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A multi-dimensional pasture condition index (PCI): Integrating bioclimatic and functional vegetation signatures to assess rangeland health

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Abstract

Rangeland monitoring programmes in Central Asia face a critical challenge: distinguishing climate-driven variability in vegetation changes from grazing impact. Standard assessments, mainly based on Soviet legacy frameworks, often attribute poor rangeland condition to overgrazing without accounting for rainfall variability, leading to misguided management interventions.

We developed a Pasture Condition Index (PCI) from field-measured fractional cover indicators (n = 439) in the Nurota District of Uzbekistan and modelled its variability using Random Forest (RF) models with Principal Component Analysis (PCA) PC1 loadings (e.g. precipitation, soil moisture) across both mapping-compatible (compact) and full predictor sets to identify the drivers. The RF-compact drivers consist of bioclimatic (Short-Wave Infrared bands (SWIR), land surface temperature (LST), precipitation) and topographic (elevation, slope) variables. The RF-full set includes field-measured grazing proxies, dung deposits, hoof marks, and distance to camps in addition to the compact set. Model robustness was assessed using spatial cross-validation (CV) to evaluate the transferability beyond sampled conditions.

The PCI captured a wide gradient of rangeland conditions with a modelled range from 0 to 1 (25^{th} percentile = 0.30, 75^{th} percentile = 0.67, mean = 0.49), indicating its performance across study site. Robustness testing revealed a significant transferability gap, with model performance (full model $R^2 = 0.95$) dropping by 61 % under spatial validation (CV $R^2 = 0.58$), indicating limited generalisability of learned relationships beyond sampled conditions. The dominant signal of pasture condition was explained by Remote sensing-derived bioclimatic factors (soil moisture, precipitation, LST) in the RF-compact set, while grazing proxies (especially hoof marks) gained high importance in the RF-full set, indicating localised effects are difficult to map continuously and thus limiting their suitability for regional monitoring.

Our machine learning modelling efficiently mirrors the PCI, based on field-derived vegetation data and indicates that pasture condition in Nurota's semi-arid landscape is primarily constrained by moisture availability, with physical signs of grazing becoming difficult

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to detect by remote sensing. As a result, apparent PCI patterns reflect climatic variability rather than grazing impact or management failure alone, necessitating the need of further development of the PCI as a robust and replicable single indicator for assessing the rangeland health.

Keywords: Bioclimatic variables, grazing proxies, pasture health, Uzbekistan, vegetation