EWN Case Study: Mangroves

The Role of Shoreline Type in Mitigating Damage due to Hurricane Irma in the Florida Keys

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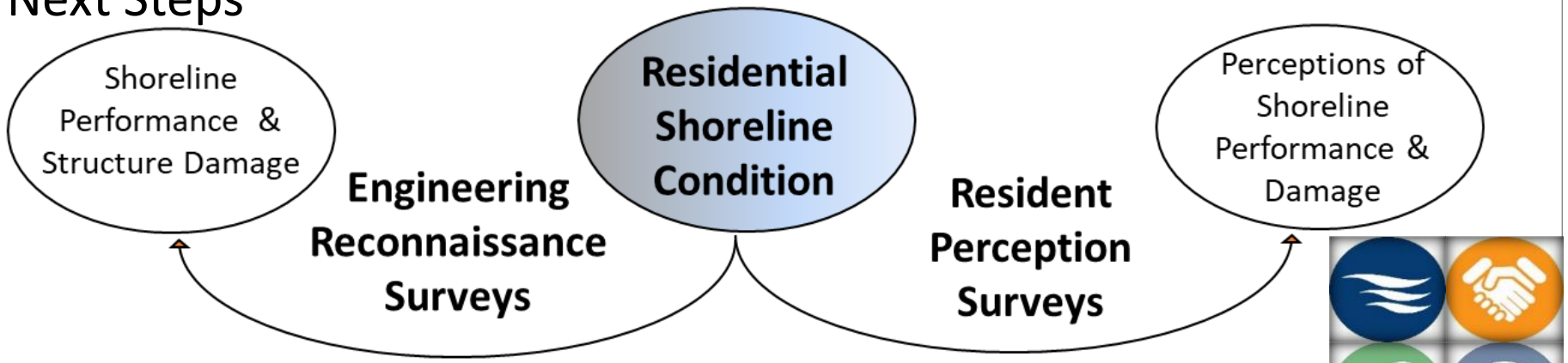
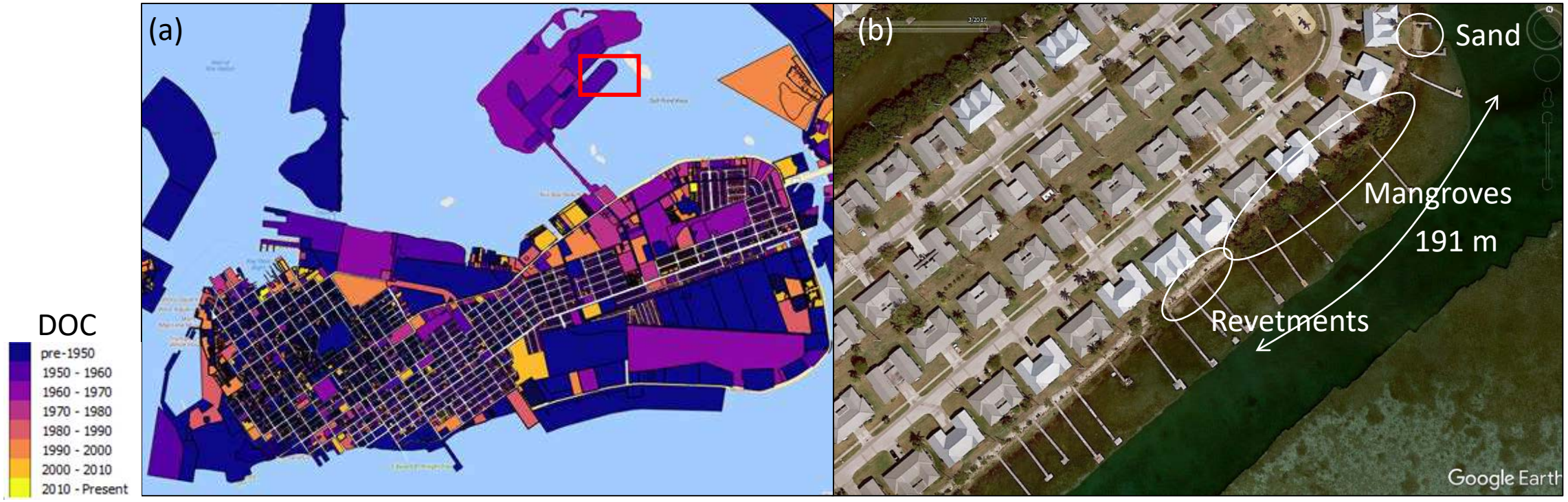
Outline

1. Introduction: The Florida Keys and Hurricane Irma
2. Post-Storm Reconnaissance
   a. Shoreline Damage- Island and Parcel Scales
   b. Structural Damage- Parcel Scale
4. Interconnectivities between Hazard, Shoreline Archetype, and Physical Damage
5. Homeowner Perceptions of Shoreline Performance
6. Quantifying Engineering Benefits
7. Conclusions and Next Steps

