Plant S.T.E.M.: Plant Mimic with Stiffness Tunability for Ecohydraulic Modeling of *Spartina alterniflora*

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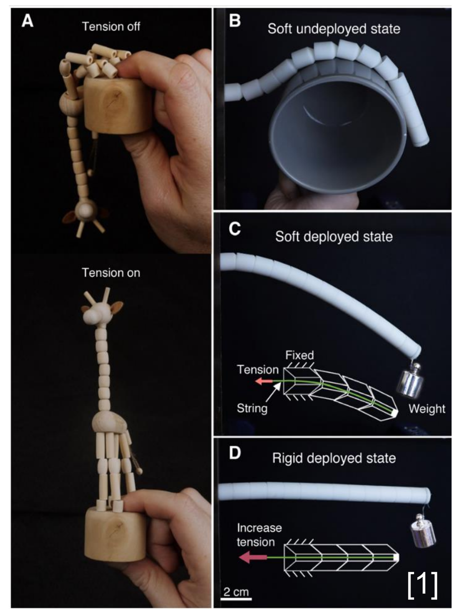
Background

- Coastal vegetation is important for coastal resiliency as it reduces hydrodynamic energy and enhances sediment deposition
- Seasonal variability in biophysical properties affect capacity for coastal protection
  - Morphological: stem spacing, stem height
  - Biomechanical: stem flexibility

Introduction

- In laboratory flume studies, artificial plant mimics with fixed mechanical properties are often used instead of real plants
- A more realistic plant mimic is needed to better study the ecohydraulic effects of seasonal biophysical variations in coastal vegetation



Our goal was to adapt existing methods of developing variable- flexibility materials to **design a plant mimic with stiffness tunability** to simulate natural biomechanical variability of coastal vegetation.

S. alterniflora Information

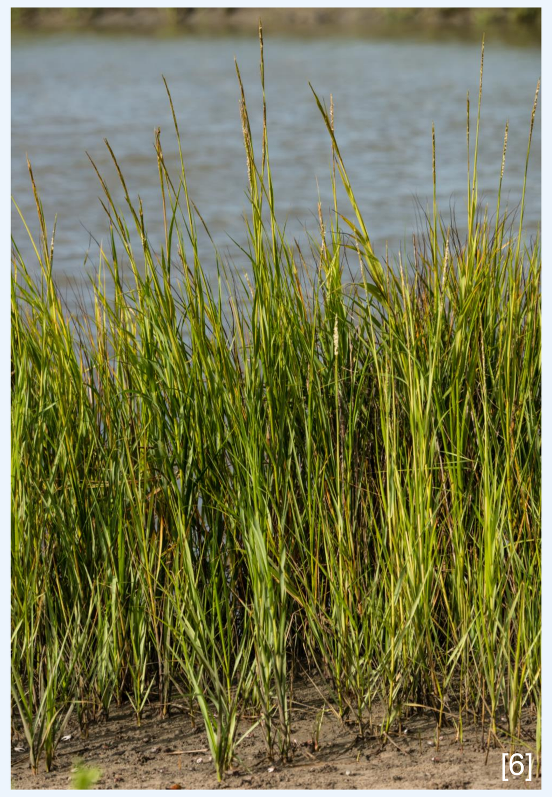
- Common name: smooth cordgrass
- Native distribution: eastern seaboard of North America, Gulf of Mexico
- Habitat: salt marshes, coastal beaches, wetlands
- Environmental zone: low marsh
- Average Properties:

Morphological:

Height (cm)	Diameter (mm)	Source
51.67	4.5 ± 1.1	[2]
62 ± 18	4.47 ± 0.89	[3]
71.6	7.97	[4]
71 ± 22	5 ± 1.5	[5]

Biomechanical:

Elastic Modulus (MPa)	Source
1410 ± 710	[2]
230 ± 40	[3]
506*	[4]
159**	[4]



*For live *S. alterniflora* with a stem height to diameter ratio over 75
**For live and dormant S. alterniflora at various times during the year

Methodology

3D Printing:

