Soil Erosion Potential

Introduction

AIM uses the soil stability of *(macro)aggregates* as an indicator of the potential of soil to erosion (soil erodibility) (J. E. Herrick et al. (2021), J. Herrick et al. (2001)). Soil aggregates are groups of soil particles which clump together to form individual strongly connected (micro)aggregates, which may then continually clump together with each other and organic matter to form larger less weakly connected (macro)aggregates (Totsche et al. (2018)). High numbers of macroaggregates at the soil surface have been shown to correlate strongly to the effects of rain, and wind, on the loss of soil from areas (Barthes & Roose (2002), J. Herrick et al. (2001)). While the relationships between soil erosion, plant cover and functional type (Cerda (1998), Greene et al. (1994), Torre-Robles et al. (2023)), landform position (Swanson et al. (1988), Torre-Robles et al. (2023)), slope shape (e.g. concave, convex) (Canton et al. (2009), Torre-Robles et al. (2023)), and the cover of biocrusts are oftentimes complex (Leys & Eldridge (1998)), the quantitative observation that soils with low macroaggregate stability have greater rates of erodibility are always evident (J. Herrick et al. (2018)).

For this report, soil aggregates refer to relatively large coherent portions of soils (> 2mm diameter) (J. E. Herrick et al. (2021)). Soil microaggregates are continually being slowly created by processes, such as the initial attraction of negatively charged clay and positively charged salts on silt particles, followed by cementation (Totsche et al. (2018)). Cementation is often achieved through organic matter and/or calcium carbonates and oxides, which then leads to biological processes. These involve the creation of numerous long organic (Carbon containing) molecules (generally polysaccharides), by organisms such as bacteria especially filamentous cyanobacteria, fungal hyphae, and plant roots, which act as 'glue' between these particles and will create macroaggregates (Six et al. (2004), Totsche et al. (2018), Moonilall (n.d.)). Soil macroaggregates in non agricultural lands are continually quickly formed, and subsequently broken back into modified microaggregates by: certain wildland fire conditions (Urbanek (2013)), rapid drying and wetting, freeze-thaw cycles, some chemical interactions with water, and compaction (Le Bissonnais (1996)). When many more soil aggregates are being broken apart than are created areas become susceptible to erosion from water, or wind (Leys & Eldridge (1998), Six et al. (2004)).

Soil erosion decreases water infiltration to soil and becomes available to plants, reduces soil nutrients available to plants and microorganisms, removes soil carbon which foster soil microorganisms, and decrease root depth and space for plants; all leading to decreases in plant diversity, abundance and production (reviewed in Pimentel & Kounang (1998)). Accordingly, soil erosion may lead to the inability of an Ecological Site to support certain plant species essential to the maintenance of the site Bestelmeyer et al. (2015). In most instances this will tend to lead a different *state* and *phase*, generally with fewer ecosystem occurrences, to occur on the site (Bestelmeyer et al. (2015)). However, in severe instances soil erosion will lead to conversion of a site into a state from which land management agencies are unlikely to be capable to restore it to an area providing even few of it's potential ecosystem services (Bestelmeyer et al. (2015)). Realistically in nearly all semi-arid lands utilized as rangelands, this equates to desertification.

Multiple other indicators collected by AIM interact to affect the implications of the Soil Stability findings, alterations in any of these metrics lead to increases in the potential of soil to erosion. Increased lengths of bareground (interspaces) between individual perennial plants - whether alive or dead (hereafter: canopy gap), and increasing patchiness of perennial plants relative to each other (e.g. are plants only densely clumped in parts of a site?), interact with decreased heights of vegetation to protect soil from wind erosion ((**cite?**) NEW MEXICO, Bradley & Mulhearn (1983), Leenders et al. (2011), Mayaud & Webb (2017), ZOBELL2022, Webb et al. (2021)). The cover of biocrusts, especially lichens, mosses, and dark cyanobacteria, work to reduce both rain and wind blown erosion (Leys & Eldridge (1998), Stovall et al. (2022),). As the shape

and slope of the terrain which a plot is located on increases from concave through linear to convex soil is more prone to erode until settling downslope at the toe of a concavity (Canton et al. (2009), Torre-Robles et al. (2023)). Finally, increasing amounts of soil surface roughness achieved via rock and litter are able to reduce wind erosion (Raupach et al. (1993)). Surface soils with higher amounts of fine sands, anecdotally the most common sand grain size in the field office, are in particuliar more prone to erosion than soils with less sand (CITE). Work to combine all of these variables into predictors into a single model which is capable of predicting soil erodibility in Western North American Semi-Arid lands is still under way (Webb et al. (2021)). However, after identifying sites not meeting benchmarks, we will use the distributions of all of these variables to identify sites we suspect may be more prone to soil erodibility.

