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TOWARDS ACCURATE MODELING OF ABOVEGROUND VEGETATION IN WHITE DUNES: BIOMECHANICS OF MARRAM GRASS (*AMMOPHILA ARENARIA*)

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1 INTRODUCTION

Coastal dunes, shaped by natural processes, particularly aeolian sediment transport driven by onshore winds, are dynamic environments where vegetation plays a pivotal role in trapping sediments, enabling dunes to reach substantial heights. However, the biomechanical traits of aboveground dune vegetation have received limited attention, impeding precise modeling in coastal engineering. Understanding dune erosion and accretion is essential for enhancing coastal resilience and the integration as ecosystem-based coastal protection measures. Notably, prior research has primarily focused on salt marshes and seagrass (e.g. Keimer et al. 2023), neglecting more detailed modeling of dune vegetation, often employing simplified methods like live vegetation (Figlus et al. 2014; Silva et al. 2016) or wooden dowels (Kobayashi et al. 2013; Bryant et al. 2019). The hypothesis tested for the first time here is that geographic expositions and seasonal growth stages can be quantified for marram grass (*Ammophila arenaria*), and that in turn, these vegetation characteristics will inform laboratory studies involving the interaction of waves, flexible vegetation and eroding dunes.

2 METHODS

For our measurements, dune surveys were conducted from January to December 2022 within a 20 m by 20 m field on a dune ridge located at the southwestern edge of the German island Spiekeroog. Different focus areas were designated based on dune shape – sea-side, dune crest, and land-side – to explore local variations and assess the impact of wind exposure on biomechanical vegetation traits. The assumption was that seaside areas, especially on the west coast, are more exposed to strong winds. Wind data were sourced from the Deutscher Wetterdienst (DWD) weather station located at approximately 53.77° N latitude and 7.67° E longitude, positioned at the west end of Spiekeroog.

2.1 Biomechanical traits of aboveground vegetation parts

Monthly measurements of canopy height of marram grass were taken using a folding ruler with an accuracy of 1 mm, with the height referenced from ground level. Horizontal shoot density and number of flowers employed manual counting with a metal frame (0.2 m by 0.2 m inner area). Monthly measurements ranged from 22 to 60 for the sea-side, 10 to 30 for the dune crest, and 19 to 60 for the land-side. For subsequent laboratory investigations, vegetation samples were collected based on the dune zone and month.

In the laboratory, plants were methodically divided into its main components: *sprout*, *stem*, and *green* or *brownish leaf*. Three-point bending tests (ISO 178) were conducted using a universal testing machine manufactured by ZwickRoell GmbH & Co KG with a load cell calibrated for a range of 0.2 N to 50 N, 40 mm span between supports, and a quasi-static deformation rate of 0.05 mm/s, following Liu et al. 2021. The sample size for sprouts ranged from 15 to 60 samples, for stems from 12 to 33 samples, for green leaves from 7 to 37 samples, and for brownish leaves from 8 to 36 samples. Stems, i.e., the flower stems, mainly occur during the flowering period, the third quarter.

3 RESULTS

The wind data revealed that around 24% of stronger winds (>8 m/s) occurred from the west, while approximately 27% originated from the north-west and 16% from the south-west in 2022 (cf. Figure 1).

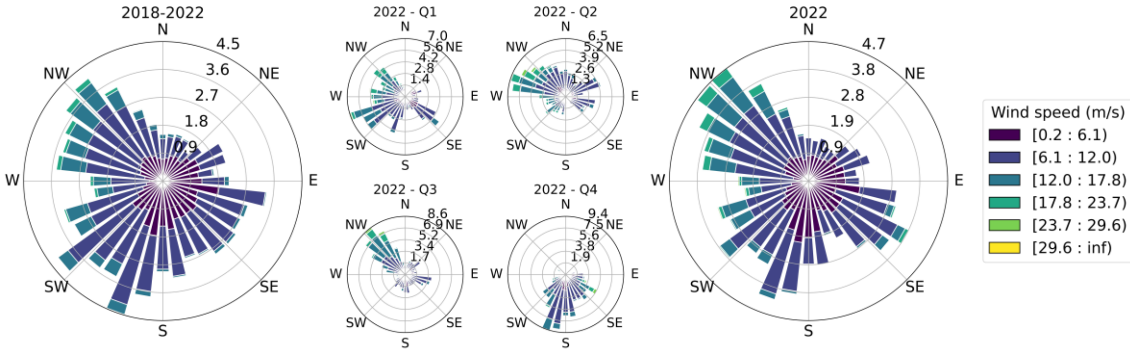

Figure 1. Wind roses illustrating wind direction and speed patterns from 2018 to 2022, segmented by quarters in 2022, and encompassing the entirety of the year 2022.

