Geomorphology of gravel-bed rivers three years after high-severity bushfire

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Key Points

- Geomorphic comparisons were made between four low-order gravel-bed rivers, which had been burned to varying degrees during the 2019-2020 Black Summer bushfires in eastern Australia.
- No significant differences were found in low-flow channel dimensions, proportion of pools, proportion of bedrock, and pebble size.
- Significant differences were found in bankfull channel dimensions, proportion of riffles, and proportion of bars.
- Bushfire severity was not an adequate predictor of geomorphic differences three years post-fire.

Abstract

Geomorphic change after bushfires is a concern for the management of many Australian rivers. Many studies skip from broad-scale assessments of burn extent and severity to downstream water quality and/or to effects on large charismatic fauna. Comparatively little attention is given to fluvial geomorphology. This study assesses the geomorphic similarities and differences in four gravel-bed rivers three years after high-intensity bushfire. At eight locations per site, we performed Wolman pebble counts and mapped in-channel geomorphic units. Cross-sections were taken at three locations per site and used to compare low flow and bankfull channel width and depth. Sites with more severely burned catchments had wider bankfull dimensions and higher proportions of bars and riffles. Sediment size and proportion of pools were also different but did not show statistical significance. Overall, either the rivers did not change much after the bushfires, or those that were more severely impacted have since recovered. The lack of geomorphic differentiation between river reaches with vastly different upstream catchment burn severities demonstrates the complex relationship between geomorphology and catchment disturbance regimes. In this case, bushfire severity alone is not a predictor of significant geomorphic change.

Keywords

Bushfire effects, fluvial geomorphology, disturbance response, southeastern Australia, gravel-bed rivers

Introduction and Study Location

Fires have many long- and short-term effects on river health and geomorphology (Bixby et al., 2015; Gomez-Isaza et al., 2022; Verkaik et al., 2013). Fires that burn at high temperatures can induce or increase water repellency in soils (Doerr et al., 2004; Shakesby & Doerr, 2006). Alternatively, in some eucalypt forests in south-east Australia, severe fires can either increase or reduce water repellency in the uppermost layer of soil (Doerr et al., 2004; Shakesby et al., 2007). Where fires remove vegetation and change water repellency such that soil erosion rates increase or hillslopes fail, rivers may experience changes to geomorphology, such as sediment slugs, which take years or decades for them to fully recover from (Nyman et al., 2011, 2019; Shakesby, 2011; Shakesby & Doerr, 2006). Post-fire rainfall plays a critical role in bushfire-driven changes to river geomorphology (Cooper et al., 2015; Shakesby, 2011; Verkaik et al., 2013). In south-east Australia, fire impacts on riverine geomorphic processes are highly variable (Shakesby et al., 2007).

During the “Black Summer” of 2019–2020, unprecedented megafires burned across > 243,000 km^2 of eastern Australia (Binskin et al., 2020; Filkov et al., 2020). In southern NSW coastal catchments, more than half (53 %) of land area burned; 17 % of all land and 10 % of all streamlines burned at extreme severity (Fryirs et al., 2022).

This study aims to add to the body of data concerning geomorphic change in rivers after bushfires. It will examine geomorphic differences among four tributaries of Dignam’s Creek, a small (≈100 km^2) coastal catchment in southern New South Wales (Figure 1). Gulaga and Kooraban National Parks occupy 77 % of the catchment, with the remaining land use a mix of bushland, agriculture, and low-density housing (NSW DPE, 2020b). Between 26 December 2019 and 3 March 2020, ≈64 % of the Dignam’s Creek catchment burned in the Badja Forest fire (NSW DPE, 2020a).

