Wind Tunnel Tests of How Plants Feedback on Dune Shape

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Casper Lab

asbpa

USGS science for a changing world

ERDC Engineer Research & Development Center

NDSEG NATIONAL DEFENSE SCIENCE & ENGINEERING GRADUATE FELLOWSHIP

Overarching Research Question

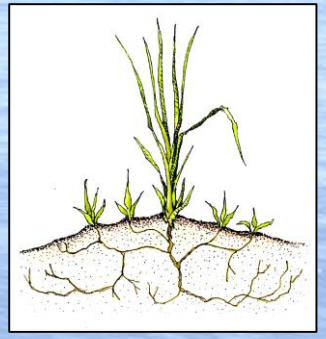
How do coastal dunes respond to & recover ecologically after episodic events like a hurricane?

- Governing biotic & abiotic controls on recovery (plant recolonization) post-disturbance

- Geomorphological consequences of recolonization

Coastal Dunes

Coastal dunes – natural buffers that absorb the destructive power of waves by physically blocking upland areas during high tides & storms → buffers to erosion



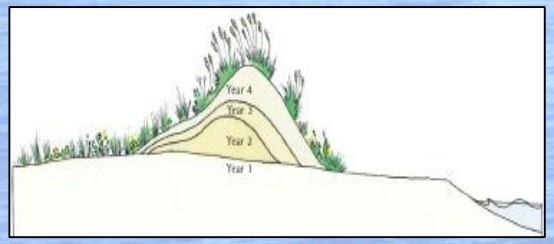
A beach with dunes is:

1. More capable of responding & withstanding storm events
2. Helps to maintain the beach system better in long-term

- Stabilized & built up over time by plants
- Roots stabilize sand
- Shoots catch windblown sand
  - Fencing mimics plant leaves

Dune Genesis: Nekha & Shadow Dunes

- Plant mediated → ecosystem engineers
  - any organism that creates, significantly modifies, maintains or destroys a habitat



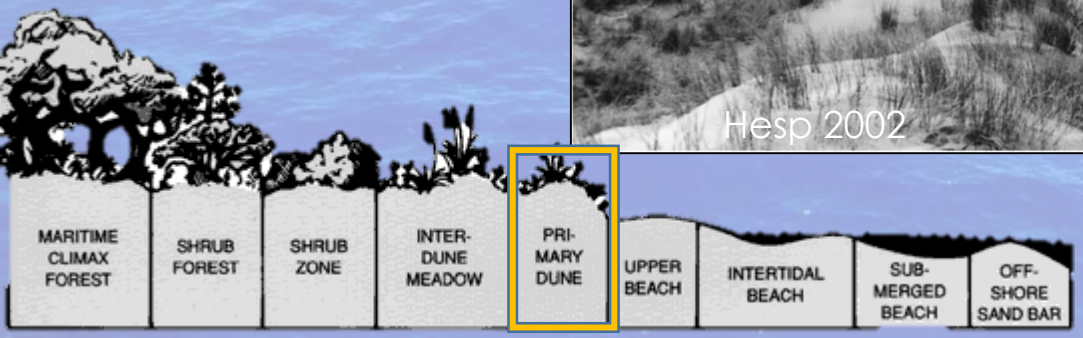
1) Nebkha & Shadow Dune

- Plant shape feeds back on dune shape (Hacker et al 2011, OIKOS)
  - Taller & steeper plant will build a taller steeper dune
  - Shorter sprawling plant will build shorter & broader dune

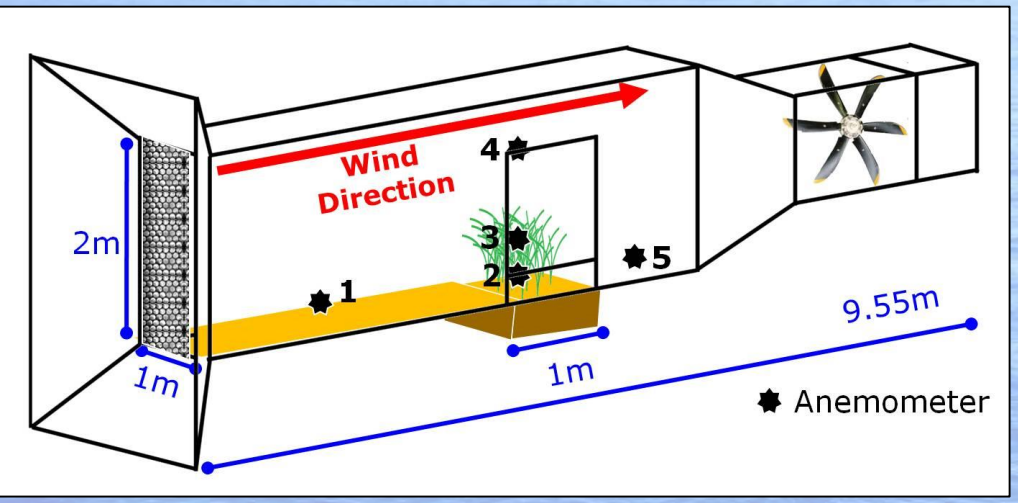
2) Incipient Foredune/ Nascent dune

Hesp 2002

3) Foredune



Research Goal



Biophysical feedback mediates effects of invasive grasses on coastal dune shape

Phoebe L. Zarnetske,[1,6] Sally D. Hacker,[1] Eric W. Seabloom,[2] Peter Ruggiero,[3] Jason R. Killian,[4] Timothy B. Maddux,[4] and Daniel Cox[5]

Build a moveable bed unilateral flow wind tunnel to test how morphology among & within dominant US East coast foredune plants feeds back on coastal dune shape at the initial level (nebkha/shadow dune) varying plant density & species at a baseline of zero accumulation (i.e. flat back beach or post storm)

Wind Tunnel

Waretown, NJ Ocean County Vocational Technical School

- Standalone Class II laser
- True mm values in all dimensions
- Height res = 80 - 670 µm precision

