Final report

Rangelands Living Skin

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Prepared by: S.E McDonald, K Andersson, A Simmons, L Beange
NSW Department of Primary Industries and Regional Development

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Meat & Livestock Australia Limited
PO Box 1961
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Abstract

To make informed decisions regarding adoption of management practices that improve landscape health, producers and land managers need evidence of the impact of management strategies and practices on soil, productivity, profitability and other environmental factors.

Rangelands Living Skin was a five-year project linking farming families, scientists, education and extension agencies, commercial carbon companies and communications experts to evaluate cost-effective practices that focused on regenerating the NSW rangelands and supporting productive, profitable and sustainable businesses. The project aimed to create an evidence-base and build capacity for widespread adoption of practices that benefit soil, plants, animals and people – the living skin of the rangelands.

A collaborative, co-design approach was employed to demonstrate the environmental, productivity and profitability impacts of a number of management interventions, including grazing management, water ponding, ripping and gypsum. The project hosted numerous extension and capacity building activities including field days, workshops, webinars, case studies and other media on a wide variety of topics related to the project theme and provided opportunities for collaboration and knowledge exchange between rangeland producers, researchers and industry stakeholders. Challenges and implications of measuring and accounting for carbon and natural capital in rangeland grazing systems were identified. Importantly, the project demonstrated the potential to remain a profitable livestock business whilst managing with an aim to regenerate the landscape.

Executive summary

Background

The rangelands of NSW consist primarily of privately managed grazing enterprises on rainfall dependent native grass and shrublands. Agricultural commodities produced in the region contribute over $673M/yr to the economy (ABS, 2021). However, historic overgrazing, uncontrolled total grazing pressure (TGP) and drought have collectively led to widespread soil degradation, erosion, loss of perennial grasses and increasingly poor landscape function (poor nutrient cycling, water infiltration). These drivers reduce community, business and landscape resilience. As a result, producers are looking for cost effective solutions to regenerate their resource base so they can remain viable into the future. To make informed decisions regarding adoption of management practices that address these issues and improve landscape health, producers and land managers need evidence of the impact of management strategies and practices on soil, productivity, profitability and other environmental factors.

Rangelands Living Skin was a five-year project linking farming families, scientists, education and extension agencies, commercial carbon companies and communications experts to evaluate cost-effective practices that focused on regenerating the NSW rangelands and supporting productive, profitable and sustainable businesses. The project aimed to create an evidence-base and build capacity for widespread adoption of practices that benefit soil, plants, animals and people – the living skin of the rangelands.

Objectives

The project was centred around four primary objectives:

1. Demonstrate, implement and measure a range of practices for rangelands production systems to increase productivity, and business and environmental sustainability.
2. Upscale for further data capture, validation and enable wider practice change.
3. Create wider awareness of a range of practices and support building of a larger rangelands stakeholder network, including advisors for ongoing implementation.
4. Validate and develop a framework for assessing and demonstrating improvements in ground cover and soil condition

Methodology

The RLS project was co-designed, with project objectives, activities, deliverables, methods and data collection developed in consultation with 12 project partners. At the centre of the project was the involvement of four 'core' producers who collaborated to identify, implement and monitor practices they decided would be beneficial to achieving the goals they set for their property. Other project partners included Resource Consulting Services (RCS), Western Local Land Services, Australian National University (ANU), CarbonLink, Select Carbon, Soils for Life and Meat and Livestock Australia. The project engaged producers from an additional 26 livestock production businesses in western NSW to build their capacity and support their decision-making regarding adoption of practice change on up to 1M ha of grazing land in western NSW. These producers were involved through data collection and monitoring across their own properties, training, online discussions with subject matter experts and field days. Reflecting the collaborative project design, over 60 researchers, producers, commercial providers, extension and education specialists contributed directly to the delivery of project outcomes.

Large-scale trials were established to investigate effects of management interventions including water ponding, deep ripping, intensive short-duration animal impact, gypsum, soil biological stimulants, hard-seeded annual legumes and mixed-species cropping. Additional monitoring investigated the effects of planned grazing management on ground cover, soil carbon dynamics and relationships in rangeland grazing systems, soil chemistry constraints in NSW rangelands, ground cover trends across NSW rangeland grazing systems, and greenhouse gas emissions from rangeland livestock enterprises.

Over the life of the project, numerous in person and online workshops, field days, webinars and communication resources were delivered to build producer awareness, knowledge and skills. These covered a broad range of topics relevant to the project theme, including soil carbon, soil biology, soil monitoring, ground cover, grazing management and natural capital.

Results/key findings

- Results of the demonstration trials of scald reclamation interventions including ripping, high intensity animal impact, water ponding and gypsum found beneficial soil and vegetation outcomes from all practices. At a property scale, planned grazing management (adapting stocking rates to carrying capacity, and strategically grazing and resting land) was demonstrated to significantly increase ground cover (by 2-7%) in NSW rangelands over the long term (>10 years), although results depended on location. Small scale trials on the use of foliar and solid biological stimulant products across four properties did not show benefit in pasture productivity and quality or soil biology.
- Assessment of soil organic carbon levels across 14 x 100ha areas showed soil carbon levels were generally low, there was little correlation with pasture variables at paddock scale, and there was considerable spatial variability across paddocks, even at short distances.
- Methane emissions from livestock were the dominant form of greenhouse gas emissions in rangeland grazing businesses. Average emissions (over five years, 2018-2023) across the four properties monitored ranged from 260 – 2233 t CO_2-e per annum, with the number of livestock carried the primary driver of this difference.
- Financial benchmarking of the four core producer properties demonstrated it is possible to remain a profitable livestock business whilst simultaneously managing for environmental outcomes in NSW rangeland grazing systems. The four core properties participating in the Rangelands Living Skin project were profitable and competitive with top Australian producers involved in the RCS ProfitProbe benchmarking program, whilst adopting and adapting management practices to regenerate their landscapes.
- Emerging environmental markets present a significant opportunity to NSW rangeland grazing businesses, however several barriers currently limit access and adoption of these markets to rangeland producers. These barriers include both off-farm challenges related to the complexity and immaturity of markets, and on-farm challenges related to cost and difficulty in measuring and reporting natural capital in extensive rangeland grazing businesses
- Overall, the project demonstrated the value of producer centric, collaborative research for achieving industry relevant outcomes and maximising engagement.

Benefits to industry

Key benefits to industry of the project results include:

- Enhanced awareness and capacity building related to management and monitoring of soil, pastures, biodiversity, landscape function, productivity and profitability in rangeland grazing systems
- Improved collaboration and knowledge exchange between producers, researchers and industry stakeholders in the NSW rangelands
- Scientific evidence demonstrating the efficacy of management practices and enhanced understanding of relationships between carbon and environmental variables in data-poor rangeland areas
- Demonstration of environmental, productivity and profitability outcomes of management practices in NSW rangeland grazing systems

Future research and recommendations

The project team has decided on the follow three research priorities to focus future efforts and work towards achieving their vision.

1. Understanding how to manage for carbon positive rangeland grazing businesses, and how to measure improvements in soil carbon and carbon cycling in rangeland environments
2. Understanding and promoting benefits and risks of rangeland management approaches to achieve positive environmental, productivity and business outcomes
3. Supporting access to emerging environmental markets, including addressing key barriers and providing information to support producer decision making

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1 Background

The rangelands of NSW consist primarily of privately managed grazing enterprises on rainfall dependent native grass and shrublands. Agricultural commodities produced in the region contribute over $673M/yr to the economy (ABS, 2021). However, historic overgrazing, uncontrolled total grazing pressure (TGP) and drought have collectively led to widespread soil degradation, erosion, loss of perennial grasses and increasingly poor landscape function (poor nutrient cycling, water infiltration). These drivers reduce community, business and landscape resilience, and as result, producers are looking for cost effective solutions to regenerate their resource base so they can remain viable into the future. Continued productivity, profitability and sustainability of low input and extensive grazing systems in the rangelands relies on strategic management of natural resources. To make informed decisions regarding adoption of management practices that address these issues and improve landscape health, producers and land managers need evidence of the impact of management strategies and practices on soil, productivity, profitability and other environmental factors.

The Rangelands Living Skin Project was co-designed over two years in collaboration with producers, researchers, education and extension specialists and carbon aggregators to focus on soil, plants, animals and people as the living skin of the rangelands and address this need. The project aimed to measure environmental, productivity and profitability impacts of a variety of interventions or practices, alongside planned grazing management, on four rangelands production systems. The project also aimed to improve the capacity of producers in western NSW to trial and adopt new practices that improve productivity, profitability and environmental outcomes by creating an evidence base for management practices and providing information and training on soil health, carbon cycling and accounting, land condition, ground cover and grazing management. This would enable producers to be prepared and resilient in a future of increased climate variability and consumer demands and provide opportunity across new markets.

2 Objectives

Objective 1: Demonstrate, implement and measure a range of practices for rangelands production systems to increase productivity, and business and environmental sustainability.

- Four core rangeland properties will be engaged to implement a variety of practices or interventions to quantify the impact towards improving production and ecosystem services. These may include:
    - Grazing management (e.g. through the Maia grazing program)
    - Total grazing pressure fencing
    - Water ponding and spreading via banks (including check-banks)
    - Mixed species plantings
    - Introduction of perennial and hard seeded annual legumes
    - Intensive, strip application of organic composts and biological inoculants (in comparison with 'nil' controls and synthetic fertilisers)
    - Various combinations of these interventions and others suggested by the producers, scientists and advisory group throughout the project

- Using agreed scientific methodology, sample collection and testing protocols, measure and report on:
  - Baseline pasture/vegetation and landscape condition, soil health (including carbon), species makeup, sward health, and livestock and business performance
  - Progressive changes in these metrics
- Measurement will be further defined as part of the detailed project plan and methods, though will be captured through a variety of methods including:
  - Remotely sensed high resolution imagery
  - In-field assessment of soil and pasture
  - Business performance and benchmarking through ProfitProbe™
  - Soil carbon measurement as per the ERF methodology up to 1m
  - Wind erosion and ground cover modelling
  - Changes in skills, knowledge and confidence of participating producers (who have established sites)
  - Wider M&E including field day participation and interventions to changes (awareness activities)

How was this objective met?

The Rangelands Living Skin project investigated the impacts of grazing management, biological stimulants, water ponding, gypsum, deep ripping, intensive animal impact, mixed species plantings and annual legumes across four core rangeland properties (and an additional three properties for soil carbon and grazing management). Across each of these trials, detailed collection of baseline and post-treatment implementation was undertaken, results of which are reported on in this report. Both on-ground and remote sensing data collection approaches were utilised. Business profitability for each property was recorded by reporting on business performance and benchmarking with ProfitProbe™. Soil organic carbon was assessed in 14 areas of approximately 100 ha across seven properties in three subregions using a spectroscopic modelling approach. Natural capital indicators were also assessed across each of these areas. Carbon accounts were generated for the past five years for each of the properties, giving an insight to the emissions profile of rangeland grazing enterprises.

Objective 2: Upscale for further data capture, validation and enable wider practice change

- In year two, train and support at least a further 20 producers to implement and measure a range of practices to increase production and environmental sustainability, over the life of the project
- These interventions will provide further data and validate the range of practices demonstrated
- Producers will be provided an opportunity to network and share learning throughout the project
- Core producers will meet monthly with RCS to discuss their grazing management plan and feed budget

How was this objective met?

Twenty-six rangeland grazing properties signed on to be ‘observers’ in the Rangelands Living Skin project, attending project field days, workshops, webinars, and receiving property-specific maps and reports of ground cover over the last 24 years. Observers also received training in soil and landscape monitoring, including monitoring kits and the opportunity for comprehensive monitoring of soil condition and chemistry. Producers had the opportunity to learn from topic experts and other producers attending events, as well as through the project email list, WhatsApp and Facebook groups. Core producers accessed monthly one-on-one coaching with an advisor from Resource Consulting Services (RCS), discussing their grazing management, business goals and performance. A pre and post-project survey of producers knowledge highlighted a considerable improvement in key areas such as: 1) the benefits of increasing ground cover and soil carbon for productivity and ecosystem services, with a 20-30% increase in participants with sound or very sound knowledge on these topics; 2) knowledge to weigh up the advantages and disadvantages of carbon farming, with an increase of almost 40% compared to the initial project survey results; 3) improvement in knowledge on all topics of feedbase and groundcover. Almost all producers indicated positive outcomes associated with their involvement in the Rangelands Living Skin project and had made changes to their management as a result of their involvement in the project.

Objective 3: Create wider awareness of a range of practices and support building of a larger rangelands stakeholder network, including advisors for ongoing implementation

- Deliver a series of field days and training activities to showcase a range of practices to drive further participation and /or producer training
- Develop four regional producers to promote the innovation and learnings identified within the project at external field days, case studies, media articles, producer forums.
- Four case studies detailing farm business profitability and environmental outcomes
- Provide a fact sheet on how producers can access and interpret remote sensed cover maps to identify and act on changes in cover.
- Provide content arising from the project results for incorporation into training and extension material
- Develop an ongoing strategy to facilitate producer engagement and adoption activities beyond the life of this project that identifies mechanisms and funding avenues to build capacity and improve production and sustainability
- Produce three project related articles in recognised agricultural publications (e.g. technical notes, case studies, newsletters, and local media) per annum, and a published scientific paper submitted before completion of the final project milestone
- Engagement of a specialist media adviser (via Soils for Life) for the project and hubs for media promotion
- Develop a working group from within the project stakeholders to establish a ten year plan, including a strategy to improve industry participation between rangelands producers, research, industry and NRM bodies
- Develop a final report outlining the outcomes of the program and recommendations for future initiatives for rangelands producers

How was this objective met?

Multiple extension events were delivered each year to communicate project findings, build knowledge and capacity of producers in NSW rangelands to adopt practice change, and develop a network of like-minded producers. This included 6 x project field days, 8 x RCS 'Keep In Touch' field days, 6 x workshops on ground cover, soil biology, soil carbon, carbon accounting, natural capital and soil monitoring, and 8 x webinars on natural capital, wind erosion, biodiversity, soil biology, climate patterns, grazing management, remote sensing and greenhouse gas emissions. Core producers promoted their results and involvement through both project field days, workshops and at external events (e.g., conferences & forums). Four digital case studies were developed through Soils For Life, detailing the management principles and practices employed by the core producers, and findings and observations collected through the Rangelands Living Skin project. Further promotion of project activities and findings was achieved via publications in newsletters, establishment of dedicated social medial channels (Facebook and WhatsApp), YouTube videos, project websites (via MLA and Soils For Life) and scientific publications. Additional resources generated through the Rangelands Living Skin project included the publication of a fact sheet on use of remote sensing for ground cover management in rangelands, and two case studies (Etiwanda and Wyndham) on rangeland carbon accounts (via Select Carbon). Project partners also collaborated to develop a future 10 year plan to increase producer and industry participation in research, extension and development activities to achieve a common vision.

Objective 4: Validate and develop a framework for assessing and demonstrating improvements in ground cover and soil condition

- Use data collected from the producer sites to identify the farm business risks of soil degradation and benefits of investing in improved soil and pasture condition
- A framework for assessing and reporting soil natural capital and environmental benefits co-designed with industry (producers, MLA, RCS, Heart and Soil Consulting and CarbonLink) and compatible with farm business software (e.g. ProfitProbe™)

How was this objective met?

Since the project establishment, there has been considerable advancement in the development of natural capital accounting frameworks and methodologies in Australia. To avoid duplication of existing frameworks and provide a clearer way forward for natural capital accounting in rangeland grazing systems, existing frameworks were reviewed against rangeland requirements and barriers and research recommendations were identified. Multiple consultation activities with natural capital experts, technical experts, producers and other industry stakeholders were undertaken to design a natural capital framework applicable to rangeland grazing systems and identify key requirements, barriers and recommendations for implementation of natural capital accounting in rangeland grazing systems. This included a review of existing frameworks and how these apply to rangeland grazing systems and potential changes required to make these more applicable and increase access and adoption to these emerging markets. This project has also generated significant data and information useful to natural capital accounting in the rangelands.

3 Methodology

3.1 Co-design approach

3.1.1 Approach

This project was co-designed, with project objectives, activities, deliverables, methods and MER collection developed in consultation with all project partners. Producers collaborated with the project team, coaches and other experts (as required) to identify interventions, practice change and goals for their properties that would be instigated and monitored through this project. Methods to monitor and evaluate the success of interventions and practices were developed to ensure attributes of interest to producers were measured and reported on. Where possible, producers were involved in the establishment of trials, collection of data and photo points following trial installation, and in communication of trial results through field days, newsletters, scientific publications, case studies, project milestone reports and the final project report. Other project partners included Resource Consulting Services (RCS), Western Local Land Services, Australian National University (ANU), CarbonLink, Select Carbon, Soils for Life and Meat and Livestock Australia.

3.1.2 Core producers

Producers from four properties across western NSW were initially engaged as partners in the project: Tony Thompson, 'Wirricanna' Bourke; Graham, Cathy and Harriet Finlayson, 'Bokhara Plains' Brewarrina, Andrew and Megan Mosely, 'Etiwanda' Cobar, and Angus and Kelly Whyte, 'Wyndham' Wentworth. In 2022, Glenn and Julie Humbert, 'Gurrawarra' Bourke, joined as a 'core' producer while Tony stepped back as an 'observer'.

Each core producer selected and installed trials on their properties to address context-specific goals. In addition, core producers were required to:

- Attend and contribute to project meetings and milestone reports,
- Receive grazing management coaching and record business productivity and profitability in conjunction with RCS
- In conjunction with carbon service providers, develop whole-farm carbon accounts to understand the emissions profiles of their business,
- Monitor soil, pasture and landscape attributes across trial sites and selected areas of their property
- Provide input and feedback to planning of extension events and activities
- Host on-property field days and workshops, presenting on their management, trials and findings
- Review project communications and extension outputs to ensure they hit the target in terms of key messages and delivery
- Promote project and project findings through networks, presentations and case studies.

3.1.3 Observers

The project engaged producers from an additional 26 livestock production businesses in western NSW to build capacity and support adoption of practice change across a wider area. Through this, the project intended to support implementation of practice change on up to 1M ha of grazing land in western NSW (Figure 1, Figure 2). Key activities and project involvement of these observer producers included:

- Collection of soil condition, soil chemistry, pasture and landscape measurements across four areas of their own properties
- Invitations and recordings to exclusive 'online discussion' webinars with selected topic experts
- Direct communications related to project workshops, field days, newsletters and access to the project Whatsapp and Facebook groups to connect with like-minded producers and topic experts.
- Discounted access to RCS grazing clinics and business management courses
- Provision of ground cover data for each property over the previous 24 years, including identification of ground cover trigger points at which management intervention may be required ahead of time, identifying areas of persistent low cover across properties and tracking trends in cover over time.
- Provision of property maps of various soil, vegetation, landscape and ground cover layers, to inform understanding and management
- Providing direct feedback regarding development of the natural capital framework and identification of key requirements and current knowledge barriers.

3.1.4 Additional engagement

To create wider engagement across the rangelands, a number of awareness activities including field days, workshops, case studies, newsletter articles, a producer support network and other virtual and face to face engagements were undertaken (see section 4.2). Communication with this network was primarily through email (alongside attendance at events) with interested people from across Australia signed up to the 'stay in touch' mailing list for project updates.

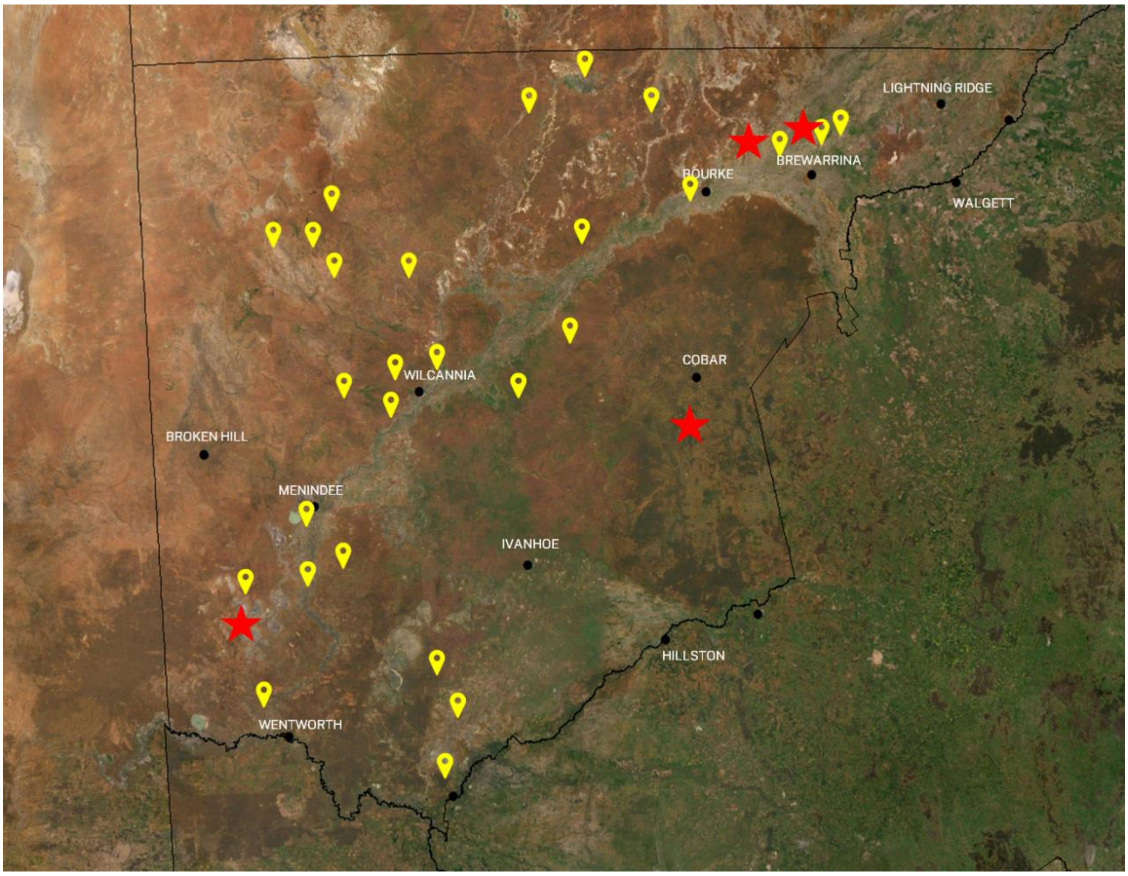


Figure 1. Location of core producer (red stars) and observer producer (yellow markers) properties in NSW rangelands

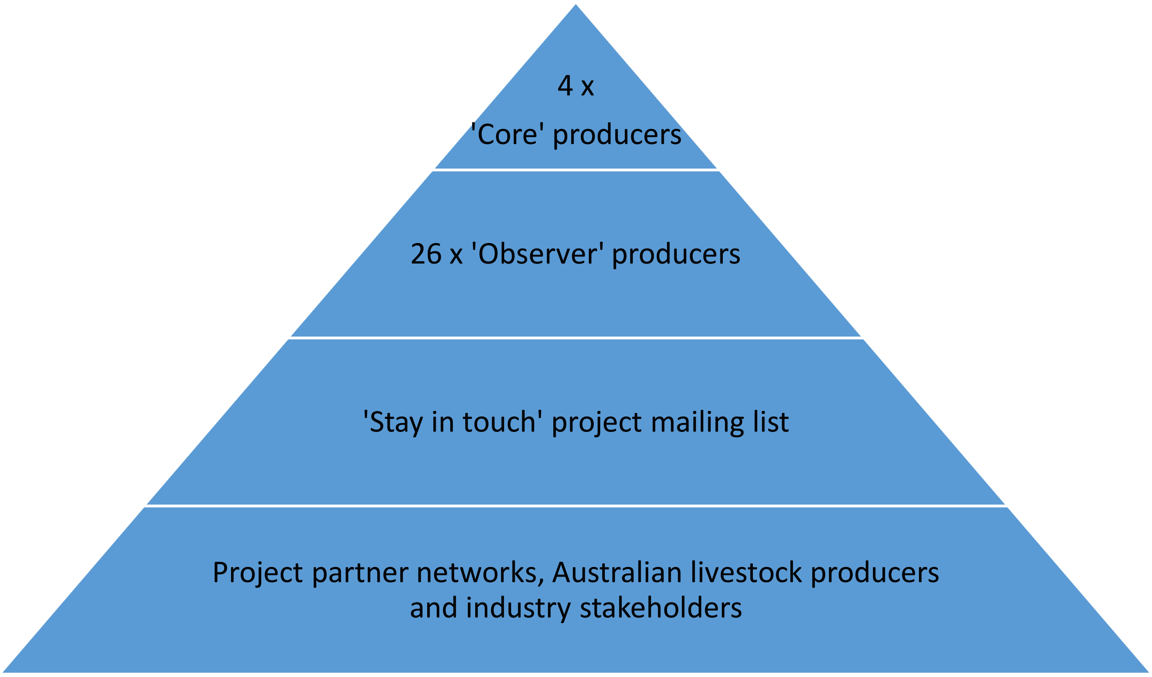


Figure 2. Structure of producer engagement within the Rangelands Living Skin project

3.2 Extension and communication activities

Increasing capacity and awareness of rangeland producers to adopt practices that improve productivity, profitability and environmental outcomes was a key component of the Rangelands Living Skin project. This was achieved through a collaborative approach with all project partners involved in delivering extension and communication information. Capacity building activities delivered through the project included hosting on-property project field days and workshops with a number of expert presenters of a wide range of topics related to the project themes, forums and workshops in major towns in western NSW, alongside online workshops, webinars and discussion sessions with expert topic presenters. These events also provided opportunities for producers to connect with other like-minded producers, advisors, researchers and stakeholders, facilitating the development of a larger rangeland stakeholder network and building relationships.

All project partners also contributed to publication of written articles, case studies and fact sheets on various aspects of the project that they contributed to, which were published in their respective newsletters, MLA newsletters and the Rangelands Living Skin website.

3.3 Baselining soil organic carbon in Western NSW rangelands

3.3.1 Research questions

1. How does position in the landscape (i.e. soil landscape) influence vegetation composition, groundcover, SOC and soil function, and what are the major soil drivers in this environment
2. How do above ground variables (cover, composition, litter etc) correlate with soil carbon measurements? To what extent do site factors influence this?
3. To what extent can the 0-10 cm soil sample be used to predict 0-30 cm SOC stocks?
4. How does soil carbon vary across different scales in NSW rangeland grazing systems?
5. How much would soil carbon need to increase to detect a significant increase in carbon at scale in these landscapes?

3.3.2 Site description

Sampling was undertaken across seven properties (including the four core producer properties + three observer properties) in three regions of western NSW rangelands:

- Brewarrina (referred to as properties 1, 2, and 3)
- Cobar (referred to as properties 4 and 5)
- Pooncarie (referred to as properties 6 and 7)

Each of these properties are managed with a method of planned rotational grazing and flexible stocking rates matched to carrying capacity. Within each property, two x 100 ha areas located in different landscape, vegetation or management types/zones were selected by the producers for monitoring.

Each 100 ha area (hereafter referred to as carbon estimation area, CEA) was stratified into two to five different strata. The initial approach of using CarbonLink's automated stratification model was not successful due to the subtle range in elevation, and the similarity of parent material, vegetation and climate across each CEA. For CEAs where the automatic stratification method was not deemed representative of the strata, CEAs were manually stratified according to the differences in soil type (e.g. surface colour), landscape position (e.g. alluvial systems, dunes), and vegetation growth evident in satellite imagery.

Characterisation of soil properties was made on three soil cores per 100 ha area. Observations made on the profiles at the surface (0-5 cm), upper rootzone (20-30 cm), and deeper rootzone (50-60 cm), were soil pH (Raupach indicator), $EC_{1:5}$, presence of soluble chloride, structural stability, structure, and texture. In alluvial areas (Brewarrina), the strata generally delineated the red meander plain soils that are often prone to scalding, the back plains of heavy soils, and the gilgai soils in between where water runs on from the red meander plain soils. In the Cobar district, the strata delineated areas that contained remnant vegetation, or some variation in cover of shrub and tree species or ground cover where cleared. The soils in the Cobar district were not saline, but may have acidic topsoils over alkaline subsoils with variable carbonate content. The stratification at sites in the Pooncarie district generally delineated dune systems, lower lying areas, and areas of patchy cover. The soils in the region were lighter (sandier) than the other districts due to the windblown sands. They had variable salinity, from low to very high (some containing sea-water equivalent concentrations in the subsoil), and were generally alkaline and commonly contained carbonates.

3.3.3 Soil sampling & analysis

Across each 100 ha CEA, 45 soil cores (to a maximum of 1184 mm depth) were taken at pre-determined locations using a Geoprobe between September 2022 and January 2023. The cores sampled in each CEA were arranged in 15 clusters of three, located along a transect at 0, 10 m and 30 m apart to enable understanding of changes in soil carbon at different scales across landscapes. Within each strata, at least 9 cores (3 clusters) were sampled. Each core was extracted into a 48 mm PVC sleeve inside an approximately 50 mm stainless steel tube which was inside a larger 100 mm diameter stainless tube with a 48 mm cutting tip (Figure 4). Compaction at the base of the core at many sites limited the amount of soil entering the sleeve; the effective depth of extraction was an average of 778 mm, ranging from 280 mm to 1184 mm.

Field data recorded at the time of extraction included:

- Target latitude and longitude documented in sampling plan
- The depth that the core tube was inserted into the ground; target depth was 1184mm.
- Core length (length of soil material present in the core liner. The average core length was 778 mm and 10% of cores less than 500 mm
- Photos of core at the site
- Photo of site
- Actual latitude and longitude that core was taken, using Trimble differential GPS that is accurate to approximate +/- 20 cm
- Any reasons if a core could not be taken at the target location, including photos.

Cores were refrigerated at the end of each day of sampling until they were processed for testing. The cores were transported intact then scanned by CarbonLink for visible to near-infrared (visible-NIR) spectroscopy for SOC modelling, and gamma attenuation for bulk density modelling. Volumetric water content was also predicted using the vis-NIR data to correct for moisture. Spectra were recorded in a 1 cm wide area centred at each 5 cm increment down the core using an ASD LabSpec 4, capturing reflectance spectra across a range of 350-2500 nm. The spectral resolution was 3 nm for the 350-1000 nm range and 10 nm for the 1001-2500 nm range. The gamma counts were recorded using a densitometer positioned at the midpoint of each soil core 5 cm sublayer.

125 x 5 cm increments of soil samples from cores in each of the three regions were selected by CarbonLink for laboratory analysis (375 samples total). The selected increments were to represent the range of spectral features observed across all the cores. Laboratory analyses included total organic carbon (6B2 or 6B3 (treated to remove inorganic carbonates), Rayment and Lyons 2011), and bulk density (including moisture and gravel content), were performed to calibrate the models. The laboratory's accredited limit of reporting (LOR) for soil organic carbon was 0.2%. 27% of the samples selected for calibration were below this limit. There were insufficient samples above the LOR to generate models, therefore data below the LOR was provided by the laboratory, with the advice that the accuracy was increasingly less certain as values decreased.

The laboratory data were used by CarbonLink to develop models to predict values for all increments based on various statistical models. Statistical outliers of laboratory values were identified by CarbonLink and were excluded where required to develop the models. Ensemble models were developed by pairing sublayer spectra with the remaining laboratory results from the project and a global library, incorporating various model types (e.g., artificial neural network (ANN), gaussian process regression (GPR), multiple linear regression (MLR), partial least squares (PLS), support vector regression (SVR)) and hyperparameters. The ensemble was derived from the best fitting options from 600 models developed for the data, then used to predict SOC% for all sublayers of the project soil cores. Statistical measures were also calculated to describe the reliability of the model predictions.

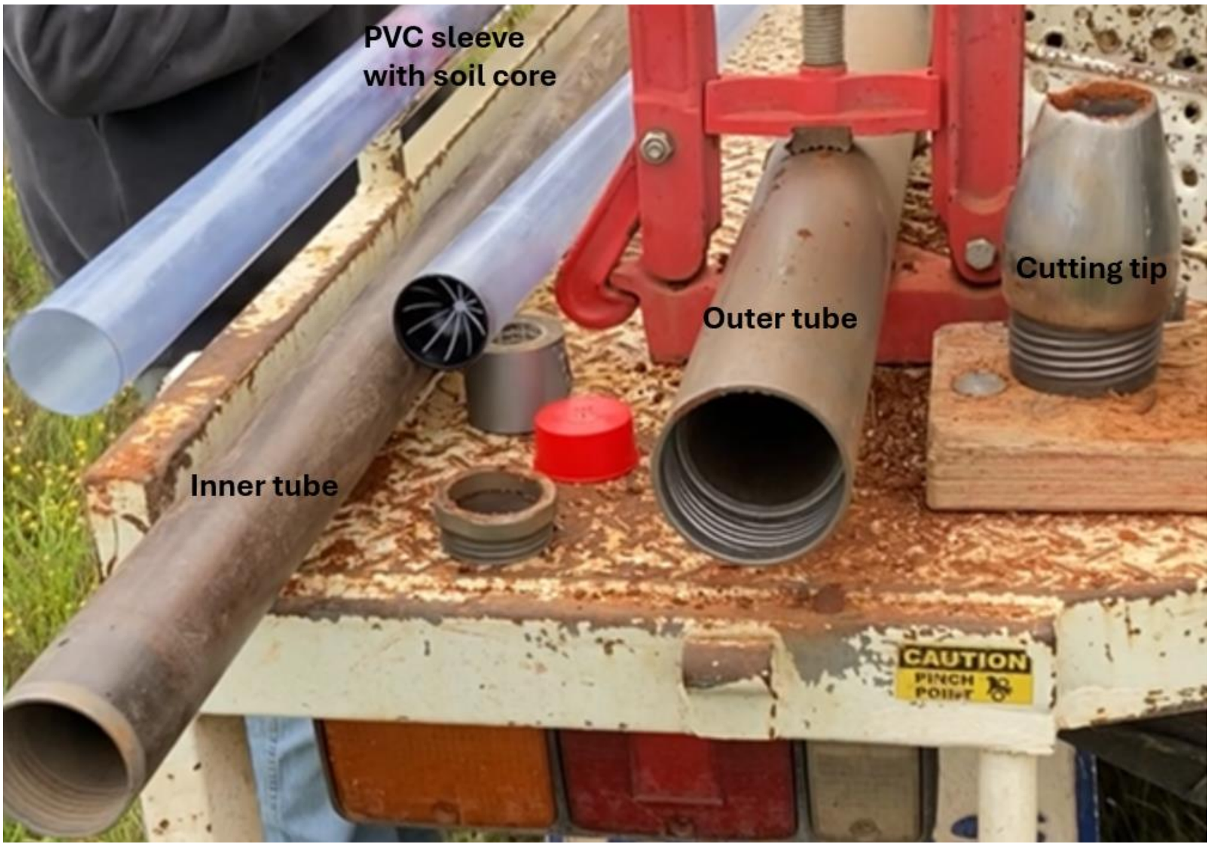


Figure 3. Soil coring tube equipment

Figure 4. Core taken for carbon measurement

3.3.4 Vegetation measurement and analysis

At each core location, a 1x1 m quadrat was placed directly over the core. Within the quadrat, ground cover components (percent cover by plant, litter, rock, cryptogam, coarse woody material, dung, other, bare ground), pasture biomass, percent greenness, composition (percent cover of each species), and amount of dung by species was recorded. Metrics of productivity and floristic and functional diversity were developed from this information. Pasture biomass was estimated using the comparative yield method and cutting, drying and weighing 20 quadrats at each property to calibrate observer estimates (Haydock and Shaw 1975).

3.3.5 Statistical Analysis

Statistical analyses were undertaken in R (R core team 2023). Correlations (R) and the variance in SOC t ha^{-1} explained (r^2) by pasture variables were obtained by fitting a linear model for each 5 cm core increment and cumulative depth increment with soil organic carbon as the dependent variable and pasture variable as the explanatory variable. A linear mixed model was fitted to test the relationships of SOC to pasture variables within a CEA using lmer from R package lme4 (Bates et. al. 2015) with CEA as a random term and with the other terms as per the linear models. The variance explained by the pasture variable (fixed term) in these models was obtained using the r.squaredGLMM command in R package MuMIn (Barton 2024). This gives the variance explained by the entire model and the variance explained by the fixed effects, which are referred to as Conditional and Marginal r^2

The relationship between SOC t ha^{-1} 0-30 cm to SOC t ha^{-1} 0-10 cm was assessed by fitting a linear model. A factor for District (CEAs located near Pooncarie, Cobar or Brewarrina) was added to the model and the two models compared with an F-test with 4 degrees of freedom on the change in residual sum of squares. Similarly, a model with CEA added was compared to the model with District added using an F-test with 22 degrees of freedom.

Spatial variability was assessed using SOC t ha^{-1} 0-30 cm. Variograms for each CEA were fitted using the variogram command from the gstat package (Pebesma 2004). To assess if the strata at each CEA was affecting the variance we also fitted a variogram for each strata within a CEA.

Minimum detectable differences (MDD) for 0-30 cm SOC t ha^{-1} at each CEA were calculated using the pwr.t.test function from the pwr package (Champely 2020), which given the number of samples (n=2-10), the power (0.8), the alternative hypothesis (greater) and the significance level (alpha=0.05, alpha=0.4) calculated the effect size d, where d is (Cohen's d), the difference between the means divided by the pooled standard deviation. MDD for alpha (0.05 and 0.40) expressed as both t C ha^{-1} and percentage change was plotted against the number of samples n. Using p = 0.40 for MDD was consistent with the SOC methodology of the ACCU scheme that credits participants on the 60% probability of exceedance (*i.e.* not statistical significance of p = 0.05).

3.4 Managing grazing to increase ground cover in rangelands

3.4.1 Objective

This component aimed to assess the impact of changes in grazing management (i.e., adoption of flexible stocking rates matched to carrying capacity and strategically resting paddocks between grazing events) on ground cover. We also aimed to understand if impacts were more apparent in certain seasons or seasonal conditions (e.g., rainfall decile years) or in different parts of the landscape.

3.4.2 Site description

Detailed information on the methodology of this study is provided in McDonald et al. (2024) (Section 8.3). A summary is provided here.

3.4.2.1 Grazing management

The research was conducted on seven large grazing properties, ranging from 7,100 to 17,000 hectares, in the semi-arid rangelands of New South Wales (Figure 5, IBRA7 2012), including four core producer properties. Across each property, livestock management was flexible, with cattle, sheep, and goats moved through 19 to 120 paddocks for short periods (one day to two weeks), followed by long rest periods (over six months). Grazing timing and stocking rates were adjusted based on feed availability, pasture condition, animal needs, and the season. Managers aimed to maintain or improve ground cover, pasture diversity, quality, and productivity. These practices had been in place for at least 10 years. Previously, paddocks were continuously grazed and set stocked across fewer, larger paddocks.

A 10 km buffer zone around each site served as a benchmark area for comparison, chosen for its similar size, landscape, and climate. Specific details on the benchmark area's management were not collected, but it generally involved continuous grazing and/or set stocking of larger paddocks. Stocking rates were estimated to be similar by site managers.

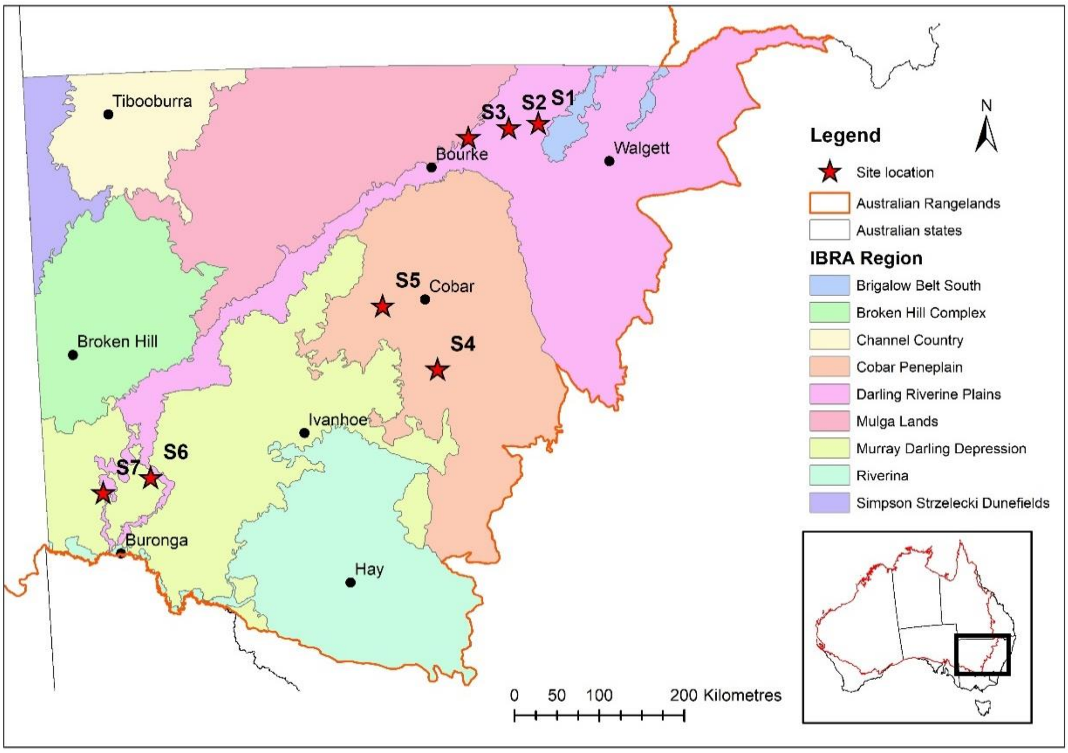


Figure 5. Location of the seven properties (study sites) included in the remote sensing grazing management analysis

3.4.3 Data collection and analysis

3.4.3.1 Overall effect of grazing management

The impact of grazing management on total ground cover was examined using an adaptation of the regional comparison method (Zhang and Carter 2018), and the principles of the Dynamic Reference Cover Method (Bastin et al. 2012) and Compere (Donohue et al. 2022), whereby cover within the study site was compared with biophysically similar areas within 10 km of the study site to control for variability associated with climate and land type (Figure 6).

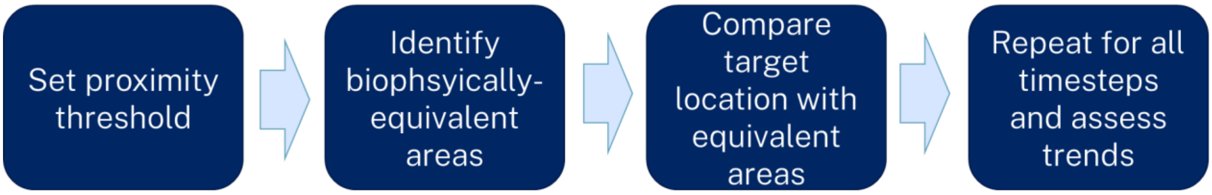


Figure 6. Depiction of process to assess impact of changed grazing management with remote sensing (adaptation of Donohue et al. 2022)

The landscapes of each study site and associated benchmark areas (combined) were classified using Cibo Lab's Land Response Units (LRUs). The LRUs consist of pixel groups that share similar values in their vegetation dynamics and landscape properties. They were created using long time series (1987-2022) of satellite-derived vegetation cover, variables derived from the 30-metre Digital Elevation Model (including slope and aspect), and the Radiometric Grid of Australia (Radmap), among others. In each property and benchmark area, the LRU segments were grouped into five groups using a k-means clustering approach with an unsupervised classification (Figure 7). Areas of mechanical intervention (ponding and ripping) across scalds at site 2 were excluded from the analysis.

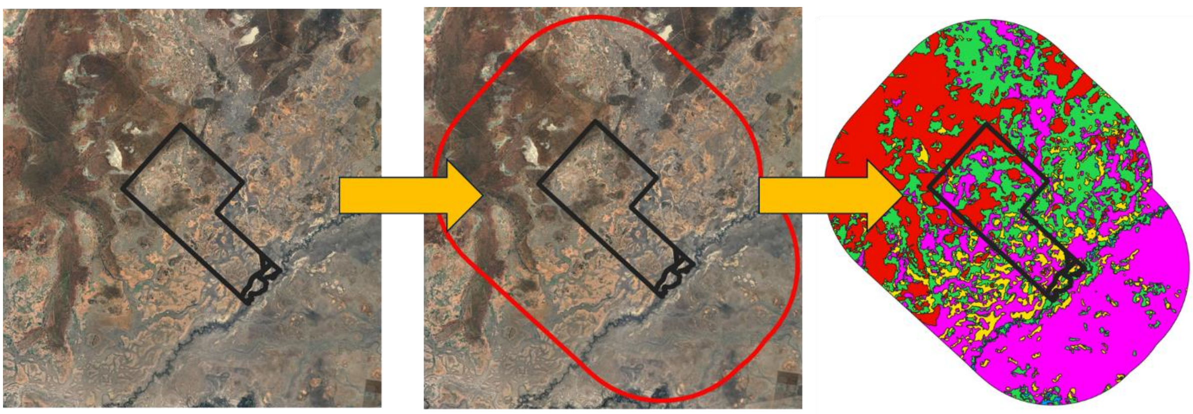


Figure 7. Depiction of the process in defining benchmark and classifying landscape into five land types

Ground cover data were obtained from the Landsat Seasonal Ground Cover version 3 (Department of Environment and Science, Queensland Government 2022). For each LRU in the study site and benchmark area, we derived the median seasonal ground cover between 1989-2023.

All data analysis was performed in R (R Core Team, 2021). For each study site, the trend in ground cover associated with changed management was assessed by examining the difference in ground cover (GC) between the study site (S) and benchmark (B) area (GC_{S-B}) for each LRU. To determine whole of site performance, we calculated a mean of the difference in ground cover for each LRU weighted by the area of each LRU on the study site. Sens slope is the median of all the pairwise slopes between all pairs of points in a data set. The sens.slope command from R package trend (Pohlert 2023) was used to estimate the linear trend before and after management change for the whole site and each LRU within each site.

3.4.3.2 Impact of land type characteristics

To determine if different attributes of each LRU affected the direction and magnitude of the sens.slope, correlations of the linear trends before and after management change with some of the attributes used to classify the LRUs were determined, including slope of land (slope), perennial ground cover (PG2020), soil texture (clay), bare ground (barestE1, barestE2, barestE3), soil moisture (NDWI50th), plant biomass (tsdmM5), greenness (green M1) and soil reflectance (Th).

3.4.3.3 Preceding 12 month rainfall trends

We hypothesised that the rainfall preceding the time at which monitoring occurs may affect the magnitude of change observed between the study site and benchmark areas. To test this hypothesis, for each site we classified each seasonal timepoint into three categories denoted 'dry' (where preceding 12 month rainfall was in the lowest tercile), 'intermediate (where preceding 12 month rainfall was in the middle tercile), and 'wet' (where preceding 12 month rainfall was in the highest tercile of rainfall years during the study period). The values of $GC_{S\text{-}B}$ and the slope of the trend in $GC_{S\text{-}B}$ at each seasonal sample time were split into pre and post management change for each rainfall category (dry/intermediate/wet) with a *t*-test used to determine significant differences between the two periods ($P<0.05$).

3.5 Effect of herd impact and ripping on scald reclamation at Bokhara Plains

3.5.1 Objective

This trial sought to understand how deep ripping, introduction of perennial shrubs, or high density and intensity grazing by cattle for short durations affects the restoration of soil, pasture, and biodiversity on degraded scalds in north-western NSW.

3.5.2 Site description

The trial was located on 'Bokhara Plains', approximately 30 km north of Brewarrina (29°40'29''S, 146°56'37'') on the Barwon River floodplain, Wongal Land System (Walker, 1991). The climate is semi-arid, with an average annual rainfall at Bokhara Plains of 385 mm and a summer dominant rainfall pattern. Soils across Bokhara Plains are predominantly grey cracking clays and yellow texture-contrast. Vegetation is predominantly open woodland and grassland, with isolated whitewood and coolabah and an understorey of Mitchell grass (*Astrebla* spp.), Native millet (*Panicum decompositum*), and annual and perennial subshrubs and forbs (*Atriplex* spp., *Sclerolaena* spp., *Maireana* spp., *Rhagodia* sp. etc). Across Bokhara Plains, and the broader landsystem, there are large areas of scalds, characterised by low (~no) vegetation cover or production and saline and sodic soils.

3.5.3 Experimental design and field method

3.5.3.1 Experimental design

Three scalded areas across different paddocks (4 – 10 km apart) on Bokhara Plains were selected as replicates of the trial. Each replicate claypan was divided into four plots, which was assigned one of the following treatments: 1) Herd impact; 2) ripping; 3) ripping + perennial shrub; and 4) control (no treatment). Further detail on treatments is provided below. Each plot was approximately 0.5ha in area.

3.5.3.2 Baseline sampling

Initial baseline sampling of the claypans occurred in April 2022, prior to establishment of the treatments.

In each plot, three transects were laid out and three soil samples were taken at set distances along each transect (Figure 8). In total, nine soil samples per plot were composited for depths 0-5 cm, 5-10 cm, 10-20 cm and 20-30 cm. Ground cover (percent cover of plant, litter, cryptogam, coarse woody debris, dung and bare ground), plant biomass, composition (percent cover by species), soil surface condition, penetrometer readings, soil crust microbiology samples were examined in 0.25m^2 quadrats at seven distances along each transect (21 quadrats per plot). At five locations, all species within a larger 5x5m quadrat were identified. Infiltration rate was assessed at two locations along each transect. Photo points were established and taken at the beginning of each transect. An assessment of soil surface roughness was undertaken to determine susceptibility to wind erosion by measuring the distance to the soil surface at seven points along a 1.5m post laid across the soil surface.

In April 2022, at replicates 2 and 3 a phenocam was established to capture daily photographs of the site.

Herd Impact treatment

Prior to introducing cattle onto the plot, two large haybales were spread throughout the plot to introduce organic material and increase excitement and dispersal of the animals. Each replicate experienced animal impact at a different timepoint, dependent on location of cattle across Bokhara Plains relative to the scald (Figure 10, Figure 11). Dates cattle grazed plots, and the livestock unit (LSU) equivalents are provided in Table 1.

Table 1. Dates of cattle impact in the herd effect treatment plots and number of livestock units used for each event

Replicate	Date	Livestock units (LSU)*
1	10 April 2024	456
	17 December 2023	406
	18 June 2023	694
2	5 April 2022	681**
3	14 March 2024	456
	8 January 2023	920
	8 May 2022	681

*Livestock held overnight on plot

**Livestock only held on plot for 2 hours.

Ripping treatment

In each replicate, a single tine behind a tractor was used to rip two plots to depth of ~30 cm, in a spiral formation (Figure 10). Each rip line was approximately 1m apart. Replicates 2 and 3 were ripped in April 2022, while replicate 1 was ripped in September 2022 (the same time that cattle initially impacted the herd impact plot).

Ripping + perennial shrub treatment

At each replicate scald, in one of the ripped plots, seed of Old Man Saltbush (*Atriplex nummularia*) was placed every 3m in the rip line, and 125ml (1/2 cup) of worm cast extract or seaweed extract added directly over seed before compacting soil over the seed (Figure 13). Worm cast extract was diluted in water at a concentration of 50ml to 1L water. Seaweed solution was diluted at a concentration of 200ml to 1L water.

3.5.3.3 Annual monitoring

In April 2023, approximately 6-12 months after the initial treatments were established across the replicates, monitoring of ground cover, pasture composition, plant biomass and composition, water infiltration rate, soil surface condition and repeat collection of photo points was undertaken using the same methodology as described for the baseline samples. As there was no germination of the saltbush, it was decided to cease monitoring and inclusion of the perennial shrub treatment in the trial (effectively being no different to the ripping treatment).

In June 2024, 20 – 26 months after the initial treatments and >1 month since the last herd impact event on replicate #3 (with a rain event following this), ground cover, pasture composition, plant biomass and composition, water infiltration rate and soil surface roughness was assessed using the same methodology as described previously, and photo points again collected. Along each transect, seven soil cores were collected at composited at depths 0-5, 5-10, 10-20 and 20-30 cm.

On each sampling day, pasture biomass was estimated for 10-15 quadrats, and then cut to ground level, dried at 80^{o}C and weighed, to calibrate the biomass estimates.

3.5.3.4 Soil analysis

Soil organic carbon (SOC), total nitrogen (TN) soil pH (water and calcium chloride), salinity and cation exchange capacity (CEC) were determined for each soil sample collected in 2022 and 2024. Soil samples were oven-dried at 40°C and passed through a 2 mm sieve. Organic matter that was <2 mm was included in the soil sample.

Chemical analyses

Samples were ground to 0.5mm for analysis of SOC and TN (Dumas dry combustion). The presence of inorganic carbonate (IC) was checked via a fizz response to 1M hydrochloric acid (HCl) (Rayment and Lyons 2011; Method 19D1). Samples that displayed effervescence had carbonates removed with sulphurous acid before C measurement (Rayment and Lyons 2011; Method 6B3). Soil organic carbon (SOC) on non-calcareous samples was measured without treatment (Rayment and Lyons 2011; Method 6B2). Total nitrogen (TN) was measured on untreated samples (Rayment and Lyons 2011; Method 7A5). Results are reported as SOC g/100 g or TN g/100g (%) on an oven-dry basis of soil

Soil pH was measured in calcium chloride solution ($CaCl_2$; Rayment and Lyons 2011; Method 4B4). The presence of various salts is in many rangeland soils requires the measurement of chloride (Rayment and Lyons 2011; Method 5A2b) and electrical conductivity (Rayment and Lyons 2011; Method 3A1) to estimate the salinity of these soils rather than simply electrical conductivity and a correction factor (Shaw 1999). Due to the presence of salts and high pH the cation exchange capacity was measured using Tucker with pretreatment (Rayment and Lyons 2011; Method 15C1).

3.5.3.5 Data analysis

Plant biomass estimates were adjusted according to the calibration curves. Indices of species richness were generated by totalling the number of unique species present within each 0.25m^2 quadrat, each 25m^2 quadrat, and within all quadrats present within the plot. Indices of functional composition were generated by totalling the percent cover of perennial, annual, exotic, native, grass, forb, subshrub, shrub species present within the 0.25m^2 quadrats. Mean and standard errors were calculated for each variable for each plot, and for ground cover and biomass the change from the baseline assessment values were also determined.

