Agriculture, Ecosystems and Environment 180 (2013) 90–102

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Using sediment tracing to assess processes and spatial patterns of erosion in grazed rangelands, Burdekin River basin, Australia

Scott N. Wilkinson[a,*], Gary J. Hancock[a], Rebecca Bartley[b], Aaron A. Hawdon[c], Rex J. Keen[c]

[a] CSIRO Land and Water, GPO Box 1666, Canberra, ACT, 2601, Australia
[b] CSIRO Land and Water, GPO Box 2583, Brisbane, QLD, 4001, Australia
[c] CSIRO Land and Water, PMB, Aitkenvale, QLD, 4814, Australia

ARTICLE INFO

Article history:
Received 4 May 2011
Received in revised form 18 January 2012
Accepted 3 February 2012
Available online 8 March 2012

Keywords:
Soil erosion
Gully erosion
Sediment fingerprinting
SedNet model
Great Barrier Reef
Caesium 137

ABSTRACT

Identifying how agricultural practices can be changed to reduce sediment loss requires knowledge of the erosion processes and spatial areas contributing to end of catchment sediment loads. The Burdekin River basin in northeast Australia is a priority for such knowledge because of its large size (130,000 km^2), ongoing public investment in changing agricultural practices, and because sediment exports are known to affect the health of a significant aquatic ecosystem, the Great Barrier Reef (GBR). This study applied sediment tracing techniques within the Burdekin River basin to identify the contributions of surface versus subsurface soil, and spatial areas to fine sediment export. Tracer properties included fallout radionuclides and geochemistry. The contributions of each sediment source to river sediment were identified with 95% confidence intervals using a Monte-Carlo numerical mixing model. Between 77% and 89% of fine sediment loss in the study area was derived from subsurface soil sources. High-resolution monitoring of river suspended sediment concentrations indicated that sediment sources were in close proximity to the drainage network, since concentrations were higher on the rising limb than the falling limb of large hydrographs. Gully erosion is likely to be the dominant subsurface soil erosion process, although channel bank erosion and hillslope rilling cannot be discounted. The results contrast with previous sediment budget spatial modelling, which predicted that hillslope erosion was the dominant sediment source in the area, thus demonstrating the need to independently verify modelling predictions where input datasets are poor. The contribution of surface soil to river sediment was generally similar between catchments which were currently grazed and two catchments where livestock grazing ceased 7 years ago. Concurrent increases in vegetation cover in the non-grazed catchments indicate that surface erosion rates had declined, suggesting that subsurface soil erosion rates had also declined by a similar amount. The estimated contributions of spatial source areas within the large study catchments had narrower confidence intervals when source areas were defined using sediment from geologically distinct river tributaries, rather than using soil sampled from geological units in the catchment, since tributary sediment had less-variable geochemistry than catchment soil. Programs to reduce fine sediment losses from the Burdekin River basin should primarily focus on reducing sub-surface soil erosion proximal to the basin's drainage network. Understanding the biophysical processes of pollutant generation is important to help guide on-ground activities to improve water quality.

1. Introduction

There is growing concern that sediments and nutrients eroded from the land and transported to the coast by rivers are having a detrimental effect on coral reef communities of the Great Barrier Reef (GBR) World Heritage Area in Queensland, Australia (McCulloch et al., 2003; Fabricius, 2005; Fabricius et al., 2005; De'ath and Fabricius, 2010; Brodie et al., 2012). It is estimated that suspended sediment exports to the GBR lagoon have increased by more than 5 times over pre-European levels (Kroon et al., 2012). Modelling of catchment sediment budgets indicates that 74% of sediment exported to the GBR is derived from livestock grazing areas (Thorburn and Wilkinson, 2013). The Australian Government Reef Rescue program has set targets of reducing sediment, nutrient and chemical loads from agricultural land to the GBR as a national priority for investment in natural resource management, and is currently investing more than $200M over 5 years, predominantly in incentives to land-holders to improve

* Corresponding author. Tel.: +61 2 6246 5582; fax: +61 2 6246 5988.
E-mail addresses: scott.wilkinson@csiro.au (S.N. Wilkinson), gary.hancock@csiro.au (G.J. Hancock), rebecca.bartley@csiro.au (R. Bartley), aaron.hawdon@csiro.au (A.A. Hawdon), rex.keen@csiro.au (R.J. Keen).

