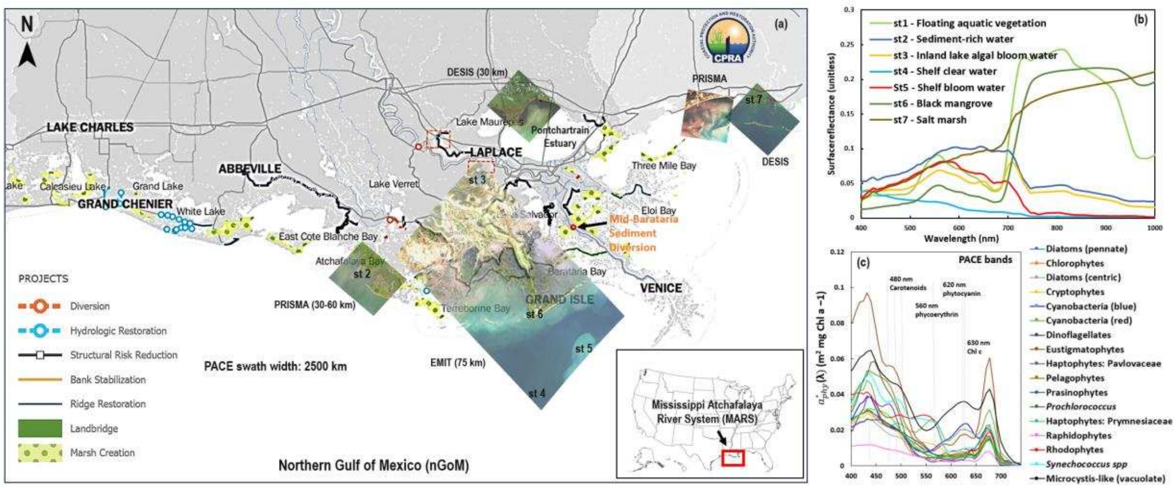

Figure 1. Conceptual representation (a) highlighting various coastal restoration projects within the Mississippi Atchafalaya River System (MARS) with hyperspectral images from different sources; (b) Hyperspectral reflectance obtained over wetland macrophytes and various water types in the MARS. (c) The mass-specific absorption spectra a^*_{phy} (m^2 mg^{-1}) of a total of 17 phytoplankton groups (Lain et al., 2023) at PACE wavelength.

1.2. Goal and Objectives

The overarching goal of this study is to develop advanced algorithms capable of determining fractional abundance of SAV species as well as phytoplankton community composition (at both group and genus levels) from hyperspectral reflectance data. These algorithms will then be transitioned to spaceborne-acquired hyperspectral imagery including PRISMA, DISES, and EMIT to investigate phytoplankton community dynamics, and examine algal blooms in greater detail within Technical Approach and Methodology

1.2.1. Hypothesis of Proposed Work

Our hypotheses are twofold:

i. By augmenting laboratory hyperspectral experiments of locally prevalent phytoplankton species, along with the utilization of advanced spectrally based approach, we can improve previous attempts to infer concurrent fractional abundance of phytoplankton at the species level using spaceborne-acquired hyperspectral images.

ii. Ecosystem responses (e.g., phytoplankton community dynamics and HABs) to environmental and climate-related perturbations and changes in coastal Louisiana (e.g., storms, hurricanes, flooding, changing river discharge, freshwater and sediment diversions for flood control and coastal restoration) can be detected through airborne/spaceborne hyperspectral-derived phytoplankton products.

1.2.2. Experimental and Theoretical Details of the Proposed Work

To test these hypotheses and to achieve the goal, we aim to accomplish the following objectives and tasks:

Objective 1: Conduct **field work** in coastal Louisiana to collect hyperspectral measurements and phytoplankton metrics: Our proposal seeks to leverage cruise opportunities arising from recently funded projects, including NOAA's coastal hypoxia research program (2023-2027), NASA's Marine Biodiversity Ocean Network – MBON (2023-2027) and USACE ERDC’s authorization of Water Resources Development Act of 2018 to implement the detection and management of freshwater HABs, including a proposed technology demonstration program (2024-2027) in Pontchartrain Estuary. On these leveraged cruises, we will collect paired hyperspectral optical measurements and phytoplankton metrics to facilitate PTC algorithms development and validation.

Objective 2: Conduct **laboratory experiment** to establish a comprehensive phytoplankton hyperspectral library: Our research entails the comprehensive assessment of hyperspectral reflectance at species level across a diverse spectrum of agal classes, including species classified as relatively abundant within major phytoplankton groups (e.g., diatoms, dinoflagellates, chlorophytes, haptophytes, cryptophytes, cyanobacteria, etc.), as well as prevalent HAB species (Microcystis aeruginosa, Heterosigma akashiwo, Akashiwo sanguinea, Scrippsiella sp., Pseudo-nitzschia sp., Dolichospermum sp., Raphidiopsis sp.) in Louisiana waters. Hyperspectral reflectance analysis at the species level will be conducted using the advanced CytoViva Hyperspectral Microscope and Macro Imaging System at various points through growth cycles.