The analysis summarizes the field data into quarters representing 3 months at a time. In the following, the results are shown for spatial and temporal variances of canopy height, horizontal density and the Young's modulus of the specific plant components. Results on the number of flowers per square meter and other parameters obtained from the bending tests are available but not shown here. Smallest values of canopy height (~70 cm) were found in the first two quarters, both in the sea-side area, whereas the maximum value (90 cm) was found in the land-side area in the third quarter (cf. Figure 2a). The horizontal density ranges from 11.5 (sea-side, Q1) to 22.9 (dune crest, Q3) shoots per square meter (cf. Fig 1b). Stems show the highest values for Young's modulus (2576-2812 MPa) representing the stiffest plant component, followed by brownish leaves (1514-2756 MPa), green leaves (875-3019 MPa) and sprouts (946-1872 MPa) as shown in Figure 3.

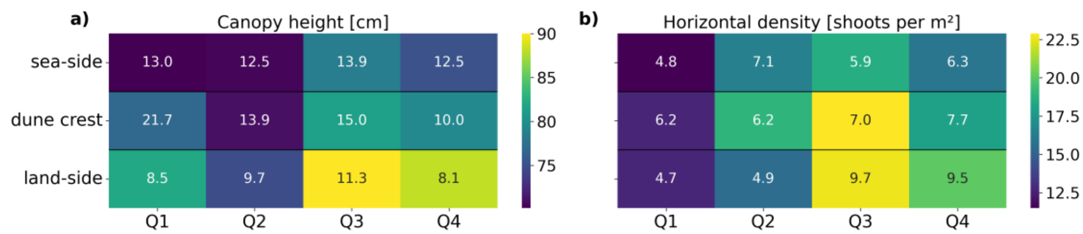

Figure 2. Spatial and temporal representation of (a) mean canopy height (in cm) and (b) horizontal density (in shoots per square meter), visualized using color gradients, and its standard deviation, presented as values in cells.

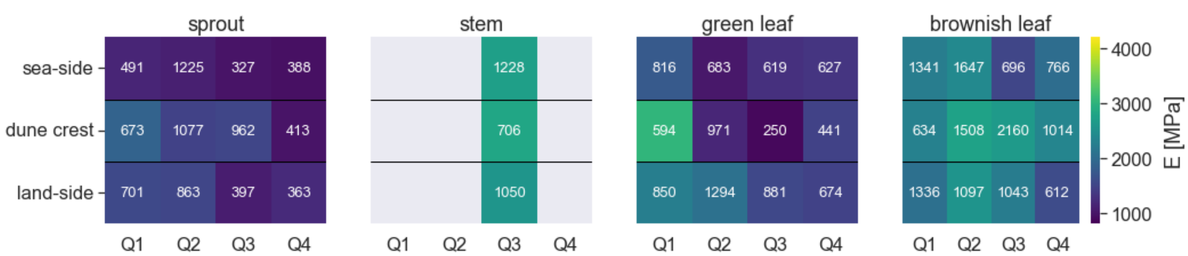

Figure 3. Mean Young's modulus (*E* in MPa), represented using color gradients, and its standard deviation, presented as values in cells, of the plant components sprout (sp), stem (st), green leaf (lg) and brownish leaf (lg) across zones and quarters.

4 CONCLUSIONS

Exposition appears to exert a less prevalent influence on biomechanics compared to seasonal vegetation growth periods in field measurements acquired throughout 2022 on the tidal barrier island of Spiekeroog. Recorded parameters show up to 50% value variations among sectors across seasons, with lower differences in inter-sector comparisons. It is crucial to note that the measured canopy height values offer only a general insight into their distribution beneath selected dune zones. For a more comprehensive understanding of dune dynamics, comparing measured plant heights with morphological changes is essential. Unfortunately, corresponding monthly Digital Elevation Models (DEMs) were unavailable and not part of the field study. Nevertheless, these results strongly support ongoing efforts to replicate natural processes in laboratory studies, addressing the lack of sufficient data on biomechanical plant characteristics needed for accurate modeling of dune vegetation.

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