Effect of land use change and grazing land management on soil fertility and runoff water quality in the Fitzroy Basin

Summary report for the 2019 to 2021 hydrological years

Queensland Government

Prepared by: Department of Environment and Science

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Contents

Abbreviations

DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus, also known as Filterable Reactive Phosphorus (FRP) and Orthophosphate (PO_4-P)
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
EMC	Event Mean Concentration
PN	Particulate Nitrogen, also known as Total Suspended Nitrogen (TSN)
PP	Particulate Phosphorus, also known as Total Suspended Phosphorus (TSP)
TDN	Total Dissolved Nitrogen
TDP	Total Dissolved Phosphorus
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids

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Summary

Ecosystem health of the Great Barrier Reef continues to decline as a result of anthropogenic pollutants. Waterhouse *et al.* (2012) analysed the relative risk of runoff pollutants from agricultural land uses and identified that the management of suspended sediment from grazing lands in the Burdekin and Fitzroy regions was the second highest priority. The loss of suspended sediments in runoff is also associated with the loss of particulate nitrogen and phosphorus, which after mineralisation processes can become bioavailable and present a similar risk to Great Barrier Reef health as dissolved inorganic nutrients (Waterhouse *et al.*, 2012).

The six priorities identified by Waterhouse *et al.* (2012) were the focus of the Reef 2050 Water Quality Improvement Plan 2017-2022 (The State of Queensland, 2018). Under this plan, a decade of research at the long-term Brigalow Catchment Study has been undertaken to address knowledge gaps on the effect of land use change and grazing land management on soil fertility and runoff water quality as part of the Fitzroy Grazing monitoring project.

The Brigalow Catchment Study is located within the Fitzroy Basin of central Queensland, Australia. Over the last 57 years, research from this study site has demonstrated impacts of land clearing, land use change and land management on hydrology, soil fertility and water quality (Thornton and Elledge, 2022) (Appendix 1.1). An integral component of this long-term study is the inclusion of a control treatment, more specifically, virgin brigalow woodland in its pre-European condition which allows anthropogenic change to be quantified separate to the effect of climate.

Although the main focus of the Fitzroy Grazing monitoring project is runoff water quality, it is important to also monitor surface soil fertility as the effective depth of interaction between rainfall, runoff and soil has been reported to 0.04 m of soil depth (Sharpley, 1985). Thornton and Shrestha (2021) reported surface soil fertility (0 to 0.1 m) from the Brigalow Catchment Study to capture land use change from brigalow woodland to either unfertilised cropping or a conservatively grazed pasture over a 32-year period (1981 to 2014) (Appendix 1.2). Similar studies were undertaken to a greater depth (0 to 0.4 m) focusing on carbon and nitrogen (Dalal *et al.*, 2021a; Dalal *et al.*, 2021b) (Appendices 1.3 and 1.4).

Hydrology and runoff water quality from these two agricultural systems was also quantified. For example, Elledge and Thornton (Unpublished) investigated the effect of leguminous pastures by comparing a grazed butterfly pea ley pasture following an extension period of cropping and a leucaena pasture to both the long-term conservatively grazed grass pasture and brigalow woodland over eight years (2010 to 2017) (Appendix 1.5).

Furthermore, Thornton and Elledge (2021) investigated the effect of grazing pressure on hydrology and runoff water quality by comparing a heavily grazed pasture with the long-term conservatively grazed pasture and brigalow woodland over 4 years (2015 to 2018) (Appendix 1.6). Results from the ongoing monitoring of these three catchments from 2019 to 2021 is provided in Appendix 2 (hydrology) and Appendix 3 (loads and event mean concentrations).

Observed data reported in the paper by Thornton and Elledge (2021) also supported modelling activities. For example, Tiwari *et al.* (2021) evaluated the suitability of the Revised Universal Soil Loss Equation (RUSLE) and the Modified Universal Soil Loss Equation (MUSLE) to estimate soil loss from the brigalow woodland, cropping and conservatively grazed pasture (Appendix 1.7). The Fitzroy Grazing monitoring project has a history of supporting modelling activities that underpin the Reef 2050 Water Quality Improvement Plan 2017-2022 (The State of Queensland, 2018), and the long-term collaboration between monitoring and modelling projects has supported both this plan and government policy.

Fitzroy Grazing monitoring project's contribution to the Reef 2050 Water Quality Improvement Plan 2017-2022

Modelling

The Fitzroy Grazing monitoring project, located at the long-term Brigalow Catchment Study, published six journal papers from 2019 to 2022, with a seventh paper that has been submitted to a journal and pending publication (Dalal *et al.*, 2021a; Dalal *et al.*, 2021b; Thornton and Elledge, 2021; Thornton and Shrestha, 2021; Tiwari *et al.*, 2021; Thornton and Elledge, 2022; Elledge and Thornton, Unpublished) (Appendices 1.1 to 1.7). The interaction of these journal papers is graphically presented in Appendix 1.8, which demonstrates the knowledge building approach used for Brigalow Catchment Study publications since 2007. While the seven recent publications present new knowledge on the effects of land clearing, land use change and land management on runoff water quality at the small catchment scale in the Brigalow Belt bioregion, data modelling frameworks allow for this knowledge to be applied to other locations that vary in space and time. This approach is a cornerstone of the Reef 2050 Water Quality Improvement Plan 2017-2022, which is the overarching source of key knowledge gaps targeted by the Fitzroy Grazing monitoring project (The State of Queensland, 2018).

The Reef 2050 Water Quality Improvement Plan 2017-2022 is supported by a robust monitoring and evaluation program known as the Paddock to Reef Integrated Monitoring, Modelling and Reporting program (Paddock to Reef program) (Carroll *et al.*, 2012). A key consideration for the Paddock to Reef program is the ability to assess progress towards achieving water quality targets at the end-of-catchment scale over relatively short timeframes (Waterhouse *et al.*, 2018). This was achieved by using a modelling framework supported by monitoring data that linked management action within reef catchments to water quality and ecological responses in receiving waters. The model framework ranges in scale from individual paddocks though to entire basins with real-world validation provided by numerous studies (Waterhouse *et al.*, 2018). The Fitzroy Grazing monitoring project was one of the paddock scale studies used to validate the effects of land management on water quality from the Fitzroy Basin. The following model outputs were supported by the seven recent journal papers:

1) Particulate nitrogen and phosphorous from <u>grazing</u> were estimated as a function of hillslope erosion within the Great Barrier Reef Dynamic SedNet (Dynamic SedNet) catchment model, which was built on the eWater Source modelling platform (Waterhouse *et al.*, 2018; McCloskey *et al.*, 2021b).
2) Dissolved inorganic nitrogen, dissolved organic nitrogen, and dissolved phosphorus from <u>grazing</u> were estimated using nutrient event mean concentration values and hydrology estimates within the Dynamic SedNet catchment model (Waterhouse *et al.*, 2018; McCloskey *et al.*, 2021b).
3) Loss of suspended solids from <u>grazing</u> was modelled using the Revised Universal Soil Loss Equation within the Dynamic SedNet catchment model (Waterhouse et al., 2018; McCloskey et al., 2021b, a).
4) Runoff water quality from <u>cropping</u> was modelled using HowLeaky to estimate sediment, particulate phosphorus, dissolved phosphorus, and herbicides (Waterhouse *et al.*, 2018; Ghahramani, 2021).

