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Degradation of the Mitchell River fluvial megafan by alluvial gully erosion increased by post-European land use change, Queensland, Australia

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ABSTRACT

Along low gradient rivers in northern Australia, there is widespread gully erosion into unconfined alluvial deposits of active and inactive floodplains. On the Mitchell River fluvial megafan in northern Queensland, river incision and fan-head trenching into Pleistocene and Holocene megafan units with sodic soils created the potential energy for a secondary cycle of erosion. In this study, rates of alluvial gully erosion into incipiently-unstable channel banks and/or pre-existing floodplain features were quantified to assess the influence of land use change following European settlement. Alluvial gully scarp retreat rates were quantified at 18 sites across the megafan using recent GPS surveys and historic air photos, demonstrating rapid increases in gully area of 1.2 to 10 times their 1949 values. Extrapolation of gully area growth trends backward in time suggested that the current widespread phase of gullying initiated between 1880 and 1950, which is post-European settlement. This is supported by young optically stimulated luminescence (OSL) dates of gully inset-floodplain deposits, LiDAR terrain analysis, historic explorer accounts of earlier gully types, and archival records of cattle numbers and land management. It is deduced that intense cattle grazing and associated disturbance concentrated in the riparian zones during the dry season promoted gully erosion in the wet season along steep banks, adjacent floodplain hollows and precursor gullies. This is a result of reduced native grass cover, increased physical disturbance of soils, and the concentration of water runoff along cattle tracks, in addition to fire regime modifications, episodic drought, and the establishment of exotic weed and grass species. Geomorphic processes operating over geologic time across the fluvial megafan predisposed the landscape to being pushed by land used change across an intrinsically close geomorphic threshold towards instability. The evolution of these alluvial gullies is discussed in terms of their initiation, development, future growth, and stabilisation, and the numerous natural and anthropogenic factors influencing their erosion.

1. Introduction

Gully erosion is a global phenomenon, a major cause of severe land degradation, and an important source of sediment pollution that reduces water quality and degrades aquatic ecosystems (Lal, 1992; Poesen et al., 2003; Valentin et al., 2005). In northern Australia, there is widespread alluvial gully erosion (sensu Brooks et al., 2009) into unconfined alluvial deposits on active and inactive floodplains and fluvial megafans (Simpson and Doutch, 1977; Payne et al., 1979; Condon, 1986; Biggs and Philip, 1995; Brooks et al., 2009; McCloskey, 2010; Sattar, 2011; Shellberg et al., 2013a, 2013b). Alluvial gullies eroding into large floodplain and megafan surfaces are a distinct end member along a continuum of gully form–process associations that are different from colluvial hillslope gullies, soft-rock badlands, and valley-bottom cut-and-fill channels in semi-confined floodplains (Brooks et al., 2009). Alluvial gully initiation and evolution can span across spatial and temporal scales in floodplain environments, from small anthropogenically enhanced alluvial gullies (e.g., Vandekerckhove et al., 2001, 2003) to large alluvial gully tributaries cut into floodplains during sea level lowstands and inundated by backwater during highstands (e.g., Mertes and Dunne, 2008; Parker et al., 2008). The existence of alluvial gullies indicates that large floodplains and fluvial megafans are not consistently depositional environments through time, but rather temporary stores of sediment along fluvial process domains (Schumm, 1977) that are subject to erosion cell dynamics (Pickup, 1985, 1991) at a variety of spatial and temporal scales.

On the 31,000 km^2 Mitchell River fluvial megafan on Cape York Peninsula in northern Queensland (Fig. 1), a minimum area of 12,900 ha of alluvial gullying and 5560 km of active gully front length were mapped using remote sensing (Brooks et al., 2009; Fig. 2). These areas of de-vegetated eroded sub-soils were concentrated in dispersible floodplain soils adjacent to incised main channels, and covered 0.4% of the megafan area and up to 10% of the local floodplain area. Using preliminary head scarp retreat data (GPS) from 2005 to 2007 at distributed gullies, along with scarp height and perimeter measurements, Brooks et al. (2008) estimated that these