Removable bed: 1m x 1m x 0.3 m boxes inserted

2.54cm continuous bed of dry sand Mean grain size 0.3-0.35 mm

Methods

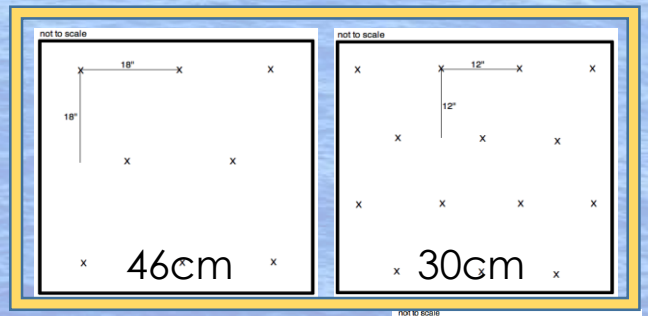
1)Plant Morphology
- Width of plant stems
- # leaves & stems
- Height: taut & bent
- Biomass

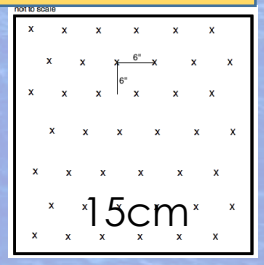
2) Exp 18.5mph (8.25 m/s) ground level 30 min

3) Harvest biomass → cut

4) Topographic 3D scan

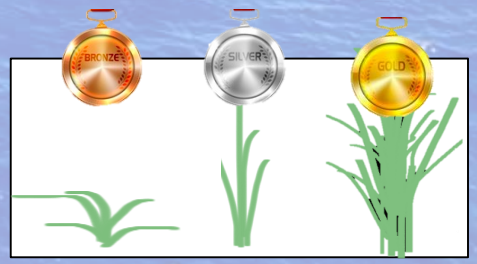
5) Analyses of bedform morphology





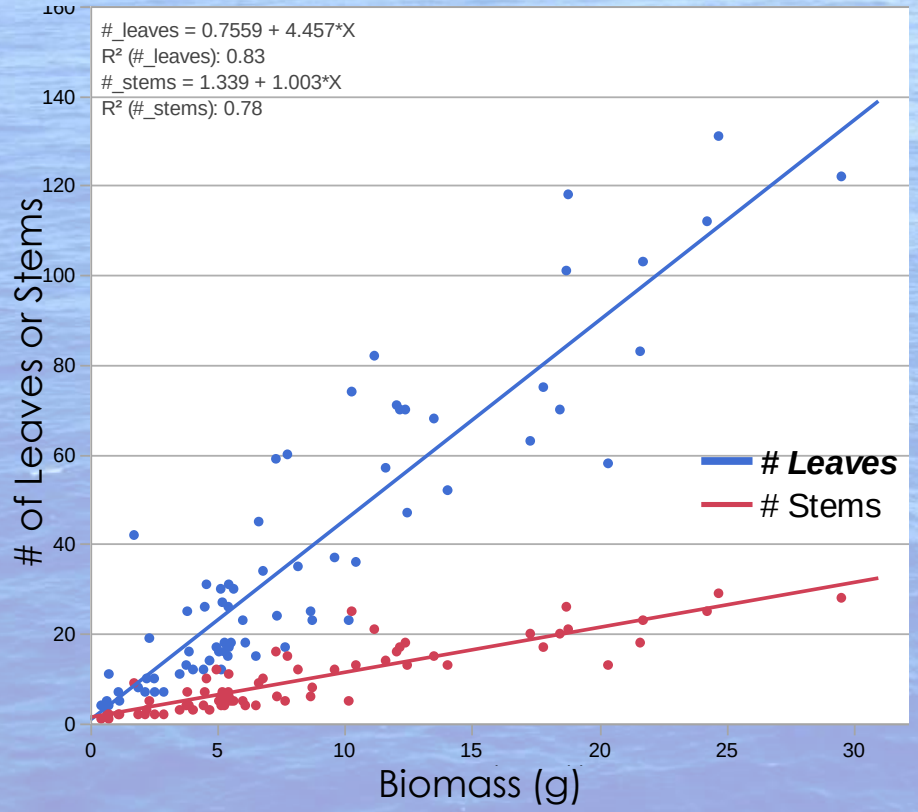
8 boxes/replicates per *spp*
- 4 per density
- Null blank box
  - 4 trials

N_{EXP} = 24

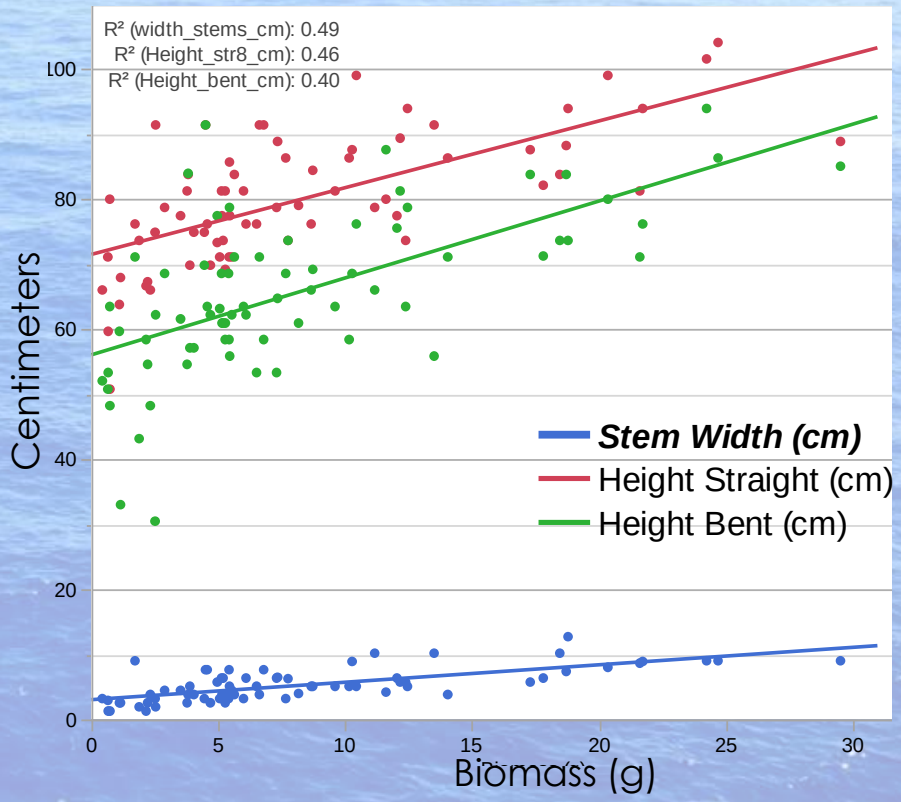


Biomass Most informative Plant Morpho Variable

Plants with greater biomass tend to also have more stems & leaves



Plants with greater biomass tend to also be of greater height & width



Model Inclusion → biomass only

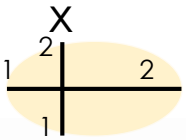
Results: Null Boxes Produced Only Ripples

