Quantifying decreased hillslope erosion rates from grazing management of pastoral lands

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Key Points

- Existing approaches for application of the Universal Soil Loss Equation (USLE) to broadacre agriculture only allow the consideration of changed ground cover through herd management.
- We present an approach that extends previous work to also consider the role of woody vegetation canopy cover in hillslope erosion.
- Our approach can be used to quantify the potential change in hillslope erosion rates through land use changes such as revegetation, and not only herd management.

Abstract

Grazing management programs typically encourage herd management to reduce hillslope erosion rates through increased ground cover. Other land restoration activities applied to pastoral lands also provide similar outcomes yet are rarely considered in erosion models. To prioritise, plan and financially support good land stewardship through grazing management programs, it is important to quantify the relative hillslope erosion reduction of these actions reliably and consistently. We have developed a hillslope modelling framework that allows land managers to explore the benefits of a wider range of activities.

Keywords

Hillslope erosion, ground cover, land management, canopy structure, dynamic reference cover method

Introduction

The loss of soil through erosion is a major consideration for Australian agricultural productivity, with the fate of eroded soil also a concern for water quality (Lu et al., 2001). While sheet and rill erosion (or 'hillslope erosion') occurs naturally across most environments, the vast areas of Australia's rangelands that support pastoral activities (grazing) are often recognised as significant sources of hillslope erosion contributing to water quality hot spots of concern. For instance, approximately 75% of the observed fine sediment load entering the Great Barrier Reef lagoon has been estimated to be derived from areas supporting grazing activities (Wilkinson et al., 2014), with a significant proportion attributable to hillslope erosion processes (McCloskey et al., 2021). The use of remotely sensed data to apply the Revised Universal Soil Loss Equation (RUSLE, a derivative of the Universal Soil Loss Equation, USLE) offers land managers the ability to estimate recent/historic hillslope erosion rates in a consistent and comparative framework. Collating the necessary data layers to apply a representative RUSLE model to an area of interest is cumbersome, and unfamiliar to many land managers. However, once the layers have been curated and placed in a suitable calculation environment, applying a RUSLE model is inherently intuitive. This could help to prioritise, plan and financially support good land stewardship through grazing and land management programs.

Many studies have confirmed the relationship between (increased) ground cover and (reduced) hillslope erosion rates. Most applications of the RUSLE for estimating erosion rate reductions in Australia have relied upon this relationship, linking herd management with ground cover only. However, there are large scale tree planting (revegetation) programs planned and underway across previously grazed lands. We will present a method of data analysis that provides the framework for estimating realistic hillslope erosion rate reductions considering a variety of land management activities, including the potential role of increasing forest (height and canopy cover) within an area of interest, a relatively unexplored RUSLE concept in Australia. The analysis will be confined to Queensland for this paper.

Methods

This method uses the Universal Soil Loss Equation (USLE) concept (and its derivative equation, RUSLE) to estimate hillslope erosion rates at the farm, or property scale. RUSLE estimates A (eroded soil mass in tonnes per hectare per year) using numerous factors:

$$A = R * K * L * S * C * P \quad (1)$$

Where *R* Factor represents rainfall erosivity, *K* Factor represents soil erodibility, *S* Factor represents slope steepness, and *C* Factor provides a representation of the combined effect of land use, canopy and surface cover. With the focus of this analysis on estimating erosion rates across large areas of grazing land management, the *P* (supporting practice) Factor value will not be considered, having no effect on estimated hillslope erosion rates. Similarly, *L* (slope length) Factor will remain at a value of 1, as Digital Elevation Models of coarse resolution will be unable to identify (accurately) points of flow concentration on natural land surfaces (Rosewell ,1993).

We have developed *R*, *K* and *S* Factor layers for this study using publicly available data sources and contemporary techniques. Due to manuscript length limitations, the data sources and processing are not published here, so absolute estimates of hillslope erosion rates will not be reported. However, the linear nature of RUSLE allows for relative erosion rate changes to be reported with some confidence with perturbations applied to just one factor, *C* Factor.

