



Fusion of pixel & object-based image analysis to improve stratification of soil carbon projects in the semi-arid rangelands, Australia

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Abstract

Soils in the semi-arid rangelands of southeastern Australia are inherently low in organic carbon (SOC) content due to a combination of climatic and historic land degradation factors. Small increases in SOC attributable to improved management in such expansive landscapes offers an opportunity to restore rangeland function and play an important role in mitigating climate change.

Soil Organic Carbon stocks and fluxes are influenced by complex interactions between plant growth, climate, soil type, topography and land management resulting in high spatial and temporal variability. Variability creates a challenge for designing soil sampling strategies to detect small, incremental changes in SOC. In the rangelands, this challenge is accentuated by low SOC stocks, low SOC sequestration rates, presence of soil inorganic carbon and cost of labour-intensive soil sampling programs across large pastoral properties. Optimal stratification by clustering homogenous areas within a paddock, combined with adequate sampling density can reduce variance and improve SOC stock estimations.

Remotely sensed earth observation data can be used to determine stratification in soil carbon projects. This paper presents a basic stratification framework that integrates multiple sources of high-resolution landscape data. The study area is a dryland crop and grazing property located in the semi-arid rangelands of New South Wales (NSW). The method fuses a temporal ground cover raster classified by pixel-based analysis, with a segmented image processed by object-based image analysis. The success of the stratification can be judged by a moderately small variance in mean SOC within each carbon estimation area (CEA) and for the total project area. A validation baseline survey is planned for February 2025.

Introduction

Rangelands play an essential role in sequestering carbon to offset greenhouse gas emissions in Australia. Semi-arid soils contain naturally low levels of soil organic carbon (SOC) (Orgill et al. 2017). Small increases in SOC which may occur over time with improved management of rangeland systems offer the opportunity to sequester a significant amount of carbon over an extensive area (Orgill et al. 2017). However, detecting the differences due to management are problematic to measure and rely on high quality soil sampling stratification (Beverly et al. 2024). Soil sampling stratification can improve SOC estimation efficiency and

accuracy to detect and monitor temporal changes (Potash et al, 2023). Current attention is focused on understanding and measuring influences of management practices and climate fluctuations on SOC (Bastin et al.2024, Orgill et al. 2017). Effective stratification is vital to capture small changes in SOC over large project areas, allowing the opportunity for carbon sequestration in rangelands to be quantified. A strategic low-cost baseline stratification of rangeland soils will be a critical first step towards accurate SOC reporting and monitoring change over time.

This paper focuses on the application of remotely sensed high-resolution temporal ground cover and soil colour imagery to enhance stratification design in soil carbon projects. Soil colour is a potentially useful attribute to stratify for SOC because the soil organic matter of which the carbon is part is a primary determinant of soil colour (ref: Leeper & Uren, 1993?). The approach fuses a temporal ground cover raster classified by pixel-based analysis (unsupervised classification), with a segmented image processed by object-based image analysis (OBIA) using dry soil colour reflectance.

Pixel-based analysis is processed on a per pixel level, using only the spectral information available for that individual pixel, values of neighboring pixels are ignored. A common example of pixel-based analysis is unsupervised classification which groups pixels based on statistical similar class means without training data. This unbiased technique can reveal hidden patterns in the landscape not clearly visible in the imagery. By comparison, OBIA groups pixels together based on how similar they are in colour and shape to adjacent pixels using both spectral and spatial information for classification. Image segmentation tends to generate objects that resemble real-world landscape features. The aim of this paper is to combine the benefits of pixel-based classified ground cover with object-based segmented soil colour in comparing landscape features to enhance the stratification process.

Methods

Temporal Ground Cover

The study area is a dryland crop and grazing property located in the semi-arid rangelands, NSW. Seasonal fractional cover Sentinel-2 (10 m resolution) created by the Joint Remote Sensing Research Program & Department of Environment and Science, was sourced to provide insight into ground cover spatial variability over time. The product is based on the JRSRP Fractional cover V3.0 algorithm applied to Sentinel-2 Level 1C data from the ESA (Joint Remote Sensing Research Program, 2023). A multilayer perceptron model was used to estimate percentage of cover in three fractions, bare ground, photosynthetic vegetation, and non-photosynthetic vegetation from surface reflectance (Joint Remote Sensing Research Program, 2023).

The bare fraction from the Seasonal fractional cover product (capture date: December 2018 to February 2019) was classified for each carbon estimation area (CEA) using the ISODATA unsupervised classification task in ENVI. Results were cleaned for isolated pixels. Zonal statistics were generated for each class within each CEA. Classes were then merged if means had less than 5% separation. Polygons <2ha in size were aggregated into larger adjacent polygons of a similar soil colour and ground cover type.

Dry soil colour segmentation

A Sentinel-2 (10 m resolution) true colour image (RGB) captured during a low rainfall period (capture date: 22nd December 2018) was segmented in ArcGIS Pro, using visible bands only (bands 2, 3 and 4). Spectral detail function (The level of importance given to the spectral differences of features in the imagery) was set high on 20 units, spatial detail (The level of importance given to the proximity between features in the imagery) was set at 6 units (minimum segment size in pixels 50). Providing a high-level representative segmentation of soil colour across the study area (Figure 1). The segmented raster output is converted to a

vector format, then cleaned and simplified by merging small polygons, then clipped to the study area. Classes were labelled based on soil colour and CEA.

Fusion

The goal is to combine two significant variables that can assistance with visualising SOC spatial variability. Soil colour is the base of the stratification for each CEA. Ground cover polygons will be nested within the soil colour polygons. A union between the two layers was completed for each CEA in ArcGIS Pro. The vector outputs are cleaned by aggregating small, fragmented polygons (<0.5 ha) and slivers. The area of strata within each CEA is reviewed. Small strata will be merged into adjacent larger strata of similar soil colour and ground cover (based on strata means of bare% ground cover).