Objective 3: Develop and validate the phytoplankton endmember spectral mixture analysis (PESMA) algorithm to retrieve PTC from hyperspectral remote sensing imagery. Spectral mixture analysis (SMA) is typically executed by creating a spectral library of potential endmembers and subsequently unmixing the hyperspectral data while minimizing the root mean square error (RMSE; Roberts et al., 1998). We will apply SMA techniques to field-collected (Objective 1) hyperspectral reflectance to estimate the fractional abundance of each phytoplankton species (F_{phy}). The SMA framework involves modeling an observed spectrum as a weighted linear combination of two or more **pure** spectra, called endmembers (Legleiter et al., 2022):

$$\mathrm{R}_i'(\lambda) = \sum_{phy=1}^{m} F_{phy\ i}\mathrm{R}_{phy}(\lambda) + E_i(\lambda)$$

Here, $\mathrm{R}_i'(\lambda)$ represents the modeled mixture hyperspectral reflectance at a given location i, $F_{phy\ i}$ is the fractional abundance of each of the m endmembers at the location i, $\mathrm{R}_k(\lambda)$ is the hyperspectral reflectance spectrum for the k_{th} endmember and the sum of F_{ki} of all m end members ($\sum_{k=1}^{m} F_{phy\ i}$) should equals one. In addition, $E_i(\lambda)$ is an error term, representing the differences between the observed and modeled spectra at wavelength λ. The goodness of the fit will be assessed using RMSE and the accuracy and uncertainties of the derived F_{phy} for each phytoplankton species will be assessed by comparing with species composition obtained from field measurements.

Subsequently, this validated PEMSA algorithm will be applied to spaceborne-acquired hyperspectral imagery to characterize phytoplankton taxonomy dynamics in responding to multiple environmental stressors in coastal Louisiana.

1. References

Bargu, S., Justic, D., White, J. R., Lane, R., Day, J., Paerl, H., & Raynie, R. (2019). Mississippi River diversions and phytoplankton dynamics in deltaic Gulf of Mexico estuaries: A review. Estuarine, Coastal and Shelf Science, 221, 39–52. https://doi.org/10.1016/j.ecss.2019.02.020

Bracher, A., Bouman, H. A., Brewin, R. J. W., Bricaud, A., Brotas, V., Ciotti, A. M., Clementson, L., Devred, E., Di Cicco, A., Dutkiewicz, S., Hardman-Mountford, N. J., Hickman, A. E., Hieronymi, M., Hirata, T., Losa, S. N., Mouw, C. B., Organelli, E., Raitsos, D. E., Uitz, J., … Wolanin, A. (2017). Obtaining Phytoplankton Diversity from Ocean Color: A Scientific Roadmap for Future Development. Frontiers in Marine Science, 4. https://www.frontiersin.org/articles/10.3389/fmars.2017.00055

Coastal Protection and Restoration Authority. 2017. Louisiana's Comprehensive Master Plan for a Sustainable Coast 184. Baton Rouge, LA: Coastal Protection and Restoration Authority of Louisiana.

Jaegge, A. C., Raabe, J. M., Phillips, Z. B., Bernard, T. L., & Stauffer, B. A. (2022). Flood-driven increases in phytoplankton biomass and cyanobacteria abundance in the western Atchafalaya-Vermilion Bay System, Louisiana. Hydrobiologia, 850(20), 4413–4441. https://doi.org/10.1007/s10750-022-05029-x

Jung, H., Nuttle, W., Baustian, M. M., & Carruthers, T. (2023). Influence of Increased Freshwater Inflow on Nitrogen and Phosphorus Budgets in a Dynamic Subtropical Estuary, Barataria Basin, Louisiana. Water, 15(11), Article 11. https://doi.org/10.3390/w15111974

Lain, L. R., Kravitz, J., Matthews, M., & Bernard, S. (2023). Simulated Inherent Optical Properties of Aquatic Particles using The Equivalent Algal Populations (EAP) model. Scientific Data, 10(1), Article 1. https://doi.org/10.1038/s41597-023-02310-z

Lefebvre, S., Verpoorter, C., Rodier, M., Sangare, N., & Andréfouët, S. (2022). Remote sensing provides new insights on phytoplankton biomass dynamics and black pearl oyster life-history traits in a Pacific Ocean deep atoll. Marine Pollution Bulletin, 181, 113863. https://doi.org/10.1016/j.marpolbul.2022.113863

Liu, B., D'Sa, E. J., & Joshi, I. D. (2019). Floodwater impact on Galveston Bay phytoplankton taxonomy, pigment composition and photo-physiological state following Hurricane Harvey from field and ocean color (Sentinel-3A OLCI) observations. Biogeosciences, 16(9), 1975–2001. https://doi.org/10.5194/bg-16-1975-2019

Liu, B., D'Sa, E. J., Maiti, K., Rivera-Monroy, V. H., & Xue, Z. (2021). Biogeographical trends in phytoplankton community size structure using adaptive sentinel 3-OLCI chlorophyll a and spectral empirical orthogonal functions in the estuarine-shelf waters of the northern Gulf of Mexico. Remote Sensing of Environment, 252, 112154. https://doi.org/10.1016/j.rse.2020.112154