The Fitzroy Grazing monitoring project was used for the calibration and validation of the Dynamic SedNet catchment model, both to estimate erosion from grazed hillslopes and to validate remotely sensed ground cover inputs to the model (Dougall and McCloskey, 2017). New knowledge published by the Fitzroy Grazing monitoring project (Elledge and Thornton, 2017; Thornton and Elledge, 2021, 2022) was used to calibrate and validate Dynamic SedNet estimates of both erosion and nutrient loss (McCloskey *et al.*, 2021b, a). Data in recent journal papers published by the Fitzroy Grazing monitoring project (Elledge and Thornton, 2017; Thornton and Elledge, 2021, 2022; Elledge and Thornton, Unpublished) were also used to validate Dynamic SedNet outputs to facilitate the next iteration of model improvement for the Paddock to Reef program, similar to previous iterative model improvements (McCloskey *et al.*, 2017b, a). This is in addition to annual validation of modelling outputs against monitoring data, which also utilises the new knowledge presented in the seven journal papers (Australian and Queensland governments, 2020). This continuous improvement approach acknowledges the feedback loop between identified gaps in knowledge required for modelling and targeted research activities of paddock monitoring studies (McCloskey *et al.*, 2021b, a). The incorporation of research findings into model improvement highlights the value of both the Fitzroy Grazing monitoring project and the long-term Brigalow Catchment Study.

The Brigalow Catchment Study had a long association with the design, calibration, and validation of the HowLeaky model well before the commencement of the Reef 2050 Water Quality Improvement Plan 2017-2022. The HowLeaky model was based on the PERFECT water balance model (Littleboy *et al.*, 1989), which was extensively validated at the study site (Lawrence, 1990; Lawrence *et al.*, 1991; Littleboy *et al.*, 1992; Lawrence *et al.*, 1993). Data from this study site was also used to calibrate and validate the HowLeaky water balance sub-model and to design, calibrate and validate the phosphorus and pesticide sub-models (Thornton *et al.*, 2007; Robinson *et al.*, 2011; Shaw *et al.*, 2011). Within the Paddock to Reef program, new knowledge published by the Fitzroy Grazing monitoring project (Elledge and Thornton, 2017; Elledge and Thornton, Unpublished) has been used to model runoff, erosion, dissolved inorganic nitrogen and atrazine loss from cropping (Ghahramani *et al.*, 2020). It has been acknowledged that data from sites such as the Brigalow Catchment Study are critical to ensure accuracy and credibility, not only of HowLeaky, but of all paddock models within the Paddock to Reef program (Jakeman *et al.*, 2019).

Policy

The accumulation of scientific evidence alone will not ensure the survival of the Great Barrier Reef, or resolve any contemporary environmental issue, unless scientific knowledge is applied in policy and practice (Evans and Cvitanovic, 2018). This was recognised by the Reef 2050 Water Quality Improvement Plan 2017-2022, which aimed to apply the best available science and knowledge to support policy, programs and practical on-ground management to improve water quality outcomes (The State of Queensland, 2018). Knowledge acquired by the Fitzroy Grazing monitoring project has contributed to the development and validation of reef protection regulations, which are government policy to address land-based sources of water pollution flowing into the Great Barrier Reef (The State of Queensland, 2021a).

Under the Environmental Protection Act 1994, grazing and cropping in specific reef regions are considered environmentally relevant activities (The State of Queensland, 2021a). This means there are regulatory requirements for record keeping and minimum practice agricultural standards, which are termed reef protection regulations. Prior to the consultation regulatory impact statement (Office of the Great Barrier Reef, 2017, 2019), which was released for public consultation in 2017, knowledge acquired by the Fitzroy Grazing monitoring project (Elledge and Thornton, 2017; Thornton and Elledge, 2021, 2022; Elledge and Thornton, Unpublished) was used by the Queensland Government to assist in the development of the reef protection regulations.

In the first instance, this knowledge contributed to the development of the agricultural definitions and minimum practice agricultural standards for all industries covered under the regulations, and then it was used to develop minimum practice agricultural standards within specific industries. For example, a submission containing knowledge on runoff water quality (Elledge and Thornton, 2017; Thornton and Elledge, 2021, 2022; Elledge and Thornton, Unpublished) was used to guide the regulatory requirements for record keeping and the minimum practice agricultural standards for beef cattle grazing (The State of Queensland, 2021c). Another submission containing knowledge on soil fertility and runoff quality (Elledge and Thornton, 2017; Dalal *et al.*, 2021a; Dalal *et al.*, 2021b; Thornton and Shrestha, 2021; Elledge and Thornton, Unpublished) was used to inform the environmentally relevant activity standard for commercial cropping and horticulture in Great Barrier Reef catchments, in addition to the minimum practice agricultural standards for grains and horticulture (Office of the Great Barrier Reef, 2020; The State of Queensland, 2021b).

The effectiveness of these policy instruments was examined during the 2020 senate inquiry into the identification of leading practices in ensuring evidence-based regulation of farm practices that impact water quality outcomes in the Great Barrier Reef (Commonwealth of Australia, 2020). Knowledge acquired by the Fitzroy Grazing monitoring project that assisted in the development of reef protection regulations was presented to the senate inquiry in both written submissions (Independent Science Panel, 2020; Morris, 2020) and verbally by witnesses during public hearings (Commonwealth of Australia, 2020). The tabling of knowledge generated by the Fitzroy Grazing monitoring project as evidence to a senate inquiry clearly demonstrates that this research has provided a substantial and original contribution to knowledge.

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Appendix 1: Publications

Journal papers

Seven journal papers that used Brigalow Catchment Study data were published during the funded period (Appendices 1.1 to 1.7), and their interactions to earlier papers from the project is shown in Appendix 1.8.

Appendix 1.1: Thornton and Elledge (2022)

Thornton, C.M., Elledge, A.E., 2022. Leichhardt, land clearing and livestock: The legacy of European agriculture in the Brigalow Belt bioregion of central Queensland, Australia. Animal Production Science 62, 913-925 [doi.org/10.1071/AN21468].

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ANIMAL PRODUCTION SCIENCE

Leichhardt, land clearing and livestock: the legacy of European agriculture in the Brigalow Belt bioregion of central Queensland, Australia

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ABSTRACT

Context. The Brigalow Belt bioregion of central Queensland has been extensively developed for agriculture since exploration by Leichhardt in 1844. About 4.5 million hectares of vegetation dominated by brigalow (*Acacia harpophylla*) was cleared as part of the Land Development Fitzroy Basin Scheme, which commenced in 1962. When the *Vegetation Management Act 1999* commenced, 93% of brigalow woodland had been cleared. Grazing is the dominant land use in the Fitzroy Basin, with 2.6 million cattle over 11.1 million hectares (72% of the catchment area). This is the largest cattle herd in any natural resource management region in Australia, accounting for 25% of the state herd and 11% of the national herd. **Aims.** The Fitzroy Basin, Queensland's largest coastal catchment, drains directly to the Great Barrier Reef, and as reef health continues to decline, there has been increased focus on the impacts of land-use change and grazing management on hydrology and runoff water quality. The Brigalow Catchment Study sought to determine the impact of land clearing, land-use change and land management on hydrology, soil fertility, water quality and animal production in the Fitzroy Basin. **Methods.** The study is a paired, calibrated catchment study. Catchment hydrology, soil fertility, water quality and agricultural productivity were monitored before and after land clearing and land-use change. **Key results.** The Brigalow Catchment Study has shown that clearing brigalow for grazing in the Fitzroy Basin doubled runoff, increased peak runoff rate by 50% and increased total suspended solid loads by 80%. Soil fertility and pasture productivity also declined under grazing compared with brigalow. Overgrazing exacerbated these results, as failure to reduce stocking rate with reduced pasture productivity more than tripled runoff, peak runoff rate and total suspended solid load compared with conservatively grazed pasture. **Conclusions.** This study demonstrates the impacts of land-use change and land management on hydrology, soil fertility and water quality. The long-term data records are a model in their own right, capable of answering land-use and land-management questions beyond the initial study scope. **Implications.** Sustainable grazing management should consider the production limitations of depleted soil and pasture resources to minimise land degradation.

