

Land-use change from indigenous management to cattle grazing initiates the gullying of alluvial soils in northern Australia

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Abstract

Catchments in northern Australia have undergone dramatic land-use changes from traditional Aboriginal management to widespread cattle grazing post-European settlement. Quantifying the soil erosion impacts of these changes is essential to the future sustainable management of the soils in these catchments. Rates of gully erosion in alluvial soils were measured using recent GPS surveys and historical air photographs. The results indicated that median erosion rates currently and historically are within the same order of magnitude (0.1 to 1m per year). Historic air photo analysis demonstrated rapid increases in gully area of 2 to 10 times their initial 1949 area. Extrapolation of gully area growth trends backward in time suggested that most gullies initiated between 1880 and 1950. European cattle were introduced into the lower Mitchell catchment in the 1880's, suggesting the contribution of land use intensification to either gully initiation or acceleration. It is hypothesized that intense cattle grazing concentrated in the riparian zones during the dry season decreased perennial vegetation cover along hollows and steep river banks, increasing the potential for gully erosion. Once initiated on steep banks into dispersible sub-soils, alluvial gullies can rapidly progress in consuming and degrading the most productive part of the landscape, the riparian zone.

Key Words

alluvial gully erosion, dispersible soils, cattle grazing, sediment dating, air photographs, historical analysis

Introduction

Detailed remote sensing mapping within the 31,000 km² Mitchell River fluvial megafan has identified that active gullying into alluvial soils occupies a minimum of 0.4% (129 km²) of the lower Mitchell catchment, with an estimated active front length of around 5,560 km (Brooks et al 2009). It is estimated that these gullies erode more than 5 million tonnes of alluvial soil per year (Brooks et al 2008). This soil erosion is concentrated along the riparian zone of the lower Mitchell River, where duplex soils that are strongly alkaline at depth have evolved from the original deposits of alluvial sand, silt and clay (BRS 1991). The erosion of these soils presents a major threat to both the local pastoral industry and downstream aquatic ecosystems. For example, the riparian 'frontage' of the Mitchell River is the most productive cattle grazing county in the catchment due to higher nutrient levels in younger soils as well as year round access to water. But it is also these dispersible riparian soils that are susceptible to accelerated erosion via gullying, which in turn pollutes downstream ecosystems with excess sediment. Therefore a management conundrum exists over the unsustainability of grazing these fragile alluvial soils.

Before soil conservation practices are implemented across catchments in northern Australia to reduce alluvial gully erosion of riparian soils, it is essential to investigate rates of alluvial gully erosion pre- and post-European settlement in order to better understand the potential human contribution(s) to land degradation. Data on erosion rates and initiation timing can be used in conjunction with process based studies on the driving and resisting factors for alluvial gully erosion, to more directly target remediation measures that will actually address the causes of human accelerated soil erosion. Some of the driving (climate, relief, floodplain hydrology) and resisting (soil chemistry, vegetation cover) factors for alluvial gully erosion are reviewed in Brooks et al (2009). In this paper, preliminary results of historical alluvial gully erosion rates in the lower Mitchell catchment are highlighted, which support the hypothesis that the introduction of cattle and the concentrated grazing in riparian zones decreased vegetation cover along hollows and steep banks of the rivers, which subsequently promoted gullying and pushed the landscape across a threshold towards instability.

Methods

Recent erosion rates (2005-2009) were measured at 20 alluvial gully fronts (scarps) sites totalling 50,040m of common gully front repeatedly measured using *in-situ* differential GPS with sub-meter accuracy (Trimble with Omnistar High Precision). Accuracy depended on signal strength and vegetation cover, but was typically within 0.5 meters for repeat surveys. Historic erosion rates (1949 to 2007) were measured from

decadal historical air photographs at 15 of the 20 study sites mentioned above. Digital copies of the photographs were georeferenced in ARC-GIS and the gully front locations were digitized, totalling 43,163m of common gully front repeatedly measured. Annual average linear erosion rates (m/yr) from GPS surveys and historic air photos were calculated by dividing the area change (m²) over two consecutive time periods (years) by the scarp perimeter (m) measured at the later timer period. Trends in gully area over time were analysed using negative exponential functions well established in fluvial geomorphology (e.g., Graf 1977; Simon and Rinaldi 2006), but slightly modified for analysing changes in gully planform area over time.