0167-8809/$ – see front matter.
doi:10.1016/j.agee.2012.02.002

management practices (Commonwealth of Australia, 2008). A technical basis for investment priorities is required to achieve the desired environmental outcomes.

Excessive grazing pressure is the primary issue in management of rangelands, worldwide (Menke and Eric, 1992), and in northern Australia it has resulting in reduced pasture productivity and invasion of exotic grass in many areas, requiring management of stocking rates to avoid further land degradation (Ash et al., 1997). Understanding the contribution of source areas and erosion processes contributing to end of catchment sediment and nutrient loads is important for identifying grazing practices that are effective in reducing sediment losses and for defining investment priorities. Spatial modelling of catchment sediment budgets using the SedNet model (Wilkinson et al., 2009a) has identified that 70% of sediment delivered to the GBR lagoon is sourced from 20% of the catchment area, mainly within 80 km of the coast (McKergow et al., 2005). Such modelling has also indicated that 60–70% of sediment delivered to the GBR is derived from sheetwash and rill erosion on hillslopes (McKergow et al., 2005; Thorburn and Wilkinson, 2013). However, the SedNet model predictions of sediment sources have received little evaluation against independent data in the GBR catchments, particularly within the main source areas identified. Recent sediment tracing studies elsewhere in northern-Australian grazing landscapes found that sediment losses there are dominated by subsurface soil sources (Wasson et al., 2002; Hughes et al., 2009; Tims et al., 2010; Wasson et al., 2010; Caitcheon et al., 2012). Sediment load monitoring can also be used to test and constrain spatial modelling predictions (Rustomji et al., 2008a; Wilkinson et al., 2009a). However, in hydrologically variable catchments such as the Burdekin, mean-annual loads derived from water quality monitoring have confidence intervals (CIs) approaching or exceeding an order of magnitude even after long monitoring periods (Rustomji and Wilkinson, 2008; Kroon et al., 2012); limiting their utility for constraining model parameters.

The relative contributions of erosion processes are especially difficult to quantify at landscape scales by direct measurement (Bartley et al., 2007); making sediment tracing an obvious choice for verifying model predictions in the GBR catchments. Sediment source tracing entails the measurement of physico-chemical characteristics (tracers) of sediment and soil that are assumed to be conservative during erosion, transport and post-depositional storage (Walling and Woodward, 1995). The fallout radionuclides (FRNs) ^{137}Cs, and ^{210}Pb are delivered by rainfall to surface soils with which they bind tightly, while subsurface soils remain unlabelled. Thus they can provide evidence of the erosion process delivering sediment to stream lines (e.g., Wallbrink et al., 1998; Walling, 2002). Additional discrimination between the catchment sources of river sediment is provided by soil geochemistry, which can help to determine the spatial origin of sediment where the regional geology (and hence soil geochemistry) is sufficiently diverse (Collins et al., 1998). Numerical mixing models then use a suite of sediment tracers to provide estimates of source soil proportions contributing to a selected sediment sample (Collins et al., 1997). These proportions can be used directly to inform catchment remediation work, and to identify differences in sediment sources between catchments, or changes over time (Wilkinson et al., 2009b). They can also be used to validate or constrain spatial models of erosion and sediment transport (Rustomji et al., 2008a).