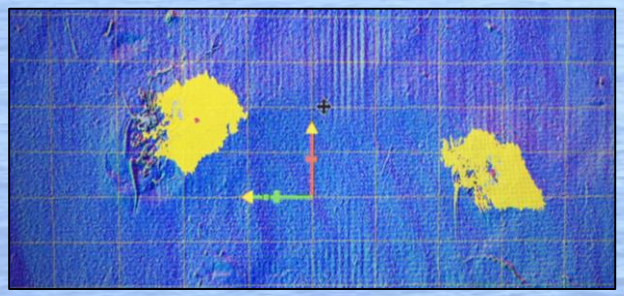
No plants = no bedform creation i.e. accretion

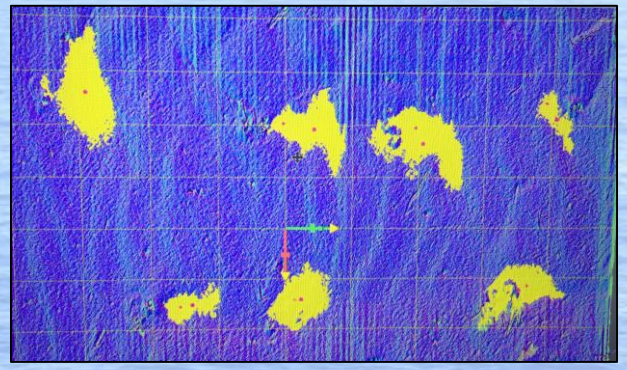
$N_{NULL} = 4$

Wind flow

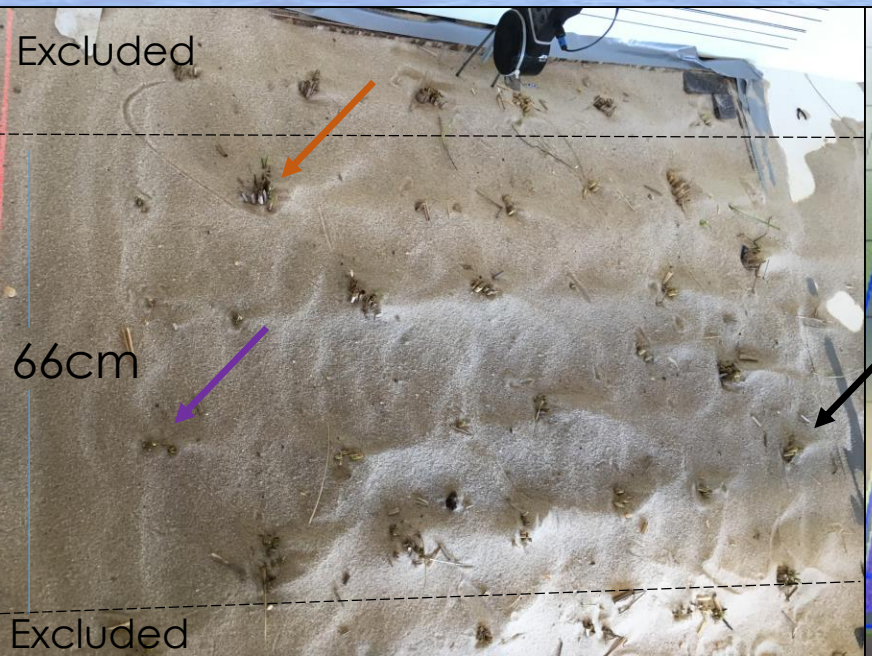
Results: Bedforms Accumulated

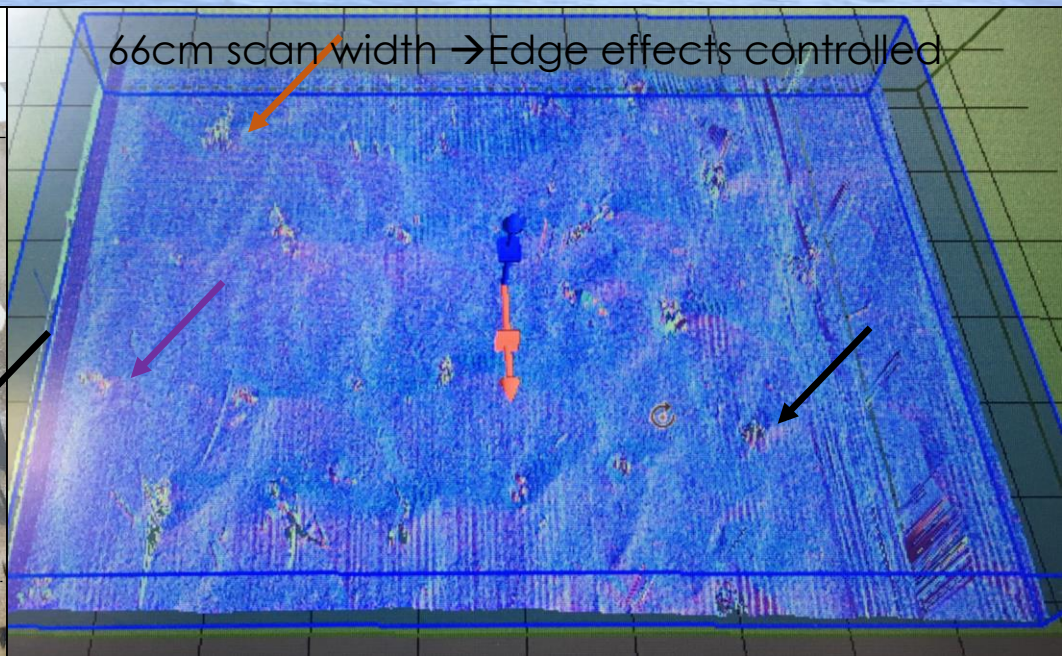






- SOPAS Blob tool locates point clusters within a defined area & height range
  - Yellow areas = blobs, i.e. bedforms

