The Use of Multiple Remote Sensing Technologies to Track Mangrove Forest Responses to Hurricanes in Estero Bay, Florida

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1. Background

- Mangrove systems in Southwest Florida (SWFL) are critical to maintaining estuarine biodiversity and health, providing critical coastal protection against storm events, sequestering carbon and mitigating atmospheric greenhouse gas accumulation.
- Unfortunately, these valuable ecosystems are also at the frontline of climate change stress, being impacted by both sea level rise and more intense tropical cyclone events.
- Climate change and tropical cyclone impacts require rapid assessment techniques to better understand and manage these critically important coastal ecosystems of SWFL.
- Working in mangrove system poses numerous challenges under the best of circumstances, including coping with high temperatures and humidity, frequent exposure to saltwater, and navigating through complex and unstable terrain.
- Such challenges make it logistically difficult for rapid assessment using traditional ecological measurement approaches, especially following hurricane impacts.
- In 2017, we established 2 long-term mangrove monitoring plots in Estero Bay with the intention of monitoring it for impacts of sea level rise, climate change and tropical cyclone impacts on forest structure and function using traditional ecological monitoring techniques.
- Following Hurricane Ian in 2022, it has become obvious that faster assessment methodologies bridging leaf to landscape spatial scales are necessary.
- Remote sensing approaches offer a variety of potential ground, aerial, and satellite technologies that may be more time efficient and cost effective than traditional mangrove ecology approaches.
- Our long-term monitoring plots are serving as an outdoor laboratory for proof-of-concept testing of these technologies in mangrove ecosystem research.
- By introducing new ground and unmanned aerial vehicle (UAV) based remote sensing technologies to our research, we aim to establish a mechanism that allows for the measurement of species-specific responses and an ability to scale from tree- to landscape-level responses at varying temporal scales.
- Here we share several ways in which we are using remote sensing to assess the ecology of our long-term monitoring plots.

2. Methods and Results

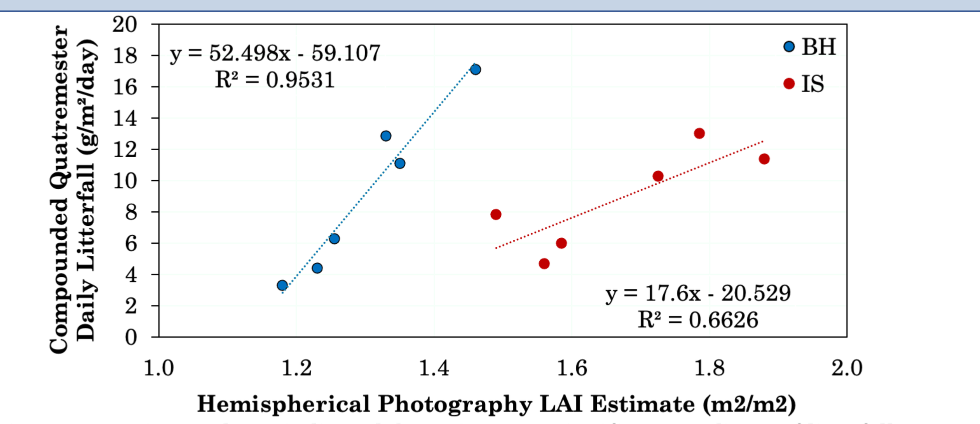
Ground-Based Remote Sensing

Hemispherical photography images being taken by one of the co-authors in a mangrove plot in this study.

Litter traps used for collection of litterfall data for comparison against remote sensed LAI (leaf area index) data.

Hemispherical Photography

An example digital hemispherical photograph of the mangrove canopy at our site. These images were then processed in CAN-EYE image analysis software to measure LAI within 10m x 10m subplots of our larger 1-ha mangrove study plot. Images were collected on a bimonthly schedule for 2 years and compared against litterfall production rates.

