QUANTIFYING ACCELERATED SOIL EROSION THROUGH ECOLOGICAL SITE-BASED ASSESSMENTS OF WIND AND WATER EROSION

Nicholas P. Webb[†], Jeffrey E. Herrick[†], Michael C. Duniway[‡]

Objective

Land use change and intensification have resulted in accelerated rates of soil erosion in many areas of the world's rangelands. Ecological models of landscape change (e.g. Fig. 1) provide a framework for assessing when erosion controls are modified by land use or management in excess of their natural variability, enabling quantification of accelerated soil erosion.

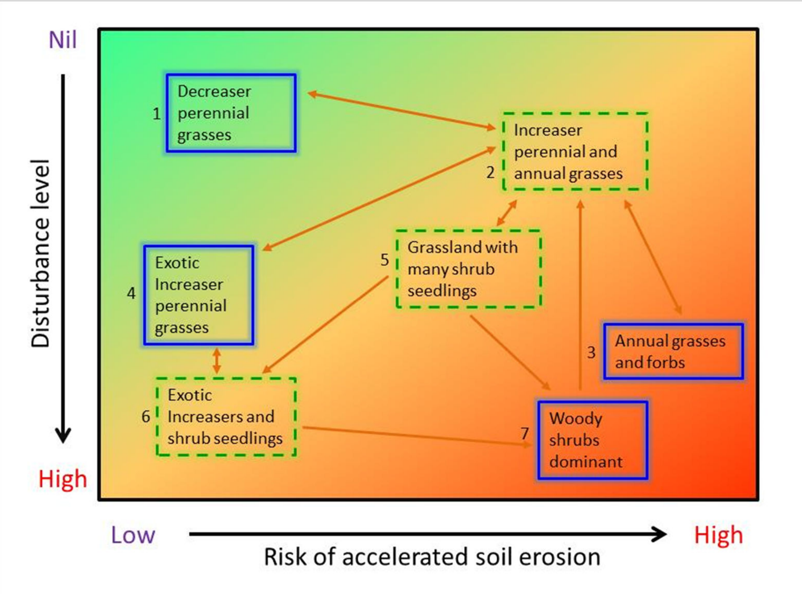

Fig. 1: Generalised state-and-transition model[1] showing potential interactions between disturbance levels, ecological state changes and accelerated soil erosion.

Here we illustrate this approach by evaluating soil erosion rates across five ecological sites in southern New Mexico, USA. We show how patterns and thresholds in erosion responses to vegetation state change and site disturbance manifest across the ecological sites, thus enhancing our capacity to identify practical management solutions.

Study area

The study area is located in the semi-arid rangelands of southern New Mexico (Fig. 2). The area covers a variety of landforms, including gravelly, limestone hills, loamy, draw and sandy ecological sites.