Keywords: agricultural systems, buffel grass, dryland farming, grazing management, pesticides, rangelands, resource management, stocking rate.

Introduction

The Brigalow Belt bioregion of Queensland and New South Wales occupies 36.7 million hectares, stretching from Dubbo in the south to Townsville in the north (Fig. 1). Since European settlement, 58% of this bioregion has been cleared. Within Queensland, rates of land clearing were among the highest in the world, with estimates of 425 000–446 000 ha cleared per year (Wilson *et al.* 2002; Lindenmayer and Burgman 2005; Reside *et al.* 2017). More than 60% of this clearing, or ~261 000 ha/year, was undertaken in the Brigalow Belt (Wilson *et al.* 2002; Cogger *et al.* 2003). It is estimated that up to 93% of brigalow scrub has

Appendix 1.2: Thornton and Shrestha (2021)

Thornton, C.M., Shrestha, K., 2021. The Brigalow Catchment Study: V. Clearing and burning brigalow (*Acacia harpophylla*) in Queensland, Australia, temporarily increases surface soil fertility prior to nutrient decline under cropping or grazing. Soil Research 59, 146-169 [doi.org/10.1071/SR20088].

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The Brigalow Catchment Study: V*. Clearing and burning brigalow (*Acacia harpophylla*) in Queensland, Australia, temporarily increases surface soil fertility prior to nutrient decline under cropping or grazing

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Abstract. In the Brigalow Belt bioregion of Australia, clearing of brigalow (*Acacia harpophylla*) scrub vegetation for agriculture has altered nutrient cycling over millions of hectares. In order to quantify the effect of this vegetation clearing and land use change on soil fertility, the Brigalow Catchment Study commenced in 1965. Initial clearing and burning of brigalow scrub resulted in a temporary increase of mineral nitrogen, total and available phosphorus, total and exchangeable potassium and total sulfur in the surface soil (0–0.1 m) as a result of soil heating and the ash bed effect. Soil pH also increased, but did not peak immediately after burning. Soil fertility declined significantly over the subsequent 32 years. Under cropping, organic carbon declined by 46%, total nitrogen by 55%, total phosphorus by 29%, bicarbonate-extractable phosphorus by 54%, acid-extractable phosphorus by 59%, total sulfur by 49%, total potassium by 9% and exchangeable potassium by 63% from post-burn, pre-cropping concentrations. Fertility also declined under grazing but in a different pattern to that observed under cropping. Organic carbon showed clear fluctuation but it was not until the natural variation in soil fertility over time was separated from the anthropogenic effects of land use change that a significant decline was observed. Total nitrogen declined by 22%. Total phosphorus declined by 14%, equating to only half of the decline under cropping. Bicarbonate-extractable phosphorus declined by 64% and acid-extractable phosphorus by 66%; both greater than the decline observed under cropping. Total sulfur declined by 23%; less than half of the decline under cropping. A similar decline in total potassium was observed under both land uses, with a 10% decline under grazing. Exchangeable potassium declined by 59%. The primary mechanism of nutrient loss depended on the specific land use and nutrient in question.

Keywords: catchment management, cropping systems, dryland agriculture, tree clearing.

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Introduction

Soil fertility decline, soil structural decline and erosion are all considered to be consequences of changing land use from virgin forest to cropping and grazing. Traditionally, nutrient cycling in undisturbed virgin ecological systems was considered a steady-state closed system, where soil nutrients are consumed by the growing plants and then released back to the soil via leaf litter, wood debris and roots (Moody 1998). In contrast, cropping and grazing systems disturb this cycle by removing nutrients in harvested products and animals (Radford *et al.* 2007), via increased surface runoff (Thornton *et al.* 2007; Elledge and Thornton 2017), increased leaching (Silburn *et al.* 2009) and increased gaseous losses from soil and animals (Huth *et al.* 2010; Dalal *et al.* 2013). Disturbance of nutrient cycles and increased losses of soil nutrients affect the viability and sustainability of farming systems. Increased nutrient loads lost to the environment impacts ecosystem health, resulting in substantial investment in harm minimisation and remediation programs worldwide (Carroll *et al.* 2012). Contemporary nutrient cycling research suggests that disturbance and nutrient loss on a local scale have ramifications on a global scale. This is demonstrated by feedback mechanisms between increasing temperature, increasing atmospheric carbon dioxide and nitrogen concentrations, and fluxes of soil organic matter as a result of concomitant change in soil carbon and nitrogen concentrations (Crowther *et al.* 2016; Tipping *et al.* 2017; Schulte-Uebbing and de Vries 2018).

In the Brigalow Belt bioregion of Australia, clearing of brigalow (*Acacia harpophylla*) scrub and land use change has substantially altered nutrient cycling over a large area. The bioregion occupies 36.7 million hectares of Queensland and New South Wales, stretching from Dubbo in the south to Townsville in the north of Australia. Since European settlement, 58% of this bioregion has been cleared. The

*Parts I, II and III, *Aust. J. Soil Res.* 45(7), 479–495; 496–511; 512–523. Part IV, *Soil Res.* 54(6), 749–759.

 www.publish.csiro.au/journals/sr

Appendix 1.3: Dalal *et al.* (2021a)

Dalal, R.C., Thornton, C.M., Allen, D.E., Kopittke, P.M., 2021. A study over 33 years shows that carbon and nitrogen stocks in a subtropical soil are increasing under native vegetation in a changing climate. Science of the Total Environment 772, 145019 [doi.org/10.1016/j.scitotenv.2021.145019].