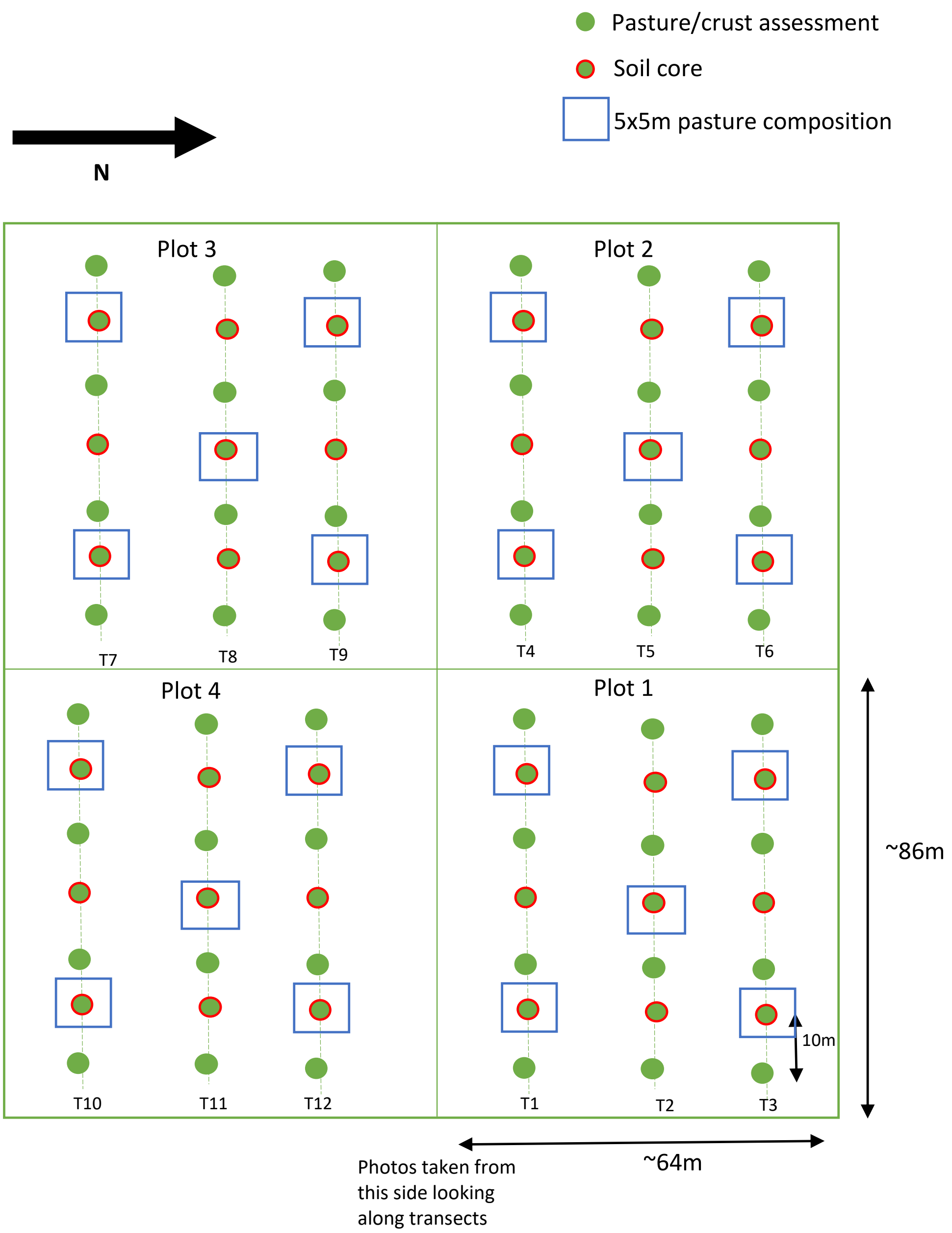


Figure 8. Typical replicate plot layout and baseline sampling design

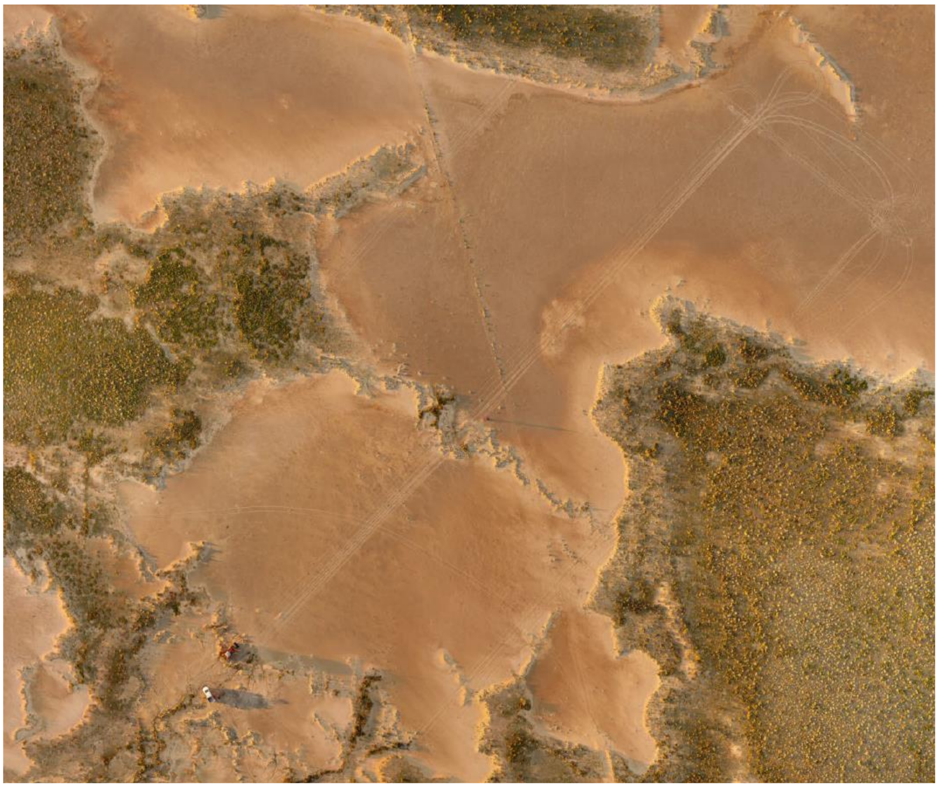


Figure 9. High resolution drone imagery and multi-spectral drone imagery was captured at each claypan replicate (Source: Kirsty Yeates, ANU)

Figure 10. Following establishment of ripping of two replicates and herd impact on one of these, drone imagery was again captured (Source: Kirsty Yeates, ANU)

Figure 11. Approximately 600 450kg cattle (and two camels) grazed the ~50x120m area for 1hr and 20 minutes

Figure 12. Soil surface and hay distribution immediately after cattle impact

Figure 13. At each of the two ripped replicates, in one of the ripped quadrats, seed of Old Man Saltbush (*Atriplex nummularia*) was placed every 3m in the rip line, and 125ml of worm cast extract or seaweed extract added directly over seed before compacting soil over the seed

3.6 Water ponding at Willow Point (Wyndham)

3.6.1 Objective

To understand and quantify how water ponding affects the restoration soil, pasture and biodiversity on degraded scalds in south-western NSW.

3.6.2 Site description

The trial was located on 'Willow Point', approximately 80 km north of Wentworth (33°23'15''S, 141°50'35'') on the Anabranch of the Darling River, Travellers Landsystem (Walker, 1991). The trial site itself is located on an eroded and degraded lunette adjacent to Yelta Lake (Figure 14). Soil across the site is a light clay, sodic and saline. Vegetation across areas in better condition near the site is shrubland with nitre goosefoot (*Chenopodium nitrariaceum*), lignum (*Duma florulenta*), canegrass (*Eragrostis australasica*), copperburrs (*Sclerolaena* spp.), saltbush (*Atriplex* spp.) and annual grasses and forbs. The climate is semi-arid, with an average annual rainfall of ~260 mm.

The Reference site is a different soil type and landform to the treated Area 1 and Area 2. Situated away from the lunette, the Reference area is a red loamy soil compared to the pale clay of the scalded lunette. The Reference area is variable on a fine scale, where plants serve to trap blowing materials, so it had patches of unconsolidated sand some centimetres deep in some areas but absent from others. In contrast, the lunette appeared to have lost an amount of soil that may measure in metres leaving the exposed saline and sodic subsoil.

3.6.3 Field method

3.6.3.1 Experimental design

In March 2022, >100 U-shaped and circular water ponds were constructed across 80 ha of degraded lunette. The banks of the ponds were built to ~50 cm high, with soil pushed into banks from both above and below the pond banks (forming borrow pits). Ponds were designed to pond water to 10 cm depth, after which water spills over the end and continues flowing downslope. Inside each bank, near the base of the bank/borrow pit, soil was ripped to 30 cm using three-five tines, in a band ~2 m wide.

Two 10 ha areas with differing soil properties were selected for monitoring within this ponded area. In addition, a small area identified as remaining unponded was selected as a control site, and a nearby 'run-on' area considered to be in good condition (high cover, diversity and biomass) was selected as a reference area, to serve as a seasonal control and comparison with high ground cover (Figure 16).

3.6.3.2 Baseline monitoring

Baseline sampling of the water ponding demonstration area on Willow Point was undertaken in February 2022, prior to the construction of the water pond banks. Within each of the two 10 ha monitoring areas, 25 random points were selected for soil and pasture monitoring. Ten random points were selected in each of the reference and control sites. At each point, a soil core to 30 cm was taken and separated into depths 0-5, 5-10, 10-20 and 20-30 cm. Ground cover (percent cover of plant, litter, cryptogam, coarse woody debris, dung and bare ground), plant biomass, composition (percent cover by species), was assessed in five 0.25m^2 quadrats at each point (within 2.5m of the point), and all plant species within a larger 5x5 m quadrat at each point were identified. On each sampling day, pasture biomass was estimated for 10-15 quadrats, and then cut to ground level, dried at 80^{o}C and weighed, to calibrate the biomass estimates. Landscape Function Analysis (LFA) was undertaken along two transects in each of the four monitoring areas.

3.6.3.3 Year 2 sampling

In March 2024 monitoring of the two 10 ha ponding areas and the reference area was undertaken, with location of sample points selected to understand changes in soil and vegetation in response to the ponding. In each area six ponds were selected for monitoring along two (area 1) and four (area 2) transects (Figure 17, Figure 18). The number of transects differed because the orientation and scale of ponds differed in the two areas. Along each transect, landscape organisation was assessed and soil surface assessment was undertaken in each patch and interpatch type along the transect using the Landscape Function Analysis method (Tongway and Hindley 2004).

At each pond, a sampling site was located at 5 m from the base of the bank, and at two thirds of the distance between the base of the bank and the spill points. An additional sampling site outside of the ponded zone was selected as a control for each pond. The slopes in Area 1 were longer and more consistent than in Area 2. The shorter and steeper slopes in Area 2 meant that transects were shorter. At each sampling location three soil cores to 30 cm were collected and composited at depths 0-5, 5-10, 10-20 and 20-30 cm (Figure 19). At each of these sampling locations, ground cover components, biomass and composition were assessed in five x 0.25 m^2 quadrats and all species within a 5 m x 5 m quadrat centred on the sample location were identified, similar to the method used for the baseline pasture assessment. An additional sampling location at the base of the ponding bank was also included for the pasture assessments. In the reference area, soil and pasture assessment was undertaken using the same methods and same locations as the baseline assessment. On each sampling day, pasture biomass was estimated for 10-15 quadrats, and then cut to ground level, dried at 80^{o} C and weighed, to calibrate the biomass estimates. One LFA transect was monitored in the reference area. The area originally designated as a control was disturbed with some ponding banks and therefore was excluded from this monitoring.

3.6.3.4 Soil analysis

For each soil sample collected in 2022 and 2024, soil organic carbon (SOC), total nitrogen (TN), soil pH (water and calcium chloride) and bulk density was determined. Soils collected in 2024 were also analysed for salinity (electrical conductivity and soluble chloride) and cation exchange capacity (CEC). Soil samples were oven-dried at 40°C and passed through a 2 mm sieve. Organic matter that was <2 mm was included in the soil sample.

Soil organic carbon (SOC) and Total N (TN)

Samples were tested for the presence of inorganic carbon (IC) using 1M hydrochloric acid (HCl) and observing the degree of effervescence (Rayment and Lyons 2011; Method 19D1). Samples that displayed effervescence and required pre-treatment for inorganic carbon (IC) prior to SOC analysis were treated with sulphurous acid on a hot plate until there was no further effervescence (Sanderman et al. 2011). Soil organic carbon (SOC) was determined on a finely ground soil using a dry combustion (Dumas 1831, in Rayment and Lyons 2011; Method 6B2b). Results are reported as SOC g/100 g on an oven-dry basis of soil. 146 of 278 samples had SOC below the laboratory limit of reporting of 0.2, of these 85% were below 5 cm and 70% below 10 cm; 41% were from Area 2, with 30% from both Area 1 and the Reference area. For presentation of overall averages, those samples are assigned a default value of 0.1% so that their exclusion does not otherwise inflate the average.

Chemical analyses

Soil pH was measured using water and calcium chloride (CaCl2; Rayment and Lyons 2011; Method 4B1). Soil salinity was calculated according to Shaw (1999) using electrical conductivity (Rayment and Lyons 2011; Method 3A1) and chloride (Rayment and Lyons 2011; Method 5A2b). Due to the presence of salts and high pH the cation exchange capacity was measured using Tucker with pretreatment (Rayment and Lyons 2011; Method 15C1).

3.6.3.5 Data analysis

Plant biomass estimates were adjusted according to the calibration curves. Indices of species richness were generated by totalling the number of unique species present within each 0.25m^2 quadrat, each 25 m^2 quadrat, and within all five 0.25 m^2 quadrats per sampling site. Indices of functional composition were generated by totalling the percent cover of perennial, annual, exotic, native, grass, forb, subshrub and shrub species present within the 0.25 m^2 quadrats.

Mean and standard errors were calculated for each variable for the ponded areas (at each distance from the ponding bank) and reference areas.

Figure 14. Ponding scald area in February 2022, prior to construction of water ponds

Figure 15. Reference area in February 2022

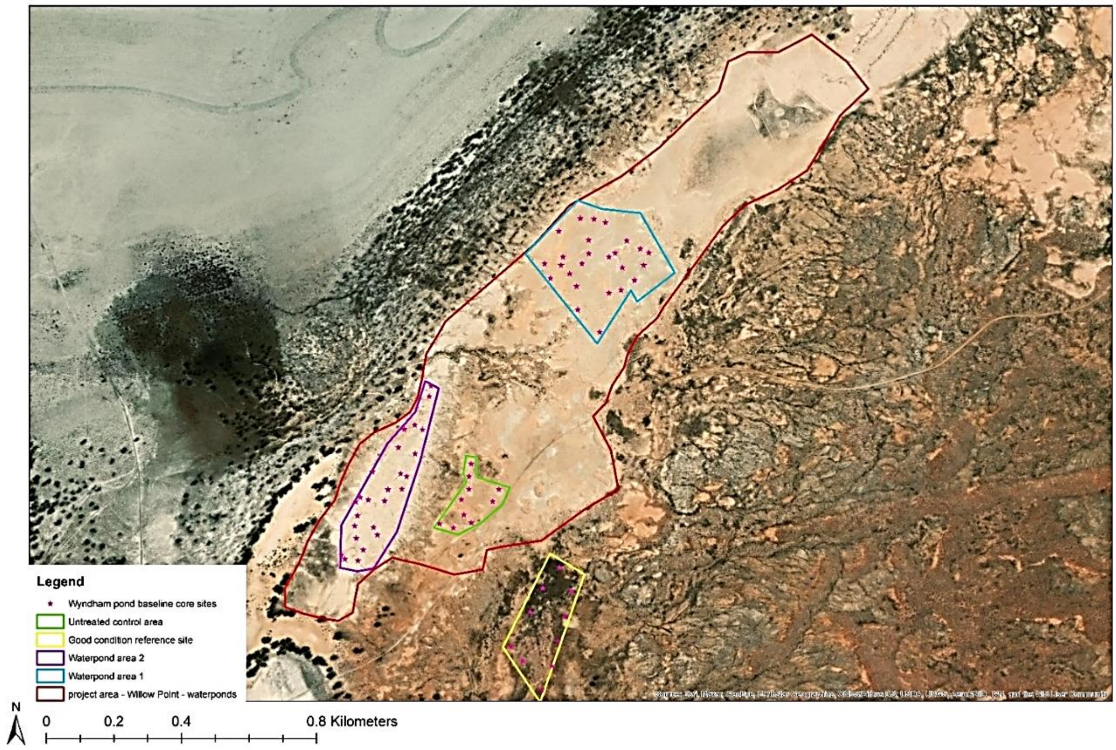


Figure 16. Area in red within which ponding works were undertaken Willow Point. Purple and blue areas were selected for monitoring impacts of the ponding, across two different soil types. Area in yellow was selected as a reference run-on areas in good condition. Area in green was selected as a control (untreated) area. Soil cores and pasture assessment occurred at random points within these areas (pink stars)

Figure 17. Ponded area #1, showing location of two transects sampled in March 2024 in red, monitoring six ponds total

Figure 18. Ponded area #2, showing location of four transects sampled in March 2024, monitoring six ponds total

Figure 19. Soil sampling in March 2024. Three cores were sampled parallel to the ponding bank at 5m and two-thirds of the distance of the pond to the spill points

3.7 Gypsum for scald reclamation at Gurrawarra

3.7.1 Objective

The objective of the gypsum trial on the scald at Gurrawarra was remediation of the persistent problem, and assessment of its severity compared to other sites. The scald does not provide any grazing value, and causes problems with saline drainage to the adjacent soils. The scald has persisted after previous ripping that was hoped to improve infiltration and plant establishment. The application of gypsum was chosen because the producers had noted the long-term effect (>10 years) at isolated spots where gypsum tailings had been dumped on the property.

The specific research questions addressed in the trial were:

1. Is gypsum a suitable ameliorant for scalded alluvial soils in a rangeland environment?
2. What are the trade-offs of cost versus application rate for amelioration?
3. What differences in soil characteristics exist between scalded sites, self-repairing scalds and scalds remediated with gypsum?

3.7.2 Site description

The trial was located on 'Gurrawarra', approximately 80 km north-east of Bourke (29o46'41''S, 146o23'19'') on a scald was situated on an old alluvial meander plain to the west of the Culgoa River in a broad sweep of mixed red and sometimes scalded soils (Figure 20), within the Toulby landsystem (Walker 1991). The climate is semi-arid, with an average annual rainfall at Gurrawarra of 370 mm, with a summer dominant rainfall pattern.

Figure 20. Satellite image of the region where the gypsum trial was located indicated by red circle. Two sites where gypsum was dumped are denoted with an 'x'

The site is slightly elevated above adjacent heavy soils. There is a gentle grade from the centre of the scald, particularly to the north-west (note the adjacent ground tank). Preliminary coring, soil analyses and observation of the isolated plants on the scald identified that high salinity was a limiting factor. The soils were also prone to dispersion, a constraint which limits infiltration. Salt efflorescence and iron staining on the surface across the scald indicates poor hydrology. The preliminary coring also identified variable subsurface stratigraphy, with sandy lenses found toward the south-eastern side. An 'island' elevated approximately 50 cm of sandy soil with a good cover is in the centre and influences surface drainage. Vegetation is more common to the edges, particularly as influenced by water being caught in the rips on the lower eastern side (Figure 21).

3.7.3 Field method

The gypsum trial was established on the 17 July 2023. A source of gypsum local to the Bourke region was used. Prior to the application of the gypsum on the scald, baseline soil sample cores were taken and analysed (at a minimum) for salt and sodicity profiles (electrical conductivity, soluble chloride, exchangeable sodium percentage). Additional soil samples were collected from an existing gypsum site and other reference areas nearby to better characterise and understand the salt and sodicity profiles in the landscape.

Three replicates of four rate treatments (listed below) were established in 50 x 50 m plots on the scald (Figure 22). Gypsum was weighed and spread evenly over the treatment areas by hand in demarcated 10 m x 10 m squares (Figure 23). Treatments included:

1. Control – no gypsum added.
2. Low – 1 t/ha gypsum (the approximate amount of gypsum dissolved through 10 cm at field capacity)
3. Moderate – 2.5 t/ha gypsum (the standard application to allow for some leaching)
4. High – 6.5 t/ha gypsum (an excessive rate to buy more time to allow leaching of other salts and replacement of sodium on the clay exchange sites).

Post application of the gypsum, the soil surface was tilled to roughen the surface and minimise wind drift and provide some incorporation of the gypsum. Photo points were also established in the corner of each plot. Banks were also mounded around the site to minimise run-on confounding the effect of the surface treatments.

Figure 21. Satellite image of Gurrawarra Gypsum site prior to installing the trial

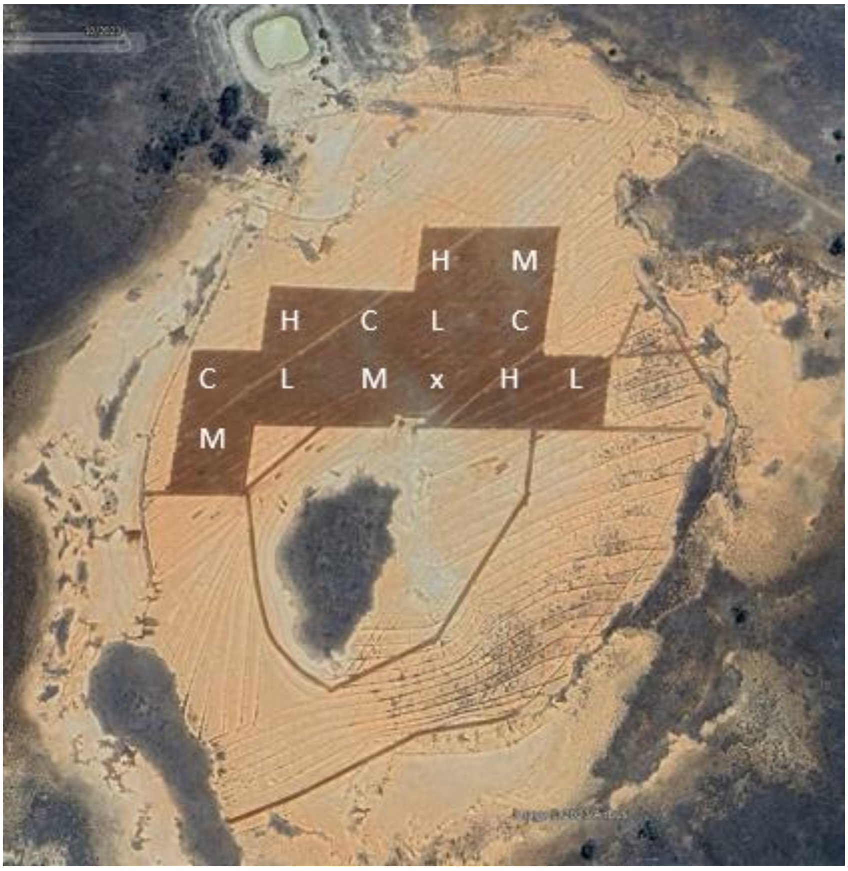


Figure 22. Satellite image of Gurrawarra Gypsum site following incorporation of gypsum and location of treatment replicates (C = control/nil gypsum, L = low rate 1 t/ha, M = moderate rate, 2.5t/ha, H = high rate, 6.5t/ha. Site x was avoided due to an adjacent sand mound). Banks were established around the site to minimise run-on

Figure 23. Project team spreading gypsum treatments on pre-marked grid on site

3.7.4 Soil and vegetation monitoring, 12 months post treatment

Monitoring was conducted in July 2024, approximately 12 months after the treatments had been applied. 20 soil samples (25 mm diameter) were collected at random in each plot and composited at 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm and 30-60 cm depths to assess the overall effect of the treatment. To assess the effect of the deep ripping undertaken in 2014-2015 across the scald, samples were also taken from in and outside the rip lines in each control plot. Samples were also taken from the rip lines in the high treatment plots, and separately from the bare and vegetated patches outside the rip lines within the high treatment plot.

Ground cover (percent cover of plant, litter, cryptogam, coarse woody debris, dung, rock and bare ground) and species composition (by percent cover) were assessed in twenty 0.5 x 0.5 m quadrats located along four transects in each plot. Indices of species richness were generated by totalling the number of unique species present within each 0.25m^2 quadrat and plot. Indices of functional composition were generated by totalling the percent cover of perennial, annual, exotic, native, grass, forb, subshrub and shrub species present within the 0.25 m^2 quadrats.

3.7.5 Remote sensing

The trial was set out to enable monitoring by Sentinel satellite imagery (accessed through the Copernicus hub; https://sentinel.esa.int/web/sentinel/home). The plots were aligned to magnetic rather than true north, but are large enough to contain 3 x 3 pixels each of 10 m x 10 m with a buffer area to the edge of each plot. The treatment areas were delineated and red and NIR data was downloaded to calculate NDVI from November 2016 – September 2024. Against the almost nil presence of plants on the site, the normalised difference vegetation index (NDVI) was selected to represent plant response. The NDVI uses the difference between red and near infra-red (NIR) reflectance to provide a surrogate index of greenness: a non-moisture stressed leaf will reflect near infra-red wavelengths, while active photosynthesis absorbs red wavelengths. The trend in NDVI prior to installation of the trial was compared against the response of different treatments after establishment. Data from dates where cloud was present was excluded from the analysis.

3.7.6 Additional scald monitoring on Gurrawarra

A nearby scald was reported by the producers to have been improving from its previously extensive scalding with increasing plant cover without mechanical intervention or use of soil ameliorants. The area was covered with patchy vegetation coverage that varied within metres (Figure 24Figure). The soil properties of a small area (termed self-ameliorating) were assessed as a comparison to the more extensively scalded demonstration site which had not improved over the same period. Eight soil samples were collected from within vegetated patches and in bare patches and composited at 0-10 cm, 10-20 cm, 20-30 cm and 30-60 cm depths.

Figure 24. Area of previously more extensively scalded area where patchy vegetation coverage had been increasing

Similarly, a comparative assessment was made on a scalded area on which coarse gypsum had been dumped over ten years prior (eastern site denoted ‘x’ in Figure 20, Figure 21, Figure 25). The gypsum had been used by the producers as part of a base when installing their watering system. The gypsum had been placed in a scalded area to facilitate easy collection, and the producers related the clearly better condition of the dump site (Figure 26). The patch also provided the impetus for the larger trial site and an opportunistic comparison of soil properties. It was evident on inspection that the dump site had collected some windblown material, so an additional increment was collected at the surface to allow comparison of the upper profile against the adjacent scalded samples. Subsamples were collected and bulked at increments of 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, and 40-60 cm (within the gypsum dump), and 0-10 cm, 10-20 cm, 20-30 cm and 30-60 cm (adjacent scald).

Figure 25. Vegetated area of gypsum where gypsum had been dumped on a scald for later redistribution

Figure 26. Vegetated area of the dump area with scalded area in the background (left), and close-up of vegetation and remaining coarse gypsum on the soil surface within the dump area (right)

3.7.7 Soil laboratory analysis method

Soil samples were oven-dried at 40°C and passed through a 2 mm sieve. Organic matter that was <2 mm was included in the soil sample. Organic matter and gravel that was >2mm was separated, weighed, and recorded.

Bulk density

Bulk density was determined on each core with subsamples (~20 g) dried at 105°C as described by Dane and Topp (2020). Results were calculated as BD in g/cm³ on an oven-dry basis to the nearest 0.01 g/cm³.

Soil organic carbon (SOC)

Samples were tested for the presence of inorganic carbon (IC) using 1M hydrochloric acid (HCl) and observing the degree of effervescence (Rayment and Lyons 2011; Method 19D1). Samples that displayed effervescence and required pre-treatment for inorganic carbon (IC) prior to SOC analysis were treated with sulphurous acid on a hot plate until there was no further effervescence (Sanderman et al. 2011). Soil organic carbon (SOC) was determined by dry combustion (Dumas) (Rayment and Lyons 2011; Method 6B2b). Results are reported as SOC g/100 g (%) on an oven-dry basis of soil.

Chemical analyses

Soil pH was measured using water and calcium chloride (CaCl2; Rayment and Lyons 2011; Method 4B1). Soil salinity was calculated according to Shaw (1999) using electrical conductivity (Rayment and Lyons 2011; Method 3A1) and chloride (Rayment and Lyons 2011; Method 5A2b). Due to the presence of salts and high pH the cation exchange capacity was measured using Tucker with pretreatment (Rayment and Lyons 2011; Method 15C1).

3.8 Biological stimulant trial

3.8.1 Objective

Determine changes in soil biology and associated pasture cover, biomass and composition changes in response to biological stimulant and biochar treatments in a semi-arid rangeland environment.

3.8.2 Site description

The trial sites (~0.5ha) were established on each of the four core producer properties: Bokhara Plains, Gurrawarra, Etiwanda and Wyndham. Sites were selected in accessible areas of better performing paddocks that were in good condition (e.g., good cover of perennial grasses), with guidance from the producers. Sites were divided into three replicate blocks, within which treatments were applied.

3.8.3 Site Characterisation

Each trial site had soil chemical analysis, soil biology analysis and plant/species analysis undertaken to 'characterise' the trial site prior to the establishment of the trial.

Each replicate had 7 or 8 soil cores of 40 cm diameter taken, split to depths of 0-5, 5-10, 10-20,20-30, 30-40 and 40-50 cm composited (at each depth) and dried at 40°C. Prior to analysis, samples were sieved to 2 mm and where required gravel removed.

Samples were analysed for pH ($CaCl_2$), pH (water), electrical conductivity (EC), ECe Calculation, field texture, sulfur (KCl40), Colwell phosphorus, total phosphorus, phosphorus buffering index (PBI), total carbon (TC), total nitrogen (TN), exchangeable aluminium, exchangeable calcium, exchangeable potassium, exchangeable magnesium, exchangeable sodium, effective cation exchange capacity (eCEC), percent aluminium saturation, exchangeable calcium percent, exchangeable potassium percent and exchangeable sodium percent (Rayment and Lyons, 2011).

Soil biology function was characterised using a whole soil food web analysis. Where soil cores for chemistry were taken, two 10 cm deep 19 mm diameter cores were taken alongside. These samples were composited across the trial site (not individual replicates) and sent for whole soil food web analysis which entails direct measure (plate read using microscope) of active bacteria and fungi, total bacteria and fungi, Actinobacteria, protozoa, and nematodes and mycorrhizal fungi.

Vegetation condition and characterisation of each site was initially assessed using the Botanal procedure (Tothill et al. 1992), where the ground cover, biomass, green biomass and composition was assessed in 10 x 0.25 m^2 quadrats in each replicate.

3.8.4 Treatment Application

The treatments were:

- Foliar spray of a biostimulant
- Solid vermicast (worm castings)
- Biochar (surface applied) (Wyndham and Etiwanda sites only)
- Control, no treatment

Solid vermicast and the foliar biostimulant (Biocast, liquid vermicast Part A and Part B) were supplied by Island Biological (https://www.biocast.com.au/product/biocast-20-l/). Biocast is a liquid extract made from fully finished worm cast. It contains a diverse range of living, plant relevant microbes; autoinducers; enzymes; plant growth-stimulating hormones; fulvic acid and other worm-created compounds. The product is promoted to improve plant health, boost plant immunity, assist recovery from shock and aid soil health.

Within each of the three replicate blocks, 20m by 5m plots were marked and treatments were randomly assigned. Treatments were applied in late July and early August 2022. The foliar bio-stimulant spray was applied using a 15L knapsack sprayer (Figure 27), the solid vermicast was applied by hand at a rate of 250kg/ha (Figure 28). Biochar, when used, was applied at a rate of 10 t/ha (Figure 29).

As a surrogate measure for biological activity (Nachimuthu 2022), degradation of cotton strips buried ~5 cm in the soil was assessed. In each plot, three 5 cm x 5 cm cotton squares were buried to 5 cm, at a consistent distance and orientation to nearby plants. These strips were removed by the core producers at 8, 12, and 14 weeks post treatment application for analysis of degradation by soil microbes. Marker flags were placed close to the sample for removal at the allotted times.

Figure 27. Application of liquid foliar biostimulant in replicated plot trial on Gurrawarra, July 2022

Figure 28. Solid vermicast on the soil surface at Gurrawarra, July 2022

Figure 29. Biochar on the soil surface at Wyndham, October 2022

3.8.5 Treatment Analysis

The cotton strips were rinsed and air dried prior to being analysed. Two methods were used to determine degradation. The first method was to use the Canopeo app, on a mobile phone which is used to identify green cover in a crop. Using a green background 5 cm x 5 cm bound by a non-green coloured edge, degraded strips were placed on the green area (Figure 30) the inverse of the percentage green identified (Figure 31) The area (cm2) remaining intact from the original 5 x 5 cm square of cotton material was calculated.

The second method was utilised where there was no sign of degradation from the Canopeo app. This was to test the breaking strength of the material using a Tensometer (Figure 32). Breaking strength of each sample was compared to a sample that had not been placed in the ground. Where cotton strips were collected but too degraded for measuring on tensometer, a value of 100% loss of tensile strength was given (Nachimuthu et al. 2022).

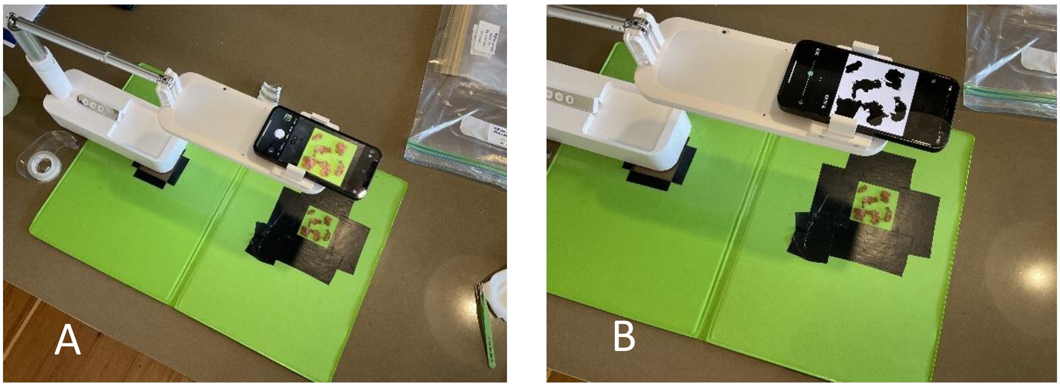


Figure 30. Setup for taking image in Canopeo (A) taking image for use in Canopeo app, (B) Sample processed in Canopeo app. Note the smartphone holder to maintain the same distance for each image

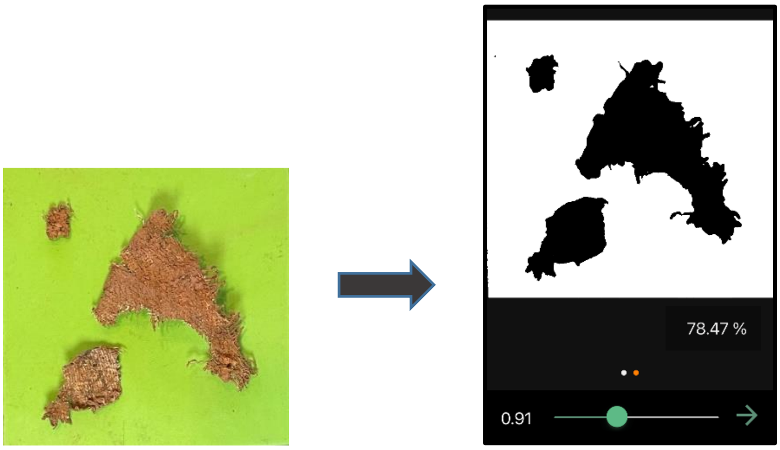


Figure 31. Photo taken of sample, run through Canopeo app. Percentage of green given. The inverse of this value is the percentage of material left intact

Figure 32. Piece of cotton strip being tested for tensile breaking strength in the tensometer

3.8.6 Post-treatment Application Biological Measures and Plant Assessment

Soil and vegetation monitoring occurred in December 2022, four months after treatment application. In each treatment plot, 10 x 10 cm depth soil samples (19 mm diameter) were taken and composited. Soils were frozen prior to analysis for microbial biomass carbon, autoclave citrate extractable protein and fungal: bacteria ratio. In addition, vegetation (biomass, greenness, cover, dominant species) was assessed using the Botanal protocol in five 0.25 m^2 quadrats in each plot (Tothill et al. 1992). Soil protein contains nitrogen and acts like a glue between soil particles (Raghavendra, 2020), higher soil protein has been correlated to plant-available N and improved soil structure, and therefore is used as an indicator of soil biological activity (Hurisso et al. 2018). Microbial biomass carbon (C) is a measure of the weight of micro-organisms in the soil and therefore another measure of biological activity (Ramesh et al. 2019). The fungi: bacteria (F:B) ratio is a measure of fungi to bacteria, systems dominated by fungal are representative of undisturbed soils, whereas bacteria dominated soils tend to dominate in more disturbed soils (Zhang et al. 2016).

3.8.7 Statistical Analysis of Results

An ANOVA with interactions was deemed suitable for the statistical comparison between treatments at each site for vegetation and biological measures with the response variables as treatment (fixed and discrete variable) and replicate (random and discrete variable). DataDesk 8.3 (datadesk.com) was used to undertake the statistical analysis. Differences between the variable of interest were considered significant when $P<0.05$.

3.9 Carbon accounting

A whole farm carbon account quantifies and benchmarks greenhouse gas emissions and carbon sequestration (in trees, note soil carbon sequestration is not typically included) on a farm. It is an opportunity to identify strategies to reduce emissions or contemplate carbon sequestration opportunities in parts of the business. There is currently very little documented evidence of emissions profiles of rangelands grazing enterprises in Australia. A greenhouse gas account is useful to benchmark and measure emissions. If you know where you are starting from you can determine strategies to reduce emissions and identify opportunities to sequester carbon in soil or trees. You can't manage what you don't measure. Benefits of a conducting a carbon account:

- To improve future market access, and improve social licence and continued market support for red meat,
- To participate in the Australian Governments ACCU Scheme (formerly known as the Carbon Farming Initiative),
- To meet the Meat and Livestock Australia (MLA) goal for the red meat industry to be carbon neutral by 2023 (CN2030), and
- To access green finance (i.e. sustainable finance).

3.9.1 Objective

A carbon account of activities on each farm was conducted to provide an estimate of their potential greenhouse impact. The objective was to understand the process involved in creating a carbon account, and to provide a starting point from which to determine strategies to reduce emissions and identify opportunities to sequester carbon.

3.9.2 Method

Each producer worked with one of two project partners, Select Carbon (Etiwanda and Wyndham) and CarbonLink (Gurrawarra and Bokhara) to conduct the carbon account. The total annual GHG emissions for the whole farm were calculated using the GHG Accounting Framework (GAF) calculators developed by the University of Melbourne and accessed via the Primary Industries Climate Challenge Centre (PICCC, https://piccc.org.au/resources/Tools.html). The SB-GAF tool was used to calculate emissions associated with sheep and beef enterprises (Lopez et al. 2023a) and the Go-GAF tool was used to calculate emissions associated with goats (Lopez et al. 2023b) MLA GAF tool includes carbon sequestration in planted trees but not from soil. GHG emissions account was performed on the previous five (5) years, as would be typical for a soil carbon project under the method (*Carbon Credits (Carbon Farming Initiative - Estimation of Soil Organic Carbon Sequestration using Measurement and Models) Methodology Determination 2021)*. The five-year baseline period (2018 to 2023) included both dry and wet years. The tools use livestock class and numbers, including purchases and sales, to estimate methane emissions. Other components of the calculation include fuel, electricity, and sequestration in vegetation.

3.10 RCS ProfitProbe & coaching

3.10.1 Objective

Improve core producer capacity to adopt practices that regenerate their landscapes, improve productivity and business performance. Document and benchmark rangeland livestock business financial performance, demonstrating potential for livestock businesses in the western division of NSW to be profitable and sustainable while at the same time regenerating the landscape they are working in.

3.10.2 Approach

Over the life of the project, each core producer met with an RCS advisor monthly to discuss their grazing management plan and feed budget. An RCS advisor also visited each property annually. Core producers monitored and supplied RCS with livestock and business performance information at the end of each year, which was entered into the RCS ProfitProbe™ program providing benchmarking information, comparing the property against data for the top 20% and average of producers participating in RCS ProfitProbe program.

3.11 Observer monitoring

3.11.1 Objective

Observers in the project were encouraged to undertake soil monitoring and testing across their properties. As detailed monitoring and testing of soil properties is not traditionally a part of rangeland management activities, the objective was to increase awareness of various properties that may influence potential productivity. The objective of using field observations with laboratory testing was to provide context to differential response to seasonal conditions or management practices, or to help identify constraints in poorly performing areas.

3.11.2 Field method

Thirty-two soil testing kits were distributed to rangeland producers (Figure 33). These soil kits contained simple tools and equipment to monitor characteristics of soil condition (Table 2). The attributes suggested for monitoring covered a range of soil properties relevant to rangeland soils and production systems. The monitoring was supplemented with fully subsidised soil laboratory testing. Participation in Rangelands Living Skin events, and uptake of the monitoring and testing, among the Rangelands Living Skin producer group (core producers and observers) was slow, and so the opportunity of monitoring and testing was widened to other producers who did attend events during the project. A full copy of the monitoring protocols and information delivered to producers is provided in **Section 8.5.**

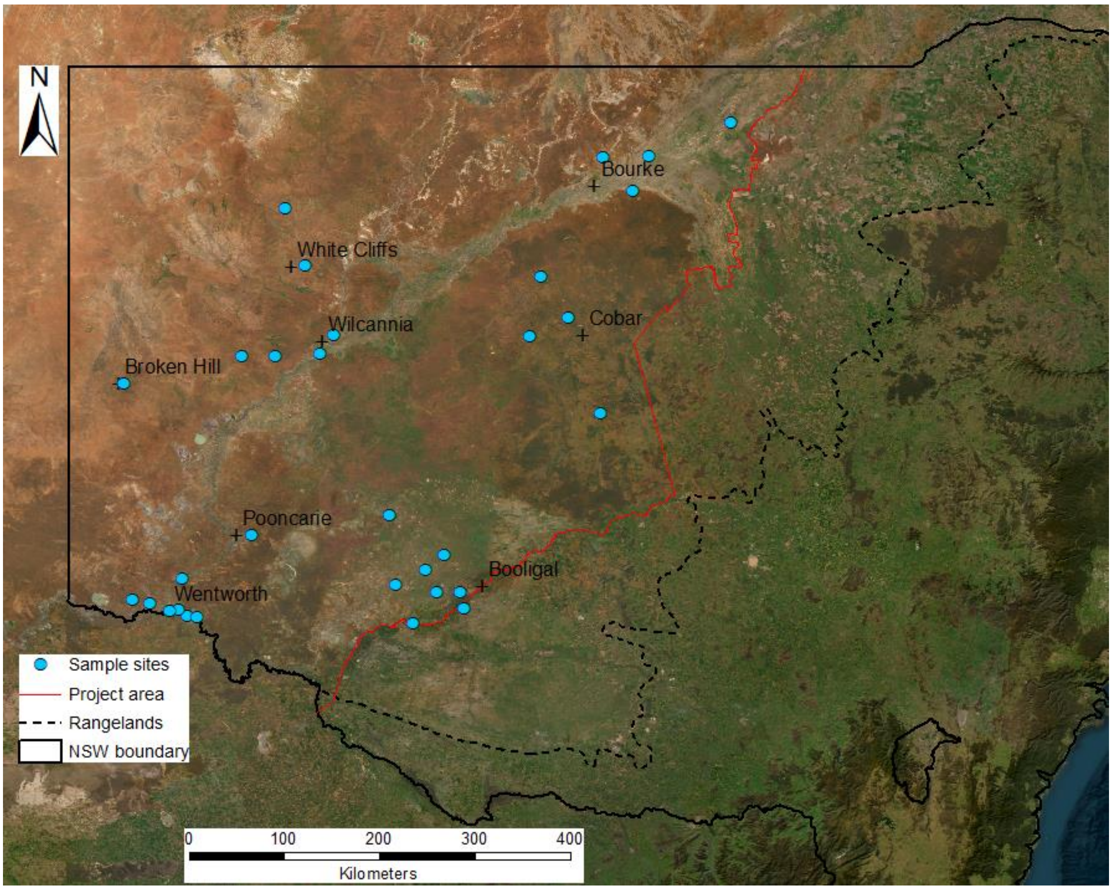


Figure 33. Distribution of sample sites throughout the rangelands of western New South Wales

Table 2. Equipment provided in observer monitoring kits and purpose of each

	Tool	Compaction	Infiltration	Topsoil depth	Structure	Root growth	Slaking and dispersion	Biological activity	Soil pH	Ground cover
In the kit	Tape measure	X	X	X				X		X
	Petri dish (container)						X			
	Soil pH kit								X	
	'Penetrometer' (steel rod)	X								
	Infiltration ring		X							
	Hand counter/clicker									X
	Sorting tray							X		
	Magnifying lens							X		
	Calico							X		
Other	Water		X				X			
	Shovel			X	X	X		X		
	Compass (on phone)									X
	Stopwatch/clock		X							

Included in the kit were instructions for producers to collect and send soil samples to a lab for analysis of soil chemistry properties. The testing provided for samples from four locations at the 0-10 cm, 10-20 cm and 20-30 cm depths. Participants were encouraged to collect at least 8 subsamples for each depth increment to minimise the effects of small scale soil variability. Laboratory soil tests included pH, electrical conductivity (EC), exchangeable cations, organic carbon (OC) and total nitrogen (TN), phosphorus (P), and sulphur (S). Chloride (Cl) was also measured on selected samples.

Training of producers in the use of the soil kits was undertaken through workshops (White Cliffs, Wilcannia, Brewarrina and Wentworth) and additional one-on-one sessions with the project team. In order to make best use of the monitoring and testing, producers were encouraged to collect the information across four sites of different management or soil/vegetation types.

3.11.3 Laboratory testing

Lab tests conducted included pH(w), pH($CaCl_2$), salinity (electrical conductivity and chloride), total organic carbon (after removal of any inorganic carbon or 'free lime'), total nitrogen, exchangeable Cations, S KCl40, Colwell P, BSES-P, and PBI (PBI was only performed on the 0-10 cm increments). Soil pH was measured using water and calcium chloride ($CaCl_2$; Rayment and Lyons 2011; Method 4A1 and 4B1, respectively). Soil salinity was assessed using electrical conductivity in 1:5 soil:water ($EC_{1:5}$, Rayment and Lyons 2011; Method 3A1) and a correction factor (Slavich and Petterson, 1993), or where $EC_{1:5}$ was greater than 0.5 dS/m in any of the 10 cm increments at a site, salinity was calculated according to Shaw (1999) using electrical conductivity and chloride (Rayment and Lyons 2011; Method 5A2b). Cation exchange capacity was measured by compulsive exchange (Rayment and Lyons 2011; Method 15E1), or by Tucker (1985) with pretreatment where soil samples were saline or alkaline (Rayment and Lyons 2011; Method 15C1). Phosphorus concentration was measured by Colwell and BSES (Rayment and Lyons 2011; Methods 9B and 9G2, respectively), and the P buffering index was measured (Rayment and Lyons 2011; Method 9I2b). Total organic carbon was measured by dry combustion with pre-treatment where required for inorganic carbonates (Rayment and Lyons 2011; Method 6B2 or 6B3), and sulphur KCl extraction at $40^{o}C$ (Rayment and Lyons 2011; Method 10D1).

Results of these tests were provided to producers and compiled to provide a greater regional understanding the distribution of soil properties. Extension material generated with Western Local Land Services (LLS) discussed the relationship of soil properties to the physical observations, and land management.

3.11.4 Field observation reporting

Observations were recorded on field sheets and submitted with soil samples. Results were recorded on a sliding scale and tallied for 5 separate measurements. Each attributed was assessed at the soil surface or top 5 cm. In addition, structure, root volume and structure, slaking and dispersion, biological activity (visual examination of soil and degradation of cotton strips) and soil pH were assessed at 20 cm.

3.11.5 Ground cover reporting

For each observer property, data on monthly fractional ground cover and rainfall between 2001-2024 was obtained from the GeoGlam RAPP online tool (CSIRO 2024). Using this data, for each property, a drought cover level was identified (defined as the 20^{th} percentile monthly minimum summer cover). A trigger month and a trigger cover level (i.e., the month in winter, and the level of cover in this month that if exceeded predicts when minimum summer cover is likely to fall below the 20th percentile level) was identified for each property using linear regression for each winter month (June, July, August) against the month with the minimum summer cover (December, January, February).

3.12 Natural capital framework for rangeland grazing systems

3.12.1 Objective

Objective #4 of the Rangelands Living Skin project was to develop a framework to assess and report on soil natural capital and environmental benefits that is co-designed with industry and compatible with farm business software. However, significant advancement in the natural capital accounting field has occurred in recent years and since the development of the Rangelands Living Skin project in 2019, particularly in the private market. This includes the development and application of multiple natural capital assessment accounting frameworks and emergence of new environmental markets and policies in Australia. To avoid duplication, and to ensure meaningful contribution relevant to NSW rangeland producers, the project shifted focus. It instead provides industry with a review of key considerations and provides recommendations of natural capital accounting (NCA) frameworks that are suitable for application in rangeland grazing systems. Specifically, we aimed to:

i. Assess current natural capital frameworks relevant to Australian grazing systems with regards to suitability for application in rangeland grazing enterprises
ii. Outline the key indicators and methods relevant to natural capital of rangeland grazing systems, identified in collaboration with technical experts and industry stakeholders, and assess these indicators with regards to i) sensitivity to management, ii) measurement and reporting requirements and limitations and iii) use in decision making
iii. Identify key requirements, barriers and knowledge gaps regarding the development of natural capital accounting in rangeland grazing systems
iv. Propose recommendations for implementing and improving access and adoption of NCA in rangeland grazing systems

3.12.2 Approach

Consultation with technical experts, rangeland producers and other industry stakeholders informed the development of the report and recommendations. Specifically, this included:

1. Technical workshop, February 2023

A workshop with natural capital experts to:

- Assess potential of NCA assessment strategies in rangelands to satisfy emerging NCA standards (UNSEEA)
- Define the key elements of an ecological framework and method to account for and report natural capital metrics in rangeland grazing systems.
- Identify research/knowledge gaps regarding natural capital for rangeland environments

17 experts in natural capital, soil carbon, biodiversity, grazing management, ground cover, remote sensing and policy. attended this workshop (with an additional 3 apologies). Key outputs of this workshop included:

1. identifying and assessing existing and emerging methods to assess natural capital in rangeland environments
2. identifying key issues regarding assessment of natural capital in rangeland environments
3. identifying key requirements of natural capital assessment in rangeland environments
4. identifying unique aspects of rangelands that are relevant to natural capital assessment
5. identifying key elements of natural capital in grazing systems
6. identifying and assessing metrics and indicators associated with each element of natural capital for use in natural capital assessment in rangeland environments

A shorter follow up discussion and presentation/summary of the workshop outputs, held virtually in March 2023. 10 people attended this meeting. During this meeting, additional feedback was received and assessment of elements and indicators was further refined.

2. Stakeholder natural capital survey, August 2023

A short survey was circulated to producers in the Rangelands Living Skin project to receive input into the development of a natural capital framework for rangeland grazing systems and guide the stakeholder workshops. Key questions included:

1. How familiar are you with the concept of natural capital and its relevance to your livestock grazing business?
2. Are you currently engaged in any natural capital related projects?
3. If you answered 'Yes' to the previous question, could you please specify what natural capital projects you are currently involved in?
4. The following list covers some of the major indicators used in the assessment of Natural Capital. Which of these do you see as most important and useful in monitoring and reporting for your property, and in your management? (Select up to 5, or suggest additional indicators in text box if needed)
5. Natural capital accounting involves measuring, valuing and reporting on stocks and flows of natural capital assets and ecosystem services. How would involvement in a natural capital accounting system impact your decision making processes related to your grazing and land management practices?
6. To what extent do you believe a natural capital accounting system can help communicate the environmental and social value of your grazing systems to stakeholders such as investors, customers or regulators?
7. What challenges or barriers do you anticipate in implementing a natural capital accounting system for your enterprise/property?
8. What type of support, resources or tools would you require to effectively adopt and integrate a natural capital accounting system for your business?
9. Are there any specific policy or financial incentives that would encourage you to adopt natural capital accounting systems?
10. If Natural Capital Assessment is voluntary, could financial incentives associated with natural capital accounting influence your on-farm decision making?
11. In your opinion, who should be the driver of including Natural Capital Assessment in extensive grazing systems

3. Stakeholder workshops, October/November 2023

Stakeholder natural capital workshops were held after each of the carbon forums in Cobar and Broken Hill, in October and November 2023 (Figure 34). In total, 30 people attended the natural capital workshop, with predominantly producers and industry (LLS, MLA) representatives participating. The objectives of these workshops were to:

1. Identify the most useful elements and indicators of natural capital for rangeland producers

2. Capture producer priorities, perspectives, and requirements regarding the development of natural capital assessment frameworks in rangeland grazing systems

The workshop ran as an interactive, facilitated discussion posing key questions around:

1. Identifying indicators and assessing on a scale of importance and sensitivity
2. Discussion around practice versus outcome payments
3. Farm software – what are you using and what is compatible
4. Self-measurement and reporting
5. Challenges and barriers
6. Support and guidance required.

Figure 34. Participants of the Natural Capital Stakeholder workshop in Cobar, identifying key important and management sensitive indicators

3.13 10 year plan

3.13.1 Objective

With collaboration and co-design at the core of the Rangelands Living Skin project, the 10 year plan captures some of the key elements and learnings from the Project and provides a strategy to improve industry participation and collaboration in rangeland research, development and extension (R, D & E) projects. Specifically, the plan:

1. Provides a collective vision for NSW rangeland grazing systems,
2. Identifies key stakeholders for inclusion in future projects and activities,
3. Provides a snapshot of the current funding environment and emerging opportunities for funding, and
4. Highlights key factors for successful producer engagement and collaboration in rangeland R,D & E to achieve the collective vision.

3.13.2 Approach

All project partners were invited to contribute to the 10 year plan. Feedback on project partners visions, recommendations for successful collaboration and future R,D&E priorities was collected through an online survey. Development of the plan occurred over a series of virtual and in-person meeting in 2023 and 2024, alongside contribution to a shared working document where project partners were invited to contribute directly to the report.

3.14 Monitoring producer knowledge, attitudes, skills and aspirations

To capture information on the knowledge and learning outcomes of core and observer producers involved in the Rangelands Living Skin project, an online survey was completed by producers at the beginning and end of the project, with the same questions repeated each time. Questions asked were:

1. How would you rate your knowledge of farm management strategies to increase soil carbon? (no knowledge; very little knowledge; some knowledge; sound knowledge (sufficient to act); very sound (can give detailed explanation))
2. How would you rate your knowledge of the benefits of increasing ground cover and soil carbon on your farm for productivity? (no knowledge; very little knowledge; some knowledge; sound knowledge (sufficient to act); very sound (can give detailed explanation)).
3. How would you rate your knowledge of the benefits of increasing ground cover and soil carbon on your farm for ecosystem services? (no knowledge; very little knowledge; some knowledge; sound knowledge (sufficient to act); very sound (can give detailed explanation))
4. I have enough information and knowledge to be able to weigh up the advantages and disadvantages of carbon farming (including trading vegetation carbon and/or soil carbon) (no knowledge; very little knowledge; some knowledge; sound knowledge (sufficient to act); very sound (can give detailed explanation))
5. Increasing soil carbon can reduce soil loss from wind and water erosion. (strongly disagree, disagree, unsure, agree, strongly agree)

6. How would you rate your knowledge of monitoring and managing the following components of the feedbase on your property? (no knowledge; very little knowledge; some knowledge; sound knowledge (sufficient to act); very sound (can give detailed explanation))
7. How do you monitor the feedbase (e.g. feed on offer, quality, composition and diversity) on your property? (Select all that are relevant)
8. In general, how often do you monitor the feedbase on your property?
9. How often do you monitor vegetation cover on your property?
10. In general, how often do you monitor vegetation cover on your property?
11. How would you rate your knowledge of the different types of ground cover and roles each have on productivity and ecosystem services? (no knowledge; very little knowledge; some knowledge; sound knowledge (sufficient to act); very sound (can give detailed explanation))
12. What information do you use when you make your grazing management decisions?
13. What tools do you use to assist in making grazing decisions
14. Select any variables that contribute to on-farm emissions of grazing enterprises (not necessarily your own)
15. How would you rate your knowledge of soil biological health? (no knowledge; very little knowledge; some knowledge; sound knowledge (sufficient to act); very sound (can give detailed explanation))
16. What methods can be used to assess soil biological health?