Cover and Crop Management (C Factor)

As per Rosewell (1997), The *C* Factor is calculated as the product of subfactors for canopy cover and surface cover, although in areas identified as undisturbed forest, a single *C* Factor has been calculated. For undisturbed forest (recognised conservation areas supporting obvious woody vegetation), a relationship was developed using the data points in Rosewell (1993) table D-4, providing the formula:

$$C = (1.3 \text{ x } 10^{-6} * CanCov^2) - (2.6 \text{ x } 10^{-4} * CanCov) + 0.0136 \quad (2)$$

Where *C* is calculated *C* Factor for undisturbed forest land, and *CanCov* is canopy cover (%) of trees and undergrowth. *CanCov* is taken from Scarth et al. (2023) Total Plant Cover Fraction.

For all other locations, *C* Factor is calculated as the product of subfactors for canopy cover and surface cover:

$$C = CanFact * SurfFact \quad (3)$$

Where *C* is calculated *C* Factor, *CanFact* is the Canopy Factor, and *SurfFact* is the Surface Factor. For rangelands or scrub, Rosewell (1997) provides a relationship for predicting Canopy Factor:

$$CanFact = 1 - (CanCov / 100) * e^{(-0.328 * CanHei)} \quad (4)$$

Where *CanFact* is Canopy Factor, *CanCov* is canopy cover (%) from Scarth et al. (2023) Total Plant Cover Fraction, and *CanHei* is Canopy Height (metres) from Scarth et al. (2023) Height of Peak Plant Cover Density.

To provide Surface Factor in rangelands, Rosewell (1997) provides an often-used conversion from ground cover percentage, however it is important to consider conversion to 'visual cover' from objective cover in that relationship. The conversion of objective cover to visual cover, and the transformation to Surface Factor, has been simplified by the VegMachine suite of products (Beutel et al., 2019), as:

$$SurfFact = e^{-5.45 \text{ x } 10^{-4}} * SurfCov^{1.9} - 0.802962 \quad (5)$$

Where *SurfFact* is Surface Factor, and *SurfCov* is objective ground cover (%). Objective ground cover is sourced from the Seasonal Fractional Ground Cover product (Department of Environment and Science 2022). For this analysis, five objective ground cover data sets have been utilised, representing the Spring season (September – November) for the years 2013-2017 (inclusive).

Potential erosion rate through land management

Modifying apparent ground cover to represent improved grazing for RUSLE application is straightforward, allowing for analysis of a potential erosion rate under altered grazing conditions. Likewise, calculation of a modified Canopy Factor for RUSLE is possible to infer a potential erosion rate through other land restoration activities. However, providing the basis for reasonable modifications to ground and canopy cover requires further analysis. To provide an estimate of potential forest characteristics achievable through natural regeneration, we have combined the Vegetation Height and Structure data from Scarth et al. (2023) with the distribution of Remnant and Pre-Clearing Broad Vegetation Groups (BVG) in Queensland (Neldner et al., 2023), and IBRA bioregions version 7.0 (Department of Climate Change, Energy, the Environment and Water, 2020). To provide an estimate of achievable ground cover increase through grazing management we have analysed ground cover frequency distribution for inferred management/cover classes within IBRA bioregions version 7.0.

Potential forest characteristics achievable through natural regeneration

Intersecting Remnant BVGs with IBRA Bioregions provides a spatial framework for calculating canopy cover and height metrics from Scarth et al. (2023). Average values of Total Plant Cover Fraction and Height of Peak Plant Cover Density were calculated, with accompanying distribution frequency of canopy cover classes (1% increments) and height classes (0.5m increments) also produced. Intersecting Pre-Clearing BVGs with IBRA Bioregions provides a spatial framework to distribute the canopy cover and height metrics for representative natural forest characteristics throughout Queensland. To provide data layers of achievable canopy cover and height, the canopy cover value from the 80th percentile of the relevant Remnant BVG/IBRA combination has been used, while the mean value of canopy height has been used.