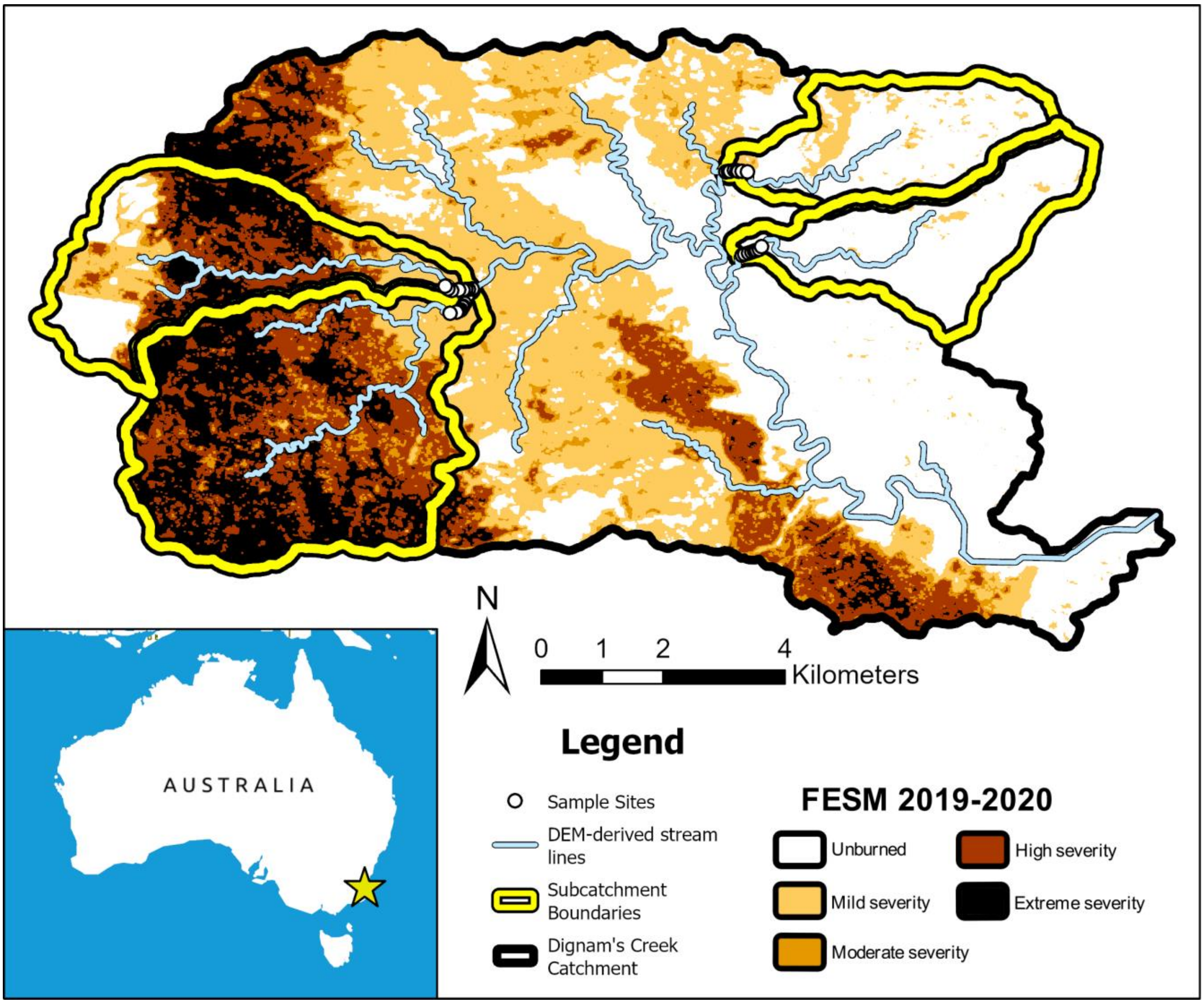

Figure 1. Map of Dignam’s Creek and tributaries with DEM-derived streamlines, subcatchment delineations, sample locations, and fire severity data. Unburned: 0 % canopy and understory burnt. Mild: > 10 % understory burnt, < 10 % canopy burnt. Moderate: 20 % – 90 % canopy scorch. High: > 90 % canopy scorch, < 50 % canopy consumption. Extreme: > 50 % canopy consumption. Inset map shows location of study site. Data from DFSI Spatial Services, 2013, 2016, 2018; NSW DPE, 2020. Service layer credits: Esri, TomTom, FAO, NOAA, USGS.

The four study site tributaries have similar catchments in terms of surface geology, soil types, and plant communities (DPIE, 2021a, 2021b; NSW DPE, 2018, 2022). At the sample locations, which are located just upstream of confluences, the tributaries are gravel bed and either confined with floodplain pockets or partly confined bedrock-controlled (Brierley & Fryirs, 2004).

