Engineering with Nature: The Engineering Performance of Mangroves to Mitigate the Coastal Flood Hazards

FSBPA National Conference on Beach Preservation Technology

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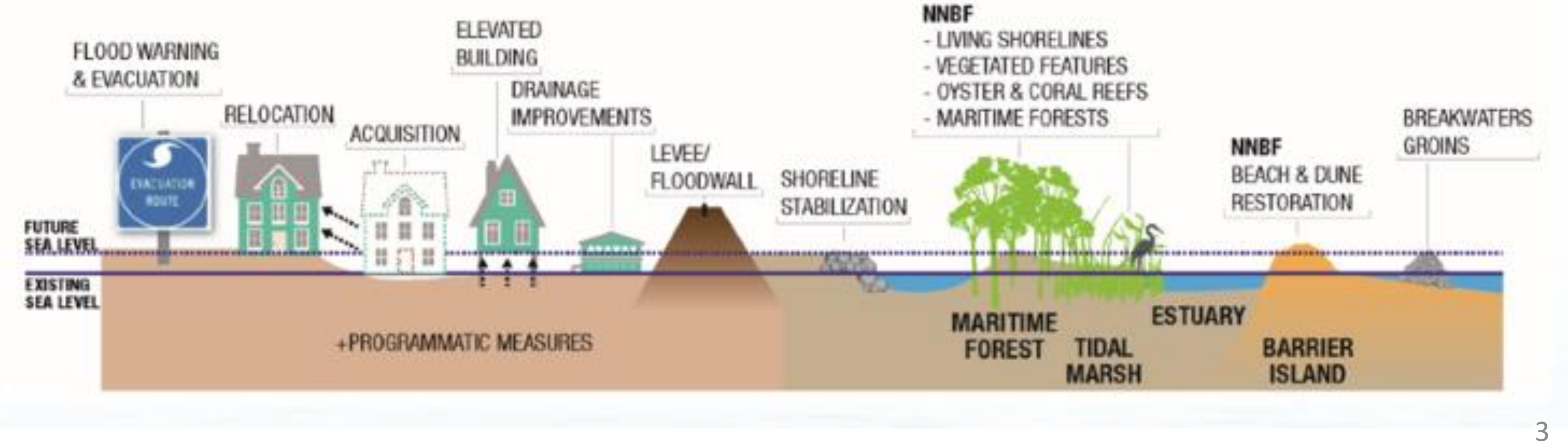
Outline

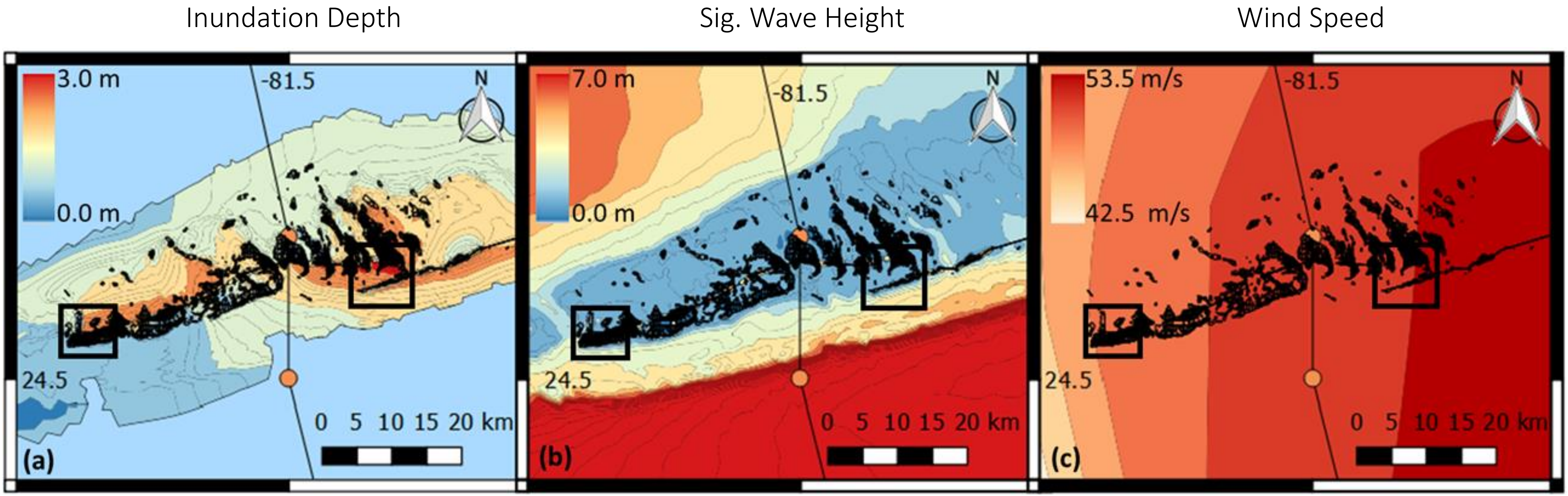
- **Motivation and Background:**
  - Damage observations after Hurricane Irma (2017) in the FL Keys
- **Quantifying mangrove performance metrics**
  - Reduced-scale physical model
  - Prototype-scale physical model
  - Field Measurements
- **Ongoing Work and Conclusions**

Importance of NNBF and Research Challenge

"The U.S. is relying increasingly on natural and nature-based features […] for coastal hazard mitigation […]. Although the ecological good and services are reasonably well known, the capacity of such systems to provide adequate protection is still an open research question." NHERI Five-Year Science Plan, 2nd Ed. (2020)



Motivation: Hurricane Irma (2017)



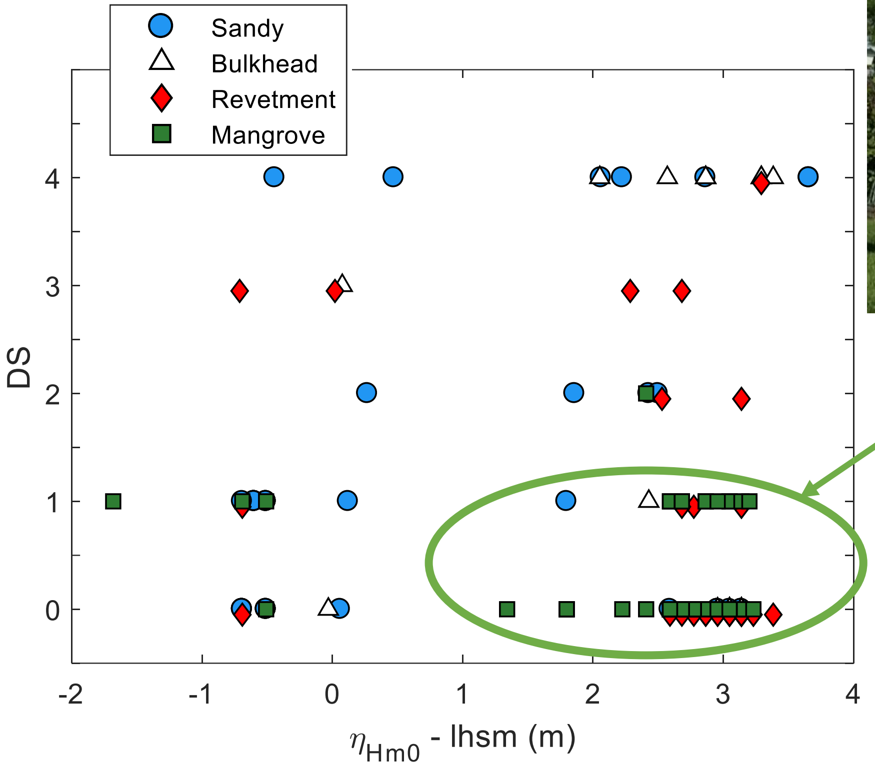
Tomiczek et al. (2020)

	Key West	Big Pine Key
Wind Velocity (m/s)	44.8-49.2	49.3-53.6
Inundation Depth (m)	1.23-2.14	1.53-2.75
Significant Wave Height (m)	0-1.83	0.92-2.74

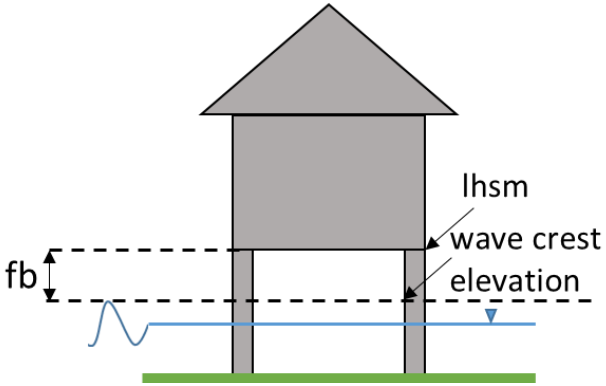
Post-Storm Damage Assessments

- NEU-USNA Collaborative Effort
  - July 2017- March, 2018
- Key West and Big Pine Key
- *Investigate relationship between shoreline resiliency, structural vulnerability, and shoreline management*
- **October, 2017 Survey**: 263 residential structures, 332 shorelines

Fragility Relationships: Relate Hazard, Shoreline Type, and Damage



- Structures with mangrove shorelines: lower damage states (*DS*) for higher hazard intensities ($\eta_{Hm0} - lhsm$)
- Similar to protection noted in other studies (e.g. India, SW FL) for km-scale forests, but for 10-50 m cross-shore forest widths

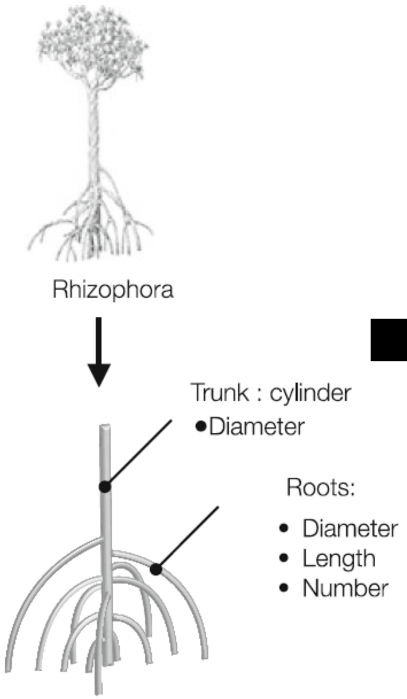


Tomiczek, T., O'Donnell, K., Furman, K., Webbmartin, B., and Scyphers, S. (2020). Rapid Damage Assessments of Shorelines and Structures in the Florida Keys after Hurricane Irma. Nat. Haz. Rev. 21 (1) 15019006. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000349.