Science of the Total Environment 772 (2021) 145019

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

A study over 33 years shows that carbon and nitrogen stocks in a subtropical soil are increasing under native vegetation in a changing climate

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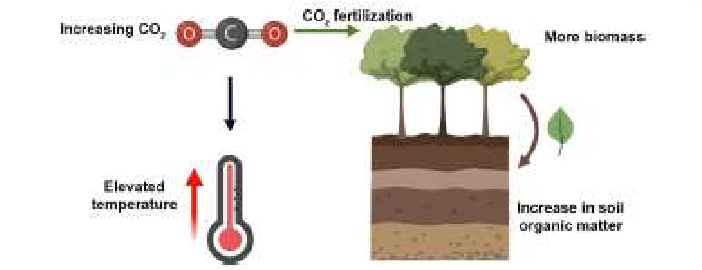
HIGHLIGHTS

- We measured SOC stocks in a subtropical soil at 0–0.3 m depths for 33 years.
- SOC stocks increased under native vegetation by 5.85 Mg C ha^{-1} over 33 years.
- Climate change actually increased SOC stocks in the clay Vertisol.
- It is likely that increases in CO_2 concentrations increased biomass productivity.
- Soil total nitrogen stocks increased by 0.57 Mg N ha^{-1} over 33 years.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil plays a critical role in the global carbon (C) cycle. However, climate change and associated factors, such as warming, precipitation change, elevated carbon dioxide (CO_2), and atmospheric nitrogen (N) deposition, will affect soil organic carbon (SOC) stocks markedly – a decrease in SOC stocks is predicted to drive further planetary warming, although whether changes in climate and associated factors (including atmospheric N deposition) will cause a net increase in SOC or a net decrease is less certain. Using a subtropical soil, we have directly examined how changes over the last three decades are already impacting upon SOC stocks and soil total nitrogen (STN) in a Vertisol supporting native brigalow (*Acacia harpophylla* L.) vegetation. It was observed that SOC stocks increased under native vegetation by 5.85 Mg C ha^{-1} (0.177 ± 0.059 Mg C ha^{-1} y^{-1}) at a depth of 0–0.3 m over 33 years. This net increase in SOC stocks was not correlated with change in precipitation, which did not change during the study period. Net SOC stocks, however, were correlated with an increasing trend in mean annual temperatures, with an average increase of 0.89 °C. This occurred despite a likely co-occurrence of increased decomposition due to higher temperatures, presumably because the increase in the SOC was largely in the stable, mineral-associated fraction. The increases in CO_2 from 338 ppm, to 395 ppm, likely contributed to an increase in biomass, especially root biomass, resulting in the net increase in SOC stocks. Furthermore, STN stocks increased by 0.57 Mg N ha^{-1} (0.0174 ± 0.0041 Mg N ha^{-1} y^{-1}) at 0–0.3 m depth, due to increased atmospheric N deposition and potential N_2 fixation. Since SOC losses are often predicted in many regions due to global warming, these observations are relevant for sustainability of SOC stocks for productivity and climate models in semi-arid subtropical regions.

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0048-9697/

Appendix 1.4: Dalal *et al.* (2021b)

Dalal, R.C., Thornton, C.M., Allen, D.E., Owen, J.S., Kopittke, P.M., 2021. Long-term land use change in Australia from native forest decreases all fractions of soil organic carbon, including resistant organic carbon, for cropping but not sown pasture. Agriculture, Ecosystems and Environment 311, 1-11 [doi.org/10.1016/j.agee.2021.107326].

Agriculture, Ecosystems and Environment 311 (2021) 107326

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Long-term land use change in Australia from native forest decreases all fractions of soil organic carbon, including resistant organic carbon, for cropping but not sown pasture

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ARTICLE INFO

Keywords:
Soil organic carbon
Soil nitrogen
^{13}C
^{15}N
C_4pasture
C_3 forest
C turnover

ABSTRACT

Soil organic matter (SOM) performs an essential function in soil fertility, biomass and crop productivity, environmental sustainability, and climate change mitigation. We examined how land use change from native forest to either pasture [sown buffel (*Cenchrus ciliaris* cv. Biloela)] or cropping [primarily wheat (*Triticum aestivum* L.) and sorghum (*Sorghum bicolor* L.)] affected total soil organic C (SOC) stocks as well as stocks of three SOC fractions, particulate organic C, humus organic C and resistant organic C. Furthermore, for the cropping system, we also examined whether the use of a ley pasture phase could reverse the loss of SOC. It was found that land use change from native forest to pasture decreased SOC stocks by 12.2 % and soil total N (STN) stocks by 24.6 % during the land development to pasture establishment ($\leq$ 1.75 y), although there were no significant ($P > 0.05$) changes thereafter up to 33 y and final values were generally similar to initial values. Furthermore, stocks of the three SOC fractions did not change with time in this pasture system. In contrast to these modest changes following conversion to pasture, for land use change to cropping, SOC decreased by 48 % at 0–0.1 m and 38 % (from 54 to 33 Mg ha^{-1}) at 0–0.3 m, due mainly to insufficient C inputs to maintain SOM at steady state. Moreover, stocks of all three SOC fractions decreased with time, including the resistant organic C fraction, indicating that this fraction was not recalcitrant under cropping. The biomass C inputs by crops, mainly as root biomass, were not sufficient to reverse or slow down the rate of decrease of SOC in this soil. However, the introduction of pasture during the last 4 y indicated that the decreases in the stocks of SOC could be arrested by a ley pasture phase.

1. Introduction

Organic C and N are the integral components of soil organic matter (SOM), which is essential for agricultural sustainability, terrestrial environmental stability, and provides a long-term terrestrial C sink (Chenu et al., 2019). However, changes in land use can markedly alter stocks of soil organic C (SOC), with the magnitude of this change depending upon a broad range of factors, including the nature of the final land use. Firstly, consider a change in land use from native forest to introduced pasture, with this generally shown to cause only a comparatively modest change in SOC stocks. A global meta-analysis found a median decrease in SOC stocks of 11.3 % (Kopittke et al., 2017), with a similar value also reported in the meta-analysis of Don et al. (2011). Indeed, a change in land use to pasture can potentially increase, decrease or cause no change in SOC stocks (Murty et al., 2002; Kopittke et al., 2017), depending upon many factors, including soil type (Schipper et al., 2010). For example, Harms et al. (2005) studied the effect of land use change from native vegetation to pasture at 32 paired-sites in southern and central Queensland, Australia. Although SOC stocks decreased by approximately 7% across all sites, significant ($P < 0.05$) decreases in SOC stocks were found mostly in coarse-textured soils but not finer-textured soils.

In contrast to a change in land use to pasture, land use change from native vegetation to arable cropping generally leads to much larger losses of SOC and soil total N (STN). In the meta-analysis of Kopittke et al. (2017), the median decrease in SOC stocks upon conversion of land

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Appendix 1.5: Elledge and Thornton (Unpublished)

Elledge, A.E., Thornton, C.M., Unpublished. Hydrology and runoff water quality from three improved pastures compared to virgin brigalow (*Acacia harpophylla*) woodland over eight years in semi-arid Australia. The Rangeland Journal. Submitted to The Rangeland Journal in July 2022.

THE RANGELAND JOURNAL

Hydrology and runoff water quality from three improved pastures compared to virgin brigalow (Acacia harpophylla) woodland over eight years in semi-arid Australia

Journal:	*The Rangeland Journal*
Manuscript ID	RJ22042
Manuscript Type:	Research paper
Date Submitted by the Author:	20-Jul-2022
Complete List of Authors:	Elledge, Amanda; Department of Environment and Science Thornton, Craig; Department of Environment and Science
Keyword:	Acacia spp., Buffel grass, Grazing management, Legumes, Semiarid rangelands, Water resources

Appendix 1.6: Thornton and Elledge (2021)

Thornton, C.M., Elledge, A.E., 2021. Heavy grazing of buffel grass pasture in the Brigalow Belt bioregion of Queensland, Australia, more than tripled runoff and exports of total suspended solids compared to conservative grazing. Marine Pollution Bulletin 171, 112704 [doi.org/10.1016/j.marpolbul.2021.112704].