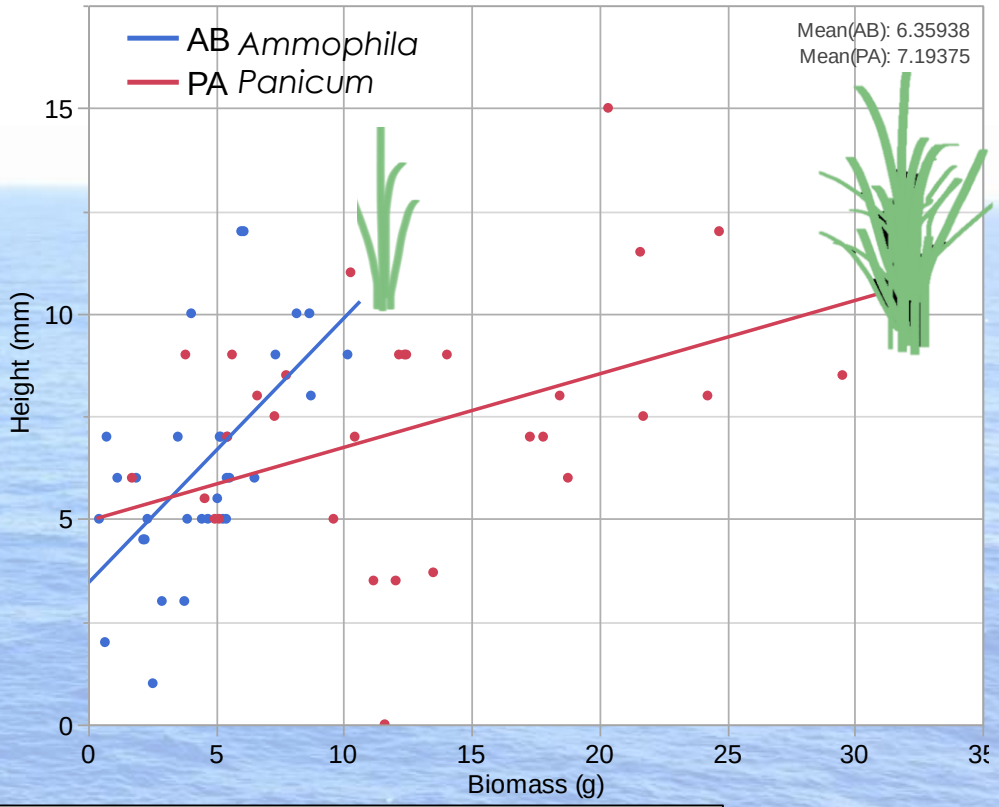




Results: Bedform Height (mm)Varied

Mixed models with unbounded variance

- Box = random effect
- Fixed Effects: Density (Dens), Species (Sp), Biomass (Biom), Row
- Interactions: row, Sp X Den, Sp x Biom, Sp x Biom x Den



Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	4.2023298	0.6825826	31.3	6.16	<.0001*	2.8107358	5.5939237
Species[AB]	1.2671534	0.5070793	39.8	2.50	0.0167*	0.2421716	2.2921352
dry_weight_g	0.411454	0.1017811	58.5	4.04	0.0002*	0.2077564	0.6151517
Species[AB]*(dry_weight_g-8.54145)	0.233988	0.1017811	58.5	2.30	0.0251*	0.0302903	0.4376857

Random Coefficients

Fixed Effects Tests

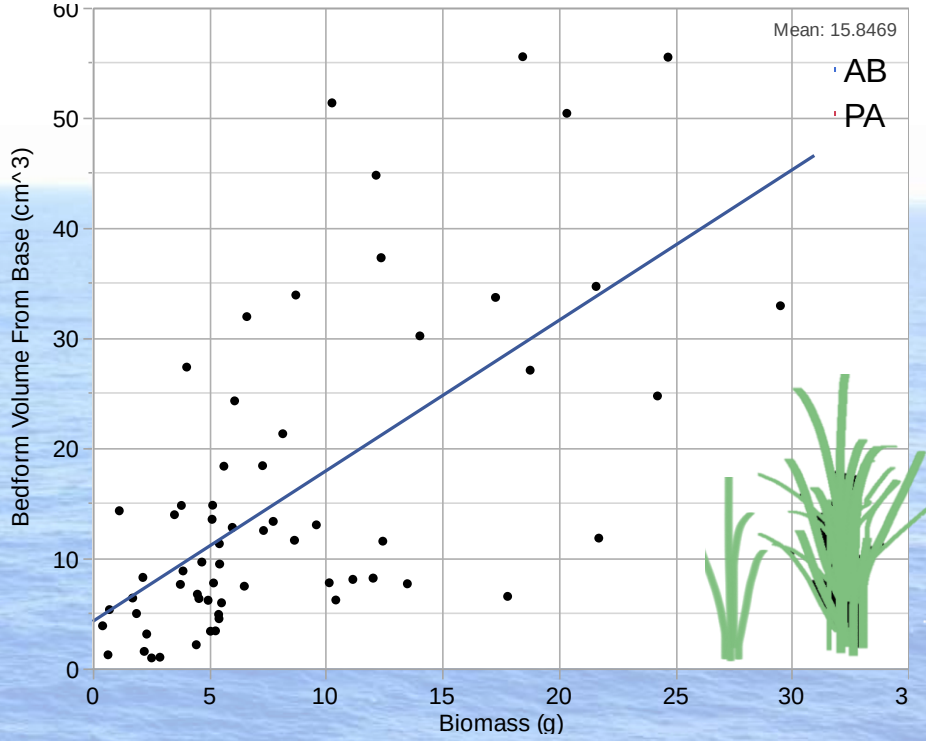
Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Species	1	1	39.8	6.2446299	0.0167*
dry_weight_g	1	1	58.5	16.342134	0.0002*
Species*dry_weight_g	1	1	58.5	5.2851006	0.0251*

Bedform height varied by biomass, which varied by species

Results: Bedform Volume (cm^3) Varied

Mixed models with unbounded variance

- Box = random effect
- Fixed Effects: Density (Dens), Species (Sp), Biomass (Biom), Row
- Interactions: row, Sp X Den, Sp x Biom, Sp x Biom x Den



Ammophila & Panicum

Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	3.8990089	3.1981791	40.0	1.22	0.2299	-2.564911	10.362929
row[2-1]	4.5109874	3.2642836	44.5	1.38	0.1739	-2.065507	11.087482
row[3-2]	-8.241661	3.5830539	51.1	-2.30	0.0256*	-15.43466	-1.048665
row[4-3]	-0.989701	5.5786726	46.0	-0.18	0.8600	-12.2187	10.239296
dry_weight_g	1.3576015	0.2225929	33.8	6.10	<.0001*	0.9051162	1.8100869

