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Combining contemporary and long-term erosion rates to target erosion hot-spots in the Great Barrier Reef, Australia

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ABSTRACT

Methods for prioritising catchment remediation are based on understanding the source of sediment over the short-medium timescales (10–10^2 years) using techniques such as sediment finger-printing, sediment flux monitoring, and catchment modelling. Because such approaches do not necessarily quantify the natural variation in sediment flux over the longer timescale, they often represent background or pre-agricultural erosion rates poorly. This study compares long-term (~100 to >10,000 years) erosion rates derived from terrestrial cosmogenic nuclides (^{10}Be) with contemporary erosion rates obtained by monitoring sediment fluxes over #11 × 10#10 years. The ratio of these two data sets provides a measure of the accelerated erosion factor (AEF), which can be used to identify erosion hot-spots at the sub-catchment scale. The study area is the Burdekin catchment, the largest source of contemporary sediment to the Great Barrier Reef lagoon. Long-term erosion rates vary from <0.0077 mm yr^{-1} in the Suttor and Belyando sub-catchments to 0.0296 mm yr^{-1} in the Bowen. The contemporary erosion rates are highest on small hillslopes with patchy ground cover (0.2726 mm yr^{-1}) and in the Bowen sub-catchment (0.2207 mm yr^{-1}), and lowest in the Belyando sub-catchment (0.0019 mm yr^{-1}). All but two of the sub-catchment sites have an AEF > 1.0, indicating higher contemporary erosion rates than estimated long-term averages. Results confirm that the contemporary or agriculturally-induced erosion rates at these sites have increased considerably. Within the context of the Reef Water Quality Protection Plan, these results provide justification for water quality targets to be set at the sub-catchment scale, particularly for large and geomorphically diverse catchments.

1. Introduction

Humans have increased the sediment transported by rivers globally through soil erosion by 2.3 ± 0.6 billion metric tons per year (Syvitski et al., 2005). Much of this sediment is stored within catchments, however, a considerable amount reaches marine systems, particularly in tropical regions. The Great Barrier Reef World Heritage area in Australia is the world's largest reef ecosystem, and general agreement exists that sediment (as well as nutrients, herbicides and pesticides) from adjacent catchments are impacting the health of coral reef (De'ath et al., 2012). McCulloch et al. (2003a) determined that the amount of sediment reaching the Great Barrier Reef (GBR) has increased 5–10 times since European settlement in ~1870. Identifying the dominant source of this excess sediment has been challenging, particularly in the large (>100,000 km^2) and physically diverse catchments draining to the GBR (Bartley et al., 2014a). There is a need to understand the sources and processes driving these excess sediment yields to support decisions related to catchment remediation of soil erosion and sediment delivery.

The detrimental effect of accelerated soil erosion is well documented (Montgomery, 2007), and significant financial investments have been made in catchment remediation to reduce soil erosion across the globe (Pimentel et al., 1995). Methods for prioritising sub-catchments for remediation have generally been based on our understanding of the source of the sediment, using isotope tracers or fingerprinting (e.g. Douglas et al., 2006; Maher et al., 2009), sediment flux monitoring (Walling and Fang, 2003) or

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catchment modelling (e.g. Kroon et al., 2012; Lu et al., 2004). Many of these approaches are very useful for identifying the contemporary (~1–100 years) sources of sediment within a catchment, however, these approaches are generally limited to small areas (Foucher et al., 2015), or they do not account for the natural variation in sediment flux over time. Even in catchments with the same land use, erosion rates can vary significantly due to factors such as slope, rainfall, geology, vegetation and soil type (Bartley et al., 2012; Cerdan et al., 2010). Without an understanding of the natural susceptibility of a catchment to erosion, resources for remediation may be incorrectly allocated to areas that appear to be producing high sediment yields, when in fact they have landscape attributes that generate large volumes of sediment even in the absence of agriculture. In addition, measurement of sub-catchment sediment yields may be biased towards the climate and rainfall regime at the time of data collection, which may exclude large episodic runoff events that have an important influence on soil erosion and delivery (Nott and Hayne, 2001).

In the GBR catchments, investment in on-ground remediation is currently allocated according to the relative risk of sediment export from a catchment to the marine system (Waterhouse et al., 2012). In this context, risk is assessed as a function of anthropogenic loads from rivers draining to the GBR (based on modelled estimates of current erosion minus modelled estimates of pre-agricultural erosion rates) (Waters and Carroll, 2013), reef condition (using long-term direct and proxy marine water quality data) and reef exposure (using a combination of remote sensing, water quality data and GIS) (Devlin et al., 2012). The effectiveness of remediation actions in reducing sediment delivery are then evaluated against single, end-of-catchment targets for each of the 26 river basins draining to the GBR (The State of Queensland, 2013). This process is largely based on the outputs of catchment models. These outputs are used to predict sediment loads in each catchment, evaluate how the loads have changed from natural (or pre-agricultural) conditions, and determine how changes in land management are improving sediment delivery to the GBR (Barson et al., 2014; Waters et al., 2013). Measured contemporary water quality data are used to validate catchment models (e.g. Turner et al., 2013). Until recently, however, no data were available to constrain the pre-agricultural modelled erosion rates (Croke et al., 2015; Nichols et al., 2014).