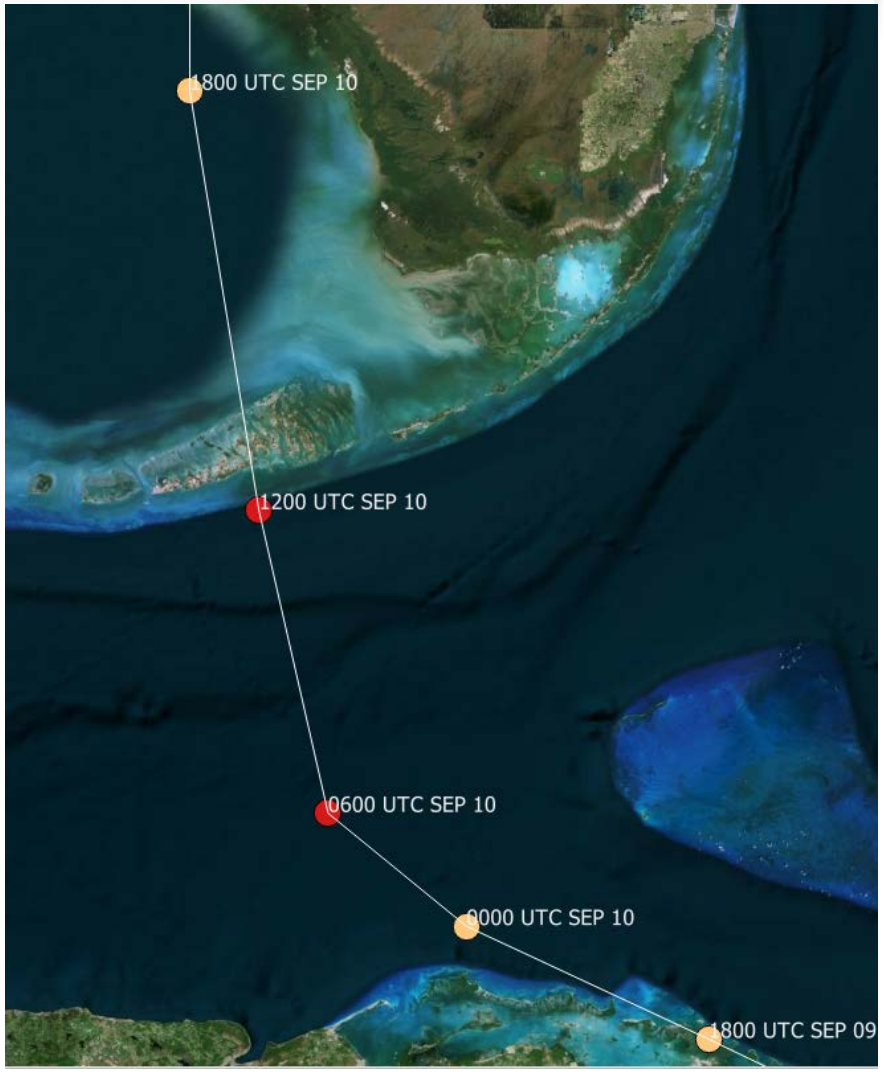


Florida Keys: Structural Consistency, Shoreline Variability



Hurricane Irma

Duration	30 August-16 September, 2017
Keys Landfall	Cudjoe Key, 10 September, 2017, 1310 UTC, Category 4
Central Pressure	914 mBar (min)*; 929 mBar (Keys landfall)
Wind Speeds	185 mph (maximum)**; 130 mph (Keys landfall)
Storm Surge	3 m (Florida Keys)
Effects	Catastrophic damage in Barbuda, USVI, Caribbean, middle Florida Keys, >146 deaths
US Property Damage	$53.4 billion***

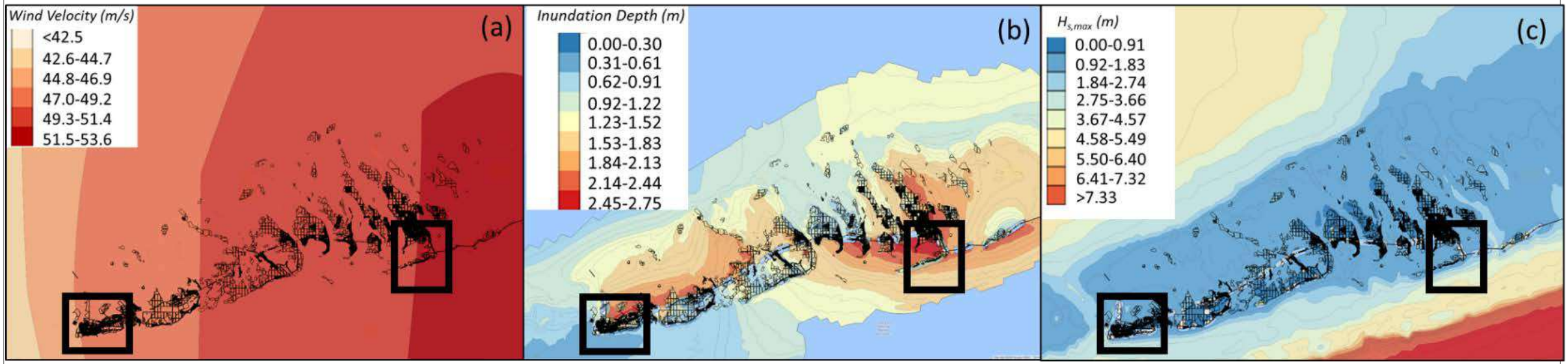


Hurricane Irma Best Track: NHC

* 2nd most intense of 2017 (behind Hurricane Maria)
** Strongest of 2017
*** 5th costliest in US History