Questions unique to baseline survey:

17. Have you previously undertaken training in the following areas? Soil carbon, Carbon farming/trading, Soil biology, Ground cover, Landscape function, Feedbase, Biodiversity, Grazing management, Greenhouse gas emissions on farm, Other (please specify)
18. What are you hoping to get out of the Rangelands Living Skin Project by your involvement? (in your own words)
19. Briefly describe your approach to managing your property – e.g. your pasture, your soil, your grazing management, your livestock, your environment, and, if you wish, your business management (in your own words)

Questions unique to final survey:

20. Have you via or because of this Living Skin project now undertaken training in the following areas? Soil carbon, Carbon farming/trading, Soil biology, Ground cover, Landscape function, Feedbase, Biodiversity, Grazing management, Greenhouse gas emissions on farm, Other (please specify)
21. What did you get out of the Rangelands Living Skin Project by your involvement?
22. Briefly describe any change you have made to your approach to managing your property as a result of the Living Skin project – e.g. your pasture, your soil, your grazing management, your livestock, your environment, and, if you wish, your business management

4 Results

4.1 Review of co-design approach and project feedback

4.1.1 Key benefits of the collaborative approach:

- **Enhanced Knowledge Exchange:** Collaboration between landholders and researchers facilitated the exchange of valuable insights and expertise, ensuring project relevance and greater impact and communication of project outcomes.
- **Resource Access and Support:** Through collaboration, producers gained access to valuable resources, such as grazing management and business coaching, soil biology coaching, carbon audits, farm planning and monitoring software (Maia Grazing and Cibo Labs) and benchmarking platforms, empowering them with the tools necessary for sustainable management practices.
- **Networking Opportunities:** Collaboration fostered networking opportunities across diverse groups and organizations, facilitating knowledge-sharing, relationship-building, and the formation of supportive networks within the industry.
- **Scale and Impact:** By collaborating across multiple organizations and stakeholders, the project achieved a broader scale and greater impact, covering extensive geographical areas and addressing diverse landscape and practice challenges.
- **Positive Industry Influence**: the collaborative nature and initiatives of the Rangelands Living Skin facilitated discussions, promoted best practices, and encouraged the adoption of sustainable management approaches, ultimately contributing to the long-term resilience and viability of the industry

4.1.2 Challenges to project delivery

- **External factors and disruptions** – disruptions caused by external factors such as COVID-19, floods and droughts, and travel restrictions impacted fieldwork, extension activities and project momentum. This was addressed through a flexible approach to the delivery of research and extension activities, including post-poning events, hosting online events, and adjusting research methodology to focus on different questions and using remote sensing technologies.
- **Staff turnover** – high turnover of key personnel, leading to a loss of continuity and knowledge transfer. In addition to periods of absence and illness of key project staff. This was addressed by involving a diversity of staff in each of the project team organisations and ensuring regular communication, although remained a challenge throughout the project.
- **Engagement**. At times, reduced potential engagement and participation, partly due to multiple project events, competing events across the region ("engagement fatigue"), low population, long distances between people and challenges in accessing remote areas. Challenges in attracting and retaining observer producers with limited personal contact and flexibility in involvement. With a long project duration, at times also challenges in maintaining engagement and communication among project team members and stakeholders. Challenges were also found in engaging producers (incl. observers) in the monitoring. This was addressed as best possible by timing events to fit the availability of producers (including a survey of producers for the timing and topics that worked best for

them), hosting events in a diversity of formats, providing as much lead-time as possible in the planning and advertising of events, utilising networks of multiple partner organisations and the core producers to promote events and hosting regular (monthly) online meetings with the whole project team to provide updates and share results.

- **Project scope and complexity -** lack of clarity regarding the projects purpose and vision lead to difficulties in achieving clear outcomes and managing competing priorities, and challenges in coordinating activities and aligning stakeholders with diverse interests and motivations. With contracted deliverables, this was challenging to address, however was met as best-possible by ensuring that all activities and outputs were provided a meaningful contribution to current knowledge and were directly related to achieving project objectives. A more targeted scope and objectives in future projects and managing expectations related to research trials and project outcomes is recommended.
- **Project management -** Balancing contracted deliverables with changing project priorities over life of project. At times, conflicting perspectives between private/public organisations and science/non-science approaches. Regular, open communication was key to addressing this over the life of the project.
- **Research -** Balancing scientific design and methods/rigor with practicalities of producer priorities, environmental context, management and seasonal conditions. This was addressed by ensuring research is meaningful and adds value for producers, and managing expectations in what can be achieved through research, incl. given project budget, resources, method and timeframes.

4.2 Extension, capacity building and communication activities

4.2.1 Field days

11 field days were hosted on core producer and observer properties over the duration of the project, covering a variety of topics (Figure 35, Table 3). Full MER datasets from the below documented events are available in corresponding milestone reports. Due to travel health restrictions in 2020 and 2021, events in this period were postponed or shifted to online webinars which provided opportunities for producers to discuss the topics with expert presenters and other producers (see below for more information).

Table 3. Summary of field days hosted through the Rangelands Living Skin project

Date	Location	Topics	Attendees	Ha managed	Livestock managed	Overall event satisfaction score
February 2022	Wyndham Station, Wentworth	RLS project field day - Producing in the rangelands - Rangeland soils as carbon sinks - Pasture walk, plant ID and diversity - Biological crusts - Living soils - Biodiversity on pastoral properties	10			
August 2022	Etiwanda, Cobar	RCS KIT day/project field day importance of 'WHY?', addressing hard capped soils through multispecies cropping & livestock integration, and improving landscape health/drought resilience and increasing production/profit	26	99,878 (where reported)		
September 2022	Glencoe, Hay	RCS KIT day importance of perennial plants and recovery/rest, infrastructure for large mobs, hydration in flat terrain and retaining organic matter in soil, and keeping living plants in the pasture 12 months of the year	8			
February 2023	Kalyanka, Wilcannia	Key topics of this day included looking after your country, managing livestock and flexibility looking for opportunity	5			
February 2023	Oakbank, Wentworth	regeneration of palatable perennial grasses, maintain perennial overstory regeneration and soil carbon management	5	50,000 (where reported)		
March 2023	Bokhara Plains, Brewarrina	Combined project field day & workshops - Bokhara Plains Management - Grazing management - Groundcover - Soil carbon - Soil monitoring	40			8.5/10

Date	Location	Topics	Attendees	Ha managed	Livestock managed	Overall event satisfaction score
November 2023	Thurmylae, Enngonia	RCS KIT day - Managing total grazing pressure - Improving severely degraded landscapes - Importance of having people connected to the land	18	518,405	20,400 cattle, 3200 sheep (where reported)	3.36/4
November 2023	Tiltagoona, Tilpa	Project field day & RCS KIT day - Grazing management in mulga country - Using fire as a tool for landscape management - Biodiversity and wildlife - Managing human health	2			
March 2024	Wyndham Station, Wentworth	End of project field day - Core producer management - RLS project summary - Virtual fencing - Sheep genetics - pasture observations - waterponding - soil carbon - financial benchmarking	42	93969 Ha (where reported)	31500 sheep, 2900 cattle (where reported)	9/10
April 2024	Bokhara Plains, Brewarrina	End of project field day - core producer management - grazing management - scald reclamation - beef and sheep genetics for rangeland grazing enterprises - young people in rangelands	32	537,669 Ha (where reported)	1,400 sheep, 17,420 cattle + calves (where reported)	9.2/10
May 2024	Gurrawarra, Bourke	End of project field day -Gurrawarra management -grazing management - property planning with RCS - Rangeland restoration and rehydration - Gypsum and scald reclamation	25	130,195 (where reported)	11,400 sheep, 6,850 cattle, 3,000 goats (where reported)	8.3/10

Figure 35. Clockwise from top left: Wyndham field day, February 2022; Wyndham field day, March 2024; Bokhara field day, April 2024; Thurmylae field day, November 2023; Gurrawarra field day, May 2024; Wyndham field day, March 2024

4.2.2 Grazing clinics and workshops

Over the duration of the Rangelands Living Skin project, over 9 workshops were held, both in-person and virtually on a range of topics including soil carbon, soil monitoring, soil biology, ground cover, grazing management, business management and natural capital. A summary of these workshops is provided in Table 4.

Table 4. Summary of workshops hosted through the Rangelands Living Skin project

Date	Location	Topic	Attendees	Outcomes
2021	Online	Recorded training videos: 1. 'Building Resilience in the Rangelands' with commentary from Dr Susan Orgill (NSW DPI), Dr Craig Strong (ANU) and Ms Kirsty Yeates (ANU and Soils for Life). 2. Series of short training videos supporting workshop learnings on topics including: Soil sampling, Pastures in the Rangelands, Soil Carbon, Landscape Function, Mapping 3. Case study video presented at the Rangelands Conference on Rehydration works on Katalpa Station	NA	Total views of all videos as of August 2024 is 2469, with an average of 352 views per video. No further information on outcomes able to be captured via this format.
March 2022	Bourke	RCS grazing clinic	22	9.2/10 overall satisfaction Of the 9 participants that responded post workshop on their skills, all responded with an increase in understanding of the skills asked: • Understanding stock numbers • Producing stock records • Photo points • Grass Budgets • Grazing Charts/MAIA Grazing • Gross margin calculations • Full Business Analysis
November 2022	Netallie station, Wilcannia	Soil monitoring Soil Biology		9.1/10 overall satisfaction • Overall, 13 of the 15 evaluations received indicated an increase in knowledge and skills regarding soil monitoring following the event. 11

Date	Location	Topic	Attendees	Outcomes
				of 15 indicated they would be making changes to their management practices. • Overall, attendees rated their increased understanding or skills in soil biology as a 7.7/10. 11 of 14 respondents indicated they would be making a change to their management practices/business as a result of attending.
March 2023	Bokhara Plains, Brewarrina	Ground cover Soil Monitoring	32	*Soil monitoring* • 16 of 27 respondents reported an increase in skills and knowledge of soils and monitoring soil condition following the workshop. • 20 of 27 respondents indicated that they would be making changes to their management as a result of attending the workshop *Ground cover* • How much do you feel you increased your understanding of the importance of groundcover today?: 7.7/10 • How much do you feel you increased your ability to assess the percentage of groundcover?: 6.9/10 • 9 of 19 respondents indicated that they would be making changes to their management as a result of attending the workshop.
March 2023	Broken Hill	RCS grazing clinic	5	9.8/10 course met expectations. 9.4/10 participants are likely to implement changes as a result of attending the course.
March 2023	Warrananga, Wentworth	Ground cover Soil Biology Soil monitoring	10	7.9 overall satisfaction *Soil biology*

Date	Location	Topic	Attendees	Outcomes
				• 6 of 9 respondents reported an increase in skills and knowledge of soil biology following the workshop. • 7 of 9 respondents indicated that they would be making changes to their management as a result of attending the workshop *Soil monitoring* • 7 of 9 respondents reported an increase in skills and knowledge of soils and monitoring soil condition following the workshop. • 3 of 8 respondents indicated that they would be making changes to their management as a result of attending the workshop *Ground cover* • How much do you feel you increased your understanding of the importance of groundcover today?: 6/10 • How much do you feel you increased your ability to assess the percentage of groundcover?: 6/10 • 2 of 7 respondents indicated that they would be making changes to their management as a result of attending the workshop
July-September 2023	Online	RCS business fundamentals workshop	13	
October 2023	Cobar	Soil Carbon, Carbon Farming, Carbon Accounting, Environmental markets, Rangeland Rehydration, Natural Capital	49	What score out of 10 would you give this event for your overall satisfaction? 8.1/10. 74% of respondents indicated they learnt something that makes them better informed to make decisions in this space in the future

Date	Location	Topic	Attendees	Outcomes
November 2023	Broken Hill	Soil Carbon, Carbon Farming, Carbon Accounting Environmental markets, Rangeland Rehydration, Natural Capital	29	What score out of 10 would you give this event for your overall satisfaction? 8/10. 81% of respondents indicated they learnt something that makes them better informed to make decisions in this space in the future

Figure 36. Demonstrations in the field at the soil monitoring and soil biology workshop at Netallie

Figure 37. Photos of the panel discussion (Cobar) and Robert Crossley presenting (Broken Hill) at the Soil Carbon and Carbon Farming workshops in October/November

4.2.3 Online Lunchtime discussions

To compensate for restrictions to in-person engagements in 2020 and 2021, the Rangelands Living Skin project hosted online lunchtime 'discussion' sessions throughout the length of the project with a variety of expert speakers, involving a short 15 minute presentation by the guest speaker and followed by a 45 minute- 1 hour discussion and Q&A session between the online participants. Sessions were recorded and available to all project participants an in addition the project 'keep in touch' email list which had a broader reach across Australia. A summary of the presenters and topics is provided in Table 5 below.

Table 5. Summary of online lunchtime discussions hosted through the Rangelands Living Skin project

Date	Guest Presenter	Topic	MER
22 October 2021	Craig Strong	Wind erosion	NA
14 Feb 2022	Sue Ogilvy & Danny O'Brien	Natural Capital	From today's discussion, have you learnt anything new? Yes No Maybe? 100% Yes (7 responses) From today's discussion, is there anything you will do differently? Yes 30% No 23% Maybe 46% (4, 3, 6 people) 23 people attended live 25 views of recording
14 June 2022	Lee Fieldhouse	Soil Biological Inputs	From today's discussion, have you learnt anything new? 2 responses, both yes Approximately 10 attendees 1 view of recording
4 July 2022	Bruce Maynard	Grazing management, self herding and no-kill cropping	11 attendees to live event 48 views of recording after the event
28 July 2023	Eren Turak	Ecology / Biodiversity	12 Live attendees 19 views of recording
1 September 2023	Greg Curran	Climate patterns Drier and Wetter Times	7 attendees to live event 21 views of recording MER question: To what extent has today's session increased your

			understanding of this topic? (On a scale of 1-5) Answers (from 4 people) 4, 3, 4, 3
19 September 2023	Terry McCosker	Grazing management	9 attendees (Note: technology did not allow for evaluation on the day) 34 views of recording
31 May 2024	Aaron Simmons	GHG and methane Greenhouse Gases in agriculture	9 attended Live 10 views of recording
12 June 2024	John Leys	Predicting Drought using Satellite Ground Cover	16 attended live 7 views
18 September 2024	Luke Beange Sarah McDonald Karl Andersson Jessica Riggs Rob Crossley Craig Strong James Barnett Harriet Finlayson Glenn Humbert Angus Whyte Mitch Plumbe	Summary presentations of key research and data components of the RLS project	39 attendees (including presenters). 13 views of the recording.

4.2.4 Presentations

A summary of presentations at events across Australia by project partners over the life of the project is provided in Table 6.

Table 6. Summary of presentations over the life of the Rangelands Living Skin project

Date	Presenter	Event	Topic
March 2021	Graham & Harriet Finlayson	MeatUp Forum, Cobar	Rangelands Living Skin
March 2021	Graham & Harriet Finlayson	MeatUp Forum, Charleville	Rangelands Living Skin
June 2021	Harriet Finlayson	MeatUp Forum, Broken Hill	Rangelands Living Skin
October 2021	Susan Orgill	NRM in the Rangelands Conference, Longreach	Rangelands Living Skin Project
October 2021	Angus Whyte	NRM in the Rangelands Conference, Longreach	'Why I consider Conservative Set Stocking a myth'
April 2023	Sarah McDonald	Rangelands Forum, Hay	Rangelands Living Skin project
September 2023	Harriet Finlayson	Soils for Life workshop, Cavan Station	Panel session
September 2023	Angus Whyte	Australian Rangelands Conference, Broome	'Achieving productivity and environment

			outcomes through collaborative research' (Figure 38).
September 2023	Sarah McDonald	Australian Rangelands Conference, Broome	Detecting change from grazing management in NSW rangelands using remote sensing'
September 2024	Mitchell Plumbe	Regenerating rangelands conference, Cunnamulla	Rangelands Living Skin project findings

Figure 38. Angus Whyte and Sarah McDonald presenting on the Rangelands Living Skin at the Australian Rangeland Society conference in Broome, September 2023

Seven abstracts relevant to the Rangelands Living Skin project outcomes have been accepted to the International Rangelands Congress, to be presented in June 2025, Adelaide. These include:

- Herd effect and deep ripping to restore claypans in western NSW rangelands (S.E. McDonald, G. Finlayson, S.E. Orgill, C. Strong, K. Andersson)
- The rangelands living skin project: lessons for co-designed, collaborative research in NSW rangelands (S.E. McDonald, M. Plumbe, S.E. Orgill, K.O. Andersson)
- Soil carbon levels in NSW rangelands (K.O. Andersson, S.E. McDonald, S.E. Orgill)
- Using gypsum to ameliorate a scalded claypan with salinity close to seawater concentrations (K.O. Andersson, S.E. McDonald, C. Strong, G. Humbert, J. Conder, D. Schneider)
- Know your numbers: soil carbon sequestration has the potential to support carbon neutral red meat and wool production in the semi-arid rangelands of Australia (JL Rigg, L Newey, B Hackney, SE McDonald and SE Orgill)
- Soil testing to support decision making in the rangelands (K.O. Andersson, S.E. Orgill, C. Strong)
- Predicting Drought Using Remotely Sensed Vegetation Cover (J. F. Leys, S. McDonald, G, Turnbull)

Copies of these abstracts are provided in Section 8.2. Full papers for each presentation will be published in the Congress proceedings.

4.2.5 Newsletter articles

Over the life of the project, numerous articles relevant to the Rangelands Living Skin project theme and outputs have been published in various newsletters and media, including:

- Strategic destocking decisions (MLA):

https://www.mla.com.au/news-and-events/industry-news/striking-the-balance-of-strategic-stock-management/?utm_campaign=477550_The%20Weekly%2024%20Nov%202023&utm_medium=email&utm_source=Meat%20%26%20Livestock%20Australia&dm_i=4PKB,A8HA,5729ZL,17JQW,1

- Waterponding for Rangelands Repair & Rehydration (Soils for Life): https://soilsforlife.org.au/water-ponding-for-rangelands-repair-and-rehydration/
- Farmer Researchers (Herd Impact trial) (Soils for Life): https://soilsforlife.org.au/farmer-researcher/
- Experimenting with bio-stimulants in the rangelands (Soils for Life): https://soilsforlife.org.au/experimenting-with-bio-stimulants-in-the-rangelands/
- Rain ready in the rangelands; Collectively learning with Rangelands Living Skin project (MLA) https://www.mla.com.au/globalassets/mla-corporate/news-and-events/documents/mla-feedback-autumn-2022-web.pdf
- Above and Below Ground Monitoring in the Rangelands (Soils for Life): https://soilsforlife.org.au/above-and-below-ground-monitoring-in-the-rangelands/
- Investing in the southern rangelands – the rangelands living skin project (CarbonLink): https://carbonlink.com.au/investing-in-the-southern-rangelands-the-rangelands-living-skin-project/
- Profitable Rangeland Landscapes (RCS): https://www.rcsaustralia.com.au/profitable-rangeland-landscapes/
- Water ponding rehydrates rangelands (MLA): https://www.mla.com.au/globalassets/mla-corporate/news-and-events/documents/mla-feedback-autumn-2023-web.pdf
- Carbon accounting in rangeland grazing systems (Select Carbon) https://www.mla.com.au/news-and-events/industry-news/the-living-skin-of-the-rangelands/
- Building a resilient Landscape and Business (RCS) https://www.rcsaustralia.com.au/wp-content/uploads/RLS-Building-a-Reselient-Landscape-and-Business-July-2024.pdf
- Successful Rangeland Living Skin Field Day held at Wyndham Station (Western LLS) https://www.lls.nsw.gov.au/news-and-events/news/w-news/2025/successful-field-day-held-at-wyndham-station
- New Rangeland Grazing Systems study shows promising results for livestock producers (NSW DPI) https://www.dpi.nsw.gov.au/about-us/media-centre/releases/2024/general/new-rangeland-grazing-systems-study-shows-promising-results-for-livestock-producers?fbclid=IwY2xjawGqD_tleHRuA2FlbQIxMAABHQUbsGpSu27X2VFYeEj_zDRkfjjo9aNcLPXfgbqJILTr6vgycv28t8tpOA_aem_o9-MBnM_W2TfSMl7_g2jUA
- Skin in the game for rangelands future (MLA) https://www.mla.com.au/globalassets/mla-corporate/news-and-events/documents/publications/mla-feedback-summer-2024-web-a.pdf

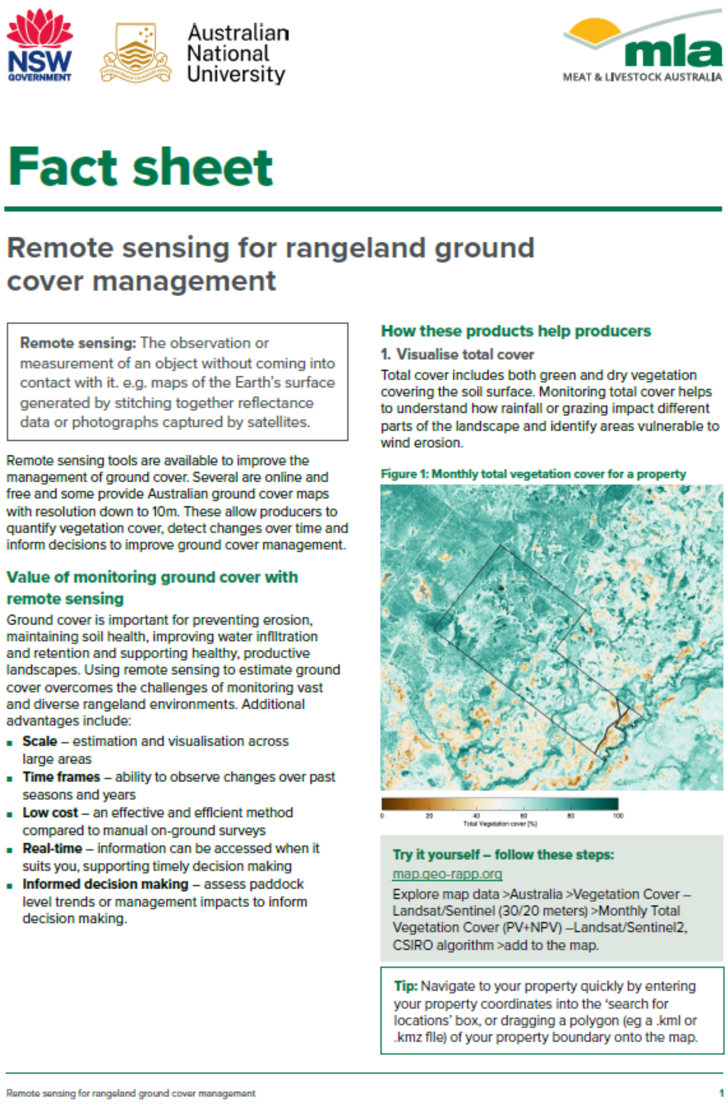
4.2.6 Case studies

For each of the core producer properties involved in the Rangelands Living Skins project, Soils for Life developed digital case studies that document the practices they are implementing, their expertise and experiences, and their specific experience, practices and findings as part of the Project. Links to each case study are provided below.

Bokhara Plains Case Study	https://soilsforlife.org.au/bokhara-plains-rangelands-resilience/
Etiwanda Case Study	https://soilsforlife.org.au/etiwanda/
Gurrawarra Case Study	https://soilsforlife.org.au/gurrawarra/
Wyndham Case Study	https://soilsforlife.org.au/wyndham-station-willow-point/

4.2.7 Fact sheet

A fact sheet, titled 'Remote sensing for rangeland ground cover management' was developed and published online, and circulated to producers and other extension and practitioners in the project mailing list (Figure 39). The fact sheet focussed on providing information on the value of monitoring ground cover with remote sensing and how these products can help producers to visualise total cover and different types of cover over different seasons, track trends in cover over time, compare ground cover with a benchmark or between management areas, identify areas of long term low ground cover and explore ground cover response to recent rainfall. A copy of this fact sheet is provided in Section 8.1 and available online here mla-remote-sensing-for-rangeland-groundcover-factsheet-0524_v07---final.pdf



Fact sheet

Remote sensing for rangeland ground cover management

Remote sensing: The observation or measurement of an object without coming into contact with it. e.g. maps of the Earth's surface generated by stitching together reflectance data or photographs captured by satellites.

Remote sensing tools are available to improve the management of ground cover. Several are online and free and some provide Australian ground cover maps with resolution down to 10m. These allow producers to quantify vegetation cover, detect changes over time and inform decisions to improve ground cover management.

Value of monitoring ground cover with remote sensing

Ground cover is important for preventing erosion, maintaining soil health, improving water infiltration and retention and supporting healthy, productive landscapes. Using remote sensing to estimate ground cover overcomes the challenges of monitoring vast and diverse rangeland environments. Additional advantages include:

- **Scale** – estimation and visualisation across large areas
- **Time frames** – ability to observe changes over past seasons and years
- **Low cost** – an effective and efficient method compared to manual on-ground surveys
- **Real-time** – information can be accessed when it suits you, supporting timely decision making
- **Informed decision making** – assess paddock level trends or management impacts to inform decision making.

How these products help producers

1. Visualise total cover

Total cover includes both green and dry vegetation covering the soil surface. Monitoring total cover helps to understand how rainfall or grazing impact different parts of the landscape and identify areas vulnerable to wind erosion.

Figure 1: Monthly total vegetation cover for a property

Try it yourself – follow these steps:

map.geo-rapp.org

Explore map data >Australia >Vegetation Cover – Landsat/Sentinel (30/20 meters) >Monthly Total Vegetation Cover (PV+NPV) –Landsat/Sentinel2, CSIRO algorithm >add to the map.

Tip: Navigate to your property quickly by entering your property coordinates into the 'search for locations' box, or dragging a polygon (eg a .kml or .kmz file) of your property boundary onto the map.

Remote sensing for rangeland ground cover management 1

Figure 39. First page of the fact sheet on remote sensing for rangeland ground cover management

4.2.8 Artwork competition

The winner of the Rangelands Living Skin Artwork competition (George Mashford from Katalpa Station, White Cliffs, Figure 40) was announced via NSW DPI media release and Soils for Life social media. Panellists included the Hon Penelope Wensley (National Soil Advocate), Janet Laurence (Earth Canvas artist) and Angus Whyte (PDS host). This was a great opportunity to get high profile awareness of the project and facilitate discussions between the National Soil Advocate and one of the Rangeland Living Skin Projects core producers.

Figure 40. The winning artwork for the Rangelands Living Skin artwork competition, by George Mashford from Katalpa Station

4.2.9 Social media/communication platforms

The Rangelands Living Skin Facebook group started in July 2021 for anyone involved in the project or generally interested in rangelands to discuss different practices, share events, build networks and learn from each other. The development of the group was particularly important due to increasing COVID restrictions causing cancellation of events and important networking opportunities. The group has a total of 89 members (as at August 2024). Group members are predominantly from NSW, however the reach of members is nation-wide and continues to grow.

A project WhatsApp group was also created for project producers and other interested producer, researcher and practitioners to share news and events, ask questions and increase producer-producer and producer-researcher-practitioner engagement.

Soils for Life also published a numbers of project related videos on YouTube (

Table 7) and shared updates and articles via their social media platforms (Twitter (X), LinkedIn, Instagram, Facebook).

Table 7. Summary of videos produced for the Rangelands Living Skin and views on YouTube

Produced videos	YouTube views*
Rangelands Living Skin: Andrew Mosley	362
Rangelands Living Skin: Gus Whyte	352
Rangelands Living Skin: Tony Thompson	353
Rangelands Living Skin: Meet Dr Susan Orgill	257
Rangelands Living Skin: Graham Finlayson	340
Rangelands Living Skin Project: Graham Finlayson (MLA branded)	176
Rangelands Living Skin: Meet Mitch Plumbe	120
Building Resilience in the Rangelands	39
Rangelands Rehydration at Katalpa Station	332
World Soils Day 2021 (Featuring RLS farmers)	592
Mapping exercise: Selecting for Carbon	66
National Soils Advocate (Dept PMC) Soil Organic Carbon Forum Farmer Case Study Angus Whyte Wentworth NSW (Vimeo) https://vimeo.com/539462971?fbclid=IwAR2BCl24gW49_gCZxTIskVCFGPIY7SAEEkwod5yZCrcbRz9y9P4NsGabNJ0	106

4.3 Baselining soil organic carbon in Western NSW rangelands

4.3.1 Relationship of soil carbon with above-ground pasture and landscape variables

As expected, many of the pasture variables explained a good proportion of the variance in the soil organic carbon variables with plant cover (%) explaining 23% of the variation in SOC 0-5 cm (R^2=0.23, R=0.48), while bare ground cover was negatively correlated (R^2=0.18, R=-0.43). These relationships weakened as depth in the soil profile increased (Figure 41). When mixed models with CEA (carbon estimation area) as a random effect were fitted the variance explained by many of the models was greater than 70%. This variation can be apportioned to the fixed (pasture variable) and random (CEA) effect(s) in each model. The variation explained by the fixed effect (pasture variable) of each model are shown in Figure 42. This shows no or very weak ($R^2 < 0.05$) relationships between the pasture and soil organic carbon variables after accounting for CEA effects. That is, at a paddock scale, within a paddock, there was little to no relationship between the pasture and SOC data.

	Plant cover (%)	Litter cover (%)	Vegetative cover (%)	Cryptogam cover (%)	Bare ground (%)	Green Biomas (%)	Biomass (kg/ha)	Nearest tree/shrub (m)	Species richness	Perennial cover (%)	Annual cover (%)	Native cover (%)	Exotic cover (%)
SOC 0−5cm	0.23	0	0.17	0	0.18	0	0.02	0.23	0.15	0.07	0.09	0.16	0.03
SOC 5−10cm	0.17	0.01	0.11	0	0.11	0	0.02	0.2	0.11	0.07	0.05	0.16	0
SOC 10−15cm	0.14	0.01	0.08	0	0.09	0	0.02	0.17	0.14	0.08	0.02	0.14	0
SOC 15−20cm	0.12	0.01	0.06	0	0.07	0	0.02	0.14	0.14	0.07	0.02	0.13	0
SOC 20−25cm	0.1	0	0.06	0	0.06	0	0.02	0.11	0.14	0.06	0.01	0.11	0
SOC 25−30cm	0.09	0	0.06	0	0.05	0	0.01	0.1	0.12	0.05	0.02	0.1	0
SOC 30−35cm	0.07	0	0.04	0	0.04	0	0.01	0.07	0.05	0.04	0.01	0.08	0
SOC 35−40cm	0.02	0	0.01	0	0.02	0	0.01	0.02	0.02	0.01	0.01	0.03	0
SOC 40−45cm	0.02	0	0.02	0	0.02	0	0.03	0.01	0.01	0.01	0.01	0.02	0
SOC 45−50cm	0.01	0	0.01	0	0.01	0	0.02	0	0	0	0.01	0.01	0
SOC 50−55cm	0.01	0	0.01	0	0.01	0	0.01	0	0	0	0.01	0	0
SOC 0−10cm	0.22	0	0.16	0	0.16	0	0.02	0.24	0.15	0.07	0.08	0.17	0.02
SOC 0−20cm	0.2	0.01	0.13	0	0.13	0	0.02	0.22	0.16	0.08	0.06	0.17	0.01
SOC 0−30cm	0.18	0.01	0.11	0	0.12	0	0.02	0.2	0.16	0.08	0.05	0.17	0
SOC 0−50cm	0.16	0	0.1	0	0.11	0	0.03	0.17	0.13	0.07	0.04	0.15	0
SOC 0−100cm	0.11	0	0.07	0	0.06	0	0.03	0.1	0.03	0.06	0.02	0.08	0.01

Figure 41. R^2 values of analysis between each pasture variable and soil organic carbon stocks (SOC t ha^{-1}) at each 5 cm depth increment (to 55 cm depth) or cumulative depth increment for the overall dataset. Blue shaded cells reflect a positive relationship, and red shaded cells a negative relationship.

	Plant cover (%)	Litter cover (%)	Vegetative cover (%)	Cryptogam cover (%)	Bare ground (%)	Green Biomas (%)	Biomass (kg/ha)	Nearest tree/shrub (m)	Species richness	Perennial cover (%)	Annual cover (%)	Native cover (%)	Exotic cover (%)
SOC 0−5cm	0.05	0	0.04	0	0.04	0	0.02	0	0.01	0.02	0.01	0.03	0.01
SOC 5−10cm	0.01	0	0.01	0	0.01	0	0	0	0	0	0	0	0
SOC 10−15cm	0	0	0	0	0.01	0	0	0	0	0	0	0	0
SOC 15−20cm	0	0	0	0	0	0	0	0	0	0	0	0	0
SOC 20−25cm	0	0	0	0	0	0	0	0	0	0	0	0	0
SOC 25−30cm	0	0	0	0	0	0	0	0	0	0	0	0	0
SOC 30−35cm	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0
SOC 35−40cm	0	0	0	0	0	0	0	0	0	0.01	0	0.01	0
SOC 40−45cm	0	0	0	0	0	0	0	0	0	0	0	0	0
SOC 45−50cm	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0
SOC 50−55cm	0	0	0	0	0	0	0	0	0	0.02	0.01	0.01	0
SOC 0−10cm	0.03	0	0.03	0	0.03	0	0.01	0	0	0.01	0.01	0.02	0.01
SOC 0−20cm	0.01	0	0.01	0	0.02	0	0	0	0	0.01	0	0.01	0
SOC 0−30cm	0.01	0	0.01	0	0.01	0	0	0	0	0	0	0	0
SOC 0−50cm	0	0	0.01	0	0.01	0	0	0	0	0	0.01	0	0
SOC 0−100cm	0	0	0	0	0.01	0	0	0	0	0	0	0	0

Figure 42. R^2 values of analysis between each pasture variable and soil organic carbon stocks (SOC t ha^{-1}) at each 5 cm depth increment (to 55 cm depth) or cumulative depth increment within each CEA. Blue shaded cells reflect a positive relationship, and red shaded cells a negative relationship.

4.3.2 Relationship of 0-10 and 0-30 cm soil carbon

Soil organic carbon concentration (%) and stock (t C/ha) at 0-10 cm depth was significantly related to that at 0-30 cm depth in all regions (Brewarrina, Cobar and Pooncarie) (Figure 43), however the relationship varied slightly with each sampling site (Figure 44). Adding District to a simple regression of 0-30 cm versus 0-10 cm SOC reduced the residual standard error from 2.14 to 2.04 and raised the R^2 from 0.88 to 0.89 with F=17.4 and p=0 for F test. The model with CEA added had an RSE of 1.67, R^2 of 0.93 and F= 14.5 p=0 for F test, and was the best model.

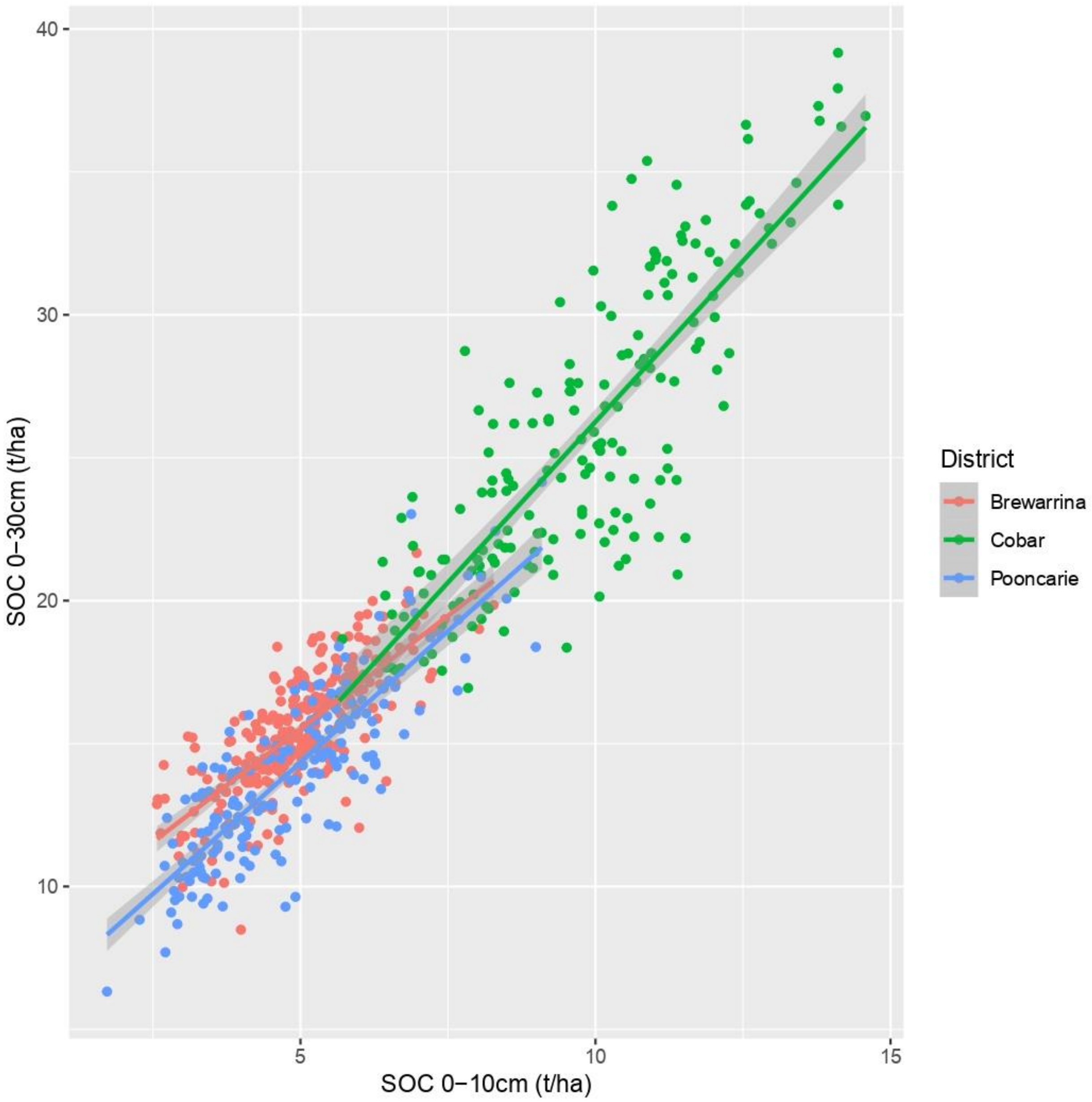


Figure 43. Correlations between SOC 0-10 and SOC 0-30 (t ha^{-1}), by sampling district

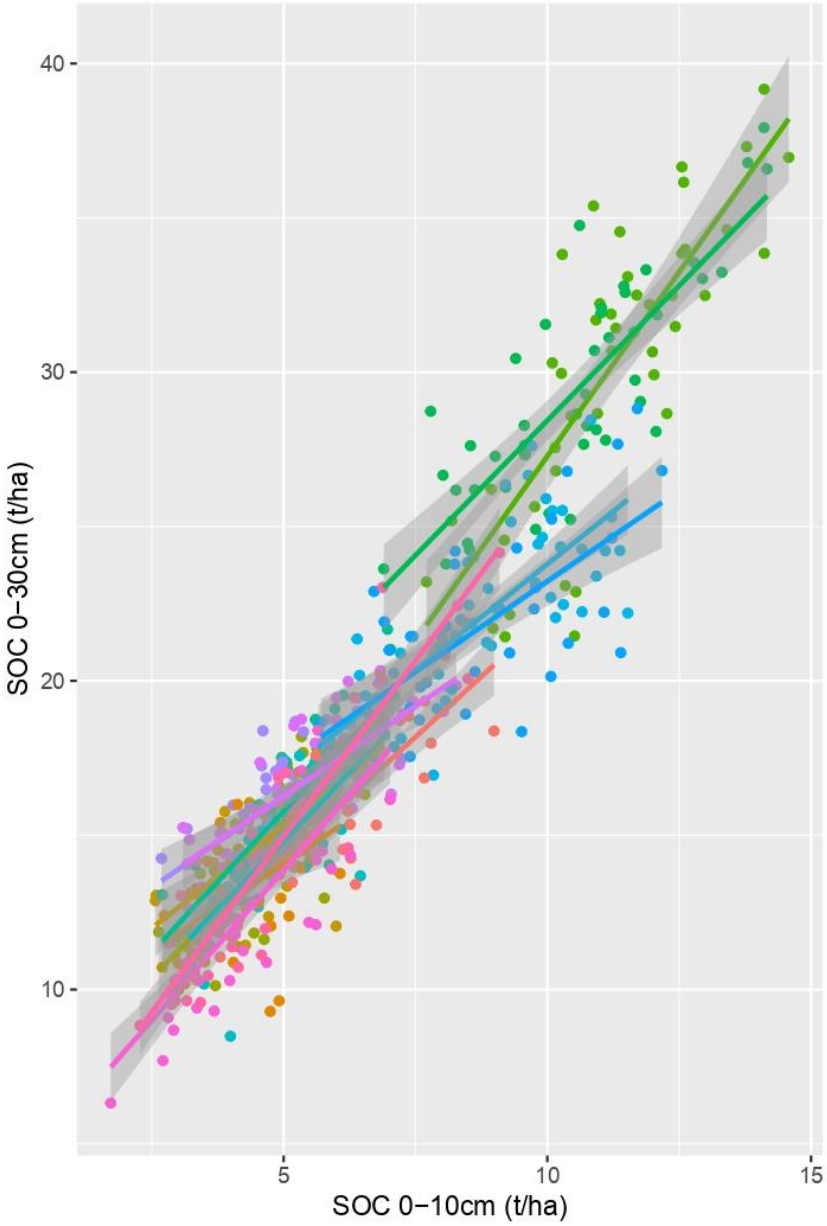


Figure 44. Correlations between SOC (t ha^{-1}) 0-10 cm and SOC 0-30 cm, by carbon estimation area (CEA). Each coloured line represents a different CEA

4.3.3 Soil carbon spatial variability

A variogram was calculated for each CEA and for each strata within each CEA to understand if differences between the strata influenced the variance between samples. The variogram analysis revealed no trend in the variance of carbon concentration or stock across a carbon estimation area, indicating significant variability across the areas regardless of sampling distance apart (Figure 50 - Figure 51Figure 49). Variability was greatest across CEAs sampled in the Cobar district and smallest across sites in the Brewarrina district.

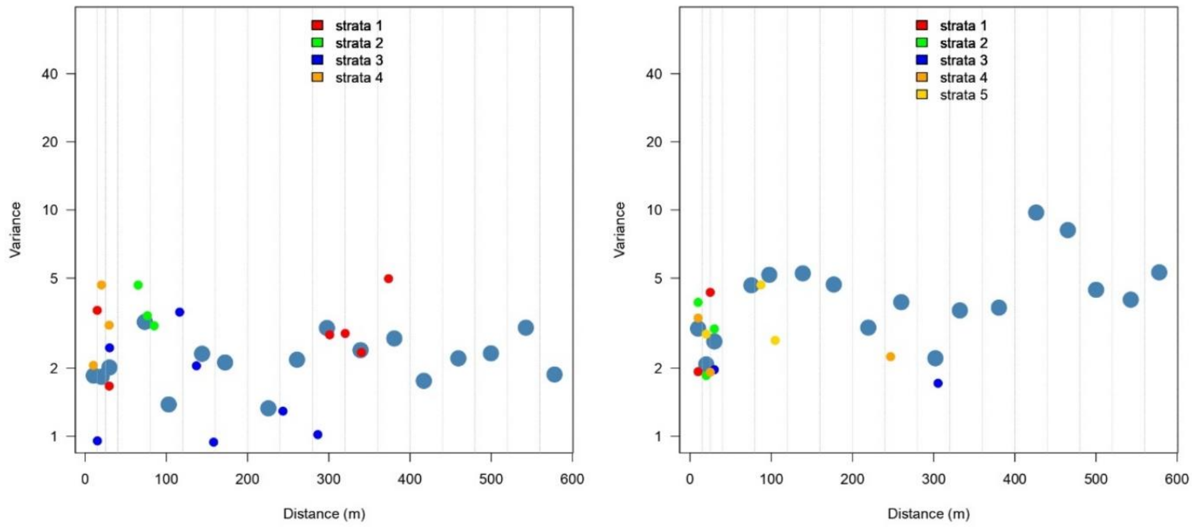


Figure 45. Variagram results for the two carbon estimation areas sampled at property #1, Brewarrina district

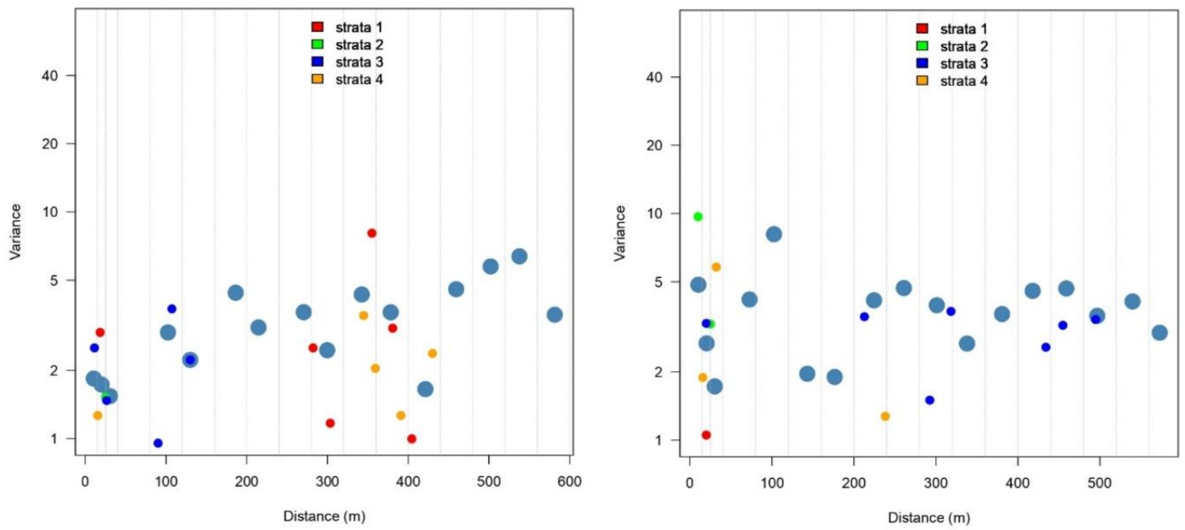


Figure 46. Variagram results for the two carbon estimation areas sampled at property #2, Brewarrina district

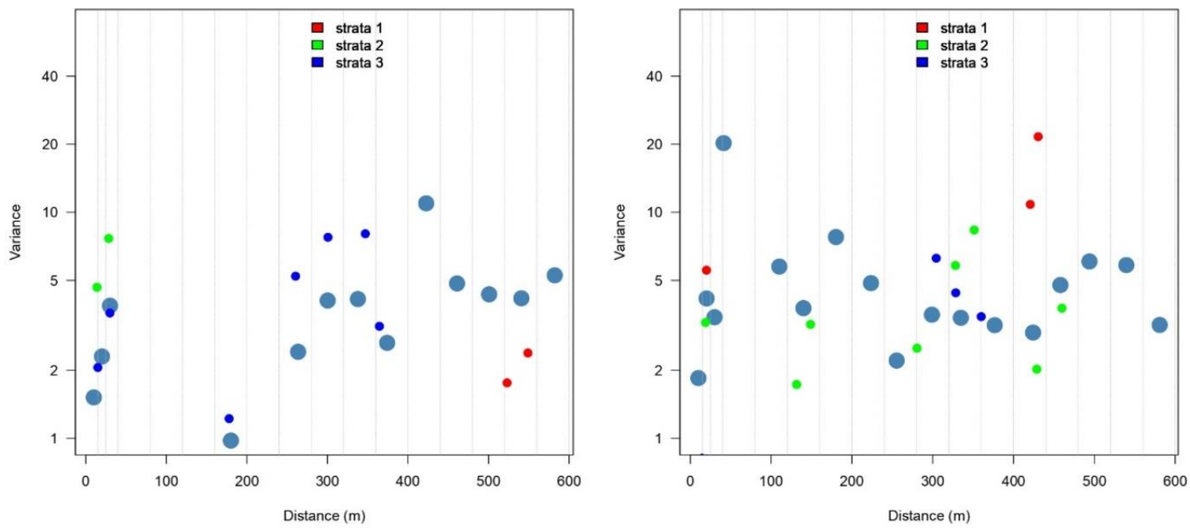


Figure 47. Variagram results for the two carbon estimation areas sampled at property #3, Brewarrina district

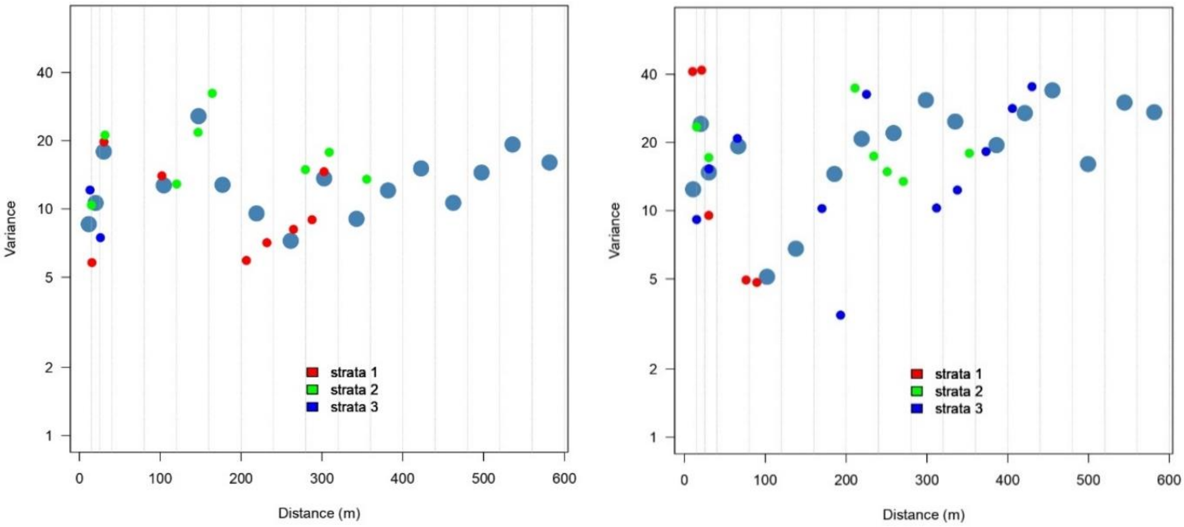


Figure 48. Variagram results for the two carbon estimation areas sampled at property #4, Cobar district

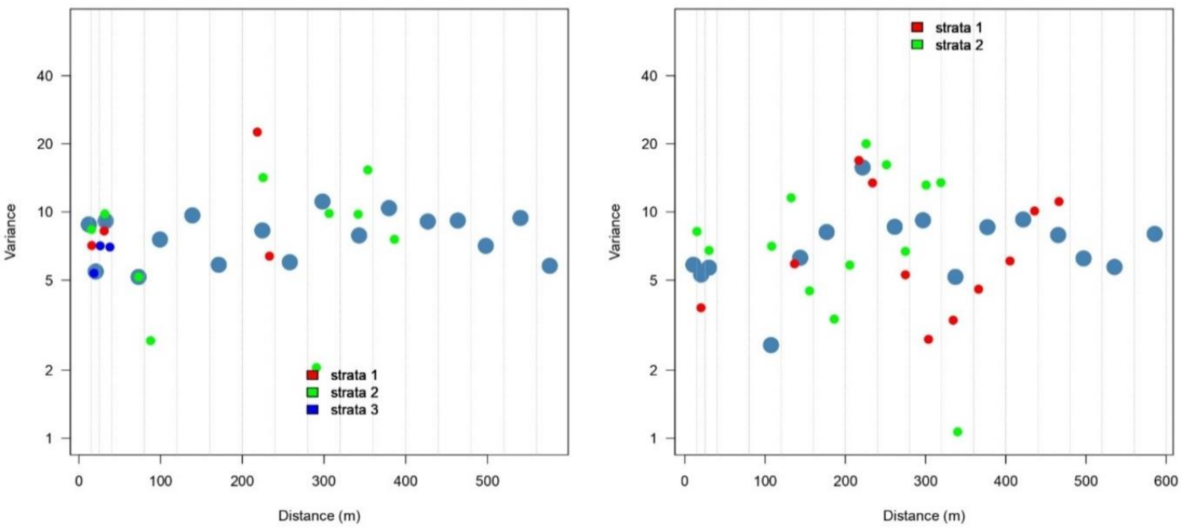


Figure 49. Variagram results for the two carbon estimation areas sampled at property #5, Cobar district

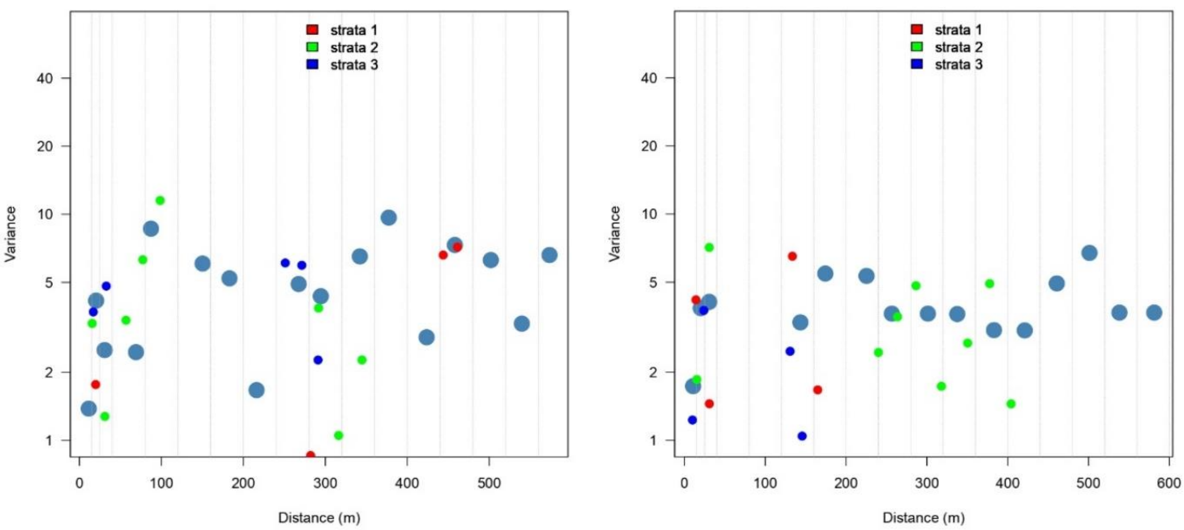


Figure 50. Variagram results for the two carbon estimation areas sampled at property #6, Pooncarie district

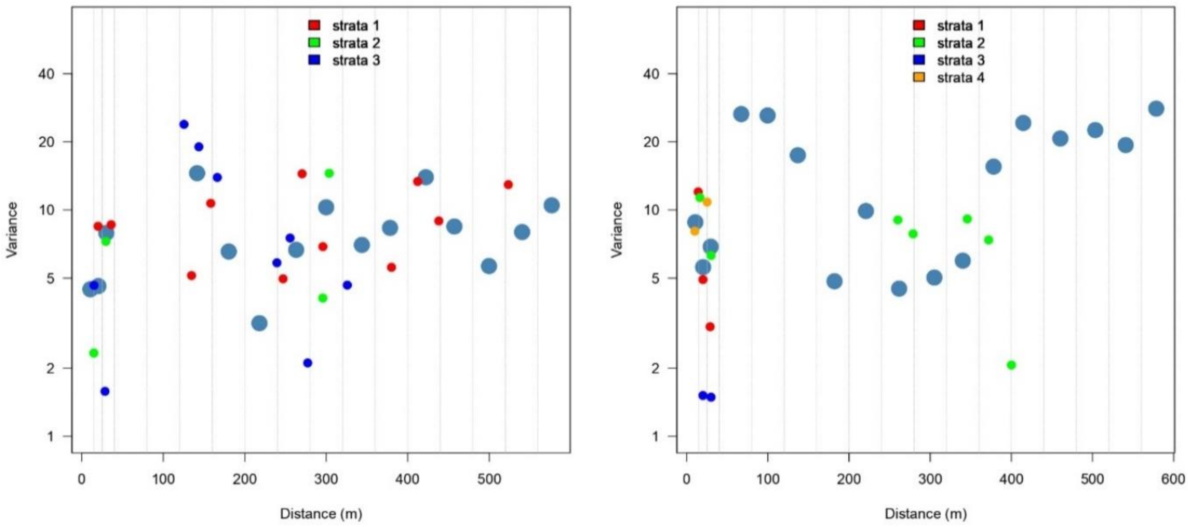


Figure 51. Variagram results for the two carbon estimation areas sampled at property #7, Pooncarie district

4.3.4 Minimum detectable change

As expected, increasing number of cores sampled reduced the amount of change in carbon that is required to detect a significant difference between sampling periods. However, this difference became minimal after approximately 10 cores. The change in soil organic carbon required to detect a significant change reflected the variability in carbon across the CEAs, with the greatest change in SOC required at property #4 in the Cobar district (~6t C/ha or 2.5t C/ha at 95% and 60% confidence levels, respectively), and the least for property #1 in the Brewarrina district (~2t C/ha or 0.2t C/ha at 95% and 60% confidence levels, respectively (Figure 52). However, when analysed as a proportion relative to current SOC, properties in the Pooncarie district require the greatest amount of change (up to 40% or 15% increase relative to existing stocks, at a 95% and 60% confidence level, respectively) (Figure 53).