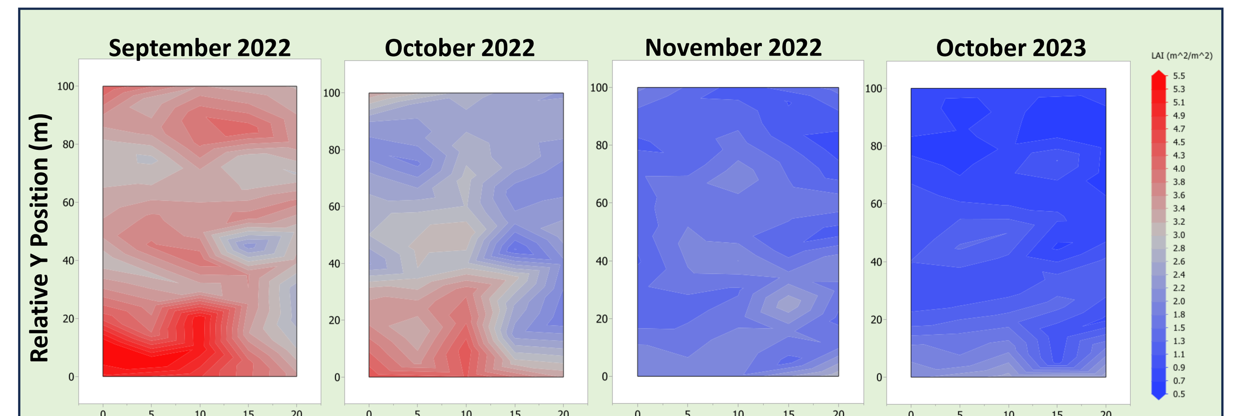


Linear regression analyses indicated that LAI was a significant predictor of litterfall production rates at our two long term monitoring sites on Big Hickory Island (BH) and Imperial Shores (IS). However, it also indicated those relationships differed by location and is likely a function of differential hurricane impacts on these sites

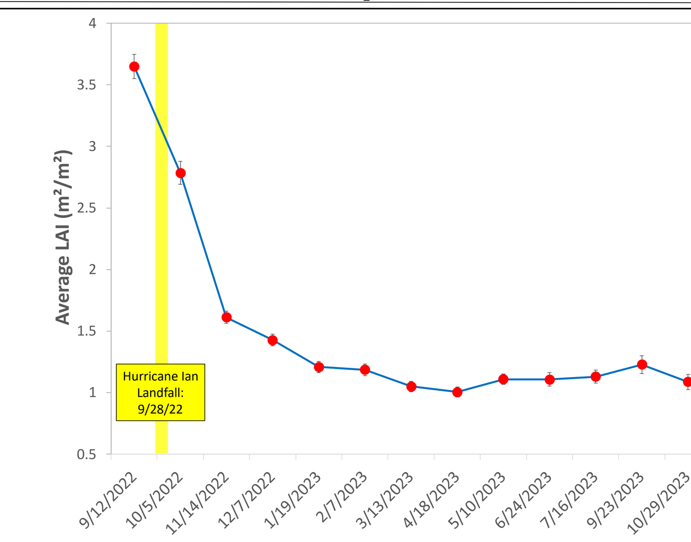
LAI 2200c Plant Canopy Analyzer

Undergraduate researchers measuring LAI with the LAI-2200c plant canopy analyzer below canopy wand.

Image of the above canopy wand placed in Estero Bay. Data from the below canopy wand is compared to this wand to compute LAI.



Example Contour plots of the LAI values measured prior to Hurricane Ian (September 2022), immediately following impact in October and November 2022 and October 2023, a year after impact.

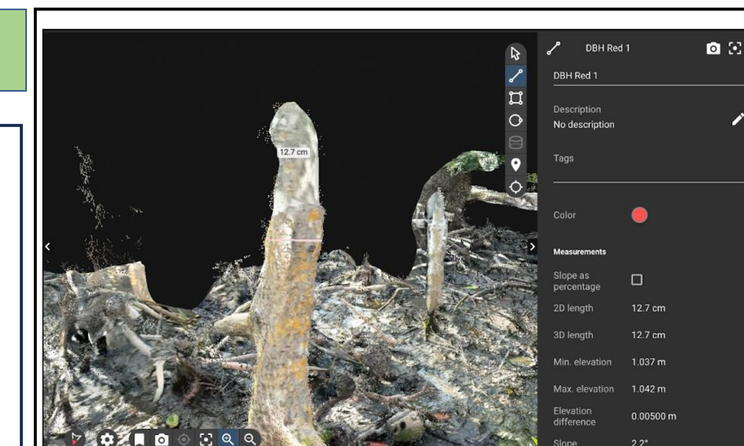


Average LAI within the 1-ha plot since September 2022. The impacts of hurricane Ian continue to be felt over year after the storm's initial impact. Even though the furthest leeward side of the plot is recovering, most of the more windward regions are not.

viDoc-iPhone LiDAR

Demonstration of the viDoc RTK system by one of the co-authors for seedling assessment on the FGCU campus.