Reduced-Scale Physical Model of *Rhizophora Mangle*

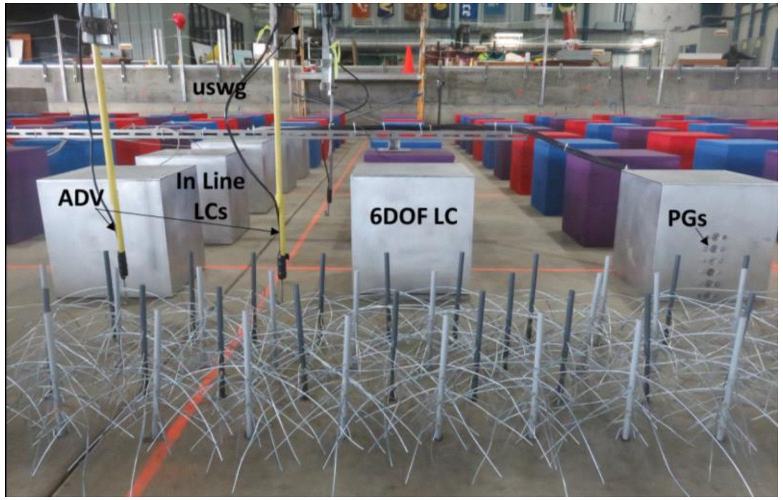
Field measurements

Parameterization



Ohira et al. (2013)

1:16 scale model

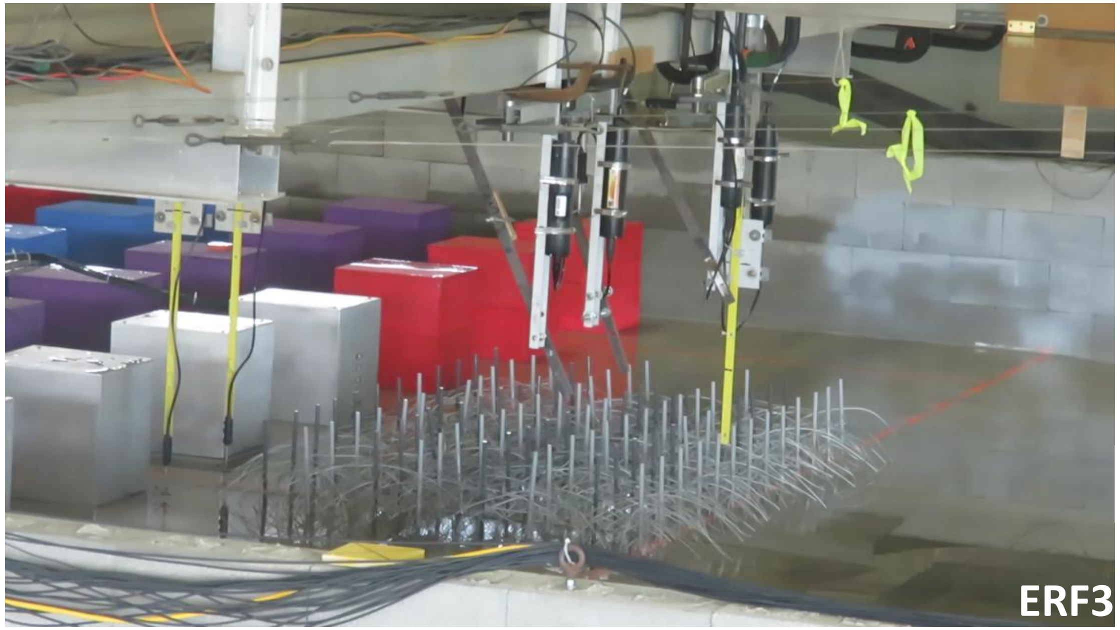


Parameter	Key West (1:1)	Model (1:16)
Material	Red mangrove	PVC + Galv. Steel
d_{trunk} (m)	0.11 – 0.28	0.013
d_{roots} (m)	0.01 – 0.06	0.0025
N_{roots}	12-24	22
h_{root}(m)	1.0 – 2.0	0.125

Reduced-Scale Experiments: Wave Conditions

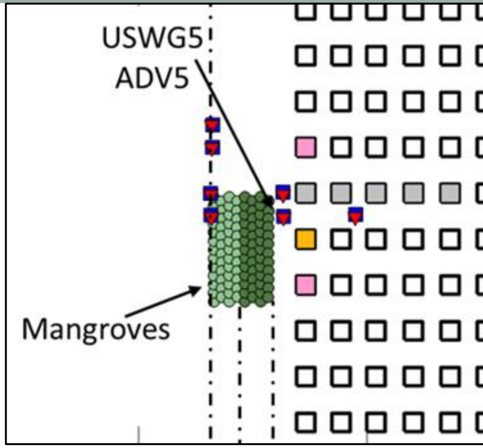
- Random (TMA) and Transient (tsunami-like) wave conditions
- With and without background current
- Focus on transient wave trials

Trial	$\bar{A}$ (m)	$\overline{T_R}$ (s)
ERF1	0.126	11.15
ERF2	0.144	8.30
ERF3	0.207	5.71
ERF1C	0.139	10.83
ERF2C	0.171	9.20
ERF3C	0.216	5.95
C	-	-