$$\frac{A}{A_0} = a + be^{(-kt)} \quad (1)$$

where A is the exposed gully area at time t , A_0 is the initial gully area at $t_0 = 0$, a and b are dimensionless coefficients determined by regression, k is a coefficient determined by regression that defines the rate of change in gully area over time, and t is the time (years) since the initial starting point or the first air photograph.

As an indicator of land-use change over time, total cattle numbers on the land aggregation unit of Wrotham Park Station in the heart of the lower Mitchell catchment from 1880 to 2007 were obtained from the Queensland State Archives of historic lease applications. These data were also compared to data on total cattle numbers in Queensland from the Australian Bureau of Statistics. Insights into land condition prior to the introduction of cattle grazing, were gained from the diaries of Ludwig Leichhardt and John Gilbert who travelled down the Mitchell River together in June 1845, past numerous sites of currently extensive alluvial gully erosion (Gilbert 1845; Leichhardt 1847).

Results and Discussion

The median annual rate of scarp retreat was estimated from recent GPS measurements (2005-2009) to be 0.23 m per year across 50,040m of gully front. Annual rates calculated from historic photos (1949-present) at most of the same locations were within the same order of magnitude (0.1 to 1.0 m/yr), but with a higher median value of 0.37 m per year across 43,163m of gully front. Historic air photo analysis demonstrated rapid increases in relative gully area (A/A_0), with area increases 2 to 10 times the initial 1949 area (Figure 1). Values of the coefficient k in Equation 1 were small (0.0007 to 0.0028), indicating that erosion rates were near linear over time. However, rapid changes in erosion rates are often measured early in gully erosion cycles (e.g., Graf 1977), suggesting that the absence of pre-1949 photos might skew the trend lines toward a more linear form. Nevertheless, extrapolation of gully area growth trends backward in time, using Equation 1 and existing data, suggested that most gullies initiated (zero area) between 1880 and 1950. This is corroborated by tree ring analysis and OSL dating of gully age, results that are not presented here. Several gullies that were slow growing, with relative gully area (A/A_0) increases of less than 2 (Figure 1), had indeterminate initiation dates. However, these gullies had the largest k -values and strongest non-linear trends, suggesting that their erosion rates were higher early in the erosion cycle and trended towards an initiation point near European settlement in the late 1800's.

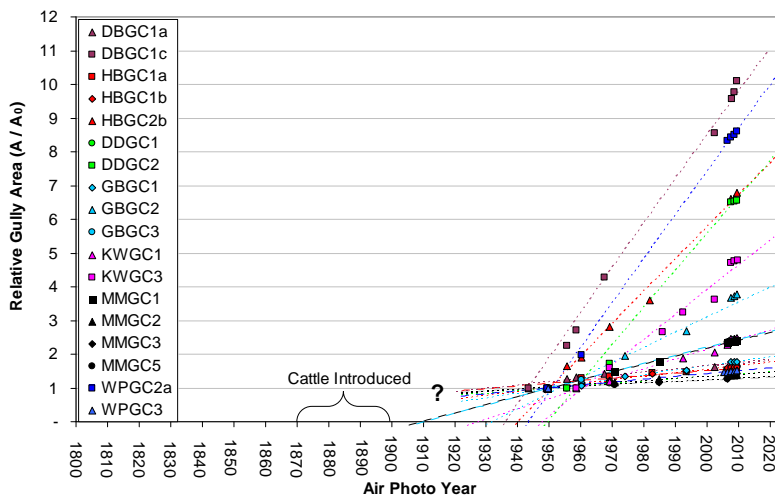


Figure 1. Relative changes in gully area over time, which is the ratio of the area at any time (A) and the initial gully area (A_0).