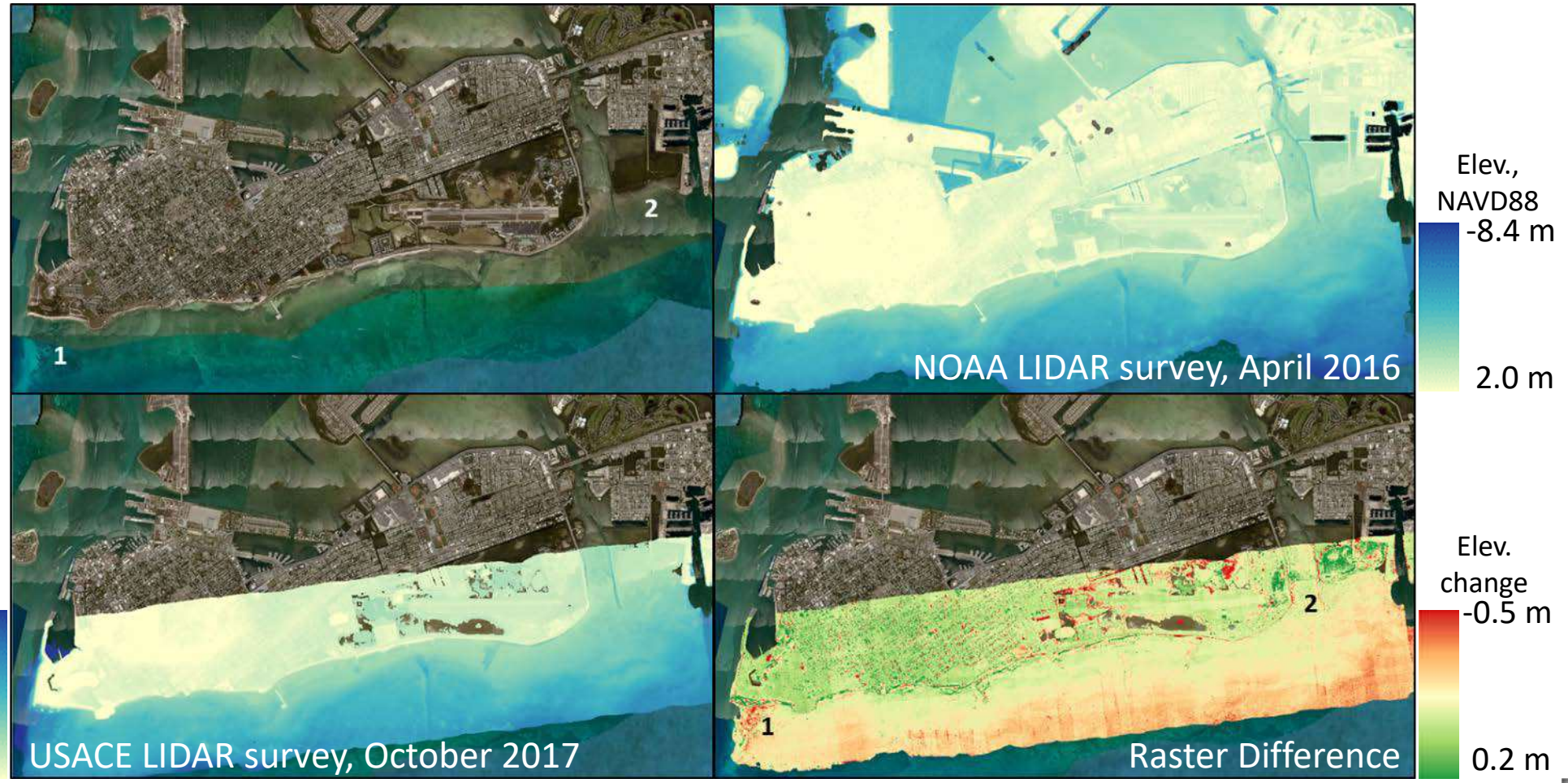
Hurricane Irma: Hazard Intensity Measures

ADCIRC + SWAN storm simulation courtesy CERA (2017)



	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

Island Scale Vulnerability



Island Scale Vulnerability

Elev. change
-0.5 m
0.2 m

Fort Zachary Taylor State Park

Roosevelt Seawall and Cow Key Mangroves

Parcel Scale Damage Assessments

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

Shoreline Archetypes

- Compiled from observations, NOAA C-CAP (2017) regional land cover classifications and USACE (1995) descriptions of shoreline structures

Shoreline Damage

Mangrove: broken branches, loss of foliage, regrowth

Sandy Beaches: erosion

- 4 point damage scale from 0 (no visible damage) to 3 (totally destroyed)
- Based on field observations, permitting data

Revetment: rocks displaced

Bulkhead: cracks, undercutting, structural collapse

Component-Based Structural Damage Assessments

Component	0	1	2	3	4
Roof	• No visible damage	• Few shingles missing (<15% of roof area) • Minor damage to gutters	• Significant amount of shingles missing 15-30% of roof area) • Minor damage to frame • Roof interior is not exposed	• Holes in roof due to debris or wind- sheathing is exposed but not house interior	• Large parts of roof are missing or collapsed; structural damage
Walls	• No visible damage	• Minor cladding removal (<10% of 1 wall) • Small scratches/ aesthetic damage	• Cladding removed from >25% of wall surfaces •Interior sheathing exposed on <25% of house but insulation and house interiors are not	• Minor structural wall damage, including debris caused holes or repairable damage	•Walls have collapsed, bent or are out of plumb, structural damage • Large holes in walls • major structural damage
Foundation	• No visible damage	• Scour <0.5 feet around foundation • Water marks around foundation • Structurally sound	• Scour 0.5-2' deep • Structurally sound foundation • Evidence of weathering/minor damage on piles	• One pile out of plumb, or damaged • Scour >2' deep • Minor damage to foundation	• Major foundation damage • Differentially settlement • >1 pile is damaged • House is missing
Landscaping, Attachments and Detached Structures (If Waterfront, Shoreline Condition)	• No visible damage	• <2 Exterior structures damaged or removed • Damage to stair, porches, detached garage, or walkways, most structures remain in tact • Shoreline- aesthetic damage	• 2 or more exterior structures are gone or destroyed • Damage/ collapse of deck, shed • Landscaping damage- >50% of trees, bushes uprooted • Shoreline- moderate damage	• Collapse of detached garage • Shoreline- complete damage	
Openings: Windows, Doors, Attached Garages	• No visible damage	• 1 window or door is broken (glass only) • Screens may be damaged or missing	• 2+ windows/doors broken or removed • Damage to frames of doors and windows • Attached garage door damaged or gone		
Interior	• No visible damage	•No flooding • Minimal/no evidence of rain intrusion- minor water damage in corners or around windows only • Minor water damage to interior furnishings	• Slight evidence of flooding • Water marks (0-1') above floor • Evidence of rain intrusion- dampness/ minor water damage on <10% of wall area or ceiling • Water damage to interior furnishings • No mold	• Water marks (1'-4') • Rain/water damage to ceiling: wet spots, dripping, or sagging • Dampness on >25% of wall areas and evidence of dripping or cracks on walls •Mold	• Water marks 4' or higher • Structural ceiling damage from rain- wet spots and sagging • Structural damage to interior walls