Marine Pollution Bulletin 171 (2021) 112704

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Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Heavy grazing of buffel grass pasture in the Brigalow Belt bioregion of Queensland, Australia, more than tripled runoff and exports of total suspended solids compared to conservative grazing

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ARTICLE INFO

Keywords:
Beef cattle
Brigalow Catchment Study
Ground cover
Land clearing
Land use change
VegMachine

ABSTRACT

Loss of sediment and particulate nutrients in runoff from the extensive grazing lands of the Fitzroy Basin, central Queensland, continue to contribute to the declining health of the Great Barrier Reef. This study measured differences in hydrology and water quality from conservative and heavy grazing pressures on rundown improved grass pastures in the Fitzroy Basin. Conservative grazing pressure was defined as the safe long-term carrying capacity for rundown buffel grass pasture, whereas heavy grazing pressure was defined as the recommended stocking rate for newly established buffel grass pasture. Heavy grazing of rundown pasture resulted in 2.5 times more bare ground and only 8% of the pasture biomass compared to conservative grazing. Heavy grazing also resulted in 3.6 times more total runoff and 3.3 times the peak runoff rate compared to conservative grazing. Loads of total suspended solids, nitrogen and phosphorus in runoff were also greater from heavy than conservative grazing.

1. Introduction

The Fitzroy Basin is Queensland's largest coastal catchment and is almost entirely contained within the Brigalow Belt bioregion of Australia. Both the basin and the wider bioregion have experienced some of the highest rates of land clearing in the world, with up to 93% of vegetation communities dominated by brigalow (*Acacia harpophylla*) cleared for agriculture since European settlement (Butler and Fairfax, 2003; Cogger et al., 2003; Tulloch et al., 2016). Grazing is the dominant land use in the Fitzroy Basin, with more than 2.6 million cattle over 11.1 Mha (Australian Bureau of Statistics, 2009; Meat and Livestock Australia, 2017a). This is the largest cattle herd in any natural resource management region in both Queensland and Australia, accounting for 25% of the state herd and 11% of the national herd (Meat and Livestock Australia, 2017a).

The 2017 Scientific Consensus Statement for Great Barrier Reef water quality identified the Fitzroy Basin as a high priority area for reducing fine sediment and particulate nutrients. This is due to their ongoing contribution to marine water quality decline and resultant damage to seagrass and coral reefs (Waterhouse et al., 2017). Increased adoption of best management practices for agriculture was identified as a key strategy to reduce sediment and nutrient loads in runoff. Within the Grazing Water Quality Risk Framework for 2017 to 2022, the lowest risk to water quality from hillslope pasture management is achieved by practices such as forage budgeting to determine carrying capacity, ground cover monitoring and the adoption of wet season spelling (The State of Queensland, 2020b). These practices are commonly recommended to maintain or improve ground cover (Jones et al., 2016; Moravek et al., 2017; O'Reagain et al., 2011), as high cover is known to reduce runoff, and hence also sediment and nutrients exported in runoff (Murphy et al., 2008; Nelson et al., 1996; Schwarte et al., 2011; Silburn et al., 2011). For example, light and heavy stocking rates were compared in the Burdekin Basin with 20 to 25% and 40 to 50% pasture utilisation, respectively (O'Reagain et al., 2008). A safe long-term carrying capacity is defined as the capacity of the pasture to sustainably carry livestock in the long-term whereas a safe pasture utilisation rate is defined as the proportion of annual forage growth that can be consumed by domestic livestock without adversely affecting land condition in the long-term (McKeon et al., 2009; Walsh and Cowley, 2011).

In below average rainfall years, the heavy stocking rate had less ground cover, a greater frequency and intensity of runoff, and higher sediment concentrations in runoff. However, there was little difference between the two stocking rates in high rainfall years due to high ground cover (O'Reagain et al., 2008). This reflects international literature from

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Appendix 1.7: Tiwari *et al.* (2021)

Tiwari, J., Thornton, C.M., Yu, B., 2021. The Brigalow Catchment Study: VI. Evaluation of the RUSLE and MUSLE models to assess the impact of clearing brigalow (*Acacia harpophylla*) on sediment yield. Soil Research 59, 778-793 [doi.org/10.1071/SR21030].

CSIRO PUBLISHING

RESEARCH PAPER
https://doi.org/10.1071/SR21030

SOIL RESEARCH

The Brigalow Catchment Study: VI.[†] Evaluation of the RUSLE and MUSLE models to assess the impact of clearing brigalow (*Acacia harpophylla*) on sediment yield

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Handling Editor:
Rosa Maria Poch

ABSTRACT

Land clearing for cropping and grazing has increased runoff and sediment yield in Central Queensland. The Brigalow Catchment Study (BCS), was established to determine the effect of land clearing on water balance, soils, and productivity, and consisted of three catchments: brigalow forest, cropping, and grazing. Factors responsible for changes in and models for predicting sediment yield have not been assessed. Objectives of this study are to identify climatic, hydrological, and ground cover factors responsible for the increased sediment yield and to assess suitable models for sediment yield prediction. Runoff and sediment yield data from 1988 to 2018 were used to assess the Revised Universal Soil Loss Equation (RUSLE) and the Modified USLE (MUSLE) to predict the sediment yield in brigalow catchments. Common events among the three catchments and events for all catchment pairs were assessed. The sediment yield was approximately 44% higher for cropping and 4% higher for grazing than that from the forested catchment. The runoff amount (Q) and peak runoff rate (Q_p) were major variables that could explain most of the increased sediment yield over time. A comparison for each catchment pair showed that sediment yield was 801 kg ha^{-1} or 37% higher for cropping and 28 kg ha^{-1} or 2% higher for grazing than for the forested catchment. Regression analysis for three different treatments (seven common events) and for different storm events (15 for forested, 40 for cropping, and 20 for grazing) showed that Q and Q_p were best correlated with sediment yield in comparison with variations in ground cover. The high coefficient of determination ($R^2 > 0.60$) provided support for using the MUSLE model, based on both Q and Q_p, instead of the RUSLE, and Q and Q_p were the most important factors for improving sediment yield predictions from BCS catchments.

Keywords: brigalow clearing, ground cover treatment, peak runoff rate, RUSLE and MUSLE, runoff, sediment yield, small dry catchments, storm events.

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Soil Research, **59**(8), 778–793.
doi:10.1071/SR21030