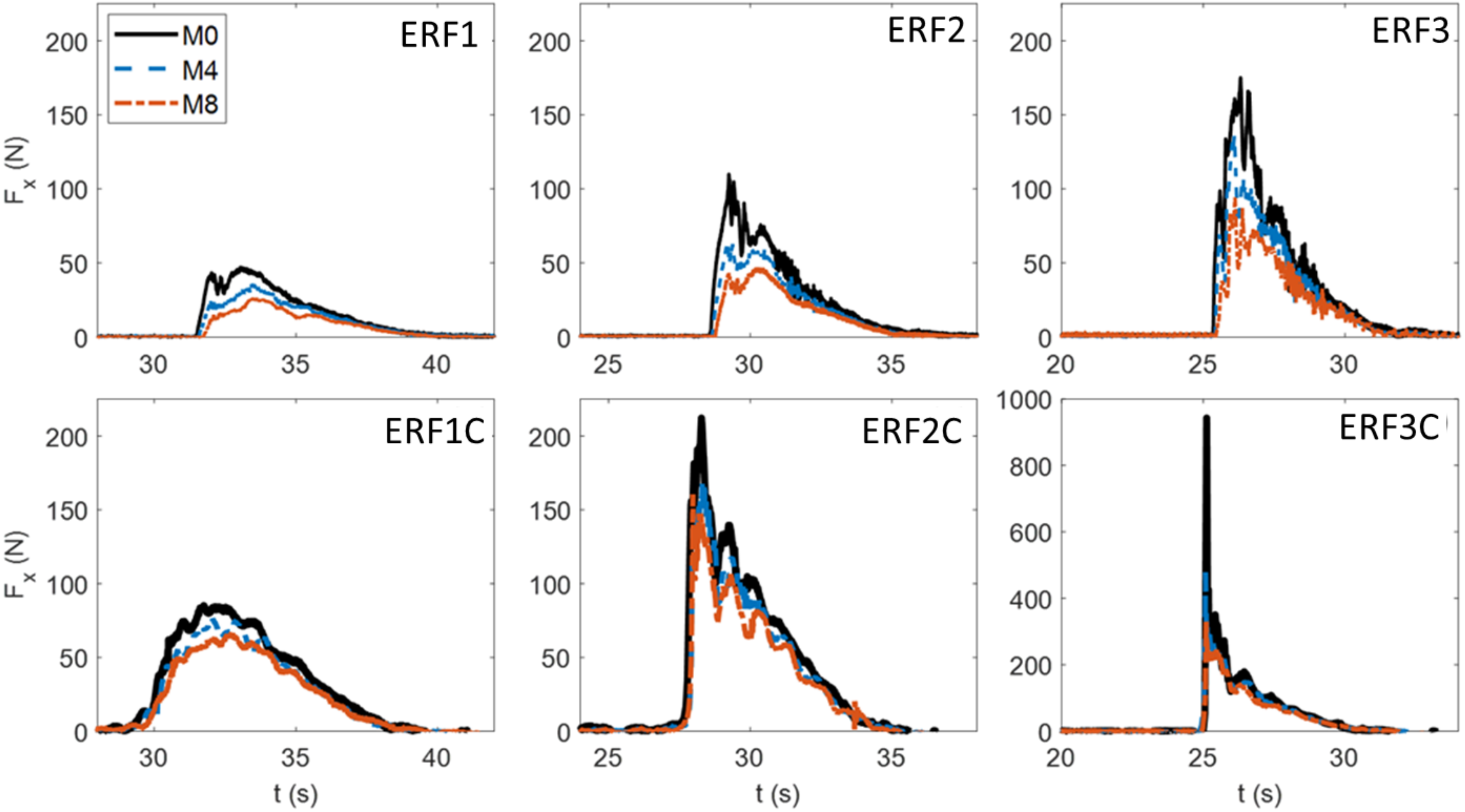
Mangrove Effects on Inland Loads

Increasing wave amplitude, Decreasing wave period



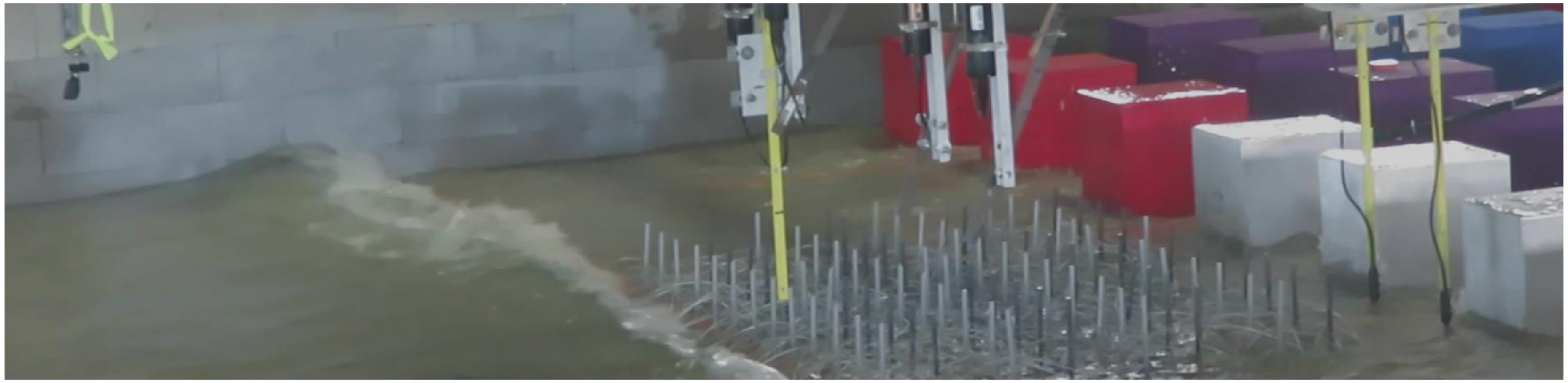
Wave only

Wave + Current



Tomiczek, T., Wargula, A., Lomonaco P., Goodwin, S., Cox, D.T., Kennedy, A.B., and Lynett, P. (2020). Physical Model Investigation of Mid-Scale Mangrove Effects on Flow Hydrodynamics and Pressures and Loads in the Built Environment. Coastal Engineering, 162 (2020). https://doi.org/10.1016/j.coastaleng.2020.103791

How does hydrodynamic response change from reduced- to full- scale?

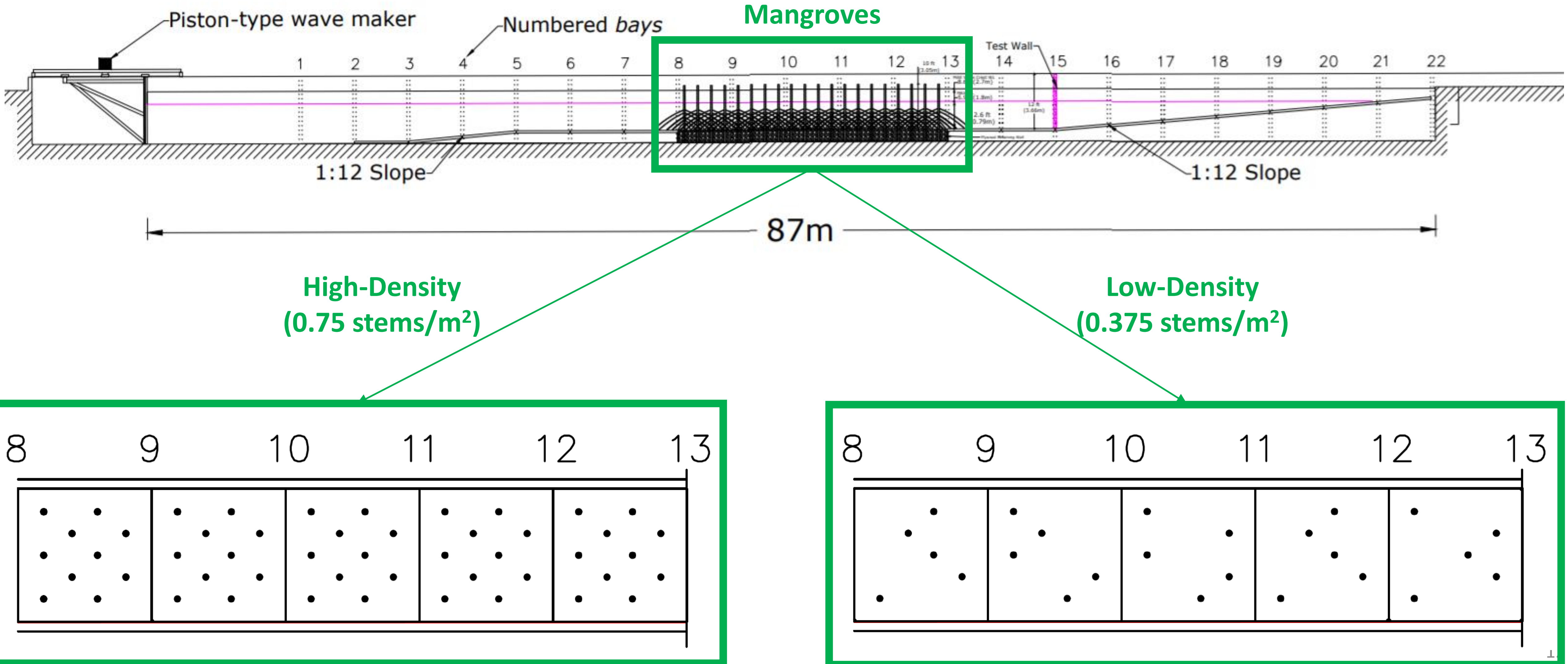


- Need to understand how reduced-scale does or does not affect wave, load attenuation measurements in the lab
- Effect of Reynolds No.
- Collaboration with U.S. Army Corps of Engineers and Oregon State University- opportunity to examine, compare wave attenuation by mangroves at large (1:2) and full (1:1) scale

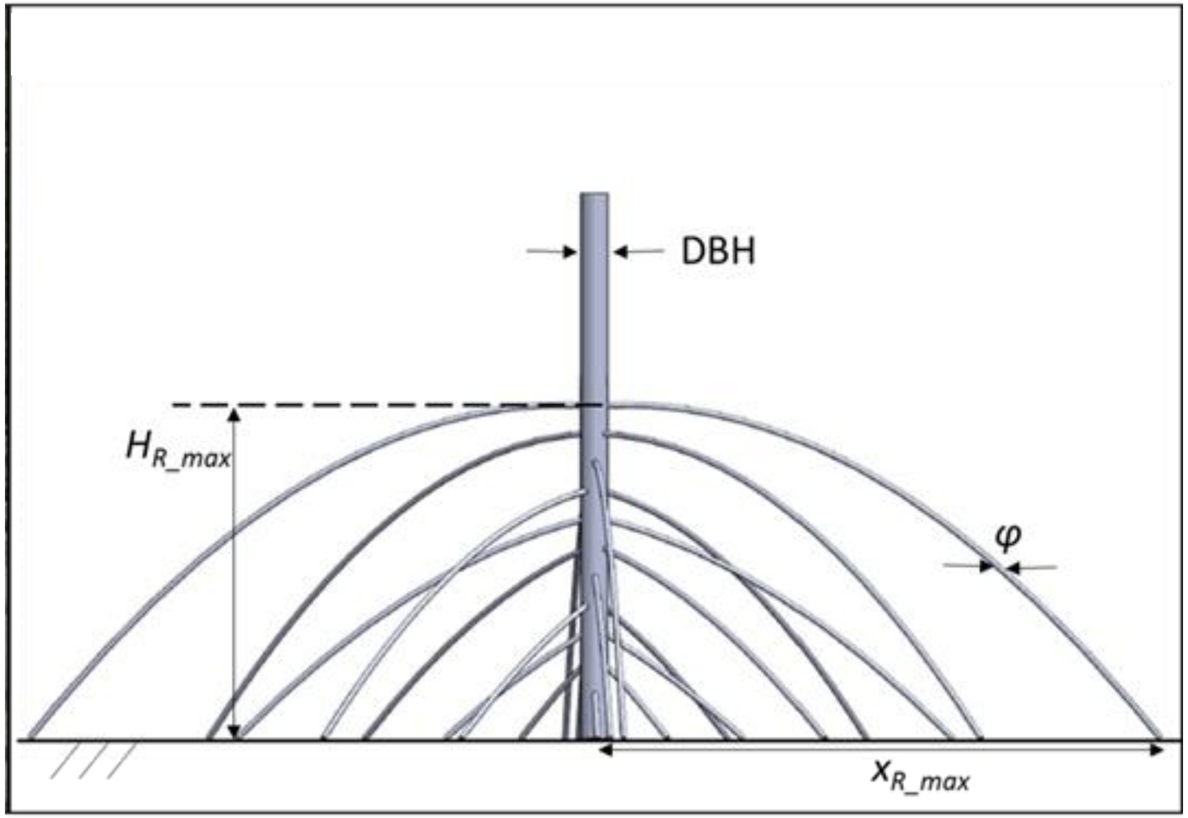
Prototype-Scale Experiments: Goals

- Quantify mangrove performance at full scale
  - Hydraulic response
  - Wave-induced load (pressure) response
- Evaluate effects of mangrove trunk density/projected area
- Assess scaling effects from 1:16 → 1:2 → 1:1 scale for idealized mangrove models