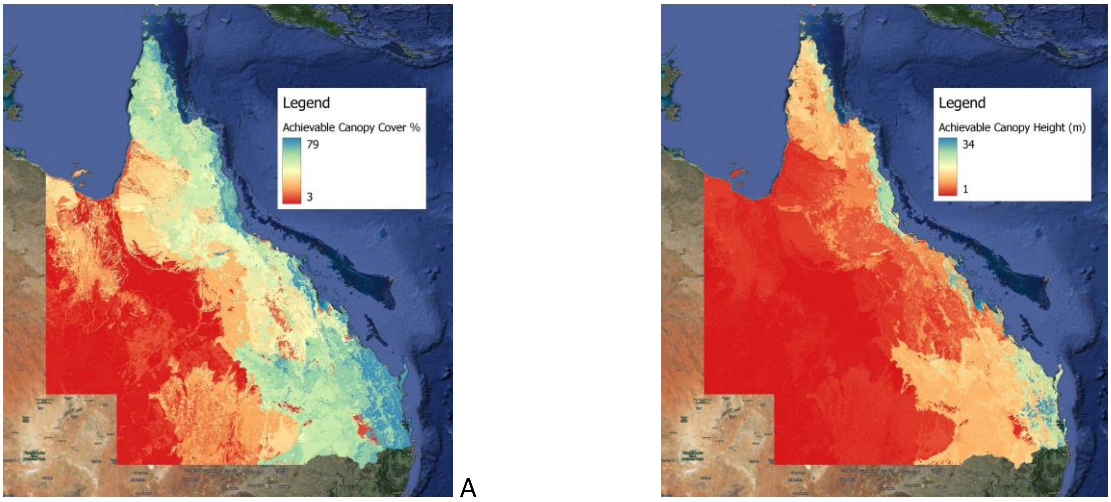


Figure 1. Distribution of assumed achievable canopy cover (A) and canopy height (B)

The achievable forest cover and height data layers are substituted into the calculation of *CanFact* (Canopy Factor, equation 4) for application of an improved RUSLE model for an area of interest. If existing forest cover or height exceeds the nominal achievable value, the existing data value is used.

Potential ground cover increases from grazing/herd management

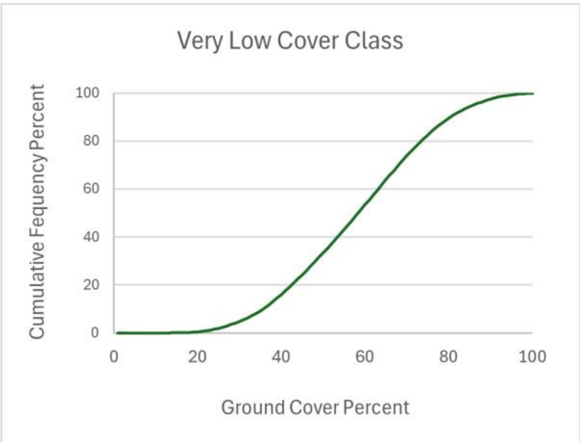
Acknowledging that no definitive data set exists that reliably depicts historical grazing management practices throughout Queensland, a surrogate spatial distribution of grazing management practice classes is needed to underpin the calculation of informative ground cover frequency distributions. The Dynamic Reference Cover Method (DRCM) (Bastin et al., 2012) can provide an estimate of satellite observed 'cover deficit' (compared to the average cover of temporally defined reference pixels over suitably broad areas). Performing the DRCM analysis using seasonal ground cover representing 2 periods responding to below-average rainfall, separated by at least 10 years, can provide an estimate of locations that have demonstrated different ground cover characteristics through time. Seasonal DRCM products for Queensland are provided by the Joint Remote Sensing Research Program & Department of Environment and Science, Queensland Government (2022). Using known farm features as a spatial basis, Wilkinson et al. (2014) performed a subtractive analysis of (property averaged) cover deficit values (using DRCM separated by more than a decade) to yield a 'Delta Delta' metric. The 'Delta Delta' metric was used to rank the probable herd management regimes applied throughout the analysis period. To fully exploit the range of DRCM values (approximately -100 to 100), and to exaggerate the extremes of both DRCM layers when combined, the analysis that we have applied instead uses an additive method of combining property average DRCM cover deficit ('Delta Delta Plus', or DD_{plus}):

$$DD_{plus} = CoverDeficit_{season1} + CoverDeficit_{season2} \quad (6)$$

Where $CoverDeficit_{season1}$ is September-November 2003 and $CoverDeficit_{season2}$ is September-November 2019.