This study applies a composite source fingerprinting technique incorporating property weightings (Collins et al., 1997, 2010a), together with a Monte-Carlo mixing model (Krouse et al., 2003; Wilkinson et al., 2009b) to identify the major erosion processes and spatial source areas within the Burdekin River basin, focusing on areas defined by previous spatial modelling as contributing high rates of sediment to the GBR lagoon. The results are compared with process inferences provided by sediment concentration monitoring data, and with predictions of previous spatial modelling of sediment budgets.

2. Methods

2.1. Site description

The Burdekin River basin (~130,000 km^2 in area) drains to the GBR lagoon adjacent to the Queensland coast, Australia (Fig. 1). The basin contains 37% of the grazing land in the GBR catchments (QLUMP, 2004), and supplies approximately 25% of fine sediment to the GBR lagoon (Kroon et al., 2012). Grazing covers 95% of the Burdekin River basin, predominantly cattle on unimproved pastures. More than 70% of rainfall occurs during summer (December–February) and runoff variability is high in Australian and world terms (Petheram et al., 2008; Rustomji et al., 2009).

Sediment tracing was applied to the Bowen and Upper Burdekin catchments within the Burdekin basin (Fig. 1). The Bowen River catchment was selected on the basis that SedNet modelling of river network sediment budgets identifies it as one of the highest contributors to the GBR on a per-hectare basis (Prosser et al., 2002; McKergow et al., 2005). Supporting this modelling, total suspended sediment (TSS) concentrations in the Bowen River during discharge events are the highest throughout the Burdekin basin (Bainbridge et al., 2007). The Bowen River catchment (~9400 km^2) is also well-connected to the GBR lagoon, being downstream of the Burdekin Falls Dam which traps 60–80% of fine sediment from upstream catchments (Kinsey-Henderson et al., 2007). Of the catchments upstream of the Burdekin Falls Dam, SedNet modelling identifies the Upper Burdekin catchment as having the largest fine sediment contribution to the GBR (Kinsey-Henderson et al., 2007). The eastern ranges of the Bowen and Upper Burdekin catchments have small areas of rainforest and wet sclerophyll forest where rainfall is highest, while the remainder of the catchments are mainly semi-arid woodlands. Native tree cover has been cleared in some areas. Ground cover is a combination of the stoloniferous grass Indian couch (*Bothriochloa pertusa*) and native perennial tussock grasses such as Black speargrass (*Heteropogon contortus*). The landforms are complex due to variations in the underlying geology and geomorphic processes (Burdekin Project Committee, 1976). The predominant soil orders (Isbell, 2002) are Chromosol, Sodosol and Vertosol, with smaller areas of Rudosol and Tenosol (ASRIS, 2011).

Within the upper Burdekin River catchment, Virginia Park Station is a cattle property which has been grazed for more than 100 years and which contains the 14 km^2 Weany Creek catchment (S19.913°, E146.494°), where monitoring of erosion and sediment transport has occurred since 2002 (Bartley et al., 2010a,b). The soil is low fertility Chromosol (Isbell, 2002), which is prone to crusting and hard setting and formed on granodiorite lithology. The vegetation is native woodland (e.g., *Eucalyptus creba*, *Eucalyptus papuana*), with ground cover dominated by Indian couch (*B. pertusa*) (Bartley et al., 2010a).

Also within the upper Burdekin River catchment is the 1200 km^2 Keelbottom Creek catchment (Fig. 1; S19.702°, E146.199°). Grazing has been excluded from more than 90% of the catchment since 2001, with the predominant land use as a military training area. Levels of ground vegetation cover and biomass are generally much higher than in adjacent grazed areas, although most of the area experiences controlled or uncontrolled burns every 1–3 years (Ash et al., 2000). The ground cover is predominantly perennial grasses with native eucalypt tree species (Ash et al., 2000). The soils are mainly Chromosol and Sodosol (Isbell, 2002; ASRIS, 2011). Thornton Creek (catchment area 85 km^2) is a tributary to Keelbottom Creek.