Random Coefficients

Fixed Effects Tests

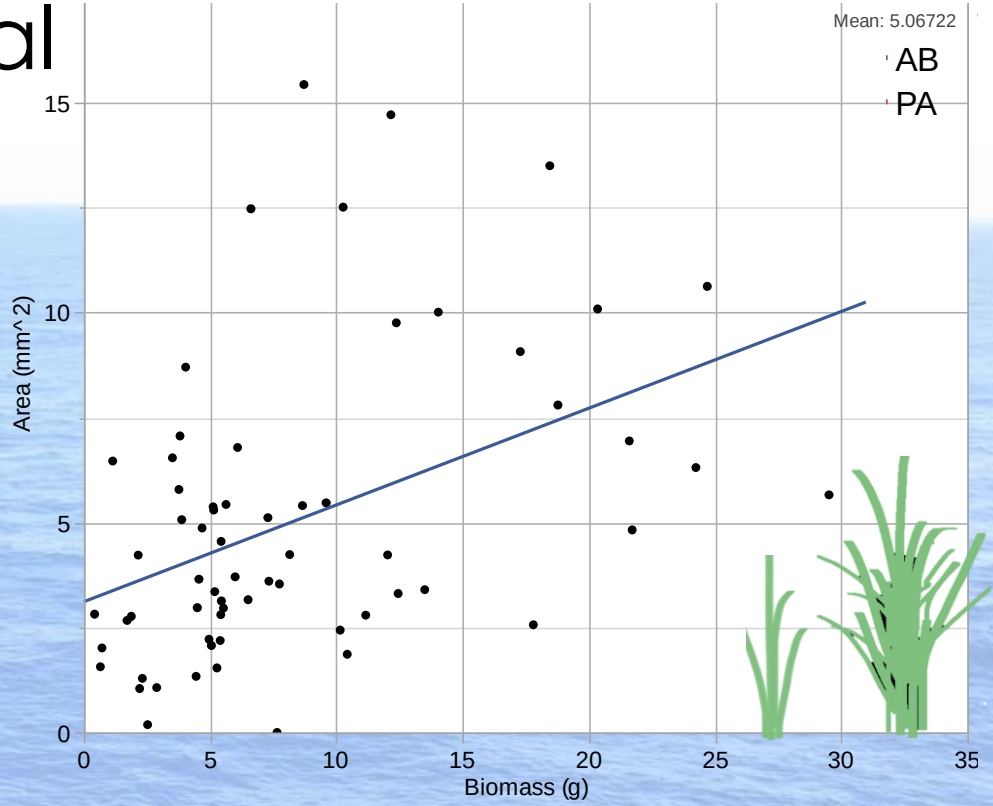
Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
row	3	3	48.5	2.2111257	0.0987
dry_weight_g	1	1	33.8	37.198194	<.0001*

Bedform volume varied by biomass

Results: Bedform Basal Area (mm^2) Varied

Mixed models with unbounded variance

- Box = random effect
- Fixed Effects: Density (Dens), Species (Sp), Biomass (Biom), Row
- Interactions: row, Sp X Den, Sp x Biom, Sp x Biom x Den



Ammophila & Panicum

Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	3790.7732	937.90715	15.1	4.04	0.0011*	1792.7563	5788.7901
dry_weight_g	177.89644	72.395611	63.9	2.46	0.0167*	33.263321	322.52956

Random Coefficients

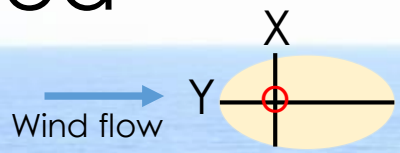
Fixed Effects Tests

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
dry_weight_g	1	1	63.9	6.0382353	0.0167*

Bedform area varied by biomass

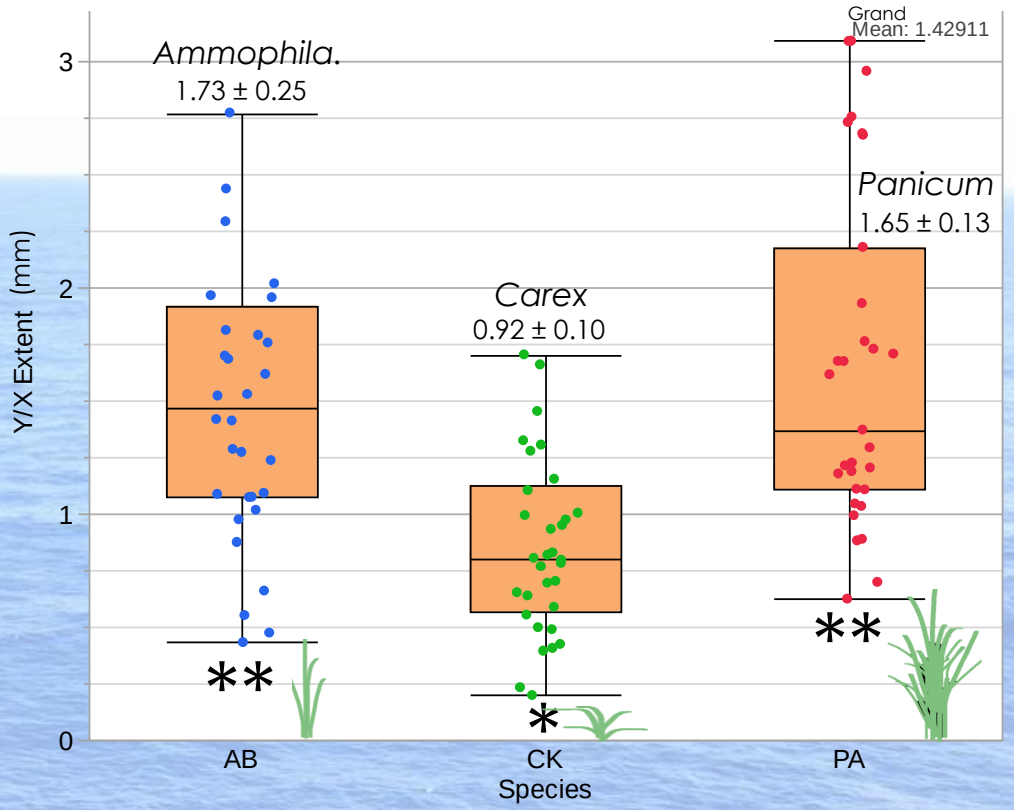
Results: Bedform Shape Varied

Variable: **Y/X**



Mixed models with unbounded variance

- Box = random effect
- Fixed Effects: Density (Dens), Species (Sp), Row
- Interactions: row, Sp X Den



Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	1.4382639	0.090165	20.3	15.95	<.0001*	1.2503838	1.6261441
Species[AB]	0.2848091	0.1271592	19.3	2.24	0.0371*	0.0189132	0.5507051
Species[CK]	-0.498514	0.1263196	20.1	-3.95	0.0008*	-0.761965	-0.235063

Random Coefficients

Fixed Effects Tests

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Species	2	2	20.3	7.8613859	0.0030*

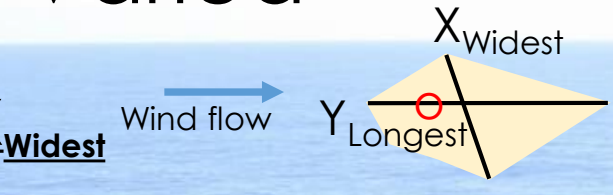
Bedform Y vs. X extent varied as a function of species

✱ Plants with different number of * are significantly different

○ denotes the peak, i.e. the crest, such that crest is X & Y intersection

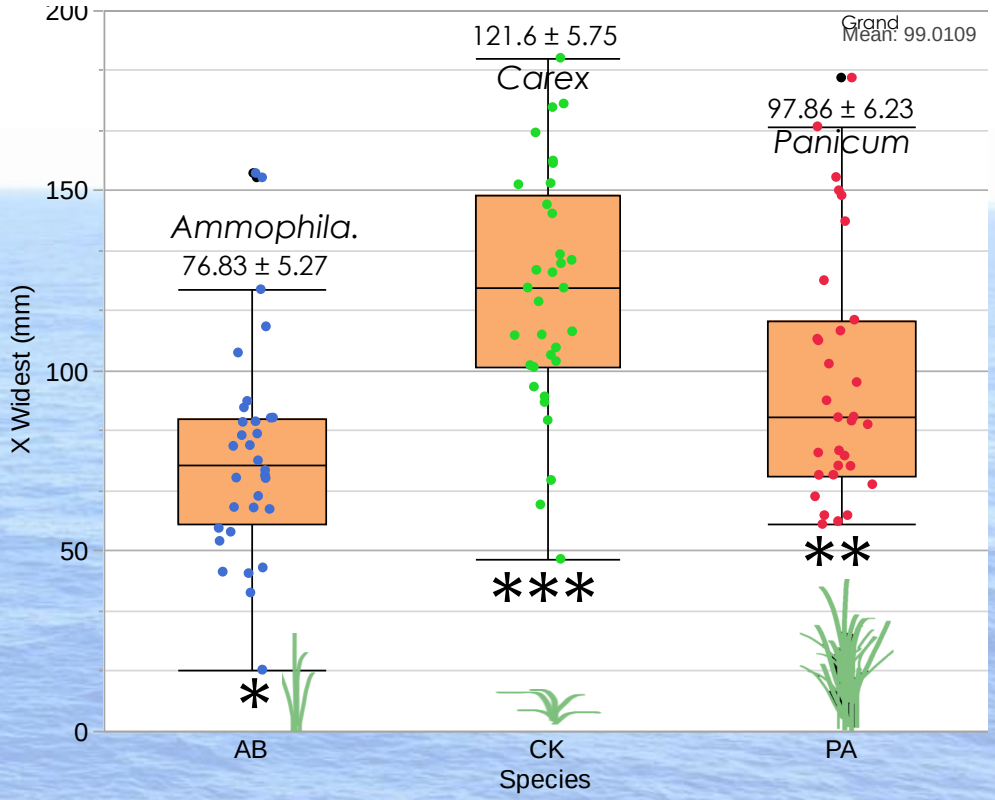
Results: Bedform Shape Varied

Variable: X_{Widest}



Mixed models with unbounded variance

- Box = random effect
- Fixed Effects: Density (Dens), Species (Sp), Row
- Interactions: row, Sp X Den



Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	98.16617	3.8453709	17.6	25.53	<.0001*	90.073856	106.25848
Species[AB]	-21.78694	5.4566239	17.2	-3.99	0.0009*	-33.29139	-10.28248
Species[CK]	22.518667	5.4019634	17.3	4.17	0.0006*	11.138964	33.89837

Random Coefficients

Fixed Effects Tests

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Species	2	2	17.6	11.152313	0.0007*

Bedform max width varied as a function of species

* Plants with different number of * are significantly different

O denotes the peak, i.e. the crest, such. The crest is not usually at the X & Y intersection for $Y_{longest}$ and Y_{Widest}

Conclusions & Next Steps

1. No bedform formation beyond ripples without obstruction

1. Density did not affect bedform formation

1. Biomass & species affected bedform formation & shape

Direct application for management & modelling

Exist in perpetuity for local high school & academic use

- **Outside researchers welcome!**
- Website: thewindtunnel.weebly.com
- Lesson plans for use to be developed
- Reproduce with staggered planting

20 sponsor/partner organizations

Over $16K donated

140+ volunteer research hrs

Thank You

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American Shore & Beach Preservation Association
Advocating for healthy coastlines

COASTAL TRANSPLANTS

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Questions?