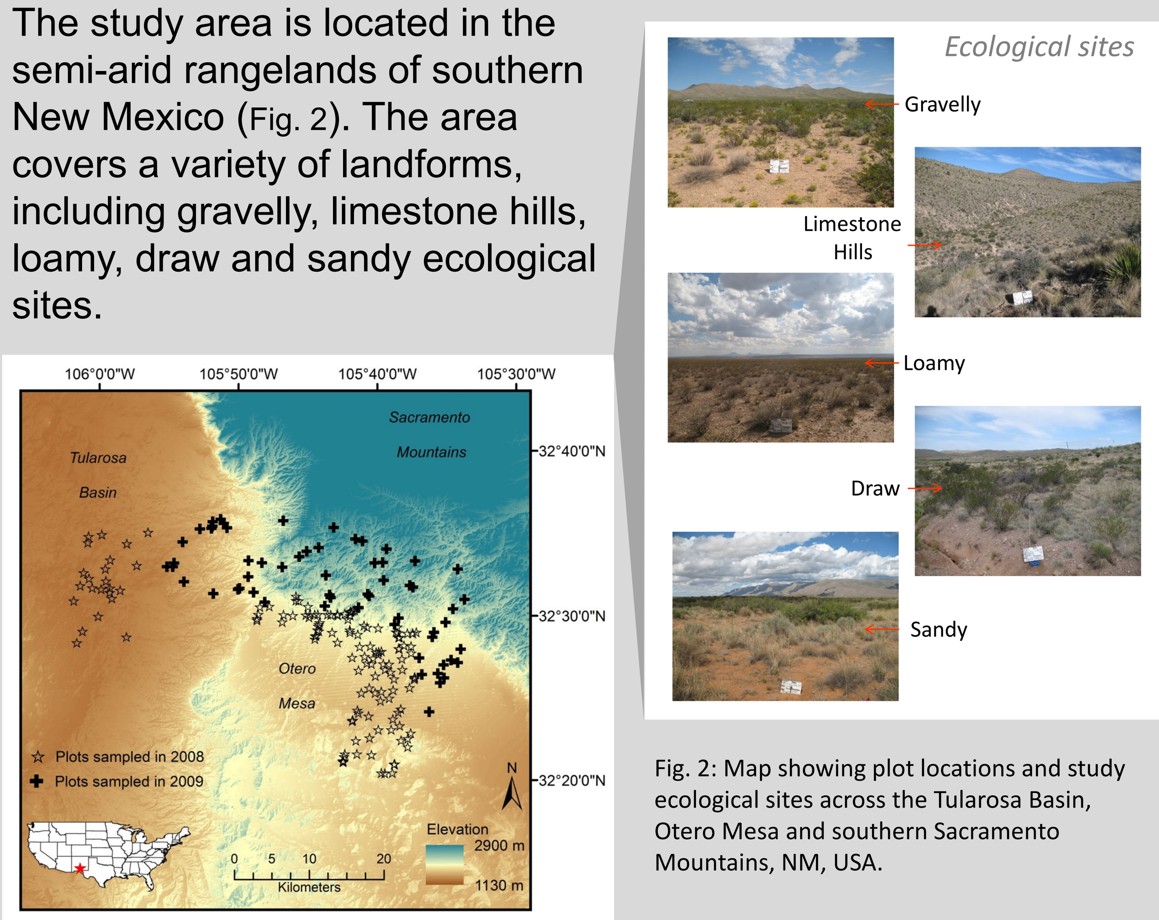

Fig. 2: Map showing plot locations and study ecological sites across the Tularosa Basin, Otero Mesa and southern Sacramento Mountains, NM, USA.

The ecological sites have six generalised vegetation states: grasslands, grass-shrub mix, grass and juniper mix, grass and succulent mix, shrub-encroached and shrub-dominated states. Transitions between these states due to management are expected to influence rates of wind and water erosion (e.g. Fig 1).

Methods

At 120 plots across the study area (Fig.2) we measured the distribution, height, and fractional cover of vegetation and soil physical properties as input to wind (WEMO[2]) and water (RHEM[3]) erosion models.

We ran the models to predict for each plot a potential horizontal aeolian sediment mass flux (g cm^{-1} day^{-1}) and soil loss (t ha^{-1}) due to water erosion. Mixed-model analysis of variance (ANOVA) was used to test for differences in simulated erosion rates among the plots stratified by ecological site, vegetation community state and the presence/absence of road disturbances.

Ecological site soil erosion

Variation in the simulated erosion rates was large among the ecological sites, reflecting patterns of vegetation cover and distribution (Fig. 3). The absence of reliable model soil erodibility estimates affected our ability to resolve true differences in erosion rates among the ecological sites.