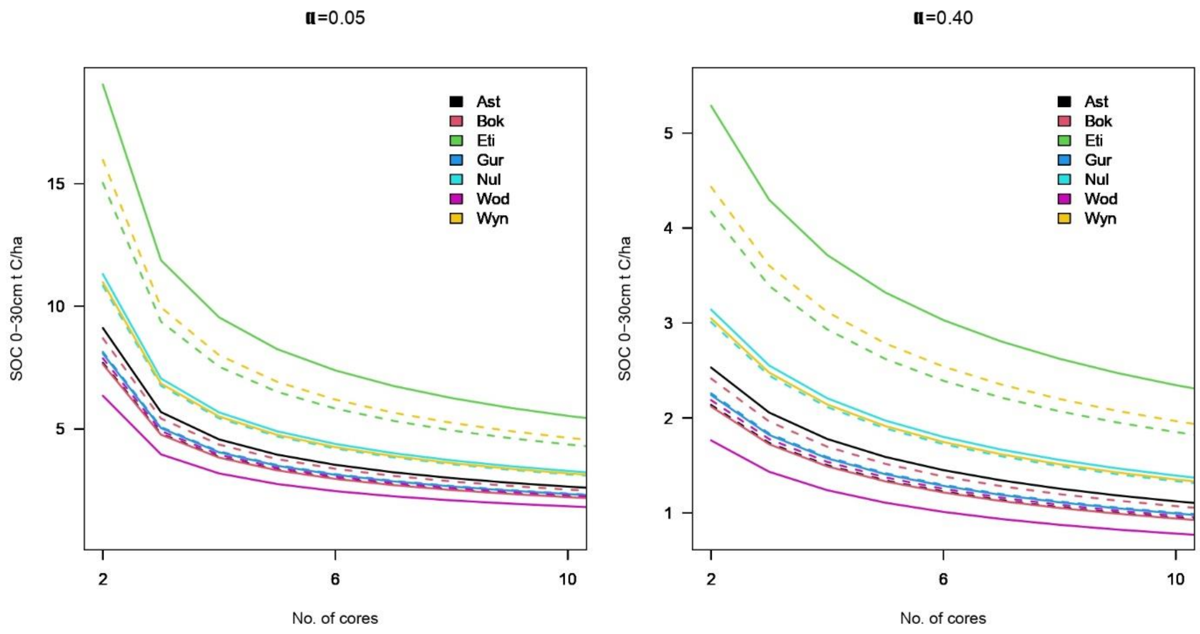


Figure 52. Change in SOC required to detect significant increase in SOC (left P=0.05, right P=0.4) for a 100 ha area, and how this changes with increasing number of cores across the 100 ha area.

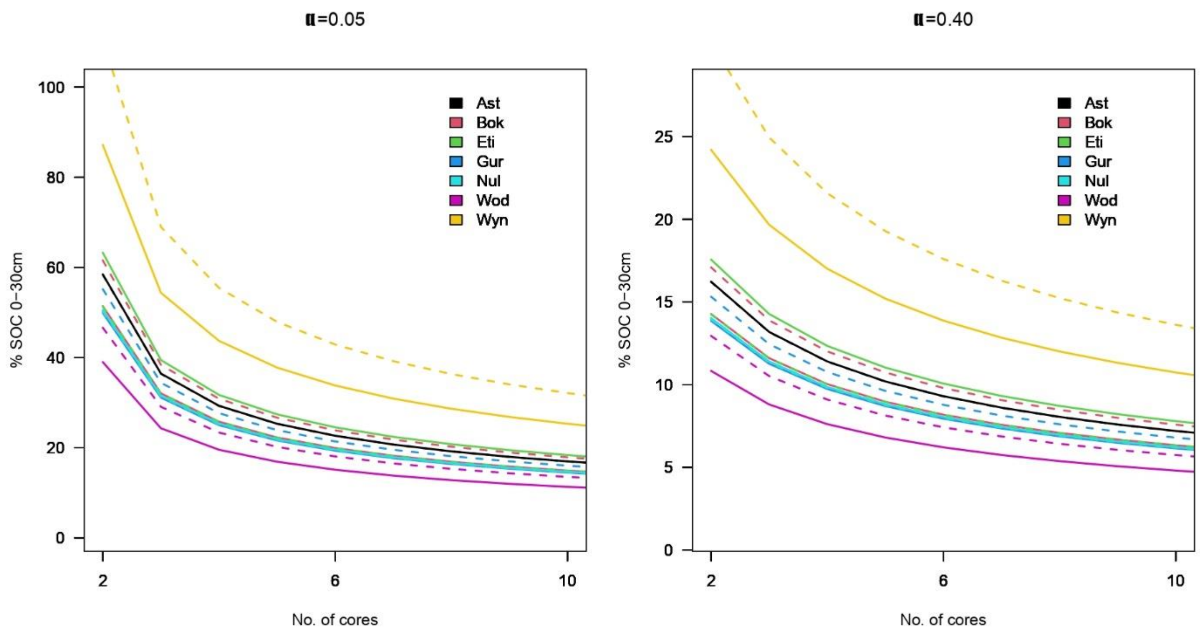


Figure 53. Change in SOC as a percentage of current SOC required to detect a significant increase (left P=0.05, right P=0.4) in SOC for 100 ha area, and how this changes with increasing number of samples across the 100 ha area

4.3.5 Estimating SOC using spectral modelling in NSW rangelands

SOC predictions via spectral modelling were generated for all districts according to the requirements of the ERF methodology as specified in the 2021 Supplement spectroscopic model requirements (Table 8).

The analysis highlighted some challenges associated with use of spectral modelling in some areas of NSW rangelands. The models for two of the regions, Pooncarie and Cobar, required statistical outliers to be excluded. Those anomalous sub-layers were identified as those where the laboratory and initially predicted value was >0.15 % SOC. These outliers for the Cobar calibration samples included seven samples with laboratory values between 0.6% to 1.1% SOC, one sample with 0.23% and one with 1.42% SOC; and for Pooncarie the laboratory values were between 0.28% to 1.01% SOC. The outliers were thought to contain fine roots, charcoal, residual carbonates after treatment with sulphurous acid (particularly increments at selected for calibration below 30 cm), or other organic particulates. The possible presence of carbonates, charcoal and fine roots in the soil being scanned affects the visible and NIR wavelengths making prediction of organic carbon more difficult (McCarty et al. 2002). The presence of any of those materials is a real artefact of the sampling, processing, and analysis of the soils. Fine roots passing the sieve or charcoal in a sample do occur in soil samples so excluding samples may misrepresent real and acceptable measures of soil organic carbon. The presence of any carbonates remaining in the soil is a procedural matter for those soil materials; sulphurous acid is used to digest carbonates but not organic matter. However, some carbonates may be resistant to dissolution and represent a real artefact that would be similarly present in subsequent sampling. The effect of excluding samples with presence of fine roots, charcoal or any residual carbonates on predictions of samples with similar spectral features reduces the overall SOC estimates compared to laboratory measurement as the NIR prediction is targeting the soil component of SOC. This is seen during the calibration phase when laboratory outliers are part of the calibration set. Laboratory outlier samples have substantially lower NIR estimates and are comparable other NIR estimates to soil samples within the same soil core and other soil cores. The effect of artefacts or their removal on detecting small changes in organic carbon is difficult to discern. However, there may remain other limitations such as inherent lack of accuracy or overfitting (McBride 2022). Alternatively, using laboratory measures that do not include carbonates may improve the results of spectroscopic modelling (e.g. Amin et al. 2020), though only the dry combustion measure of SOC is currently approved in the ERF.

An additional consideration in the use of spectral modelling for SOC estimation in NSW rangelands identified through this project, was that the values and range of SOC% across all CEAs were relatively low, restricting sensitivity of the spectral features (Viscarra Rossel & Behrens, 2010) and potentially reducing the ability to attribute features to an adequate spread of values. While the ERF Supplement uses LCC as a measure or accuracy, published studies use different statistical measures. The statistical measure for accuracy of performance for non-normal data is the ratio of performance to interquartile range (RPIQ, the ratio of the difference between the third quartile and first quartile values to the root mean square error (RMSE)), recommended over the more commonly used RPD (ratio of performance to deviation; standard deviation of the measured values to the RMSE) (Bellon-Maurel et al. 2010). Compared to a four-grade scale of Ng et al. (2022), the RQIP for Cobar and Pooncarie (3.4, and 2.4 respectively) indicate SOC predictions of relatively high accuracy, while predictions for Brewarrina were of medium accuracy.

Table 8. Cross-validation model metrics for each of the districts

Metric	Pooncarie	Cobar	Brewarrina
RMSE	0.068 %SOC	0.101 %SOC	0.067 %SOC
R2	0.608	0.681	0.684
Lins Concordance Criteria (LCC)	0.752	0.799	0.791
Mean Error	-0.006 %SOC	-0.005 %SOC	-0.001 %SOC
RQIP	2.4	3.4	2.1

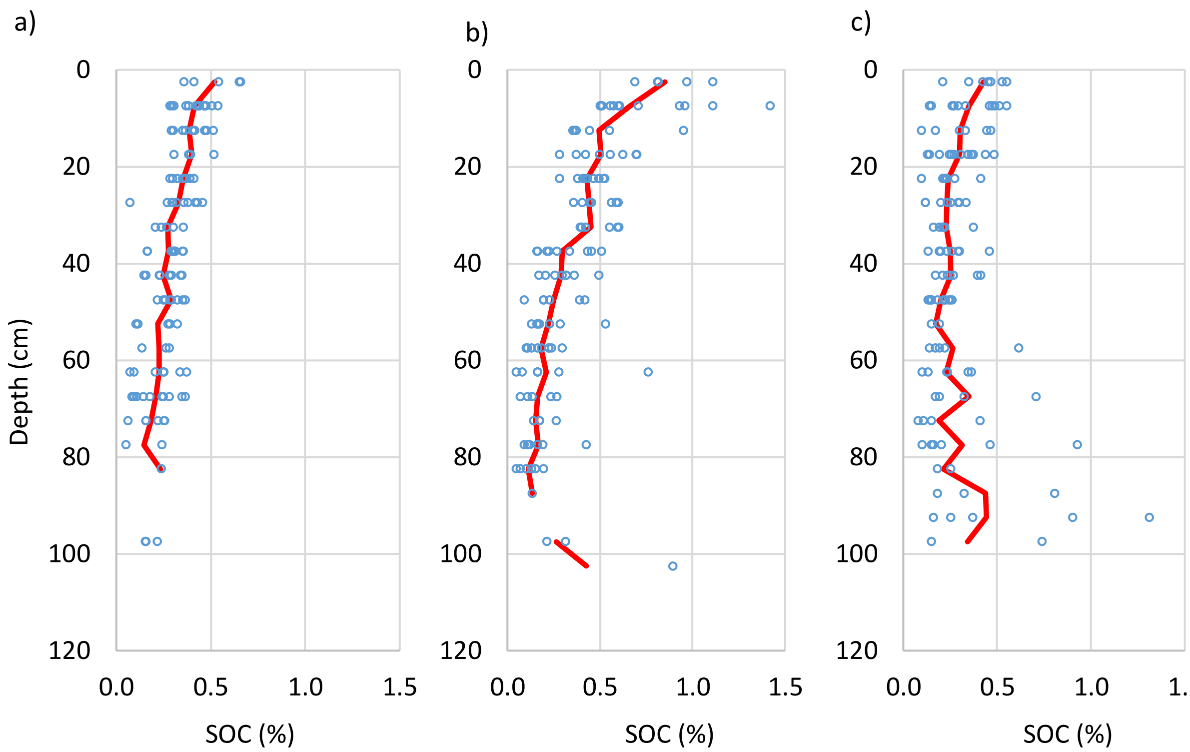


Figure 54. Laboratory analyses on samples for Brewarrina (a), Cobar (b), and Pooncarie (c). The red line indicates the average of SOC % of samples analysed for the region

4.4 Managing grazing to increase ground cover in rangelands

Results reported here are published in McDonald et al. (2024) (Section 8.3).

Average median ground cover across the seven study sites between 1989-2023 ranged from 43 % (S2) to 72 % (S4), with significant temporal variability (depending on site, a difference of approximately 50-80 % between maximum and minimum cover over this period) precluding the ability to detect any obvious trends over this period (Table 9, Figure 55). Overall, ground cover was approximately 15 % higher in winter than summer.

Table 9. Average seasonal and annual median ground cover for each study site between 1989-2023

Site	Autumn	Winter	Spring	Summer	Annual
S1	60.3	68.4	53.7	51.7	58.5
S2	44.3	52.1	38.2	37.3	42.9
S3	54.7	60.9	47.9	47.6	52.8
S4	69.6	79.5	71.4	67.0	71.8
S5	64.5	75.8	65.4	62.2	66.9
S6	53.1	65.3	55.8	49.8	56.0
S7	55.1	67.6	54.4	49.6	56.6
Overall site average	57.3	67.0	55.4	52.2	57.9

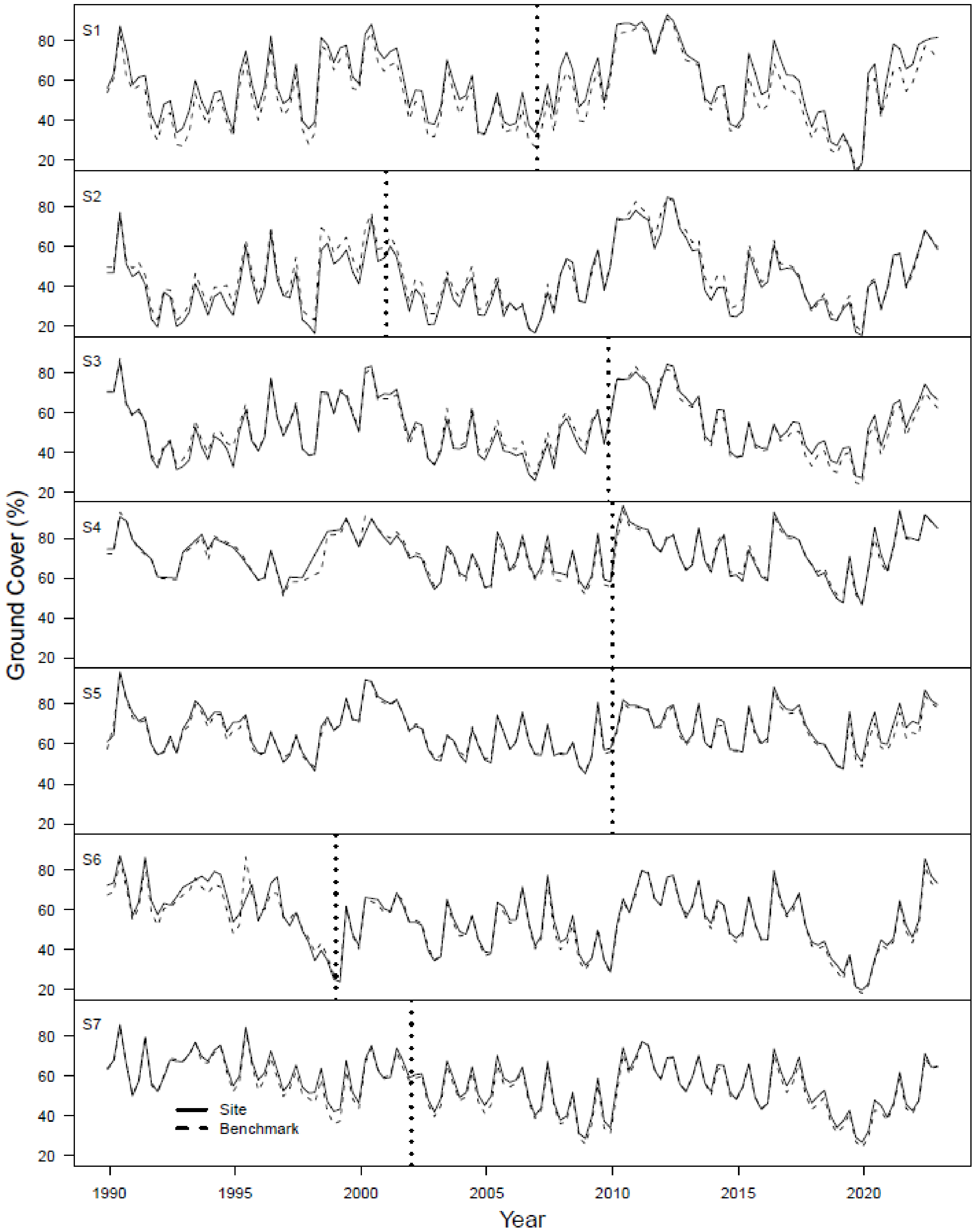


Figure 55. Median seasonal ground cover (%) across each site and associated benchmark area between 1989 and 2023. The vertical dotted line represents the date at which grazing management began to change across each site

Prior to implementation of management changes, ground cover across five of the seven study sites was decreasing relative to that of the benchmark areas (Figure 56). Following the management change of flexible stocking rates and introducing rest in the grazing system, a significant positive change in ground cover (ranging from 2 – 7 % from the time of management change, P<0.05), as determined by a significantly different slope between the pre- and post-management periods, was observed at four of the seven study sites (S2, S3, S5, S6; Figure 56, Figure 57). A non-significant positive change was observed at a fifth site (S1, P = 0.45; Figure 57). At S4, there was no significant difference overall, although this site had confounding impacts of a clearing and an occasional cropping cycle and had the highest average ground cover of all the sites. At S7, there was no significant change in ground cover in the 20 years from management change relative to the benchmark area.

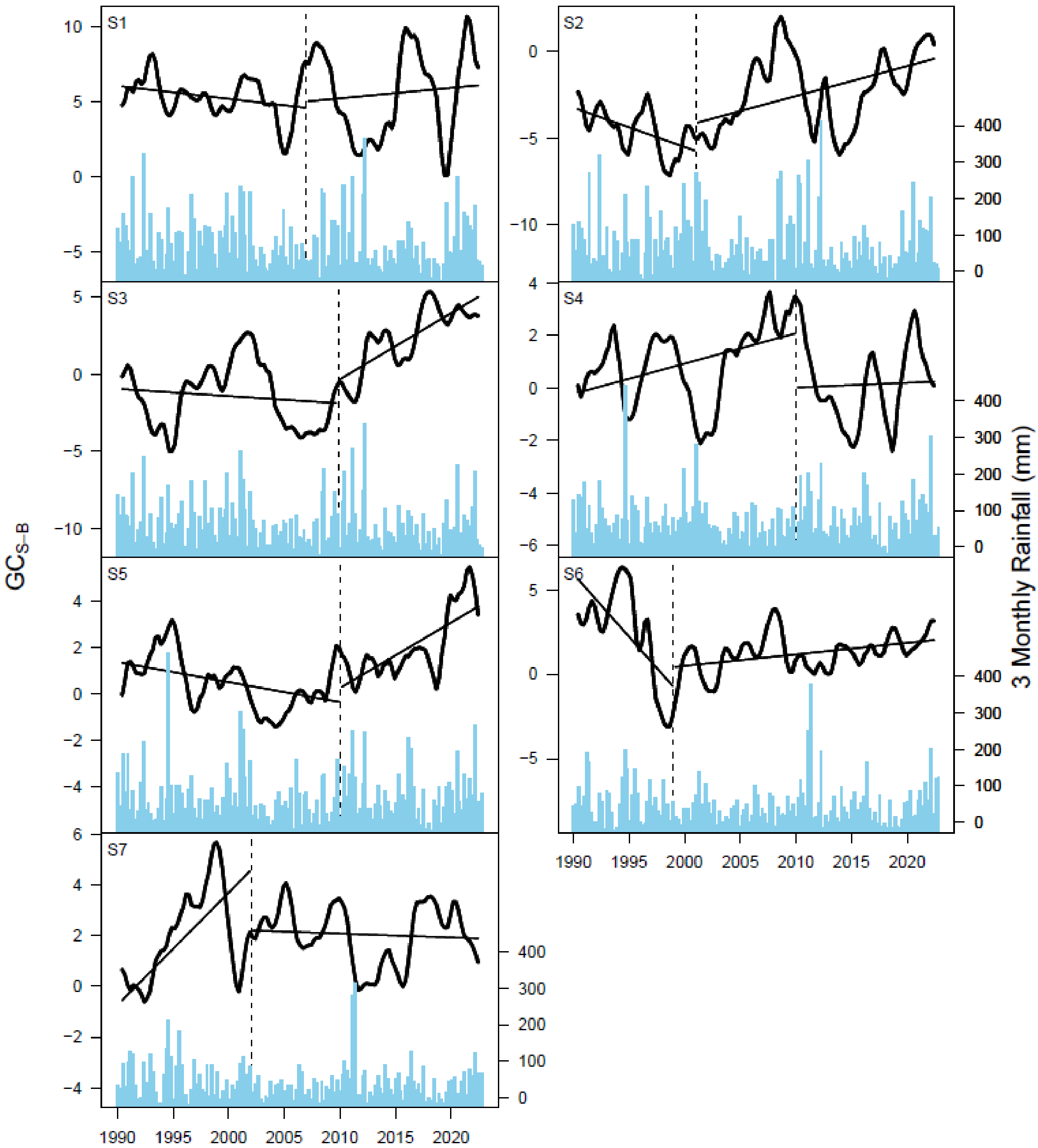


Figure 56. The trend of difference in total ground cover (%) between the study site and benchmark areas (GC_{S-B}). The straight lines represent the median slope of the trend pre- and post-management change (Pohlert, 2023). Seasonal (3 monthly) rainfall totals are represented by blue bars on secondary axis

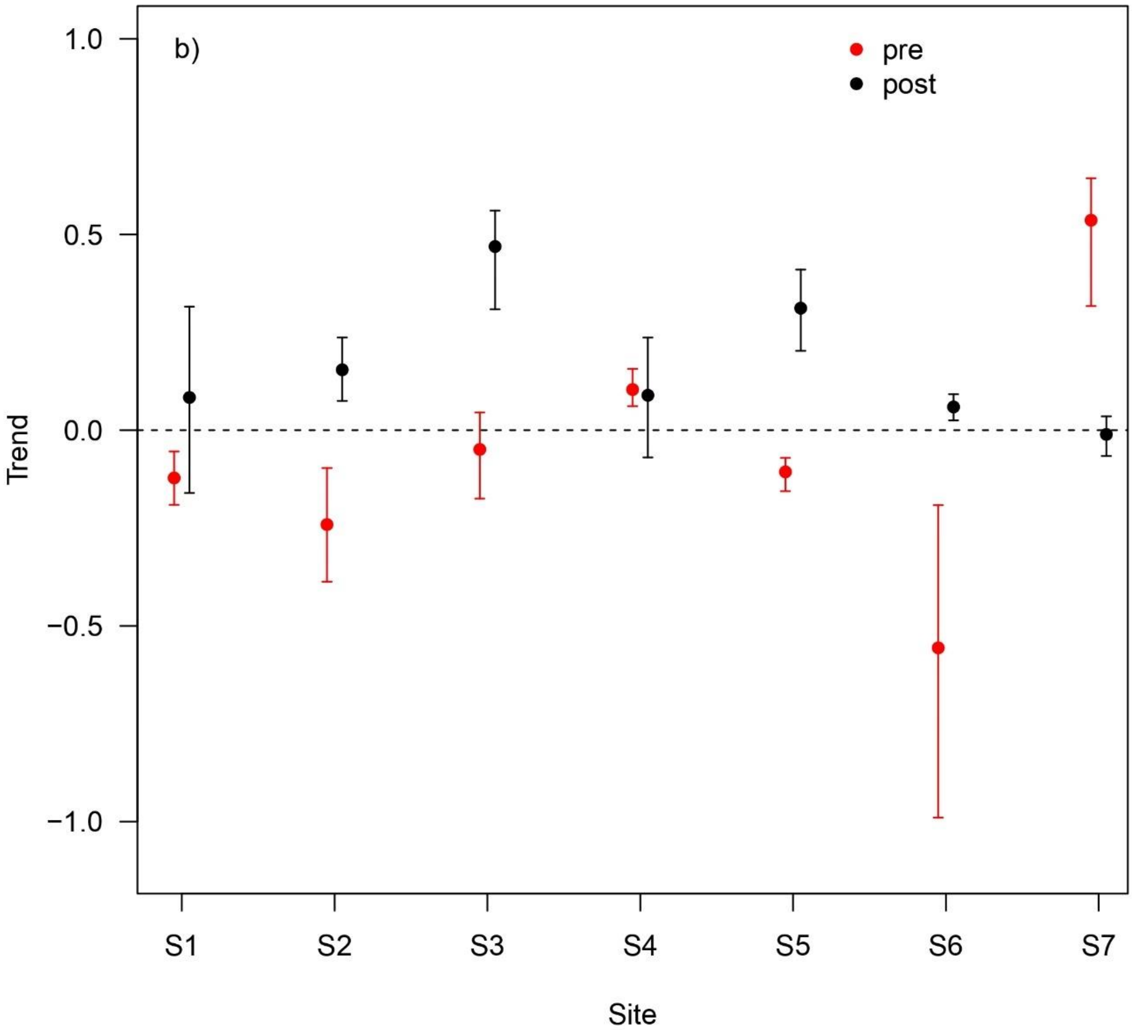


Figure 57. The median (+/- 95 % confidence intervals) slope (analysed as sens.slope, Pohlert, 2023) of the trend of the difference between the study site (S1-S7) and benchmark areas pre- and post-management change. Positive values represent increasing cover on the property relative to the benchmark and negative values vice versa. Where the confidence interval overlaps zero, this indicates no significant trend in the change in ground cover between site and benchmark areas

Trends reported here are a simplified representation of temporally dynamic time series. When examined at a finer temporal resolution, trends over time are non-linear and at times are comprised of shorter-term reversals in trends. Assessment of the linear trends for each land type within a property also indicate that the direction and magnitude of change was dependent on land type (Figure 58). There was a weak negative association between the trend in GC_{S-B} post management change with the normalised difference water index (NDWI), total standing dry matter (TSDM) and green reflectance (R = -0.36, -0.15 and -0.16 respectively), potentially indicating that less productive land types had the greatest positive response to the management change (Figure 59).

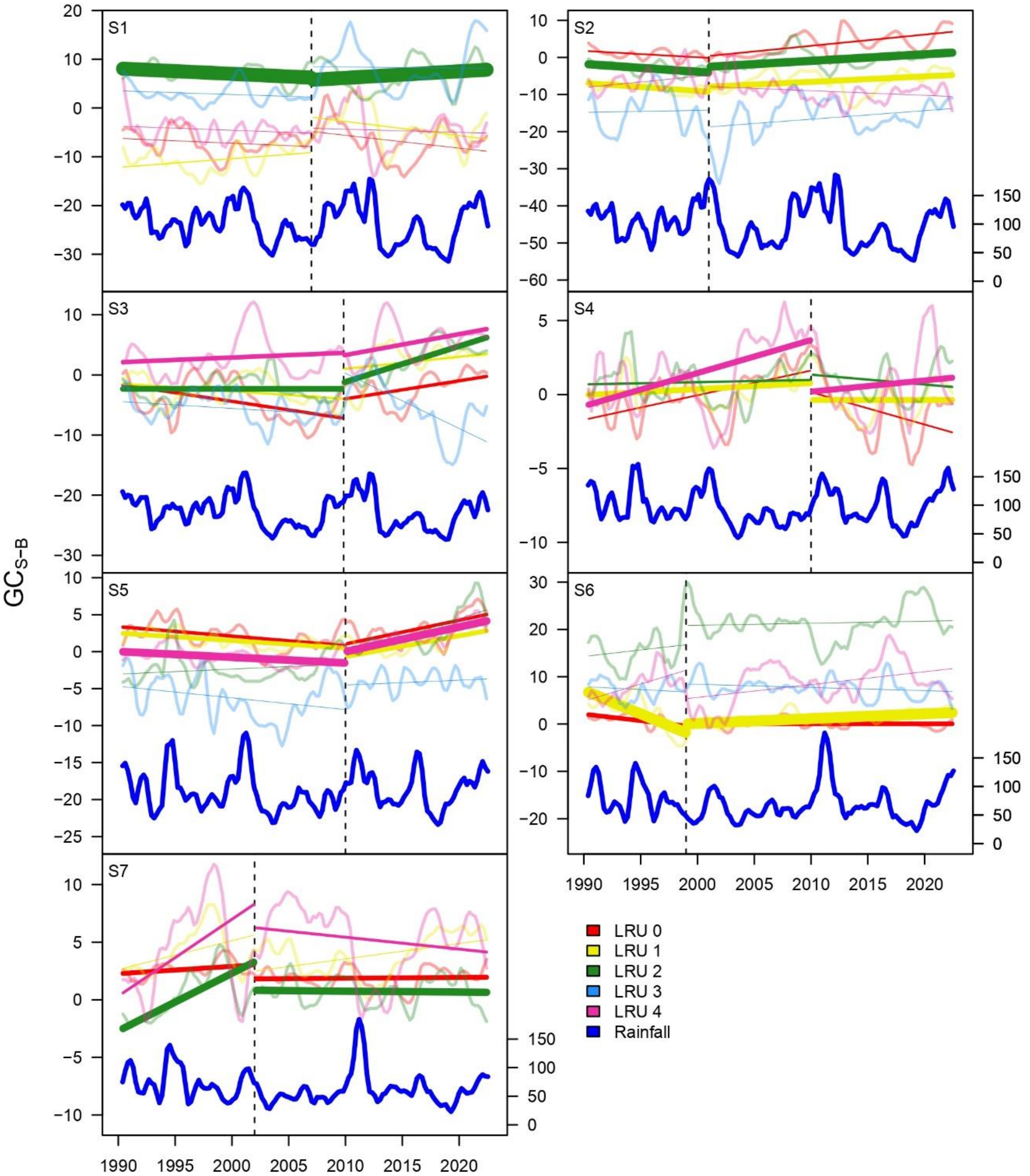


Figure 58. Trend in GC_{S-B} over time for each land response unit (LRU) at each site. Straight lines indicate the median slope of the trend pre- and post-management change (Pohlert, 2023). Thickness of the slope line is proportional to the area of the LRU at the site. Characteristics of LRUs differ between sites, see Table A1 for detail on LRUs at each site

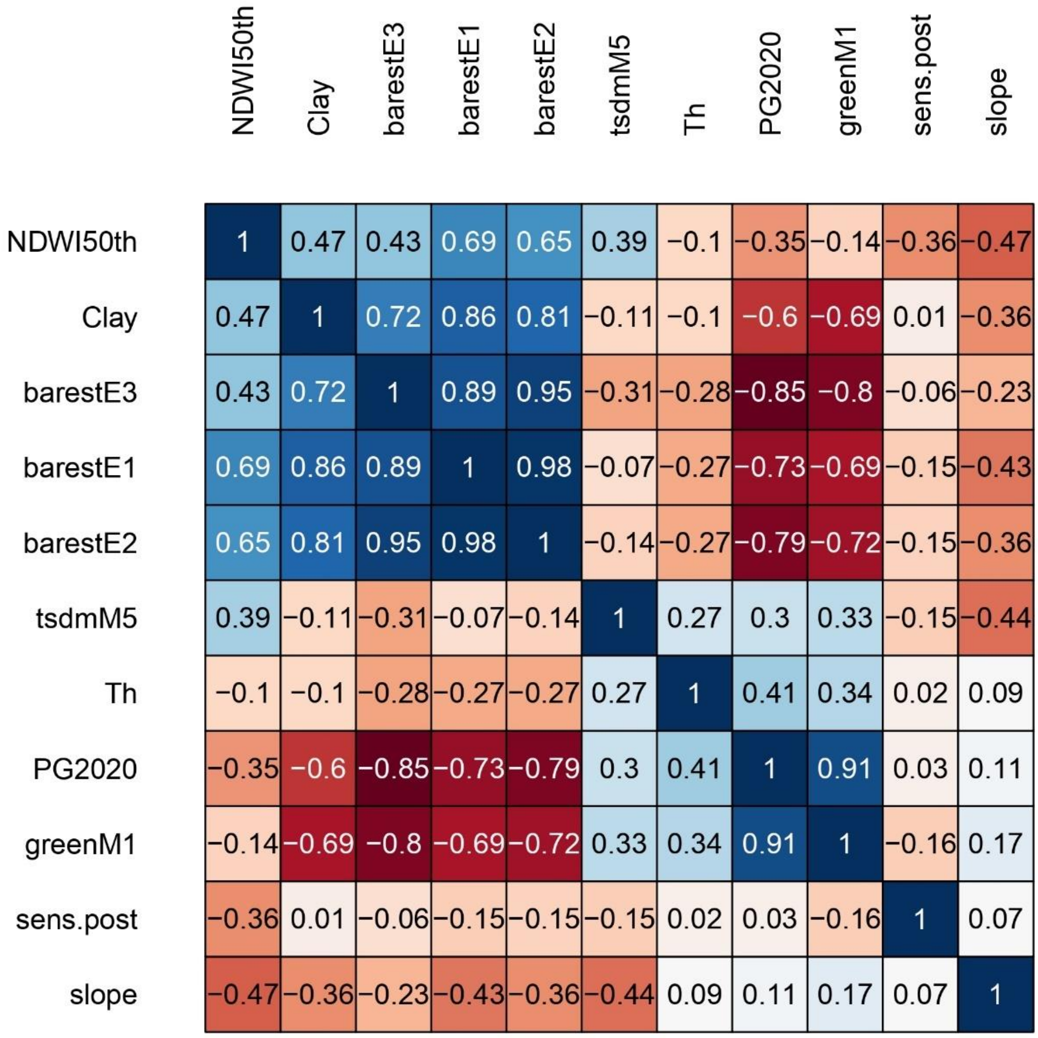


Figure 59. Correlations (R) between the slope of the trend pre and post management change and characteristics of the land response units. Sens.post = the slope of the trend in $GC_{S\text{-}B}$ post management change; slope = the slope of the land unit; PG2020 = perennial vegetation cover, Clay = soil clay content, barestE1,2,3 = estimated bare ground; NDWI50th = Normalized Difference Water Index, tsdmM5 = total standing dry matter, green M1 = vegetation greenness, and Th = thorium (measure of near-surface radiactive decay, indicator of soil parent material or provenance)

Analysis of the effect of preceding 12 month rainfall on $GC_{S\text{-}B}$ and the trend of $GC_{S\text{-}B}$ pre- and post-management change (Figure 60a) showed that in wet years the trend in $GC_{S\text{-}B}$ was negative across all sites (significant at S1 and S7; Figure 60b). This indicates that ground cover in the benchmark areas increased more (or decreased less), than the study sites during these periods. There was no significant difference in the trend in $GC_{S\text{-}B}$ pre- and post- management change at any study site during dry periods, but in intermediate rainfall years the trend in $GC_{S\text{-}B}$ was significantly more positive post management change at S2 (Figure 60a).

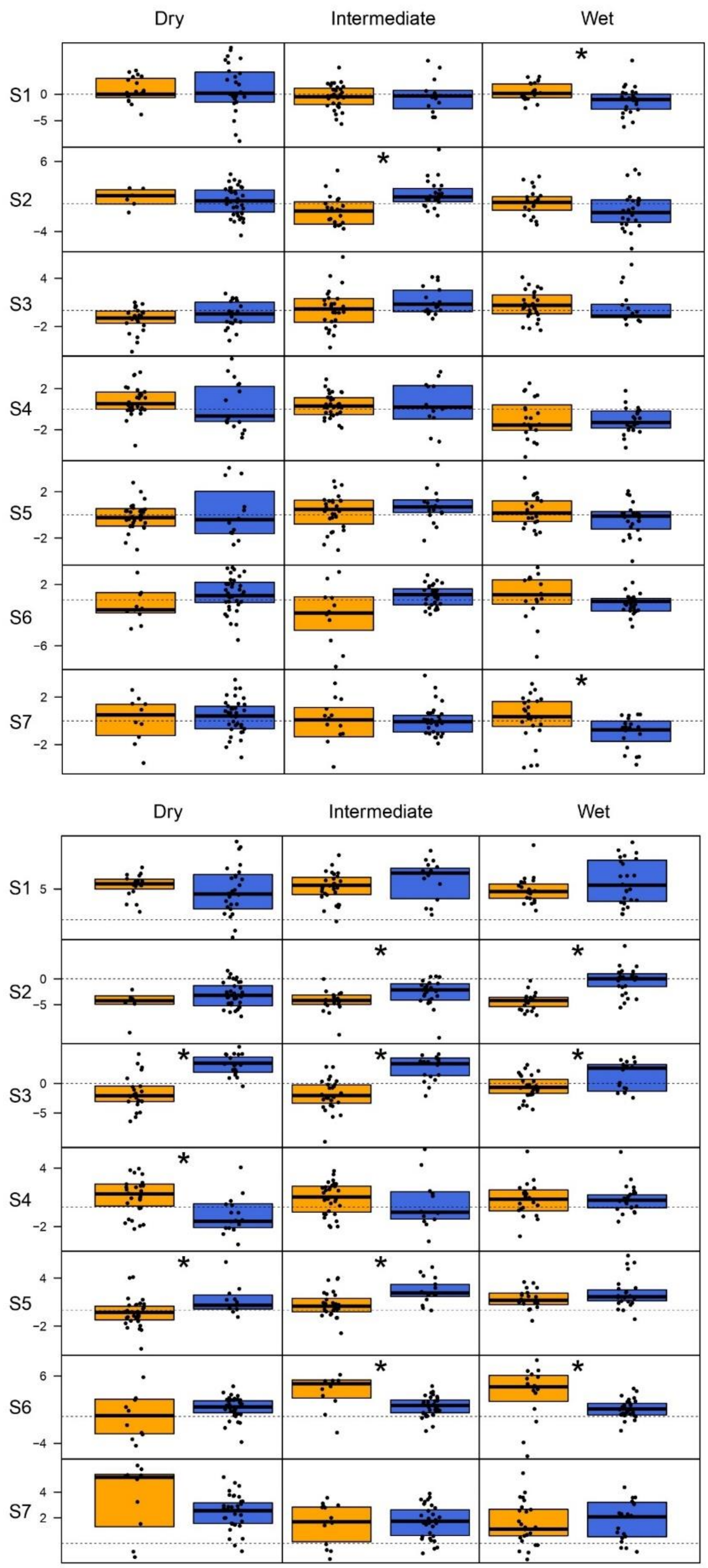


Figure 60. Comparison of A) the trend of the slope of difference in ground cover between the study site and benchmark (GC_{S-B}) and B) median ground cover GC_{S-B} between pre (yellow) and post (blue) management change for sampling periods where preceding 12 month rainfall was in the lowest (Dry), middle (Intermediate) and highest (Wet) tercile of rainfall years during the analysis period. Black dots indicate individual data points for the slope (A) and median difference (B) for each sampling period, and the boxes represent the inter quartile range of data. Significant differences (P<0.05) of the mean between pre and post management change are indicated by an asterisk

The study has highlighted that livestock producers can potentially achieve improvements in ground cover and associated ecosystem services through changes in grazing management (management of stocking rates and introduction of planned rest into grazing systems). However, the magnitude and direction of response observed may be dependent on specific grazing management decisions, the timing of monitoring, land type and preceding rainfall during which the management change is evaluated. With increasing pressure for livestock producers to demonstrate sustainable management and emergence of environmental markets rewarding producers for provision of ecosystem services, this study supports the use of remote sensing using biophysically similar, dynamic benchmarks (Bastin et al. 2012; Zhang and Carter 2018; Donohue et al. 2022,) to detect and measure change and support the adoption of management of the timing and intensity of livestock grazing in variable semi-arid rangeland environments.

See Section 8.3 for manuscript published in The Rangeland Journal, providing greater discussion of results.

4.5 Effect of herd impact and ripping on scald reclamation at Bokhara Plains

4.5.1 Impact of high intensity animal impact and ripping on ground cover and vegetation

There was a noticeable visual difference in ground cover, biomass and plant species composition between the three plots at each replicate (Figure 61 - Figure 66). There was an increase in vegetation cover and plant biomass at two of the three replicate scalds in response to cattle, while the ripping treatment had a positive effect across all three scalds. The greatest response (including a reduction in the amount of bare ground and >50% increase in plant and litter cover, >1500 kg/ha increase in plant biomass) was apparent at the third replicate where cattle had impacted the area overnight twice in the two years prior to the final monitoring occasion (Figure 68 - Figure 74). Cattle impacted replicate 1 three times, with the last event occurring only two months prior to sampling. Despite this, results were comparable with the ripped treatment. Replicate 2 experienced the least cattle impact, with only two hours of cattle impact in April 2022, >2 years prior to sampling, and had the smallest response, similar to that of the control treatment.

Compositional differences between the three treatments were most apparent in the third replicate, which included a greater proportion of perennial grass cover in the cattle treatment than the ripping and control treatments (Figure 72). Species richness at the smallest quadrat scale (0.25 m^2) was higher under the cattle and ripping treatments in the first and second replicates in the second year of the trial. In the larger quadrats (25 m^2), species richness was greater in the cattle treatments at the first and second replicates, while the control and ripping treatments had similar richness values to each other.

Above-average rainfall in spring/summer 2022 also resulted in some improvement in the control areas in 2023 relative to that recorded in 2021, however this increase was generally greater in the cattle and ripping treatments.

Figure 61. Replicate 1, June 2024. (left to right: Cattle, control and ripping treatments)

Figure 62. Replicate 1, April 2023. (left to right: Cattle, control and ripping treatments)

Figure 63. Replicate 2, June 2024. (left to right: Cattle, control and ripping treatments)

Figure 64. Replicate 2, April 2023. (left to right: Cattle, control and ripping treatments)

Figure 65. Replicate 3, June 2024. (left to right: Cattle, control and ripping treatments)

Figure 66. Replicate 3, April 2023. (left to right: Cattle, control and ripping treatments)

Figure 67. Arial image of the third replicate scald, taken in April 2024, two years post initial treatment. Clockwise from top left = control, ripping, ripping+perennial shrub and cattle treatments

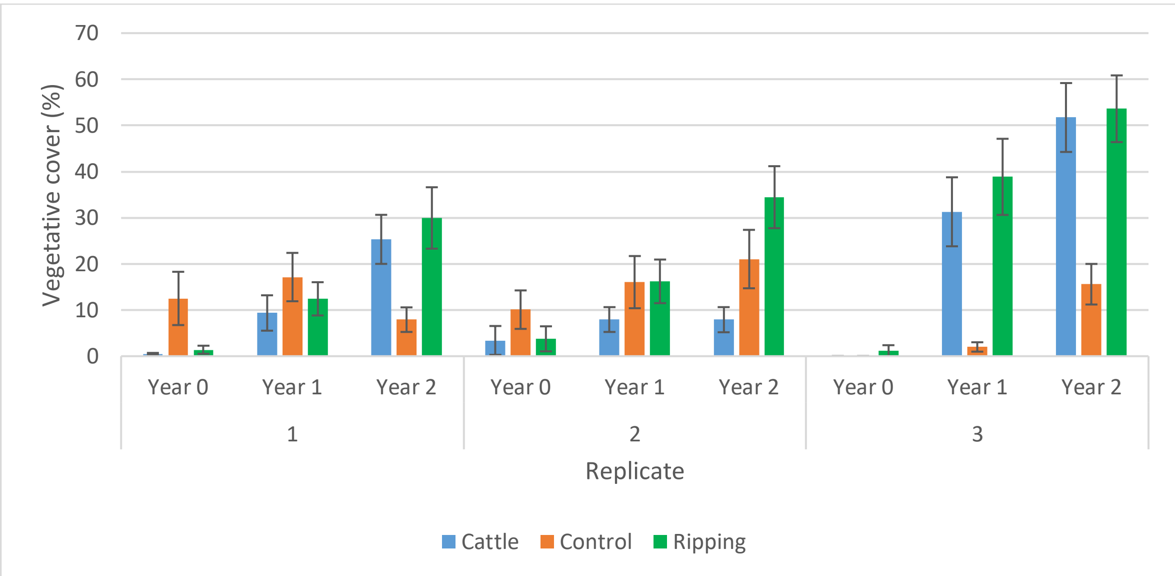


Figure 68. Vegetative ground cover (%) across each treatment, replicate and year of monitoring (+/- 1 standard error)

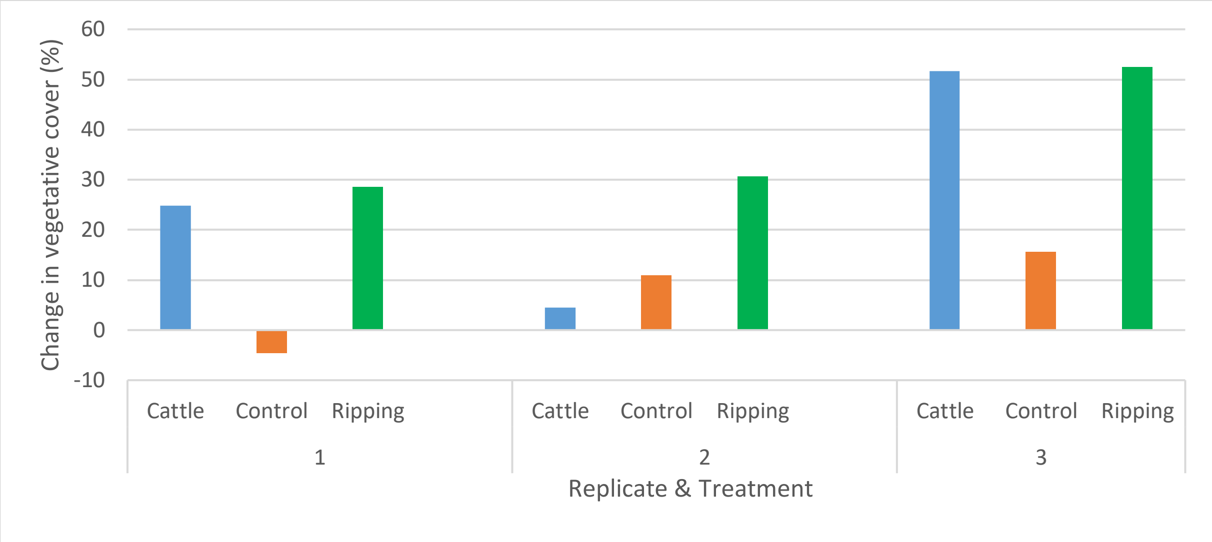


Figure 69. Change in vegetative (plant & litter) cover in June 2024 compared to baseline measurements in 2022

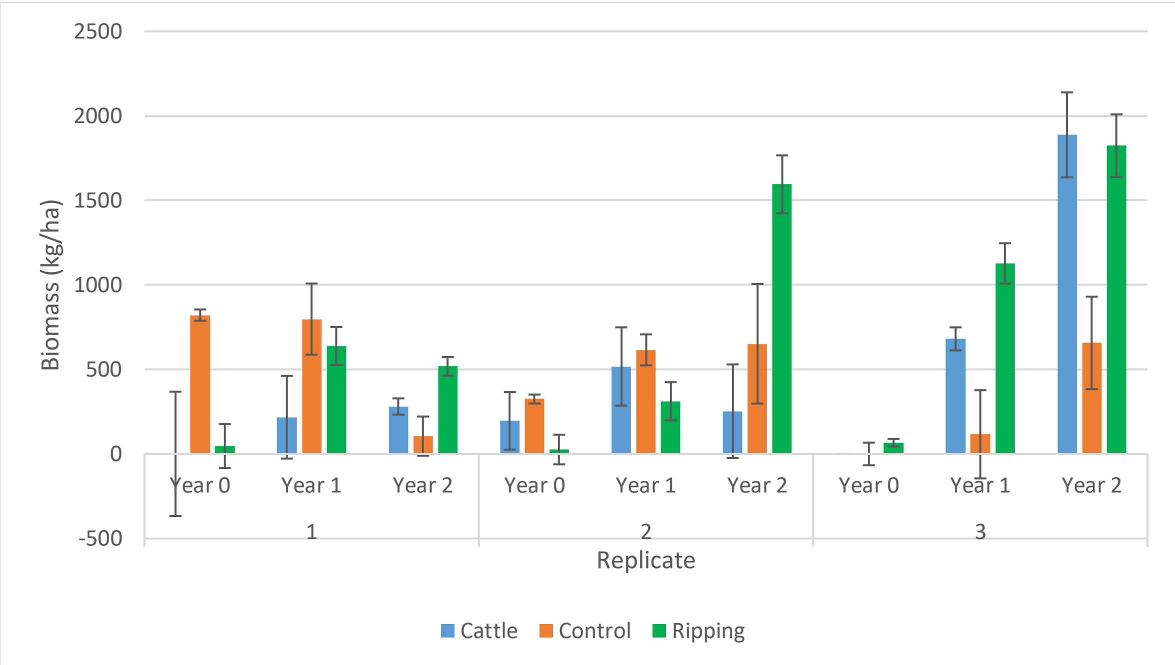


Figure 70. Plant biomass (kg/ha) across each treatment, replicate and year of monitoring (+/- 1 standard error)

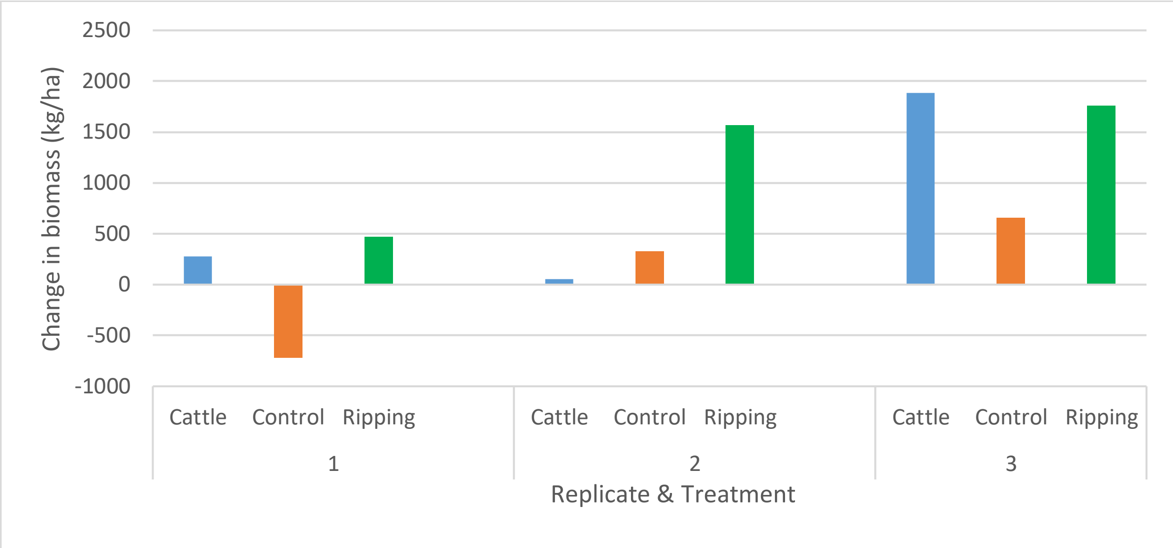


Figure 71. Difference in plant biomass (kg/ha) in June 2024 compared to baseline measurements in 2022

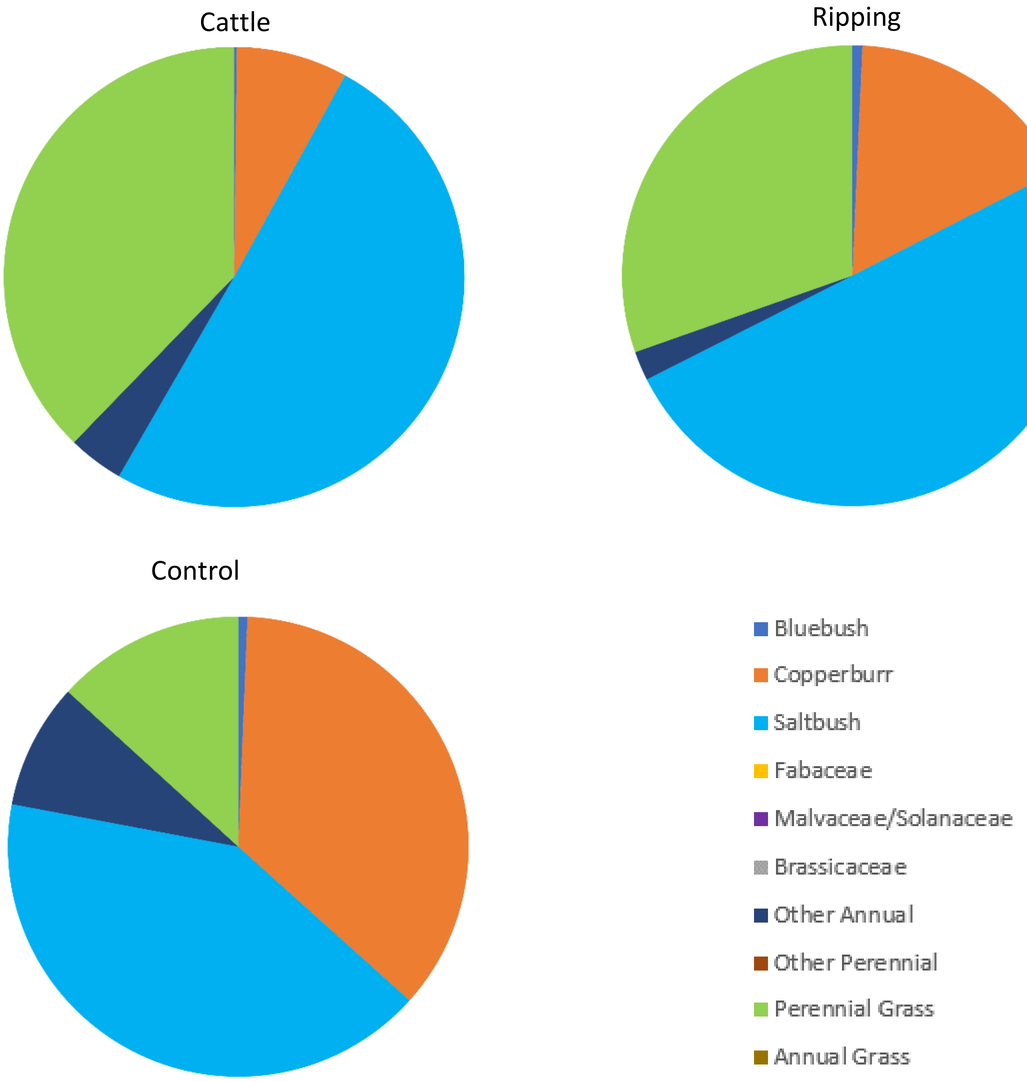


Figure 72. Comparison of plant composition (by proportion of cover) between the three treatments at Replicate #3 in 2024, two years after treatment establishment

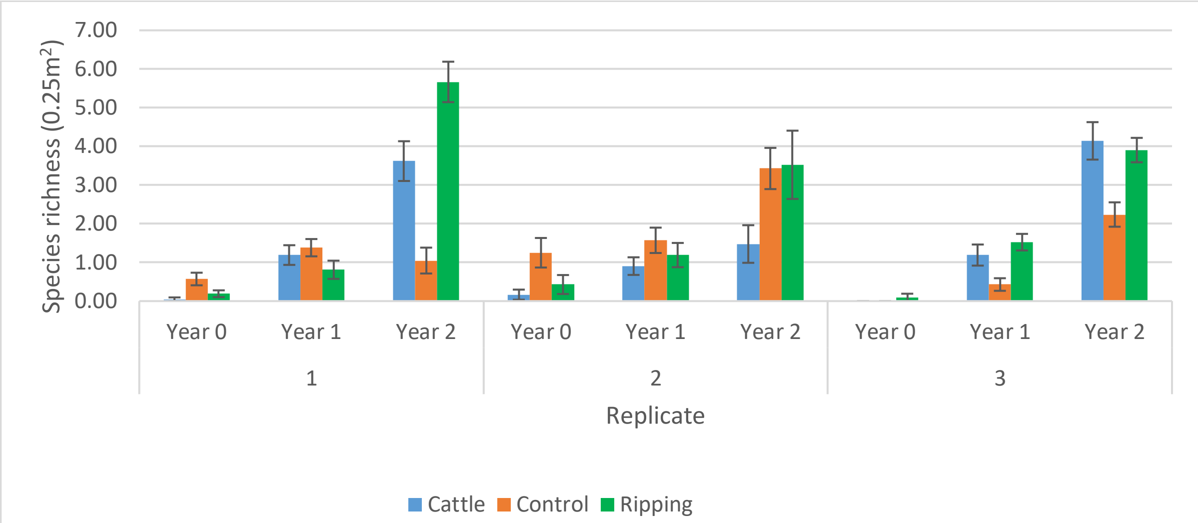


Figure 73. Species richness (average number of species in 0.25m² quadrats) across each treatment, replicate and year of monitoring (+/- 1 standard error)

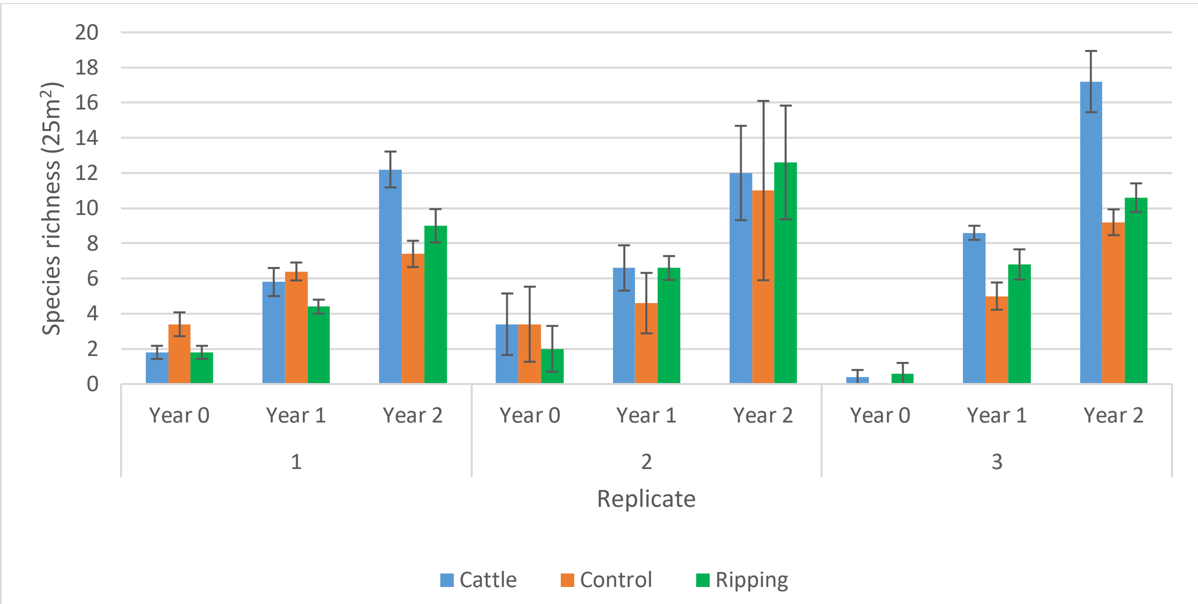


Figure 74. Species richness (average number of species in 25m² quadrats) across each treatment, replicate and year of monitoring (+/- 1 standard error)

4.5.2 Impact of high intensity animal impact and ripping on soil chemistry

4.5.2.1 Baseline soil characteristics

Each of the replicate scalds on Bokhara Plains had a number of constraints prior to installation of the trials. Most notably, salinity was very high through the top 40 cm analysed (Figure 75), exceeding the concentration of sea water at over 50 dS/m. These levels exceed plant tolerance through limiting plant uptake of soil moisture (osmotic effect) and direct toxicity of ions such as chloride. Salinity is a transient condition, where infiltration and drainage can leach salts lower in the profile. The presence of lower salinity in the surface 5 cm than below likely reflects relatively recent flushing of salts. Conversely, dry conditions combined with low surface cover will lead to surface evaporation and wicking of moisture from deeper in the profile, leaving salts to accumulate at or near the surface. This concentration is evident with slightly higher salinity in the 5-10 cm increment than the lower depth increments.