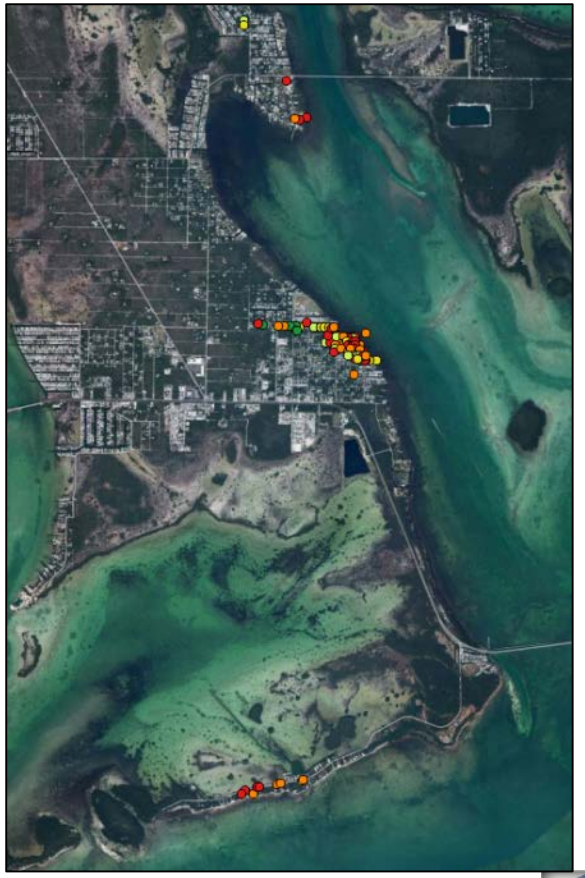
Component-based Structural Damage Assessments