Results

Stratification based on temporal ground cover resulted 4-5 classes per CEA (Figure 1). Dry soil colour segmentation generated a 4-5 classes per CEA (Figure 2). Combining the two stratification data sets generated 8-10 strata per CEA (Figure 3).

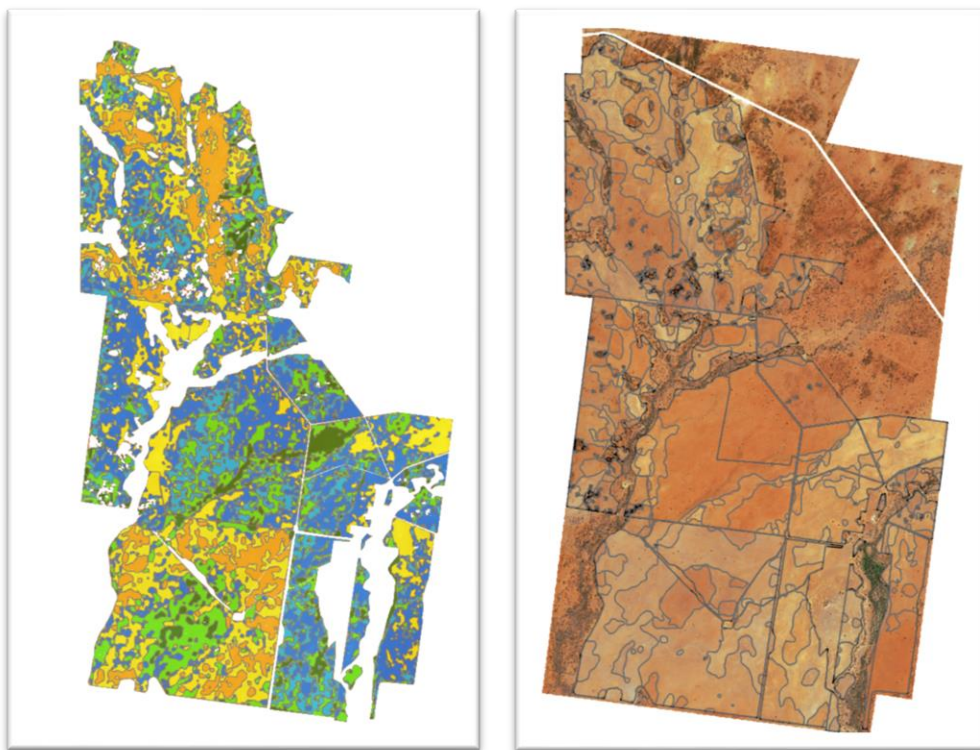


Figure 1. Temporal ground cover classification. Figure 2: Dry soil colour segmentation results.

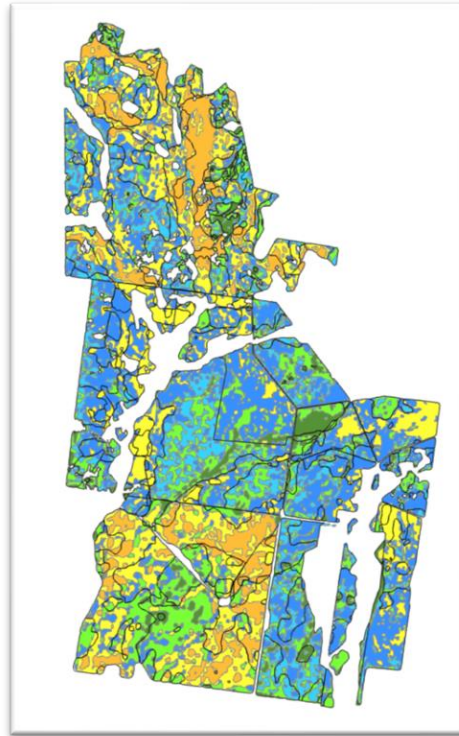


Figure 3. Stratification of ground cover and soil colour.

Discussion

The quantity of SOC in soils is influenced by a combination of factors, predominantly climate, soil type and recent vegetation cover management, plus other factors including topographic position (Grey 2021). The amount of ground cover can also be influenced by soil characteristics (informed by soil colour), management, and differences in topographic position/aspect. Merging ground cover with soil colour increased the number of strata in each CEA.

The patterns of temporal ground cover classification align with the soil colour segmentation outlines (Figures 1 2, & 3). There are similar patterns of stratification when comparing the two layers side-by-side and when both are overlaid (Figure 3). For example, note the center of the bottom southwest paddock, there is a dark red island surrounded by lighter red soil, delineated in both datasets (Figure 3). Similar patterns can be expected due to the interrelationships of soil properties and groundcover. However, there are also differences between the two datasets, that could be related to management practices impacting ground cover within the composite fractional cover timeframe (capture date: December 2018 to February 2019). A validation baseline survey, planned for February 2025, will collect SOC data from each CEA. The success of the stratification will be quantified by comparing the variance in mean SOC within each CEA and for the total project area with that of each individual stratification approach.

While this desktop approach offers a relatively quick and data-driven approach to stratification, it is important to couple it with consideration of on-ground management factors that may influence the results. For example, in drier areas of cropping zones it can be common to incorporate a fallow into a cropping rotation to preserve moisture for a following crop, therefore this may reduce ground cover in those areas. Similarly, the presence of high numbers of feral herbivores (e.g. goats) may result in patch overgrazing of

specific areas of the landscape resulting in periodic reduction in ground cover that may not necessarily be indicative of soil production or carbon storage potential.

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