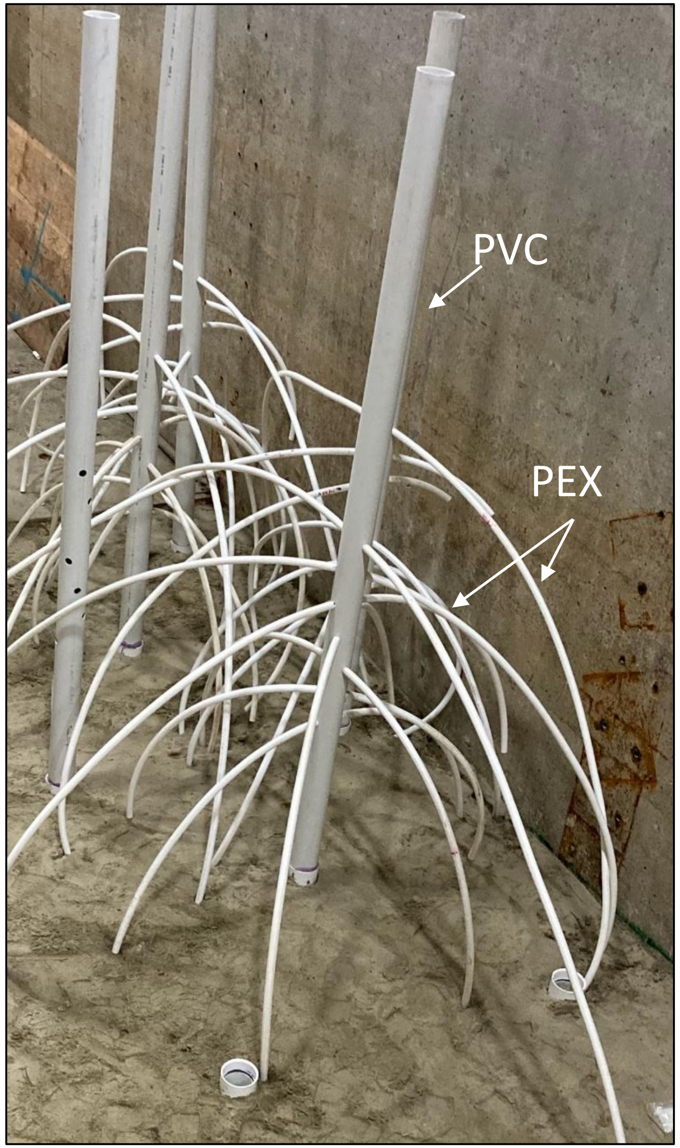
Experimental Layouts



Specimen Design

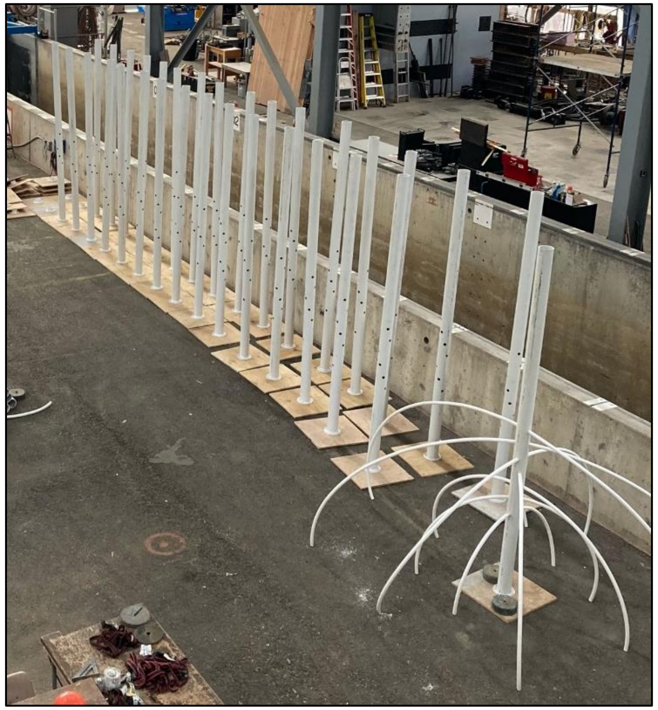


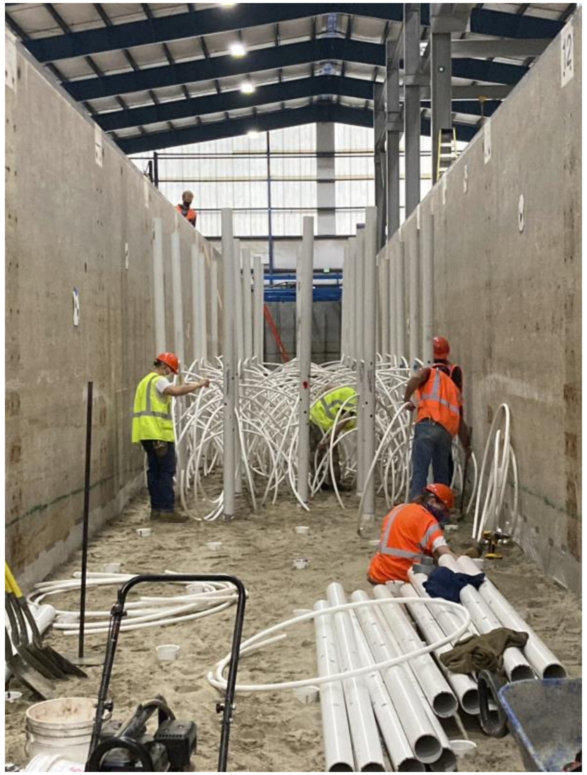
Dimension	Full Scale (m)
DBH	0.114
φ	0.029
H_{R_max}	1.445
x_{R_max}	2.58
N	14



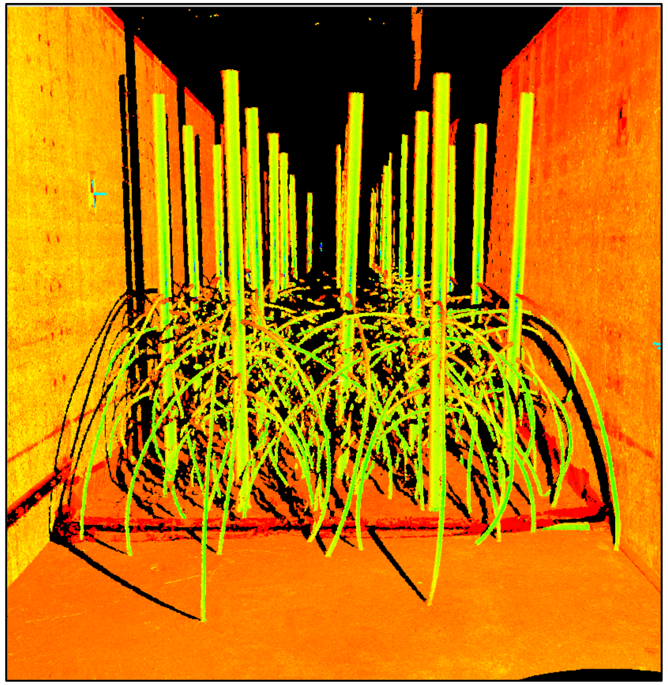
Model Construction

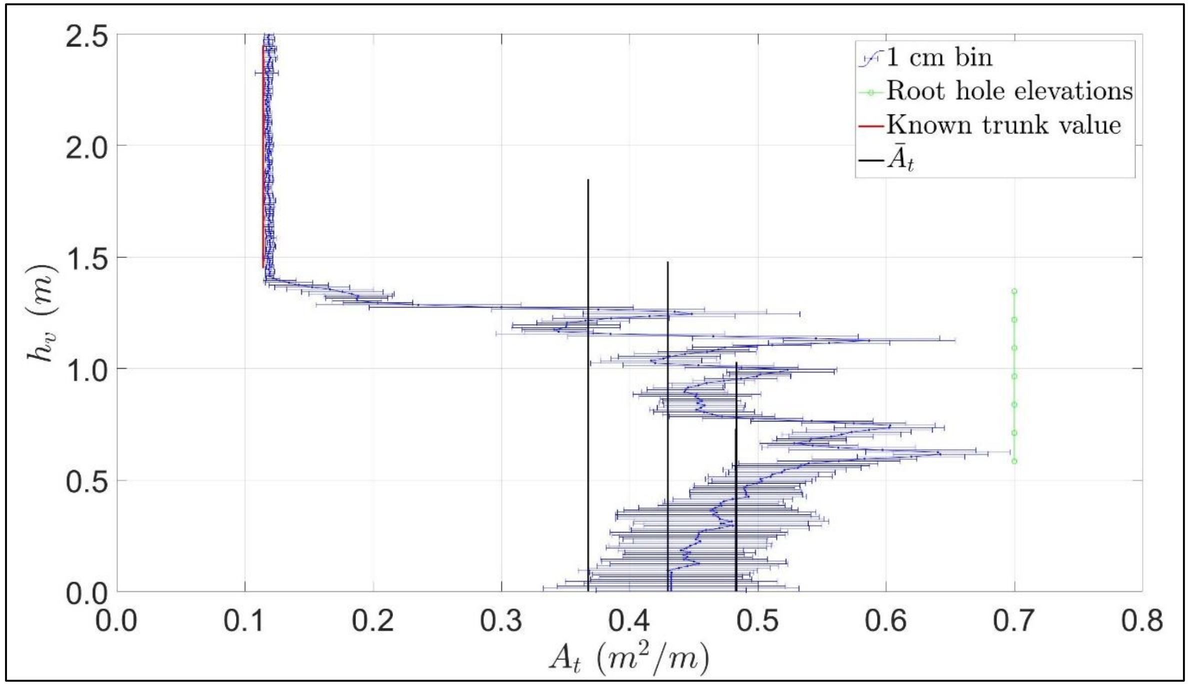
Material	Total Length
PEX	3867 ft
PVC	625 ft





