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Hydrological recovery of rangeland following cattle exclusion

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Abstract There is concern that the Great Barrier Reef World Heritage Area (GBRWHA) is being impacted by a decline in the quality of water exported from adjacent catchments. Approximately 90% of the catchment area draining to the GBRWHA is used for cattle production, and at present there is a limited understanding of the time periods required for water and sediment runoff to respond to changes in pasture management and over what period changes in grazing land management may impact water and sediment runoff. The quantity and quality of water exported from two hillslopes in the Burdekin River catchment was monitored for a period of seven years. Both hillslopes were grazed during the first two years of monitoring and cattle were excluded from the treated hillslope prior to the beginning of the third year. The suspended sediment yield of the treated hillslope declined from 150% to 50% of the control hillslope after the first year of treatment and remained at this level or less for the following four years. However, hillslope runoff of water showed little response to treatment despite the surface pasture condition having improved. This means that the amount of runoff available to cause downstream gully and river bank erosion would not be affected within five years.

Key words recovery; hillslope; grazing; runoff; sediment; Great Barrier Reef World Heritage Area

INTRODUCTION

There is concern that a decline in the quality of water exported from adjacent catchments is having an impact on the Great Barrier Reef World Heritage Area (GBRWHA). The Reef Water Quality Protection Plan (The State of Queensland and Commonwealth of Australia, 2003) aims to halt and reverse the decline of water quality entering the reef within 10 years. The main issues identified are the 5- to 10-times increased export of sediment following European settlement, the impact of this sediment and associated nutrients on the GBRWHA (McKergow, 2005a,b) and the time required for erosion rates to respond to changes in pasture management. The Burdekin River has the second largest catchment (130 126 km^2) that drains into the GBRWHA, delivering 3.77 million tonnes of fine sediment into the GBRWHA annually (Furnas, 2003). This is the largest contribution of any catchment draining into the GBRWHA and equates to about 26% percent of the total fine sediment exported to it. Since around 90% of the catchment is used for cattle production, any natural resource management systems which are put in place have to take into account the impacts of cattle grazing on water quality.

Growing evidence suggests that in certain areas, inappropriate grazing land management has resulted in increased sediment and nutrient export from within the Burdekin catchment (Roth *et al.*, 2003; Post *et al.*, 2006). Studies have shown how wet season spelling, better stock management, and riparian fencing can benefit both pastoral production and water quality by improving landscape function (McIvor, 1995; Scanlan *et al.*, 1996; Ash *et al.*, 2001; Post *et al.*, 2006). There is, however, limited understanding about the response time of erosion rates and infiltration following the implementation of improved pastoral management. Roth (2004) suggests that full recovery can occur after 15 to 20 years and that recovery must therefore begin sometime before then. The time required for changes in grazing land management to result in improvements in water quality is largely unknown. While complete removal of cattle from the Burdekin catchment is not practical, we will use this treatment as an end member to the time of response.

Over a seven-year period, the quantity and quality of water exported from two hillslopes on Meadowvale Station, a commercial grazing property located in the Burdekin River catchment, was monitored (Fig. 1). This paper uses a controlled experiment to investigate the changes of water and sediment runoff resulting from the removal of grazing by cattle.

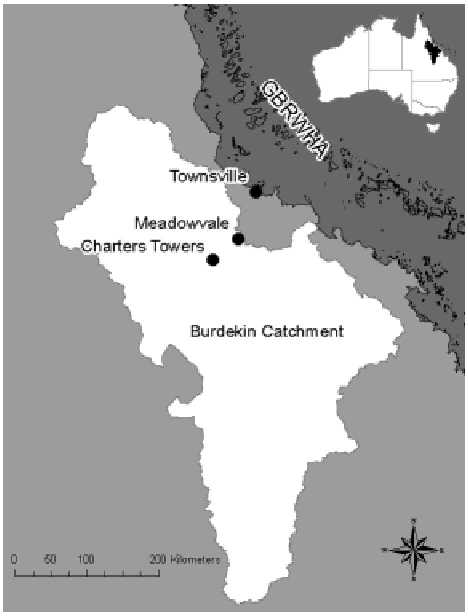

Fig. 1 Locality map.