Key West

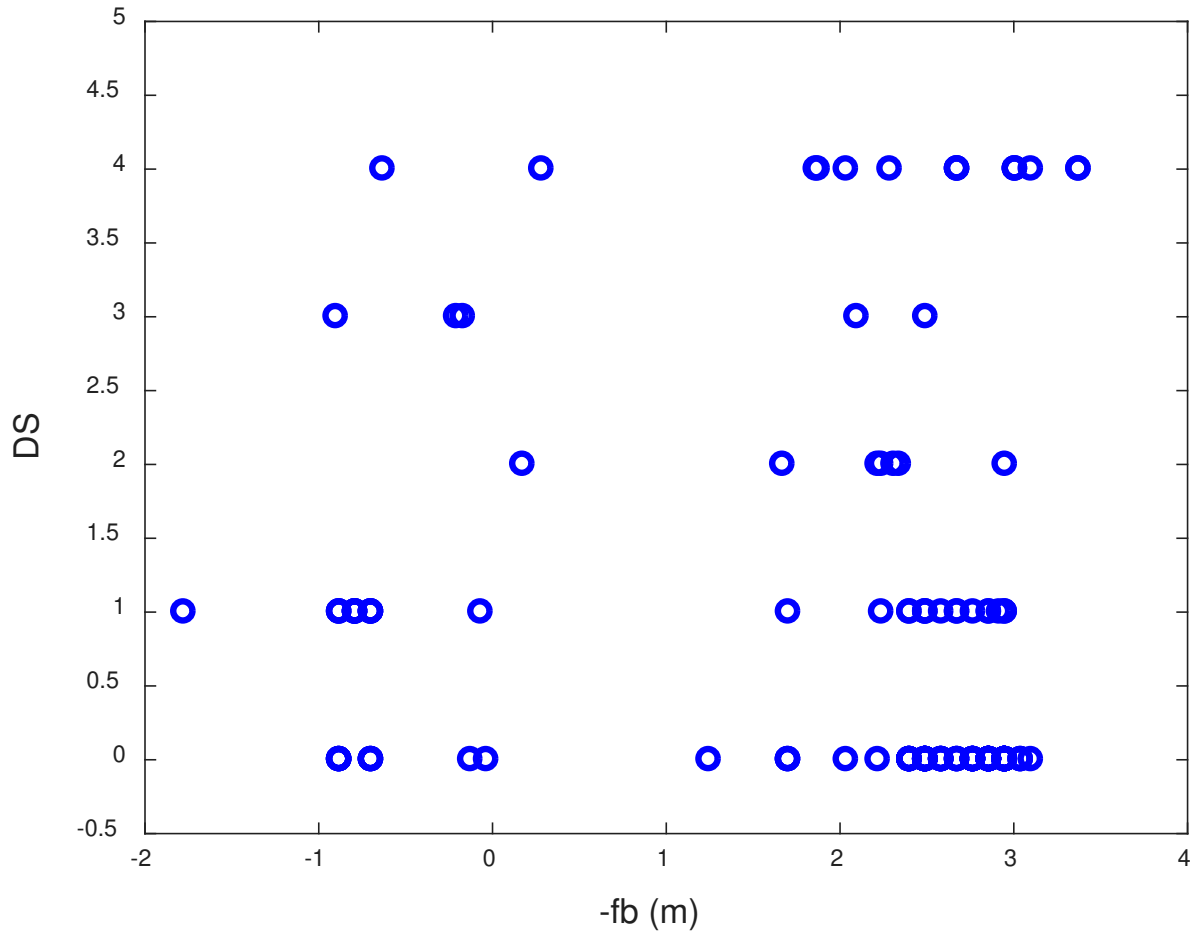
Big Pine Key

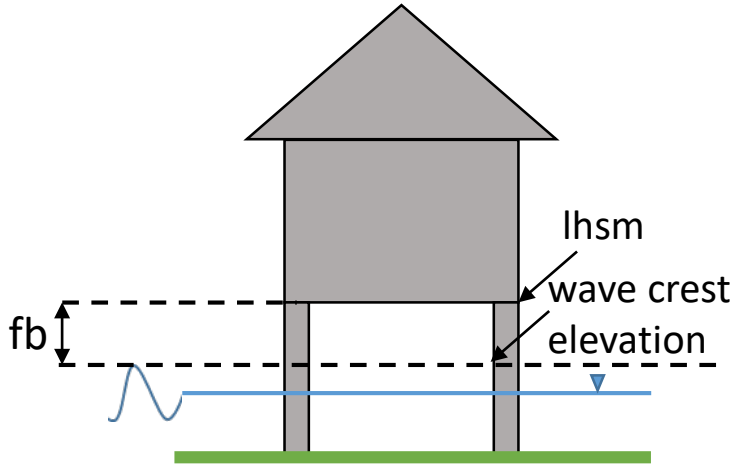
Damage State

- 0
- 1
- 2
- 3
- 4



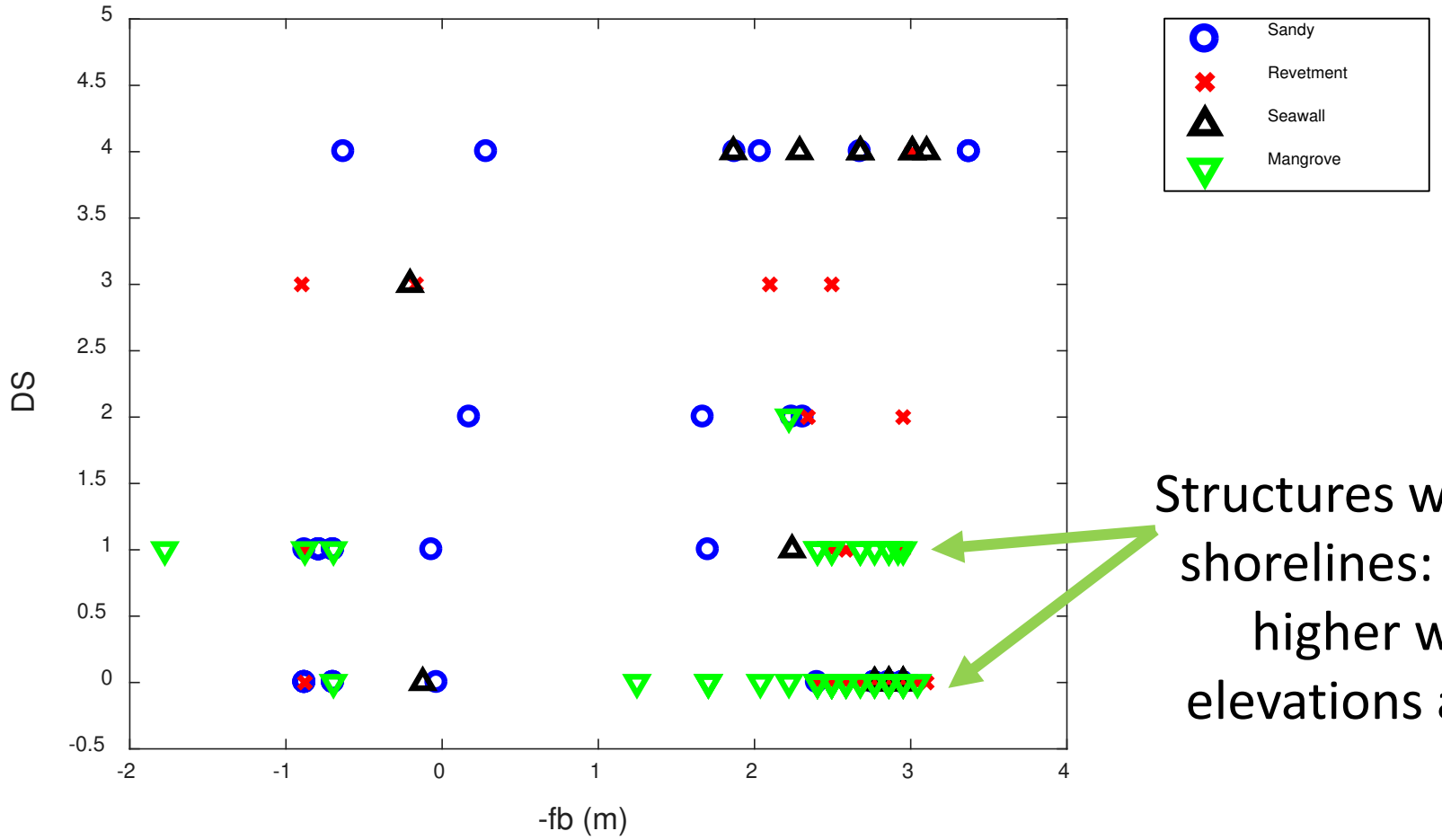
Structural Fragility: Relate Hazard, Structural Damage (?)