The DD_{plus} metric has been averaged for identified rural properties using the 'Rural Properties – Queensland' service, built from the Queensland Digital Cadastral Database (State of Queensland, 2023). To enable ground cover frequency distribution analysis in a useful framework, the rural properties with averaged DD_{plus} values were intersected with IBRA Bioregions version 7.0. Within each IBRA Bioregion, intersected rural property features were ranked by descending DD_{plus} and ascending feature area, and sequentially assigned to a ground cover class zone. Assignment of ground cover class zones in this order assumes that properties with highest DD_{plus} values have experienced grazing/herd management that promotes the retention of higher ground cover over longer periods of time. Using historical estimates of grazing management distribution for the Great Barrier Reef Catchments as a guide, four classes of ground cover class zone were assigned to classes: High Cover (class A), Moderate Cover (class B), Low Cover (class C) and Very Low Cover (class D). With appropriate supporting data, the number of ground cover classes could be expanded for other purposes.

The ground cover class zone features now provide the spatial framework to derive ground cover frequency distributions (ground cover in 1% increments) for all cover classes in all IBRA Bioregions using the Seasonal Fractional Ground Cover product for Spring (September-November) of 2013-2017 inclusive. Figure 2 shows the ground cover frequency distributions for 2 ground cover class zones in a IBRA Bioregion.



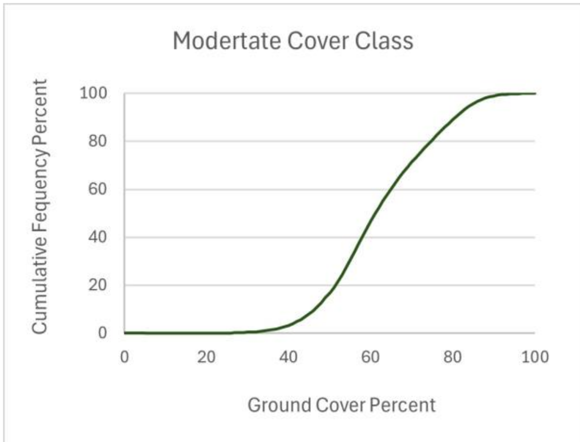


Figure 2. Ground cover frequency distribution examples for Very Low Cover (A) and Moderate Cover (B)

Using the ground cover frequency distribution data, each possible cover transformation (improvement only) can be related through log regression, taking the form:

$$ImprovedCover = Coeff1 * ln(ExistingCover) + Coeff2 \quad (7)$$

The ground cover class transformation relationships can now be projected throughout Queensland using the IBRA Bioregions as a framework. Figure 3 shows the ground cover class transformation relationships for the Desert Uplands Bioregion.

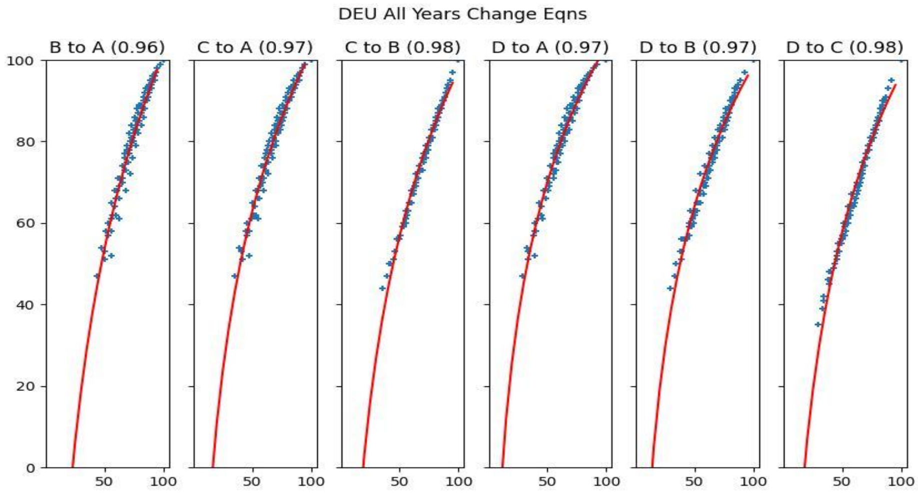


Figure 3. Ground cover class transformation relationships for the Desert Uplands Bioregions

Final erosion rate calculation

Using the potential forest and ground cover improvements provided by the described analyses, the *C Factor* layers can be easily recomputed for any grazing area in Queensland, with different combinations of grazing/herd management and other land management activities able to be investigated. For the purpose of demonstration, we have applied a variety of conceptual grazing and other land management improvements within the described framework to investigate the outcomes.