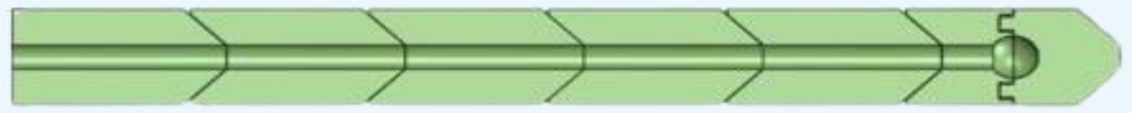
- Method: FDM (fused deposition modeling)
- Materials:

Filament	Young's Modulus (MPa)	Density (g/cm^3)
Thermoplastic Polyeruthane	9.7 ± 1.0	1.18*
Polylactic Acid	3250 ± 119	1.27

*at 21.5°C

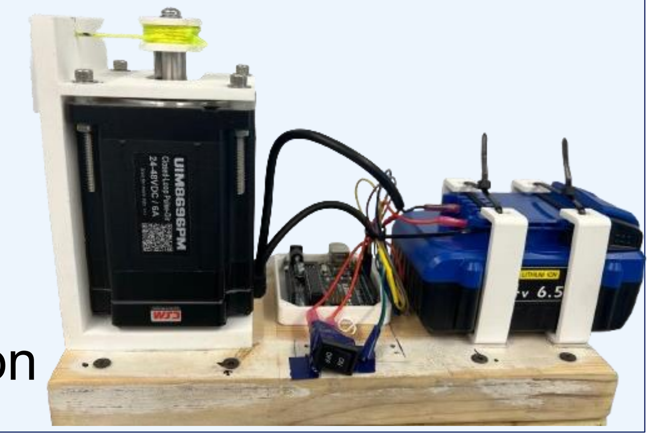
Plant Model:

- Beads: Matching conical concavo-convex interfaces
  - Hollow interior for contracting cord
  - 8mm diameter
  - 15mm height each



Tunable Tension Mechanism:

- Stepper Motor: NEMA 34
  - Step resolution of up to 1/16th
  - Torque of 6.5 Nm
  - Communication through Arduino
  - Powered by 24V Battery
- Contracting cord: Nylon Twine
  - Threaded through beads
  - Fixed to collar on shaft of stepper motor
  - Shaft rotation adjusts tension

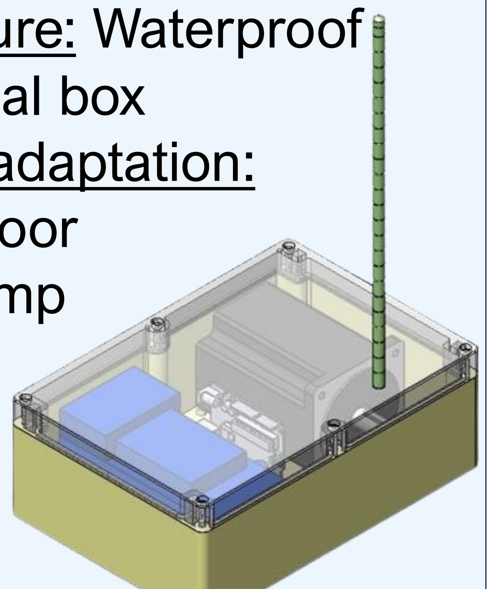


Mechanical Testing:

- Plant orientation: Horizontal
- Machine: Zwick/Roell zwickiLine
- Load cell: 100N
- Test Type: 2-point flexure test
- Testing procedure:
  1) Load mimic into bending fixture
  2) Actuate stepper motor to add tension
  3) Perform flexure test (speed of 2mm/s)
  4) Return upper die to original position
  5) Release tension repeat steps 2-5