The viDoc RTK rover uses high-precision GNSS technology with either iPhone Pro or iPad Pro photography and LiDAR to develop 3-dimensional models of systems. This technology has been used previously in temperate forest ecosystems to measure tree diameters for estimating stand biomass. We are developing similar methodologies for our more complex mangrove systems in SWFL. Output files are spatially resolved, georeferenced point clouds with centimeter-level positioning accuracy. These files allow for species identification and the calculation of DBH, basal area and volumes.



The viDoc RTK rover system has shown promise for mapping and measuring DBH at our site. While processing time is a limitation, the data collection speed significantly reduces time in the field where heat stress can be problematic for researchers. Measurement accuracy appears similar to *in situ* DBH tape measurements. Unfortunately, satellite signal strength may be a limiting factor for the RTK unit in dense mangrove canopy systems.

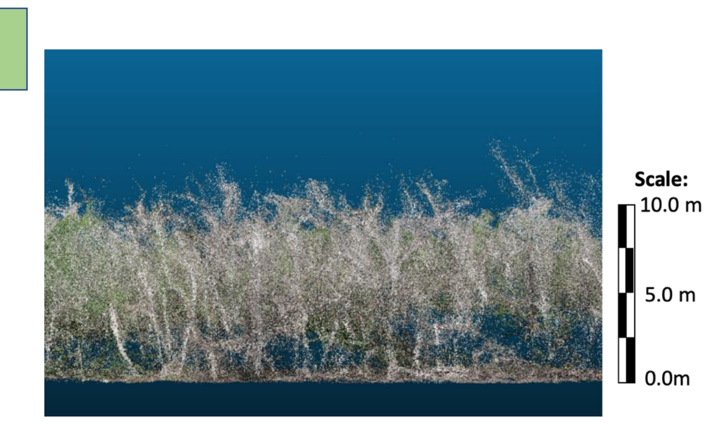
Aerial-Based Remote Sensing

Photogrammetry

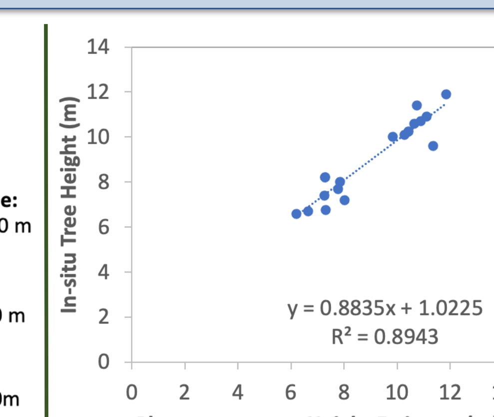
A Phantom 4 Pro V2 was used to collect aerial imagery of the 1-ha plot. This type of technology offers a relatively cheap means of rapidly collecting data over relatively large spatial scales that could not be covered using traditional ecological methods.

Image of telescoping pole used to measure the height of a tree for comparison against the UAV imagery approach.

Aerial orthomosaics of our long-term monitoring site in Estero Bay, FL, prior to and following hurricane Ian landfall in Sept. 2022.

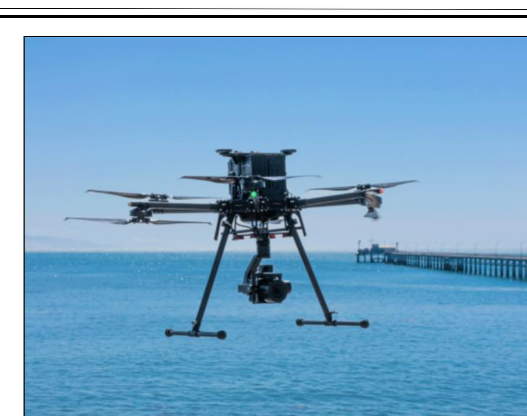


"True color" point cloud obtained from UAV photogrammetry data collected at the Imperial Shores site on 3/5/2023. These data were used to successfully measure tree heights in the analysis to the right.

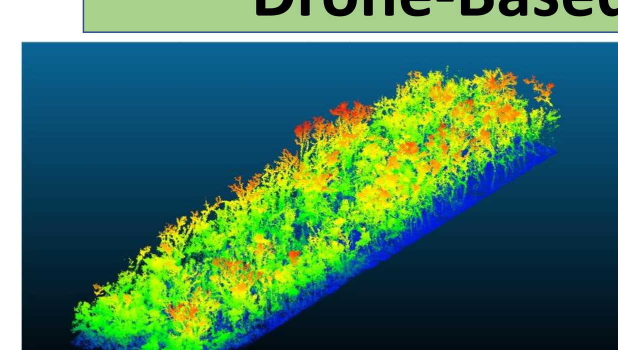


Linear regression of tree height measurements using a telescoping pole vs point cloud data obtained from drone photogrammetry.