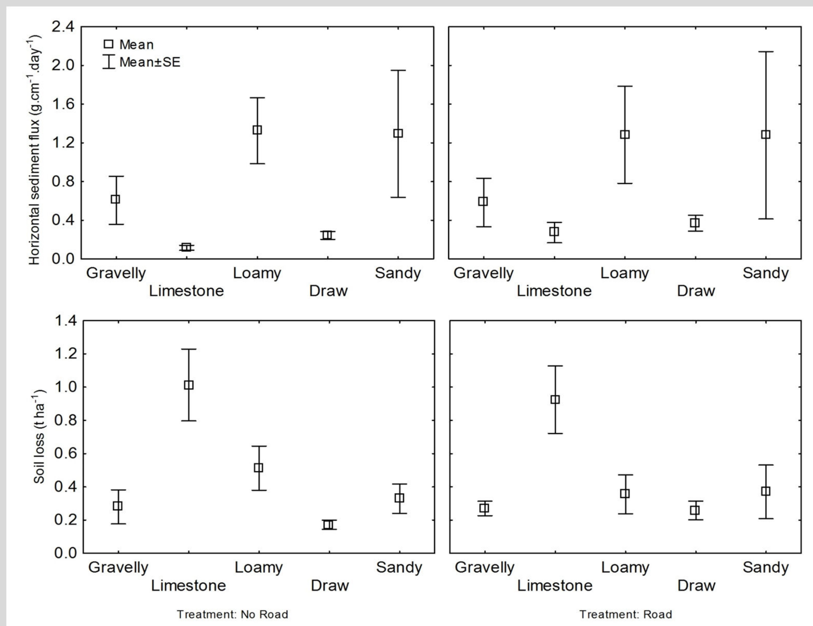

Fig. 3: Simulated wind and water erosion rates for the five ecological sites, separated for those away from and adjacent to road disturbances.

The presence of graded roads did not have a significant effect on either the simulated horizontal aeolian sediment mass flux (P = 0.60) or rates of water erosion (P = 0.68).

State changes and wind erosion

Plant community state had an overall significant effect on simulated wind and water erosion (P < 0.0001) (Fig. 4).

Sediment flux for shrub-dominated plots was significantly larger than for shrub-encroached plots (P < 0.01) and plots with a mix of grasses and shrubs (P < 0.0001) or grasses and succulents (P < 0.05).

Sediment flux for some grassland plots was also large, increasing the state mean.

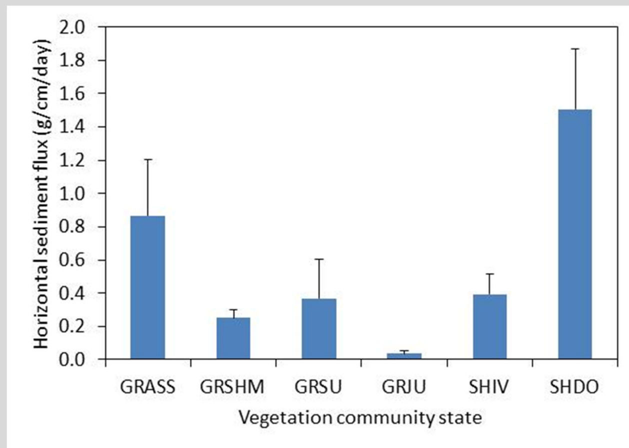

Fig. 4: Simulated wind erosion rates (mean +SE) for the six vegetation states: grassland (GRASS), grass-shrub mix (GRSHM), grass-juniper (GRJU), grass-succulent (GRSU), shrub encroached (SHEN) and shrub dominated (SHDO).

State changes and water erosion

Soil loss for plots with a grass-succulent mix was larger than that for the other vegetation states (P < 0.05).

Shrub-dominated and shrub-encroached plots had larger water erosion rates than plots with a grass-shrub mix (P < 0.05).

Grassland plots had the smallest simulated water erosion rates (Fig. 5).