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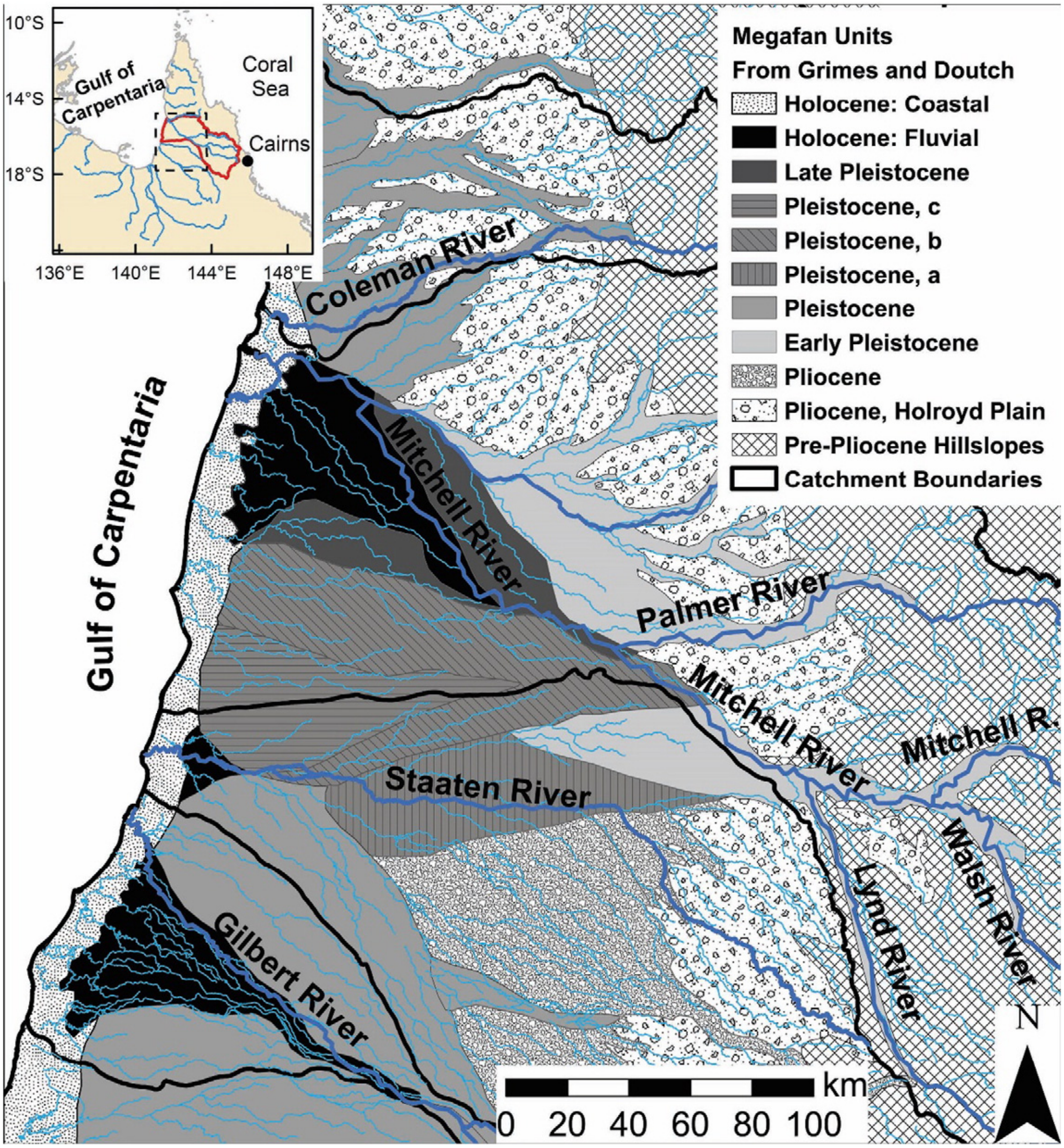

Fig. 1. Location and evolution of the Mitchell and Gilbert megafans from the Pliocene to Holocene (modified from Grimes and Doutch, 1978). The inset map of northern Queensland, Australia, shows the large map extent and the Mitchell catchment boundary.

gullies erode ~5 Mt yr^{-1} of alluvial soil from the megafan. Shellberg et al. (2013b) measured sediment yields of 89 to 363 t ha^{-1} yr^{-1} (2009–2010) at a stream gauge in a 33 ha gullied catchment (WPGC2a this study) on the Mitchell megafan. The degree to which these high erosion rates represent natural or human accelerated conditions is an important research question, toward which this current study will provide supporting data. Since soil erosion threatens the sustainability of the local cattle industry, aquatic ecosystems and the cultural use of water bodies, understanding rates of gully erosion pre- and post-European settlement is important to define past human land use impacts and the sensitivity of the landscape to further development.

Savanna catchments across northern Australia have undergone major land use changes from traditional Aboriginal management to widespread cattle grazing on unimproved rangelands since European settlement in the 1800s. Major alterations in grass cover, woodland thickening, exotic vegetation species, and fire regimes have resulted (Neldner et al., 1997; Fensham and Skull, 1999; Crowley and Garnett, 1998, 2000; Sharp and Whittaker, 2003; Bowman et al., 2004; Sharp and Bowman, 2004). Many assessments have documented, but not fully quantified, changes in sheet and gully erosion and sediment yield as a result of cattle grazing and/or European settlement in northern Australia (Medcalff, 1944; Payne et al., 1979; Condon, 1986; Wasson et al., 2002, 2010; Bartley et al., 2007, 2010; McCloskey, 2010; Hancock and Evans, 2010). Other sediment tracing studies in northern Australia have shown that current sediment loads are dominated by sub-surface erosion (typically >90%) from primarily gully erosion, channel erosion, deep rilling and scalded soils (Hughes et al., 2009; Caitcheon et al., 2012; Wilkinson et al., 2013; Hancock et al., 2014; Olley et al., 2013); but to date few studies have looked at how these rates and processes of erosion have changed through time. Elsewhere in south-eastern Australia, sediment yields clearly increased from accelerated soil, gully, and channel erosion associated with post-European land use (Condon et al., 1969; Eyles, 1977; Wasson and Galloway, 1986; Pickup, 1991; Prosser and Winchester, 1996; Brooks and Brierley, 1997; Wasson et al., 1998; Fanning, 1999; Olley and Wasson, 2003; Rustomji and Pietsch, 2007).

The main objectives of this study were to investigate the growth rates of alluvial gullies and their evolution over time, and the stability of floodplain features and their threshold response to disturbance.