METHODS

Study site

The study site is located on Meadowvale station, near Charters Towers in Queensland, Australia. Meadowvale Station has been used for cattle production for over five decades. The vegetation is dominated by Narrow-leafed Ironbark (*Eucalyptus crebra*) with an Indian couch (*Bothriochloa pertusa*) dominated understory. The major soil type is a red chromosol (Dalrymple series) overlying a granodiorite substrate. This region has a pronounced wet season over the summer months, with most of the 660 mm of mean annual rainfall occurring between November and April.

Experimental design

The experiment used four runoff troughs originally installed by Scanlan *et al*. (1996) in the 1980s. The four troughs were re-activated prior to the 2001 wet season. The control hillslope was grazed for the duration of the monitoring, while the treated hillslope had grazing removed after the second wet season. A tipping bucket raingauge was installed on the treated hillslope. Both hillslopes had evenly distributed ground cover over the entire monitoring period with no large bare spaces between grass patches. The amount of ground cover varied seasonally and annually. The hillslopes are located approximately 500 m apart on the same ridgeline. They have similar slope and aspect with the troughs located at similar positions on each hillslope.

Instrumentation

Runoff and sediment loads were monitored using four runoff troughs. Each trough was approximately 10 m long and 0.2 m wide and fitted with a self-logging tipping bucket and a sample collection vessel (Fig. 2). Each tipping bucket was calibrated over a range of flow intensities. Hillslope runoff collected in the trough where it was channelled into the tipping bucket. When the bucket becomes full it tips and the logger stores the time of the event. A subsample of the runoff was collected as it flowed into the bucket. Rainfall was measured using a tipping bucket raingauge connected to a data logger.

Sampling

All loggers were downloaded and water samples were collected as close as possible to the end of each runoff event. It was not always possible to know when a runoff event had occurred; therefore

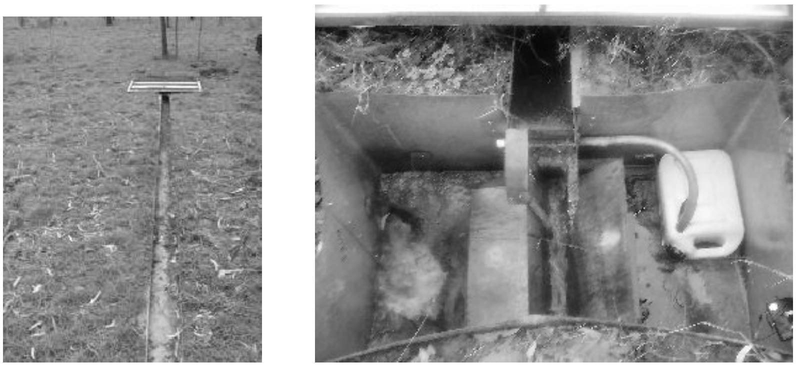

Fig. 2 Runoff trough installed at Meadowvale Station (left). Tipping bucket, logger and sample collection vessel during a runoff event (right).

the sample sometimes contained water from multiple small events. To account for this, "a runoff event" was defined as to be the sum of all events that occurred between sampling intervals rather than by individual events.

Data analysis

Although vegetative cover, soil erodibility, rainfall erosivity and slope are known to be important factors in influencing runoff and sediment generation from a hillslope, they are not investigated in this paper. Bartley *et al*. (2006) found no relationship between rainfall intensity and runoff rate at similar spatial scales on the same land type. There was also poor correlation between ground cover and suspended sediment yield. This was attributed to factors such as the arrangement and connectivity of ground cover controlling hydrological processes at the hillslope scale, as demonstrated by Kinsey-Henderson *et al.* (2005). The control hillslope approach avoided these confounding factors by allowing the effect of the treatment to be investigated by comparing the relative differences between the treatment and a control. All rainfall and runoff data were grouped by runoff events as per the sampling methodology. Discharge for each trough was converted to runoff depth by dividing the total volume of runoff for each event by the catchment area. A runoff coefficient was calculated for each event by dividing the total amount of runoff by the event rainfall depth. Sediment yield was calculated by multiplying the event discharge by the concentration of total suspended sediment (TSS) measured in the water samples. The results from the two troughs in the same treatment were then averaged to give a single result for each treatment from each event. Annual comparisons are made over water years, where 2006 is the water year from 1 July 2005 to 30 June 2006.