The high exchangeable sodium percentage shows that the soils are also strongly sodic (Figure 76). Sodicity makes soils prone to dispersion when wet, then sealing of the surface. While the high salinity induces flocculation, the leaching of salts as infiltration increases will allow dispersion to occur, effectively a negative feedback against improving the soil condition.

The result of these unfavourable chemical conditions for plant growth and a likely history of eroded topsoil leaves the surface with low carbon concentrations (<0.4%, Figure 77). With low rainfall in the region, low levels of carbon are expected in these soils. The decrease in carbon concentration with depth is similarly expected as the accumulation of plant material occurs mostly at the surface.

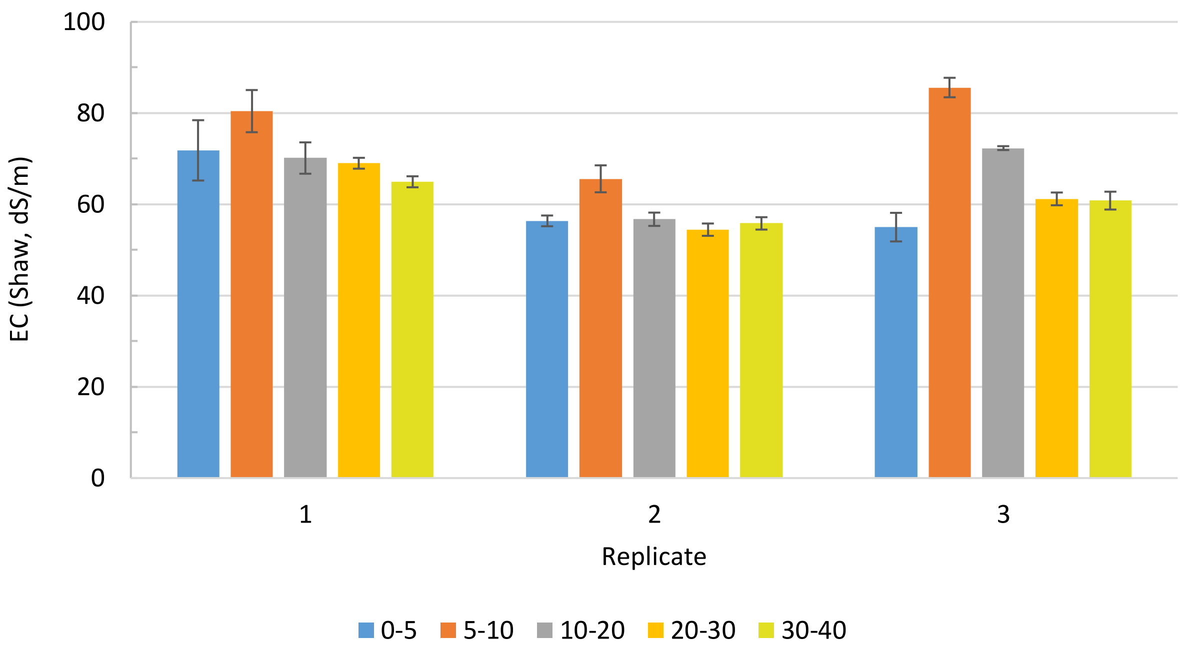


Figure 75. Average salinity (electrical conductivity, EC, dS/m) at each of the replicates prior to treatment (+/- 1 standard error)

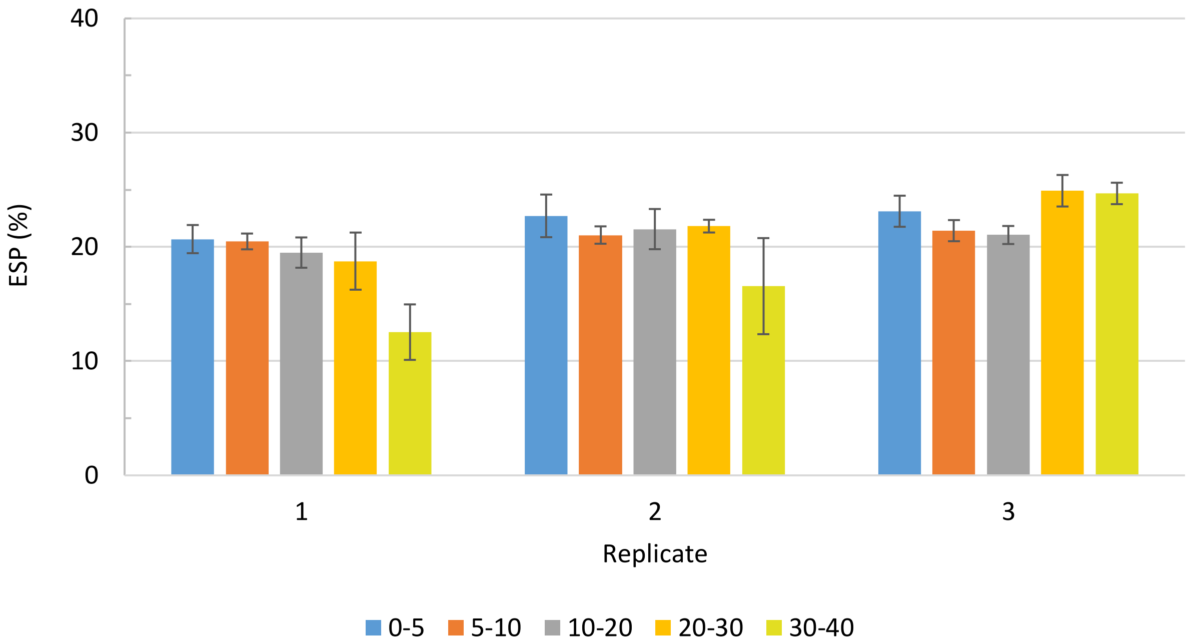


Figure 76. Average exchangeable sodium percentage (ESP) at each of the replicates prior to treatment (+/- 1 standard error)

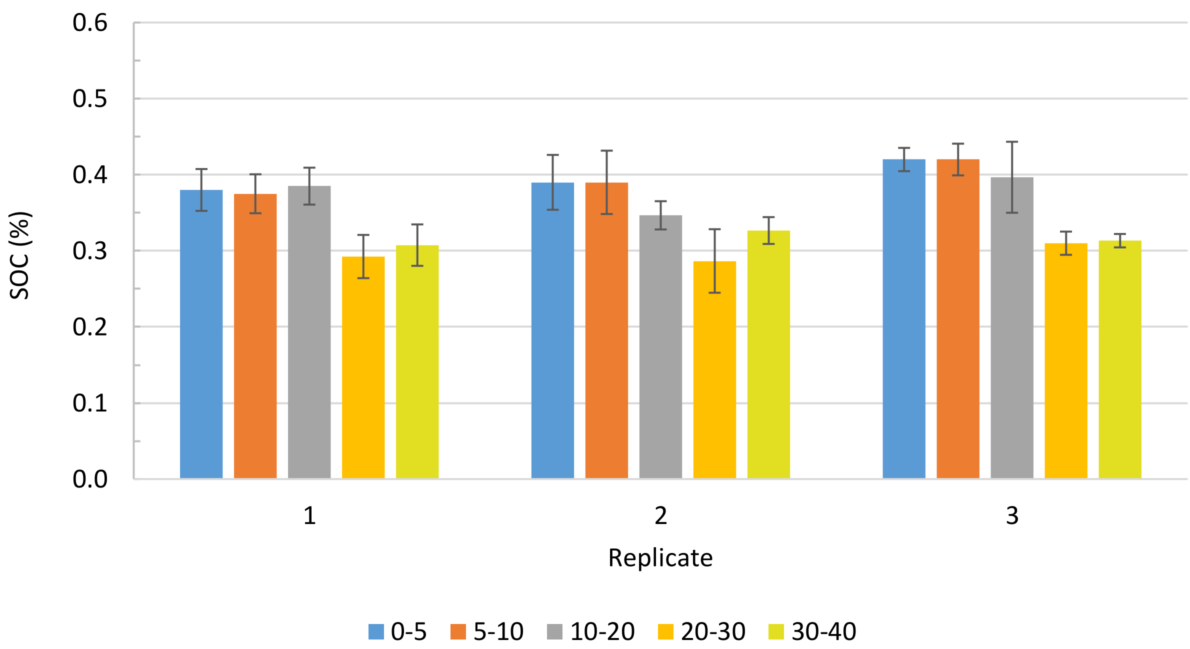


Figure 77. Average soil organic carbon concentrations (SOC %) at each of the replicates prior to treatment (+/- 1 standard error)

4.5.2.2 Changes in soil characteristics two years after intervention

Between the initial testing in April 2022 and subsequent testing in June 2024, salinity in the control plots decreased in the surface 5 cm at replicate 2 and top 20 cm at replicate 3 (Figure 78). This decrease reflects the dynamic nature of salinity in soil. Two years post cattle and ripping treatment, salinity of the upper soil layers (0-20 cm) at replicates 1 and 3 was lower under cattle and ripping, while differences at replicate 2 were smaller and constrained to the 0-5 cm surface layer. What is desirable for the remediation is that changes are sustained; that leaching of salts is effective enough to keep them lower in the profile. For the leaching to persist, any response of plant growth needs to be widespread enough and sustained to minimise wicking of salts back to the surface. The greater groundcover at replicate 3 with the ripping and cattle treatment is required to entrench the improvements, while the abundance of bare ground observed at replicates 1 and 2 in particular will allow the high salt store to move again toward the surface in dry conditions.

The soils on each replicate were still sodic (Figure 79) as expected because sodicity does not change appreciably without some change to chemistry (such as the addition of ameliorants such as gypsum).

Higher soil carbon concentrations were observed in the upper soil profile (0-5 cm) in the cattle treatment at replicate 1 and in the cattle and ripping treatments at replicates 2 and 3 relative to the respective controls (Figure 80). This an encouraging sign for the condition of the soil surface following these interventions. It is important to note that soil carbon levels are prone to fluctuation with plant growth and the activity of soil organisms particularly when salinity decreases (Dong et al. 2022). The continual threat of erosion in areas of high bare ground preferentially removes organic material (Webb et al. 2013). The significantly lower levels of soil carbon in 2024 compared to the baseline (2022) measurement at replicates 1 (0-5 cm and 10-20 cm) and 3 (0-5 cm and 5-10 cm) highlights how prone to loss organic matter can be in these environments.

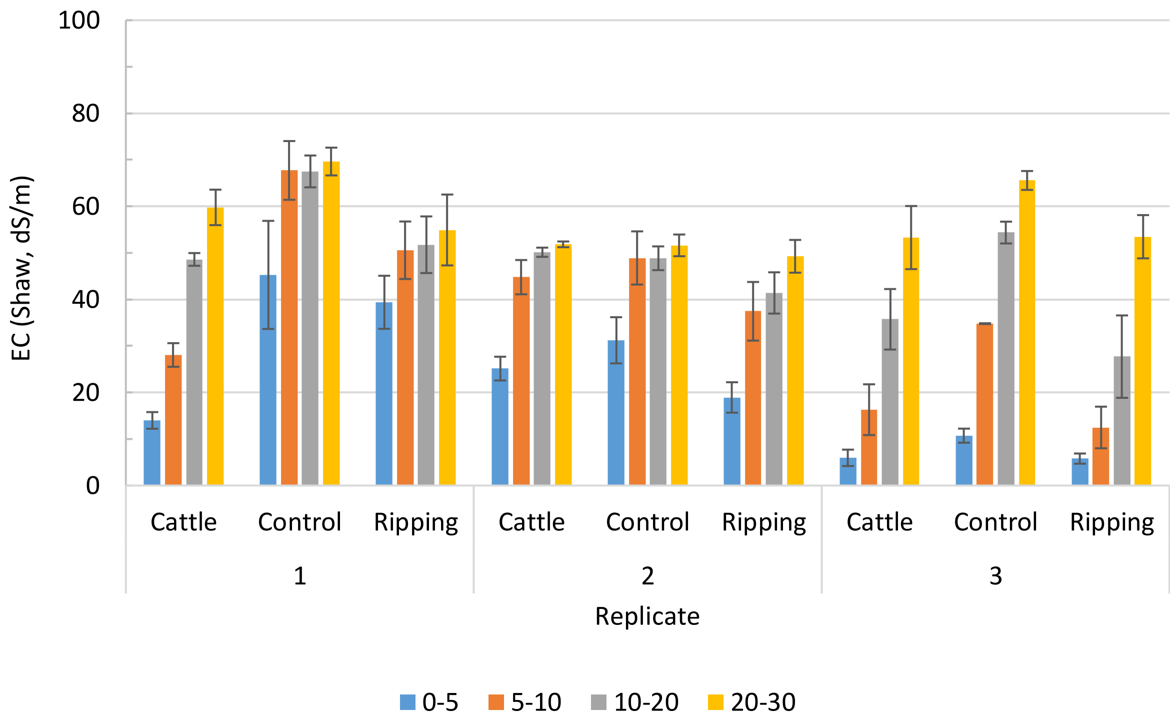


Figure 78. Salinity (+/- 1 standard error) (measured as ECe, estimated electrical conductivity and soluble chloride; Shaw 1999)) at each depth increment for each treatment and replicate for year 2

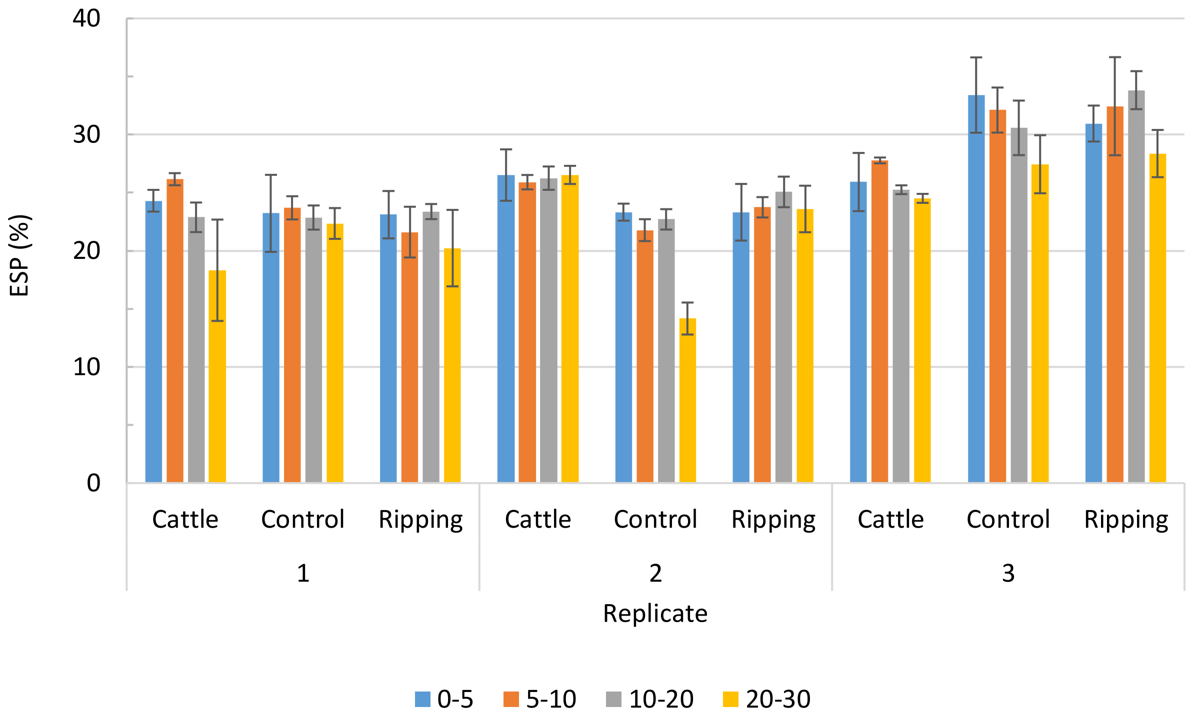


Figure 79. Sodicity (exchangeable sodium percentage) (+/- 1 standard error) for each treatment and replicate in year 2

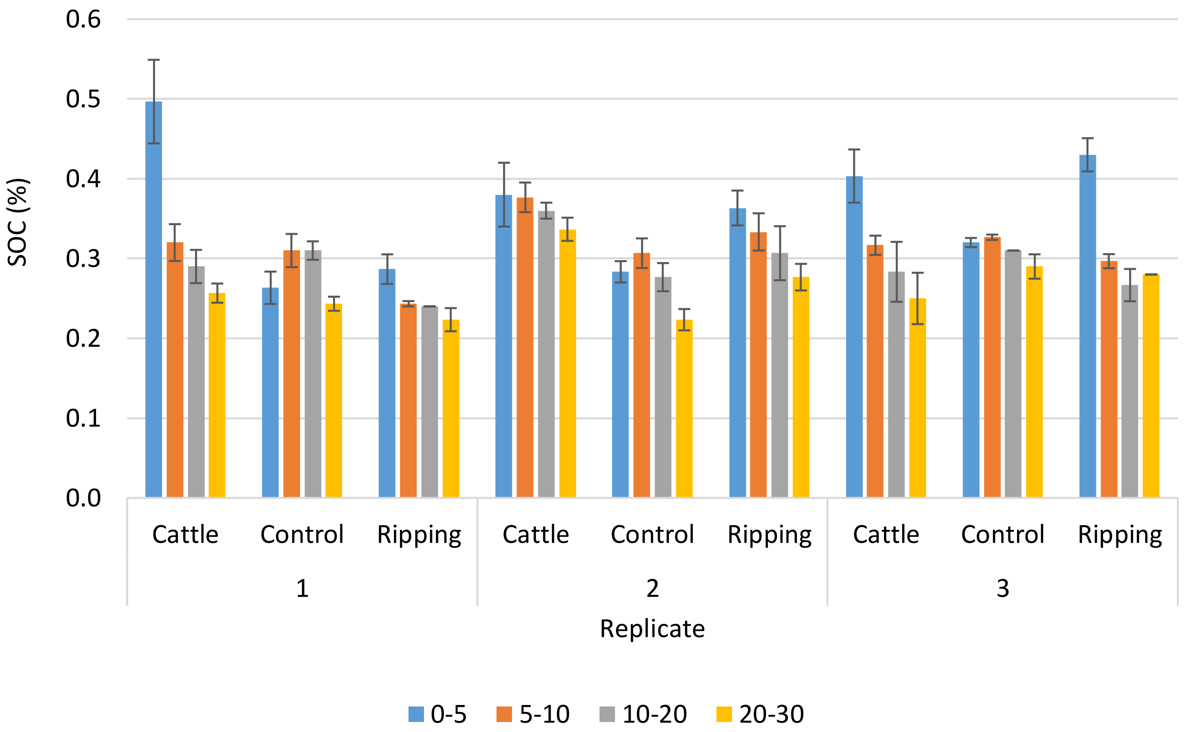


Figure 80. Soil organic carbon (SOC) (+/- 1 standard error) for each treatment and replicate in year 2

Taken together, the high levels of salinity and sodicity of these scalded areas contribute to low plant growth across the scalds. The reduction in salinity in the ripped and cattle treatments is reflected in the higher levels of groundcover and biomass in the ripped treatments measured in year 2 (all replicates), and the cattle treatments (Replicates 1 and 3). As ground cover and plant biomass increase, this provides a positive feedback cycle to further improve soil condition. The deeper effect of ripping compared to trampling would facilitate greater leaching, and subsequent establishment would decrease wicking. How sustained the effects are will however be subject to seasonal conditions and management to allow consolidation of the effects. There has been three years of high rainfall in the region, so a reversion to the mean rainfall or lower will test plant survival.

4.5.3 Conclusion

Both ripping and high intensity animal impact for a short duration had a positive impact on the restoration of degraded scalds across Bokhara Plains, increasing ground cover up to 50% (from an initial 0% cover) and increasing biomass up to 1.8 tonnes per hectare). The decrease in surface salinity under the cattle and ripping provides improved conditions for plant establishment and growth going forward. Salinity is the main constraint at the site, and being soluble the changes seen are as hoped for from the treatment. Changes to SOC are dynamic but better appreciated over a longer timeframe of a few more years. Sodicity as an underlying condition would only change appreciably with chemical amendment or physical disturbance (such as ripping and mixing of soil layers). The somewhat perverse effect of induced dispersion due to leaching of salts can be managed to an extent by maintaining as much plant and biological activity and groundcover as possible to protect and bind the soil. These results demonstrate the effectiveness of targeted management actions in restoring scalded areas on the Darling Riverine Plains.

4.5.4 Impact of historic ponding and ripping on ground cover

Following ripping and/or waterponding, total ground cover significantly increased across the 22 mechanically treated areas, averaging >25% increase. However, in some areas (particularly those where ponding or ripping occurred >30 years prior, an increase of over 50% was observed (Figure 81)

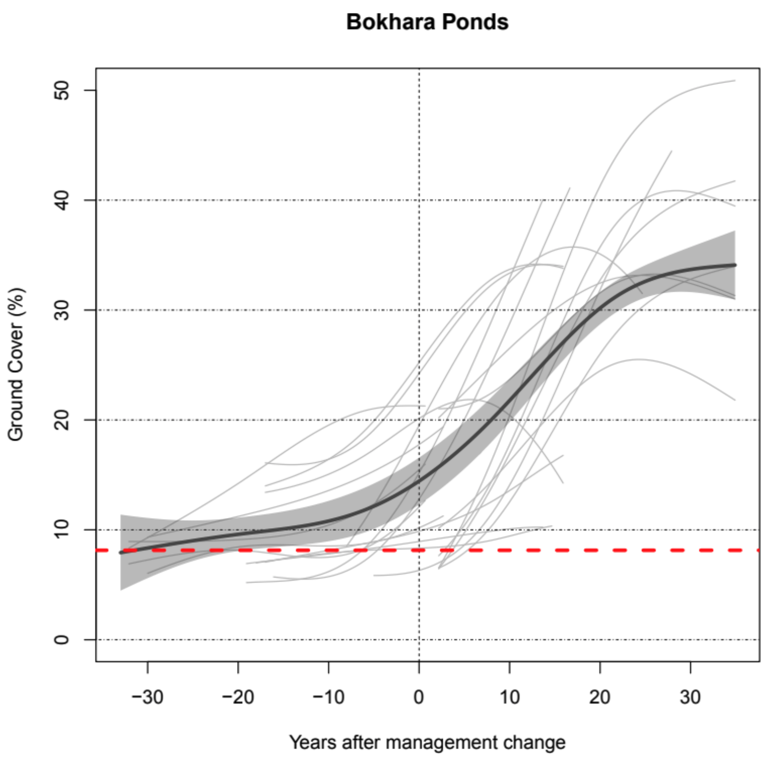


Figure 81. Change in ground cover on scalds across Bokhara Plains to ripping and/or ponding over the past 33 years. Each light grey line represents a different scald, the solid black line shows the average response across all scalds with the shaded area showing the 95% confidence interval of the response. The red dash line represents the average ground cover across four control (untreated) scalds. Each scald was

treated at a different point in time, and therefore data has been centred around the time at which the intervention occurred

4.6 Water ponding at Willow Point (Wyndham)

4.6.1 Impact of water ponding on ground cover and vegetation

Assessment of the water ponding and reference sites in March 2024, two years after establishment of the ponding banks, showed a decrease in bare ground and an increase in plant and litter cover, biomass and plant richness predominantly at the bank and nearby (within 5m) of the bank (Figure 82 - Figure 86). In particular, vegetative ground cover (plant & litter) increased from 0% to 20-30% cover at the banks and up to 20% at 5m from the banks, with a corresponding increase of biomass from 0 kg/ha to 700-1100 kg/ha at the banks and up to 700 kg/ha at 5 m from the banks (Figure 87 - Figure 91). There is an indication of improvement further out from the banks also, although the improvement was only small (<10% cover change and <100 kg/ha biomass improvement) at the time of measurement. Species growing along the bank or near the bank were predominately early successional species of the *Sclerolaena* or *Atriplex* genus *(*i.e, *A. angulata, A. holocarpa, A. lindlyei, S. divaricata, S. patenticscuspis*). Total cover and plant biomass in the reference area at the time of measurement in 2024 was almost 70% and 2000 kg/ha, respectively. The results indicate that some areas of the ponded areas, in particular those closest to the banks where more water is ponded, are on a trajectory towards the improved condition and function.

Indices of landscape function, including stability, nutrient cycling, water infiltration, patch area and landscape organisation were slightly higher in Area 2 than Area 1, and greatest in the reference area, as expected (Figure 92).

Figure 82. Response to ponding following rain, October 2023

Figure 83. Before (left, April 2021) and after (right, April 2023) satellite images of ponding at Wyndham, showing plant growth across the area

Figure 84. Growth of vegetation along and near to ponding banks, 2 years following construction of ponding banks (March 2024)

Figure 85. Growth of vegetation along and near to ponding banks, and changes to soil surface in ponded zone, 2 years following construction of ponding banks

Figure 86. Cracking of soil surface as salts leach down the soil profile

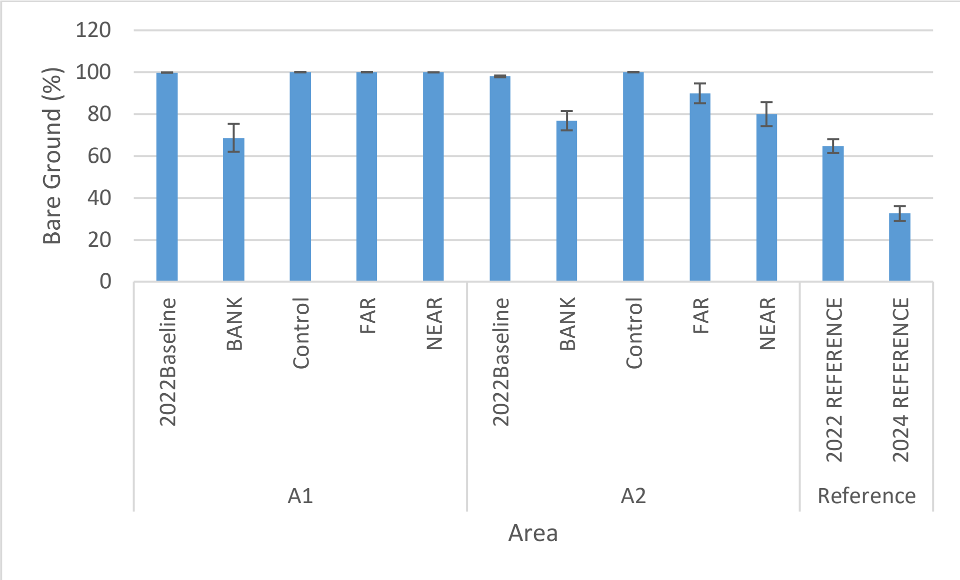


Figure 87. Average bare ground (%) in 2022 and 2024 at different locations (+/- 1 standard error). Areas A1 and A2 represent two areas of the scald that had slightly different soil types, and the reference area represents a high productivity run-on area nearby

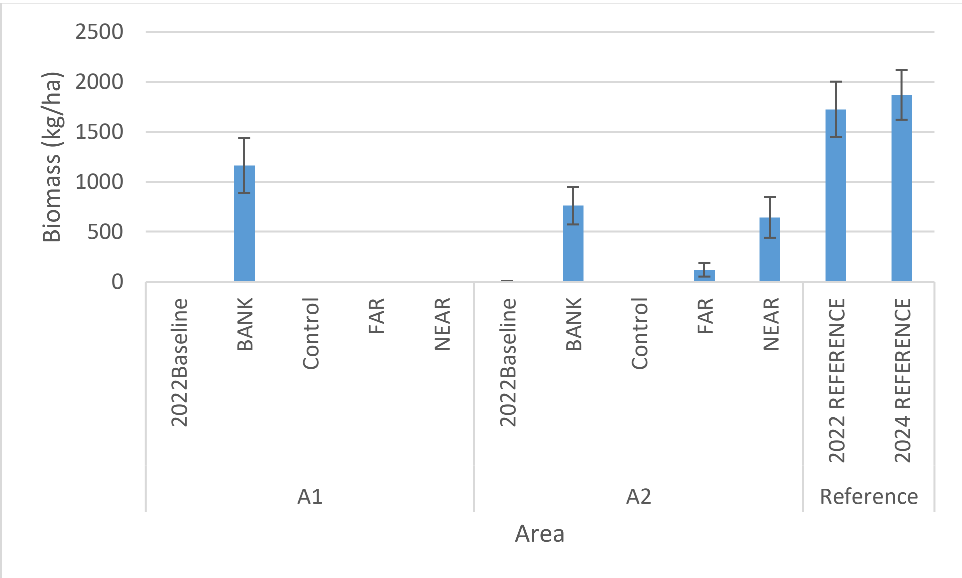


Figure 88. Average plant biomass (kg/ha) in 2022 and 2024 at different locations (+/- 1 standard error). Areas A1 and A2 represent two areas of the scald that had slightly different soil types, and the reference area represents a high productivity run-on area nearby

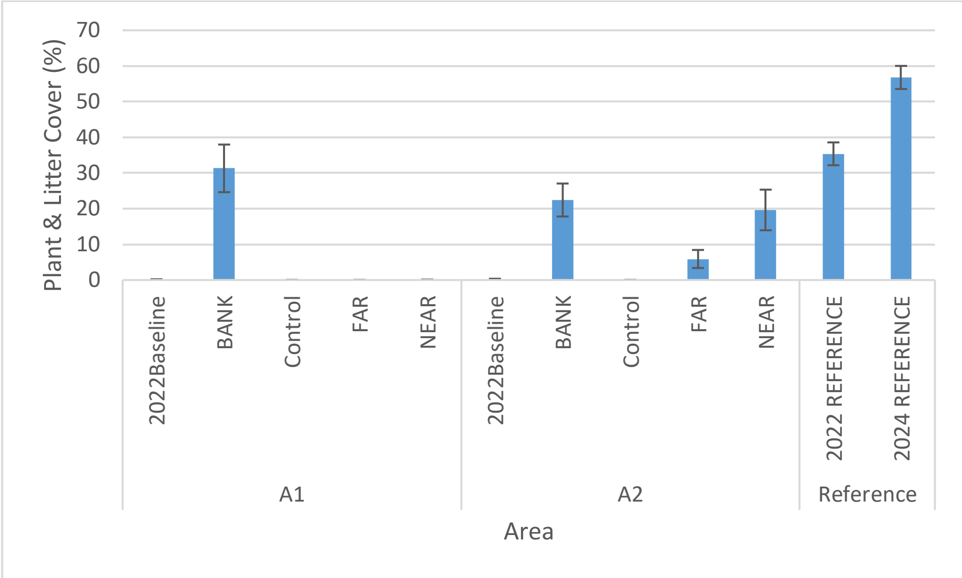


Figure 89. Average vegetative (plant and litter) cover (%) in 2022 and 2024 at different locations (+/- 1 standard error). Areas A1 and A2 represent two areas of the scald that had slightly different soil types, and the reference area represents a high productivity run-on area nearby

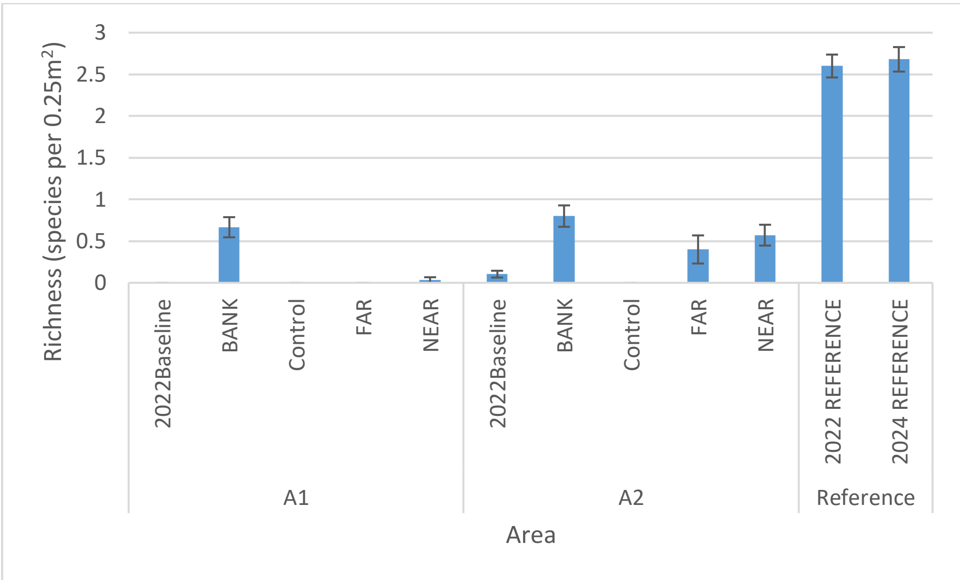


Figure 90. Average plant species richness within 0.5x0.5m quadrats in 2022 and 2024 at different locations (+/- 1 standard error). Areas A1 and A2 represent two areas of the scald that had slightly different soil types, and the reference area represents a high productivity run-on area nearby

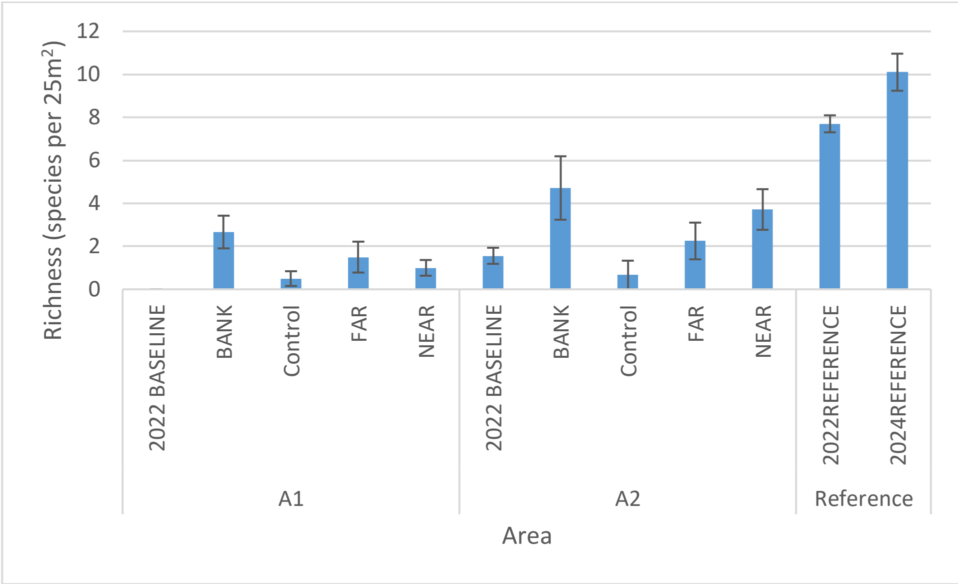


Figure 91. Average plant species richness within 5 x 5m quadrats in 2022 and 2024 at different locations (+/- 1 standard error). Areas A1 and A2 represent two areas of the scald that had slightly different soil types, and the reference area represents a high productivity run-on area nearby

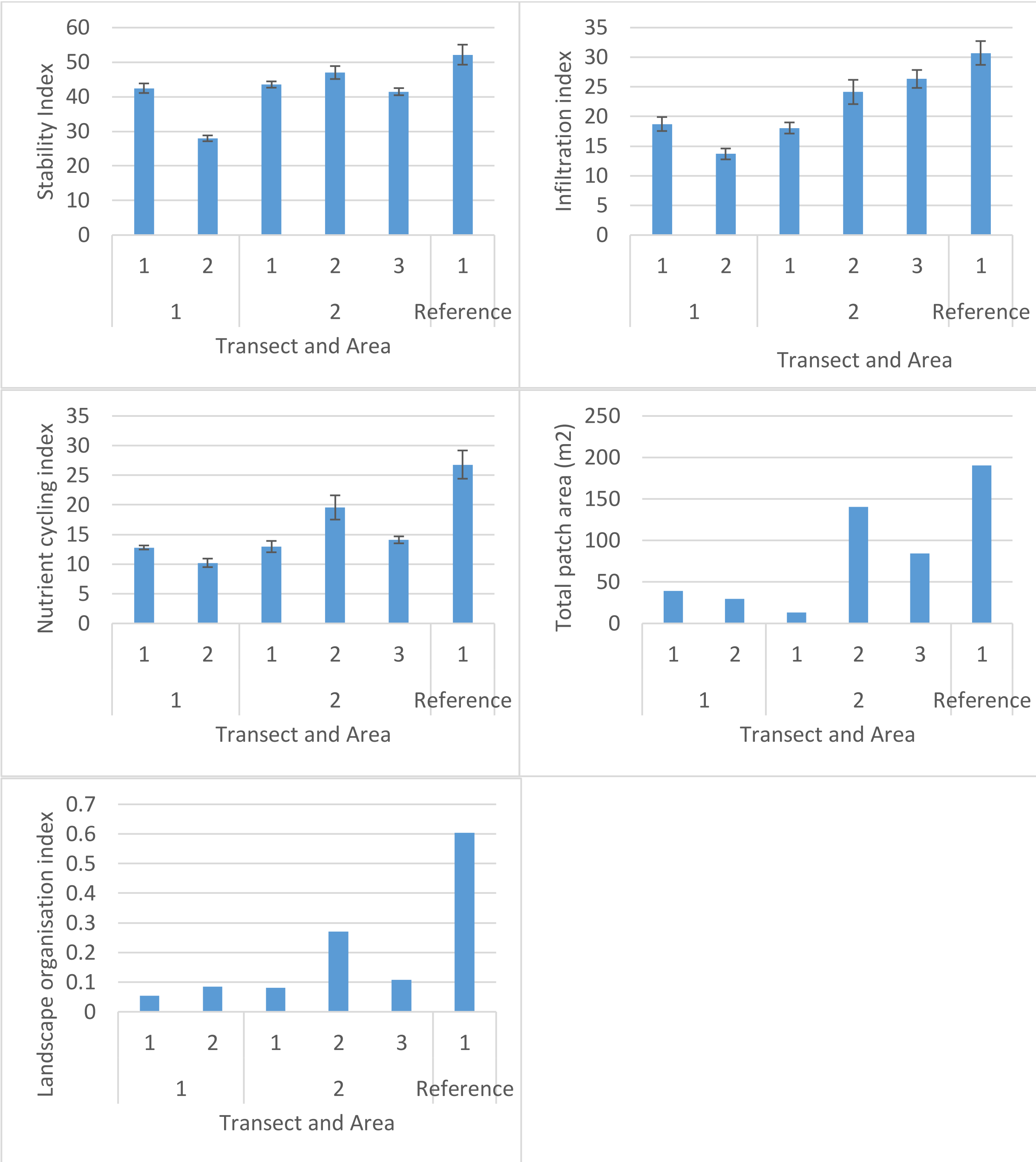


Figure 92. Indices of the landscape function analysis across the two water ponding areas and the reference area (+/- 1 standard error)

4.6.2 Impact of water ponding on soil chemistry

The reference area is not saline, is less sodic and has higher carbon than the scalded Area 1 and Area 2 (Figure 93 - Figure 95). In turn, Area 1 was less saline and had a higher concentration of carbon that Area 2. The main constraint that ponding can address on the scalds is slow water flow, increase water infiltration and thereby flush the salinity deeper. While the area ponded in Area 1 could be clearly seen with a darker hue and cracked surface and salinity was slightly lower in the upper surface (0-10 cm) within the ponds relative to the control , two years following establishment of the ponding banks there was no difference in salinity at each increment either within the pond (near to or far from the bank) nor compared to the outside control area. In contrast, the ponded sites in Area 2, both near and far, were less saline in the upper 20 cm than the non-ponded control. Looking at the vertical distribution of salts in Area 1 and Area 2, there was a consistent salinity in the control to a flushing and increasing of salinity with depth. This effective leaching of salts supports the establishment of plants, as reflected in the groundcover and biomass measurements.

Soil carbon concentration across both Areas 1 and 2 was low, with no significant different in SOC% at within and outside of the ponds (Figure 95). There was also no difference in SOC between 2022 and 2024 (Figure 96). We are unable to infer much from these carbon results after a short period of time, and we recommend further long-term monitoring to better understand changes in SOC associated with the waterponding at Willow Point. In Area 1, soil carbon concentration was slightly lower close to the pond bank than further out.

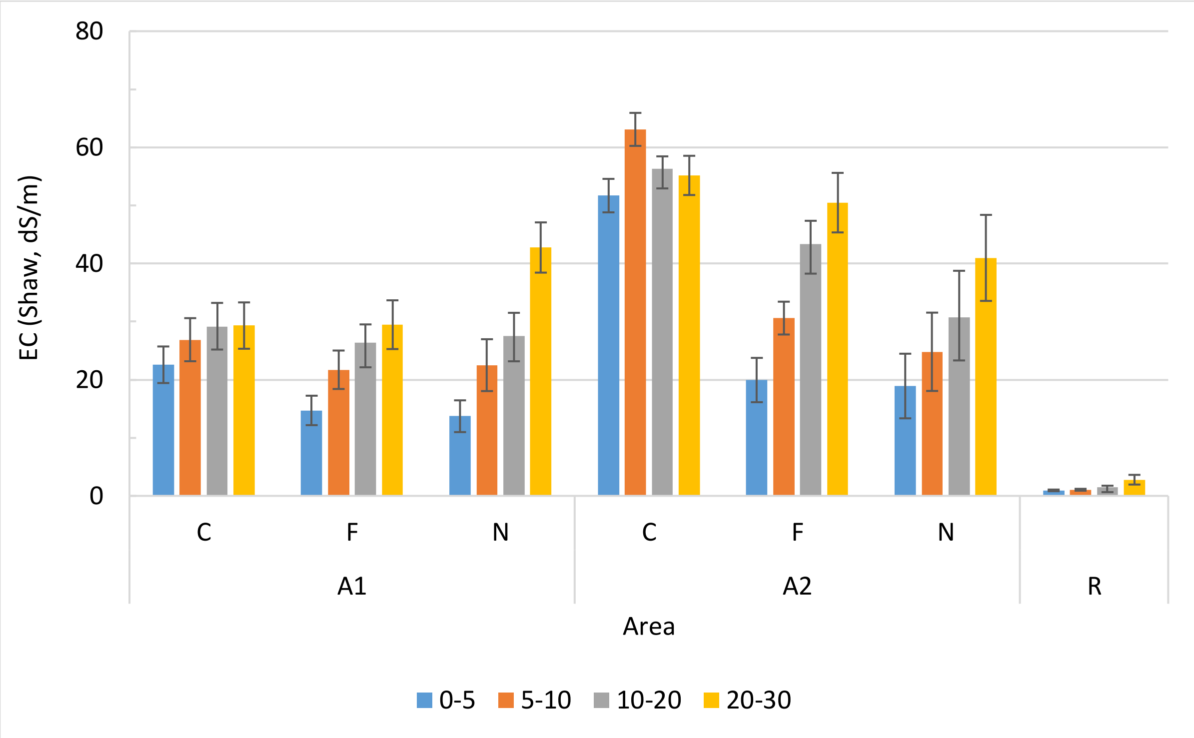


Figure 93. Salinity concentrations at different soil depths at the Willow Point ponding site in March 2024. A1 and A2 represent two areas of slightly different soil types on the scald (+/- 1 standard error). C = control (unponded), F = inside pond but far from the bank (two thirds of the distance to the spill point of the pond), N = near to the bank (5m from top of bank). R = the nearby Reference area on red soils to the east of the lunette

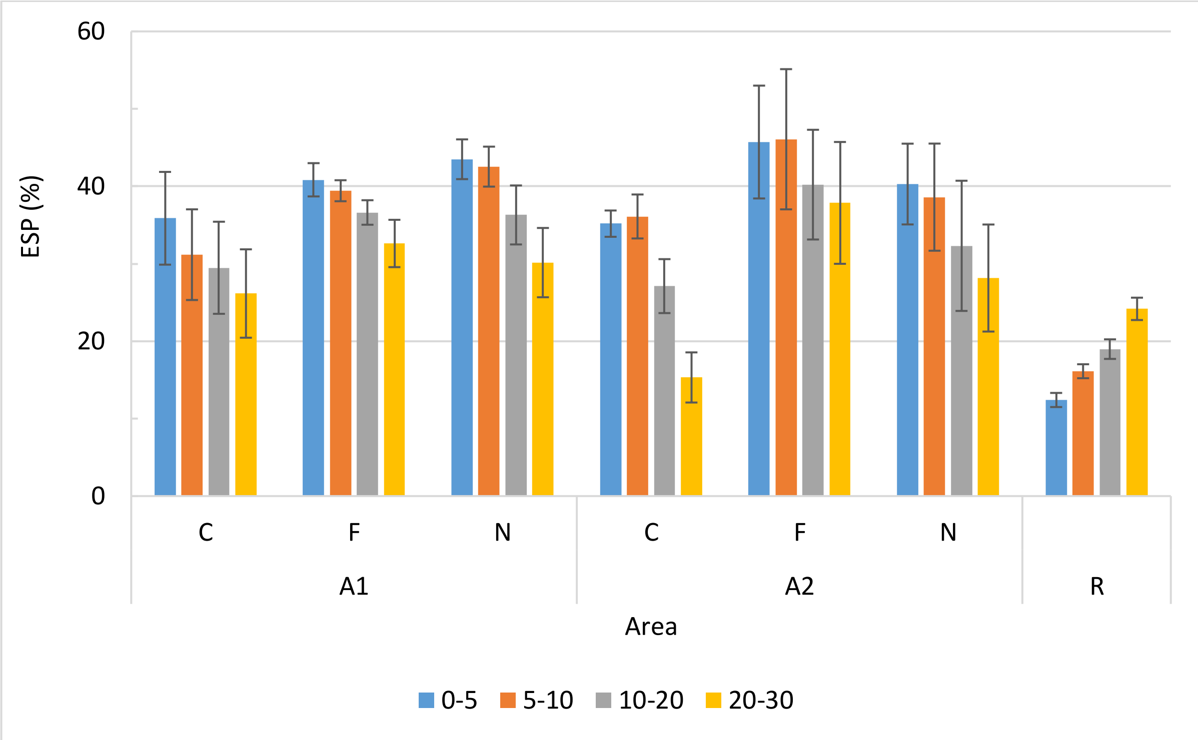


Figure 94. Sodicity (exchangeable sodium percentage, ESP) at the Willow Point ponding sites, area 1 (A1) and area 2 (A2), and the nearby Reference site (R) (+/- 1 standard error)

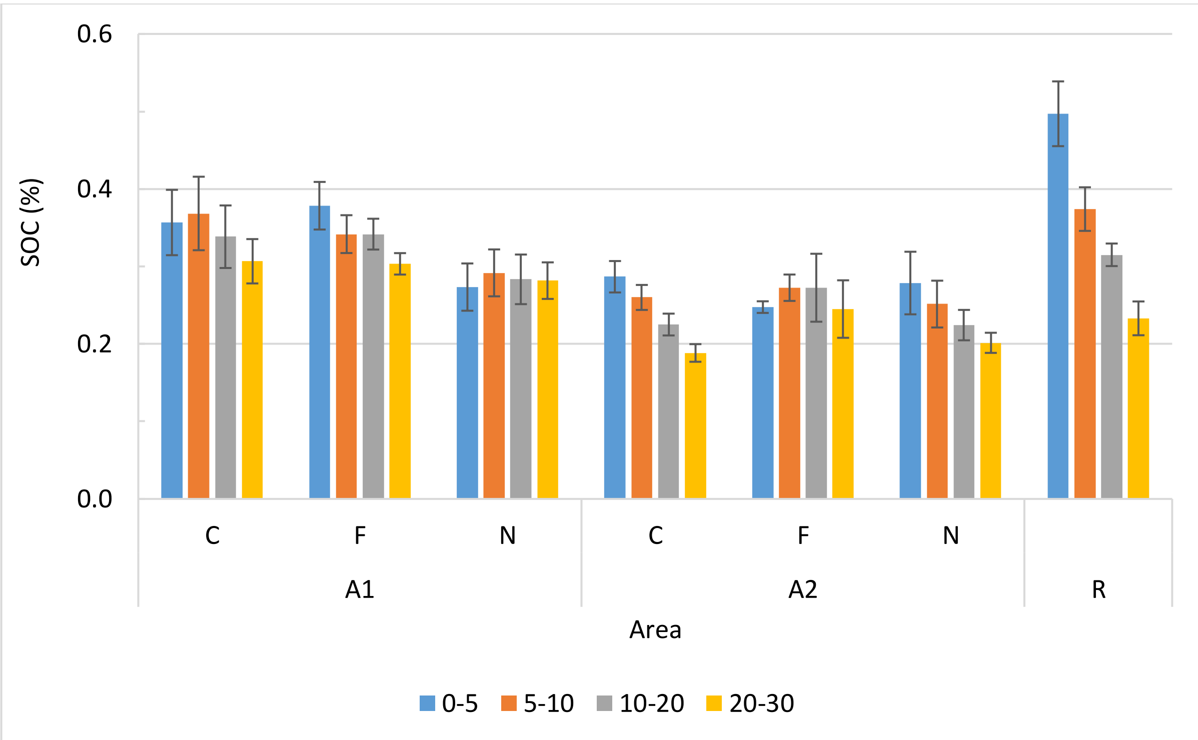


Figure 95. Total soil organic carbon (SOC) at the Willow Point ponding sites, area 1 (A1) and area 2 (A2), and the nearby Reference site (R) (+/- 1 standard error)

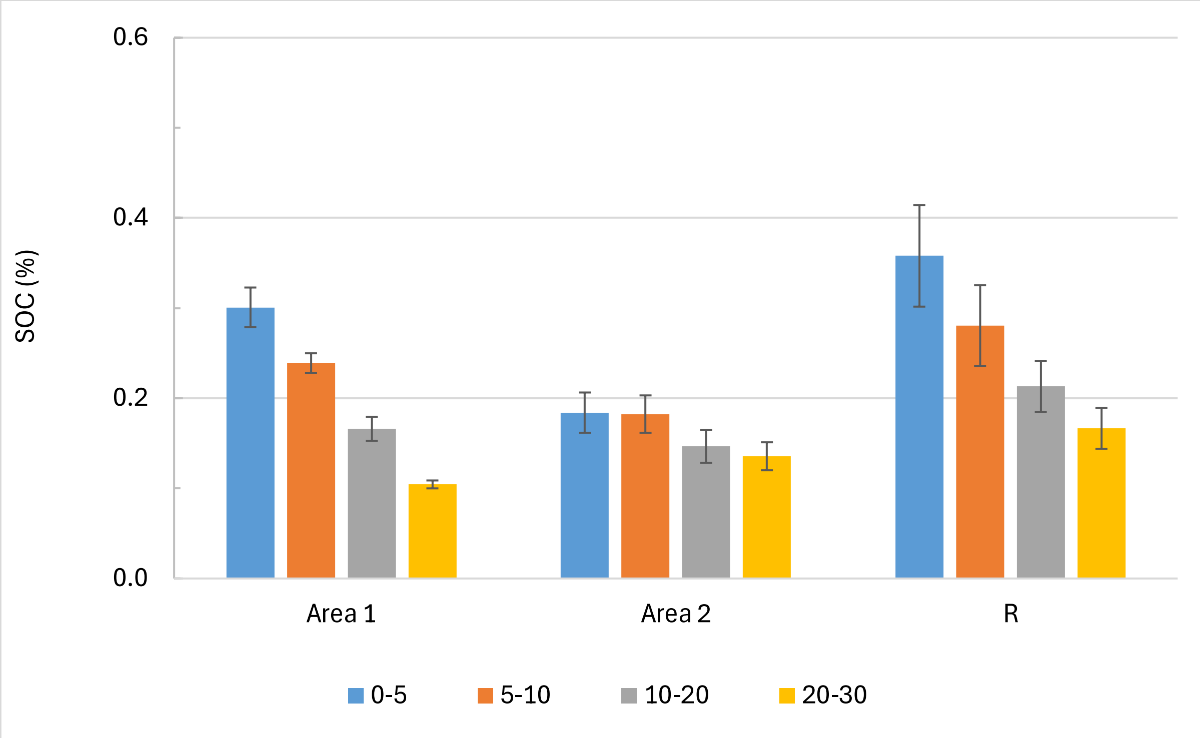


Figure 96. Total soil organic carbon (SOC) at the Willow Point ponding sites in 2022 before the ponds were constructed; area 1 (A1) and area 2 (A2), and the nearby Reference site (R) (+/- 1 standard error)

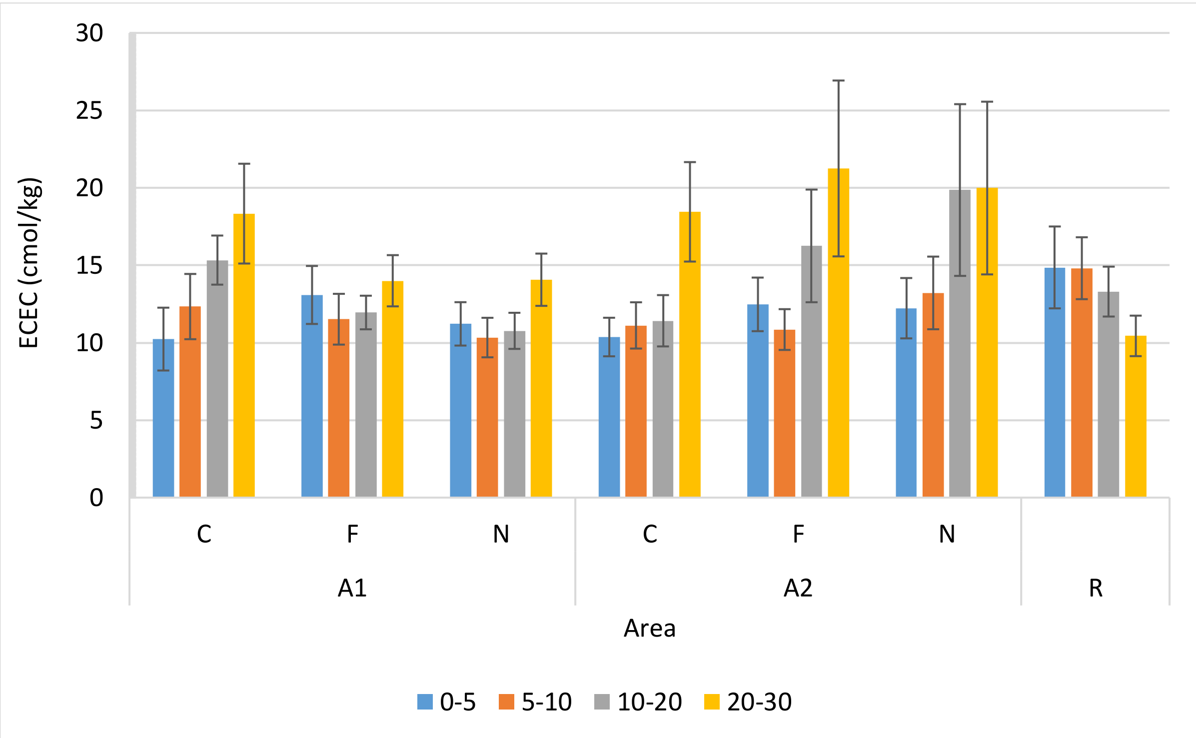


Figure 97. Cation exchange capacity (ECEC) at the Willow Point ponding sites, area 1 (A1) and area 2 (A2), and the nearby Reference site (R) (+/- 1 standard error)

An observation we can make about soil carbon is in relation to the apparent sodicity in the Reference area. Organic matter, as assessed by the SOC concentration, has a high cation exchange capacity compared to mineral soil (Rengasamy & Churchman, 1999). As SOC decreases with depth in the Reference area, sodicity increases (Figure 97). That is, it appears that the underlying mineral properties of the soil are more apparent (sodicity) compared to the more beneficial suite of exchangeable cations on the organic matter.