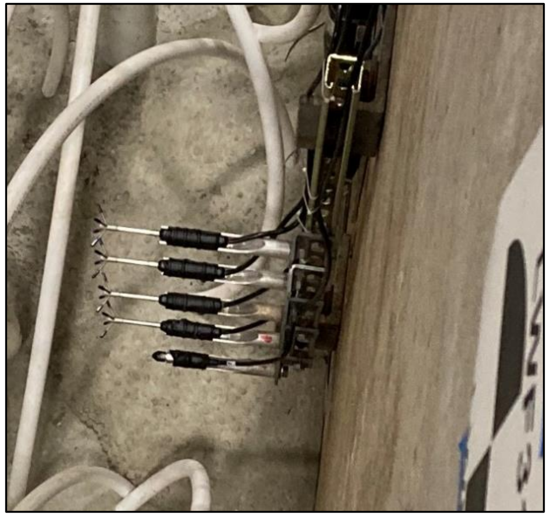
LiDAR Characterization

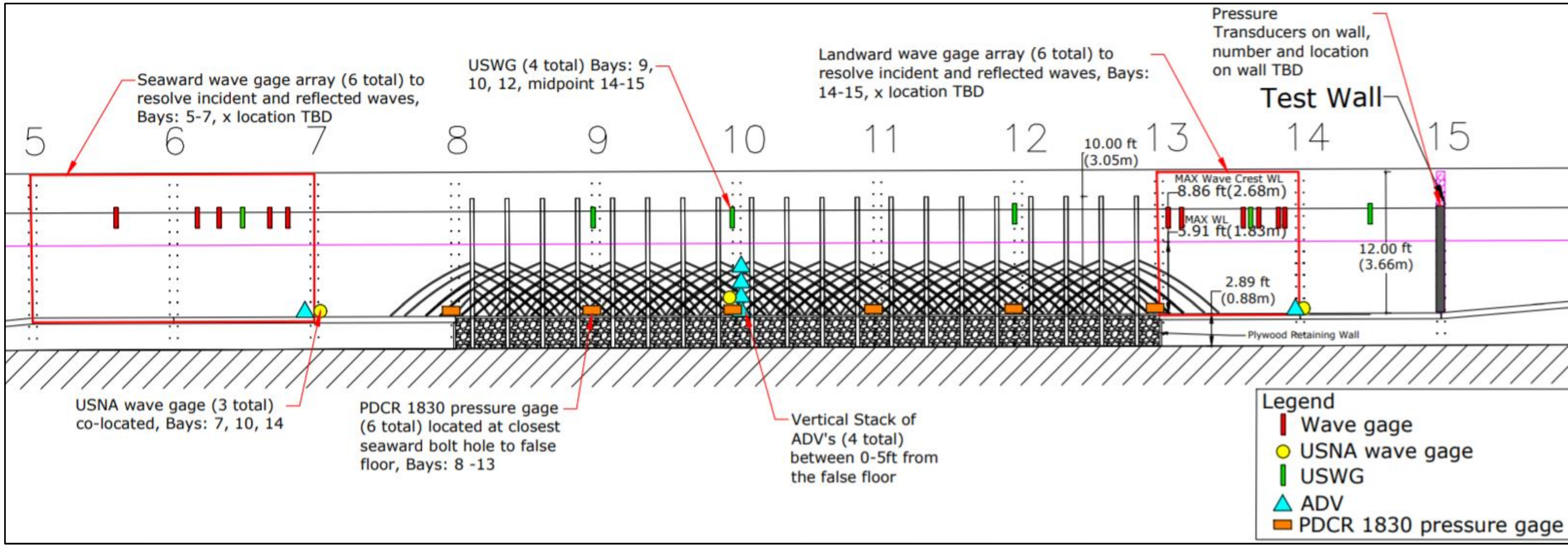


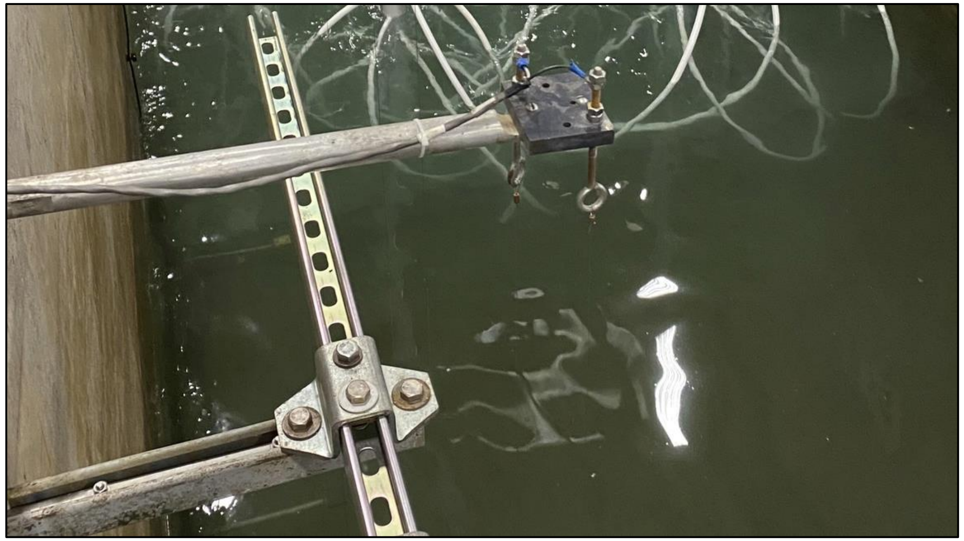


- LiDAR methodology for quantifying projected area of forest
- Accurate to within 2% of known stem diameters, 10% of known root diameters
- Allows full characterization of vertical variation of projected area, uncertainty