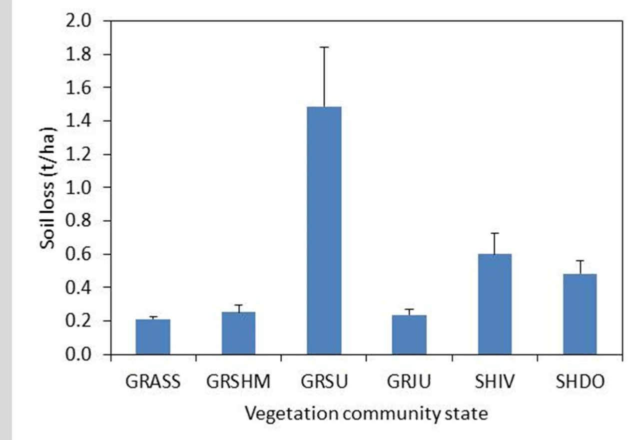

Fig. 5: Simulated water erosion rates (mean +SE) for the six vegetation states: grassland (GRASS), grass-shrub mix (GRSHM), grass-juniper (GRJU), grass-succulent (GRSU), shrub encroached (SHEN) and shrub dominated (SHDO).

Underpinning threshold responses

Wind and water erosion display threshold-type responses to changes in vegetation cover (Fig. 6) and distribution (Fig. 7) across the landscape.

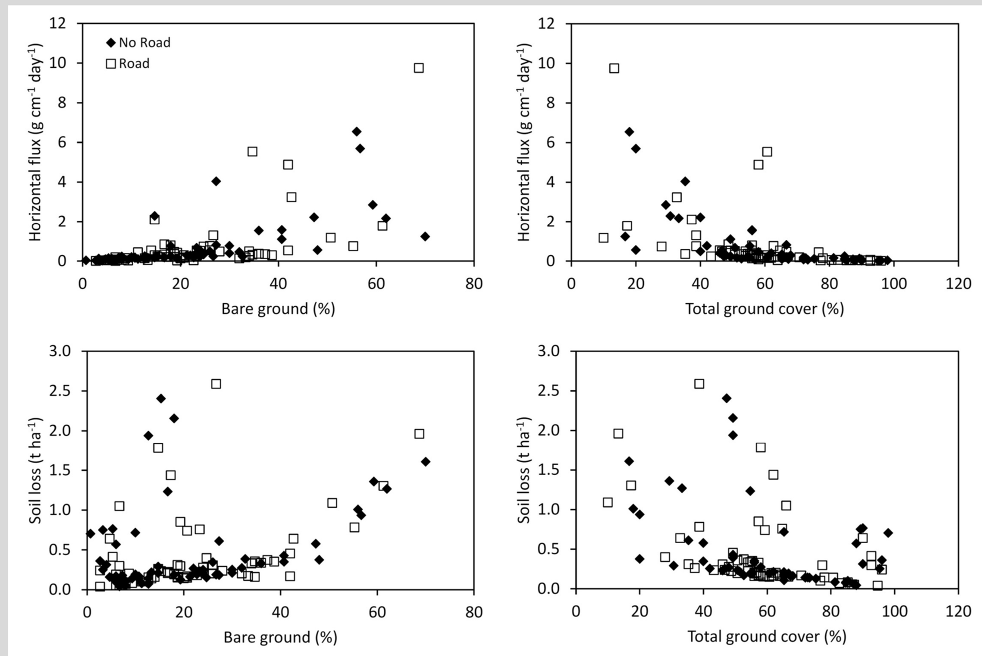

Fig. 6: The relationship between simulated horizontal sediment flux due to wind erosion, soil loss due to water erosion and the measured fractional cover of bare ground and total ground cover for the 120 study plots.

These thresholds are influenced by vegetation height and hillslope gradient, but for the most part transcend the ecological sites and their respective vegetation states.