Methods

Each site's catchment was assigned an area-weighted catchment burn severity (WCBS) value based on GIS analysis in ArcGIS Pro 3.0.3 (*ArcGIS Pro*, 2022) of 2019–2020 Fire Extent and Severity Maps (FESM) (NSW DPE, 2020a). The FESM dataset categorizes each 10 m pixel of land into one of five burn severity categories based on changes in the normalized difference vegetation index (NSW DPE, 2023). The WCBS value ranges from 0 (unburned) to 5 (full canopy consumption across entire catchment).

Fieldwork occurred in April and May 2023, just over three years after the Black Summer fires. Eight pools, each at least 10 meters apart, were selected as sample locations at each site. Each sample location pool and the surrounding area were sketched in the field. Planform sketches depicted geomorphic units (e.g. pools, riffles, bars, flood channels) and the current water level. Sketches were digitized to determine percent composition of within-channel geomorphic units. Modified Wolman pebble counts (Wolman, 1954) were taken at each sample location, with a total of 60 pebbles measured per sample location. Tape and clinometer cross sections were taken at three sample locations per site. These locations were selected to capture the physical diversity of each site. Each cross-section spanned bank to bank and crossed the sample pool at its deepest point. Bankfull and low-flow dimensions were derived from these cross-sections.

Statistical analysis and visualization were performed in R 4.3.3 (R Core Team, 2024), using RStudio (RStudio Team, 2020) and the agricolae (Felipe de Mendiburu and Muhammad Yaseen, 2020), ggplot2 (Wickham, 2016), ggpubr (Kassambara, 2023), multcomp (Hothorn et al., 2008), multcompview (Graves et al., 2024), and tidyverse (Wickham et al., 2019) packages. Pebble counts and proportions of geomorphic units were individually evaluated with one-way ANOVAs to determine if differences between the four sites were statistically significant. Tukey's HSD post-hoc test was used to assign groups. Low-flow and bankfull dimensions had few samples (n = 3 per site) and were evaluated via non-parametric Kruskal-Wallis rank sum tests with Bonferroni p-adjustments to determine if differences were significant and assign groups.

Results

The sites had a range of WCBS values: 0.12, 0.55, 3.28, and 4.40. Median pebble b-axis length did not significantly vary among sites (Figure 2). More severely burned sites showed reduced variability and reduced amounts of small-diameter pebbles (< 20 mm) and sand. In-channel proportion of pools and exposed bedrock did not significantly vary among sites (Figure 3b, 3c). In-channel proportion of bars and riffles did vary significantly (Figure 3a, 3d). The site with the highest WCBS value had a significantly higher proportion of riffles. Among proportion of bars, one site with a high WCBS value was significantly higher than one site with a low WCBS value, but no overall trend was apparent.

Low-flow width, depth, and cross-section area did not significantly vary among sites (Figure 4a, 4c, 4e). However, bankfull width, depth, and cross-section area did vary significantly (Figure 4b, 4d, 4f). In each bankfull dimension, a site with a higher weighted catchment burn severity value was significantly larger than a site with a lower WCBS value. A limitation of this result is that bankfull dimensions were not standardized to catchment area.

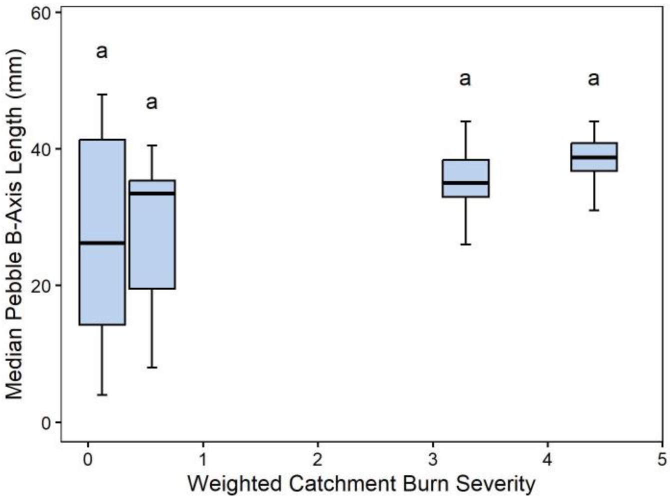

Figure 2. Median pebble b-axis length of four study sites and results of Tukey's HSD post-hoc test. Sites with shared letters are not significantly different.