Historical data on the numbers of cattle in both the lower Mitchell catchment (Wrotham Park Aggregation) and the state of Queensland are shown in Figure 2. Cattle introduction in the Mitchell occurred around 1880, much later than in the rest of Queensland. The initial peak of cattle in the Mitchell catchment occurred between 1910 and 1920, similar in timing to the second Queensland peak. Subsequent fluctuations in cattle numbers both locally and regionally were strongly influenced by world cattle prices, droughts and grass availability, and the increased use of Brahman cattle (*Bos indicus*) in the early 1970's.

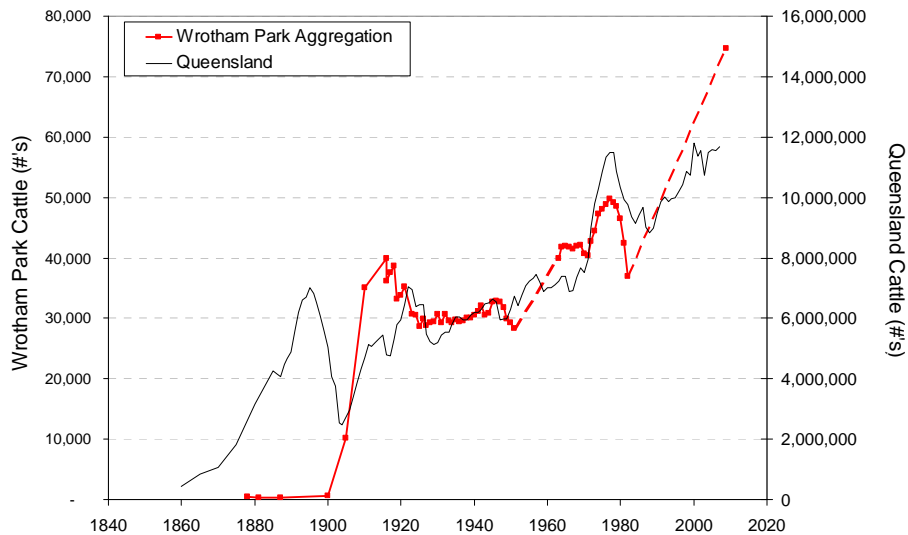


Figure 2. Historic trends in the numbers of beef grazing cattle at the historic Wrotham Park Aggregation cattle station (including Wrotham Park, Gamboola, Gamboola South, Highbury, Drumduff), in addition to historic trends in Queensland beef cattle numbers.

While the upward trend in cattle numbers (Figure 2) follows the upward growth trend in gully area (Figure 1), this correlation does not support a *continued* cause and effect relationship between cattle grazing and gully area. More likely, the similarity in these trends suggests that the *timing* of the initiation of many of these gullies coincided with the *timing* of the introduction of European cattle near the turn of the century. That is, the causal mechanisms for the initiation of these gullies might be different that the mechanism that continue to propagate these gullies across the landscape once initiated (Brooks et al 2009).

Descriptions of the lower Mitchell landscape by Gilbert (1845) and Leichardt (1847) included references such as:

1. "The banks of the river were so steep, that the access to its water was difficult." (Leichardt 1847)
2. "[We] keep well back [from the river] to avoid the deep gullies frequent on the immediate banks of the river." (Gilbert 1845)
3. "...the [floodplain] was interrupted by gullies, and occasionally by deep creeks, which [were] the outlets of the waters collecting on the [floodplain]." (Leichardt 1847).
4. "We as usual had very distant gullies and hollows to cross; the banks of the river being very steep with very indifferent camping places." (Gilbert 1845)

These observations indicate that at least hollows and some form of gullies existed along the immediate banks of the Mitchell River pre-European settlement. However, nowhere in either Liechardt (1847) or Gilbert (1845) were the terms erosion, eroded, bare, stripped, de-vegetated, dissected, unstable, incision, head cut, scarp, drop off, break-away, badland, or wasteland used to describe the soil surface, gullies, hollows, or creeks. These are terms and descriptions that would be used to describe these areas today (Brooks et al. 2009). It is more likely that they observed the precursor unchannelled hollows and small creeks that subsequently eroded into the massive alluvial gullies observable in air photos and measured in Figure 1.