Not only then does organic matter help stabilise a soil from being physically unstable (slaking) but moderates chemical instability (sodicity).

4.7 Gypsum for scald reclamation at Gurrawarra

4.7.1 Impact low, moderate and high gypsum rates

Vegetation cover did not differ significantly between the control, low and medium gypsum application treatments, averaging 4.2-7.2%. Vegetation (plant and litter) cover was greater on the high gypsum treatment (average 18.0%, Figure 98, Figure 103). Plant species richness was also higher in the high gypsum rate plots, and lowest in the control plots (Figure 99, Figure 100). Plant species composition across the four treatment plots was relatively similar, dominated by copperburrs (incl. *Sclerolaena divaricata, S. lanicuspis, S. tricuspis, S. brachyptera*)., followed by perennial grasses (*Sporobolus actinocladus, S. caroli, Chloris truncata, Tripogon loliiformis),* saltbush (*Atriplex holocarpa*) and other annual species (Figure 101).

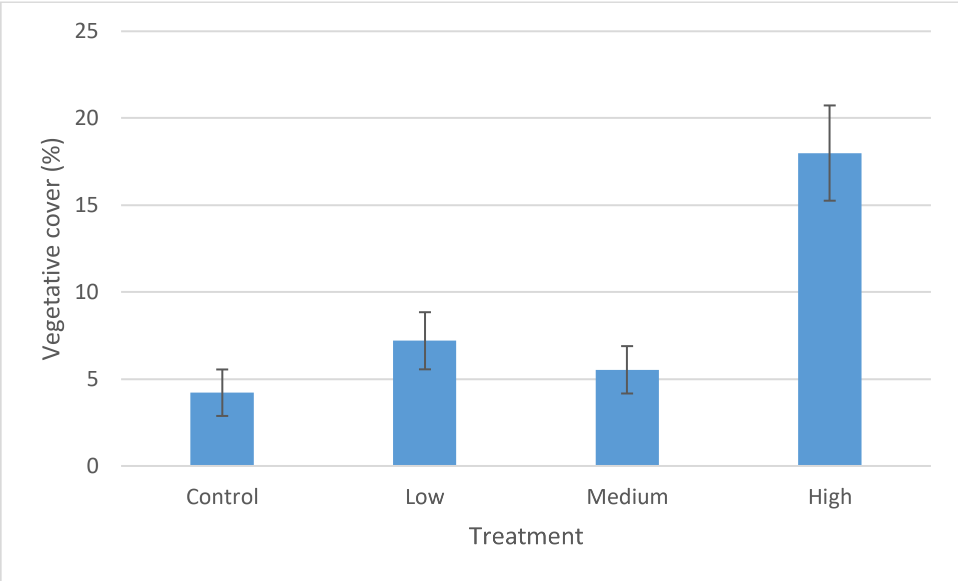


Figure 98. Average vegetative (plant + litter) cover within the different gypsum treatment plots, recorded in July 2024 (+/- 1 standard error)

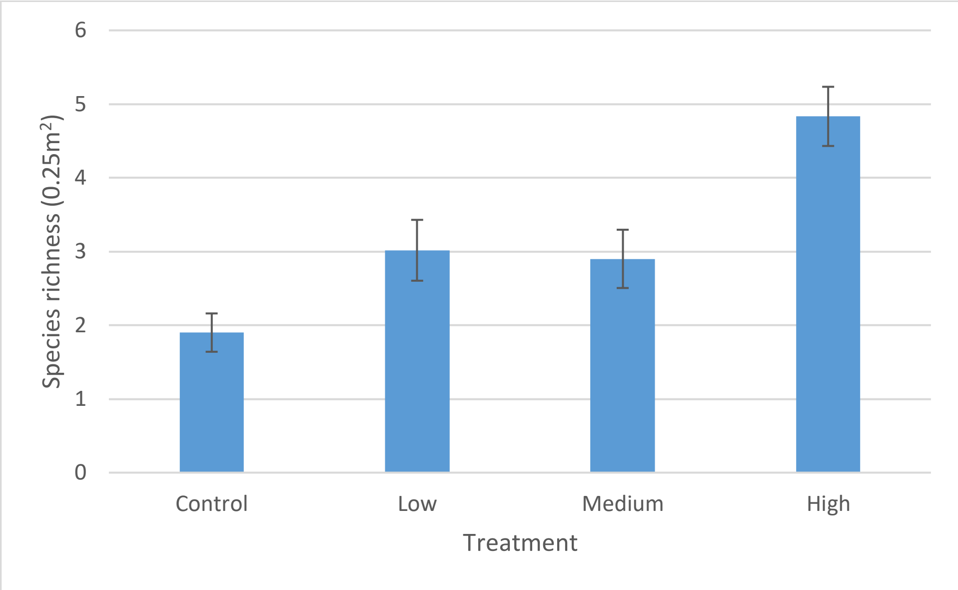


Figure 99. Average species richness within 0.25m² quadrats within the different gypsum treatment plots (+/- 1 standard error)

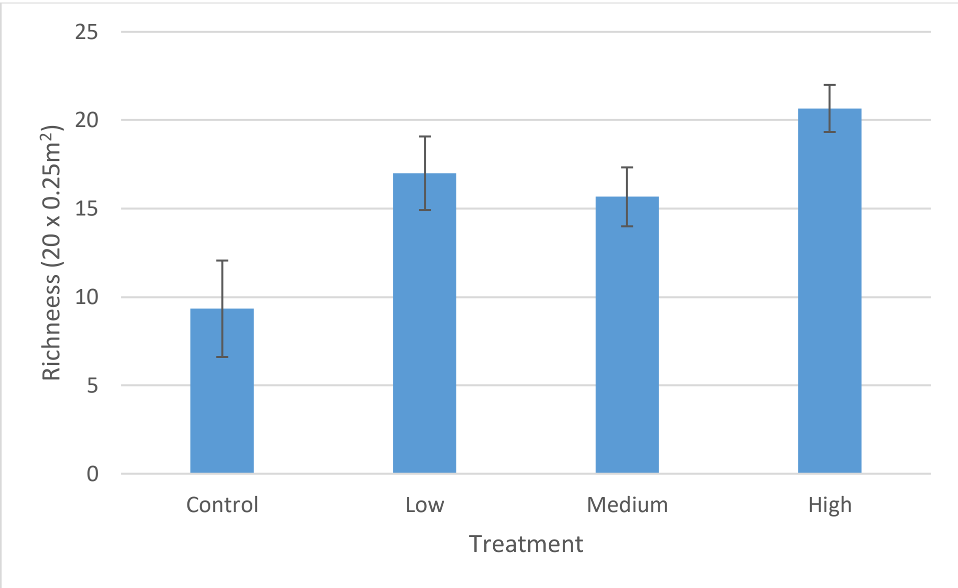


Figure 100. Average of total species richness from all 20 x 0.25m² quadrats monitored within the different gypsum treatment plots (+/- 1 standard error)

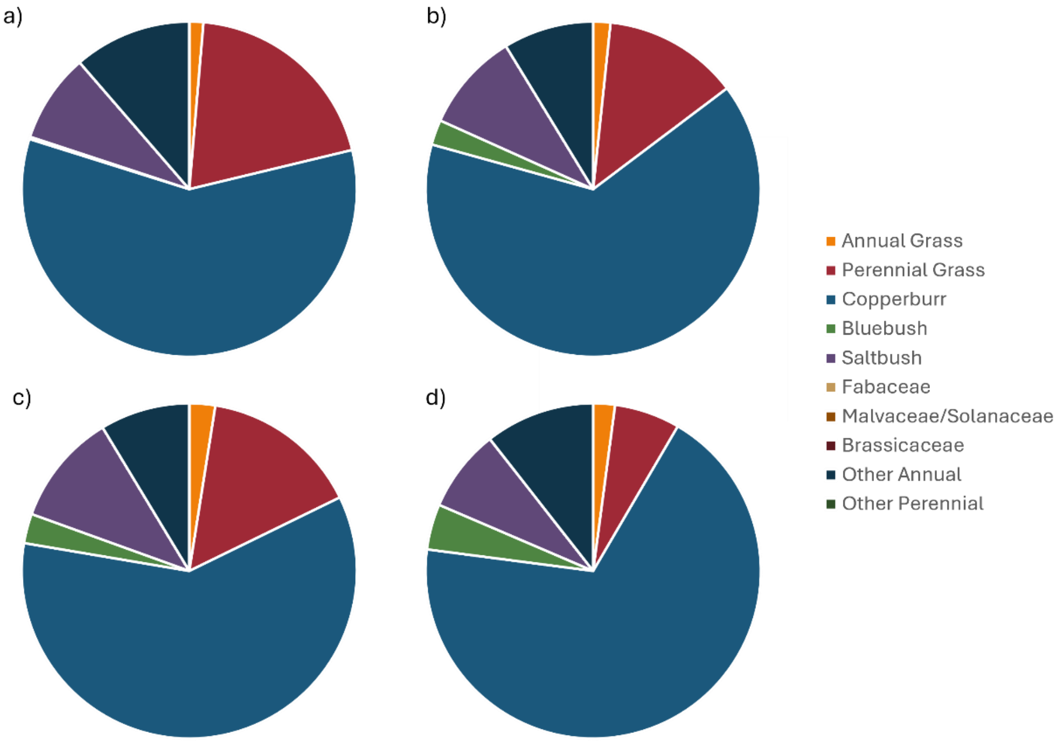


Figure 101. Composition (mean percent of total plant cover) of the a) Control, b) Low, c), Medium, and d) High gypsum treatment plots

Measurements taken prior to the start of the trial showed no difference in soil properties (salinity, sodicity, pH nor carbon, cation exchange capacity) across the site between the treatment areas. Following establishment of the trial in July 2023 there was little rainfall for the remainder of the year. Good rainfall arrived in 2024 and continued above average through the winter and spring. With the rainfall a visual difference was observed with greater infiltration in the high gypsum treatment plots but the usual surface ponding and runoff from the low and control treatment plots

(

Figure 102). The response of vegetation to the gypsum application, particularly at the high rate, at plot boundaries was marked (Figure 103 - Figure 105).

Figure 102. Photograph following rainfall in March 2024. High gypsum plot on the left of the post and low on the right. Photo: Julie Conder

Figure 103. Photograph looking across Control (C), High gypsum (H) and Low gypsum (L) plots (non scalded area in background), July 2024

Figure 104. Vegetation in a High gypsum plot, July 2024

Figure 105. Plot boundary (yellow line) between a Control (left of the dashed line) and High gypsum plot (right), July 2024

The NDVI (normalised difference vegetation index) uses reflectance from red and near infra-red wavelengths. The index is used to assess red absorbance (e.g. by chlorophyll during photosynthesis) and NIR reflectance (e.g. from a leaf that is not moisture-stressed), providing a physiological basis for an effective measure of greenness. These reflectances can be affected by anything in the footprint, so the increase detected at installation in July 2023 was likely due to the disturbance of the surface. An increase in NDVI (up to 0.2) within the high treatment compared to the other plots was evident, while there was little difference in NDVI between the control, low and medium treatment plots (Figure 106). The relatively good 2024 growing season was also seen with the higher NDVI (up to 0.13) at the other plots compared to the long-term preceding NDVI of approximately 0.1.

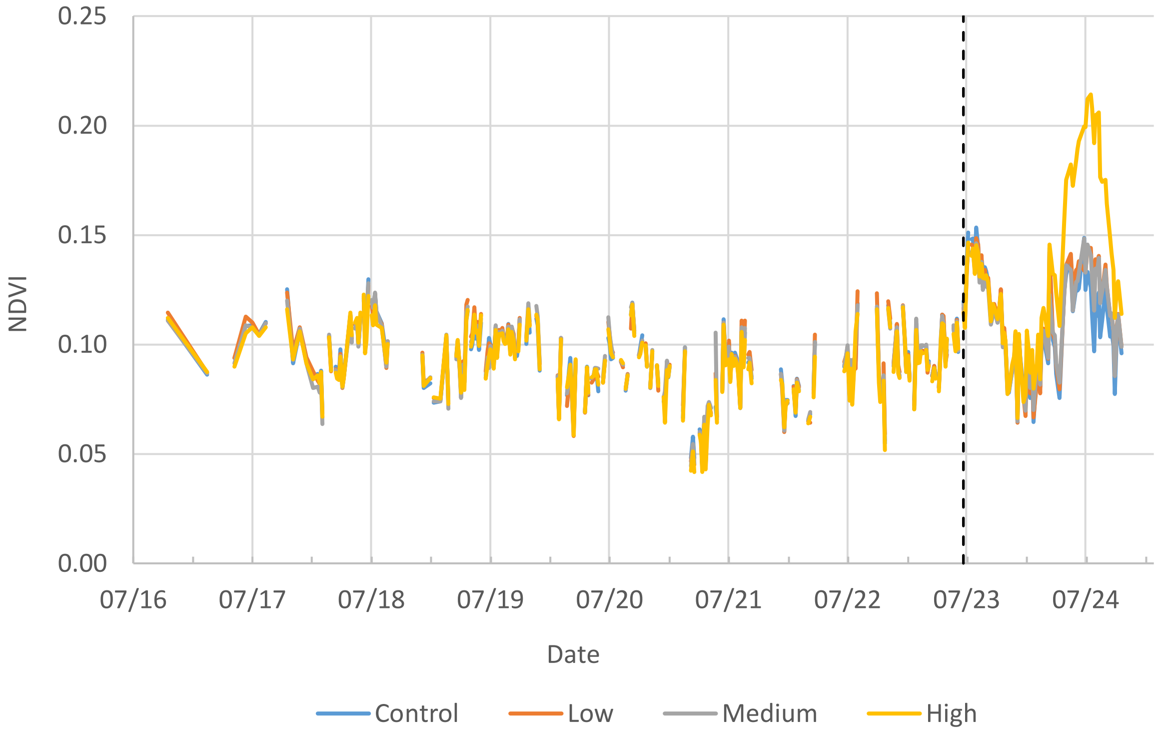


Figure 106. Remotely sensed NDVI over time at the gypsum demonstration site by treatment (vertical dashed line indicated date in installation)

The increase in vegetation with the high rate of gypsum was relatively patchy. After installation the subtle variability in topography became more evident, with some of edge effects becoming more apparent. Such effects were run-on from adjacent saline areas, or more buffering from banks, rips, or proximity to the edge of the scald. At a finer scale, vegetation was more abundant in the pre-existing rip lines than elsewhere in each plot (treated and untreated).

Despite the response of vegetation to the high rate of gypsum, there was little difference in salinity between the treatments down the soil profile (Figure 107). Note that the surface 10 cm was sampled in two increments in 2024; some surface mixing with the incorporation following the application of gypsum. However, there was an overall decrease in salinity at the surface, and translocation to depth, compared to 2023 following good rainfall. There was an apparent decrease in sodicity with the high rate of gypsum, though given variability after one year this was not significant (Figure 108). Note that the surface 10 cm was sampled in two increment in 2024 and there was some surface mixing with the incorporation following the application of gypsum. Persistent vegetation cover (even if senesced) would minimise wicking and re-occurrence of surface salinity, while ongoing exchange of Na for Ca would improve the inherent dispersibility. The marked difference between the salinity and sodicity indicates how much more dynamic fluctuations in salinity are compared to exchange processes.

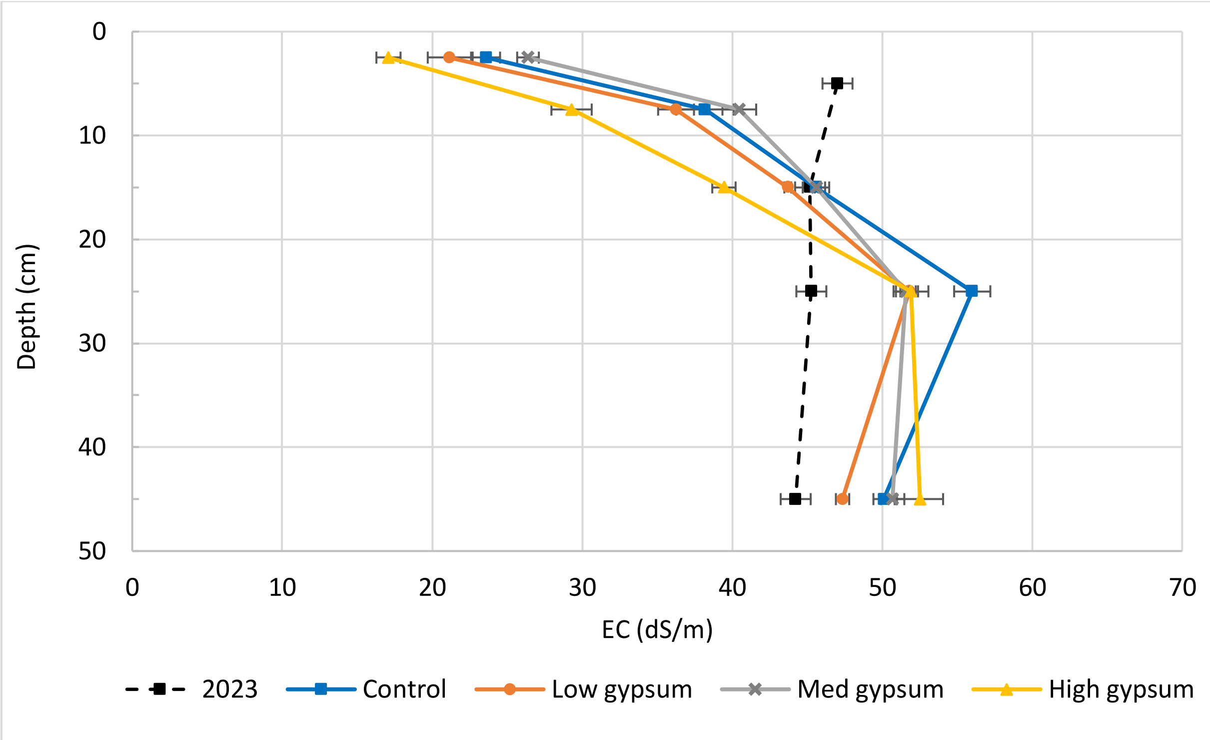


Figure 107. Average salinity (electrical conductivity, EC) down the soil profile of the Control and Low, Medium and High gypsum application plots and the site average in 2023

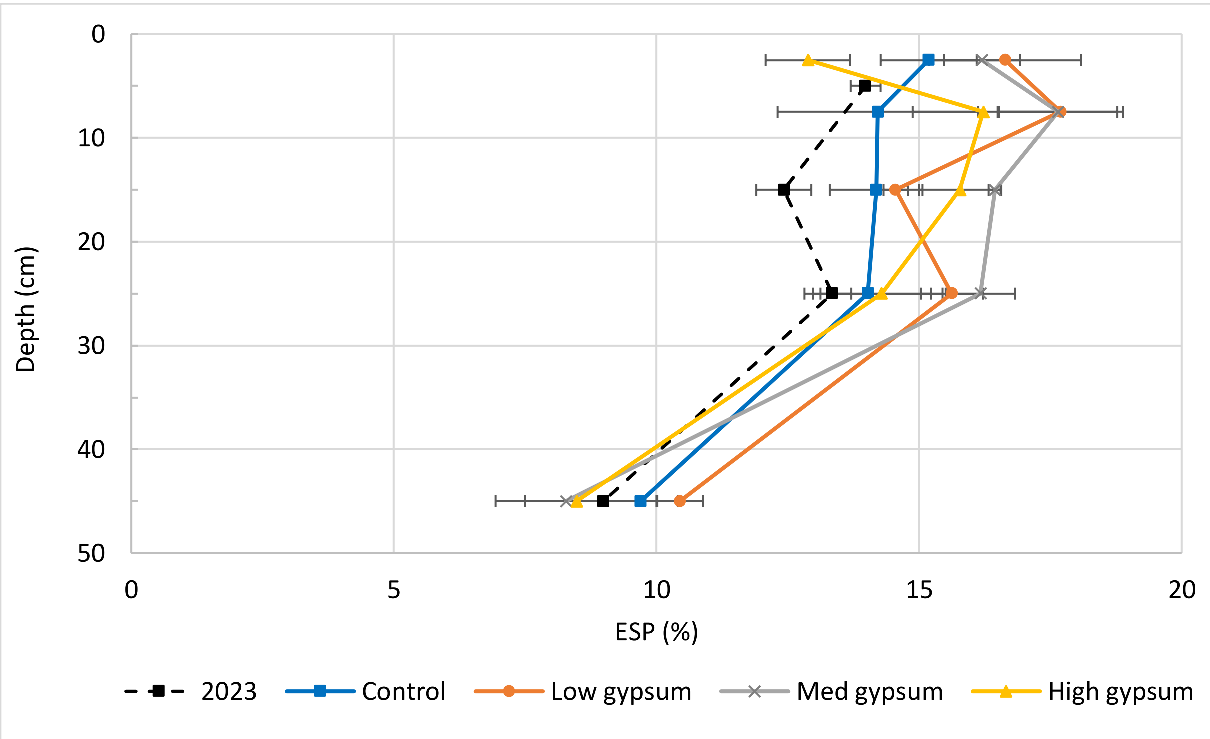


Figure 108. Average sodicity (exchangeable sodium percentage, ESP) down the soil profile of the Control and Low, Medium and High gypsum application plots and the site average in 2023

4.7.2 Impact of vegetation patches and historic ripping

The soil under vegetation in the high gypsum application plots had lower salinity through to 20 cm depth than the Bare control and (below the top 5 cm) under the Bare patches within the High treatment plots (Figure 109). The existing rip lines also affected salinity. Within the High gypsum are the salinity was lower in the Rip lines compared to the Bare areas in the surface 5 cm and deeper 20-30 cm increments). The salinity in the Control Rip also tended to be lower than the Bare areas under the High gypsum rate, but only marginally so at 10-20 cm. Within the Control plots, the salinity was lower in the Rip lines than the broader area through the to 20 cm).

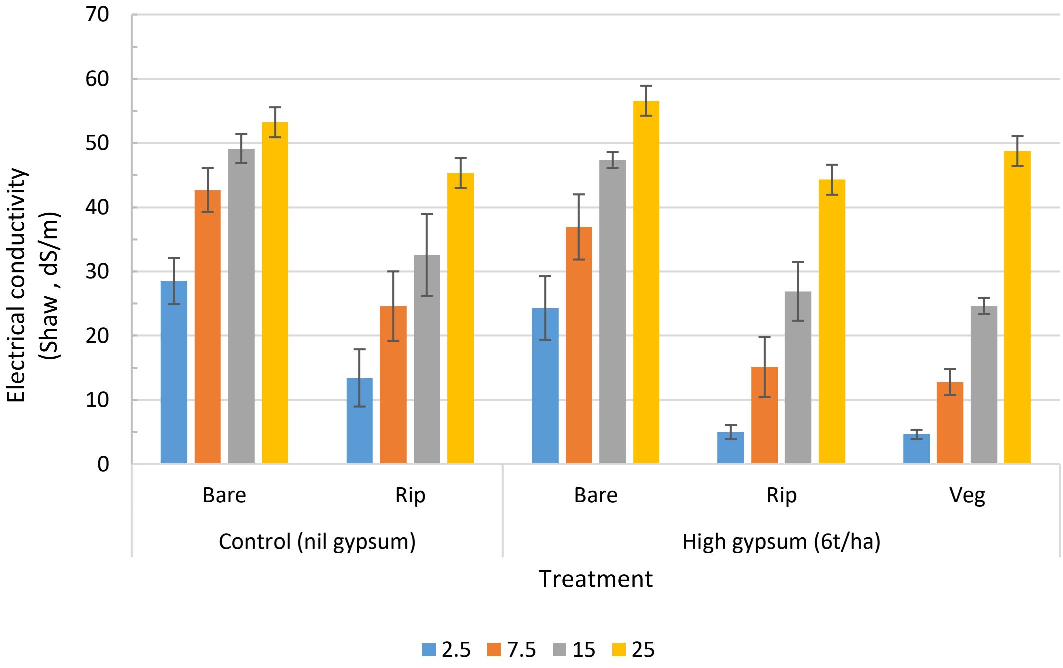


Figure 109. Salinity (electrical conductivity, EC) within the Control and High treatment areas (+/- 1 standard error)

The implication of these measurements of the soil properties and responses to the gypsum application and earlier ripping on the scald is one of plant establishment and positive feedback. The ripping did appear to allow better infiltration and flushing of salts with a visual response of increased vegetation. However, these rip lines are narrow, and particularly in the Control areas the vegetation is still sparse. The effect of the gypsum was promising but only at the High rate, where substantial patches of vegetation have established. These areas give more of a buffer against salinity coming back to the surface. While they senesced at the time of reporting (late spring 2024), the surface cover remains. The test will be how it responds in the coming season and for the effect to last through dryer periods.

4.7.3 Impact of plant patches and gypsum dump

Opportunistic samples taken on nearby areas of a patchy semi-scald and the site of the gypsum dump showed patterns of salinity that could explain the evident differences in vegetation present. The samples collected were not replicated so are indicative only and significant differences can't be assessed. The samples taken from the vegetated patches on the self ameliorating scald and within the gypsum dump indicated much lower salinity than the adjacent bare patches at both sites (Figure 110). The subsurface salinity of the patchy area was lower than that for both the gypsum dump area and scalded demonstration site. The scald has high salinity, approaching sea water concentrations, throughout the profile.

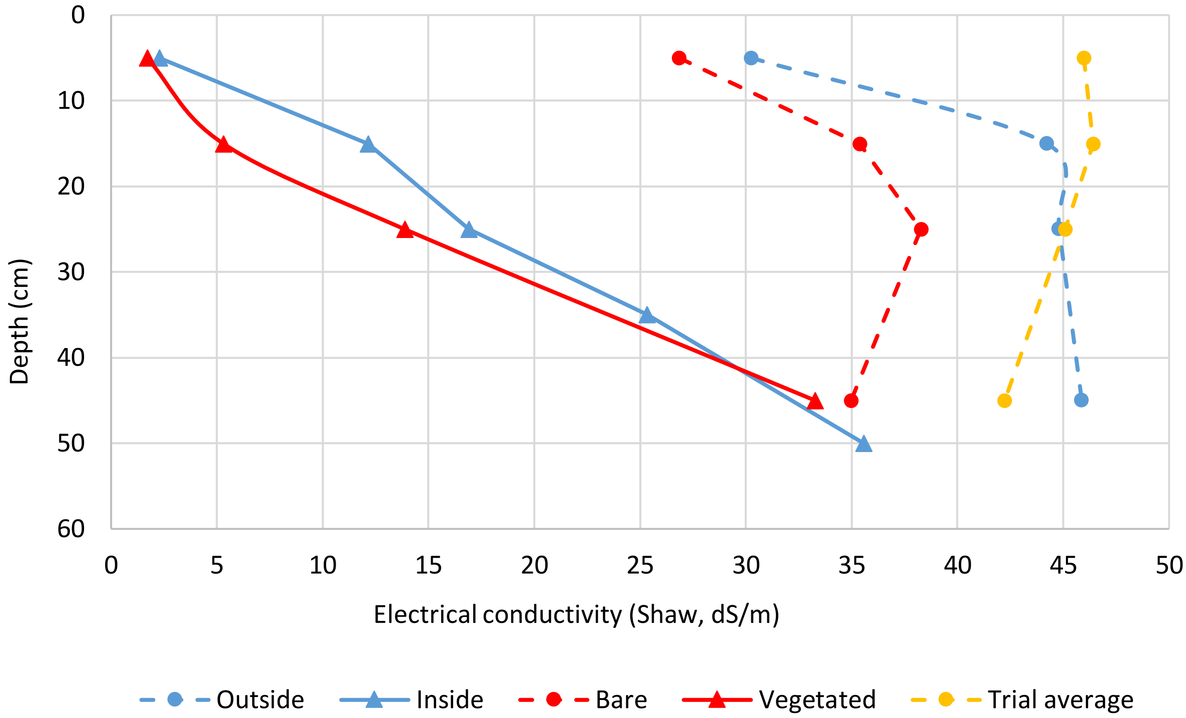


Figure 110. Salinity levels Inside and Outside the gypsum dump area, the Vegetated and Bare patches of the self-ameliorating previously scalded area, and the average of the scalded demonstration site (trial average)

Two observations can be made from the lower salinity of the vegetated area compared to the adjacent bare areas. Firstly, lower salinity supports more plant growth. Secondly, plant growth provides cover which increases infiltration thus incrementally flushing salts deeper while also decreasing evaporation that would concentrate salts at the surface. These processes would result in the salinity profiles (Figure 110) of the two adjacent patches, while reinforcing the difference in cover. The presence of plant cover and relatively high recent rainfall would lead to the situation of increasing vegetation that has been observed.

The soil at each of the sampled sites was sodic (Figure 111). Two factors have contributed to the lower sodicity of the surface soil in the gypsum dump: accumulation of wind-blown sand due to the presence of plants, and displacement of exchangeable sodium with calcium from the gypsum.

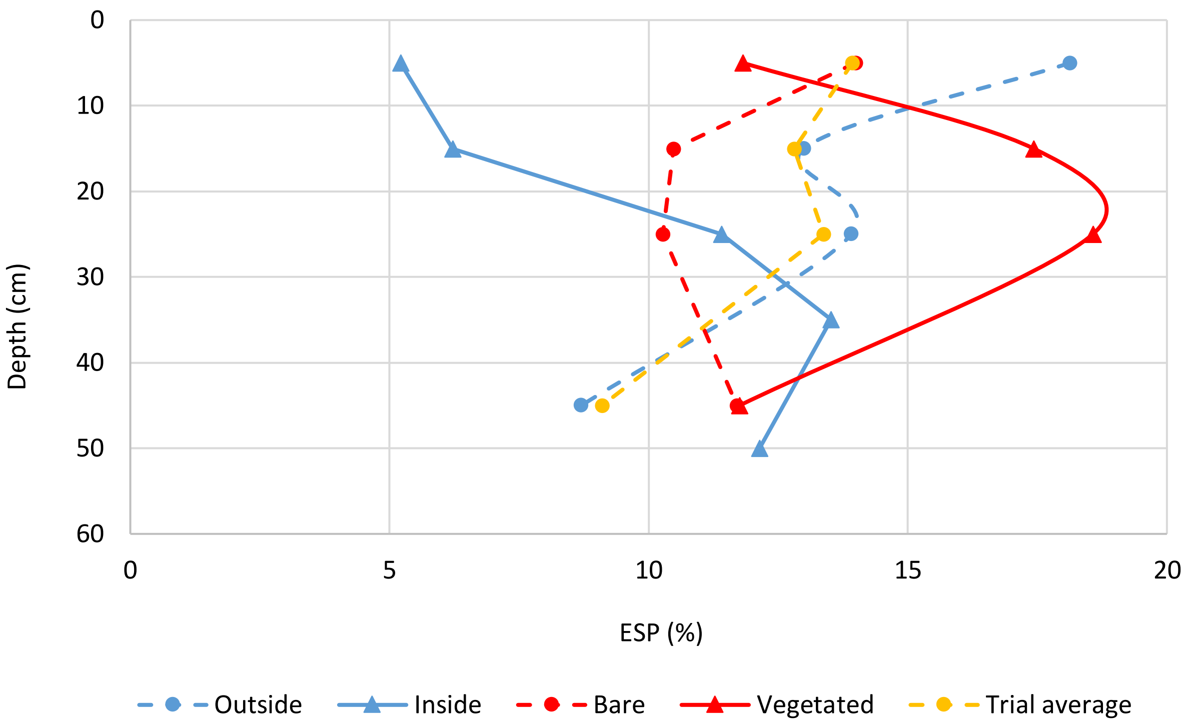


Figure 111. Sodicity (ESP%) of the gypsum dump area, the patchy vegetation area, and an average of the scalded demonstration site

The salinity of the gypsum dump area was higher outside the dump than in the patchy area, which would make it harder for plants to establish and survive. Considering the snapshot provided by the single sampling, the lower salinity and the surface may reflect two processes. Firstly, recent higher rainfall may have leached salts at this location. Secondly, more transpiration than evaporation from under the vegetated dump area may be minimising surface evaporation that would accumulate salts. The surface salinity outside the dump was still very high. Because gypsum has lower solubility than other common salts in the area such as sodium chloride (common salt, not to be confused with exchangeable sodium), the salinity of a soil containing gypsum will be a maximum of approximately 2 dS/m, while a soil with other salts can be very high, as observed. Within the dump area, the balance between gypsum stabilising the soil, some leaching of the undesirable salts along with the gypsum would result in a lower salinity. It can be noted that field measurements of salinity (using a hand-held EC meter) were taken at numerous other sites in the project. At each instance scalded areas were saline while non-scalded sites were non-saline.

The exchange of sodium for calcium decreases the fundamental dispersibility of the soil and is a long-term improvement. Such a change is desirable but hard to achieve with high ESP on clayey soils (Awad & Abbott, 1976; Loveday, 1976). The shift observed after 10 years under a residue of dumped gypsum is not realistic for a broader paddock. The realistic broadscale effect gypsum application is to stabilise the soil and promote plant growth which then helps sustain an improved soil condition.

4.8 Biological stimulant trial

4.8.1 Site Characterisation – Whole Soil Food Web Analysis

A key soil ecosystem process is the breakdown of organic matter in soil mediated by microbial activity, which enhances nutrient cycling (Cui et al. 2019; Nachimuthu et al. 2022). A whole soil food web-analysis was undertaken to understand the soil biological value prior to the application of treatments, which is a direct measure (plate read using microscope) of soil biology accounting active bacteria and fungi, total bacteria and fungi, Actinobacteria, protozoa, and nematodes and mycorrhizal fungi. The range that indicates a suitable value for the vegetation type is derived from a large international database. Due to the term ‘rangelands’ describing northern and southern hemisphere rangelands which are different, native vegetation is selected for the range values for the Australian rangelands.

Three of the four locations were identified as having very dry soils when samples were collected, the remaining location, Gurrawarra, had soil moisture withing the normal range, but tending towards drying. Prior to sampling, this trial area had prolonged inundation. Soil moisture is very important for biological and biochemical reactions in soil (Bian et al 2022), and in particular, the semiarid regions and can be the key constraint that has impact on processes controlling soil microbial activity (Cui et al. 2019). The absence of moisture has a flow-on effect to the cycling of organic material and the availability of some nutrients.

Fungi

The total fungi biomass measures active, dormant and dead fungi biomass, while the active fungi is a measure of live and active fungi. At Bokhara Plains, and Etiwanda trial sites, the active fungi was in a suitable range for this type of vegetation, however the ratio of active fungi to total fungi was low, largely in part due to the drying conditions in the soil. Total fungi was in the recommended ranges for this vegetation at Bokhara Plains and Etiwanda.

Wyndham Station was still under drought conditions at the time of sampling, this was reflected in the low active fungi and low total fungi values. However, the ratio of active fungi to total fungi was in the recommended range, in balance for this type of vegetation, indicating a return of moisture would see fungi functioning as expected for this type of soil, climate, vegetation.

The Gurrawarra replicated plot trial site had no active fungi present and low total fungi values, the producers had noted there had been water laying over the trial site for a period of time. There is potential that the prolonged inundation of soil, the soil type (clay), which give small spore space, and slow drainage and aeration after flooding had a negative effect on the fungal population (Moche et al. 2015).

At multiple locations mycorrhizal fungi was absent from most samples taken due to no roots in the sample or very few roots in the sample. This is potentially a by-product of the sampling as the larger soil cores for chemistry were taken on bare earth and the cores for the whole soil food web analysis were taken alongside. The lack of mycorrhizal fungi may also be affected by the patchiness that is inherent in the rangelands environment.

Bacteria

The total bacteria measures active, dormant and dead bacteria biomass. The active bacteria biomass is a measure of live active bacteria. At Bokhara Plains and Etiwanda, the active bacteria was low, which is expected in a stable native vegetation habitat and dry conditions. Bacteria have less resilience to drying conditions than fungi as bacteria require films of water for motility and substrate diffusion (Evans and Wallenstein 2012) as well as being a single cell organism. In contrast, fungi can transfer moisture from water-filled macropores via their hyphae (Evans and Wallenstein 2012), having an extended network to find moisture. The total bacteria biomass was low at Bokhara Plains, in part due to the stable environment but also the dry conditions. The total bacteria biomass at Etiwanda was in good numbers.

Similarly, Gurrawarra, had low active bacteria biomass, which may be due to the soil drying out but may be compounded from the potential loss of bacteria from the previous inundation of water over the trial site. The prolonged drought conditions that preceded the soil sampling at Wyndham Station is reflected in the low active bacteria biomass and the low total bacteria biomass.

Fungi: Bacteria ratio

The individual active and total fungi and bacteria values for each site have been discussed for each location, however the ratio of fungi : bacteria can also be looked at, which can indicate microbial community structural shifts (Bailey et al. 2002). It is often considered that a ratio in favour of fungal is the preferred, as stable environments such as undisturbed forests are often seen as 'healthy'. However, where disturbance has occurred, the fungi:bacteria ratio can tend towards being bacteria dominated. The soil food web analysis indicated that the TF:TB ratio at Bokhara Plains (29:1) and Etiwanda (13:1) tended towards fungal domination, whereas the TF:TB ratios at Gurrawarra (0.09:1) and Wyndham Station (0.13:1) tended towards bacterial domination. This may be due to the prolonged drought conditions at Wyndham Station and previous prolonged inundation of the trial site at Gurrawarra.

4.8.2 Impact on soil biology

Cotton strip assays provide a low cost but useful soil biology activity indicator (Nachimuthu 2022). Where samples could be recovered and were intact enough to be measured on the tensometer for tensile strength, there was no significant difference between the treatments including the control (no treatment applied) at each site (Table 10). The differences in each measure could not be directly attributed to treatments applied. Figure 112 shows an example of cotton strips recovered from one site (Gurrawarra).

Table 10. The mean and range (in brackets) and sample size [] for loss of tensile strength (%) for buried cotton strips over a time period. The number in the square brackets identifies the sample size. A dash indicates no sample could be found upon excavation

Loss of Tensile Strength (%)			
Bokhara Plains			
Treatment	8 weeks	12 weeks	14 weeks
Control	44.5 (16 – 73) [2]	-	-
Bioprimer- Foliar	51.5 (41 – 62) [2]	-	-
Bioprimer – Solid	74 (45 – 100) [3]	-	-
Etiwanda			
Treatment	8 weeks	12 weeks	14 weeks
Control	91 (73 - 100) [3]	100 [2]	100 [2]
Bioprimer- Foliar	84 (75 - 100) [3]	100 [2]	100 [2]
Bioprimer – Solid	87 (71 - 100) [3]	100 [3]	100 [2]
Biochar	83 (48 - 100) [3]	96 (92 - 100) [2]	100 [1]
Gurrawarra			
Treatment	8 weeks	12 weeks	14 weeks
Control	63 (32 - 94) [2]	89 (66 - 100) [3]	97 (93 – 100) [2]
Bioprimer- Foliar	94 (82 - 100) [3]	90 (70 - 100) [3]	100 [3]
Bioprimer – Solid	71 (36 – 100) [3]	90 (83 - 100) [3]	98 (93 – 100) [3]
Wyndham Station			
Treatment	8 weeks	12 weeks	14 weeks
Control	63 (48 - 88) [3]	-	-
Bioprimer- Foliar	44 (25 - 66) [3]	-	-
Bioprimer – Solid	76 (60 - 90) [3]	-	-

Loss of Tensile Strength (%)			
Biochar	67 (52 - 87) [3]	100 [1]	-

Table 11. The mean and value range (in brackets) for area of cotton strip remaining intact (cm^2) for buried cotton strips over a time period. The number in the square brackets identifies the sample size. A dash indicates no sample could be found upon excavation

Area Intact (cm^2)			
Bokhara Plains			
Treatment	8 weeks	12 weeks	14 weeks
Control	25.0 (25.0 – 25.0) [2]	-	-
Bioprimer- Foliar	25.0 [1]	-	-
Bioprimer – Solid	23.4 (20.2 - 25.0) [3]	-	-
Etiwanda			
Treatment	8 weeks	12 weeks	14 weeks
Control	16.7 (4.3 – 25.0) [3]	7.8 (4.0 - 11.5) [2]	8.0 (6.8 - 9.2) [2]
Bioprimer- Foliar	22.2 (17.0 – 24.9) [3]	16.9 (16.0 - 17.6) [2]	6.7 (4.3 - 9.1) [2]
Bioprimer – Solid	23.6 (21.0 - 24.9) [3]	12.6 (8.2 - 20.7) [3]	9.9 (4.72 – 12.8) [3]
Biochar	17.7 (9.3 – 25.0) [3]	14.3 (5.4 – 23.3) [2]	-
Gurrawarra			
Treatment	8 weeks	12 weeks	14 weeks
Control	24.2 (23.5-25.0) [2]	17.5 (11.5 – 23.4) [3]	18.5 (13.5 - 23.4)[2]
Bioprimer- Foliar	14.3 (8.5 - 22.5)[3]	15.6 (0.7 - 23.8) [3]	4.9 (0.7 – 11.1) [3]
Bioprimer – Solid	20.3 (12.2 - 25) [3]	20.6 (13.4 - 24.2) [3]	11.5 (2.11 – 24.6)[3]
Wyndham Station			
Treatment	8 weeks	12 weeks	14 weeks
Control	24.5(23.5 - 25.0) [3]	14.2 [1]	-
Bioprimer- Foliar	25.0 [3]	-	-
Bioprimer – Solid	24.8 (24.5 - 25) [3]	-	-
Biochar	24.7 (24.2 -25) [3]	-	-

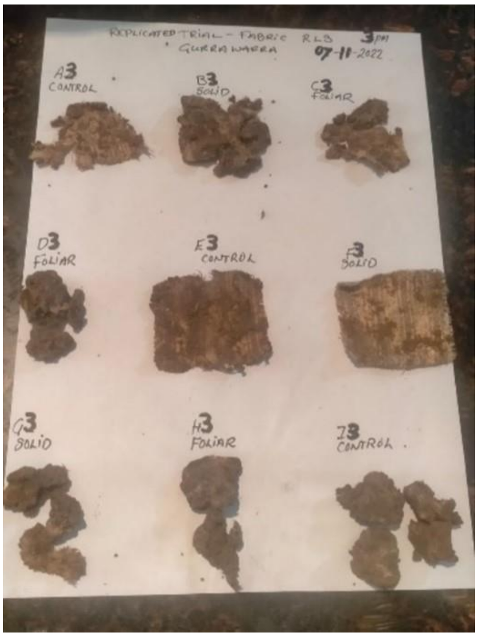


Figure 112. Cotton Strip assays removed from Gurrawarra trial site (photo. Glenn Humbert)

Soil biological measures

Following analysis, there was no significant difference in soil protein, microbial biomass carbon, or the fungal bacteria ratio between treatments (Table 12). Overall, the values measured by the PFLA derived F:B ratio are expected for sites that have been disturbed and comparable and above F:B values of semi-arid regions elsewhere in Australia native pastures (Wong et al. 2015). These results differed from the values obtained in the whole soil food web analysis with some sites tending towards fungal domination, multiple factors need to be taken into consideration, a different method was used to determine fungal and bacteria ratio for the post treatment application and pre-treatment application, and the samples were taken at different times of the year, opportunities to negate these issues are raised in the discussion.

Table 12. Mean (and range) of soil biology measures across different treatments for each property

Treatment	Bokhara Plains Heavy Clay	Etiwanda Light clay	Gurrawarra Heavy Clay	Wyndham Station Sandy clay loam
		Soil protein (mg/kg)		
Control	1.80 (1.55 - 2.10)	3.62 (2.80 - 4.26)	1.62 (1.43 - 1.79)	1.9 (1.27 - 2.99)
Bioprimer - Foliar	1.72 (1.39 – 2.31)	2.48 (1.14 - 3.61)	2.58 (1.36 - 3.34)	2.12 (1.13 - 3.92)
Bioprimer - Solid	1.41 (1.32 – 1.56)	2.42 (1.18 - 4.48)	1.48 (1.27 - 1.65)	1.99(1.07 - 3.57)
Biochar		2.73 (1.07 - 3.95)		1.98 (1.26 - 3.20)
		Microbial Biomass Carbon (mg/kg)		
Control	0.36 (0.31 – 0.39)	0.22 (0.15 - 0.29)	0.46 (0.37 - 0.60)	0.28 (0.26 - 0.29)
Bioprimer - Foliar	0.34 (0.28 – 0.45)	0.19 (0.12 - 0.23)	0.29 (0.27 - 0.31)	0.26 (0.21 - 0.29)
Bioprimer - Solid	0.34 (0.33 – 0.36)	0.25 (0.18 - 0.31)	0.32 (0.30 - 0.36)	0.24 (0.22 - 0.28)
Biochar	-	0.21 (0.18 - 0.25)	-	0.26 (0.18 - 0.34)
		Fungi bacteria ratio		
Control	0.21 (0.19 – 0.23)	0.17 (0.15 - 0.21)	0.22 (0.19 - 0.25)	0.23 (0.20 - 0.25)
Bioprimer - Foliar	0.22 (0.21 – 0.23)	0.19 (0.17 - 0.21)	0.23 (0.21 - 0.24)	0.2 (0.18 - 0.23)
Bioprimer - Solid	0.22 (0.20 – 0.26)	0.18 (0.17 - 0.18)	0.24 (0.23 - 0.25	0.19 (0.18 - 0.2)

Biochar	-	0.17 (0.16 - 0.19)	-	0.2 (0.16 - 0.23)

4.8.3 Impact on vegetation and cover

Vegetation measures

As with results of the cotton strip assays and soil biological measures, there were no significant differences in dry matter, greenness, cover between treatments (Table 13).

Table 13. Mean (and range) of vegetation measures across different treatments for each property

Treatment	**Bokhara Plains** Heavy Clay	**Etiwanda** Light clay	**Gurrawarra** Heavy Clay	**Wyndham Station** Sandy clay loam
		Average Dry Matter (kg/Ha)		
Control	1967 (1294 – 2493)	2021 (1523 - 3008)	1402 (897 – 1754)	1111 (777 - 1453)
Bioprimer - Foliar	2430 (1893 – 2713)	1796 (1342 – 2221)	1615 (1296 – 1874)	1236 (526 - 1879)
Bioprimer - Solid	2388 (1799 – 2682)	2095 (1379 - 2456)	1654 (1176 – 2312)	1144 (977 - 1328)
Biochar	-	1820 (1628 – 2170)	-	1453 (1353 - 1603)
		Average green biomass (%)		
Control	63 (37 – 92)	74 (62 - 84)	37 (18 – 46)	92 (91 - 94)
Bioprimer - Foliar	71 (48 – 90)	70 (68 - 74)	21 (11 – 35)	89 (82 - 93)
Bioprimer - Solid	54 (42 – 77)	76 (66 - 89)	29 (5 – 60)	93 (86 - 98)
Biochar	-	80 (71 – 88)	-	85 (75 - 93)
		Average total ground cover (%)		
Control	50 (30 – 71)	75 (56 – 92)	28 (16 – 44)	34 (25 – 48)
Bioprimer - Foliar	45 (37 – 52)	71 (46 – 96)	28 (21 – 31)	39 (15 - 60)
Bioprimer - Solid	53 (40 – 60)	77 (60 – 90)	31 (24 – 39)	27 (23 - 33)
Biochar	-	80 (61 – 90)	-	36 (26 - 48)

4.8.4 Soil Biology and Moisture

There was no significant difference between the control (no treatment applied), the foliar liquid bioprimer and the solid vermicast for the cotton strip assays during the trial, and the vegetation assessments and soil sampling post five months application. As identified in the soil food web analysis, the soils were considered dry or drying. There is a high potential that the wetting and drying cycles associated with climate of the semi-arid rangelands environment of New South Wales are a key driver in the microbial activity in the soil and may limit the potential benefit of applied treatments (Evans & Wallenstein 2012; Moche et al. 2015; Bian et al. 2022).

It has been noted that the foliar application of the bioprimer would have been more suitable applied when soils were moist. Three of the four sites were considered dry when applied, however due to the wetting and then long drying periods, the effect of moisture would most likely be an overarching driver in the functioning of the soil biology, potentially negating any benefits of the application of the foliar biostimulant. Similarly, the solid biostimulant had dried out prior to application due to a delay in trial installations, whereas it may have benefited being applied when more moisture was still present in the material. However, as there are wetting and drying cycles in the rangeland environment which affect microbial populations, the benefit of the application of the vermicast at the rate applied may have been negated due to lack of moisture. On review of the literature post-trial, it has been noted in other biostimulant research including in the rangeland environment, that a strong consistent response from biostimulant applications in soil microbial communities or abiotic soil parameters was not seen in the trial timeframe (Carey et al. 2022), such has been reflected in this trial in western NSW. Carey et al. (2022) also noted that it is thought that the application to leaf of microbial biostimulants to improve plant growth, quality and resilience is through the plants stomata (see Preininger et al., 2018).

As moisture is a limiting factor in plant growth and microbial function in these semi-arid environments, methods, products and management practices that improve moisture retention should be encouraged. The biochar applied should have been incorporated to depth (5-10 cm) as it is known to improve moisture retention, particularly on coarser particle soils (Wang et al. 2019). The use of biochar provides its own set of drawbacks in environments such as semi-arid rangelands where producers are trying to encourage vegetation cover (largely through grazing management) and not disturb the soil through cultivation, this has been noted as a potential issue elsewhere in the world in semi-arid rangelands (Gao and DeLuca, 2020). Biochar may be suitable in locations where cultivation is allowed and useful, however, some soils may be more fragile and the disturbance may prove less beneficial for plant production than not disturbing the soils.

The management of grazing to improve vegetation cover can provide a basis for increased organic matter which in turn can provide improved water infiltration, which in turn will assist in maintaining more biological activity in the soil for potentially longer periods.

Notwithstanding seeing any difference between treatments and constraints of the trial implementation as discussed, there was still biological activity as determined by the degradation of the cotton strips over the period of sampling. It was initially anticipated that biology would be “slow” and therefore eight weeks after application of the treatment was the removal of the first sample. This proved not to be the case and considerable degradation had occurred on some samples at some locations.

