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Grazing impacts on the susceptibility of rangelands to wind erosion: The effects of stocking rate, stocking strategy and land condition

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ABSTRACT

An estimated 110 Mt of dust is eroded by wind from the Australian land surface each year, most of which originates from the arid and semi-arid rangelands. Livestock production is thought to increase the susceptibility of the rangelands to wind erosion by reducing vegetation cover and modifying surface soil stability. However, research is yet to quantify the impacts of grazing land management on the erodibility of the Australian rangelands, or determine how these impacts vary among land types and over time. We present a simulation analysis that links a pasture growth and animal production model (GRASP) to the Australian Land Erodibility Model (AUSLEM) to evaluate the impacts of stocking rate, stocking strategy and land condition on the erodibility of four land types in western Queensland, Australia. Our results show that declining land condition, over stocking, and using inflexible stocking strategies have potential to increase land erodibility and amplify accelerated soil erosion. However, land erodibility responses to grazing are complex and influenced by land type sensitivities to different grazing strategies and local climate characteristics. Our simulations show that land types which are more resilient to livestock grazing tend to be least susceptible to accelerated wind erosion. Increases in land erodibility are found to occur most often during climatic transitions when vegetation cover is most sensitive to grazing pressure. However, grazing effects are limited during extreme wet and dry periods when the influence of climate on vegetation cover is strongest. Our research provides the opportunity to estimate the effects of different land management practices across a range of land types, and provides a better understanding of the mechanisms of accelerated erosion resulting from pastoral activities. The approach could help further assessment of land erodibility at a broader scale notably if combined with wind erosion models.

1. Introduction

Wind erosion is widespread across the world's drylands, including the arid and semi-arid rangelands of Australia (Shao et al., 2011). Cultivation and grazing can accelerate wind erosion rates above natural levels by reducing vegetation cover and soil surface stability (Zender et al., 2004; Fister and Ries, 2009; Colazo and Buschiazzo (2010); Webb and Strong, 2011). However, quantifying the impacts of land management on wind erosion rates is an inherently challenging task given the sensitivity of wind erosion to spatial patterns of soils, vegetation and climate variability (Ervin and Lee, 1994; Mahowald et al., 2002; Belnap et al., 2009). Resolving the impacts of grazing land management on the erodibility of rangelands remains crucial as land use and climate changes increase pressures on dryland environments. This requires improved understanding of the effects of stocking rates and stocking strategies on land erodibility; on how management activities influence wind erosion through their impacts on land condition, and how these impacts vary among different land types in space and time.

Research into the effects of land management on wind erosion has primarily focussed on the impacts of intensive cultivation. These impacts are highly dependent on such management activities as crop cycles and tillage practices (Hagen, 1996; Bielders et al., 2002; Gomes et al., 2003; Zhang et al., 2004). Practical management options have been developed to reduce wind erosion from agricultural fields. These options seek to maintain high surface roughness by establishing critical cover levels (Lyles and Allison,

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1981; Michels et al., 1995; Toure et al., 2011), preserving soil aggregates using reduced tillage systems and chemical fallow (López et al., 2000; Eynard et al., 2004; Feng et al., 2011), and reducing the wind erosivity by establishing ridging or windbreaks (Bielders et al., 2000; Liu et al., 2006).

Knowledge gained from this research has been effective in reducing wind erosion in croplands. Less research has been conducted to quantify the effects of grazing land management on wind erosion (Hoffmann et al., 2008; Vermeire et al., 2005; Belnap et al., 2009). There has been an increasing, and now fairly substantial, body of work on the impacts of grazing disturbance in drylands on biological soil crusts and vegetation, and therefore indirectly on land erodibility (Williams et al., 2008; Tabeni et al., 2014). However, research is yet to focus on the direct impacts of pastoral land management on landscape erodibility.

Rangeland managers can influence the susceptibility of landscapes to wind erosion (herein land erodibility) by changing stocking rates in response to forage supply. Over time, grazing pressure from livestock can affect soil erodibility, the structure and resilience of vegetation communities, land condition, and increase the potential for accelerated soil erosion (Ash et al., 1994). There is a growing body of plot-scale research investigating livestock impacts on soil aggregates and crusts (Eldridge and Leys, 2003; Fister and Ries, 2009; Baddock et al., 2011), while there is a significant body of research into grazing impacts on rangeland vegetation (e.g. Hunt et al., 2014; Orr and O'Reagain, 2011; Rietkerk et al., 2000). These studies have quantified the direct impacts of grazing on rangeland systems and their resistance to degradation pressures. However, few studies have directly addressed grazing impacts on wind erosion at spatial scales that are relevant for land managers (e.g. Li et al., 2003, 2005; Belnap et al., 2009).