Results

Including canopy factor in recent/historical erosion estimation

Applications of RUSLE ignoring the effect of existing canopy features prevents the use of those models to consider the erosion reduction potential of forest growth through land management. Additionally, neglecting the influence of canopy structures on hillslope erosion rates could be inflating estimated erosion rates (and any associated reductions). Figure 4 shows that in some environments, including existing canopy structure in RUSLE models could reduce estimated hillslope erosion rates by 5-7%.

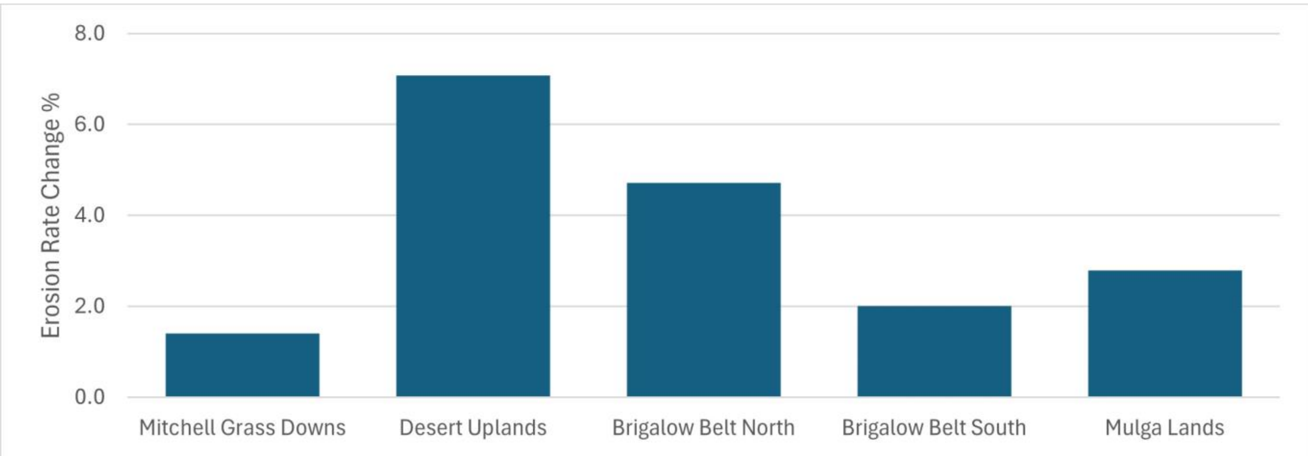


Figure 4. **Reductions (percent) in estimated hillslope erosion rates when canopy structures are considered**

The largest influence of canopy structures on hillslope erosion rates is observed in Bioregions where existing forest structures would be expected to provide effective cover and reduce drop fall, i.e. forests with a shrub/scrub form (Desert Uplands and, to a lesser extent, Bigalow Belt North). It is interesting to note that as observed canopy increases beyond about 5 or 6 metres, the relative influence of canopy cover (on hillslope erosion rates) decreases.

Representing canopy factor only in erosion rate reduction

Figure 5 depicts the potential for land management targeting only natural forest growth (i.e. no specific herd management) to reduce hillslope erosion rates. The reductions can be significant. The potential reductions for forests that are naturally dense and low to the ground, i.e. Mulga Lands, are evident here. Environments that are not expected to support significant forests show little potential.

