Soil Erosion Potential

AIM uses the stability of *(macro)aggregates* as an indicator of the potential for soil to erode (soil erodibility; Section VII) (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 reduce 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 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 more susceptible to erosion from water, or wind (Leys & Eldridge (1998), Six et al. (2004)).

Soil erosion decreases water infiltration into the soil and less water is 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 to a different or altered *state* and *phase*, generally with lower ecosystem diversity, 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 of restoring basic ecosystem services absent extensive and costly inputs (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 for soil to erode. 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 (Bradley & Mulhearn (1983), Leenders et al. (2011), Mayaud & Webb (2017), Zobell et al. (2020), Webb et al. (2021)). The cover of biocrusts, especially lichens, mosses, and dark cyanobacteria, work to reduce both water and wind 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, are particularly more prone to erosion than soils with less sand or more coarse sands. **(NRCS Soil surveys San Miguel, Paonia & Ridgway)**. 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)). 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 are expected to increase soil erosion (Chen et al. (2018)).

Soil stability will be the only core-indicator 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. 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. 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. 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': 1) Interspaces (the distance between plant canopies), 2) Under Canopy (areas beneath plant cover), 3) Site 'average' (hereafter: median).

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). 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.

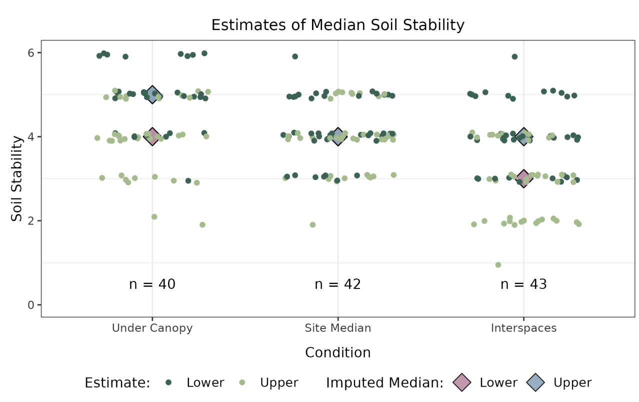

Figure 1: Specified benchmarks at all ESDs which included all three metrics and derived imputed value

The original AIM soil stability data were pulled from TerrAdat and imported to R. The median of Soil stability for each plot, under both of the conditions, and a site average, were calculated (Figure 1). 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.

Results & Discussion

Of the 258 sites analyzed 95 were meeting the benchmark for median soil stability across the entire plot, a similar number of plots were meeting the lower benchmarks for canopy (85) and inter-spaces (98). Accordingly, hereafter for the sake of simplicity we only discuss the overall plot conditions, rather than all three benchmarks because it alone appears to capture this variation. Across the general UFO 39.9% (LCL 36.2, UCL 43.7) of land was meeting this benchmark condition, the estimates of uncertainty around the total area of the field office which were meeting these objectives were relatively narrow, and showed that roughly only half of the land in the field office was within reference condition for soil stability, and much of the area is more susceptible to erosion. Of the remaining three management areas none were meeting the objectives for the percent of land in acceptable condition. The Gunnison Gorge National Conservation Area had the highest estimate of stability, 54% (LCL 39, UCL 69.1), the breadth of the confidence intervals is due partially to the relatively small sample size (n plots = 18), and the true value likely falling much closer to the estimate, which more closely agrees with the estimates for BLM land overall. Relative to the other ares Dominguez Escalente National Conservation Area had much lower estimates of lands achieving soil stability benchmarks, 14.7% (LCL 7.6, UCL 21.8), with a sample size of 33 plots, hence these low values are not an artifact of sampling. While the Areas of Critical Environmental Concern-Wilderness Study Areas had a relatively small sample size (n plots = 12), their values, 20% (LCL 7.4, UCL 32.6), are congruent with the values for the remainder of BLM Land (Figure 2).

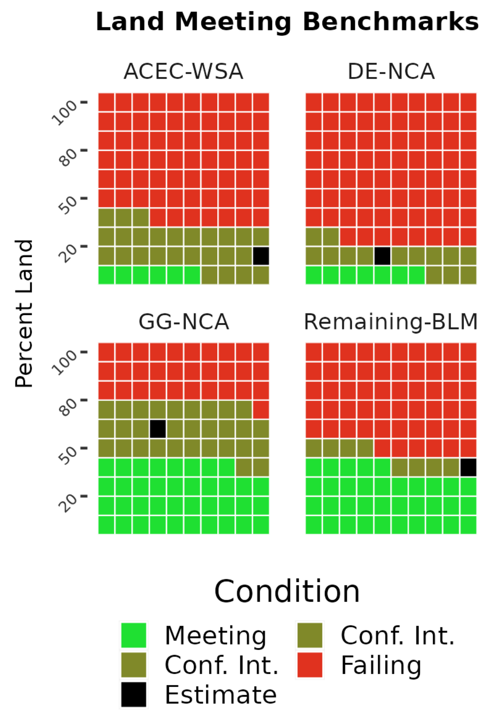

Figure 2: Percent land meeting reference benchmark conditions

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