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Effect of changing land use from virgin brigalow (*Acacia harpophylla*) woodland to a crop or pasture system on sediment, nitrogen and phosphorus in runoff over 25 years in subtropical Australia

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ABSTRACT

Native vegetation has been extensively cleared for agricultural systems worldwide, resulting in increased pollutant loads that often have adverse impacts downstream. This study uses 25 years of flow data and 10 years of sediment, nitrogen and phosphorus (total and dissolved) event mean concentrations from paired catchments to quantify the effect of changing land use from virgin brigalow (*Acacia harpophylla*) woodland in a semi-arid subtropical region of Australia into an unfertilised crop or conservatively grazed pasture system. Both the cropped and grazed catchments exported higher loads of sediment and phosphorus than the virgin brigalow catchment; however, the grazed catchment exported less total, oxidised and dissolved nitrogen than the virgin brigalow catchment. The cropped catchment exported higher loads of all water quality parameters compared to the grazed catchment. The simple hydrology and water quality model presented was effective for measuring the effect of land use change on runoff water quality. Variations in water quality between the three catchments are likely due to the presence of native legumes, ground cover, tillage practices and pasture rundown.

1. Introduction

Worldwide, the total area of forests in 2010 was estimated to be four billion hectares, or 31% of the total land area (Food and Agriculture Organization of the United Nations, 2010). Deforestation is typically associated with natural causes, such as fire and drought, and change of land use to agriculture. However, rates of net gain and loss vary between country and agro-ecological zones (Food and Agriculture Organization of the United Nations, 2010). For example, in Australia the Fitzroy Basin Land Development Scheme commenced in 1963 resulting in 4.5 Mha of virgin brigalow woodland being cleared for agriculture. This scheme continued through to the 1990s (Department of Lands, 1968; Partridge et al., 1994), with broad-scale clearing in Queensland only ceasing in 2006 (Thornton et al., 2012). In 2009, 74.8% (11.7 Mha) of the Fitzroy Basin was being used for agricultural purposes, with 71.5% grazed and 3.2% cropped (Australian Bureau of Statistics, 2009).

Pollutant loads exported in runoff have increased from natural rates as a consequence of broad-scale clearing of native vegetation and subsequent change of land use to agriculture. For example, Kroon et al. (2012) estimated that since European settlement mean annual loads exported from six catchments along the coast of Queensland, Australia, into the Great Barrier Reef have increased 5.5 times for total suspended sediment (17,000 kt yr^{-1}), 5.7 times for total nitrogen (80,000 t yr^{-1}) and 8.9 times for total phosphorus (16,000 t yr^{-1}). Transport of sediment and nutrients from the landscape into the Great Barrier Reef causes increased eutrophication and turbidity (Brodie et al., 2011; Hansen et al., 2002), which can lead to crown-of-thorns starfish (*Acanthaster planci*) outbreaks and coral mortality (Brodie and Waterhouse, 2012; De'ath et al., 2012). The impact of different agricultural activities on downstream water quality is an issue in common with other parts of Australia and the world (Barlow et al., 2007; Bossa et al., 2012; Brion et al., 2011; Dilshad et al., 1996; Jarvie et al., 2010; Lal, 1996; Singh and Mishra, 2014; Vink et al., 2007).

It is well documented that runoff volume and/or sediment load increase when native forest is cleared for agriculture (Cowie et al., 2007; Hunter and Walton, 2008; Siriwardena et al., 2006; Thornton et al., 2007). Numerous studies have also demonstrated higher runoff volume and/or sediment loads from cropped than grazed areas (Freebairn et al., 2009; Murphy et al., 2013; Stevens et al.,

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2006; Wilson et al., 2014). However, studies that have reported nutrient loads from agricultural systems tend to focus on total loads rather than dissolved loads (O'Reagain et al., 2005; Povilaitis et al., 2014; Stevens et al., 2006; Wilson et al., 2014). Dissolved nutrients pose a great risk to aquatic systems, as they are less likely to settle than nutrients bound to sediment (Silburn et al., 2007). For example, Devlin and Brodie (2005) mapped flood plumes from rivers exporting into the Great Barrier Reef over nine years and found that most suspended solids and associated particulate nutrients were deposited within 10 km of the river mouth while dissolved nutrients were transported with the plume 50–200 km from the river mouth.

Studies that have reported both total and dissolved nutrients are typically at the catchment scale (Joo et al., 2012; Li et al., 2014; Packett et al., 2009), but catchments often have multiple land uses within the monitored area so it is difficult to separate the impacts of each land use on water quality (Bartley et al., 2012; Li et al., 2014; Povilaitis et al., 2014). Bartley et al. (2012) reviewed 755 sediment, nitrogen and phosphorus data points from studies across Australia for use in catchment scale water quality models. They found that a catchment with less than 90% of a specific land use could have its water quality signature influenced by the other land uses, whereas a catchment dominated by a single land use (>90%) was a more appropriate representation of that specific land use. However, using data from sites with more than 90% of the area dominated by a single land use dramatically reduced the number of data points and also biased data towards smaller plot sizes for intensive land uses, such as sugar cane, which rarely cover large areas of a catchment (Bartley et al., 2012). Thus, there is currently a paucity of total and dissolved water quality data from areas greater than plot scale that are dominated by a single land use.