Brooks et al (2009) developed a conceptual model for the evolution of alluvial gullies in the Mitchell catchment over time. These alluvial gullies initiate as surface erosion and/or disturbance along unchannelled hollows and/or the steep banks of rivers and lagoons (Figure 3, stage 1a). As gully erosion proceeds and incises (cuts) into the dispersible sub-soils of the riparian zone, the dominant sources of water for erosion

switch from surface floodwater and rainfall runoff to subsurface seepage erosion and erosion by soil piping. Once initiated, the data from Figure 1 suggests that erosion continues at a relatively consistent rate regardless of driving factors such as climate or changes in vegetation cover from grazing or fire. These factors are likely more important in the gully *initiation* process.

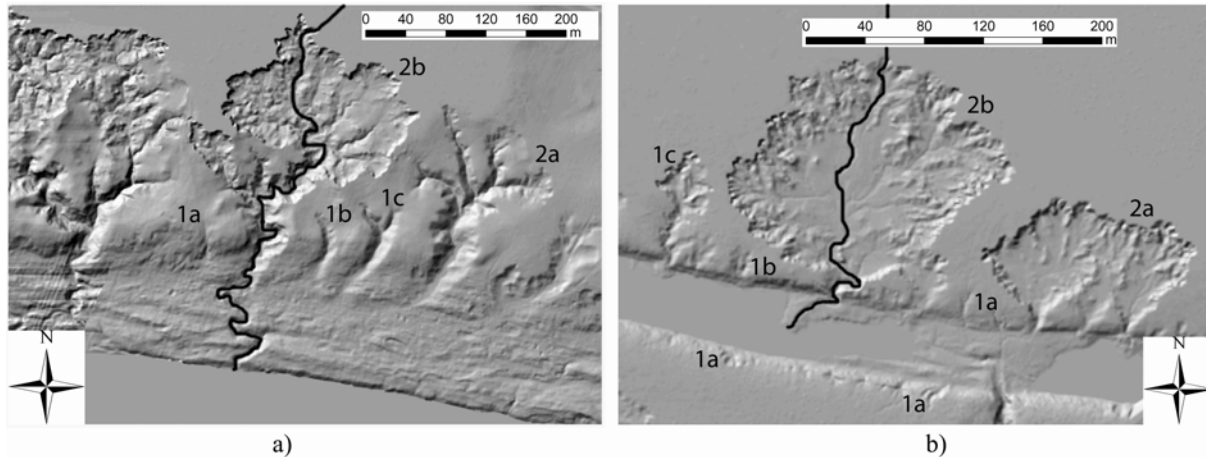


Figure 3. LiDAR DEM hillshades of alluvial gullies at different stages of evolution. Numbered gully labels in figures refer to stages of gully evolution: 1a to 1c are incipient gully stages, 2a and 2b are respectively, bounded and unbounded proximal gully stages.

Conclusions

Similar to analysis of Condon (1986) on the Victoria River in northern Australia, it is hypothesized that intense cattle grazing concentrated in the riparian zones of the Mitchell River during the dry season, in addition to fire regime modification and weed introduction, decreased perennial vegetation cover along hollows and the steep banks of river, both observed by Gilbert (1845) and Leichardt (1847). This land use change initiated a new larger phase of gully erosion and pushed the landscape across a threshold towards instability, which it was already close to as a result of the riverine landscape evolution over geomorphic time (Brooks et al 2009). Once initiated on steep banks into dispersible sub-soils, alluvial gullies can rapidly progress in consuming and degrading the most productive part of the landscape, the riparian zone. The conceptual model of the evolution of these alluvial gullies prepared by Brooks et al (2009) supports these hypotheses and describes their initiation, development, and potential stabilization over time. Overall, these data demonstrate the fragility of northern Australia's soils to land-use change and the potential for land-use change to cross erosional thresholds that permanently destabilize riparian landscapes.

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