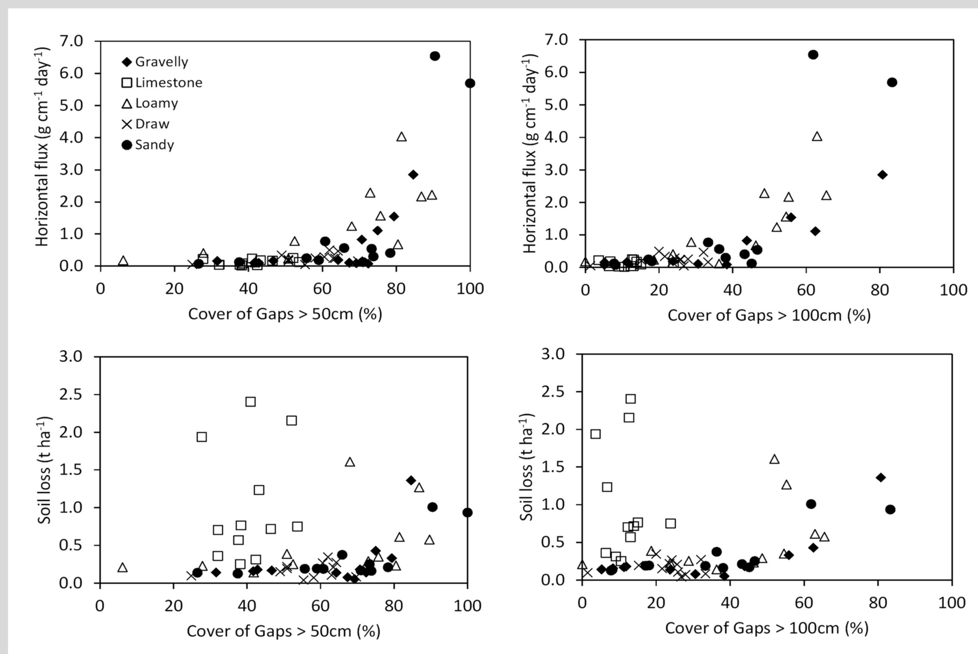

Fig. 7: The relationship between simulated horizontal sediment flux due to wind erosion, soil loss due to water erosion and the measured proportion of inter-canopy vegetation gaps for the 120 study plots.

Sensitivity to site disturbance

The impacts of soil surface disturbance for wind erosion can be large.

Sensitivity analyses can show the effects of soil surface disturbance on erosion rates. For example, through changes in the threshold friction velocity for soil entrainment by wind, u_{*t} (Fig. 8).

Small soil disturbance can result in large and nonlinear changes in soil erosion.

Representing these changes in models will be critical for applications to quantify the effects of land use and management on erosion rates.

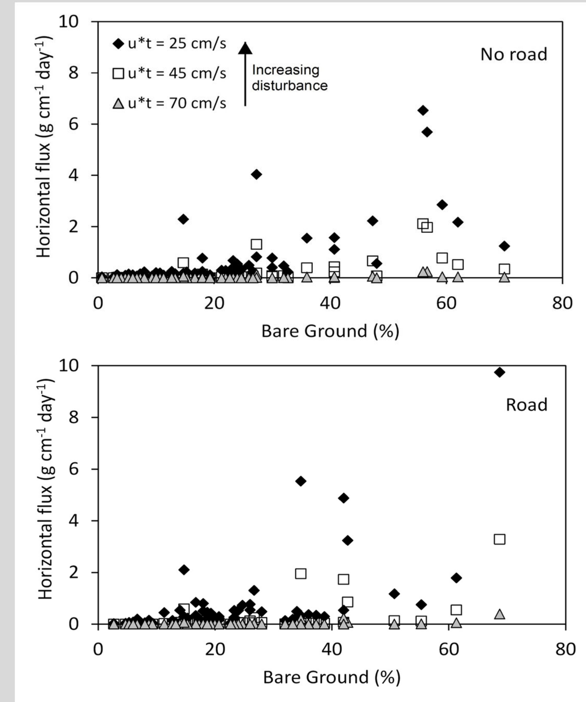

Fig. 8: Modelled effect of soil disturbance on the sediment flux due to wind erosion, represented by a change in the soil entrainment threshold (u_{*t}).