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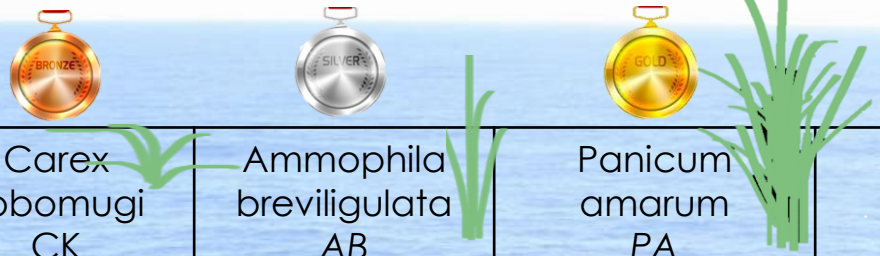
Results: Plant Morphology Varies By Species

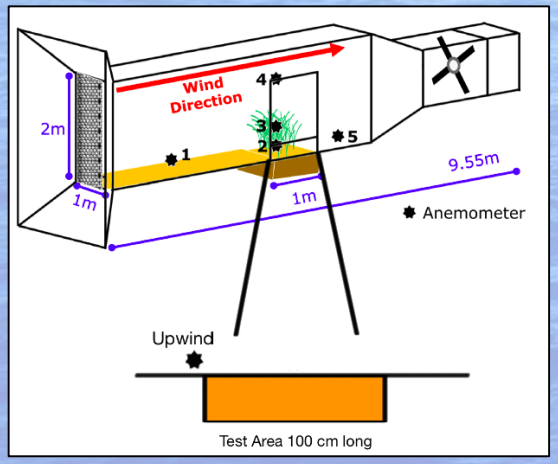


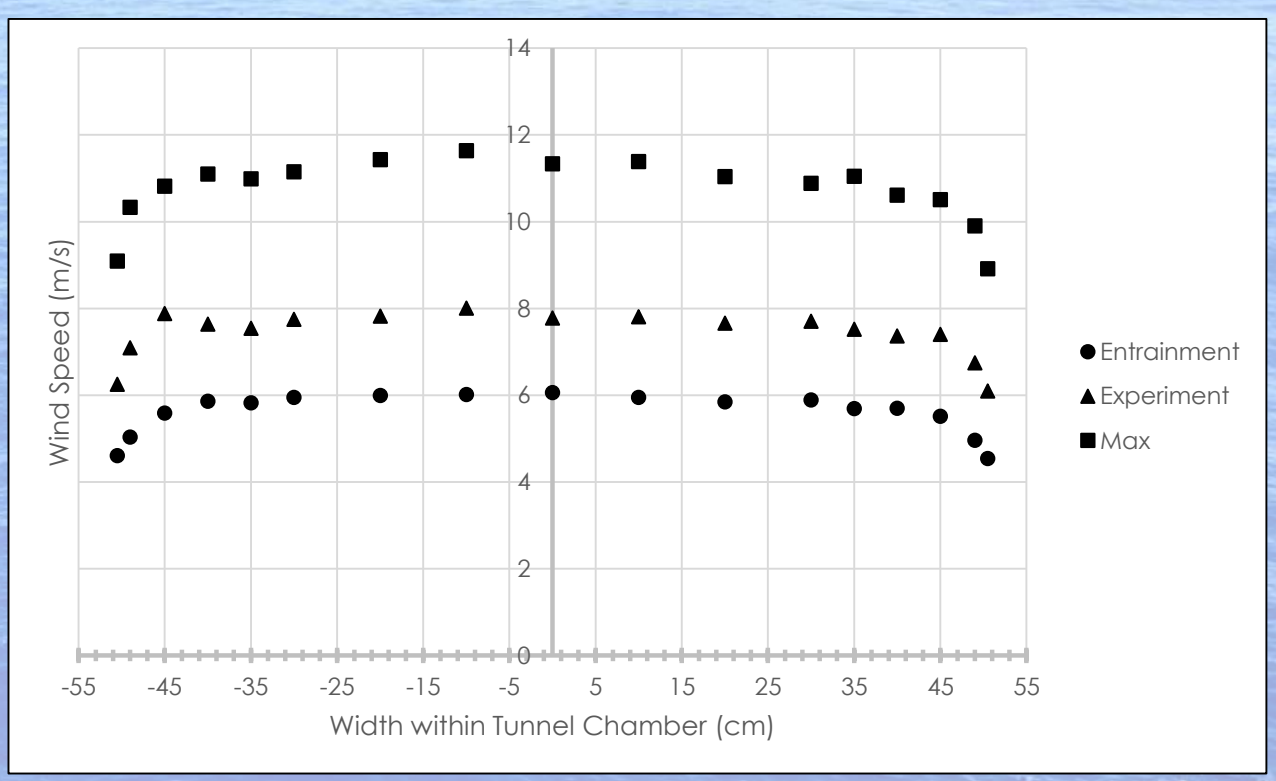
N = 36 sp^{-1} Sp. Means ± S.E. →	Carex kobomugi *CK*	Ammophila breviligulata *AB*	Panicum amarum *PA*	*Species Effect Test*
# leaves	$\bar{x}$=17.6 ± 0.94	$\bar{x}$=14.9 ± 1.26	$\bar{x}$=59.7 ± 5.34	$F_{2,15} = 28.88$ $P < 0.0001$
# stems	$\bar{x}$=1.39 ± 0.09	$\bar{x}$=4.17 ± 0.37	$\bar{x}$=14.94 ± 1.17	$F_{2,12} = 63.80$, $P < 0.0001$
Width of stems (cm)		$\bar{x}$=3.72 ± 0.25	$\bar{x}$=6.72 ± 0.41	$F_{1,11} = 27.19$ $P = 0.0002$
Height (Straight: cm)	$\bar{x}$=57.48 ± 0.89	$\bar{x}$=75.29 ± 1.18	$\bar{x}$=84.60 ± 1.76	$F_{2,16} = 102.49$, $P < 0.0001$
Height (Bent: cm)	$\bar{x}$=15.90 ± 0.85	$\bar{x}$=58.27 ± 1.48	$\bar{x}$=73.26 ± 1.77	$F_{2,18} = 258.69$, $P < 0.0001$
Start Leaf on Culm (cm)		$\bar{x}$=3.39 ± 0.34	$\bar{x}$=5.81 ± 0.39	$F_{1,8} = 3.26$, $P = 0.11$
Blades/culm	$\bar{x}$=13.12 ± 0.49	$\bar{x}$=3.88 ± 0.27	$\bar{x}$=4.01 ± 0.15	$F_{2,20} = 104.21$, $P < 0.0001$
Biomass (dry: g)		$\bar{x}$=4.48 ± 0.42	$\bar{x}$=11.91 ± 1.23	$F_{1,9} = 16.01$, $P = 0.0029$
Avg Dry Biomass (g)	$\bar{x}$=45.70 ± 6.89	$\bar{x}$=57.40 ± 12.73	$\bar{x}$=120.96 ± 60.32	$F_{2,20} = 11.11$, $P = 0.0006$

- Mixed models with unbounded variance
  - Box = random effect
  - Density & Species = fixed effect → Density was never a significant effect
- Avg Dry Biomass = total box biomass divided by # of plants per box