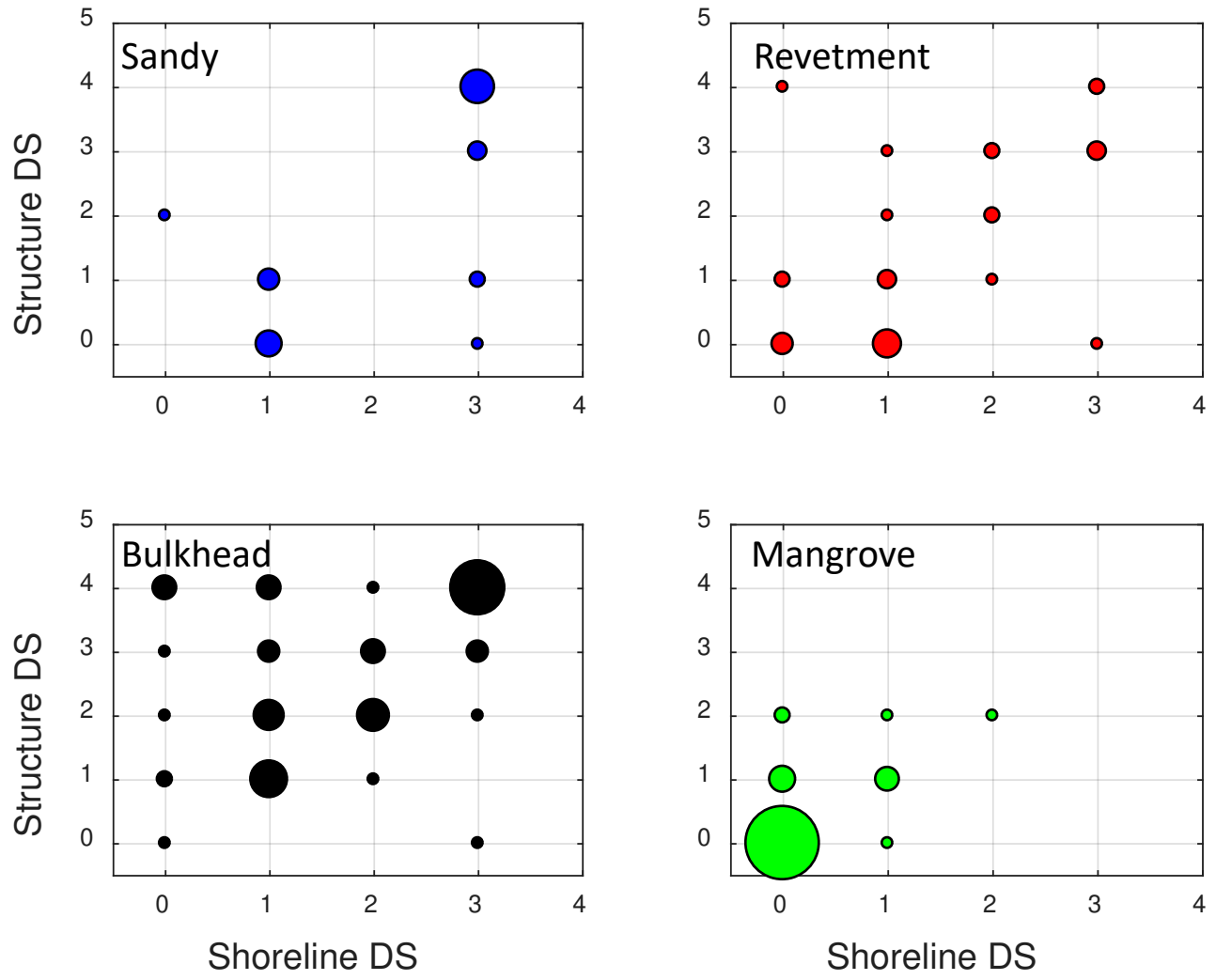
fb=freeboard
DS= damage state

Relate Hazard, Structural Damage, and Shoreline Type



Structures with mangrove shorelines: lower DS for higher wave crest elevations above LHSM

Shoreline Damage Affects Structural Damage



Structural & Shoreline Fragilities: Multinomial Regression

Multinomial Logistic Regression:

- Shoreline Damage, Structural Damage as ordinal response variables
- Shoreline type (mangrove vs. other) as a categorical predictor variable

$$Y_{i,k} \sim \prod_{i=0}^{1} \frac{N!}{Y_{i,k}!} P(DS = DS_i | x_k)$$

Log Odds/ Relative risk
$\frac{P(DS = 0)}{P(DS > 0)}$
$\frac{P(DS \leq 1)}{P(DS > 1)}$
$\frac{P(DS \leq 2)}{P(DS > 2)}$
$\frac{P(DS \leq 3)}{P(DS > 3)}$

Statistical Significance and AIC for Empirical Multinomial Fragility Models

Model	p_{fb}	$p_{\eta wave}$	$p_{Shoreline}$	AIC
Shoreline	---	0.0028	1.32×10^{-23}	161
Structure	0.041	---	4.89×10^{-24}	271

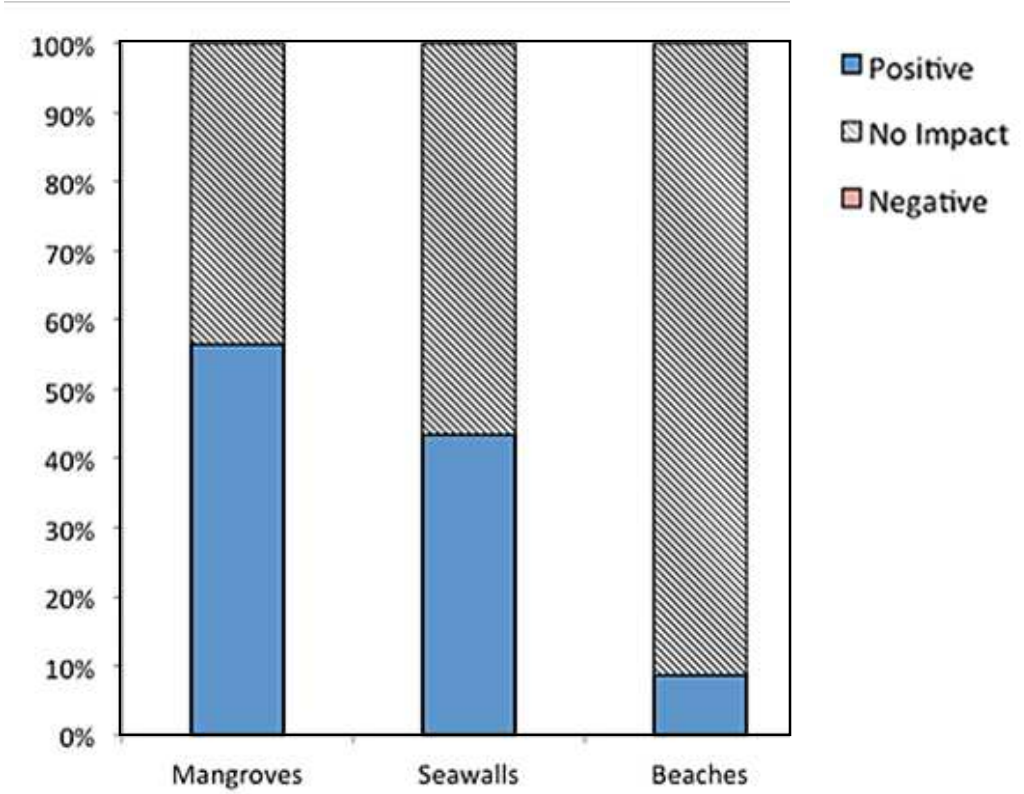
Interconnectivities between Shoreline Type, Structural Damage, and Homeowner Perceptions