Practical management outcomes

Vegetation cover levels in rangelands naturally move above and below the vegetation thresholds that make sites susceptible to soil erosion, producing a range of potential erosion rates. Land use and management activities that alter vegetation cover and/or soil erodibility can put a landscape at risk of crossing an erosion threshold, potentially resulting in accelerated soil erosion and an ecological state change.

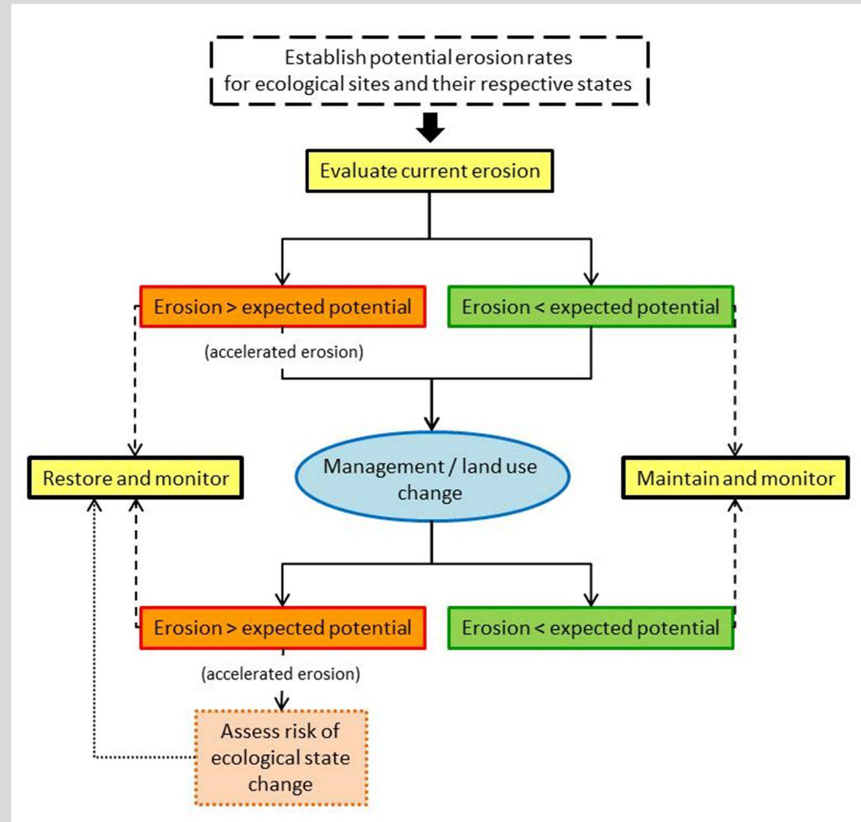

Fig. 9: Framework for structuring soil erosion assessments to evaluate the effects of land use and management changes and identifying appropriate management responses.

Applying an ecological site-based framework (Fig. 9) enables quantification of expected (potential) erosion rates. These can be used as a reference for assessing the extent to which land use and management stressors affect site conditions, relative to the vegetation thresholds, and quantification of accelerated wind and water erosion.

References:
[1] Ash et al. (1994) Tropical Grasslands. VOL. 28, 223-228
[2] Okin (2008) JGR. VOL. 113, F02S10, doi:10.1029/2007JF000758, 2008
[3] Nearing et al. (2011) Trans. ASABE. VOL. 54(3), 1-8

Authors:
[†] USDA-ARS Jornada Experimental Range, Las Cruces, NM, USA
[‡] US Geological Survey, Moab, UT, USA

We thank the Jornada field crew for assistance with data collection, D James for analysis and G Okin and M Nearing for access to WEMO and RHEM.

contact: Nicholas Webb
phone: 575-646-3584
email: nwebb@nmsu.edu
web: http://jornada.nmsu.edu

USDA · The Jornada (http://jornada.nmsu.edu, Dryland Research Programs) · USGS science for a changing world