Terrestrial cosmogenic nuclides (TCN), such as Beryllium-10 (^{10}Be), have been used to estimate the long-term (0.5–5 Ma) erosion rates of catchments around the world (Portenga and Bierman, 2011). Denudation rates are calculated as the time it takes to erode ~60 cm of regolith. Where erosion rates are high, the period can be just a few centuries. Where erosion is low, the period can be up to 100×10^3 years (Wasson, 2012). Beryllium-10 (^{10}Be) is a very rare radioactive nuclide produced when cosmic rays strike Earth's atmosphere, producing particle reactive forms of ^{10}Be that

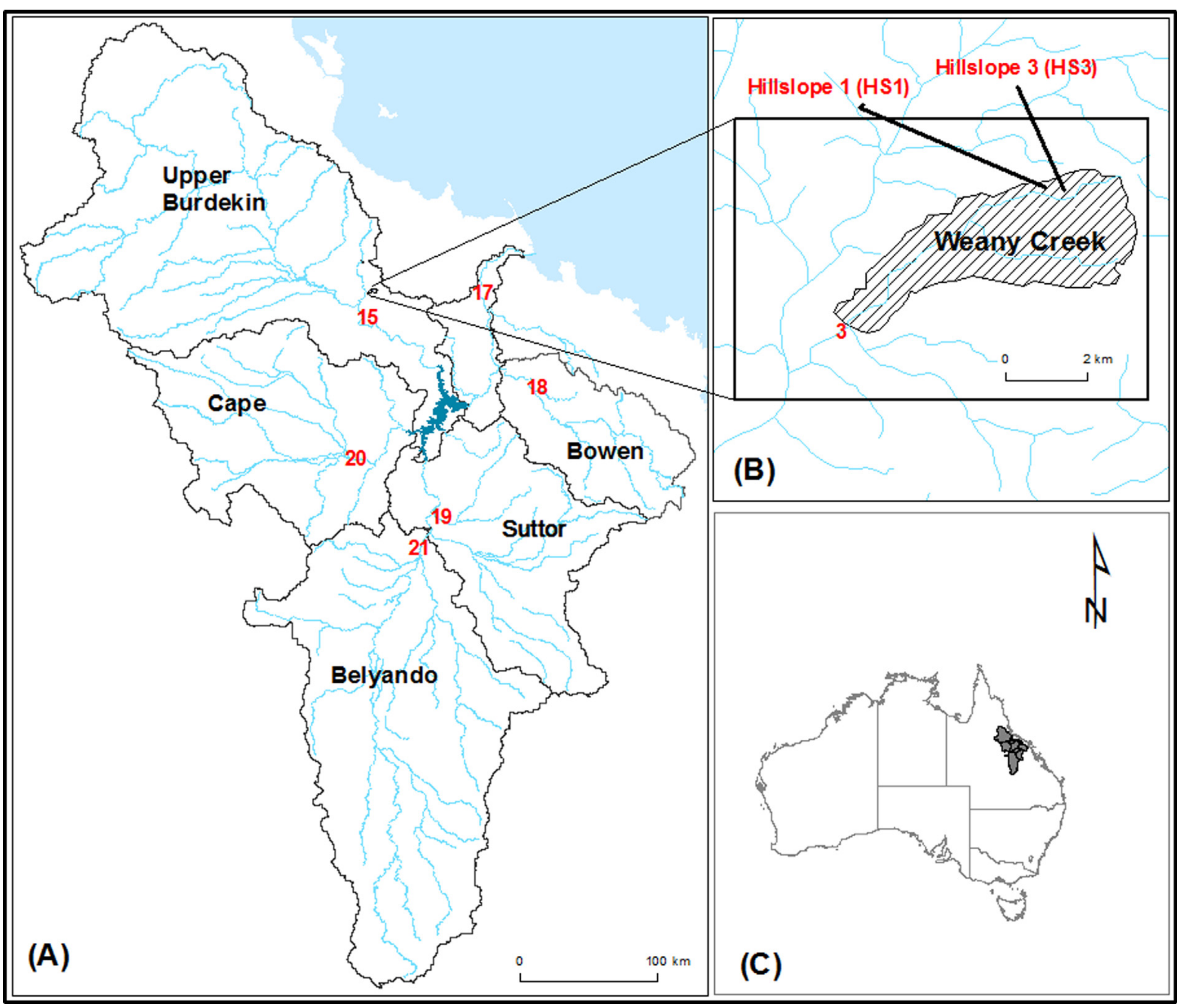

Fig. 1. (A) Location map of sampled sites in the Burdekin catchment. Site numbers correspond to sites in Croke et al. (2015) and Table 1; (B) The Weany Creek catchment; and (C) the location of the Burdekin catchment on the Australian continent.