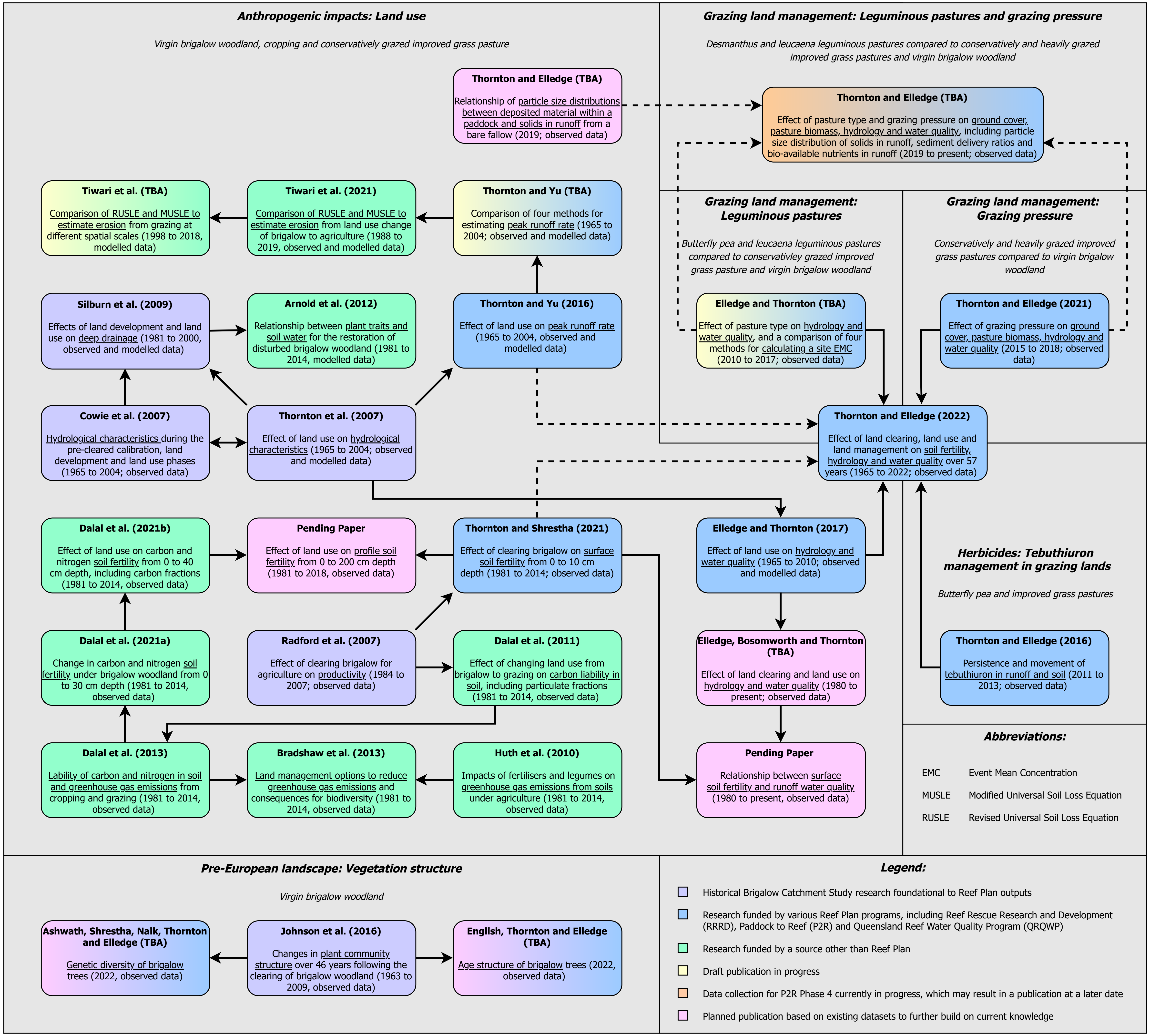
Introduction

Broad-scale clearing of native vegetation for agricultural systems, including grazing, has strongly affected hydrological processes and sediment yield in Australia and around the world (Siriwardena *et al.* 2006; Thornton *et al.* 2007; Ehigiator and Anyata 2011; Borrelli *et al.* 2017; Cheng and Yu 2019; Aghsaei *et al.* 2020). At the global level, soil erosion from the area of 125 million km^2 covering ~84.1% of Earth's land surface has increased by 2.5% (baseline of 35 Pg year^{-1}) due to spatial land use change occurring only in 3.3% of study area (Borrelli *et al.* 2017). In Australia, according to the Scientific Consensus Statement (Bartley *et al.* 2017), a three- and eight-fold increase in the total sediment yield has occurred across the Great Barrier Reef (GBR) catchments, depending on the region, of which approximately 80% could be attributed to changes in land

[†]Parts I–III, *Australian Journal of Soil Research* 45(7), 479–495, 496–511 and 512–523. Part IV, *Soil Research* 54(6), 749–759. Part V, *Soil Research* 59(2), 146–169.

Appendix 1.8: Conceptual model of journal paper linkages

Conceptual model of journal papers published by the Brigalow Catchment Study project from 2007 to 2022, which shows the knowledge building approach used and their interactions.


Anthropogenic impacts: Land use
Virgin brigalow woodland, cropping and conservatively grazed improved grass pasture
Thornton and Elledge (TBA)
Relationship of particle size distributions between deposited material within a paddock and solids in runoff from a bare fallow (2019; observed data)
Grazing land management: Leguminous pastures and grazing pressure
Desmanthus and leucaena leguminous pastures compared to conservatively and heavily grazed improved grass pastures and virgin brigalow woodland
Thornton and Elledge (TBA)
Effect of pasture type and grazing pressure on ground cover, pasture biomass, hydrology and water quality, including particle size distribution of solids in runoff, sediment delivery ratios and bio-available nutrients in runoff (2019 to present; observed data)
Tiwari et al. (TBA)
Comparison of RUSLE and MUSLE to estimate erosion from grazing at different spatial scales (1998 to 2018, modelled data)
Tiwari et al. (2021)
Comparison of RUSLE and MUSLE to estimate erosion from land use change of brigalow to agriculture (1988 to 2019, observed and modelled data)
Thornton and Yu (TBA)
Comparison of four methods for estimating peak runoff rate (1965 to 2004; observed and modelled data)
Grazing land management: Leguminous pastures
Butterfly pea and leucaena leguminous pastures compared to conservativley grazed improved grass pasture and virgin brigalow woodland
Grazing land management: Grazing pressure
Conservatively and heavily grazed improved grass pastures compared to virgin brigalow woodland
Silburn et al. (2009)
Effects of land development and land use on deep drainage (1981 to 2000, observed and modelled data)
Arnold et al. (2012)
Relationship between plant traits and soil water for the restoration of disturbed brigalow woodland (1981 to 2014, modelled data)
Thornton and Yu (2016)
Effect of land use on peak runoff rate (1965 to 2004, observed and modelled data)
Elledge and Thornton (TBA)
Effect of pasture type on hydrology and water quality, and a comparison of four methods for calculating a site EMC (2010 to 2017; observed data)
Thornton and Elledge (2021)
Effect of grazing pressure on ground cover, pasture biomass, hydrology and water quality (2015 to 2018; observed data)
Cowie et al. (2007)
Hydrological characteristics during the pre-cleared calibration, land development and land use phases (1965 to 2004; observed data)
Thornton et al. (2007)
Effect of land use on hydrological characteristics (1965 to 2004; observed and modelled data)
Thornton and Elledge (2022)
Effect of land clearing, land use and land management on soil fertility, hydrology and water quality over 57 years (1965 to 2022; observed data)
Dalal et al. (2021b)
Effect of land use on carbon and nitrogen soil fertility from 0 to 40 cm depth, including carbon fractions (1981 to 2014, observed data)
Pending Paper
Effect of land use on profile soil fertility from 0 to 200 cm depth (1981 to 2018, observed data)
Thornton and Shrestha (2021)
Effect of clearing brigalow on surface soil fertility from 0 to 10 cm depth (1981 to 2014; observed data)
Elledge and Thornton (2017)
Effect of land use on hydrology and water quality (1965 to 2010; observed and modelled data)
Herbicides: Tebuthiuron management in grazing lands
Butterfly pea and improved grass pastures
Dalal et al. (2021a)
Change in carbon and nitrogen soil fertility under brigalow woodland from 0 to 30 cm depth (1981 to 2014, observed data)
Radford et al. (2007)
Effect of clearing brigalow for agriculture on productivity (1984 to 2007; observed data)
Dalal et al. (2011)
Effect of changing land use from brigalow to grazing on carbon liability in soil, including particulate fractions (1981 to 2014, observed data)
Elledge, Bosomworth and Thornton (TBA)
Effect of land clearing and land use on hydrology and water quality (1980 to present; observed data)
Thornton and Elledge (2016)
Persistence and movement of tebuthiuron in runoff and soil (2011 to 2013; observed data)
Dalal et al. (2013)
Lability of carbon and nitrogen in soil and greenhouse gas emissions from cropping and grazing (1981 to 2014, observed data)
Bradshaw et al. (2013)
Land management options to reduce greenhouse gas emissions and consequences for biodiversity (1981 to 2014, observed data)
Huth et al. (2010)
Impacts of fertilisers and legumes on greenhouse gas emissions from soils under agriculture (1981 to 2014, observed data)
Pending Paper
Relationship between surface soil fertility and runoff water quality (1980 to present, observed data)
Abbreviations:
EMC Event Mean Concentration
MUSLE Modified Universal Soil Loss Equation
RUSLE Revised Universal Soil Loss Equation
Pre-European landscape: Vegetation structure
Virgin brigalow woodland
Ashwath, Shrestha, Naik, Thornton and Elledge (TBA)
Genetic diversity of brigalow trees (2022, observed data)
Johnson et al. (2016)
Changes in plant community structure over 46 years following the clearing of brigalow woodland (1963 to 2009, observed data)
English, Thornton and Elledge (TBA)
Age structure of brigalow trees (2022, observed data)
Legend:
Historical Brigalow Catchment Study research foundational to Reef Plan outputs
Research funded by various Reef Plan programs, including Reef Rescue Research and Development (RRRD), Paddock to Reef (P2R) and Queensland Reef Water Quality Program (QRWQP)
Research funded by a source other than Reef Plan
Draft publication in progress
Data collection for P2R Phase 4 currently in progress, which may result in a publication at a later date
Planned publication based on existing datasets to further build on current knowledge