- Mixed mode interviews
- Perceived impact of mangroves, seawalls, and beaches, on social and ecological systems during Hurricane Irma

"Mangroves are the only thing keeping the island from eroding"

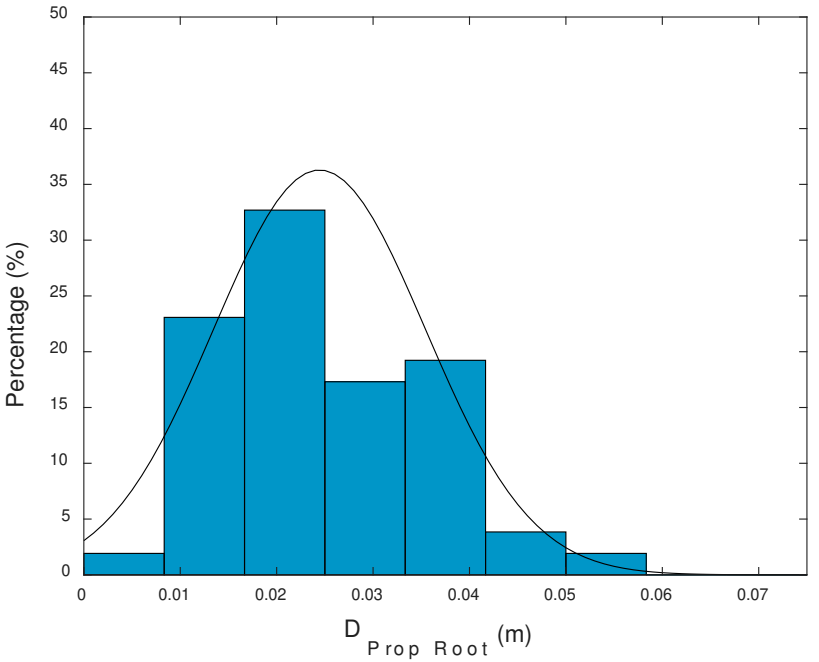
"90% of beaches were swept away"

"Without mangroves, the impact of the storm would have been much worse"



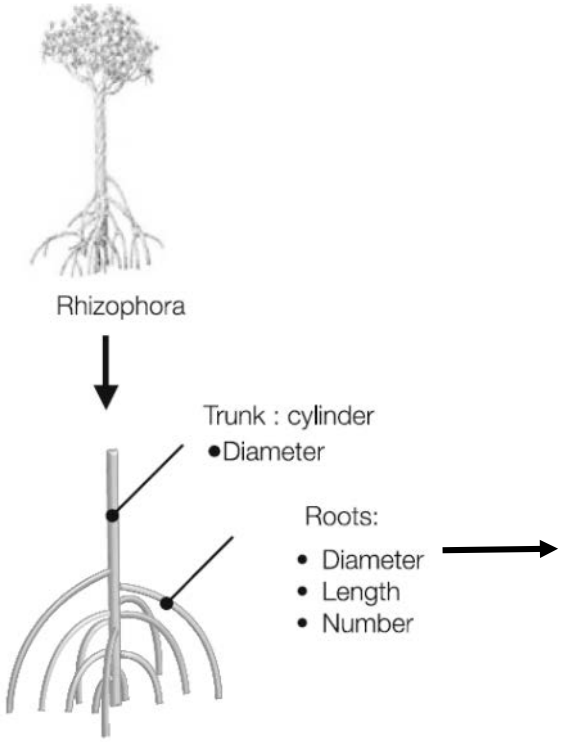
Field Characterization of Mangrove Shorelines

- Field study to characterize mangrove prop root density, average diameter, elastic modulus, canopy characteristics

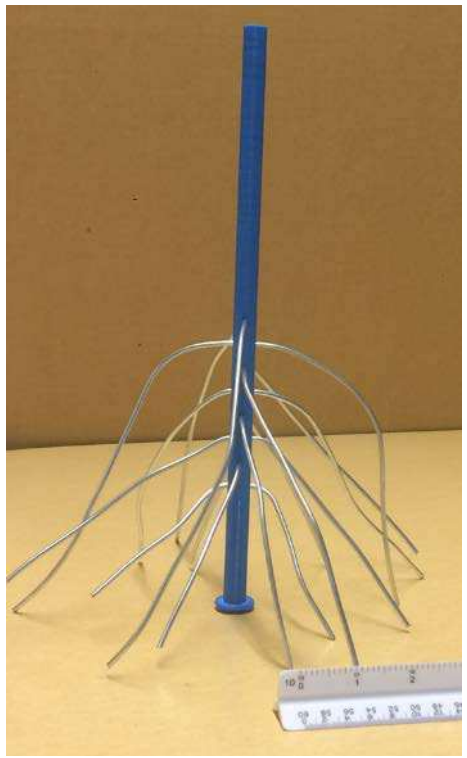


Laboratory Characterization of Mangrove Effects on Wave Propagation/Transformation

