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Response of vegetation stability and groundwater depth to spatial variability in sediment transport; White Sands National Monument, New Mexico

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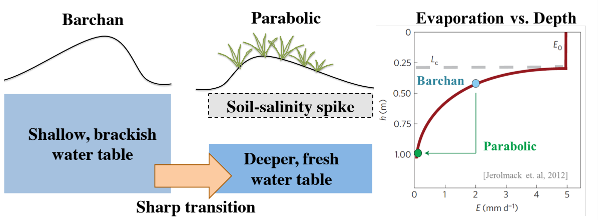
Abstract

Spatial variability in sediment transport can drive changes in dune morphology and vegetation cover across desert dunefields. Due to the complex interaction of vegetation with both water table dynamics and the soil-salt balance a discontinuous ecosystem response may exist. A theoretical model predicts that salt-vegetation feedback can lead to two stable states; one with sparse or no vegetation cover and a shallow brackish water table, and another with dense vegetation and a deep, fresh water table (Runyan and D'Odorico, 2010). Results presented here suggest that both stable states are present at White Sands National Monument, New Mexico – a gypsum dune field with a shallow, saline groundwater table – as actively-migrating barchan dunes abruptly transition to stable, vegetated parabolic forms. Vertical profiles of soil salinity, soil moisture, and depth to groundwater table were measured across the barchan-parabolic transition. Groundwater depth drops from ~0.5 m to ~1 m across this transition, likely a response to increasing transpiration. Salinity is uniform with depth in the unvegetated dunes; parabolics with dense vegetation exhibit a strong partitioning of salts.. Groundwater salinity drops by more than an order of magnitude, while there is a spike in soil salinity at the surface; consistent with model predictions. The spatial transition in dune-plant stability may therefore be applied to understand temporal shifts in dune field stability that may result from environmental change.

Two Equilibrium States for Vegetation Cover: A Theoretical Model

Two stable states proposed for vegetation-groundwater relationship:

1. Bare surface with *no vegetation* and a *shallow, brackish water table*.
2. *Fully-vegetated* surface with high soil-salinity and a *deeper, fresh, water table*

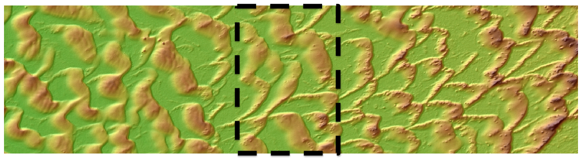


- Increased transpiration rates draw equilibrium water table depth down
- Evaporation decreases rapidly below capillary length, leads to low salinity water table
- Plants take up groundwater and precipitate excess salts into the shallow rooting zone

White Sands National Monument, NM

A. Barchan interdune with dune in the background
B. Vegetated, parabolic dune

The barchan-parabolic dune transition occurs rapidly about 7-8 km from the origin of the dunefield to the west.

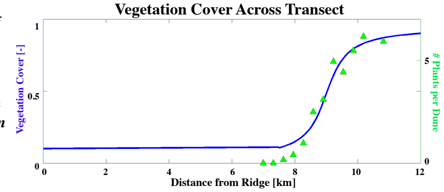


Does White Sands, NM demonstrate these two theorized equilibrium states at the transition between dune morphologies?

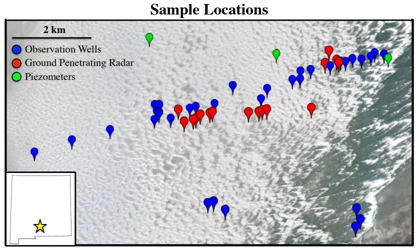
Surface Vegetation Cover

Average grayscale value of each column of pixels was used as a proxy for vegetation.