To our knowledge, no studies have evaluated the effects of different grazing management strategies on wind erosion. Such information is required to formulate practical erosion management solutions. Difficulties in assessing the long-term impacts of grazing practices on wind erosion, and their variability among land types, has undoubtedly added to the challenge.

Modelling approaches have the potential to provide a means for evaluating the long-term impacts of grazing management strategies on wind erosion across multiple land types. While models have been applied to simulate wind erosion mass flux for rangelands in response to vegetation change, they have not been used to quantify the effects of different grazing management practices on wind erosion (Marticonera and Bergametti, 1995; Shao et al., 1996; Okin, 2008). Webb et al. (2006, 2009) developed the Australian Land Erodibility Model (AUSLEM) to investigate land erodibility changes induced by climate variability and grazing in Australian rangelands. AUSLEM draws input data from a spatially distributed pasture production model (AussieGRASS). The one-dimensional version of this model, the grass and livestock production model GRASP, can be applied to assess pasture degradation risk in response to climate variability and change (Day et al., 1997; Ash et al., 2000; McKeon et al., 2000, 2004; Howden et al., 1999; Webb et al., 2012). We use GRASP here to provide a scenario-based analysis of the effects grazing management practices on landscape elements that control wind erosion across a range of land types.

The objective of this paper is to quantify the long-term impacts of grazing management practices (stocking rate, stocking strategies) and outcomes (land condition) on land erodibility across different land types. We couple the pasture growth and livestock production model GRASP with the land erodibility model AUSLEM to (1) evaluate the long-term effects of stocking rates on land erodibility, (2) identify the sensitivity of land erodibility to different stocking strategies, and (3) determine what effects grazing can have on land erodibility for land in different conditions. We apply the models to make erodibility assessments for four land types in the rangelands of western Queensland Australia. By evaluating the effects of different grazing strategies on the erodibility of the rangelands at a management relevant-scale, the study provides new information on how grazing activities influence wind erosion and the identification of where and when accelerated soil erosion may occur within these landscapes.

2. Study area

The study area covers the semi-arid rangelands of western Queensland, Australia (Fig. 1).

These rangelands are used for cattle and sheep grazing and are a frequent source of dust emissions (McTainsh et al., 1989). Mean annual rainfall varies from 260 mm to 500 mm and the mean maximum temperatures range from 20 °C in winter (June, July, August) to more than 35 °C in summer (December, January, February). The study area can be divided into three bioregions (DEWR, 2007), including the Mulga Lands, Mitchell Grass Downs and the Channel Country. Within these bioregions, four land types are differentiated with a range of soil and vegetation characteristics that influence their sensitivities to climate, land management and wind erosion. The Mitchell Grass Downs land type comprises fertile open grasslands with cracking clay soils, with vegetation dominated by Mitchell grasses (*Astrebla* spp.) and Queensland bluegrass (*Dichanthium sericium*). The Mulga and Gidyea land types both have light sandy clay to medium clay soils, with shrublands and low woodlands (*Acacia* spp.). The Spinifex land type has sandy to sandy loam soils and supports Spinifex (*Triodia* spp.) and desert bluegrass (*Bothriochloa ewartiana*). A summary of the soil and plant species characteristics of the study land types is provided in Table 1.

3. Methods

3.1. GRASP modelling system

GRASP is an empirical point based model which simulates a daily soil–water balance, pasture growth and animal production in response to climate inputs and land management. The model inputs include daily rainfall, minimum and maximum temperature, evaporation, solar radiation and vapour pressure. The GRASP soil water balance simulates, in response to the climate inputs, the processes of runoff, infiltration, soil evaporation and pasture and tree transpiration. The above-ground pasture biomass is modelled as a product of pasture growth, senescence, detachment of standing dry matter, litter decomposition, animal trampling, and consumption. Animal production can be modelled for either sheep or cattle, with cattle being the focus of this study. Forage intake (utilisation) follows feed quality restrictions for the proportion of growth that can be consumed and a limitation for consumption at low pasture biomass levels. The animal liveweight gain is determined as a function of the daily intake, including the duration of grazing. The total biomass consumed is finally calculated as function of the daily intake for the number of livestock specified (by the stocking strategy) equivalent to 200 kg weaner steers.

The GRASP model structure, calibration and validation are described in detail by Day et al. (1997) and Littleboy and McKeon (1997) and summarised by McKeon et al. (2000).

Because GRASP is a one-dimensional pasture growth model it does not explicitly represent the effects of grazing distribution on the pasture, or how this may impact the landscape susceptibility to wind erosion. In real landscapes livestock grazing distributions, for example with respect to the location of watering points, is expected to have a significant impact on spatial and temporal