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The association of land cover with aeolian sediment production at Jornada Basin, New Mexico, USA

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ABSTRACT

We investigated amounts and particle size distributions (PSDs) of aeolian sediments collected at five heights in five ecosystem types at the Jornada Basin, Chihuahuan Desert, New Mexico, USA. Particle size distributions, mass fluxes, and percent of dust-sized ($\leqslant 50\ \mu m$) mass flux were determined for all heights and all ecosystem types. Differences between sites were determined using ANOVA followed by Tukey–Kramer post hoc tests to find groupings. For creosote shrublands, grasslands, and two tarbush-dominated alluvial flats, samples collected at 5, 10, and 20 cm had >80% sand-sized (>50 μm) particles, while one playa and tarbush site yielded $\sim$45% dust-sized particles at 5 and 10 cm. The transition from saltation to suspension was $\sim$20 cm for most sites. Two mesquite dune sites and an anthropogenically devegetated site, all with high overall mass fluxes, shifted to suspension at $\sim$50 cm. Highest dust fluxes occurred at the devegetated site, followed by the playa, a mesquite site with unvegetated "streets," and tarbush sites. These field observations are consistent with laboratory-based dust emission experiments and remote sensing studies in the Chihuahuan Desert. Playas and tarbush sites are major dust producers due to high proportions of fines, whereas the mesquite site produces much dust because of greater overall mass flux. Mesquite dunes covering most of the basin likely produce the most dust overall, though playas and tarbush-dominated alluvial flats (which cover about 8%) can emit large amounts of dust. Continuing shrubland encroachment will likely increase dust emissions from the Jornada Basin, as well as in other arid regions.

1. Introduction

The expansion of woody plants, typically into semiarid and mesic grasslands, has been documented in both North and South America, southern Africa, Australia, Asia, and Europe (e.g., Altesor et al., 2006; Angassa, 2005; Archer et al., 1988; Cabral et al., 2003; Cheng et al., 2004; Costello et al., 2000; Kraaij and Milton, 2006; Peters and Gibbens, 2006; Scholes and Archer, 1997; Van Auken, 2000). Conversion from grasslands to woody plant-dominated landscapes has important local, regional, and global consequences, including changes in carbon dynamics, loss of biodiversity and forage production, changes in hydrological budgets, and wind and water erosion of soil and nutrients (Peters et al., 2006; Safriel and Adeel, 2005).

The type and amount of vegetation cover is an important factor in determining wind erosion. Although models differ in what aspect of vegetation cover is most important (such as total cover versus lateral cover), there is general agreement that shrublands provide less protection from wind erosion than grasslands (e.g., Hesse and Simpson, 2006; Okin et al., 2006). Redistribution of soil material by wind occurs from the local scale (from the interspace to under shrubs), the patch scale (dust removed for long-distance transport), and the global scale (deposition of nutrients in downwind ecosystems) (Okin et al., 2006). The size of the eroded particle will determine its transport mechanism, with larger particles more likely to be transported relatively short distances via saltation, while smaller particles can be transported larger distances via suspension. Saltating particles are more likely to influence local processes, while suspended particles are more likely to influence regional to global processes. The transition between saltation-dominated and suspension-dominated transport depends upon surface conditions and wind velocity, and is often found $\sim$20–30 cm above the surface for dryland soils (Fryrear and Saleh, 1993). In locations with low surface cover and/or high wind velocities, the larger particles can be lifted higher above the surface, increasing the height of the transition layer (Warren et al., 2007). Thus, understanding how types of and changes in land cover impact aeolian processes is critical for both local and global systems, understanding past processes, and predicting future changes in aeolian processes as climatic change leads to ecosystem changes (Reynolds et al., 2003). Landscape characteristics – including both geomorphology and vegetation type and cover – modulate

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the location as well as the intensity of wind erosion. Playas (dry lake beds in topographically closed desert basins) have long been considered to be primary "hotspots" of dust emission (Engelstaedter et al., 2003; Gill, 1996; Ginoux et al., 2001; Prospero et al., 2002; Reynolds et al., 2007) to the point that the distribution of topographic lows in drylands has been used as a proxy for source areas in models of long-distance transport of dust (Ginoux et al., 2004; Mahowald et al., 2002; Zender et al., 2003). In an analysis of global dust storm frequency (DSF) records, Engelstaedter et al. (2003) suggested that DSF is highest in bare ground areas and increases as the fraction of closed topographic depressions increases. DSF in shrublands was found to be ~1/3 that of topographic depressions yet an order of magnitude higher than in grasslands (Engelstaedter et al., 2003). In the Mojave Desert/Southern Great Basin of North America, Reheis and Kihl (1995) found that playas and alluvial sources produce roughly equivalent amounts of dust per unit area, although total dust production from the more spatially extensive alluvial sources is much larger.

Vegetation protects soils from wind erosion through three primary mechanisms: (1) providing direct shelter from the force of wind by covering a fraction of the surface and creating a lee-side wake where wind speeds are dramatically reduced, (2) extracting momentum from the wind, thus reducing erosivity, and (3) trapping windborne particles, reducing total flux and providing a loci for sediment deposition (Okin et al., 2006; Wolfe and Nickling, 1993). Many modeling efforts have shown that three aspects of vegetation are important predictors of wind erosion: (1) percent cover, which is related to simple surface protection, (2) lateral cover (the total frontal silhouette area of vegetation intercepted by wind), which affects how much momentum the vegetation can extract from the wind, and (3) the spatial distribution of the vegetation, which impacts the fetch distance (Li et al., 2007; Okin et al., 2009, 2006; Wolfe and Nickling, 1993). The longer the fetch distance, the more aeolian sediment flux occurs. Desert grasslands tend to have greater overall cover, greater lateral cover, and shorter aeolian fetch distances than do shrublands (Gillette and Monger, 2006), all characteristics that should reduce aeolian erosion from grasslands compared to shrublands.