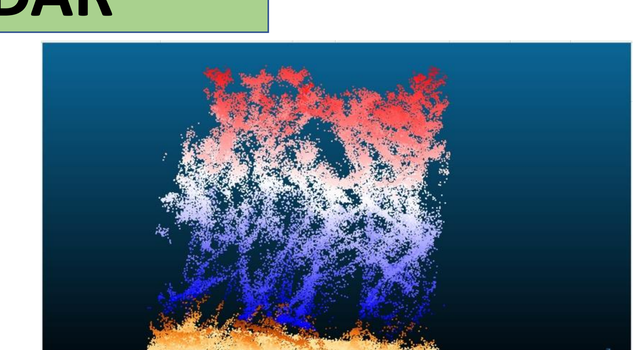
Drone-Based LiDAR



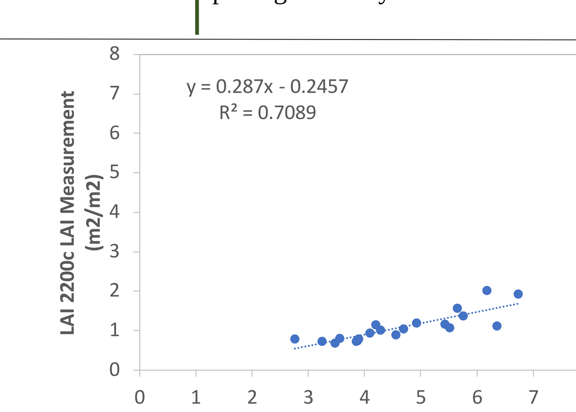
Inspired Flight's IF1200A UAV equipped with LiDAR USA's LiDAR unit used in this study.



LiDAR (10/20/2023) point clouds of subplots A and B, colored by elevation of the individual points.



Subplot data were extracted from the point cloud on the left and LAI was computed using a model from the literature using points above breast height.



Linear regression of LAI (collected 10/20/2023) derived from UAV LiDAR data and LAI 2200c LAI data (11/14/2023). Data indicated a strong significant relationship between the two approaches, however the LiDAR model significantly overestimated LAI suggesting a need for additional data.

3. Conclusions

Hemispherical photography has been used in ecological research for decades to assess LAI and by proxy, ecosystem productivity. In our research, we have found strong but differing relationships between LAI and litter production. These differences appear to result from differences in hurricane impacts on the locations. This technique vastly improves data collection speed compared to measuring litterfall or DBH, but compared to methods below, requires significant time to produce usable imagery and process the images for LAI.

The LAI 2200c Plant Canopy Analyzer provides a compact and rapid means of measuring LAI in mangrove forests. The data from this approach compares well to hemispherical photography and has allowed us to resolve patterns of productivity over relatively small spatial scales (meters) and temporal scales (monthly or smaller). This approach has proven insightful in identifying patterns of delayed mortality following Hurricane Ian. This approach may have the potential, if combined with other types of data to provide faster estimates of plot level biomass. We found a significant relationship with stand biomass and LAI using this approach prior to Hurricane Ian.

The viDoc RTK rover system is the newest technology tested in our study system. We have successfully used it to develop 3-dimentional point cloud models of 100 m^2 mangrove plots at our site. From these models, we have been able to successfully identify species and measure the DBH of trees. Data collection in the field is significantly faster than measuring and identifying all the trees in a plot in the field. This approach also provides a permanent digital snapshot of the system for future reference. Unfortunately, computer processing to develop and measure the models is still relatively time consuming.

UAV-based photogrammetry and LiDAR measurements have shown great promise within the context of our mangrove monitoring site. Photogrammetry estimates of tree height appear to be as good if not better than ground-based measures due to limited line of site in these dense mangrove systems. LiDAR based measures may provide even higher precision but has not been tested yet. The use of models from the literature for estimating LAI from LiDAR point clouds shows promise for estimating LAI and may provide a quick means of assessing leaf productivity moving forward. However more data is required to improve the accuracy of these models (e.g. denser point clouds, species composition, light extinction coefficients, etc. This approach is also becoming cheaper and more accessible with the rapid advancement in these technologies. We anticipate current work on multispectral and hyperspectral imagery will further advance this approach.

4. Acknowledgements

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