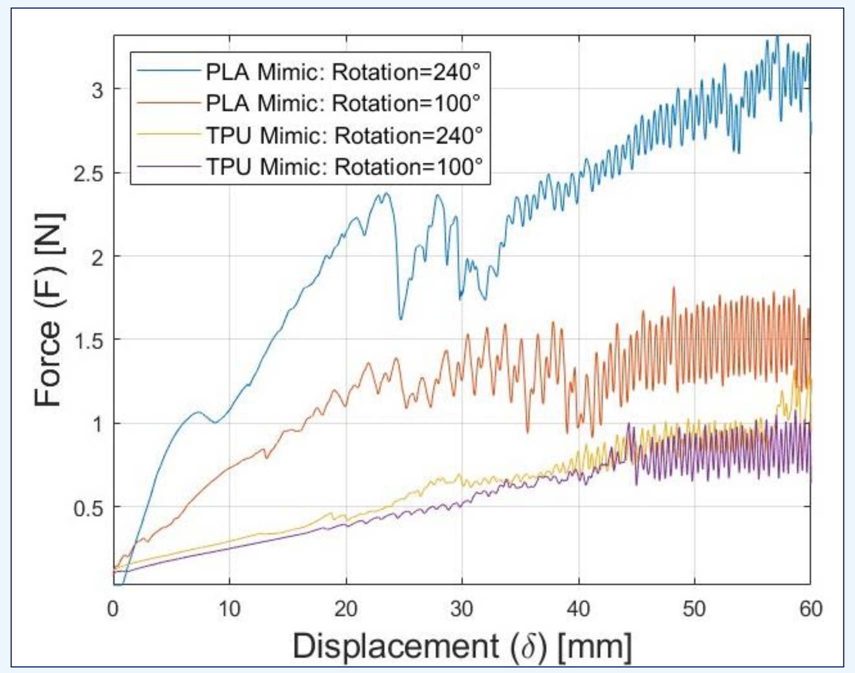
Flume Deployment Plan:

- Plant orientation: Vertical
- Enclosure: Waterproof electrical box
- Flume adaptation: False floor with ramp



Results

Force-Displacement Curves



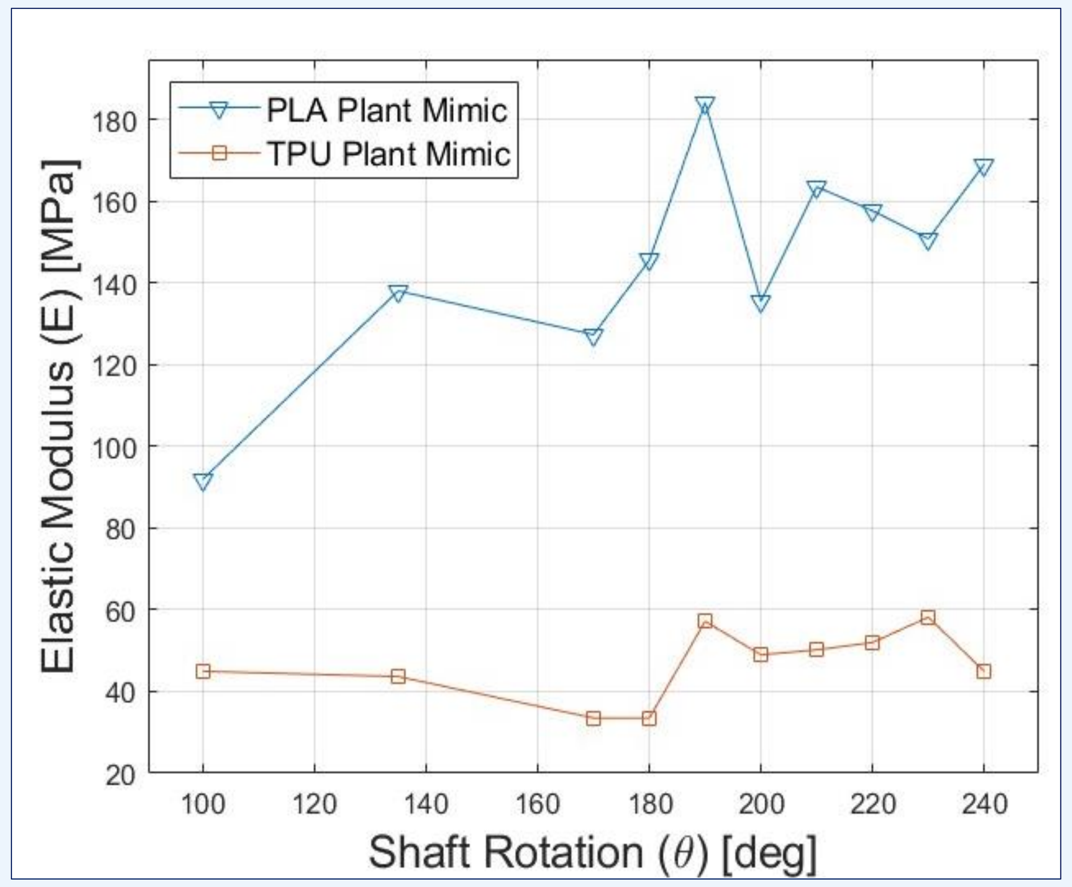
Elastic modulus equation is found from beam deflection equation:

