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Aeolian sediment transport following wildfire in sagebrush steppe

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A B S T R A C T

Wind erosion of soil is an appreciable but unstudied event following fires in cold desert. We examined aeolian transport of sediment for 1 year following fire in semi-arid shrub steppe on loess soils in southern Idaho, USA. Sediment collectors were used to determine horizontal mass transport of soil and saltation sensors and anemometers were used to determine saltation activity (fraction of time having saltation) and threshold wind speed in an area burned in August and an unburned control site. Horizontal mass transport (per 30-day period) was negligible in the unburned area, but in the burned area was 5.40 kg m^{-1} in October and decreased to 2.80 kg m^{-1} in November and 0.32 kg m^{-1} in December. Saltation activity was high enough to determine threshold wind speeds only in the burn site during fall, when values ranged from 10.0 to 10.6 m s^{-1}. Sediment flux and saltation activity in the burned site became much less pronounced following the emergence of herbaceous vegetation in the spring. Post-fire sediment flux in the shrub steppe we examined was of greater magnitude but shorter duration than post-fire fluxes in warm deserts or sandier regions that experience more frequent wind erosion.

1. Introduction

Aeolian sediment transport is a fundamental geomorphic process that has wide-ranging environmental implications for human and environmental health (Whicker et al., 2006), ecological functioning at multiple spatial and temporal scales (Okin et al., 2006), local and global biogeochemical cycling (Chadwick et al., 1999; Okin et al., 2004; Reynolds et al., 2001), and contaminant transport (Whicker et al., 2004). Aeolian sediment transport is a function of the wind's ability (impeded by vegetation and terrain) to entrain soil particles, and the soil's susceptibility to this entrainment (Bagnold, 1941; Okin et al., 2006). Field-based research on aeolian transport in non-agricultural systems has largely focused on dunefields and arid landscapes, however, sediment transport via wind is substantial in semi-arid shrublands and can exceed that by water (Breshears et al., 2003). Wind erosion can be especially significant following fire, as shown for prairie and warm desert in the southern United States, dunes of the south-western Kalahari desert of Africa, and arid and semi-arid dunefields of Australia (Ash and Wasson, 1983; Thomas and Leason, 2005; Vermeire at al., 2005; Wasson and Nanninga, 1986; Whicker et al., 2002; Wiggs et al., 1994, 1995, 1996; Zobeck et al., 1989).

Increased wind erosion has been reported immediately following prescribed fires in mixed prairie (Vermeire et al., 2005), at various intervals following summer wildfire in warm desert shrublands and rangelands (Whicker et al., 2002; Zobeck et al., 1989), and following wildfire in linear dunes of the southwestern Kalahari (Thomas and Leason, 2005; Wiggs et al., 1994, 1995, 1996), in dunefields of Australia (Ash and Wasson, 1983; Wasson and Nanninga, 1986), and in model simulations of semi-arid dunefields (Nield and Baas, 2008) (additionally see Table 1). It is generally known that the removal of vegetation cover by fire or other disturbance can increase the potential for wind erosion. Relationships between vegetation cover and aeolian transport have been determined for specific landscapes, both burned and unburned. For example, a vegetative cover of 14% is commonly cited as a threshold for sand transport on the linear dunes of southwestern Kalahari (Wiggs et al., 1995). A threshold of 15% grass cover was determined for sand transport at Owens Lake, California (Lancaster and Baas, 1998). In northern Australia, sand transport was estimated to occur decreasingly with up to 45% vegetative cover on unvegetated dunes and sandplains (Wasson and Nanninga, 1986). When vegetation is reduced specifically by fire, substantially increased wind erosion has been estimated to occur for up to 5 years in the southwestern Kalahari and 10 years in northern Australia, based on observations and estimates of erosion, post-fire plant re-colonization, and fire

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Table 1
Summary of sediment transport from burned and unburned areas, as assessed with passive sediment collectors following summer/fall fires in ungrazed areas of Western North America.

Study	Biome and location	Period (days)	Height[a]		n[b]	Burn (g day^{-1})	Unburn (g day^{-1})	Burn/unburn
Zobeck et al., 1989	Shinnery Oak Rangeland	~43 Mar–May	Low		9	1.0147	0.0014	727
(Table 2)	Southern High Plains, TX		High		9	0.0867	0.0012	75
Whicker et al., 2002	Desert Shrubland	~272 Jun–Feb	Low		3	0.3500	0.0500	7
(Fig. 7)	Chihuahuan Desert, NM		High		3	0.1500	0.0100	15
Vermeire et al., 2005	Sand Sagebrush Mixed	~166 Dec–Apr	Low		4	0.1146	0.0047	24
(Table 1, Fig. 2)[c]	Prairie, NW OK		High		4	0.0343	0.0028	12
		~168 Dec–Apr	Low		4	0.0250	0.0046	5
			High		4	0.0074	0.0007	10
Current study	Shrub steppe, cold desert	323 Sep–Aug	Low	Burned	6	0.0250	0.0004	67
	Snake River Plain, SE ID			Unburned	3			
			High	Burned	6	0.0051	0.0002	28
				Unburned	3			
Mean (SE) at low (approximately 0.2 m) collection height						0.31 (0.19)	0.01 (0.01)	166 (141)
Mean (SE) at high (approximately 0.5 m) collection height						0.06 (0.03)	0.00 (0.00)	28 (12)