References for the conceptual model:

Arnold, S., Thornton, C., Baumgartl, T., 2012. Ecohydrological feedback as a land restoration tool in the semi-arid Brigalow Belt, QLD, Australia. Agriculture, Ecosystems and Environment 163, 61-71.

Bradshaw, C.J.A., Bowman, D.M.J.S., Bond, N.R., Murphy, B.P., Moore, A.D., Fordham, D.A., Thackway, R., Lawes, M.J., McCallum, H., Gregory, S.D., Dalal, R.C., Boer, M.M., Lynch, A.J.J., Bradstock, R.A., Brook, B.W., Henry, B.K., Hunt, L.P., Fisher, D.O., Hunter, D., Johnson, C.N., Keith, D.A., Lefroy, E.C., Penman, T.D., Meyer, W.S., Thomson, J.R., Thornton, C.M., VanDerWal, J., Williams, R.J., Keniger, L., Specht, A., 2013. Brave new green world: Consequences of a carbon economy for the conservation of Australian biodiversity. Biological Conservation 161, 71-90.

Cowie, B.A., Thornton, C.M., Radford, B.J., 2007. The Brigalow Catchment Study: I. Overview of a 40-year study of the effects of land clearing in the brigalow bioregion of Australia. Australian Journal of Soil Research 45, 479-495.

Dalal, R.C., Cowie, B.A., Allen, D.E., Yo, S.A., 2011. Assessing carbon lability of particulate organic matter from δ13C changes following land-use change from C3 native vegetation to C4 pasture. Soil Research 49, 98-103.

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Technical reports

One technical report that used Brigalow Catchment Study data was published during the funded period:

(1) Landsberg, L., Cox, H., Nothard, B., Thornton, C., Moravek, T., 2020. Gross margin analysis of grain cropping at the Brigalow Catchment Study with APSIM simulations to evaluate the effect of nitrogen fertiliser application. State of Queensland, Queensland [www.publications.qld.gov.au/dataset/grains-economics/resource/a64f2262-8767-4b51-9f5d-29b48934e1a0].

Presentations

Three seminars that used Brigalow Catchment Study data were presented during the funded period:

(1) Thornton C.M. and Elledge A.E. (2021). Clearing and burning brigalow increases soil fertility prior to nutrient decline under cropping or grazing. *Joint Soil Science Australia and the New Zealand Society of Soil Science Conference: Soils, investing in our future.* Cairns, Australia.

(2) Thornton C.M. and Elledge A.E. (2022). Leichhardt, land clearing and livestock: The legacy of European agriculture in the Brigalow Belt bioregion of central Queensland, Australia. *34th Australian Association of Animal Sciences Conference: Anchoring knowledge, exploring animal science ecosystems.* Cairns, Australia. Craig was an invited keynote speaker to deliver the McClymont Lecture, which pays tribute to the contributions of eminent Australian animal scientists.

(3) Thornton C.M. and Elledge A.E. (2022). What are the impacts of land use change on soil fertility in the Fitzroy Basin? Lessons from both long-term and broad scale monitoring. *Fitzroy Basin Association's CQ2022 Big Data Forum*. Rockhampton, Australia

Field tours

Three field tours of the Brigalow Catchment Study were conducted during the funded period:

(1) Paddock to Reef scientists from the Department of Environment and Science (formerly the Department of Resources) visited the Brigalow Catchment Study as part of their paddock monitoring team meeting in Rockhampton (August 2019).

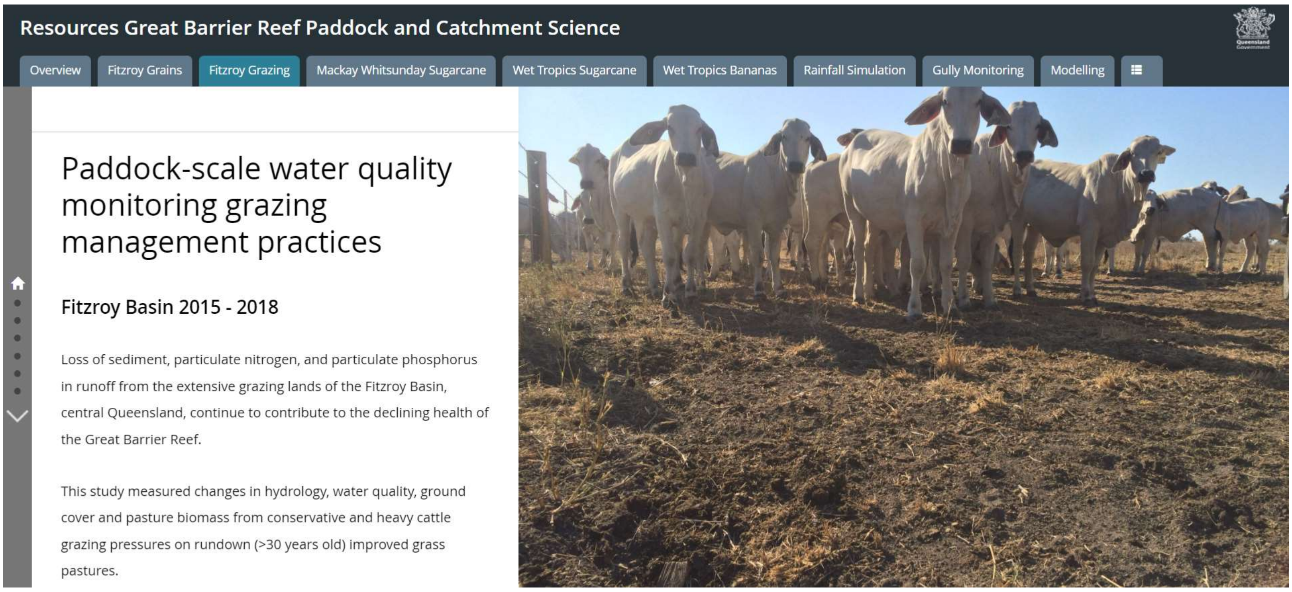
(2) Aleisha Keating (Acting Principal Scientist) from the Department of Resources visited the Brigalow Catchment Study to learn about one of the Paddock to Reef monitoring projects that she would oversee while acting in a management role (September 2021).