RESULTS AND DISCUSSION

Annual rainfall

Annual rainfall (Fig. 3) was below the 100-year average for Charters Towers (Fig. 1) of 660 mm for all years. The lowest annual rainfall was 256 mm in 2003, which is below the 10th percentile for Charters Towers, and the highest, 591 mm, was measured in 2007. The seven-year average annual rainfall at the site was 455 mm. The first four years of the study, 2001–2004, were below this average with 420 mm or less per annum. The last three years, 2005–2007, received more than 540 mm per year and are herein referred to as wet years.

Event rainfall

Runoff was generated from 25 rainfall events over the seven-year study period and ranged in size from under 10 mm to 383 mm (Fig. 4.) The mean rainfall event size was 117 mm (±18 mm). Three quarters of these events occurred from December to March. The two largest rainfall events occurred on 24 January 2005 (268.8 mm) and 7 February 2007 (383 mm).

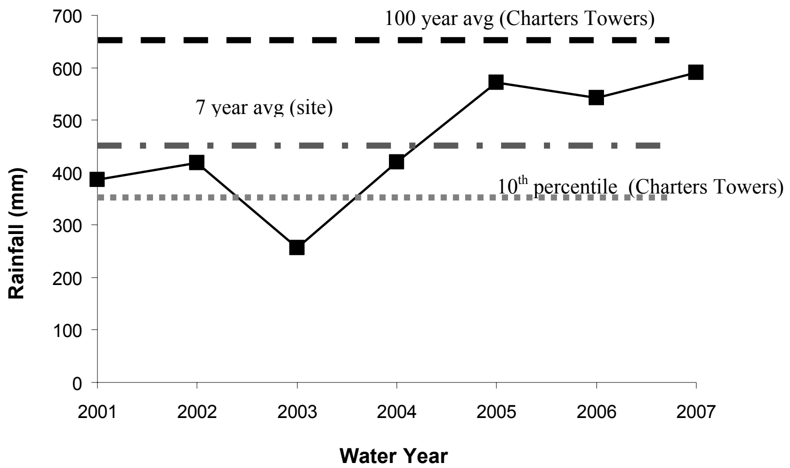

Fig. 3 Annual rainfall for the seven years of monitoring.

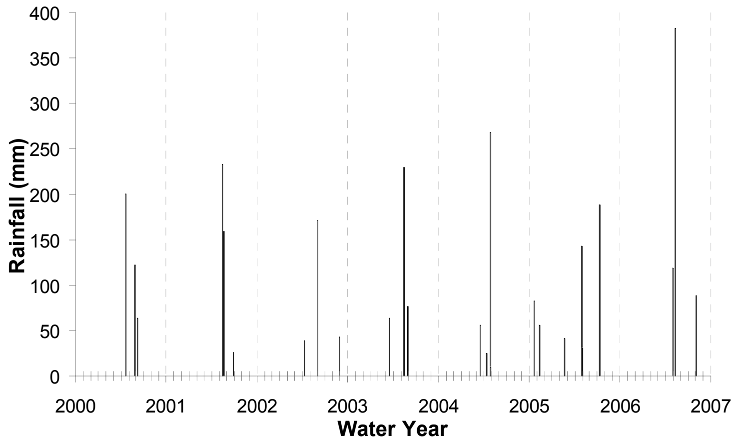

Fig. 4 Event rainfall distribution.

Water yield

Twenty five runoff events were recorded over the seven-year study period. Six of these events occurred prior to treatment. A comparison of total discharge, the ratio of discharge and runoff coefficients between treatment and control, is used to determine if the removal of grazing led to a reduction in hillslope runoff over this five-year period and also to determine if the observed reduction in sediment yield was due to a reduction in water yield.