- Parametrization following Ohira et al. (2013), Maza et al. (2017)
- 1:16 scale physical model



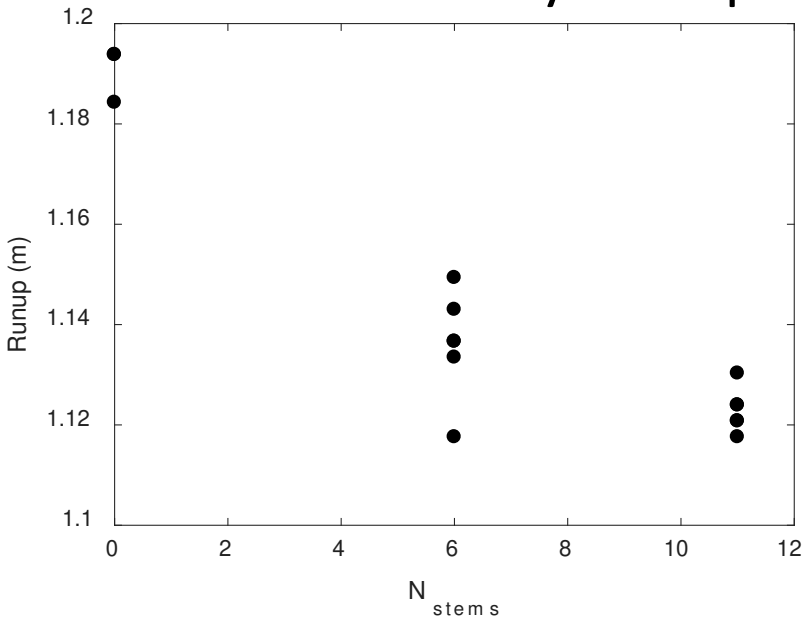
Ohira et al. (2013)

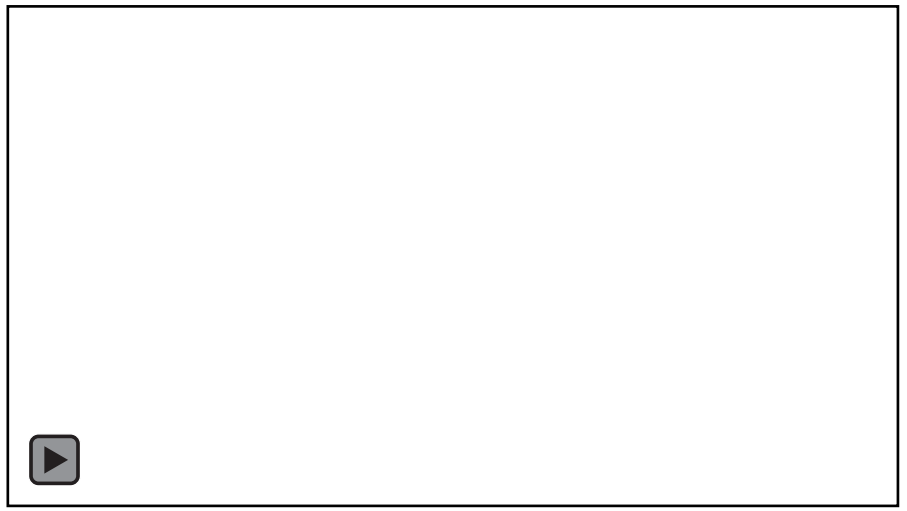


Parameter	Key West (1:1)	Model (1:16)
Material	Red mangrove	ABS (3D Printed)/ Galvanized Steel
d_{trunk}	0.11 m - 0.28 m	0.013 m
d_{root}	0.01 m – 0.06 m	0.0025 m
N_{roots}	12-24	16
h_{root}	1.0 m - 2.0 m	0.125 m

Laboratory Characterization of Mangrove Effects on Wave Propagation/Transformation

- Preliminary run-up tests in USNA Hydromechanics Laboratory





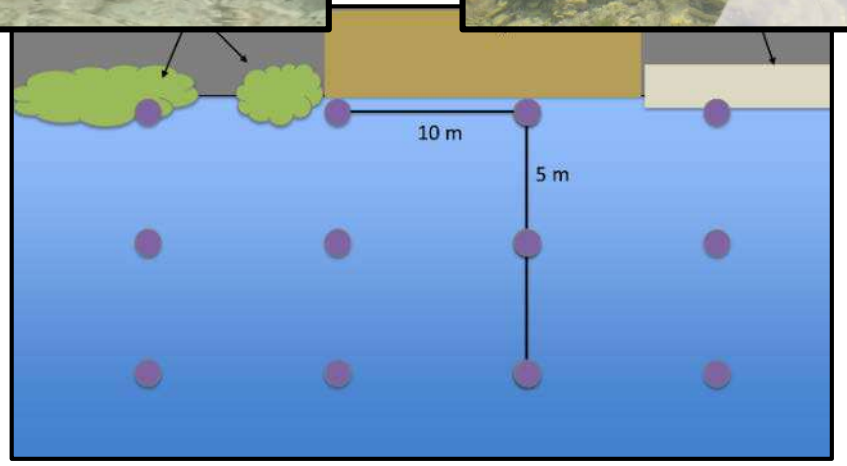
Compared to bare earth baseline

1 row: 4.7% run-up reduction

2 rows: 6.0% run-up reduction

Field Measurements of Mangrove Effects on Wave Transformation/Propagation

- Measurements fronting seawalls, mangroves, hybrid
- Boat wakes, wind waves
- Collaboration and coordination with City of KW, TNC



Conclusions

- Case study of damage to shorelines, structures after Hurricane Irma
- Ongoing longitudinal investigation to identify recovery trends, repair decisions, quantify mangrove benefits
- **Natural and nature-based features** may mitigate overland flow and resulting inland damage during storm events **in coordination with engineered structures**




Thank you for your kind attention!