4.8.5 Recommendations

As noted by Nachimuthu (2022), “soil biological functions are key components of soil health”, therefore, understanding how the rangelands of New South Wales soil biology behave and where improvements can be gained or limitations identified is very important. It is recommended that to be able to benchmark and understand what is considered “good” or “healthy” biological measure values for the semi-arid region of NSW, more soil testing be encouraged so a database of localised information can be created and utilised. There is opportunity to incorporate some of these measures into farming programs so producers can identify trends over time of changes in soil biology or chemistry. The development of this information both on-farm and regionally would provide a realistic guide to producers on what they should be aiming for or can manage (e.g. a sandy soil may have a different limit to that of a clay soil in its biological activity measures) in their locations.

Given the variability of biological function with climate and seasonal conditions, and challenges in applying soil biological stimulant products to pasture at scale in a time efficient and economical manner, practical consideration of use of these products in extensive rangeland grazing systems is important. The results of this study suggest that it is unlikely these products will provide significant benefit in a commercial setting in western NSW rangelands.

4.8.6 Research Opportunities

There is little information on targeted research in the semi-arid rangeland environment for key drivers, mechanisms and benefits of applying various soil treatments and how they interact with the climate and landscape of these regions. Research to better understand the function of native soil biology in rangelands, and impact of management and other climate and biophysical factors on the soil biological function is recommended.

In discussing effectiveness of biostimulants in improving yield or other beneficial factors (water stress resilience), the information in the literature is largely focussed towards horticultural and agricultural monocrops (Li et al. 2022). It would be useful to consider research of preferable plant species from the rangelands in a controlled environment to understand if or what benefits are derived from biostimulant applications and what the drivers of these processes are.

There is little literature on the role of moisture effects on microbial populations in semiarid rangelands grazing systems and how wetting and drying cycle affect microbial populations. The dry and wetting cycles in the rangelands of NSW could also influence the benefit of the application of biostimulants, and therefore research into the effects of wetting and drying on microbial populations in soils, plant measures and the addition of treatments, be it biochar, biostimulants or organic matter. Elsewhere it is known for other factors in soil (e.g. phosphorus,) that wetting and drying cycles can affect retention and release (Ponnamperuma 1972, Clarendon 2017), therefore it could affect effectiveness and length of effectiveness of biostimulants applied to plants. This could include research to see if plants sustain the effectives of applied treatments over multiple wetting-drying cycles.

4.9 Carbon accounting

4.9.1 Carbon account summary and comparison for each property

Select Carbon performed the carbon accounts for Etiwanda and Wyndham Station, while CarbonLink performed the accounts for Bokhara Plains and Gurrawarra. Full reports, including methodology and results for each of these properties is provided in Section 8.4, with overall results summarised below in Figure 113 - Figure 116.

The major source of GHG emissions across each property was methane from livestock. Annual average farm emissions for each station were:

- Wyndham station = 1,078 t CO_2-e
- Etiwanda = 2,233 t CO_2-e
- Bokhara Plains = 880 t CO_2-e
- Gurrawarra = 260 t CO_2-e

For each property, Select Carbon and CarbonLink performed some scenarios relating to management change to estimate potential SOC sequestration. It was noted that even a conservative (e.g., a 0.05% increase over 25 years) increase in SOC sequestration would be enough to offset the average annual emissions produced by each property.

Emissions intensity was calculated for the different livestock enterprises on both Etiwanda (Table 14) and Wyndham (Table 15) stations, and varied over the five year period and depended on the enterprise. Trends in emissions intensity were driven by livestock sales.

Table 14. Emissions Intensity (kg CO2-e / kg live weight (LW)) for Beef, Sheep and Goat enterprises for the 5-year period on Etiwanda

Enterprise	Emissions Intensity (kg CO2-e / kg LW)				
	Year 1	Year 2	Year 3	Year 4	Year 5
Beef	10.6	9.0	778.5	29.2	15.8
Sheep	49.2	15.6	16.0	15.4	13.3
Goat	5.8	45.5	25.2	27.5	6.73

Table 15. Emissions Intensity (kg CO2-e / kg live weight (LW)) for Beef, Sheep and Wool enterprises for the 5-year period on Wyndham. Beef emission intensity could not be calculated for years where there were no sales or purchases

Enterprise	Emissions Intensity (kg CO2-e / kg LW)				
	Year 1	Year 2	Year 3	Year 4	Year 5
Beef	24.5	-	-	-	-
Sheep meat	8.0	9.1	30.6	10.9	17.2
Wool	25.9	28.9	95.1	34.7	53.4

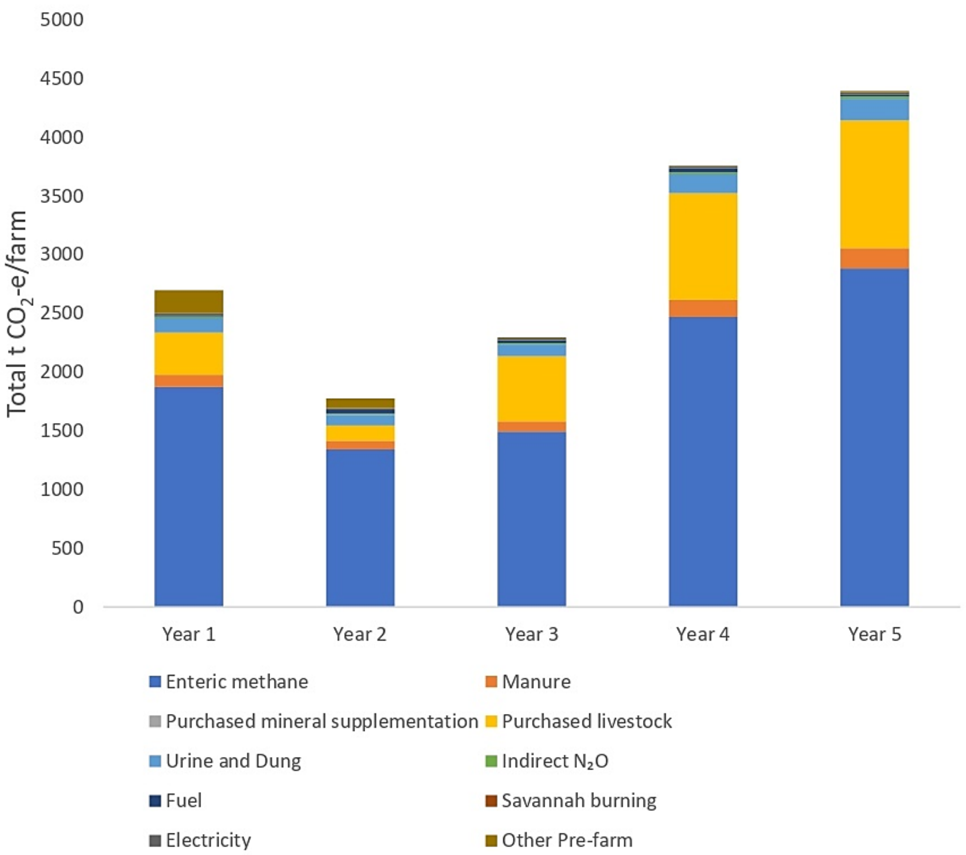


Figure 113. Annual net farm emissions (total t CO2-e/ farm) for Etiwanda. Total emissions are the sum of all livestock enterprises on Etiwanda including Sheep and Beef (SB-GAF) and Goat (Go-GAF). Year 1 was the start of June 2018 to end of May 2019, year 2 was the start of June 2019 to the end of May 2020, year 3 was the start of June 2020 to the end of May 2021, year 4 was the start of June 2021 to the end of May 2022 and year 5 was June 2022 to May 2023. Electricity, fuel and diesel were apportioned to each enterprise (therefore, not double counted). The category 'other Pre-farm' includes fertiliser, purchased feed, herbicides and pesticides lime and livestock away on agistment (Source: Select Carbon)

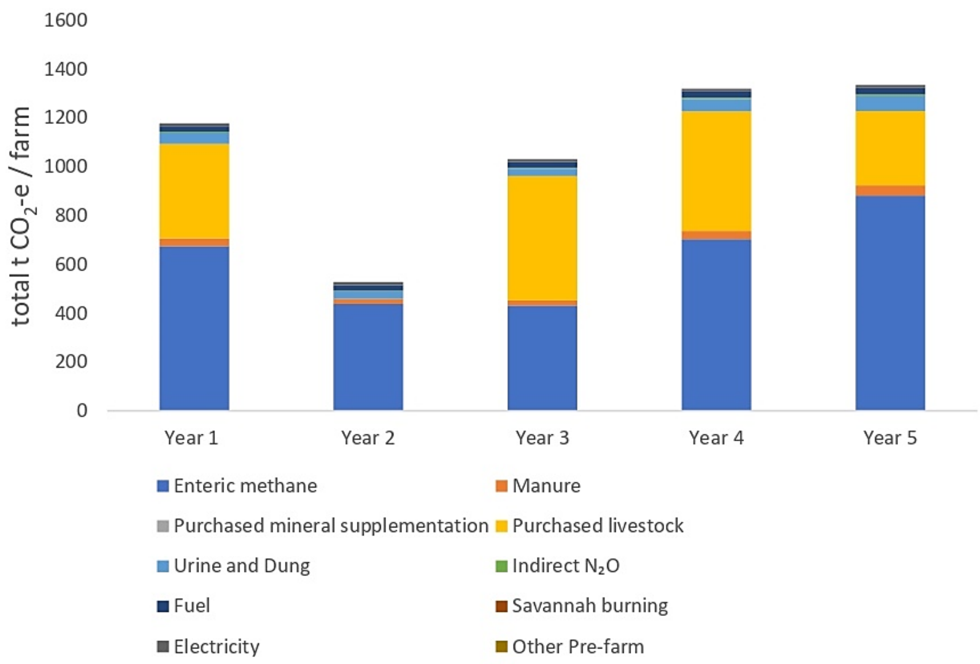


Figure 114. Annual net farm emissions (total t CO2-e/ farm) for Wyndham Station. Total emissions are the sum of all livestock enterprises on Wyndham Station including Sheep and Beef (SB-GAF). Year 1 was the 2017-18 financial year (FY), year 2 was the 2018-19 FY, year 3 was the 2019-20 FY, year 4 was the 2020-21 FY and year 5 was the 2021-2022 FY. Electricity, fuel and diesel were apportioned to each enterprise (therefore, not double counted). The category 'other Pre-farm' includes fertiliser, herbicides and pesticides, lime production, purchased feed, and livestock away on agistment (Source: Select Carbon)

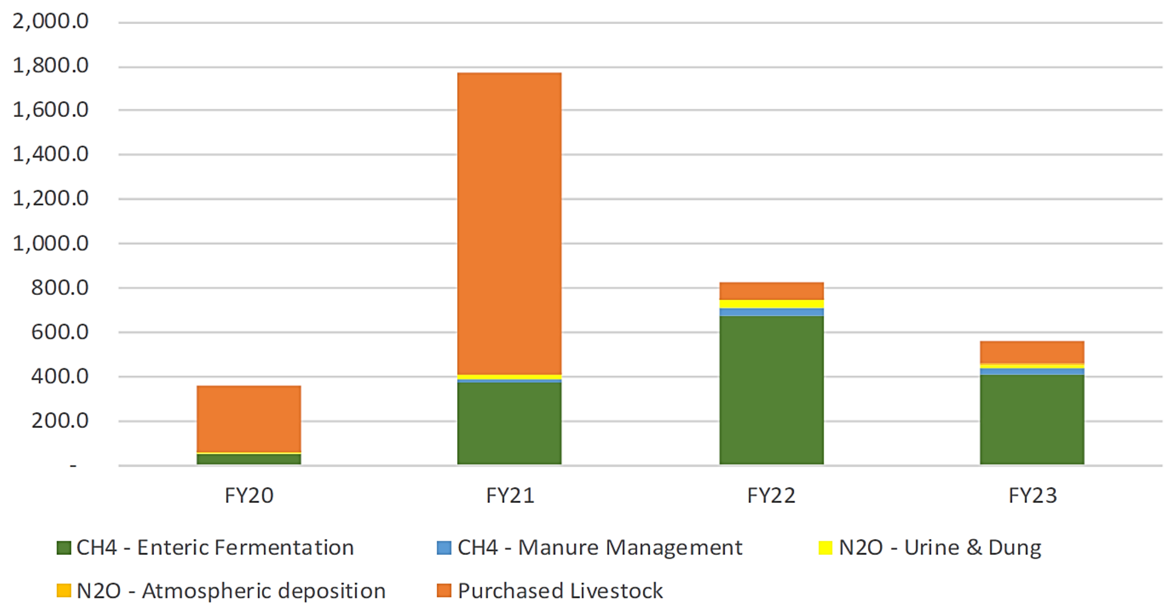


Figure 115. Bokhara Plains emissions profile CO_2-e for 2020-2023 (Source: CarbonLink)

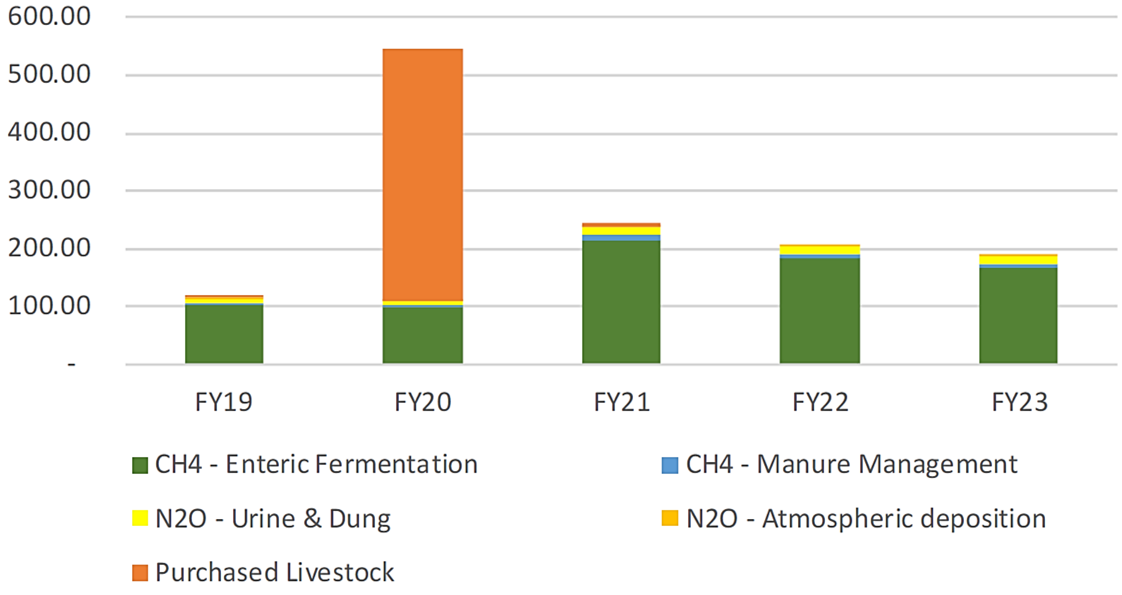


Figure 116. Gurrawarra emissions profile CO2-e for 2019-2023 (Source: CarbonLink)

4.10 RCS ProfitProbe & coaching

4.10.1 Summary of key economic metrics for each property for past 4 years

Core producers participated in the RCS financial benchmarking program ProfitProbe™ as well as submitted financial budgets. The results below compare the average performance of the Core Producers over the last four years against the Top 20% of producers and the Average of producers participating in ProfitProbe™ over the same period (

Table 16). These results include financial data from livestock enterprises across a wide range of regions across Australia. The final year, 2023-2024, takes into account the actuals for the four core producers and estimates for the Top 20% and Average.

There are four key ratios that drive business success; Return on Assets (ROA), Asset Turnover (ATO), Gross Margin (GM) and Overheads (OH). The aim is to increase the first three of these ratios and to reduce the Overheads ratio. Over the last 23 years, these ratios have sat around 7% for ROA, 15% ATO, 68% GM and 30% for OH for the Top 20% of producers.

Return on Assets (ROA)

ROA is calculated as Earnings before Interest and Tax (EBIT) based on Gross Product divided by (Total closing assets – non-farm assets). The core producers have performed credibly against the cohort taking into account the difficult seasons. The financial year 22-23 was a particularly challenging period for grazing businesses in general. The Eastern Young Cattle Indicator fell from its June 2022 average of $5.78 to $3.01 in June 2023, a fall of 48% over the 12-month period. For the sheep industry, MLA's Mutton Indicator fell from a June 2022 average of $6.22 to $3.69 in June 2023; a fall of 41%. This had a drastic impact on livestock inventory values as well as actual sales which in turn impacted on Return on Assets. This impact was felt by all producers in the profit probe dataset and does not influence relative difference to the project group.

Asset Turnover Ratio (ATO)

ATO = Total gross product divided by (Total closing assets – non-farm assets). ATO in the livestock industries is largely a function of herd or flock fertility and weight gain. In the case of the core producers, 3 of the 4 have sheep and goats and it is the high level of fertility in these two species that gives them advantage.

Gross Margin Ratio (GM)

GM = Total gross product – (Direct costs + Opportunity cost) divided by Total Gross Product. In most cases increased direct costs were related to selling costs and freight as a proportion of the diminished price received. In the case of producers in the Western Division, this involved choosing to sell stock that were not in anticipated condition and often had large distances to market. The core producers would prefer to sell stock and maintain ground cover rather than bear the cost and logistics of feeding. In many other cases feed costs can be a large component of direct costs in dry seasons.

Overheads OH

OH = (Total overheads + lease payments) divided by Total Gross Product. Overheads have crept up across the livestock industries after a run of favourable seasons and increasing commodity prices. This is a common theme across the years. The core producers are included in this trend. Core producers have also taken on additional labour in the form of children coming back to the property and contributing to the business. In many cases that has also allowed a catchup process in repairs and maintenance which has exacerbated the increase in overheads.

Conclusion

The purpose behind the monitoring and benchmarking of the Core Producers was to determine if livestock businesses in the Western Division of NSW can be profitable and sustainable while at the same time regenerating the landscape they are working in. The results, from the benchmarking over the period of the project supports this premise.

The results achieved by the core producers demonstrate that by taking a holistic approach to management, it is possible to manage a profitable business while at the same time building resilience into the landscape. It is the attention to detail through planning, monitoring and managing that allowed these managers to focus on building a landscape that can make more effective use of rainfall in a region where rainfall is erratic. To quote one of the core producers, *"it's not how much rain that falls but how we use it that* *counts."* They take a long-term view and in adverse times make decisions that may have short-term financial consequences to ensure that the long-term profitability and sustainability is preserved.

These producers demonstrated that livestock businesses in a region with erratic rainfall and a degraded landscape can generate positive economic returns . Their willingness to share and question through open group discussion combined with coaching and mentoring has facilitated the progress of these businesses.

Table 16. Summary of key performance indicators over the four years of reporting for the four core producers, top 20% and average of producers involved in the RCS benchmarking program

	4 Year Average		
Key Performance Indicators	**RLS Average**	**Top 20%**	**Average**
ROA	3.8%	5.5%	1.8%
Asset Turnover	11.5%	11.1%	7.3%
Gross Margin	51.6%	59.6%	57.3%
Overhead Ratio	52.9%	34.6%	60.8%
People			
Gross Product ($/FTE)	496,017	734,777	481,878
DSE Managed/FTE	6,125	9,324	6,775

4.11 Observer monitoring

4.11.1 Uptake of the monitoring and testing

Thirty-two landholders participated in this monitoring, 10 of whom were officially signed as core or observer producers in the Rangelands Living Skin project. Aside from producers reporting other pressing demands on their time, the soil was often too dry to sample. These concerns reflect the limited testing and monitoring of soil condition in the rangelands that this aspect of the project intended to address. The scope of the monitoring was narrowed to producers selecting one or more of the monitoring exercises that they found most relevant or useful. Despite the limitations, interested producers discussed their soil condition with the project team and collected samples for laboratory analysis and took monitoring observations for context.

4.11.2 Summary of soil chemistry results across the region

Locations sampled were at the discretion of each participant. As such, the results do not represent the relative frequency of soil properties. Instead, sample sites represent areas of concern, a comparison of soil types, or areas of relative performance.

4.11.2.1 Soil pH

Across all sites, the pH of the 0-10 cm samples were distributed around slightly acidic to slightly alkaline, while the deeper samples more commonly had a higher pH (

Figure **117**). This increase in pH with depth is common in rangeland conditions; free lime or dolomite may even be present in the soil as white nodules or segregations, being closer to the surface the more evaporation exceeds infiltration. The pH measured in water (pHw) is more variable than pH in calcium chloride (pHCa), reflecting fluctuations in seasonal conditions (Slattery et al., 1999). The difference fundamentally reflects the ions in solution, and it varied from zero in the most saline soils, up to two units in the soils with the lowest salinity.

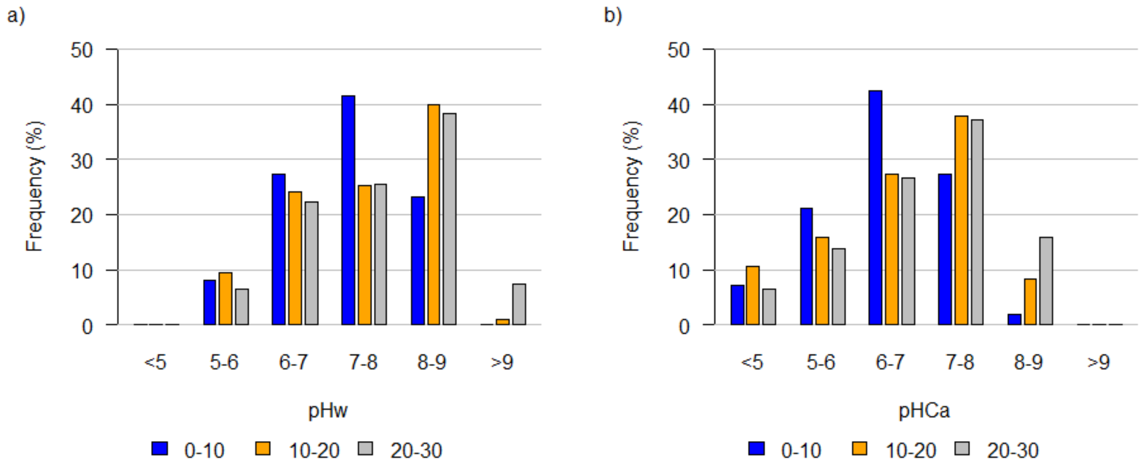


Figure 117. Frequency distribution of soil a) pHw and b) pHCa across the project area.

4.11.2.2 Electrical conductivity

Salinity was generally low in the samples collected from the upper 30 cm at each site, though there were more instances of high salinity in alluvial areas than the non-alluvial areas sampled (Figure 118). Where approximately 10% of sites were sampled as problem areas, such as some low productivity areas or scalds, the salinity was above 8 dS/m. In a few of those instances, the ECe was in the mid-twenties to mid-fifties dS/m, which is brackish to sea water levels.

Salinity was a consistent feature of scalded areas assessed during the project in the rangelands. These areas routinely had salinity >10 dS/m within the upper 30 cm of the soil profile, and some areas approached double the concentration of seawater. Managing the extremes requires identification and using appropriate techniques that improve infiltration to leach the salts.

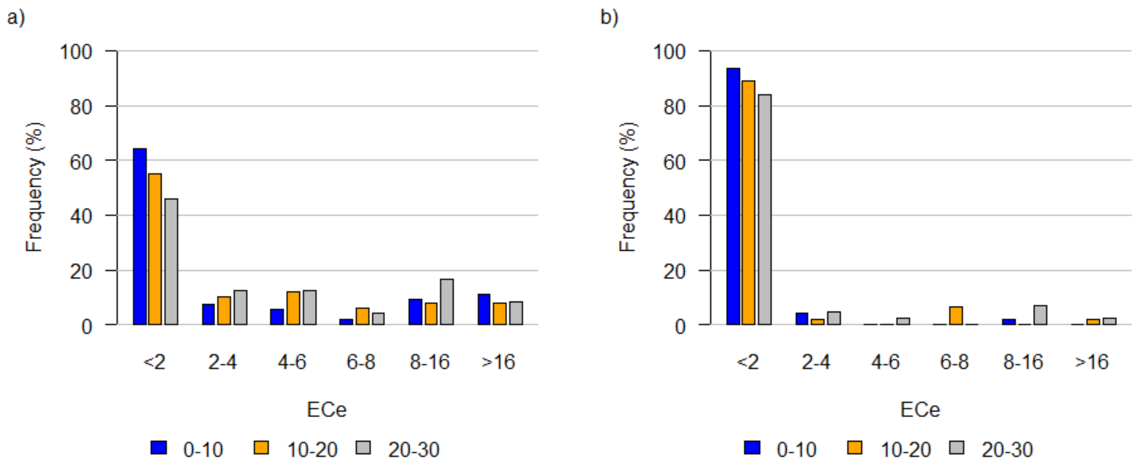


Figure 118. Salinity (electrical conductivity, ECe (dS/m) in a) alluvial and b) non-alluvial areas.

4.11.2.3 Soil Organic Carbon

It is usual to see more organic matter and SOC at the surface than deeper in the soil, as occurred in our samples (Figure 119). This distribution pattern was consistent for the alluvial and non-alluvial soils, as well as for the northern and southern sites. While the SOC are low, they are around what is to be expected in the rangelands. Low rainfall means plant growth is limited, and with episodic rainfall soil microbes respond more quickly to decompose organic matter than plants do to grow, and the microbes function longer at warm to hot temperatures than do plants.

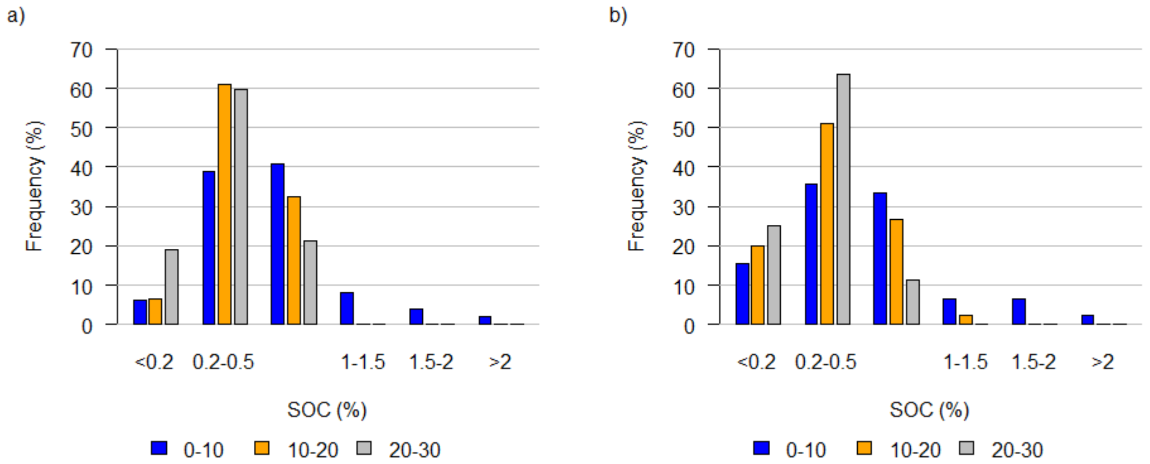


Figure 119. Distribution of soil organic carbon in a) alluvial and b) non-alluvial areas.

4.11.2.4 Soil Structural Stability

Where participants assessed slaking (at 51 of the 98 sites), 70% had good resilience against slaking. The thin layer of stability provided by the surface crust highlights the importance of protecting the soil surface to maintain a good environment for rainfall infiltration and plant growth.

4.11.2.5 Chemical stability (Sodicity)

Soils are commonly classified as sodic when the exchangeable sodium percentage (ESP) is greater than 6%. Sodicity was more common on the alluvial soils than the non-alluvial soils (Figure 120). This abundance is expected because the Cobar pediplain is renowned for having little sodicity, while the alluvial areas receive sodium during their deposition as sediments and subsequent accumulation (Isbell, 1996).

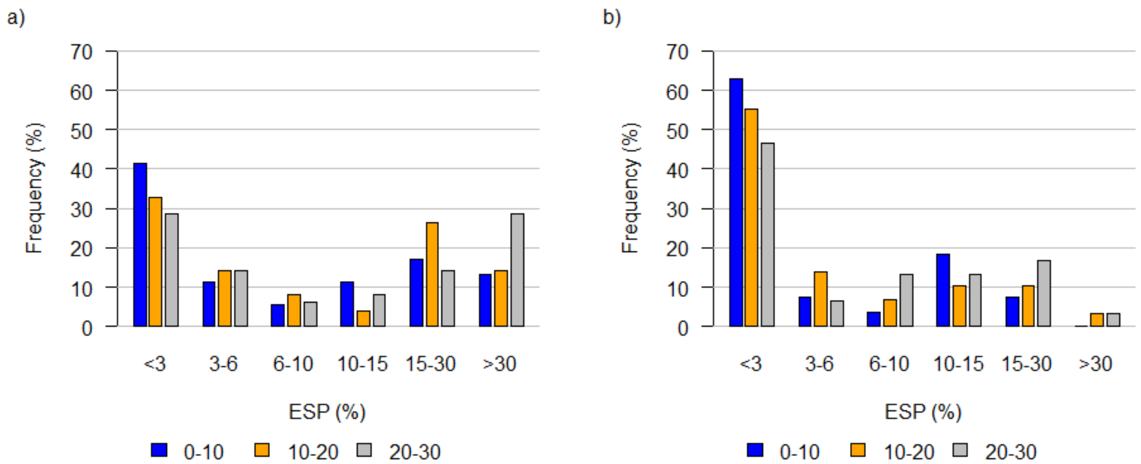


Figure 120. Distribution of ESP (exchangeable sodium percentage) in a) alluvial and b) non-alluvial areas.

4.11.2.6 Relationships between soil organic carbon, salinity and sodicity

There was a pattern of lower SOC in samples of increasing salinity and sodicity (Figure 121). While low sodicity or salinity does not mean the SOC% will be high, high sodicity or salinity does tend to limit the accumulation of SOC (Figure 121). Understanding their levels can inform producers of the potential for increasing carbon levels, particularly if there is interest in a soil carbon project.

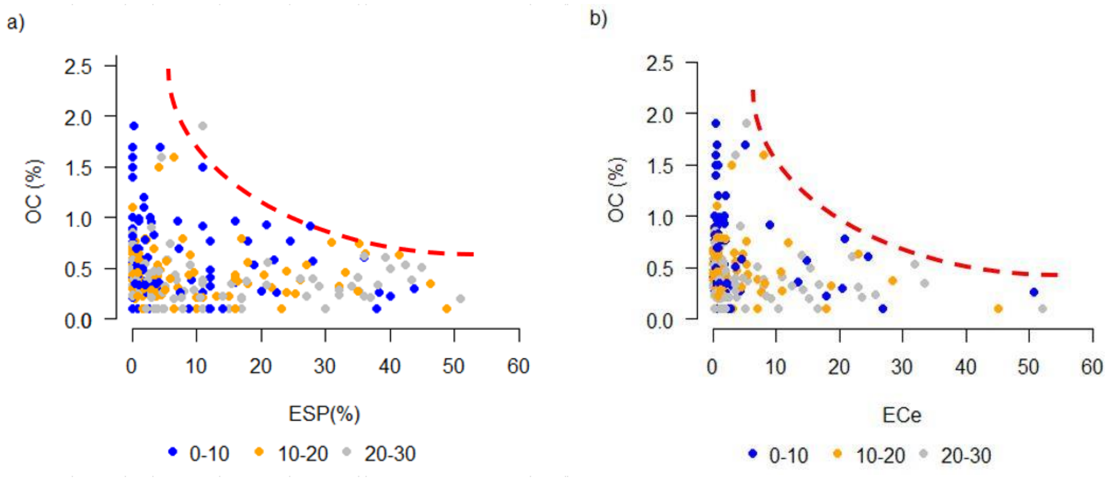


Figure 121. Relationship between soil organic carbon and a) ESP and b) salinity.

4.11.2.7 Phosphorus

The Colwell-P results ranged from the below laboratory's limit of reporting (<2 mg/kg) up to 160 mg/kg (Figure 122). Across the region, the Colwell-P is higher in the surface than the deeper increments, a pattern more evident on the non-alluvial sites. The non-alluvial soils had a distinctly lower Colwell-P levels than the alluvial sites, particularly in the subsurface increments. The grouping of Colwell-P concentrations broadly reflects deficient levels (<8 mg/kg), low to moderate (15-25 mg/kg), adequate (25-50 mg/kg), and relatively high levels (>50 mg/kg). Areas with Colwell-P below 5 mg/kg and marginal to 8 mg/kg may see effects of P deficiency on livestock (Jackson 2012, Jackson et al. 2012, Schatz et al. 2023). Those areas were predominantly on non-alluvial areas characterised by mulga and ironbark (Sahukar et al., 2003, Jackson, 2012). The potential extent of the concern in the non-alluvial areas is represented by 33% of samples having Colwell-P below 5 mg/kg, and a further 15% less than 8 mg/kg. If there is not enough variability with higher P areas accessible to livestock, their nutrition may be deficient, even if at sub-clinical levels. Further investigation would be warranted for those areas.

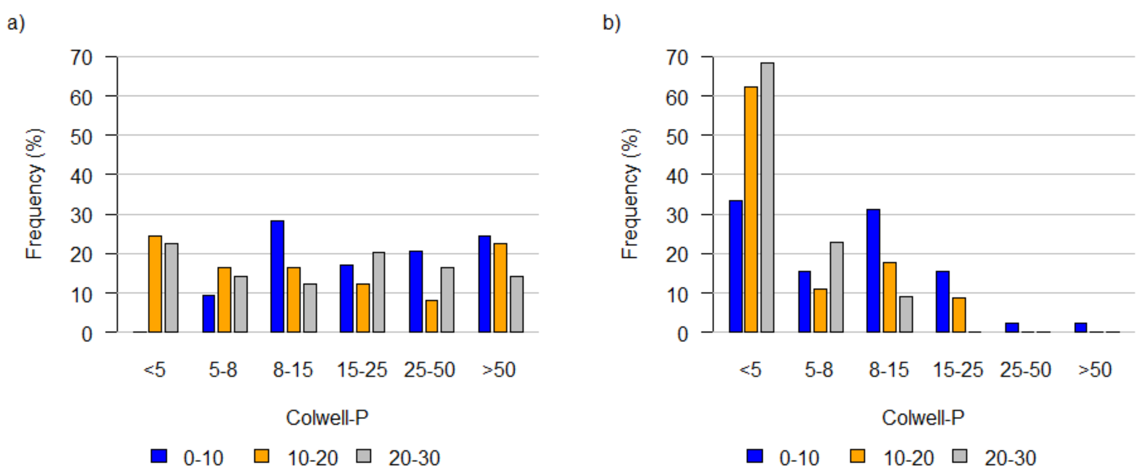


Figure 122. Frequency distribution of Colwell-P (mg/kg) from a) alluvial and b) non-alluvial sites.

A pattern of distribution somewhat similar to the Colwell-P values for the alluvial and non-alluvial sites was found in the acid-soluble BSES-P values. The groupings for BSES-P may be considered as very low (less than

10 mg/kg), low (less than 30 mg/kg), moderate (up to 100 mg/kg), and high (greater than 100 mg/kg). In the alluvial soils, 60% of each depth increment had BSES-P greater than 30 mg/kg, with 35% of the 0-10 cm samples over 100 mg/kg (Figure 123). At the non-alluvial sites, BSES-P concentrations were substantially lower, with the largest grouping at the very low level. The higher BSES-P soils tended to be the more alkaline alluvial soils, where the high P store represents a bank accessible via rhizosphere acidification.

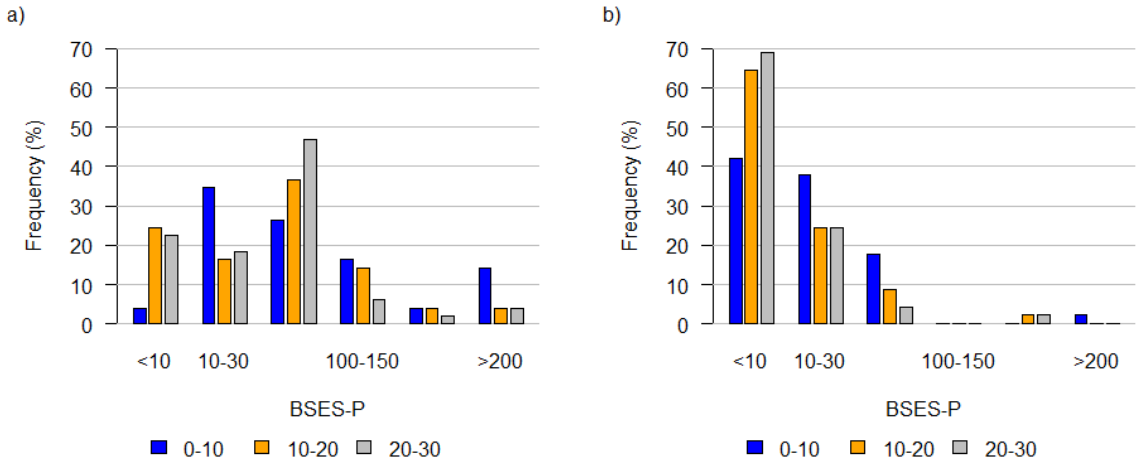


Figure 123. Frequency distribution of BSES-P (mg/kg) from a) alluvial and b) non-alluvial sites.

4.11.2.8 Sulphur

As for P, the frequency distribution of sulphur skews to low values in the non-alluvial areas (Figure 124). Values below 5 mg/kg in the 0-10 cm increment would be considered low, and in these areas there is generally no substantial store at depth. By comparison, while 40% of alluvial sites had S less than 5 mg/kg in the surface, half of those did have appreciable S in the lower depth increments. A likely form of the S at depth, particularly the higher concentrations measured, is gypsum.

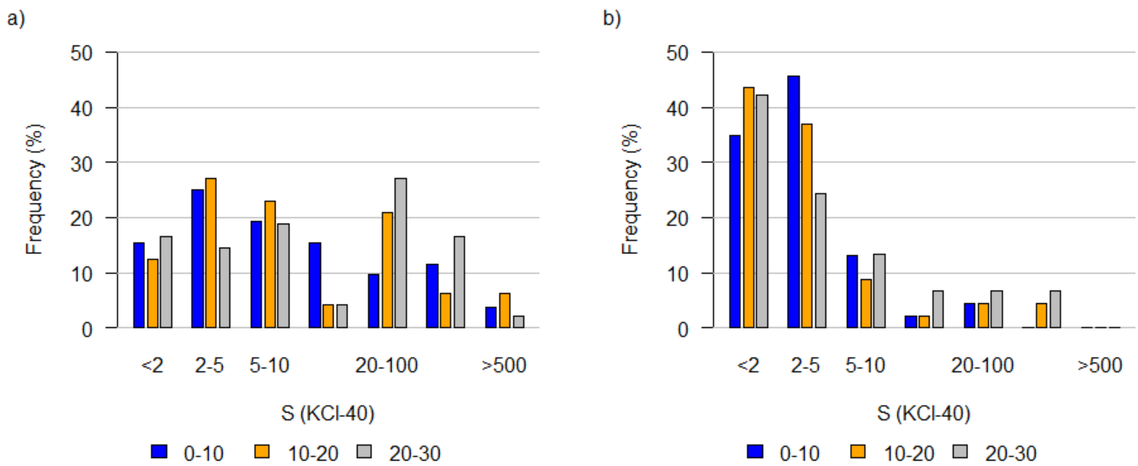


Figure 124. Frequency distribution of sulphur (mg/kg) from a) alluvial and b) non-alluvial sites.

The targeted soil testing undertaken by producers highlighted areas that could explain why some areas were less productive than others. The initial results provide a basis for further investigation to address any constraints.

4.11.3 Properties of representative soil profiles

Soil cores were collected to describe type profiles and rootzone conditions in each CEA. Profiles were collected from the majority (70%) of the strata. General observations on soil condition from these profiles collected showed distinct features in the three regions.

- Cobar district:
  - Red soils with gradational increase in texture from loamy surface to light clay at depth and weak to moderate structure in the subsoil (Kandosols and Dermosols)
  - Slightly to moderately acidic surface, neutral upper rootzone and moderately alkaline deeper rootzone.
  - Fine to nodular carbonates present from 30 to 60 cm depth in 10 of 12 profiles. The profiles without carbonates had the same trend of increasing pH with depth as the other profiles.
  - Generally low salinity: only three cores had appreciable salinity (6-9 dS/m including chlorides) present below 50 cm.
  - Non-dispersive surface soils, and only moderate dispersion in the upper rootzone of 3 of the 12 profiles. The soils were more dispersive in the lower subsoils of 6 of the 12 profiles.
- Brewarrina district:
  - The pH of the surface soils ranged from slightly acidic to neutral then increased to moderately and strongly alkaline by the lower rootzone.
  - Red and brown soils with gradational increase in texture from loamy surface to clay at depth and moderate structure in the subsoil (Dermosols) were on the slightly higher meander plains and prone to scalding. These soils had variable salinity commonly increasing with depth. The surface soils were non-saline to moderately saline in the surface (up to 8 dS/m ECe) and upper rootzone (up to 25 dS/m). The deeper rootzone was commonly strongly saline (12 to 60 dS/m) with a high chloride content. Carbonates were generally present from between 10 to 30 cm, and some of the deeper layers had contained gypsum. These soils had nil to only low dispersion, likely stabilised by the presence of salts.
  - Brown and grey cracking clays (Vertosols) adjacent to the meander plains. Run-on from the higher meander plains results in relatively frequent shrinking and swelling and the formation of gilgai. The single profile available had similar salinity and presence of carbonates as the adjacent meander plain soil.
  - Brown and grey cracking clays (Vertosols) on the broader lower lying areas had stable surfaces and variably stable to dispersive lower rootzones. Some of these profiles were not saline (<4 dS/m) through the upper 60 cm, though some, likely above the current flood areas, had accumulated moderate to high salinity (10 to 40 dS/m). Carbonates were also generally present from between 10 to 30 cm in these soils.

- Pooncarie district:

  - Red soils with gradational increase in texture from loamy surface to light clay at depth and weak to moderate structure in the subsoil (Kandosols and Dermosols) and some calcareous throughout (Calcarosol).
  - All soils were alkaline at the surface increasing to strongly alkaline at depth.
  - Carbonates were present in all profiles, in some from the surface, and in some as distinctly hard nodules.

- Observed salinity was low in the surface and also generally low (<2 dS/m) in the upper rootzone, but commonly increased to moderate levels (8-12 dS/m) and occasionally high levels (30 to 100 dS/m) in the lower rootzone depth.

The above properties of the soils from each region provide context for the differences between regions and variability within. The observations are in alignment with samples taken as part of the observer monitoring and suggest properties below that tested at the laboratory.

- Carbonates in the soil reflect parent material. Present in each region (e.g., Figure 125 - Figure 127)Figure 119 carbonates were conspicuous in the Pooncarie soils where hard nodules were present in some of the subsoils. These nodules may be difficult to dissolve in sulphurous acid but not readily visible during processing so may persist in material used for analysis. The apparent organic carbon levels of those samples would therefore be elevated. If an area was used for a carbon project the higher level would not matter because with sufficient sampling they would be present at each sampling round. Their presence would however likely make detecting small changes in organic carbon more difficult.
- In general, the depth that carbonates appear in the soil indicates a long-term wetting front. As such, it is to be expected that salts will accumulate at or below the depth they appear. The important aspect of the natural presence of salt in the dry rangelands is to keep them at depth where they don't restrict the rootzone or lead to plants dying or unable to establish.
- Dispersive soils are common in areas of the rangelands. While generally considered absent from the Cobar pediplain, there was dispersive material at depth in half of the profiles inspected. Similar to salinity, where this constraint occurs it is better to be deeper in the profile that near or at the surface. Where dispersive surface soils are found, more care is required to maintain groundcover that enhances rainfall infiltration.

In conjunction with the acidic soils measured with the observer monitoring, the acidity observed at the surface reinforces the importance of maintaining plant cover. An established plant can tolerate acidity more than a seedling trying to find good conditions for root growth.

Figure 125. Profile 28048 from Pooncarie Region (Property #7 Site 2, stratum 4). This soil had a sandy surface and visible carbonates from 30 cm. The carbonates were mainly soft with some hard nodules. While not evident, the upper profile displayed effervescence of the fine-earth fraction indicating the presence of carbonates

Figure 126. Profile 26550 from the Brewarrina region (Property # 3, Site 2, stratum 2). The heavy soil from a drainage area had low salt content. There was only a small abundance of carbonate nodules from 15 cm increasing below 25 cm though still <2% from a visual estimate

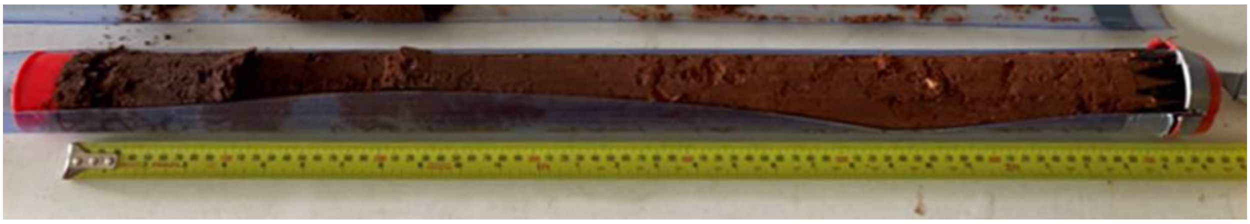


Figure 127. Profile 27705 from the Cobar region (Property #5, Site 1, stratum 2). Fine earth carbonates were present throughout but no nodules were evident (the pale nodule at approximately 55 cm was a gravel)

4.11.4 Summary of ground cover trends across observer properties

Ground cover trends reflect the variable and episodic rainfall characteristic of rangeland environments (Figure 128). Typically, cover is greatest in winter and lowest in summer. A ground cover trigger threshold (ranging from 35-70%) for the months of either June, July or August was identified for each property as an early indicator of when cover is likely to fall below the drought threshold (<20th percentile cover for that property) the following summer (Table 17). By observing cover levels in winter and identifying when cover is dropping below the trigger threshold, producers can choose to enact management actions such as reducing stocking rates prior to this episode.

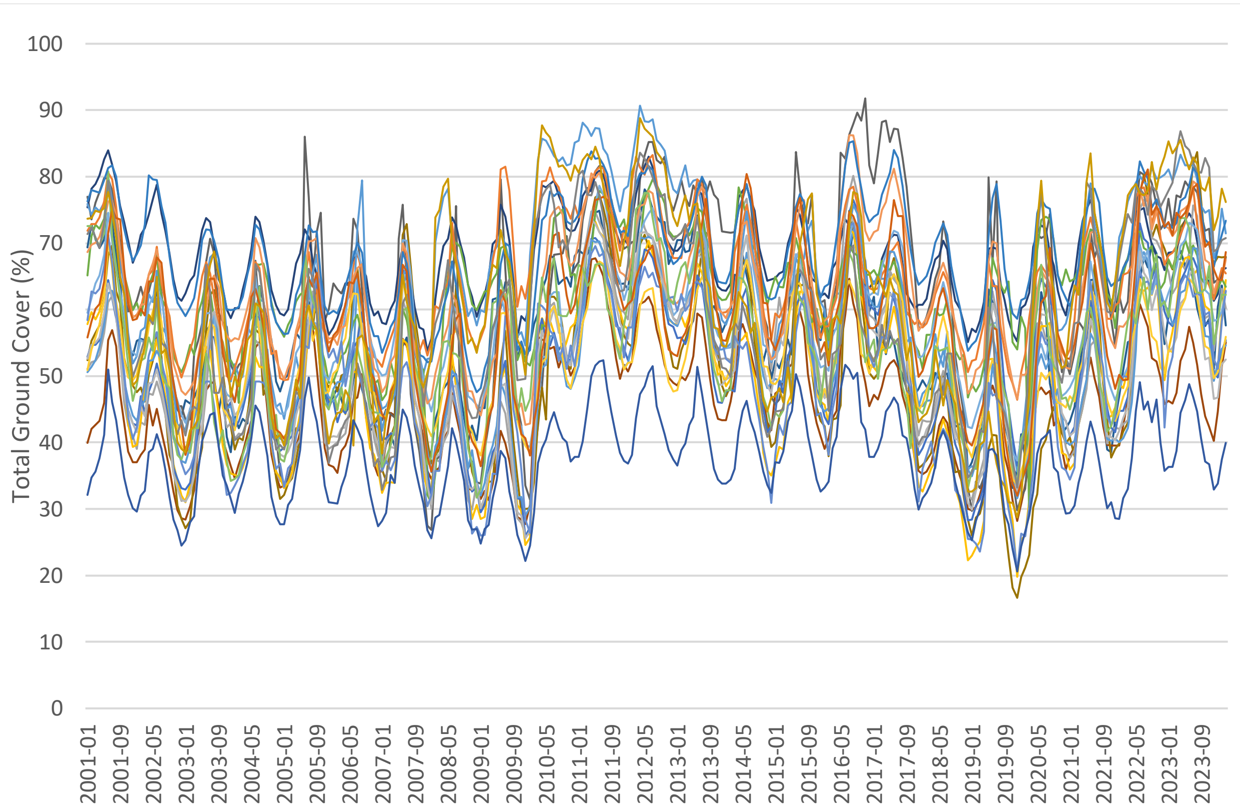


Figure 128. Ground cover trends across 24 Observer properties (each shown in a different colour as separate lines) between 2001-2024

Table 17. Summary of identified drought trigger month and cover level, drought level and number of times the drought cover level occurred between 2001-2024

Property	Trigger month	Trigger Cover	Drought Cover	Droughts	Country Type	Location
1	Aug	50	40	5	Floodplain - irrigated	Bourke
2	Jun	45	30	4	Stoney alluvial plains	Packsaddle
3	Aug	55	35	6	Floodplain	Booligal
4	Aug	45	30	4	Dunes sandplains	Pooncarie
5	Aug	60	45	6	Dunes sandplains	Pooncarie
6	Aug	70	60	11	Sandplain floodplain - woody	Fords Bridge
7	Aug	55	45	7	Floodplain scalds sandhills	Narren Lake
8	Aug	50	30	3	Stoney plains and sandplains	Wilcannia
9	Aug	50	30	4	Floodplain and stoney plains	Tilpa
10	Aug	50	35	5	Sandplain floodplain	Wilcannia
11	Aug	60	50	5	Floodplain stoney ridges dunefield	Narren Lake
12	Aug	60	50	4	Cobar Pediplain, alluvial plains	Bourke
13	Aug	45	35	4	Stoney hills, dunes and sandplains	Wilcannia
14	Aug	60	45	7	Sand hills and plains	Pooncarie
15	Aug	60	45	2	Dune and sandplains	Emmdale
16	Aug	45	30	2	Dune sand flood plains	Wilcannia
17	Aug	55	40	5	Dune sand flood plains and scalds	Coombah
18	Aug	45	30	4	Floodplain, lakes lunettes and dunes	Tilpa
19	Jul	50	35	4	Floodplain and scalds	Bourke
20	Aug	70	55	5	Dunefield with mulga	Emmdale
21	Aug	60	40	6	Dunefield with mallee discharge basins	Wentworth
22	Jul	60	40	6	Floodplain with scalds	Brewarrina
23	Jul	60	40	6	Floodplain with scalds	Narren Lake
24	Aug	35	25	4	Stoney hills creeks and scalds	Packsaddle

4.12 Natural capital framework for rangeland grazing systems

See Section 8.6 for a detailed report on the natural capital component. A summary of the key findings and outcomes is provided here.

4.12.1 Why do we need a natural capital framework for the rangelands?

Measuring and accounting for natural capital in grazing systems is complex, especially in rangeland systems where there are unique environmental and production pressures at play. Specific unique characteristics of NSW rangeland grazing systems that require specific consideration and potential adjustments in NCA frameworks and methods to increase access and adoption of NCA in these systems, as identified by producers, researchers and other key stakeholders (Rangeland Natural Capital Workshop, Canberra, February 2023) include:

- Large scale
- Low, highly variable rainfall
- Event driven systems
- Native vegetation
- Heterogenous landscapes/paddocks/properties
- Unmanaged Total Grazing Pressure (TGP)
- Tree/shrub cover
- Distance regional centres or services
- Low input, natural grazing systems.
- Rangeland pastoralists often have a holistic view

4.12.2 Key indicators relevant to rangeland grazing systems

Key environmental assets and indicators that were identified as being most important to report on and sensitive to management by technical experts, producers and other stakeholders in NSW rangelands included:

- Vegetation (including ground cover, vegetation condition, perenniality, floristic diversity, weeds)
- Soil (including soil condition, soil carbon, soil erosion)
- Fauna (key indicator fauna species such as birds, habitat for threatened species, pest animals and unmanaged TGP)
- Ecosystem (connectedness, habitat type and extent, landscape function)
- Livestock productivity (including stocking rates and stock type, TGP, feedbase quantity & quality)

Additional assets and indicators were also identified but considered lower priority by producers and stakeholders, primarily as they were considered to be outside the control of producer's management. These included:

- Air (quality)
- Water (quantity and quality)
- Rainfall/weather/climate
- Soil (soil type)

- Fauna (animal biodiversity)

Each of the key indicators identified were assessed with regards to i) method and ease of measurement, ii) sensitivity to management, and iii) use in management decisions.

Overall, only ground cover and plant biomass were identified as being suitable in meeting all three assessment criteria (ease of measurement, sensitive to management and use in management decisions). Perenniality, and indicators of productivity including carrying capacity and stock type were also identified as suitable in all categories, although are not currently able to be assessed remotely. Assessment of most indicators was identified as being resource intensive for on-ground measurements (e.g., floristic diversity, weeds, animal diversity, key indicator species, pest animals, connectedness, landscape function, soil carbon, soil condition, soil erosion and pasture composition). Use of remote sensing products for assessment of these indicators is either not yet developed or had limited development.

Reflecting the dynamic rainfall and slow change nature of rangeland environments, the majority of indicators were considered to be slow in their response to management or dependent on external factors. However exceptions included ground cover, perenniality, soil condition and erosion, carrying capacity, stock type, biomass and pasture composition. This contributes to the difficulty or lack of suitability for the majority of indicators identified to be used in short-term management decisions. The most suitable indicators for use in management decisions were ground cover, perenniality, carrying capacity, stock type, biomass and pasture composition, along with TGP.

4.12.3 Are these indicators used within existing frameworks?

Diversity in indicators mirror the diversity in frameworks. Six existing NCA reporting frameworks (ecological outcome verification (EOV); Accounting for Nature (AfN NV 03 and AfN NV 10); Farming for the Future (FftF index); Clean Energy finance corporation (CEFC); and Science Based Targets (SBTN)) identified as having relevance to rangeland grazing systems were reviewed to identify which frameworks are suitable to monitor and report against the key indicators of natural capital identified as most important by rangeland stakeholders. Overall, EOV and CEFC included measurement and reporting of the majority of indicators (at least to some extent) identified by producers and other rangeland stakeholders. There are considerable differences in the type of indicators each reports on, reflecting their unique purposes and posing challenges for producers in selecting appropriate frameworks and for industry at regional and national levels in comparing and reporting overall progress towards sustainability and environmental targets.

4.12.4 Barriers to natural capital accounting in rangeland grazing systems

Barriers to natural capital assessment in NSW rangelands can be broadly summarised into off-farm and on-farm challenges. Off-farm challenges relate primarily to the complexity and immaturity surrounding the concepts of natural capital accounting creating confusion about the value of the frameworks, how to engage and where to acquire appropriate, credible guidance. There is also a lack of developed markets and uncertainty regarding potential changes in policy and government. On-farm challenges and barriers reflect these off-farm challenges, in particular the uncertainty associated with selecting frameworks and methods and uncertainty regarding data collection, analysis and reporting, the time and resource commitment required and a lack of rangeland specific standards and benchmarks from which to compare with. Greater detail on each of these is provided in Table 18.