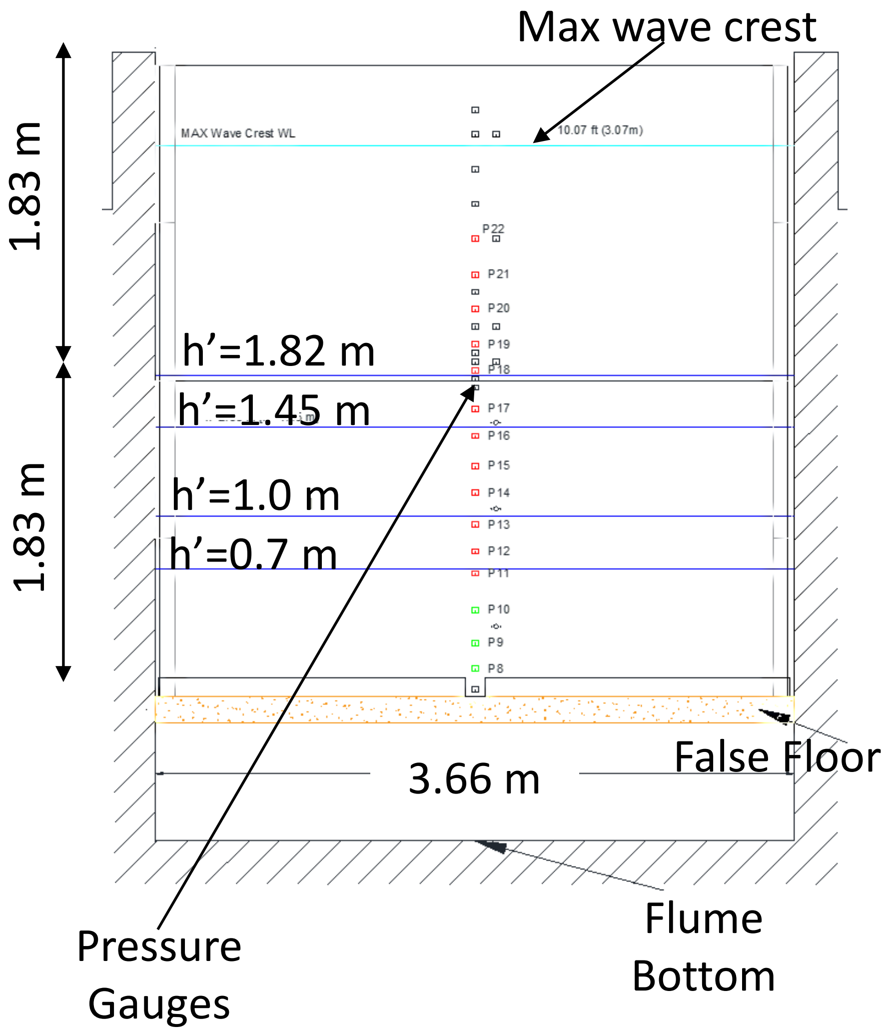
Instrumentation







Wave-Mangrove-Structure Interaction



Mangrove Effects on Hydrodynamics

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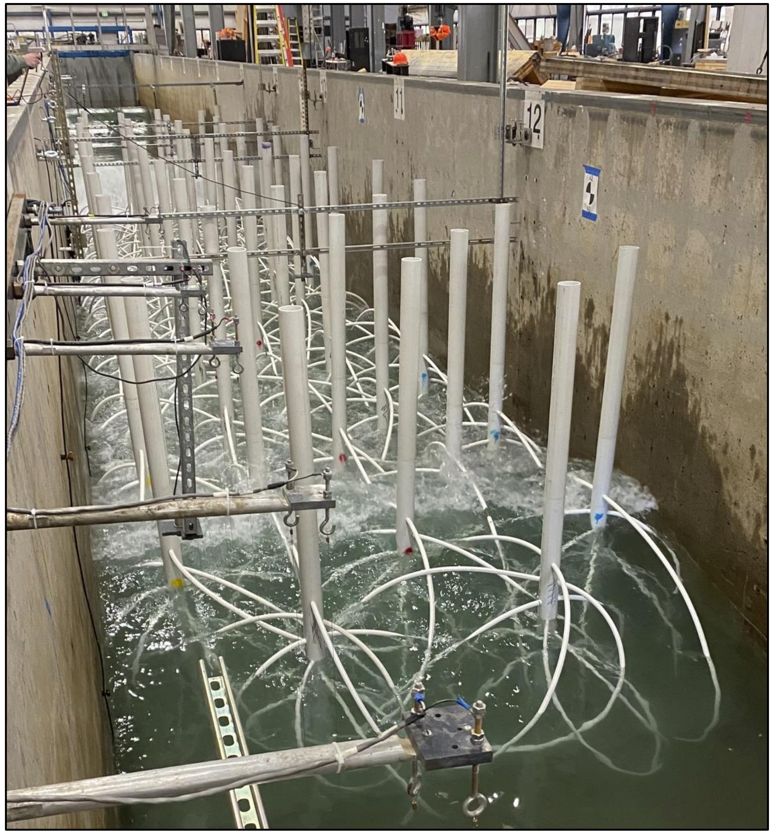
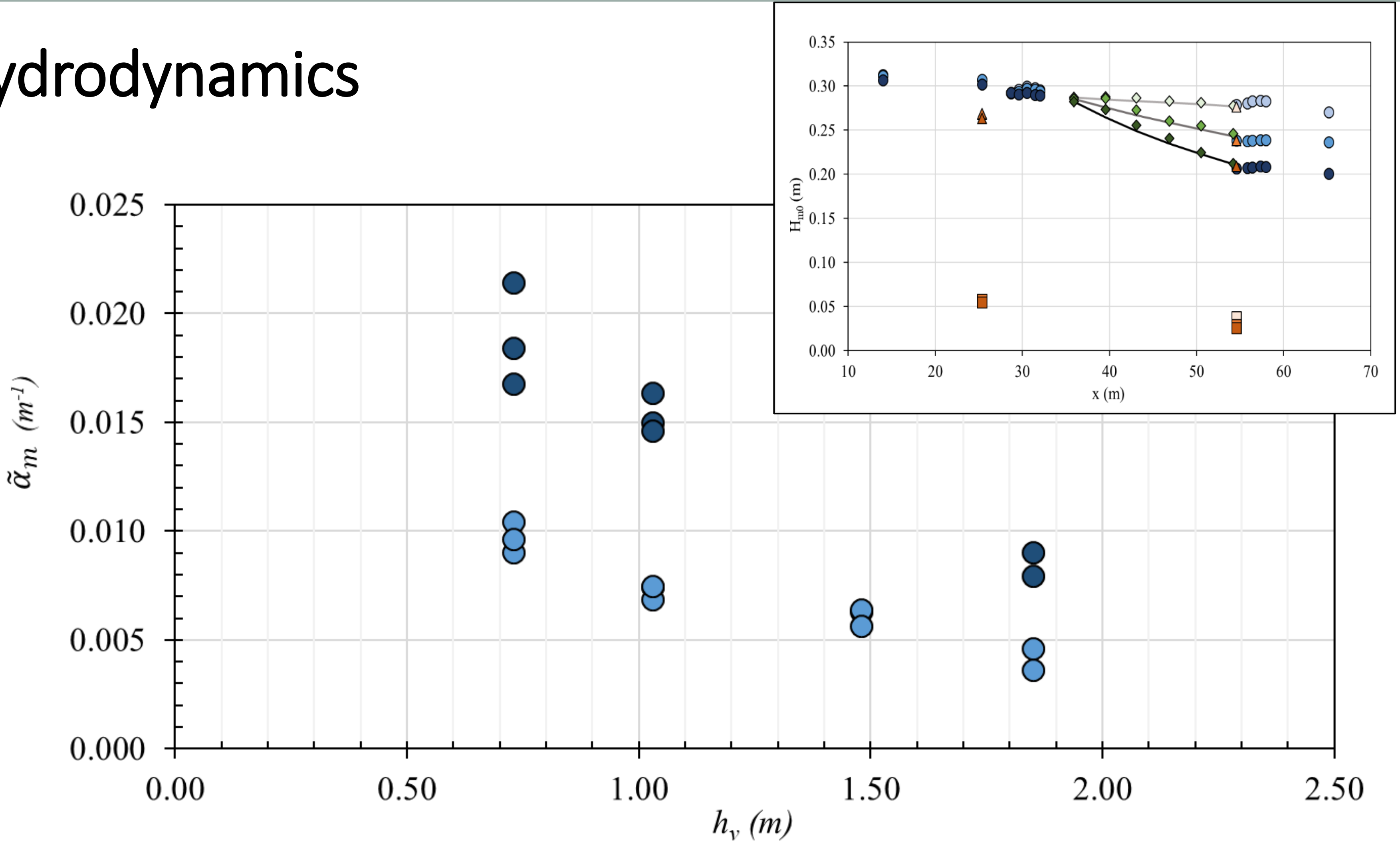