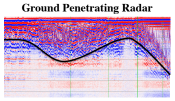
- ***Lighter*** → ***Less Vegetation***
- ***Darker*** → ***More Vegetation***

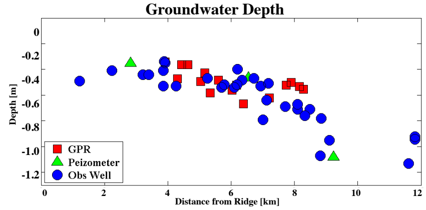


Groundwater Depth & Salinity

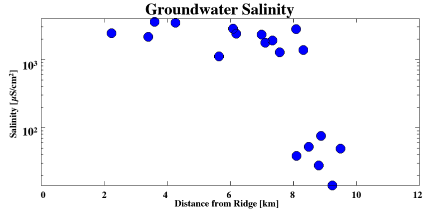


Sampling Methods



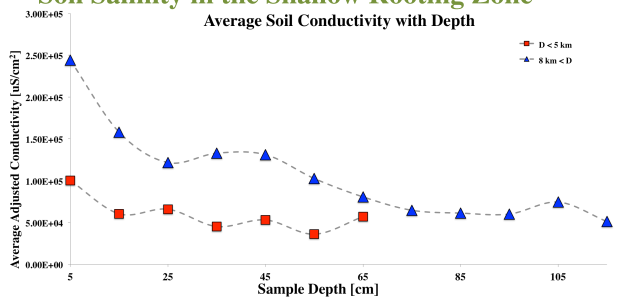


We observe a sharp increase in water table depth from ~0.5 m to >1 m between 7 and 9 km from the western ridge of the dunefield.



Groundwater salinity decreases rapidly from ~1.2 x 10^3 μS/cm² to ~10 μS/cm² over the same region of observed changes in groundwater depth and increased plant cover.

Soil Salinity in the Shallow Rooting Zone



Testing the Theoretical Model

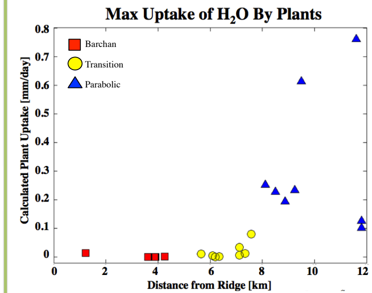
Runyan and D'Odorico [2010] propose that the two theoretical stable states can be modeled by the intersection of the following equations:

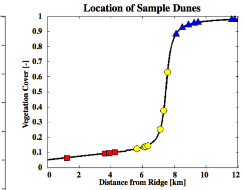
$$[1] \quad S_a = -\frac{1}{\sigma_s} \cdot \left(\frac{V}{V_0}\right) \qquad [2] \quad S_a = \frac{C_P \cdot P + C_2 \cdot \left[(1-V) \cdot Min\left[1, \left(\frac{h_{lim}}{h}\right)^a\right] \cdot ET_{2max}\right]}{P - \left((\varepsilon + (1-\varepsilon) \cdot V) \cdot g_\vartheta \cdot ET_{1max}\right)}$$

S_a = Salinity in shallow rooting zone
V = Vegetation Cover
V_0 = Max Vegetation Cover (1)
σ_s = Sensitivity Term

$Min[1,(hlim/h)^a]$ = depth control
$g\theta$ = specific yield
ε = % of ET from evaporation
ET_{2max} = H_2O uptake by plants

Due to the difficulty of constraining the model, we choose to solve for ET_{2max} in Equation 2 for primary assessment of model feasibility. ET_{2max} is a transpiration term, which will allow for a better assessment of the water balance that determines equilibrium groundwater depth.





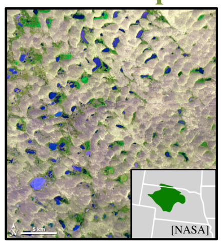
- Modeled transpiration rate increases rapidly at about 8 km.

This finding is consistent with the observed changes in vegetation cover, groundwater depth, and groundwater salinity across the same transect. Preliminary model output is qualitatively reasonable and matches expectations compared to observational data.

Conclusions & Future Directions

- Two stable states are qualitatively observed in the field
- Model estimations of transpiration rates at depth are reasonable but must be better constrained with further data collection and experimentation
- A continuous solution to the model using both Equations 1 and 2 needs to be determined to better examine vegetation stability in arid environments similar to White Sands

Broader Implications



- The Nebraska Sand Hills are a fully vegetated, stable dunes covering about 60,000 km²
- C14 and OSL data show the stable dunes mobilized in the past [Muhs & Maat, 1993]
- Possible result of increased sediment supply or decrease in vegetation due to drought

Can the relationships observed in White Sands be used to predict reactivation of stable dunefields similar to the Nebraska Sand Hills?

References

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