Total discharge

The control hillslope generated three times the amount of runoff as the treated hillslope both prior to, and after, treatment. The total discharge after seven years was 396 mm and 122 mm for the control and treated hillslopes, respectively. For the five years following treatment the totals were 339 mm for the control hillslope and 102 mm for the treated hillslope. The mean annual discharge was 68 mm (±28 mm) for the control and 20 mm (±9 mm) for the treated hillslope. The cumulative discharge for each treatment is shown in Fig. 5. The differences between hillslopes are apparent during the two largest rainfall events, the first in January 2005 (~270 mm) and the second in February 2007 (~385 mm). While these results show that differences between the treatment and control exist, they do not show any trend in this difference.

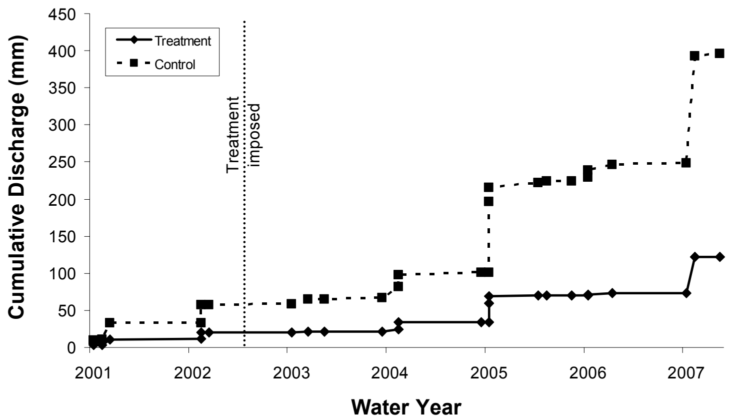

Fig. 5 Cumulative discharge per treatment for each runoff event between 2001 and 2007.

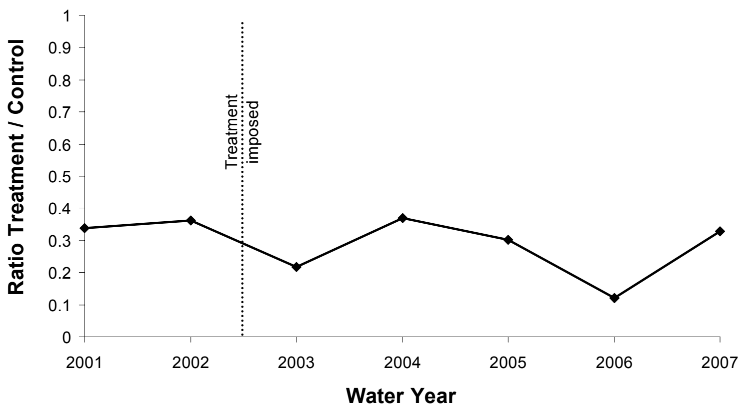

Fig. 6 Ratio of annual discharge (mm) for treated *versus* control.

Ratio of discharge

The ratio of discharge from treated to control is shown in Fig. 6. If the removal of grazing has an effect on discharge, we would expect this ratio to decrease after the 2002 water year. However, the ratio at the beginning of the experiment was 0.338 and 0.329 seven years later. The lowest ratios occur in 2006 after a previous wet year (0.12) and in 2003, the first wet season after treatment (0.218). The rainfall for 2006 was more evenly distributed across the whole year with no single event greater than 200 mm. The 2003 water year was also the driest of the study. There was little difference in the ratio of discharge for 2005 or 2007, which had the highest quantities of discharge monitored (Fig. 5).Our data showed no relationship between the ratio of discharge and total rainfall at the event scale, annual scale, prior to treatment or post treatment. These results show that there is no treatment response with respect to annual discharge although there may be a short-term response to infrequent seasonal events, as seen in 2003 and 2006.