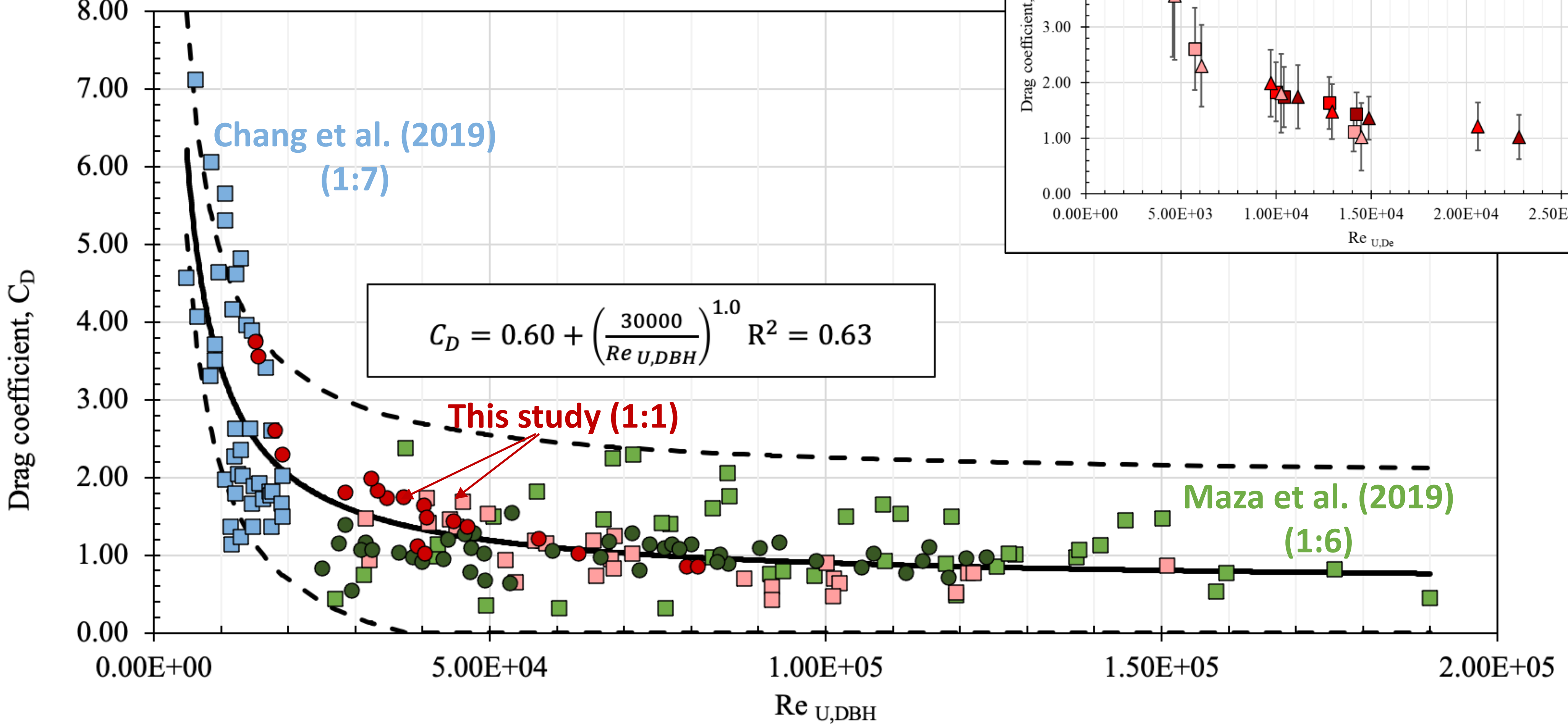


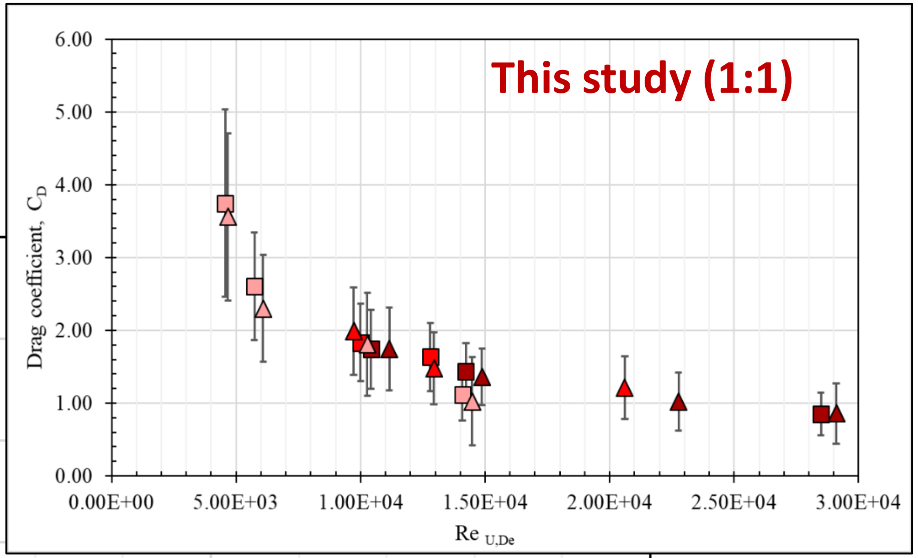
- Decay coefficients are a function of water depth
- Doubling forest density increased decay rate by factor of ~2

$$\frac{H_t}{H_i} = \frac{1}{1 + \tilde{\alpha} x}$$

Drag Coefficient Including Uncertainty

- Rescale reduced-scale models’ Re by $\lambda^{3/2}$



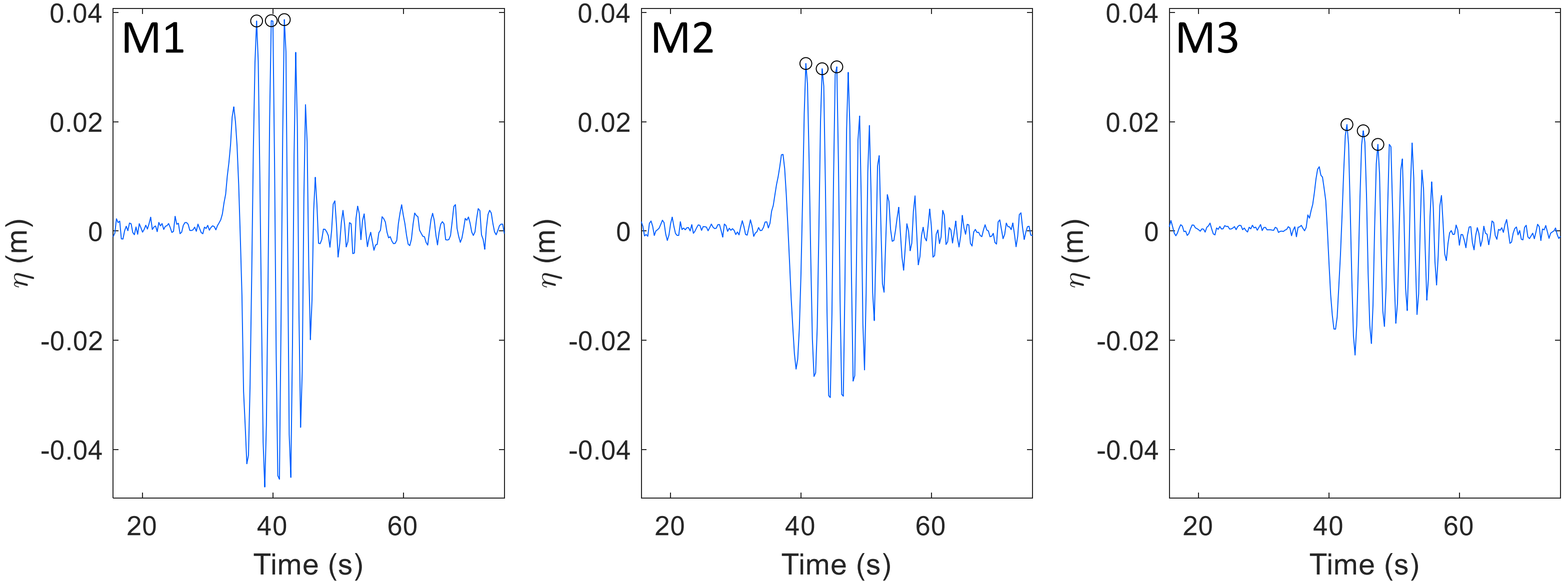


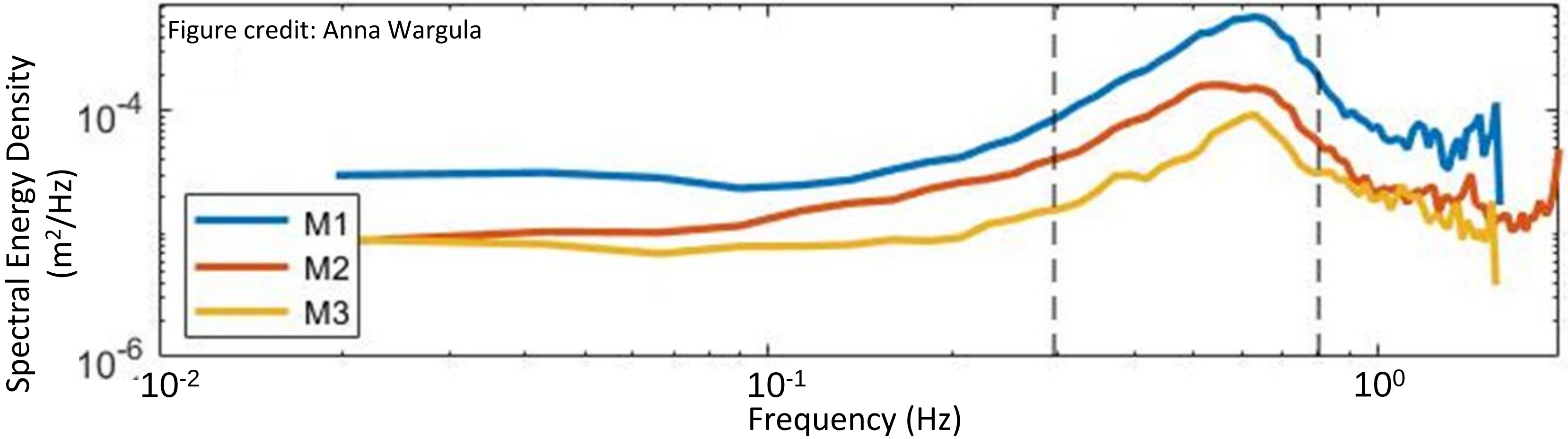
Kelty, K., Tomiczek, T., Cox, D., Lomonaco, P., and Mitchell, W. 2022. Prototype-Scale Physical Model Study of Wave Attenuation by a Mangrove Forest of Moderate Cross-shore Thickness: LiDAR-based Characterization and Reynolds Scaling for Engineering With Nature. Frontiers In Marine Science, https://doi.org/10.3389/fmars.2021.780946.

Vessel-Generated Wake Attenuation by Mangroves

- Measured 236 vessel-generated wakes at fringe (M1), middle (M2), and rear (M3) of a 12.6 m mangrove island
- Transmission coefficients calculated at middle and rear
- Wave transformation due to mangroves (energy dissipation), bathymetry (depth/flow over LCS)