This study investigates the impact of changing land use from a virgin brigalow woodland into a crop or pasture system on runoff water quality. It models data based on a 17 year calibration period of three catchments in their virgin condition before changing the land use of two catchments to agriculture, and subsequent monitoring of all three catchments to collect 25 years flow and 10 years water quality data. The model presented uses long-term event mean concentrations (EMCs) with a regression based flow model described by Thornton et al. (2007). This research is unique as it: 1) reports on total and dissolved nitrogen and phosphorus in addition to sediment; and 2) compares both cropped and grazed catchments with a virgin woodland control catchment. This study improves understanding on the impact of agriculture on runoff water quality relative to the pre-European landscape and provides a comparison of water quality from crop and pasture systems.

2. Methods

2.1. Site description

The Brigalow Catchment Study (24°48′S and 149°47′E) is a paired, calibrated catchment study located near Theodore in central Queensland, Australia (Fig. 1). It was established in 1965 to quantify the impact of land development for agriculture on hydrology, productivity and resource condition (Cowie et al., 2007). The study site was selected to represent the Brigalow Belt Bioregion which covers an area approximately 36.7 Mha from Townsville in north Queensland to Dubbo in central-western New South Wales (Thornton et al., 2007). The site in its native state was dominated by brigalow (*Acacia harpophylla*) trees, either in a monoculture or in association with other species, such as belah (*Casuarina cristata*) and Dawson River blackbutt (*Eucalyptus cambageana*) (Johnson, 2004). The extant uncleared vegetation at the Brigalow Catchment Study is classified as regional ecosystems 11.4.8, woodland to open forest dominated by *Eucalyptus cambageana* and *Acacia harpophylla*, and 11.4.9, open forest and occasionally woodland dominated by *Acacia harpophylla* (Queensland Government, 2014). Slope of the land averages 2.5% (range from 1.8 to 3.5%) and soils are an association of black and grey Vertosols, black and grey Dermosols, and black and brown Sodosols. Vertosols and Dermosols (clay soils) cover approximately 70% of Catchments 1 and 2, and 58% of Catchment 3; Sodosols cover the remaining area (Cowie et al., 2007). These soil types are representative of 67% of the Fitzroy Basin under grazing: 28% Vertosols, 28% Sodosols and 11.3% Dermosols (Roots, 2016). The region has a semi-arid, subtropical climate and mean annual hydrological year (October 1965 to September 2014) rainfall at the site was 661 mm.

2.2. Calibration and development of catchments

Three contiguous catchments were monitored for rainfall and runoff from 1965 to 1982 (17 years). Each catchment was instrumented to measure runoff using a 1.2 m steel HL flume with a 3.9×6.1 m concrete approach box. Water heights through the flumes were recorded using mechanical float recorders and converted to discharge using a rating table. Rainfall was recorded adjacent to each flume and at the top of the catchments using a tipping bucket rain gauge (Thornton et al., 2007). A runoff event was defined as commencing when stage height exceeded zero and finished when it returned to zero. These data were used to derive mathematical relationships to predict runoff from Catchment 2 (C2) and Catchment 3 (C3) given known runoff from Catchment 1 (C1) (Thornton et al., 2007). During this period, it was found that C2 and C3 in their uncleared state had 95% and 72% of the runoff from C1, respectively. Each catchment had its own intrinsic hydrological signature; for example, C3 had more runoff events but less total runoff volume on an annual basis compared to C1 and C2. Nonetheless, approximately 5% of the mean annual rainfall become runoff in all three catchments (Thornton et al., 2007).

Land development occurred between 1982 and 1983; that is, C1 remained virgin brigalow woodland to provide an uncleared control treatment, while C2 and C3 were cleared using a chain dragged between two dozers and the fallen timber burnt in-situ (Cowie et al., 2007). C2 was then developed for cropping with the construction of contour banks and grassed waterways, while C3 was developed for grazing by the planting of improved buffel grass pasture (Fig. 2).

2.3. Land use comparisons

Rainfall and runoff were monitored from the virgin brigalow woodland (C1), cropped (C2) and grazed (C3) catchments from 1984 until 2010 (Thornton and Elledge, 2013). This equates to 25 full hydrological years (October to September) monitoring and two incomplete hydrological years; July 1984 to September 1984, and October 2009 to January 2010. Over the 25 years, C2 had one sorghum crop followed by nine monoculture wheat crops, and then was opportunity cropped with sorghum (*Sorghum bicolor*), wheat (*Triticum* spp.), barley (*Hordeum vulgare*) or chick peas (*Cicer arietinum*). Zero or reduced till fallows were introduced in 1990. There were no fertiliser inputs in the cropped catchment (Radford et al., 2007). C3 was grazed at industry recommended stocking rates with utilisation to result in no less than 1000 kg ha^{-1} of pasture available at any time. Conservative management of this catchment has resulted in groundcover averaging 91% since 2000 (earlier data not available), which is greater than paddocks of the same land type within a 50 km radius which averaged only 74% (Fitzroy Basin Association, 2016). The foliage projective cover of tree regrowth in C3 has remained below 15% (Department of Science, Information Technology and Innovation, 2016). There was