Runoff coefficient

The runoff coefficients of each hillslope over the entire period were 13.6% for control and 4.2% for the treated hillslope. This includes the two years prior to treatment. The 5-year, post treatment runoff coefficient for the control hillslope was 16.0% and 4.8% for the treated hillslope. The annual runoff coefficients for each treatment are shown in Fig. 7. Both hillslopes had almost identical runoff coefficients (only 0.67% difference) during the first water year after treatment (2003) which was also the lowest rainfall year. The greatest difference occurred during 2005 (the first wet year), although both treatments had high runoff coefficients. The runoff coefficients for

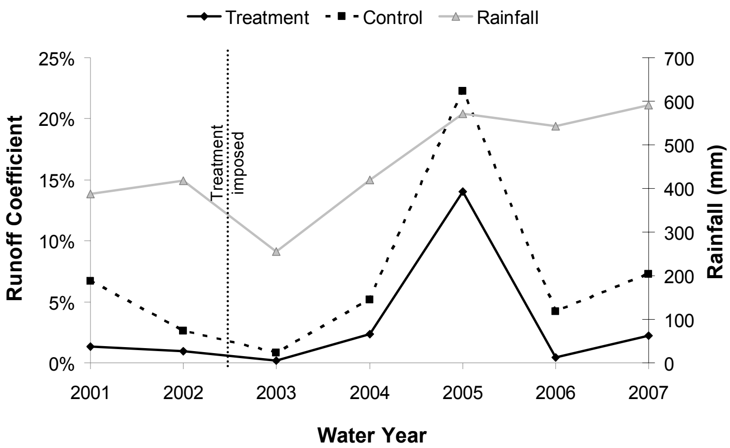

Fig. 7 Annual runoff coefficients for treated and control hillslopes.

the following two years remained below 10%, even though annual rainfall was similar and the dominant rainfall event in 2007 was larger than that in 2005. Interestingly, the difference between the treatments at the end of 2007 (5.07%) was less than at the beginning of the experiment in 2001 (5.35%) even though rainfall was much higher (Fig. 4). Our data showed no relationship between the runoff coefficient and total rainfall for either hillslope at the event or annual scale.

Sediment loss

Eighty-seven water samples were collected across the four troughs. A comparison of suspended sediment concentration, total suspended sediment yield and the ratio of suspended sediment yields was used to determine if the removal of grazing has an effect on suspended sediment loss.

Suspended sediment concentration

The range of concentrations of total suspended sediments (TSS) for the control hillslope was from 0.002 to 2.320 g/L, whilst for the treated hillslope they ranged between 0.005 and 6.810 g/L. Although the treated hillslope had a larger range and maximum TSS than the control hillslope, the histogram in Fig. 8 shows that the TSS concentration of the treated hillslope was more consistently lower than the control. The TSS concentration of the treated hillslope remained below 0.25 g/L for over 86% of all runoff events and close to 0.005 g/L for the largest number of events. The control hillslope had less than 65% of samples under 0.25 g/L with most samples between 0.15 and 0.25 g/L.

Suspended sediment yield

The control hillslope liberated approximately three times more sediment than the treated hillslope over the entire period. There was little difference between sediment yields prior to treatment (Fig. 9). Differences between the treatment and control yields started during 2004 and peaked during the large rainfall event in January 2005. Sediment yields after this event were similar for both the control and treated hillslopes.

For the five years after treatment, on average, the control hillslope yielded 2.30 t/ha/year and the treated hillslope yielded 0.69 t/ha/year. In contrast, the average yields prior to treatment were 0.33 t/ha/year and 0.44 t/ha/year, respectively. The difference between the annual sediment yields of each treatment is expressed as a ratio in Fig. 10.

Prior to the removal of grazing, the treated hillslope exported approximately 1.5 times more sediment than the control hillslope. After this time, the treated hillslope contributed approximately half the amount of sediment as the control hillslope. This reduction occurred during the first water year and was sustained over the duration of monitoring. If the reduction in suspended sediment yields was simply due to a reduction in water yields, Fig. 10 would closely mirror Fig. 6. As this is