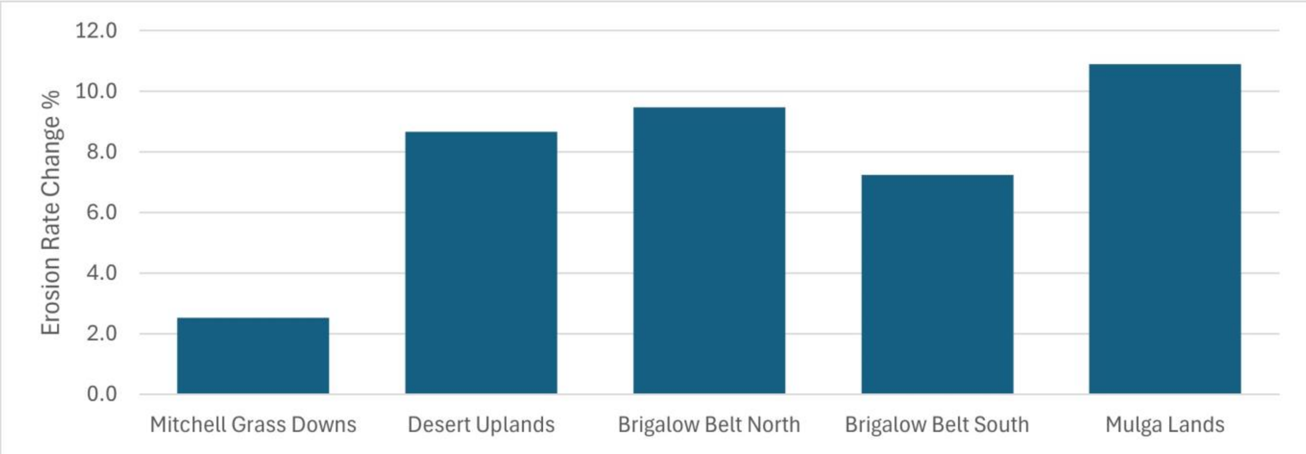


Figure 5. Reductions (percent) in estimated hillslope erosion rates when only canopy structures are considered (no change to surface/ground cover)

Representing surface/ground cover only in erosion rate reduction

The ground cover frequency distribution data, and subsequent cover class transformations, provide realistic potential groundcover increases (with associated decrease estimated hillslope erosion rate). Figure 6 shows how the estimated erosion rate changes significantly depending on the cover class transformation applied.

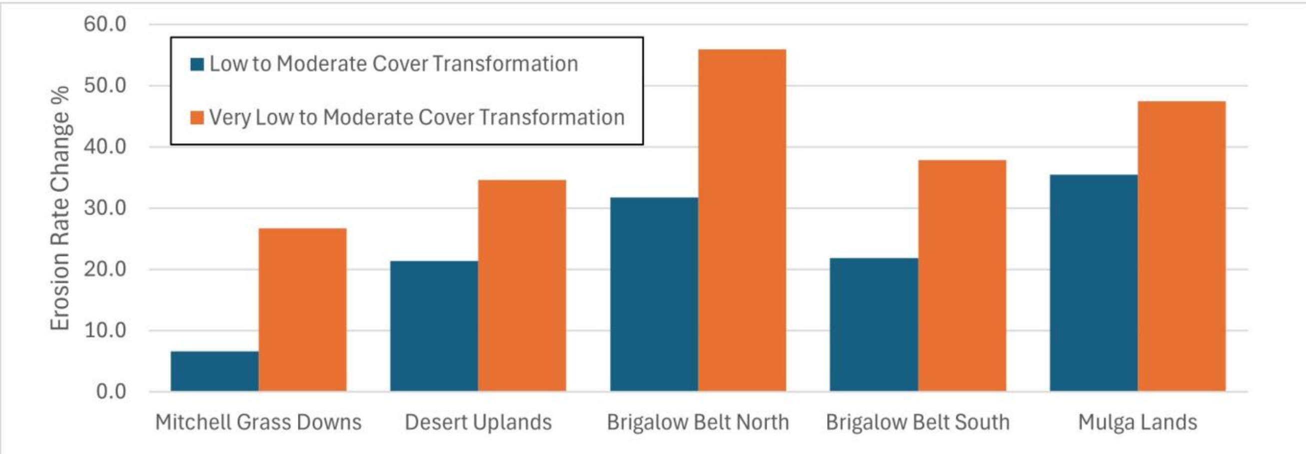


Figure 6. Reductions (percent) in estimated hillslope erosion rates when different cover class transformations are applied without considering canopy structures

Representing combined surface/ground cover and canopy structures in erosion rate reduction

Combining the effects of surface/ground cover improvements (from herd management) with an increase in canopy structures can demonstrate that there can be a larger erosion rate reduction than perhaps has been considered in many RUSLE applications to date. Figure 7 compares the erosion rate reductions when ground cover classes are assumed to transform from Low Cover to Moderate Cover, with and without the inclusion of an increase in canopy structures.

