Researchers uncover a mechanism to explain dune field patterns

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In a study of the harsh but beautiful White Sands National Monument in New Mexico, University of Pennsylvania researchers have uncovered a unifying mechanism to explain dune patterns. The new work represents a contribution to basic science, but the findings may also hold implications for identifying when dune landscapes like those in Nebraska's Sand Hills may reach a "tipping point" under climate change, going from valuable grazing land to barren desert.

The study was conducted by Douglas Jerolmack, an assistant professor in the Department of Earth and Environmental Science; postdoctoral researcher Federico Falcini; graduate students Raleigh Martin, Colin Phillips and Meredith Reitz; and undergraduate researcher Claire Masteller. The Penn researchers also collaborated with Ryan Ewing of the University of Alabama and Ilya Buynevich of Temple University.

Their paper was published in *Nature Geoscience*.

Much of the study's data was collected during field trips taken by students in an undergraduate and graduate course Jerolmack teaches at Penn, Geology 305: Earth Systems Processes. Each year, the class has traveled to White Sands to do fieldwork during spring break.

"It's a magnificent place to go, and one of the reasons I take my students there is really because it's so visually striking and compelling," Jerolmack said. "I want it to be memorable for them."

White Sands National Monument, located near Alamogordo in south-central New Mexico, is an enclosed basin that housed an ancient lake during the last ice age. Unlike most dune fields, which are composed of quartz sand, it's the world's largest dune field made of gypsum. Its blindingly white dunes cover 275 square miles.

The dune fields' groundwater table is located just a meter below the surface.

"So it means you're in a very hot arid place, but when you walk around you feel moisture on your feet," Jerolmack said.

The moisture creates a somewhat "sticky" surface, he added, "so, if the sand blows off a dune and lands, it sticks to the surface and can get deposited and left behind."

White Sands has long been the site of geologic inquiry. Scientists have put forward theories to explain individual elements of the dunes, including their shape, their movements over time and the presence or absence of plants. The novelty of this study lies in showing how all of these problems are a consequence of the interaction of wind with the dunes.

While the majority of Jerolmack's work examines how water moves sediment, wind becomes the dominant shaping force in deserts.

The researchers began by analyzing high-resolution elevation maps, measured each year for five years using aerial laser scans of the dune field surface. These data showed that dunes migrated fastest at the upwind (western) edge of the dune field, where the field transitioned into a flat and barren plain. Moving along the prevailing wind direction (northeast) into the dune field, the speed of the moving dunes consistently slowed down. The researchers reasoned that the friction resulting from the dunes was likely causing the wind to slow down over the dune field. They employed a simple theory to provide quantitative confirmation of this idea, demonstrating that aerodynamics was the cause of the dune migration pattern.

Small specks in the high-resolution images, which indicate where plants grow, also showed that the wind and dune migration activity appeared to impact vegetative growth. "There is a rapid transition from bare dunes to dunes that are almost entirely covered with vegetation," said Jerolmack. "We recognized that this transition occurs because the dunes are slowing down, and slowing down, and slowing down; eventually the dunes are moving so slowly that plants can grow on them."

According to the researchers' observations, dunes that are hit with stronger winds have fewer plants, as the plants cannot grow roots quickly enough to keep up with the shifting sands. By contrast, the dunes that experience the slower-moving winds are stable enough to support plants.

The plants then exert their own influence on dune shapes, as their root systems help stabilize the sand in which they grow. Because plants generally take hold first to a dunes' "horns" — the narrow slopes of boomerang-shaped dunes — before reaching the center, the researchers observed that dunes with plant-stabilized horns inverted as the wind blew the center inside out.

Where plants grew, the underlying groundwater was fresher and farther below the surface than areas bare of plants. The Penn researchers demonstrated that plants impacted the groundwater, rather than the other way around. By taking up water, the plants draw the groundwater table down. This also lowers the evaporation at the groundwater table, leaving the groundwater less salty than in unvegetated areas with high evaporation rates.

"What makes this so interesting is that, by understanding the changes in the wind pattern over the dunes, we can also understand the migration of the dunes, the plant and groundwater dynamics and even the long term deposition rate within the dune field," Jerolmack said. "This helps us to understand very well what's going on at White Sands, but these are all fundamental mechanisms that we think can apply in many other places."

North-central Nebraska's Sand Hills, located on a grass-stabilized dune field, is one example where this mechanism may apply. Under some climate change predictions, rainfall could decline in the upper Midwest. Even a small reduction in rainwater could mean that the grasses that stabilize the Sand Hills' dunes would no longer be able to survive. The dunes would then go back to being a barren migrating dune field, no longer serving the half-a-million cattle that now graze there.

"It happened during the Dust Bowl and it could happen again," Jerolmack said.

Provided by University of Pennsylvania