$$\delta = \frac{Fx^3}{3EI} \rightarrow E = \frac{Fx^3}{3\delta I}$$

Where δ = deflection, F = force, x = distance at which load was applied, I = area moment of inertia, and E=elastic modulus.

Linear regression was used to find the slope (F/δ) of the linear region of the force-displacement curve. Then, E was calculated.

Elastic Modulus of Plant Mimic at Various Tensions

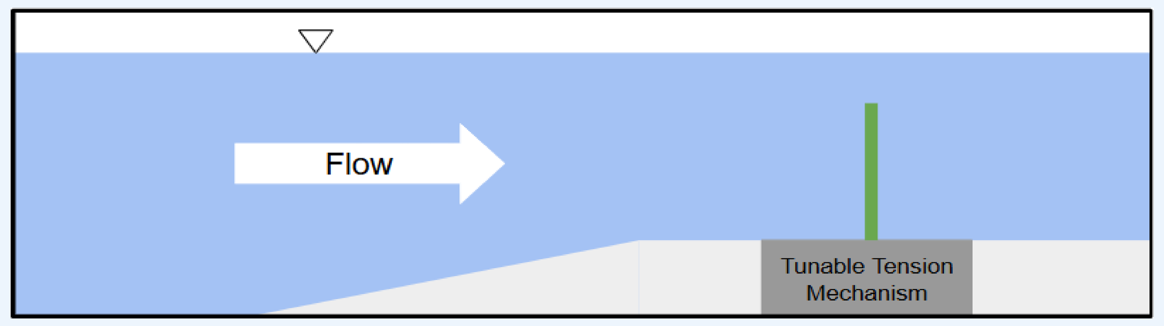


Conclusion

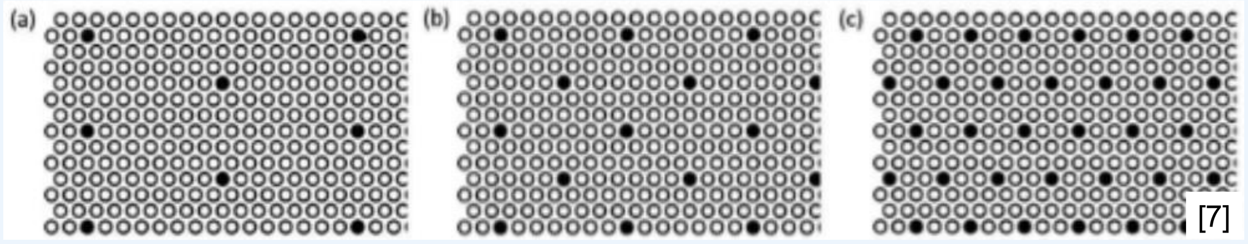
The **PLA plant mimic is better suited to modeling the biomechanical variability of *S. alterniflora*** as it can be adjusted to **simulate stem flexibilities between 92 MPa and 184 MPa.** In addition, stem height of the model is adjustable. Further testing and modification of this model can be executed to ensure that the scaled model accurately represents the flow-vegetation interactions of *S. alterniflora* and encompasses greater morphological variability.

Next Steps

- Conduct a flume study to quantify key dimensionless parameters (e.g., Cauchy and Reynolds numbers) of plant mimic



- Develop a “meadow” of tunable stiffness plant mimics with various options for stem spacing



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