Vessel-Generated Wake Attenuation by Mangroves



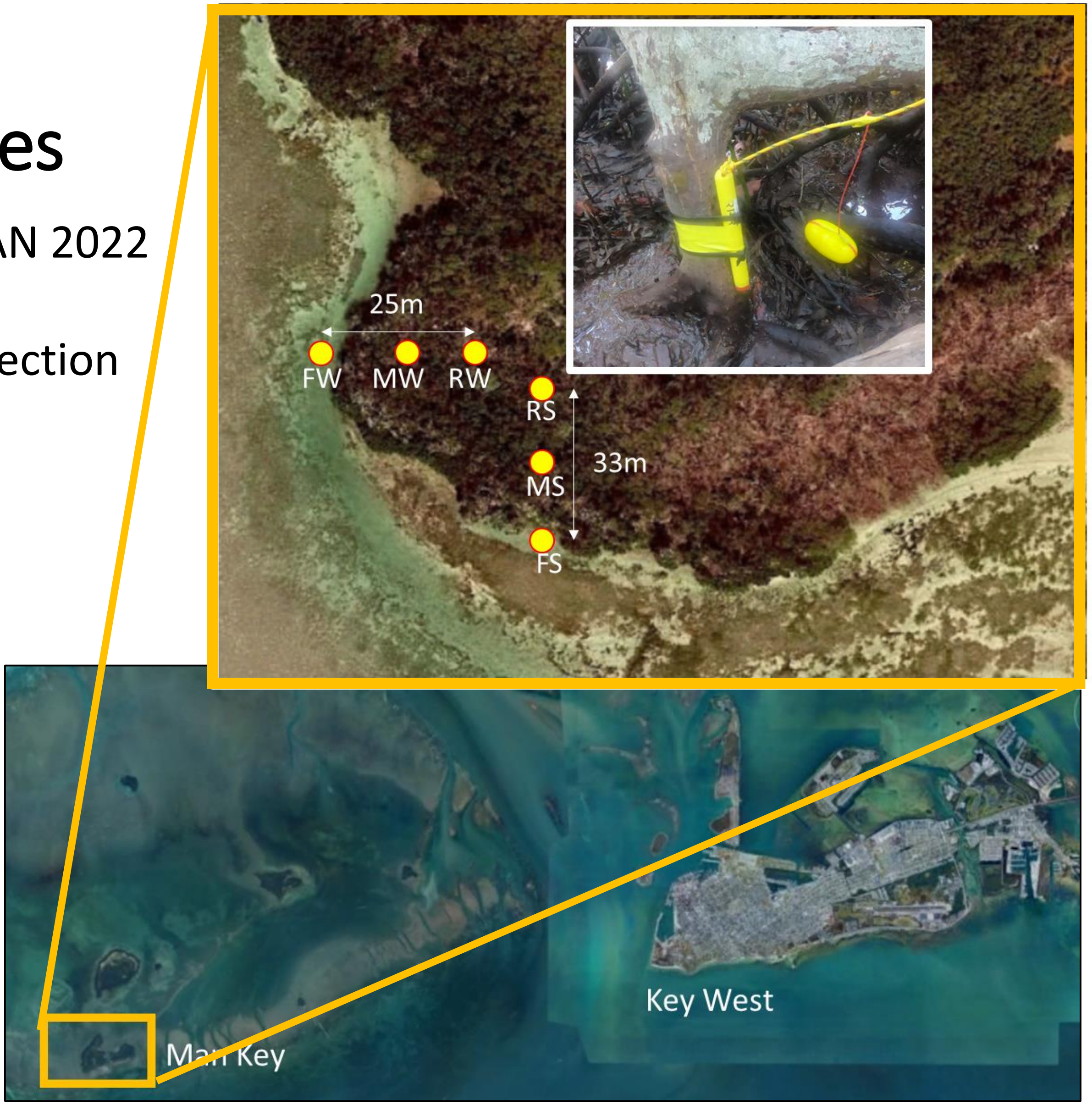


- Wave height decreases from fringe to middle to rear
- Spectral energy similarly decreases, with greater reduction more for shorter period waves, higher incident wave heights
- Separate bathymetric and mangrove contributions using analytical solutions

Tomiczek, T., Wargula, A., O'Donnell, K., LaVeck, K., Castagno, K., and Scyphers, S. 2022. Vessel-generated Wake Attenuation by *Rhizophora Mangle* in Key West, FL. Journal of Waterway, Port, Coastal, and Ocean Engineering, In Press., https://doi.org/10.1061/(ASCE)WW.1943-5460.0000704.

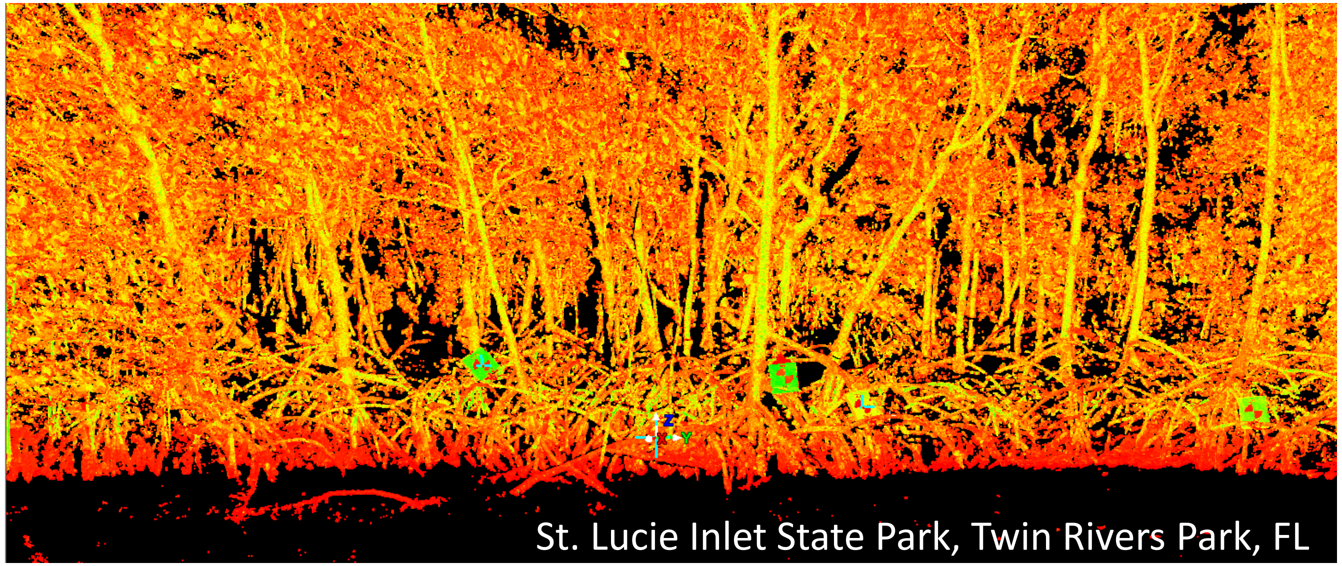
Ongoing Work:
Wind- Wave Attenuation by Mangroves

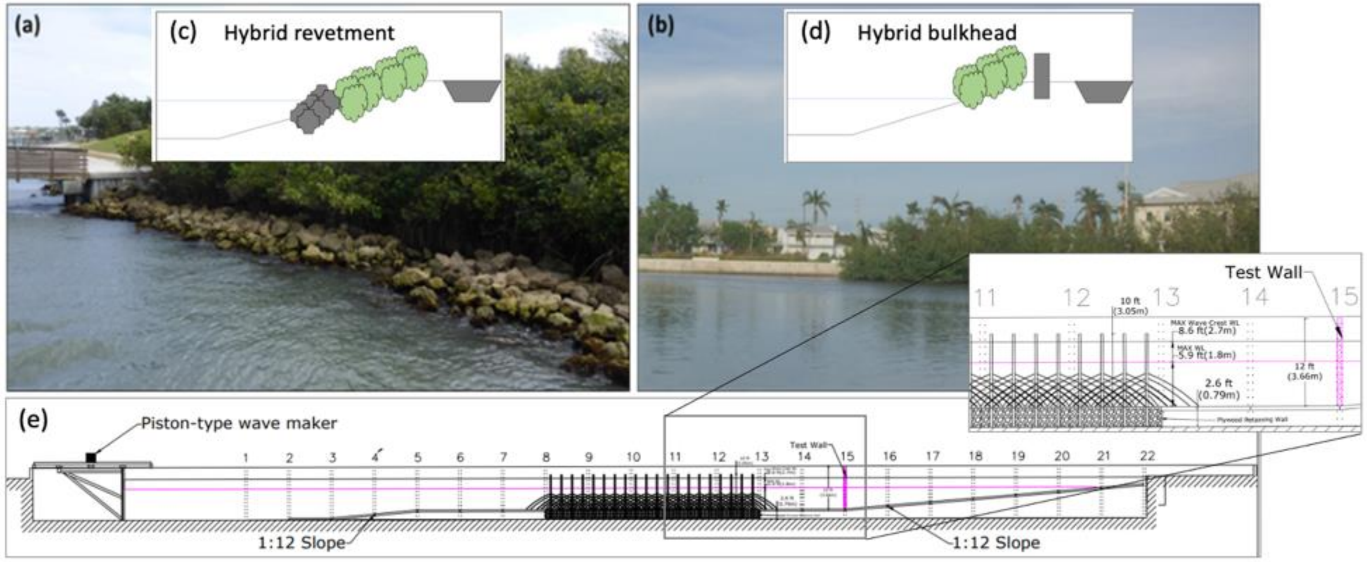
- Sensors deployed 16 AUG – 14 OCT 2021, 15 OCT – 5 JAN 2022
- Sampling Rate: 8 Hz
- Field protocol to characterize sites for engineering protection



Ongoing Work: Understanding Performance of Green-Gray Infrastructure for Engineering With Nature

- NSF-funded project #2110262,
- kicked off 1 January 2022
  - *Identify and parameterize fundamental interactions among incident wave and surge conditions, bathymetry, emergent vegetation, and subsequent overtopping of coastal bulkheads and revetments*
  - *Quantify interaction uncertainties to enable stochastic approaches for assessing range of expected performance of hybrid coastal systems*
- Field Protocols for Engineering With Nature: understand variability in projected area, relate to other geometric parameters
  - *Field work planned for Summer, 2022 to inform physical model tests at Oregon State University (Summer, 2023)*





Please contact Tori Tomiczek if interested!
vjohnson@usna.edu

Summary and Future Work

- Field observations, reduced scale tests show potential of mangroves as effective NNBF solutions for coastal protection
- Prototype-scale tests ongoing to quantify wave attenuation, load reduction, and assess scaling impacts from laboratory to field
- **Future Work:** Research, Outreach, Incorporation into design guidance

Thank you!

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