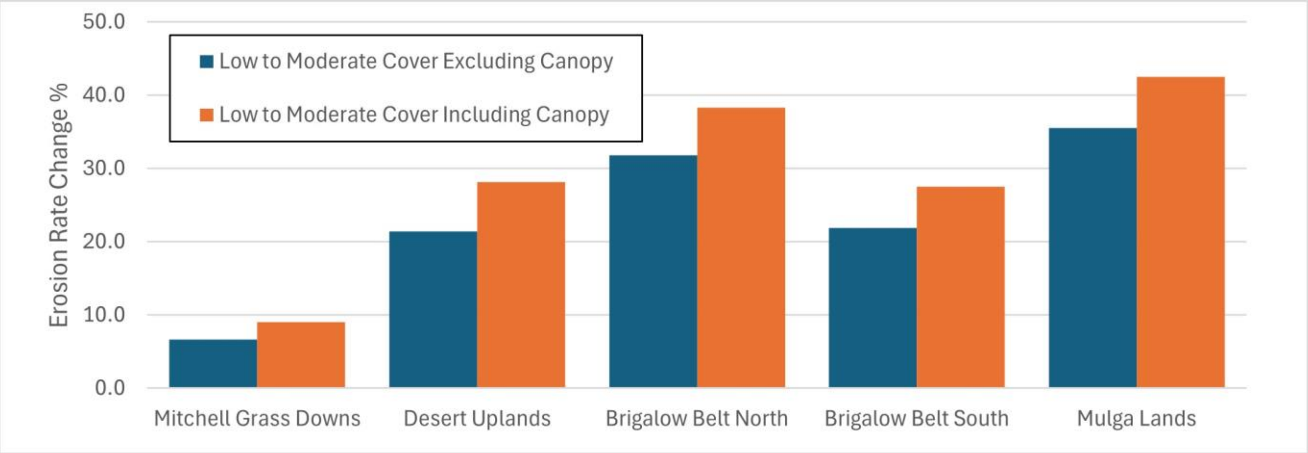


Figure 7. Reductions (percent) in estimated hillslope erosion rates when ground cover class transformations are applied, with and without considering canopy structures

Discussion

The application of altered canopy structures for investigating erosion rate reductions is oversimplified in this analysis. Most forests would take at least 15-20 years to achieve the canopy cover and height characteristics modelled in this analysis. Applying a growth rate function to the canopy structure modification is possible, however it would also require the prediction of erosion over a longer period of time than this analysis has considered. Nevertheless, this analysis has shown the potential for RUSLE to demonstrate a significant hillslope erosion reduction from activities other than explicit herd management. Additionally, consideration of existing canopy structures in estimating recent/historical rates of hillslope erosion could provide a better understanding of regional erosion processes to help inform land management programs.

The use of existing DRCM products to create ground cover classes has alleviated the need for land managers to perform this very intricate analysis themselves. Combined with an automated cover frequency distribution process and associated surface/ground cover class transformation analysis, realistic estimates of achievable erosion rate reductions can be applied to all grazing lands throughout Queensland. With equivalent seasonal DRCM products yet to be readily available, the potential for applying these techniques elsewhere in Australia could be limited.

This analysis has also exposed potential issues with the ground cover class zone analysis. The existing Rural Properties layer contains some very large features that dominate some IBRA Bioregions. The ranking of these features by 'Delta Delta Plus' and area has probably not provided a clear distinction for the ground cover class zones in these regions. Also, the 'Delta Delta Plus' values used have been based on seasonal DRCM representations from 2003 and 2019, whereas the ground cover frequency distributions used the period 2013-2017. Different selection of analysis periods might provide slightly different outcomes.

There is an ever-increasing body of data becoming available to support land management planning. Our analysis has shown that navigating the Big Data and Remote Sensing space to put farm scale modelling tools into the hands of land managers is a reality. Moreover, considering the erosion rate improvement of a wider range of activities, i.e. forest regrowth, presents this technique for wider adoption.

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