Horizontal Profile

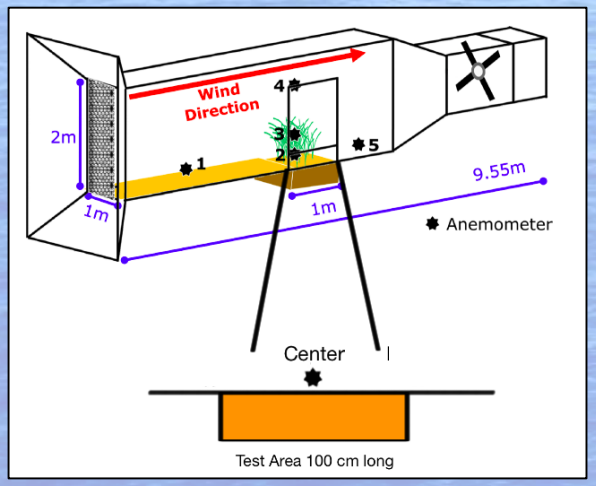
Mean wind speed

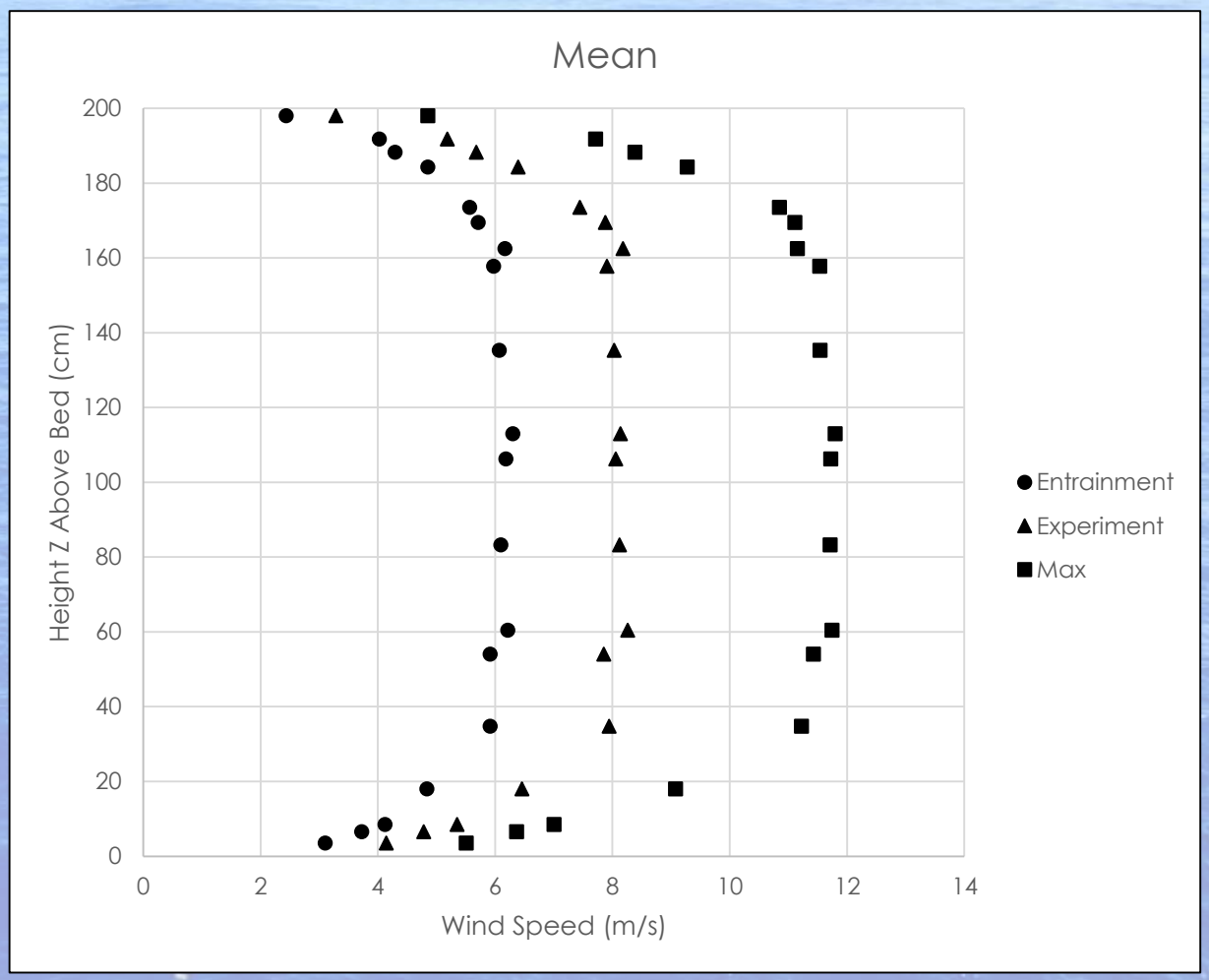




Vertical Test Area Profile

Mean wind speed





Wind Tunnel Specs

1. 40 boxes + 1 with top panel to create continuous chamber

2. Wind Speed
   - Max Theoretical = 27.3 mph (12.2 m/s)→ Max actual = 27 mph (12.1 m/s)
     - 27 mph considered strong breeze (Beaufort Wind Scale)
     - Beyond this is near gale and gale force winds
   - Entrainment at 12.8 mph (5.7 m/s) → mild/moderate breeze (Beaufort Wind Scale)

3. Topo Scans – SICK Trispector 1060 & wiredraw encoder
   - Standalone Class II laser, integrated data processing
   - Scans: W = 66 cm, L = 1.25 m, 2500 profiles X length^{-1}
   - Factory calibrated, true mm values in all dimensions
   - Height resolution = 80 µm … 670 µm precision

Methods: Wind Tunnel Trials

1. Plant morphology

2. Bobcat box onto platform, insert via pallet jack, seal box in

3. Sand added to box & 6m bed upwind to create a smooth 1" continuous bed of dry sand

4. Trial wind speed 18.5 mph (8.25 m/s) ground level for 30 min
   - Moderate breeze (Beaufort Scale)

5. Cut plants at base & harvest biomass
   1. Biomass per box & per scanned bedform

6. Topographic 3D scan→ profile every 0.42 mm
   - Pre- & post-scan

7. Post-trial box weight → around 1200lbs

8. Analyses of bedform morphology
   - Manual & tool guided with SICK SOPAS Engineering Tool