Table 18. Summary of the key barriers of natural capital accounting in rangeland grazing systems

Key barrier	Description
Off-farm	
Markets are embryonic	At present, market opportunities to be rewarded for maintaining or improving NC are limited. There is little evidence of a value proposition with environmental markets still embryonic. There is no evidence at this stage that rangeland farmers are being rewarded through market premiums or market access opportunities. Nature certificates as part of Australia's Nature repair bill, Biodiversity Offsets or as co-benefits as part of carbon based projects remain nascent and clarity on who are the purchaser of these instrument or where or how demand will manifest remains opaque at best.
Operation scale of available frameworks - global to farm.	There is a mismatch with producers and natural capital assessment policies and methodologies in rangelands, with existing global and industry frameworks often taking a top-down approach which is less useful at a property scale.
Multiple standards and frameworks	With over 600 ESG disclosure tools and over 3000 NCA tools brings complexity and confusion to producers in determining the best approach to adopting NCA in their business. Lack of harmonisation or consistency also brings risk to a potential lack of integrity in NCA, and difficulty for industry or government bodies in combining data to report progress at regional or national levels.
Policy and/or government change	Frequent changes and uncertainty regarding policy, funding and/or governmental priorities and commitments reduces producer confidence and enthusiasm in entering natural capital project agreements.
On-farm	
Uncertainty in selecting frameworks and methods	As seen in this report there is a multitude of frameworks, standards, goal setting/disclosure tools which can lead to confusion and increases complexity of undertaking a natural capital accounting approach. This will be a challenge for farmers wrestling with the most appropriate pathway and how choices will allow farmers to meet external demands.
Uncertainty in data collection and analysis	Currently capturing core data for natural capital projects requires physical onsite assessments which is supplemented using remote sensed data. Given the long-term nature of establishing and maintaining natural capital accounts reducing costly on ground data collection for remote sensed will be a key factor. How data is captured will impact validity of results. Data validity has been called into question in recent years around voluntary programmes. Certainty and understanding of what, when and how different indicators are to be measured and reported is required.
Integration with existing management systems	To minimise time and costs, increase transparency and increase adoption of NC reporting, measurement and reporting needs to be streamlined with existing farm business or management software. Currently, there are few available platforms that facilitate collation and reporting of farm-scale natural capital indicators, and those that do exist are limited to only a few indicators.
Time and financial commitment	Engagement in NCA will require additional time allocation and financial investment to establish, measure monitor, and report the natural capital accounting results. This will be dependent upon several variables including property size, existing data collected by farmers, number of monitoring sites, types of data collection tools and methods and reporting. In addition, it is likely there will be additional time and financial investment required to implementing any practice change or build infrastructure to adopt new practices.
Value proposition	Up until recently there has been limited evidence of the value proposition to farmers undertaking natural capital accounting. In some instances, it may be seen as a stick rather than a carrot. A recent study presented case studies exploring NCA in agricultural decision making and identified there was a lack of value proposition in undertaking the approach, along with the perception that any price premiums associated with the approach would likely be eroded away. There was a strong sense however that undertaking practice change would be required for future market access (Martin, 2022). Given the anticipated cost of establishing, ongoing monitoring and reporting, a clear value proposition is required to increase adoption of NCA in rangelands livestock industry.
Rangeland specific	While there are a multitude of existing robust methods available for monitoring indicators of natural capital, application of these methods in a rangelands context may not be technically

	or financially viable given the unique characteristics of rangelands. Many of the tools identified in this report may not be operable in a rangelands context and complexity of tools make it difficult to assess which are appropriate. Furthermore, relative to other regions of Australia, there is a lack of data and high degree of uncertainty underpinning some methods and management practices, as relatively little research has been undertaken in NSW rangelands. Associated with this, there is a lack of benchmarks for land condition and different standards for different land types, increasing the complexity of measurement and reporting.

4.12.5 Recommendations to improve adoption of natural capital accounting in rangeland grazing systems

1. Increase knowledge sharing. As highlighted in this report, natural capital, natural accounting frameworks and standards etc are diverse, disconnected and growing. Increasing collaboration across industries and developing knowledge and education as part of this process is likely to assist in unravelling complexity that can influence change and increase adoption of natural capital practices. Support to assist pastoralists in understanding, implementing and seeing the value in NCA.
2. Increase producer understanding of natural capital accounting frameworks, and purpose and differences in requirements across different scales (e.g., the rigor needed to inform farm management decisions versus generate saleable credits) to inform their adoption of NCA practices, depending on the outcome they are wanting to achieve.
3. Development of a centralised data system that allows rangeland producers to control and leverage the value of their natural capital data effectively and securely.
4. Development of natural capital reporting platforms integrated with existing farm software programs would assist with adoption, streamlining training and on farm office workflows.
5. Financial support to reduce costs of NCA. Agricultural industries seek long term government support to offset costs of running natural capital measurement and monitoring programs. The benefits from incentivising or informing practice change through NCA are both public and private and are focused on rangelands environments
6. Harmonise reporting requirements and mechanisms. Currently there is a wide range of tools available that risks duplication, poor quality data and costly collection tools. Agreement on tools and data requirements can result in future opportunity for rangeland farmers. Engagement with the supply chain may provide opportunities to accelerate this although given evidence it is unlikely to result in sustainable or meaningful premiums.
7. Where possible, ensure availability of NCA frameworks and metrics that assist pastoralists in making management decisions and forecasting, suited/of benefit to pastoralists. Information collected should be communicated simply and timely so that pastoralists can make a management decision using this information
8. Software systems that will automatically capture data (ie. satellite ground cover and vegetation) to reduce time and cost of monitoring, and provide independent assessment, and interface that with subjective date provided by the land manager.
9. Where necessary, normalise indicators for seasonal conditions or similar to account for management impacts against other external drivers of change
10. To maintain integrity, NCA in rangeland grazing systems should focus on outcomes, rather than the practice or activity (e.g, report on outcomes, not necessarily types of management that is contributing to the outcome)

11. Ensure metrics are robust and easy to use, alongside robust and easy to use methodologies that enable consistent natural capital assessment methodology across Australia, that can be monitored and reported by producers
12. Maximise existing data for on-ground validation to support product development – for example, use of existing commonwealth sites and monitoring vegetation data, and coordination and collation of privately owned data to generate benchmarks or improved models, for example.
13. Where possible, keep metrics and reporting simple to maximise adoption and ensure value is clearly communicated.
14. Development of case studies to show how, when, why and cost and benefits.
15. Prioritise low cost data collection and analysis, minimising time requirements also.

4.13 Ten year plan

With collaboration and co-design at the core of the Rangelands Living Skin Project, the 10 year plan captures some of the key elements and learnings from the Project that contribute to successful producer and industry collaboration in rangeland research, development and extension (R, D & E) projects. Specifically, the plan provides a collective vision for NSW rangeland grazing systems, identifies key stakeholders for inclusion in future projects and activities, provides a snapshot of the current funding environment and emerging opportunities for funding, and highlights key factors for successful producer engagement and collaboration in rangeland R,D & E to achieve the collective vision. A full copy of the plan is provided in Section 8.7, and a summary of key elements of the plan is provided below.

4.13.1 Vision

Rangelands managed sustainably with improved environmental health, economic viability and resilience to challenges like drought and climate change.

4.13.2 Key factors for successful producer engagement

Due to the large areas of land managed by producers, and the low population density in this extensive environment, it is critical that rangelands RD&E actively, intentionally, and successfully engages producers to optimise value and adoption. The following points outline key strategies for fostering meaningful engagement with producers, thereby enhancing the overall impact and value of collaborative projects.

- → **Set realistic and achievable R,D&E objectives** and priorities with both producers and industry
- → **Co-design** R&D projects with producers and industry stakeholders to ensure activities are relevant, practical and of interest to target audience and end users of information
- → Outline a **clear value proposition** for producers, including the project outcomes that will be of value to them and their business
- → **Engage producers in all aspects of project**, encouraging active participation and contribution and practical feedback (including project development, monitoring, hosting events, presenting results, reviewing project outputs)
- → **Incorporate producer knowledge** and feedback into project design, activities and outputs

- → **Value the time, expertise and contribution** of producers in project team with payments for provision of services, also ensuring equal partnership and ownership in project and accountability
- → Establish research and demonstration sites '**on the ground'**
- → **Encourage producer-led initiatives** and peer-peer learning. Where possible, have producers present and talk to the experience and results of projects on their property
- → **Highlight success stories, make the research accessible and showcase** R,D&E findings via multiple avenues including field days, workshops, media articles, case studies, podcasts and webinars, to increase reach and engagement
- → **Work with existing producer-led groups** or establish enduring producer networks that collaborate on multiple initiatives to ensure longevity beyond short-term projects
- → **Time events** to avoid 'busy' periods in the production calendar, avoid conflicts with other events, and plan ahead to 'save the date'
- → **Personal connection** is important – ensure regular one-one communication between producers and project team
- → **Provide opportunities for connection** between producers and also with industry experts
- → **Provide summary of research or project results** and project data to producers in a timely manner and in an appropriate format.

4.13.3 Key factors for successful design and delivery of collaborative projects

Designing and delivering effective collaborative projects requires careful planning and execution. This section outlines the critical elements necessary for the success of such projects, ensuring they are well structured, inclusive, and aligned with the needs of all stakeholders involved.

- → **Identify what is trying to be achieved** – keep the R,D&E relevant and valuable to stakeholders, ensuring activities provide tangible benefits and address pressing concerns on farm. Frame research questions from the bottom up – i.e. what information producers need to make better land management decisions.
- → **Identify key stakeholders/partners** – collaboration and contribution from various organisations, including government agencies, research institutions, private sector representatives, and producers
- → **Involvement of producers** – take a farmer centric approach, involving producers in all aspects of the project, to increase engagement and adoption of project outputs. Where possible, projects should be producer owned and led.
- → **Project scope, objectives and deliverables** – well defined, clear deliverables that are developed collaboratively with project partners, to ensure efforts are focussed and aligned with desired project outcomes and provide a common purpose
- → **Strong leadership –** especially with large teams, both from the funding organisation and lead organisation. Ensure project leaders are passionate, knowledgeable, capable to drive the collaboration and coordinate activities across different groups
- → **Communication** – open, respectful, regular communication that ensures clear understanding of project activities, clarity in roles, accountability, expectations and deliverables
- → **Common language and messages** – e.g. language guide and collating key messages for communications

- → **Skills and expertise** – diverse skills as well as a depth of experience to ensure project activities are achievable
- → **Engagement and input from all stakeholders** – critical to success of collaborative efforts is buy-in from all stakeholders from the project outset. Recognise and respect the skills and knowledge that all stakeholders bring to the project team
- → **Engage local people** – involvement and ownership of/by local people (including producers, extension staff, researchers, advisors or other local organisations) with experience and knowledge in rangeland systems in the project team is critical to success of rangeland projects.
- → **Establish on-property research & trials** to maximise engagement research relevance and adoption by producers, and ensure projects are designed to be practical and scalable
- → **Design projects and initiatives to be responsive to seasonal conditions** (to the extent practical)
- → **Avenues to connect people and disseminate information** – identify and use a variety of communication avenues to connect the project team, producers and the broader community, including WhatsApp, Facebook, newsletters, webinars, workshops, field days, scientific publications, websites, case studies and fact sheets. Peer-peer communication, direct staff contacts and targeted extension events are important to maximise adoption. Recognise that impact may be achieved through smaller numbers of key stakeholders and acknowledge their role and responsibility in sharing and incorporating project findings into extension resources.
- → **Project timeframe** – ensure project length is long enough to achieve objectives, allowing time to install and monitor trials and carry out project activities. Consider also future sampling and monitoring requirements and plans beyond the project timeframe.
- → **Flexibility and adaptation** – allow for flexibility in responding to external challenges, hosting events, addressing emerging research questions or opportunities, and adapting plans and strategies based on feedback and changing circumstances.
- → **Manage relationship with funding body** via regular meetings, clear communication

4.13.4 Conclusion

The Rangelands Living Skin project demonstrated the potential and application of co-designed, collaborative research and extension to understand and promote management practices that can achieve ecosystem sustainability, productive landscapes and profitable businesses in the NSW rangelands. The project highlighted the value of producer involvement in all aspects project design and delivery, alongside a diverse team of stakeholders, and their role in promoting and communicating project findings to support wider adoption beyond the project. Engaging producers is critical in maximising the value of R, D & E and can be encouraged by ensuring a clear value proposition and outcomes of a project that are relevant to producer needs. Projects should also value the time, knowledge and services provided by producers in the project team, supporting producer-led initiatives and ensuring 'local' support and research activities.

Developing and delivering collaborative R, D & E is not without challenges; however, projects will be more successful if they have a clear project scope and deliverables that are developed collaboratively with all project partners, with regular open communication, flexibility in the delivery of project activities and ensuring sufficient time and budget to achieve project objectives. As political and industry R, D & E priorities and associated funding avenues change, there is an increasing need for a strong value proposition and co-investment by stakeholders to support continued R, D & E in the rangelands. New work will need to consider and facilitate links to First Nations people and would benefit from incorporation of indigenous knowledge and management. Furthermore, future R, D & E would benefit from connecting rangeland regions (across borders, e.g., NSW, QLD, SA, WA), bringing together investment under unified programs of work and sharing information and learnings across broader networks with similarities in production systems. Rangeland grazing systems are a unique and valuable asset for both livestock production and natural capital in Australia. Fostering strong, collaborative relationships among producers and other stakeholders for R, D & E and striving to meet the key principals and strategies for collaborative R, D & E identified in this plan we can drive meaningful progress towards the collective rangelands vision.

4.14 Changes in producer knowledge, attitudes, skills and aspirations

See Section 8.8 for a complete copy of the baseline and end of project KASA survey results. Below is a summary of the key trends and findings from these.

4.14.1 Core producer and Observer KASA baseline

Below are a summary of baseline KASA survey results for the core producers and observer group.

Soil

Baseline KASA results indicate potential to improve knowledge regarding soil carbon and related benefits amongst the producers. The majority (>50%) of producers reported 'some knowledge' of farm management strategies to increase soil carbon and knowledge on carbon farming methods while 23% reported very little knowledge and the remainder either sound or very sound knowledge. The majority (>58%) of producers indicated sound or very sound knowledge regarding benefits of increasing ground cover and soil carbon on productivity and ecosystem services, though a considerable proportion still indicated very little or some knowledge (~40%). Approximately 30% of producers reported no or very little knowledge regarding information to weigh up advantages and disadvantages of carbon farming.

Less than one-quarter of the producers indicated sound or very sound knowledge of soil biological health, highlighting lack of current knowledge and potential for improvement.

Feed base & cover

Producers' confidence in knowledge of attributes related to feedbase and cover was higher than responses received for soil carbon. The majority of producers (>50%) indicated sound or very sound knowledge regarding their knowledge on monitoring and managing feed on offer, quality, composition and diversity and ground cover. However, results indicate potential to improve knowledge on these, in particular composition, where still a large proportion of respondents rated only very little or some knowledge of these areas.

Only 4% of producers indicated they don't monitor the feedbase or cover, with the vast majority (92%) using a visual assessment to monitor the feedbase. Only 4% of producers used remotely sensed tools and images for monitoring feedbase, though 23% use these tools for monitoring cover. Monitoring is undertaken monthly or daily by the majority of the producers.

Grazing management

In regards to information used to make grazing management decisions, overwhelmingly groundcover, feed availability and feed quality were selected most frequently by producers (with 85%, 69% and 62%

of producers selecting these options, respectively). Only 15% of producers selected indicator species, highlighting a potential area of improvement. Production metrics were also less commonly selected, with no producers selecting market price in their top three.

46% of producers indicated they do not use any specific tools to assist in making grazing decisions. Of those that do use tools, grazing charts (or variation of), feed budgets and online management products were common (58%, 46% and 27%, respectively).

Previous training

Few of the producers had undertaken training in carbon farming/trading and on-farm greenhouse gas emissions. Most of the producers have undertaken training on ground cover and grazing management. Almost equal numbers of producers either had or hadn't undertaken training in soil carbon, soil biology, landscape function, feedbase, and biodiversity.

4.14.2 Core producer and Observer KASA end of project

Below is a summary of final KASA survey results for the core producers and observer group (n = 19), and some commentary on the comparison to the baseline results as above.

Soil

Overall, producer knowledge related to topics of soil (carbon, biology and carbon farming) increased relative to the beginning of the Rangelands Living Skin project. Final KASA results indicate the majority (>73-84%) understand the benefits of increasing ground cover and soil carbon for productivity and ecosystem services (aka, indicated sound or very sound knowledge), representing an increase of 20-30% compared with initial project results. 95% of producers indicated they understand the role of increasing soil carbon in reducing soil loss from wind and water erosion. The majority (68%) of producers indicated sound or very sound knowledge to weigh up the advantages and disadvantages of carbon farming, a considerable increase of almost 40% compared to the initial project survey results, however still ~30% indicate only some or very little knowledge on this topic. Less than half of the producers indicated sound or very sound knowledge of soil biological health, and while this is an increase relative to the initial project results, overall further extension in this field may be required.

Feed base & cover

Producers' confidence in knowledge of attributes related to feedbase and cover was again higher than responses received for soil carbon, and followed a similar trend with improvement in knowledge of all topics. The majority of producers (>75%) indicated sound or very sound knowledge of monitoring and managing feed on offer, quality, composition and diversity and ground cover.

All of the producers indicated they monitor their feedbase or cover, with the vast majority (95%) using a visual assessment to monitor the feedbase. Only 26% & 36% of producers used remotely sensed tools and images for monitoring feedbase and vegetation cover, respectively, although this represents an increase of 22% & 13% from the baseline survey. Similar to the initial project results, monitoring is undertaken monthly or daily by the majority of the producers.

Grazing management

Information used to make grazing management decisions did not differ considerably to that indicated in the baseline survey where again groundcover, feed availability and feed quality were selected most frequently by producers (with 84%, 89% and 63% of producers selecting these options, respectively). A greater proportion (31%) of producers also selected indicator species, while production metrics including condition score, lambing/calving time had a similar proportion selecting these.

A lower proportion 26% of producers indicated they do not use any specific tools to assist in making grazing decisions at the end of the project (a reduction of 20%). Of those that do use tools, feed budgets, grazing charts (or variation of), and online management products were common (52%, 31% and 26%, respectively).

Training

The majority of producers (57 – 80%, depending on topic) indicated they had not undertaken training as a result of the Rangelands Living Skin project, however it is likely that the definition of training confused results. Almost all producers indicated positive outcomes associated with their involvement in the Rangelands Living Skin project and had made changes to their management as a result of their involvement in the project, a summary of these responses, in the words of the producers, is provided below.

Q – What did you get out of the Rangelands Living Skin Project by your involvement?

- *Broader knowledge*
- *I learned from the other producers in the group and visited some different properties.*
- *A network of passionate people, support to improve our management, access to researchers and industry consultants that are able to help us*
- *The opportunity to work and collaborate with other producers and industry experts. The opportunity to carry out research trials to gain new knowledge, quantify outcomes, and share information. We gained third party assessment of our ground cover of our property highlighting the changes in ground cover after our change in management. Opportunity to use some latest technology of Cibo labs pasture Key product for assessing biomass and ground cover. We had the opportunity to Benchmark our properties financial performance and to receive excellent coaching from RCS James Barnett. Many soil tests have help us identify some underlying causes of poor soil and plant performances. Soil test to determine current carbon levels in our soils. Opportunities to attend many educational courses e.g., grazing workshops and field days, Financial fundamental, Natural capital and Carbon workshops. Learning from other core producers and observers. Organize and run a field day of relevant information for producers.*
- *Got me thinking about things, and saltbush. I didn't go to too many seminars*
- *A greater focus on our land & soil & the care of it rather than just the animals that we graze on it*
- *An improved understanding of soil carbon and carbon farming methods. A more motivated approach to our land management through discussing our practices with others working on and involved in the project.*
- *Lifted our business to a higher level due to use of consultant. Better understanding of our carbon account. Ideas to work on to improve soil health & productivity*
- *We were able to relate and comprehend the information easier than past presentations due to it being closer to our landscapes within our business. All presentations were great and we were able to take many things away to add to our farming and grazing businesses.*
- *Support network*

- *a greater understanding of the soils and vegetation in my Rangeland environment. look forward to more projects in this region*
- *It is always good to trial any different approach to managing or improving landscapes, and being involved with a positive group like RLS always helps. Certainly, we are interested in looking more into soil biology and how we can positively influence that to be more active.*
- *I enjoyed watching the webinars from experts presenting in the field. Specifically topics around ground cover and grazing management.*
- *The webinar on methane production in ag was excellent.*
- *A good appreciation of groundcover and plant diversity. The increased use of technology in this field.*
- *Better understanding of having to measure what feed is ahead and how to manage that feed better*
- *Access to some professionals to better inform me of how to manage in the rangelands*

Q - Briefly describe any change you have made to your approach to managing your property as a result of the Living Skin project – e.g. your pasture, your soil, your grazing management, your livestock, your environment, and, if you wish, your business management (in your own words)

- *More fencing and controlled grazing*
- *I really haven't changed anything. I have been a member of a Grazing Naturally group for four years; that has brought about considerable change in pasture assessment, grazing management and livestock management.*
- *Improving our grazing diversity to suit individual paddocks*
- *We are always seeking new knowledge and we have taken away many 1% to help our pastures, soils, our grazing, livestock and business management which will help us improve the environment where we live.*
- *planting of saltbush for C sequestration, sowing legumes (periodic), livestock management*
- *Increased awareness of our environment*
- *Not over grazing, moving stock of sooner to keep the diversity in our pastures.*
- *Sharpening our grazing management practices to balance livestock production and soil/pasture health for a more productive environment.*
- *Expanded our business. Working on ideas to improve soil health & productivity*
- *We are now in the process of re-fencing the property for better performance and increase diversity which we know now will increase both profitability and sustainability within our businesses and landscapes.*
- *Soil sampling*
- *Keep my stocking rate to a more conservative amount to keep my ground cover above 60% This is essential in the rangeland environment with limited variable rainfall.*
- *No serious changes directly attributable to the RLS project, but we will be intensifying the management of our livestock to increase biodiversity, animal impact and increase recovery times.*
- *I am to maintain a high level of groundcover and have pastures which are "rain ready".*
- *No major changes. A lot of the principals of the Living Skins project I was already implementing in our enterprise.*

- *Thinking more about stock density and timeliness of moves from paddock to paddock.*
- *Better records of stock movements and what's ahead and behind them*
- *No changes. Was hoping to gain confidence in soil carbon sequestration in rangelands but do not see adequate evidence to start a project at this stage.*

4.14.3 Summary of producer involvement in the Rangelands Living Skin

Overall, 31 producer enterprises were directly involved in the Rangelands Living Skin project (either as core producers, observer producers or with trials on property, and over 200 rangeland producers and stakeholders attended project events over the duration of the project (Table 19), with overall high satisfaction of events and majority of producers improving knowledge and implementing management change as a result of project involvement.

Table 19. Summary of key statistics related to producer involvement in the Rangelands Living Skin project

Number of Core producers	4
Number of Observer producers	26
Total area managed of producers directly involved in project[1]	1,015,276 ha
Total livestock managed of producers directly involved in project[2]	Sheep: 149,580; Cattle: 12,112; Goats: 4,500
Proportion of participants who indicated they have made a management change as a result of their involvement in the project[3]	79%
Proportion of participants who increased knowledge in topics of soil carbon, carbon farming, ground cover, ecosystem services, or soil biology[4]	83% (average increase by 1.13 points on 5 point Likert scale)
Overall satisfaction score for project events[5]	8.7/10
Total unique participants attending project events	>200[6]

[1]core + observer participant and an additional producer that hosted project research and trial sites
[2]data collected in 2021/2022 following a dry period, stock numbers across properties vary significantly year to year. Some producers did not provide stock numbers.
[3]of the 19 participants who completed the final project MER survey
[4]of the 18 participants for which pre and post project MER data was available
[5]for ten field day and workshop events for which overall satisfaction was reported
[6]not all participants registered or provided names at events, this figure is conservative, and does not include duplicates of participants who attended more than one event.

5 Conclusion

Rangelands Living Skin was a five-year project linking farming families, scientists, education and extension agencies, commercial carbon companies and communications experts to evaluate cost-effective practices that focused on regenerating the NSW rangelands and supporting productive, profitable and sustainable businesses. The project aimed to create an evidence-base and build capacity for widespread adoption of practices that benefit soil, plants, animals and people – the living skin of the rangelands. Reflecting the collaborative project design, over 60 researchers, producers, commercial providers, extension and education specialists contributed directly to the delivery of project outcomes. Research trials were established to investigate effects of management interventions including water ponding, deep ripping, intensive short-duration animal impact, gypsum, soil biological stimulants, hard-seeded annual legumes and mixed-species cropping. Additional monitoring investigated the effects of planned grazing management on ground cover, soil carbon dynamics and relationships in rangeland grazing systems, soil chemistry constraints in NSW rangelands, ground cover trends across NSW rangeland grazing systems, rangeland grazing business profitability, and greenhouse gas emissions from rangeland livestock enterprises. Over the life of the project, the project hosted 17 in-person field days and workshops on a variety of topics relevant to the project theme, including soil carbon, soil biology, soil monitoring, ground cover, grazing management and natural capital. Additional online workshops, webinars and recorded videos were hosted through the project on a broad range of topics. Combined, these events engaged over 200 rangeland producers and stakeholders (unique attendees), with further extension of project outcomes to a broader audience achieved via fact sheets, newsletter and media articles, presentations and social media. These engagement led to an overall increase in knowledge and skills for 83% of the core and observer producers, with 79% reporting changed practices as a result of participating in the project. Specific project findings and outcomes are detailed below.

5.1 Key findings

1. **Planned grazing management (adapting stocking rates to carrying capacity, and strategically grazing and resting land) can significantly increase ground cover (by 2-7%) in NSW rangelands over the long term.** Ground cover is an important indicator of land condition and is associated with the support and provision of numerous ecosystem services. Significance and magnitude of this increase is dependent on property, land type and seasonal condition. Remote sensing provides an accurate, cost-efficient method to monitor and benchmark ground cover in extensive, variable rangeland grazing systems and this project demonstrated the practical application of remotely sensed cover data and dynamic regional comparison techniques to document environmental outcomes at the property scale from grazing management in low input, extensive rangeland grazing systems.
2. **Monitoring long term trends in fractional ground cover can be used to identify trigger points to predict drought effect in NSW rangeland grazing systems**. The trigger cover threshold ranged from 70% to 35%, depending on property, and the trigger month ranged from June to August during the growing season. These thresholds can be used to inform when cover is likely to fall below a threshold the following summer, enabling managers to adjust stock levels to reduce the risk of negative landscape and business outcomes in this time.
3. **Targeted management interventions, including water ponding, deep ripping, gypsum and strategic, intensive animal impact can be used successfully to rehabilitate degraded, sodic and saline scalds in NSW rangelands.** These practices work to increase water infiltration, soil surface roughness and provide an opportunity for seed capture and establishment. Across

demonstration sites on three properties in NSW rangelands, short term responses measured through the project included an increase in ground cover, plant diversity and plant biomass and a reduction in salinity.

4. **Foliar and solid biological stimulant products did not benefit pasture productivity and quality**. There was no significant difference in soil biological activity between plots with the biological stimulant products and control plots, as measured by the tensile strength and area remaining intact of cotton assays buried in soil, or in the measurements of soil protein, microbial biomass carbon, and fungal bacteria ratio between plots. Similarly, there was no difference in vegetation (composition, biomass, greenness, ground cover) between treatments. These findings suggest it is unlikely that biostimulants will have a role in rangeland grazing systems. The effect of inoculating seed with a biostimulant was not trialled in this project.
5. **Across NSW rangeland grazing properties, salinity, sodicity, low phosphorus and acidity are the primary soil chemistry constraints limiting productivity.** Soil testing is not commonly done in rangeland systems. The soil testing undertaken by producers through the project allowed them to compare productive and unproductive areas. The identification of these limiting factors informs options to manage them. The demonstration trial sites established identified the severity of the relevant constraint (such as salinity or dispersive surfaces), informed the appropriate amelioration method and showed early stages of improvement. Further investigation into constraints were not as readily obvious, but for which well-established options exist, such as acidity or low fertility can inform options around amelioration or supplements. Economic case studies were not conducted, but the findings point to the need for further investigation.
6. **Soil organic carbon levels in NSW rangelands are generally low, with considerable spatial variability**. This has implications for measuring, monitoring and detecting changes in SOC in response to management. Combined with the difficulty and relatively slow nature of achieving changes in SOC in low and variable rainfall environments, this may limit access or benefit of soil carbon markets in this region. Measuring SOC accurately and reliably to represent landforms in large complex environments requires careful consideration, and a greater number of soil samples is required to overcome challenges of variability. Other benefits associated with improved land management, including improved land condition, pasture production, soil moisture capture and retention and improved nutrient cycling, may provide greater opportunity or reward in livestock businesses and environmental markets than soil organic carbon alone.
7. **Across the 14 x 100ha soil carbon monitoring areas sampled in western NSW rangelands, a change of approximately 0.5-2.5 t C/ha would be required to detect a significant increase in soil carbon between sampling periods under the Australian carbon credit system (60% confidence level).** These numbers depend on significance threshold for reporting, a greater increase (2 – 7 t C/ha) is required at a 95% confidence level. These values reflect the variability in soil carbon across the carbon estimation areas, and a larger number of soil samples are required to detect increases as variability in SOC across a sampling area increases.
8. **Soil organic carbon was not strongly related to above-ground vegetation variables, such as ground cover, plant biomass, perenniality or plant diversity.** Within a sampling district or property, relationships between above ground vegetation variables and soil organic carbon were weak, further weakening with depth in the soil profile. This data indicates that within this region, these above ground pasture variables are not suitable as direct surrogate measures for soil organic carbon, and further research is required to better understand and predict SOC,

perhaps using remote sensing techniques in this environment at a property level and over longer timeframes. However, at a regional (across all sites) scale, higher ground cover and plant biomass was correlated with SOC, likely reflecting the rainfall and productivity gradient across western NSW.

9. **Soil organic carbon in the upper layers of the soil (0-10 cm) was significantly correlated with SOC at lower depths in the soil profile.** Despite a lack of correlation of SOC with pasture variables, SOC in the upper soil layers may provide an indication of SOC at depth (e.g. to 30 cm). This highlights the potential for developing pedotransfer functions to predict C stocks at depth from surface concentrations. This would help to reduce the cost of monitoring and provide an opportunity to increase monitoring between sampling periods to better (more frequently) inform management and reflect temporal/seasonal changes, and make it easier to use soil C in insetting of emissions. However, this method also adds uncertainty to SOC stock estimates and any cost reductions should be assessed against the increase in difficulty detecting a creditable change associated with the increase in uncertainty.
10. **Methane emissions from livestock are the dominant form of greenhouse gas emissions in rangeland grazing businesses.** Average emissions across the four properties monitored ranged from 260 – 2233 t CO_2-e per annum (excluding offsets), with the number of livestock carried the primary driver of this difference. These values are relatively low compared to livestock businesses in other regions of NSW, and relatively low levels of carbon sequestration would be required to offset these emissions (e.g., an increase of 0.05% SOC over 25 years).
11. **It is possible to remain a profitable livestock business whilst simultaneously managing for environmental outcomes in NSW rangeland grazing systems**. The four core properties participating in the Rangelands Living Skin project were profitable and competitive with top Australian producers involved in the RCS ProfitProbe benchmarking program, whilst adopting and adapting management practices to regenerate their landscapes.
12. **Emerging environmental markets present a significant opportunity to NSW rangeland grazing businesses, however several barriers currently limit access and adoption of these markets to rangeland producers**. These barriers include both off-farm challenges related to the complexity and immaturity of markets, and on-farm challenges related to cost and difficulty in measuring and reporting natural capital in extensive rangeland grazing businesses. Rangeland producers and stakeholders identified several key indicators related to environmental assets such as vegetation, soil, water, fauna and ecosystem function, however currently no frameworks or reporting tools include the ability to report on all of these indicators. Incorporating rangelands data and rangelands specific indicators into current accounting frameworks is needed to increase access and adoption of natural capital accounting in rangeland grazing systems. Increasing knowledge sharing, development of data collection and reporting platforms, harmonization of approaches and ensuring simple, low-cost methods of monitoring and reporting farm natural capital for rangeland grazing systems is recommended.
13. **Producer centric, collaborative research is important for industry relevant outcomes and maximising engagement.** The Rangelands Living Skin project demonstrated the potential and application of co-designed, collaborative research and extension to understand and promote management practices that can achieve ecosystem sustainability, productive landscapes and profitable businesses in the NSW rangelands. The project highlighted the value of producer involvement in all aspects of project design and delivery, alongside a diverse team of stakeholders, and their role in promoting and communicating project findings to support wider

adoption beyond the project. Engaging producers is critical in maximising the R, D &E and can be encouraged by ensuring a clear value proposition and outcomes of project that are relevant to producer needs, valuing the time, knowledge and services provided by producers in the project team, supporting producer-led initiatives and ensuring 'local' support and research activities

5.2 Benefits to industry

- **Enhanced awareness and capacity building related to management and monitoring of soil, pastures, biodiversity, landscape function, productivity and profitability in rangeland grazing systems**
    - Raised profile of NSW rangelands Australia-wide, promoting positive management outcomes and showcasing improved capacity in these regions.
    - Opportunities for landholders to attend field days, workshops, and training events, facilitating knowledge exchange and skill development in Western NSW rangelands.
    - Exposure of good land management practices, demonstrating opportunities and benefits of changed management in NSW rangelands.
    - Development of case studies on regional producer properties to promote the innovation and learnings identified within the project
- **Improved collaboration and knowledge exchange**
    - Enhanced connections and understanding between researchers, extension agencies, other topic experts and landholders, making research more relevant and fostering collaboration between producers and different organisations.
    - Establishment of a network of producers interested in achieving common environmental, productivity, and profitability goals, providing opportunities for likeminded individuals to meet and connect.
    - Sharing of perspectives and introduction to new stakeholders, facilitating information exchange and building relationships within the industry, including other states.
    - Collation of project learnings and recommendations and development of strategies to improve industry participation and engagement between rangelands producers, research, industry and NRM bodies and guide future collaborative research projects.
- **Data collection and monitoring**
    - Collection of scientific data on various trials and monitoring across different landscapes, addressing data gaps in data-poor areas and contributing to better understanding of soil carbon, biology, diversity, grazing management, and business management.
    - Identification of key interventions and practices preferred by producers, such as water ponding, gypsum application, and herd impact, with a drive to gather more data for better understanding and implementation into other systems
    - Information on soil carbon to depth across a range of landscapes and identification of challenges in measuring and increasing soil carbon in rangeland environments
    - Documentation of rangeland livestock enterprises greenhouse gas emissions and carbon balance, and outlining key recommendations to further improve and develop carbon accounting methodologies and tools to improve accuracy and relevance to rangeland grazing systems
    - Demonstration of a novel paired site and remote sensing approach to documenting and evaluating change in cover over time (>10 years) following grazing management

interventions and future considerations for higher spatial and temporal resolution for more meaningful and management sensitive information

- **Demonstrating environmental, productivity and profitability outcomes of management practices in NSW rangeland grazing systems**
    - Scientific evidence of the benefits of grazing management, water ponding, ripping, gypsum and intensive animal impact to regenerate rangelands
    - Evidence of financial resilience and profitability whilst managing to regenerate rangelands

6 Future research and recommendations

The project team identified a number of recommendations for future research, development and extension, building on project activities and findings to support productive, profitable and sustainable rangeland grazing businesses into the future. These are summarised below, with more specific priorities outlined in the Ten Year Plan, Section 8.7.

1. **Understanding soil health, biology and carbon sequestration impacts associated with management over time.**

- Through the Rangelands Living Skin project, we gained an understanding of current soil carbon concentration and stock, and the spatial variability of soil organic carbon across a number of livestock business in western NSW rangelands. Resampling study sites at frequent (3-5 year) intervals in the future is important to understand sequestration of carbon under rangeland livestock grazing systems and how this is affected by different management interventions, in addition to better capturing and understanding temporal variability in rangeland soil carbon.
- The Rangelands Living Skin project collected information on soil biology metrics and facilitated training and extension activities to build the understanding of rangeland producers as to the importance of soil biology and how to measure soil biological activity. However, the project highlighted the dearth of information regarding soil biology in western NSW rangeland grazing systems, and how management and climatic drivers impact this.
- Producers involved in the Rangeland Living Skin project had the opportunity to monitor and test the chemical and physical health of their soils, which highlighted a number of potential constraints to improving productivity and regenerating landscapes. Greater research on the extent of these limiting conditions and cost-efficient, practical methods to overcome these in extensive rangeland systems is required.

2. **Understanding environmental, productivity and profitability benefits and risks associated with various management practices.**

- The Rangelands Living Skin project established a number of demonstration trials examining the effects of water ponding, ripping, gypsum and intensive animal impact. However, ongoing monitoring is required to understand the long-term effects of these practices and better understand associated cost and benefits, to aid producers in deciding management interventions most suitable for their enterprise. Additional interventions, including the use of mixed-species cropping, hard seeded annual legumes, total grazing pressure management and invasive native species control would also benefit from research in this environment. Given the distance and variability in land types across NSW rangelands, establishment of more on-farm demonstration sites of different practices would also aid in increasing producer knowledge and adoption.
- Controlling the intensity, timing, frequency and duration of grazing is the most important tool livestock producers are able to use at a property scale to achieve change in landscape condition. While this project quantified the effects of grazing management on ground cover, further

research is required to understand effects on other environmental and production variables in different rangeland systems, including plant diversity, soil carbon, carrying capacity and landscape function. Research to provide more specific guidance as to best practice grazing management to achieve environmental and productivity outcomes in rangeland grazing systems is also required, for example on specific cues or trigger points of when to destock, or optimum timing of graze and rest periods.

3. Understanding how climate change affects rangeland grazing businesses and natural capital, and how practices that regenerate land can aid in adapting and mitigating impacts

- With increasing pressure to account for, reduce and offset GHG emissions across all sectors, greater reporting and accuracy of accounting for carbon, methane and nitrous oxide cycles and emissions in rangeland grazing systems is required.
- Evaluating the effects of future climate change, and the effects of practices that regenerate landscapes under different climate scenarios would increase producer confidence and uptake of sustainable and regenerative management practices.

4. Linking the impact and benefit of management practices to economic drivers and markets

- In order to increase adoption of practices that achieve positive environmental and ecosystem outcomes, linking changes observed with economic drivers and markets would aid in developing understanding of cost benefits and producers in decision making
- Development of rangeland specific natural capital accounting methods and incorporate rangeland specific metrics into existing frameworks to increase access and adoption of NCA in rangeland grazing systems.

5. Improve methodologies and techniques for rangeland monitoring, in particular leveraging use of remote sensing

- The Rangelands Living Skin project highlighted challenges and barriers to monitoring some environmental variables across variable, extensive grazing properties, in particular, soil organic carbon, plant biomass and biodiversity. Development of remote sensing technology and associated analysis and reporting platforms would enhance research outcomes and improve accuracy, frequency and access to monitoring data to inform management decisions,
- Technology such as GPS collars, virtual fencing and use of drone technology was not explored in the Rangelands Living Skin project however further work in development of these tools for application in rangeland monitoring and decision making would aid in achieving environmental, productivity and potential business outcomes.
- Successfully modelling and predicting soil organic carbon in the rangelands may benefit from revisiting known technologies such as mid-infrared spectroscopy where problematic carbonate content is better resolved.

6. Extension of key messages to improve adoption and capacity of sustainable management practices

- Collate and coordinate scientific information to communicate better stories to promote adoption of sustainable land management practices. In particular, greater education and support is required for topics around of grazing management, financial literacy and business management. Communication and extension material should be developed in a variety of accessible formats, with a focus on encouraging collaboration and information sharing between producers and their networks.

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8 Appendix

8.1 Fact sheet - Remote sensing for rangeland ground cover management

See Appendix 8.1 for published fact sheet on use of remote sensing for ground cover management in rangeland grazing systems

8.2 Abstracts accepted for presentation at the XII International Rangelands Congress, Adelaide 2025

8.2.1 Predicting Drought Using Remotely Sensed Vegetation Cover

J. F. Leys*, S. McDonald, G, Turnbull*****

* CSIRO, Black Mountain, Canberra, Australia
** New South Wales Department of Primary Industries, Australia
*** Department of Regional New South Wales Local Land Services Agency - Western, Bourke, Australia

ABSTRACT:

In Australia, more land degradation occurs during droughts when ground cover is low, and erosion levels are high. Predicting drought is a complicated task (McKeon *et al.* 2004). In New South Wales (NSW), Australia, drought is determined by several indicators, such as rainfall deficiencies, soil water, pasture growth, water availability, agricultural production, and community impact. Many of the above indicators influence total vegetation cover (denoted as cover), which includes photosynthetic and non-photosynthetic cover), as this parameter directly controls soil erosion, which influences onsite soil loss and off-site dust storms (Leys *et al.* 2023). Many studies in rangelands have reported that the impact of drought on soil erosion has been exacerbated by failing to destock before the drought (O'Reagain 2011).

This study uses a 22-year record (2001-2022) to investigate if cover can be used to predict the low cover levels that have occurred in previous droughts (denoted as drought) and defined as the 20th percentile monthly minimum summer cover) and determine a “trigger point”, i.e., the trigger month and the cover level that would trigger (trigger cover) destocking four to 6 months before a drought.

Twenty-four predominantly rangeland properties in western NSW were evaluated to determine the drought cover, trigger cover and trigger month. The drought cover ranged from 70% to 25%, The trigger cover ranged from 70% to 35%, and the trigger month ranged from June to August during the growing season. Over the 22 years, 22% of years were in drought. The method correctly predicted 70% of droughts, i.e. those years below the trigger cover had a drought the following summer. The method failed to predict drought in six percent of years. In four percent of years it predicted drought, but no drought occurred.

The study provides a new tool to help land managers prepare for drought.

8.2.2 Know your numbers: soil carbon sequestration has potential to support carbon neutral red meat and wool production in semi-arid rangelands

J.L. Rigg*, L. Newey *, B. Hackney*, S. Baldry*, S.E. McDonald and S.E. Orgill***

*Select Carbon, 275 George Street, Brisbane, QLD 4000, Australia**Trangie Agricultural Research Centre, NSW Department of Primary Industries, Trangie, NSW 2823, Australia.

ABSTRACT:

There is growing global pressure for agriculture, in particular red meat production, to reduce net greenhouse gas emissions. A greenhouse gas estimate (GHGe) is useful to benchmark and measure emissions and is useful to inform strategies to reduce or offset farm emissions. The average annual net farm emissions for two extensively grazed rangelands properties (Property A and B) in the semi-arid rangelands of southeastern Australia were calculated using the Primary Industries Climate Challenges Centre (PICCC) Greenhouse Gas Accounting Framework (GAF) tools over 5 years. Property A is 19,794 ha, has an average annual rainfall (AAR) of 390 mm and grazes cattle, sheep and goats for red meat production. Property B is 11,831 ha, has an AAR of 290 mm and grazes cattle and sheep for red meat and wool production. The average annual net farm emissions were 2,233 t CO_2-e/farm for Property A and 1,078 t CO_2-e/farm for Property B. As expected, in these low input systems, methane from livestock was the largest source of emissions for both enterprises.

Carbon neutrality within a farm business can be achieved when GHG emissions are balanced by carbon sequestered in soil and vegetation on farm. Soil is an important and large store of carbon in the landscape. In the rangelands, managed well, grazing animals are important tools to build soil organic matter, the first step in accumulating SOC. Using Property A as an example, our calculations demonstrate that even a conservative increase in SOC through grazing management could increase SOC concentration by 0.05 % (e.g. from 0.53 to 0.58 % SOC; 0 to 100 cm) over a 25-year period (one of two permanence periods under the Carbon Credits (Carbon Farming Initiative) Act 2011). Calculated at property scale, this equalled 18,497 t CO_2-e per year sequestered in soil which could offset the average annual emissions produced.

8.2.3 Soil carbon levels in NSW rangelands

K.O. Andersson*, S.E. McDonald, S.E. Orgill*****

* NSW Department of Primary Industries, Tamworth, NSW, 2340, Australia

** NSW Department of Primary Industries, Trangie, NSW, 2823, Australia
*** Select Carbon, 275 George St, Brisbane QLD 4000 Australia

ABSTRACT:

Soil organic matter (SOM) underpins soil health, providing among other properties a substrate for soil organisms, a source of nutrients for plants, and imparting physical stability. Soil organic carbon (SOC) concentration (%) is measured to estimate SOM levels, and with bulk density (BD) used to quantify SOC stock (t/ha).

Stocks of SOC were assessed on seven grazing properties in the NSW rangelands with average annual rainfall ranging from 190 mm to 370 mm. Sampling areas of ~100 ha on each property were delineated into strata according to landscape and soil type. In each area, 45 soil cores were extracted to a depth of 50 cm to 1.1 m. The SOC% and BD were estimated using modelling based on spectroscopy and laboratory measurements. Other than some likely inorganic carbonate at depth, there was little variation in both SOC concentration and stock down the profile at the lower rainfall sites; SOC% (±standard error) was typically between approximately 0.2±0.02% and 0.4±0.04% in the various strata. The soils from the higher rainfall areas displayed an accumulation of SOC concentration and stock near the soil surface as is typically seen due to near surface root growth and litter fall. The surface SOC% of the different strata on the Cobar Pediplain was generally between 0.65±0.03% and 0.85±0.05%, and on the alluvial soils 0.4±0.02% to 0.5±0.02%. Below 40 cm the SOC% at the higher rainfall sites was between 0.2±0.02% to 0.35±0.04%.

With the variability and relatively low levels of carbon stock measured in most of the strata, minimum increases of 12% would be required to be detected under the ACCU scheme, or 24% by standard scientific significance. Focussing on productivity and remediation of degraded sites is likely to yield more benefits than expecting sustained changes in soil carbon in the variable climatic conditions in the rangelands.

8.2.4 Using gypsum to ameliorate a scalded claypan with salinity close to seawater concentrations

K.O. Andersson*, S. Clarendon, G. Humbert***, J. Conder***, D. Schneider****, C. Strong*****, S.E. McDonald******

* NSW Department of Primary Industries, Tamworth, NSW, 2340, Australia

** Department of Primary Industries and Regional Development WA, 444 Albany Hwy, Albany, WA, 6330, Australia

*** Gurrawarra, West Culgoa Rd, Bourke, NSW, 2840, Australia

**** University of New England, Armidale, NSW, 2351, Australia

***** Australian National University, Acton, ACT, 2601, Australia

****** NSW Department of Primary Industries, Trangie, NSW, 2823, Australia

ABSTRACT:

Scalds are a common problem on red alluvial soils in the rangelands of western NSW. Plant growth and biological activity are restricted due to dispersive (sodic) sealing surfaces and high salinity. Sodic soils can be stabilised by the addition of gypsum. In the short term, dissolving gypsum allows clay particles to remain closer together, and in the medium to longer term decreases the tendency to disperse. As gypsum dissolves it can also leach but so too will less favourable chloride salts. This study examined the use of gypsum to remediate a scald in the Culgoa valley, north western NSW, that has lost topsoil, is sodic (ESP >10%), and has high salinity (ECe ~45 dS/m) through 60 cm. Mechanical disturbance (ripping with a single mouldboard plough) has previously been trialled on the scald but there has been only minimal establishment of halophytes with shallow roots and no survival. A replicated trial was established to examine the response of soil and pasture to four rates of gypsum: nil, 800 kg/ha (low), 2.5 t/ha (moderate), and 6.5 t/ha (high). The design will allow monitoring by Sentinel imagery. Photo observation points were also established.

After nearly 12 months the site has received 300 mm of rainfall. Despite site variability and some artefacts from the earlier disturbance (such as banking water) within treatments, indicative results to date show that the medium and higher rate treatments have improved infiltration (approximately 40 cm deeper), have had volunteer plants establish where there were nil, and have less topsoil salinity (~2 dS/m) under plant cover. Satellite imagery indicates significantly higher cover of green vegetation (NDVI) in the high gypsum treatments. While the timing of rainfall and any leaching will influence the effectiveness of the amelioration, the results so far show that extreme scalds can be ameliorated with appropriate techniques.

8.2.5 The Rangelands Living Skin project: lessons for co-designed, collaborative research in NSW rangelands

S.E. McDonald*, M. Plumbe, S.E. Orgill***, K.O Andersson******

* NSW Department of Primary Industries, Trangie, NSW, 2823, Australia
** Meat and Livestock Australia, Armidale, NSW, 2350, Australia

*** Select Carbon, 275 George St, Brisbane QLD 4000 Australia

**** NSW Department of Primary Industries, Tamworth, NSW, 2340, Australia

ABSTRACT:

The value of conducting research with multidisciplinary and inter-disciplinary teams, involving both researchers and practitioners to develop problem-orientated and solution-focussed research is well recognised. 'Rangelands Living Skin' was a five-year project linking farming families, scientists, education and extension agencies, commercial carbon companies and communications experts to evaluate cost-effective practices that focused on regenerating the NSW rangelands and supporting productive, profitable and sustainable businesses. In total, the project brought together 13 project partners, plus additional expert consultants. The project aimed to create an evidence-base and build capacity for widespread adoption of practices that benefit soil, plants, animals and people – the living skin of the rangelands.

Collaboration and co-design were at the core of the project, which took a farmer-centric approach. Producers from four grazing enterprises in western NSW were involved in all aspects of project design and delivery. An additional 25 producers were also signed up as 'observers', attending project events, collecting data across their own properties and creating a community of like-minded pastoralists in western NSW. Benefits of this approach included improving the breadth, robustness and relevance of the scientific research, bringing together diverse experience and perspectives, connecting stakeholders and increasing the project reach, producer engagement and participation. However, this approach was not without challenges, including increasing project complexity and scope creep, managing varying expectations of different partners, changing project priorities, staff turnover, maintaining engagement and balancing the need for scientific design and rigor with practicalities of producer priorities and the environmental context. This presentation provides a summary of the key findings and recommendations from the Rangeland Living Skin project in undertaking collaborative, co-designed research for successful producer engagement, industry collaboration and adoption of research outcomes in rangeland grazing systems.

8.2.6 Herd effect and deep ripping to restore claypans in western NSW rangelands

S.E. McDonald*, G. Finlayson, S.E. Orgill***, C. Strong****, K. Andersson*****

* NSW Department of Primary Industries, Trangie, NSW, 2823, Australia
** Bokhara Plains, Goodooga Rd, Brewarrina, NSW, 2839, Australia
*** Select Carbon, 275 George St, Brisbane QLD 4000 Australia

**** Australian National University, Acton, ACT, 2601, Australia

***** NSW Department of Primary Industries, Tamworth, NSW, 2340, Australia

ABSTRACT:

Historic soil degradation, primarily due to overgrazing and drought, has led to the widespread formation of bare, scalded ‘claypans’ throughout the rangelands of south-eastern Australia. These soils are often saline and dispersive, with sealed surfaces that constrain water infiltration and nutrient cycling. With no or little vegetation growth or cover, they are exposed to wind erosion and are unable to support livestock production, and despite conservative grazing management, many have failed to recover naturally. Mechanical interventions such as ripping and water ponding have been used to restore claypans over the last ~70 years, with varying success. Strategic management of livestock to restore degraded land has increasingly gained attention in recent decades as an alternative to resource-intensive mechanical restoration methods or complete destocking. This study compared the effects of intense cattle impact (600 cattle held overnight on <1ha of claypan + hay) with deep ripping (a single tine, to 30 cm depth with one meter row spacings) across three replicate claypans on ‘Bokhara Plains’ in the semi-arid rangelands of western NSW, Australia. Two years following the interventions, results show a significant increase in plant cover (up to 40%), biomass (up to 1 t/ha) and plant diversity for both the cattle and ripping treatments, compared to the control (initially 0% cover and 0 t/ha biomass). Differences between the cattle and ripping treatments were less obvious, with slightly greater ground cover and plant biomass in the ripping areas, and different plant composition. Across a longer time scale (>30 years), analysis of remote sensing data shows a significant improvement in ground cover across ‘Bokhara Plains’ as a result of improved grazing management, and restoration of > 700 ha of claypans through mechanical intervention and grazing management. These results demonstrate the effectiveness of targeted management to restore scalded areas and regenerate land condition in rangeland grazing systems.

8.2.7 Soil testing to support decision making in the rangelands

S.E. Orgill, K.O Andersson*, C. Strong*****

* Select Carbon, 275 George St, Brisbane QLD 4000 Australia

** NSW Department of Primary Industries, Tamworth, NSW, 2340, Australia

*** Australian National University, Acton, ACT, 2601, Australia

ABSTRACT:

Rangelands are not regions where soil testing is typically conducted due to the extensive and low input systems. However, soil function influences productivity and resilience. To assess the usefulness of quantifying soil properties, we benchmarked soil physicochemical properties with producers in the semi-arid rangelands of NSW.

In this study, producers from 33 properties selected soil sampling locations to compare productive potential on different soil types and landscape position. Field observations were taken to parameterise site condition (e.g. groundcover, relative productivity, water infiltration soil biological activity, and soil structure and stability). Soil samples were collected in 10 cm increments to 30 cm to characterise the upper rootzone. Laboratory tests included pH, salinity, exchangeable cations, sulphur, phosphorus (P), soil organic carbon (SOC) and total nitrogen.

There was generally increasing soil pH with depth on alluvial soils to alkaline levels. The pH of aeolian and bedrock-derived soils was evenly distributed from moderately acidic to moderately alkaline, though some areas were identified with acidity constraints. Soil salinity was generally low, but some targeted sites had salinity approaching sea water concentrations. Importantly, variability in salinity was sometimes observed within metres between bare ground and plant cover. Sodic soils were found in many areas. High salinity and sodicity limited SOC levels. Soil P was high in some areas, particularly the alkaline alluvial soils. However, some sites on bedrock-derived soils had P concentrations low enough to limit livestock productivity and reproduction, suggesting supplementation of P may be required.

Benchmarking soil properties proved a strategic tool for rangeland producers to identify constraints not previously quantified and assess management options. Some targeted ameliorants or supplements may lead to substantial returns on investment. Even in areas of no input, understanding the nature of constraints can help illustrate the importance of maintaining perenniality where conditions for plant establishment are unfavourable.

8.3 Journal publication

See Appendix 8.3

McDonald, S.E., Simmons, A.T., Harden, S., Orgill, S.E., Guerschman, J. and Strong, C., 2024. Managing grazing to increase ground cover in rangelands: using remote sensing to detect change. *The Rangeland Journal*, *46*(4).

8.4 Carbon account case studies

See Appendix 8.4.1, 8.4.2, 8.4.3, 8.4.4 for carbon account reports for each core producer property.

See Appendix 8.4.5 and 8.4.6 for carbon account case studies of Etiwanda and Wyndham stations

See Appendix 8.4.7 for summary of recommendations provided by Select Carbon for improving carbon accounting in NSW rangelands.

8.5 Observer monitoring protocol guide

See Appendix 8.5 for a copy of methodology for monitoring on observer properties

8.6 Natural capital framework

See Appendix 8.6 for the report ‘Assessing natural capital for rangelands livestock producers: a review’

8.7 10 year plan

See Appendix 8.7 for 10 year plan developed in collaboration with project partners

8.8 KASA survey results

See Appendix 8.8 for a copy of the baseline and end of project producer MER