... Current concerns regarding soil stability are to be compounded with climate change (Munson et al. (2011)), soil crusts, perhaps with the exception of 'light' cyanobacteria, are slow to regenerate. More episodic, and intense rainfalls, badddd. (Chen et al. (2018))

Soil stability will be one of the only core-indicators in this report that is treated as a *categorical* variable. The way that crews collect soil stability means that it is an ordinal categorical variable, i.e. an object with discrete categories which are ordered. Soil stability measures are on a scale of 1-6, where '1' indicates little to no stability and '6' indicates very high stability. While it is tempting to treat these values as *continuous*, it is generally inappropriate to do so. These values represent data which are *ordinal categorical variables*, and while these types of information *can* readily be, and are oftentimes, treated as continuous values they should meet a few conditions first. One condition where ordinal variables can be transformed is when the values they represent are at equal distances from each other, *e.g.* if we estimate the number of number of jelly beans in a jar from 1-10, where 1 encompasses 1-10 beans, and 2 21-30 beans etc., However, our rankings of 0-6 all show different 'distances' between them. For example:

> "Stability class 4: 10–25% of soil remains on sieve after five dipping cycles;
> Stability class 5: 25–75% of soil remains on sieve after five dipping cycles" — AIM 2021, V. 1 p. 51

As can readily be seen, from these two classes which are the most similar, breaks are of wildly different sizes (15% and 50%), and clearly violate this assumption. Another condition where ordinal values can be treated as continuous is when they represent a great range. E.g. if you had a quiz of 100 questions, and you can get each answer either 'Correct', or 'Wrong', we could turn your score into a continuous value, and combine it with other scores to get an aggregate. Lenient opinions differ on whether you should have 10+ or 5+ classes to do this (CITE). Finally, we have few replicates per site. Soil stability is measured at only 18 locations per plot, roughly only half of the recommended observations for using parametric statistics. While non-parametric statistics are often applied to numeric data, they perform very well with small samples sizes. Accordingly, we end up in relatively the same place statistically by treating these values as ordinal categorical variables.

Methods

The first step in assessing whether the field office was achieving benchmark conditions regarding soil stability was to impute the measurements for these values at Ecological Sites which were lacking Descriptions, or which had incomplete descriptions. Similar to section (X.X), these values were imputed by *feature engineering*, however since they were ordinal categorical variables the *median* of the values were used.

A relatively high amount of Ecological Sites Descriptions (33 of 52, 63.5%) contained soil stability reference benchmarks under two conditions as well as a site 'average':

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1) Interspaces (the distance between plant canopies)
2) Under Canopy (space beneath plant cover)
3) Site 'average' (hereafter: median)
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A hand-full of sites (n = 7) contained values for both under canopies and interspaces, but lacked a site wide median; a dozen sites had only one value (n = 9 'site', and n = 3 'interspaces'). To calculate these estimates for ESD's which were missing them, the median for each category was gathered using each observation (Figure 1, Table 1). The missing values were then imputed in each ESD which was missing a value, as well as for each ES which was missing all values.

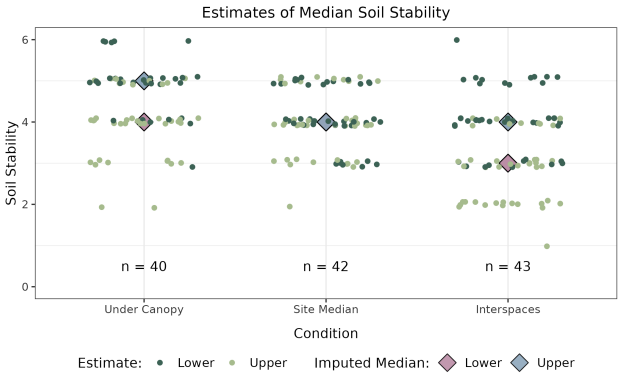

Figure 1: Specified benchmarks at all ESDs which included all three metrics and derived imputed value

The original AIM soil stability data were imported from *DB*, and the median of Soil stability for each plot, under both of the conditions, and a site average, were calculated. These values then underwent categorical analysis using *cat_analysis*, in the 'spsurvey' package, with confidence interval of 0.8, (Dumelle et al. (2022)), and the 'local' (default) variance estimator.

Subsequent to generating the categorical outcomes from sp, confidence estimates were calculated using *'binconf'*, in the Hmisc package, with an $\alpha = 0.2$, confidence interval of 0.8, (Harrell Jr (2022)).

Results

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