Blowing dust and sand is frequent in the Chihuahuan Desert (CD) of southwestern North America (Bowker et al., 2008), making it one of the aeolian hotspots of the continent (Prospero et al., 2002). Shrublands are the predominant land cover type of the CD, especially the uplands, while grasslands are the typical lowland vegetation of the desert (Beltrán-Przekurat et al., 2008; Gibbens et al., 2005), and playas of varying size are scattered throughout. Remote-sensing-based analyses of regional dust events throughout the Chihuahuan Desert have suggested that shrublands are the most important dust source areas overall and grasslands are relatively minor contributors (Rivera Rivera et al., 2010), although playas/unvegetated lands are clearly also major dust sources (Rivera Rivera et al., 2010) and dominate some individual events within the CD (Dominguez Acosta, 2009; Gill et al., 2009; Lee et al., 2009).

The Jornada Long Term Ecological Research site (LTER), located in the northern CD of south-central New Mexico, USA, has been the site for several studies on aeolian processes in arid environments (Belnap and Gillette, 1998; Bergametti and Gillette, 2010; Gillette and Monger, 2006; Gillette and Chen, 2001; Gillette et al., 2006; Gillette and Pitchford, 2004; Okin and Gillette, 2001). Much of the work has compared emissions from bare surfaces with those from areas dominated by mesquite (*Prosopis grandulosa*) shrubs. Okin and Gillette (2001) found areas of extremely long aeolian fetch distance (termed "streets") tending to be aligned with the direction of the prevailing wind in some mesquite (*Prosopis* sp.)-dominated shrublands (but not reported in the literature from other types of shrublands in the CD or elsewhere). The faster wind flow down these "streets" (Bowker et al., 2006) makes them the dominant local sources of wind-eroding sand (Bowker et al., 2008) Mesquite-dominated areas in the Jornada LTER were shown by Gillette and Pitchford (2004) to have roughly 10 times the amount of aeolian sand flux as areas with other vegetation types. The flux was greatest at the end of the "streets" in-between mesquite patches, while sediment collectors placed just downwind of mesquite bushes had less flux (Gillette and Pitchford, 2004). This demonstrates the importance of spatial distribution of vegetation, as flux in mesquite areas was not well explained by simply describing the vegetation coverage.

Less work has been done investigating the effects that different vegetation types have on aeolian processes (although see Gillette and Pitchford, 2004). The five most common vegetative types in the Jornada LTER are honey mesquite (*Prosopis grandulosa*) dune shrublands, black grama (*Bouteloua eriopoda*) grasslands, creosote bush (*Larrea tridentata*) shrublands, tarbush (*Flourensia cernua*) shrublands on alluvial flats, and grass-dominated (characterized by *Pleuraphis mutica*) playas (Huenneke et al., 2001, 2002; Peters and Gibbens, 2006). The Jornada LTER has experienced major changes in its plant communities over the past 100 years (Gibbens et al., 2005; Peters and Gibbens, 2006). Black grama grasslands have decreased from covering about 19% of the Jornada in 1915–1916 to only about 8% in 1998 (Gibbens et al., 2005). Honey mesquite increased from covering about 26% of the Jornada to 59% total coverage in 1998, with 27% classified as mesquite dunes (soil accumulations at the base of plants 20 cm to about 3 m in height) and 17% as mesquite sandhills (accumulations greater than 3 m in height) (Gibbens et al., 2005).

Three study sites in each of these vegetative types were established in 1989 to study net primary productivity (NPP) and vegetation change (Huenneke et al., 2002). Bergametti and Gillette (2010) found significantly higher horizontal mass flux at mesquite sites from 1998 to 2005 than at each of the other four vegetation types. The mass fluxes at the other four vegetation types (grasslands, creosote bush, tarbush, and playa) were statistically indistinguishable from each other. Saltation was determined to be the mechanism for flux at the mesquite sites, but did not explain the flux patterns at the other vegetation sites. Size distributions of the transported particles were not examined by Bergametti and Gillette (2010) nor in previous studies of aeolian processes at the Jornada LTER.

In this study, we investigate the amounts and particle size distributions (PSDs) of material collected in Big Spring Number Eight (BSNE) aeolian sediment samplers (Fryrear, 1986) in late spring–early summer (the windy season) 2006 near each of the NPP sites in the five vegetative types the Jornada LTER. We also estimate amount of silt- and clay-sized particles ($\leqslant 50$ μm, "dust") produced at these different sites. The mesquite-dominated regions have been shown to experience more aeolian mass flux than other vegetation types (Bergametti and Gillette, 2010; Gillette and Monger, 2006; Gillette and Pitchford, 2004), and understanding the characteristics of particle size composition of aeolian erosion from within these different vegetation types will be important as mesquite and creosote continue to replace historical grasslands at the Jornada and other sites in the Chihuahuan Desert, and as woody shrubs replace grasslands worldwide.

2. Methods

2.1. Sample collection

Detailed descriptions of sample collection can be found in Bergametti and Gillette (2010). Briefly, Big Spring Number Eight (BSNE) aeolian sediment samplers (Fryrear, 1986) were deployed at sites adjacent to the 15 NPP sites described above (see Bergametti and Gillette (2010), for a map of the study sites). There are three sites