(3) Fitzroy Basin Association staff and stakeholders (i.e., landholders, rural bankers) visited the Brigalow Catchment Study to learn about the long-term project outcomes and discuss implications for the future of cropping and grazing enterprises in the region (April 2022).

Website

The Brigalow Catchment Study website (www.brigalowcatchmentstudy.com) provides access to real-time rainfall and runoff data from all monitored catchments, in addition to information on publications that have resulted from the long-term project. The website was also updated recently to provide more background information on the long-term project, to provide links to additional real-time data sources that have been installed (i.e., COSMOS soil moisture sensors), and introduce project staff.

The Fitzroy Grazing monitoring project also had a webpage on the Paddock to Reef story map released in 2021 (apps.information.qld.gov.au/StoryMaps/GBR_PaddockCatchmentScience/), which provides a summary of the research published in Thornton and Elledge (2021).



Appendix 2: Annual rainfall and runoff

Table A2.1: Observed annual hydrology from the three monitored catchments.

Year	Rainfall (mm)	Total runoff (mm)		
		Brigalow woodland	Conservative grazing	Heavy grazing
2019	437	17	16	49
2020	490	10	33	66
2021	602	0.3	4	24

Appendix 3: Annual loads and event mean concentrations

2019

Table A3.1: 2019 hydrological year loads and event mean concentrations (EMCs) of total suspended solids, nitrogen, and phosphorus in runoff from the three monitored catchments.

	Parameter	Brigalow woodland	Conservative grazing	Heavy grazing
TSS	Total load (kg/ha/yr)	171	203	229
	Mean EMC (mg/L)	989	1379	470
TN	Total load (kg/ha/yr)	5.36	1.46	1.37
	Mean EMC (mg/L)	31.07	9.91	2.81
PN	Total load (kg/ha/yr)	3.59	1.01	1.07
	Mean EMC (mg/L)	20.79	6.89	2.20
TDN	Total load (kg/ha/yr)	1.77	0.45	0.20
	Mean EMC (mg/L)	10.27	3.03	0.42
DON	Total load (kg/ha/yr)	0.36	0.18	0.08
	Mean EMC (mg/L)	2.10	1.24	0.17
DIN	Total load (kg/ha/yr)	1.41	0.26	0.12
	Mean EMC (mg/L)	8.17	1.79	0.25
TP	Total load (kg/ha/yr)	0.41	0.23	0.32
	Mean EMC (mg/L)	2.37	1.60	0.65
PP	Total load (kg/ha/yr)	0.38	0.20	0.21
	Mean EMC (mg/L)	2.22	1.39	0.43
TDP	Total load (kg/ha/yr)	0.03	0.03	0.06
	Mean EMC (mg/L)	0.16	0.21	0.13
DOP	Total load (kg/ha/yr)	0.00	0.00	0.01
	Mean EMC (mg/L)	0.03	0.03	0.02
DIP	Total load (kg/ha/yr)	0.02	0.03	0.06
	Mean EMC (mg/L)	0.13	0.18	0.12

2020

Table A3.2: 2020 hydrological year loads and event mean concentrations (EMCs) of total suspended solids, nitrogen, and phosphorus in runoff from the three monitored catchments.

	Parameter	Brigalow woodland	Conservative grazing	Heavy grazing
TSS	Total load (kg/ha/yr)	56	562	398
	Mean EMC (mg/L)	574	1828	678
TN	Total load (kg/ha/yr)	2.95	3.73	1.73
	Mean EMC (mg/L)	30.38	11.98	2.66
PN	Total load (kg/ha/yr)	1.30	2.49	1.13
	Mean EMC (mg/L)	13.37	8.00	1.79
TDN	Total load (kg/ha/yr)	1.65	1.28	0.60
	Mean EMC (mg/L)	17.03	3.99	0.87
DON	Total load (kg/ha/yr)	0.34	0.48	0.27
	Mean EMC (mg/L)	3.53	1.47	0.36
DIN	Total load (kg/ha/yr)	1.31	0.78	0.34
	Mean EMC (mg/L)	13.51	2.52	0.50
TP	Total load (kg/ha/yr)	0.13	0.48	0.36
	Mean EMC (mg/L)	1.33	1.53	0.55
PP	Total load (kg/ha/yr)	0.11	0.42	0.26
	Mean EMC (mg/L)	1.16	1.34	0.42
TDP	Total load (kg/ha/yr)	0.02	0.06	0.10
	Mean EMC (mg/L)	0.17	0.19	0.13
DOP	Total load (kg/ha/yr)	0.00	0.01	0.01
	Mean EMC (mg/L)	0.02	0.03	0.02
DIP	Total load (kg/ha/yr)	0.02	0.05	0.10
	Mean EMC (mg/L)	0.17	0.16	0.13

2021

Table A3.3: 2021 hydrological year loads and event mean concentrations (EMCs) of total suspended solids, nitrogen, and phosphorus in runoff from the three monitored catchments.

	Parameter	Brigalow woodland	Conservative grazing	Heavy grazing
TSS	Total load (kg/ha/yr)	2	15	148
	Mean EMC (mg/L)	No data	690	667
TN	Total load (kg/ha/yr)	0.04	0.13	0.70
	Mean EMC (mg/L)	No data	3.84	2.97
PN	Total load (kg/ha/yr)	0.03	0.04	0.40
	Mean EMC (mg/L)	No data	1.71	1.70
TDN	Total load (kg/ha/yr)	0.03	0.09	0.29
	Mean EMC (mg/L)	No data	2.14	1.26
DON	Total load (kg/ha/yr)	0.01	0.05	0.15
	Mean EMC (mg/L)	No data	0.96	0.59
DIN	Total load (kg/ha/yr)	0.02	0.04	0.14
	Mean EMC (mg/L)	No data	1.18	0.67
TP	Total load (kg/ha/yr)	0.00	0.01	0.14
	Mean EMC (mg/L)	No data	0.44	0.62
PP	Total load (kg/ha/yr)	0.00	0.01	0.10
	Mean EMC (mg/L)	No data	0.36	0.43
TDP	Total load (kg/ha/yr)	0.00	0.00	0.04
	Mean EMC (mg/L)	No data	0.08	0.19
DOP	Total load (kg/ha/yr)	0.00	0.00	0.00
	Mean EMC (mg/L)	No data	0.02	0.02
DIP	Total load (kg/ha/yr)	0.00	0.00	0.04
	Mean EMC (mg/L)	No data	0.08	0.19