Sediment collection rates (g d^{-1}) were estimated from data presented with other units in the previous studies.
[a] "Low" collection heights: 0.15 m (Zobeck et al., 1989); 0.225 m (Whicker et al., 2002); 0.2 m (Vermeire et al., 2005 and this study). "High" collection heights: 0.5 m (Zobeck et al., 1989); 0.525 m (Whicker et al., 2002); 0.4 m (Vermeire et al., 2005); and 0.55 m (this study).
[b] Number of collectors used per burn (or unburn) site in study.
[c] Results presented for only the ungrazed treatments in Vermeire et al., 2005 (note a 2-year study).

return intervals (Wasson and Nanninga, 1986; Wiggs et al., 1994). Similar time scales of increased dune activity following vegetation removal were recently reported for model simulations of semi-arid dunefield evolution (Nield and Baas, 2008).

Substantial pulses of erosion have recently been noted (qualitatively) following wildfires in cold desert between 40 and 45°N latitude. Wind erosion has been previously known only to occur on unvegetated surfaces in these landscapes (e.g. agricultural fields, active sand dunes, playas, and floodplains). It is not well known whether wind erosion persists through plant re-colonization of burned areas in mid-latitude cold desert, however, where plant reestablishment can be delayed in cold or dry dormancy periods following burning seasons. Moreover, previous studies of fire effects on wind erosion have all occurred on sandy soils. We examined the course of wind erosion as it related to changes in plant abundance following a fire in cold desert sagebrush steppe occurring on fine-textured loess soils, which appeared to otherwise have not been affected by recent fire or aeolian losses of soil.

Cold desert sagebrush steppe is a vast habitat type that is uniquely characterized by warm, dry summers, and cold, snowy winters. Snowmelt and rain in spring provide most of water available to plants, and spring "green-up" is followed by summer drought and leaf senescence by August (Smith et al., 1997). Fire frequencies and area burned per year have increased substantially in the recent decade in sagebrush steppe, with area burned approaching 500 ha in some years (e.g. 2007 Murphy complex fire in western North America). Fire typically occurs in summer, and charred soils frequently remain unvegetated until resprouting of grasses (and some forbs and occasionally shrubs) occurs in the subsequent spring and summer (Harniss and Murray, 1973). Herb cover, especially grasses, dominate vegetation cover for decades following fire, while species such as sagebrush slowly recover to pre-fire levels. Seeding and planting are commonly used in an attempt to bolster cover in the first years after fire (United States Department of Interior, Bureau of Land Management) (e.g. Hilty et al., 2003), which implicitly assumes that natural plant recovery is not adequate to stabilize soil.

Observations of saltation activity (the fraction of time in which saltating particles can be detected) and critical aeolian threshold (hereafter "threshold", the minimum wind speed required for saltation) were useful for distinguishing erodibility of soil surfaces with expectedly different susceptibility to erosion by wind (Stout, 2007). We examined whether saltation activity and threshold, in conjunction with sediment flux measurements, could also reveal differences between the wind erosion potential of burned and unburned rangelands. Saltation activity, threshold, and actual rates of horizontal sediment transport can be determined from simultaneous micrometeorological measurements of wind and other boundary layer atmospheric characteristics, passive sediment sampling systems for measurement of horizontal sediment mass flux, and observations of soil loss and deposition at the soil surface (Stout, 2004; Vermeire et al., 2005; Whicker et al., 2002; Zobeck et al., 1989). Our objective was to use these approaches to determine differences in wind erosion potential, and the longevity of these differences for a burned and an unburned (control) area in semi-arid cold desert shrub steppe. We hypothesized that: (1) wind erosion potential would be greater at burned compared to unburned sites during fall; and (2) differences in wind erosion potential between burned and unburned sites would not be detectable following the spring emergence of herbaceous vegetation.

2. Materials and methods

2.1. Study sites

The study sites are located in the southern portion of the eastern Snake River Plain, near Aberdeen, ID (Lat. 43° 00′ N, Long. 113° 00′ W, 1460 m elevation). The area is located in a zone of 200–280 mm of mean annual precipitation and 7–13 °C mean annual temperature (NCSS Web Soil Survey,). This portion of the Snake River Plain is characterized by near surface winds that trend generally from SW to NE throughout the year (Clawson et al., 1989).

The rangeland vegetation includes Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* Rydb.) and the less abundant shrubs "three-tip" sagebrush (*Artemisia tripartita* Rydb.) and green rabbitbrush (*Chrysothamnus viscidoflorus* [Hook.] Nutt.), bluebunch wheatgrass (*Agropyron spicatum* Pursh.), prairie junegrass (*Koeleria macrantha* Ledeb.), and sandberg bluegrass (*Poa secunda* J. Presl) (NCSS Web Soil Survey). Soils at the study sites are predominately Xeric Haplocalcids that have developed from silty loess overlying basalt bedrock (NCSS Web Soil Survey). Depth to bedrock ranges from 20 to 150 cm, and surficial soil textures are silt loam in deeper loess-derived soils and a stony loam in some locations where fractured bedrock is nearer the surface (NCSS Web Soil Survey). Soils at the sites are rated with a wind erodibility index