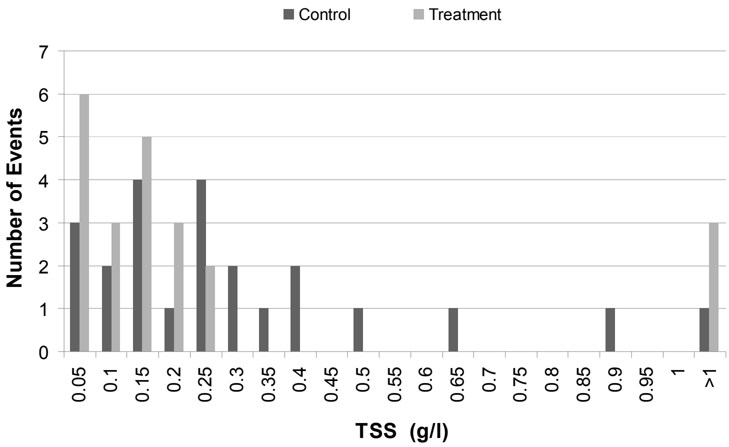

Fig. 8 Histogram of suspended sediment concentration for each event per treatment.

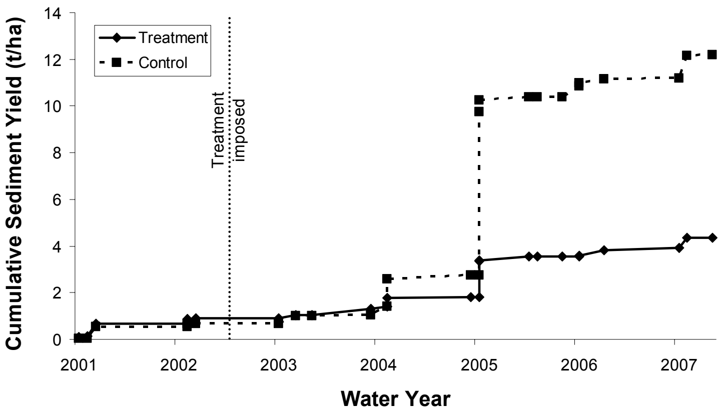

Fig. 9 Cumulative suspended sediment yield (t/ha) for all runoff events.

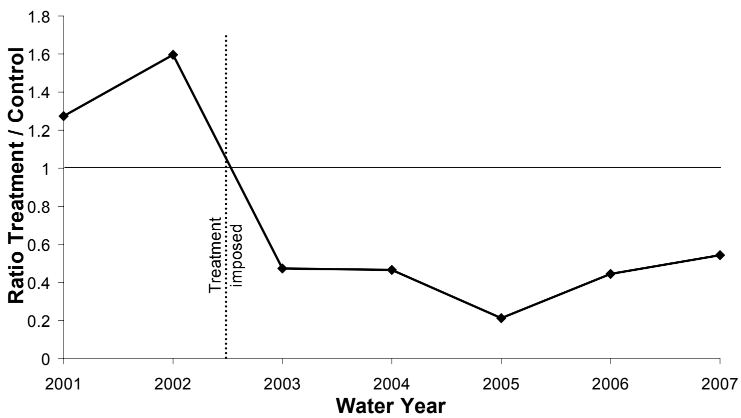

Fig. 10 Ratio of annual suspended sediment yield (t/ha) for Treated *vs* Control.

not the case, the reduction in sediment yield on the treated hillslope must be a result of some other factor. The largest post-treatment difference occurred during the 2005 wet season when the treated hillslope generated only a fifth of the control hillslope yield. This occurred even though both hillslopes had high runoff coefficients (Fig. 7) and therefore high transport capacity, suggesting that the sediment supply from the treated hillslope was limited by improved pasture condition. McIvor *et al*. (1995) found hillslope erosion in similar systems to be limited by supply capacity.

Soil surface condition surveys (Tongway & Hindley, 2004) of both hillslopes, conducted in 2003 and 2006, showed that the treated hillslope had better infiltration, less erosion potential and higher nutrient cycling capacity than the control, although the condition of both hillslopes showed improvement between surveys.

CONCLUSIONS

The water and sediment yields of two hillslopes were monitored to quantify the magnitude and period of response to the removal of grazing in a dry tropical environment. It has been shown that excluding cattle results in a 50% reduction of sediment yield, relative to a control, within one year. Excluding cattle did not result in a reduction of runoff over five years. There was no relationship between the reduction in sediment yield to the amount of rainfall or runoff, which is consistent with the sediment yield being limited by erosion rate rather than by transport capacity. This means that the amount of runoff available to cause downstream gully and river bank erosion would not be affected within that time.

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