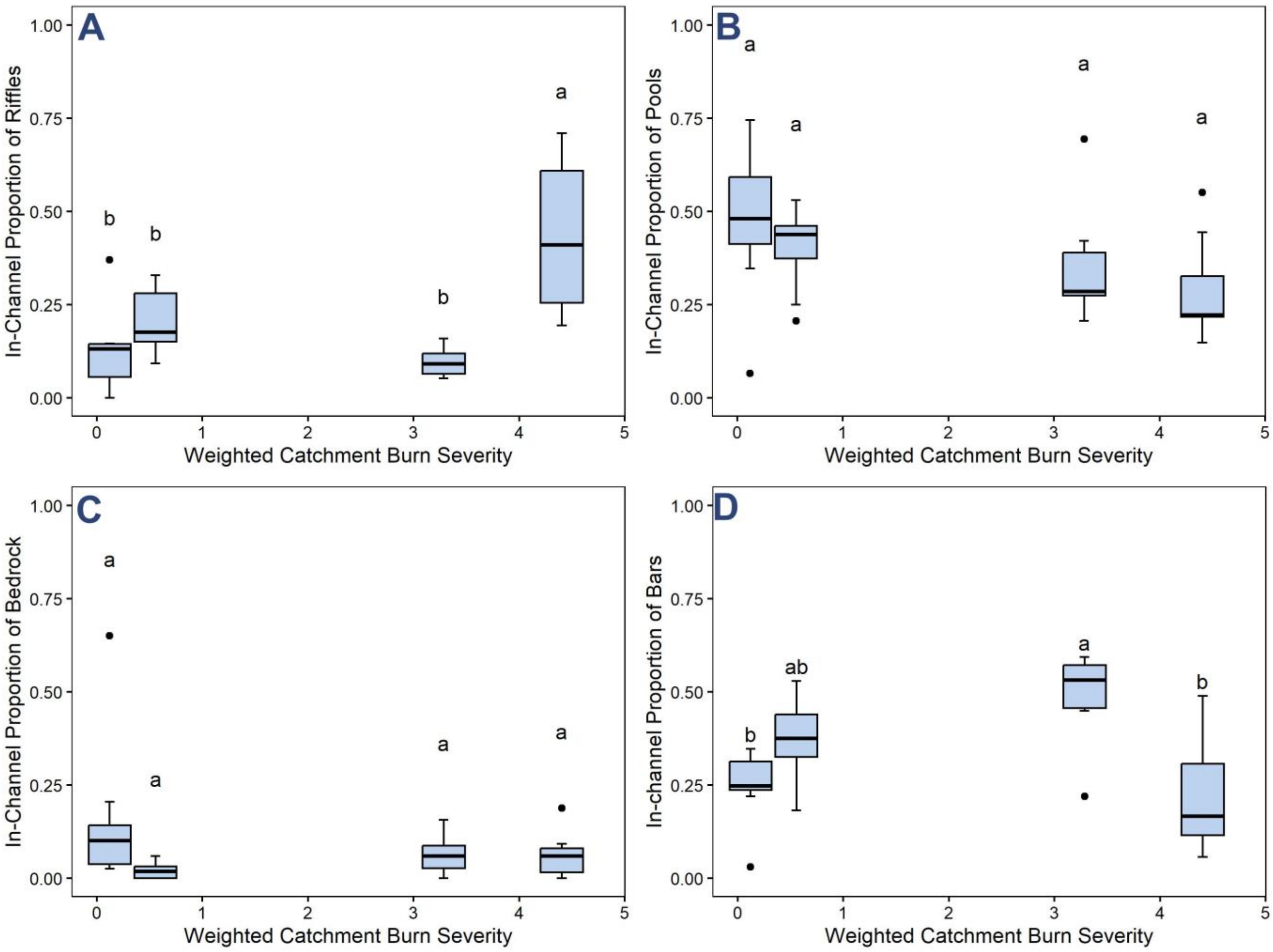

Figure 3. Geomorphic unit proportions of four study sites and results of Tukey's HSD post-hoc tests. Sites with shared letters are not significantly different.

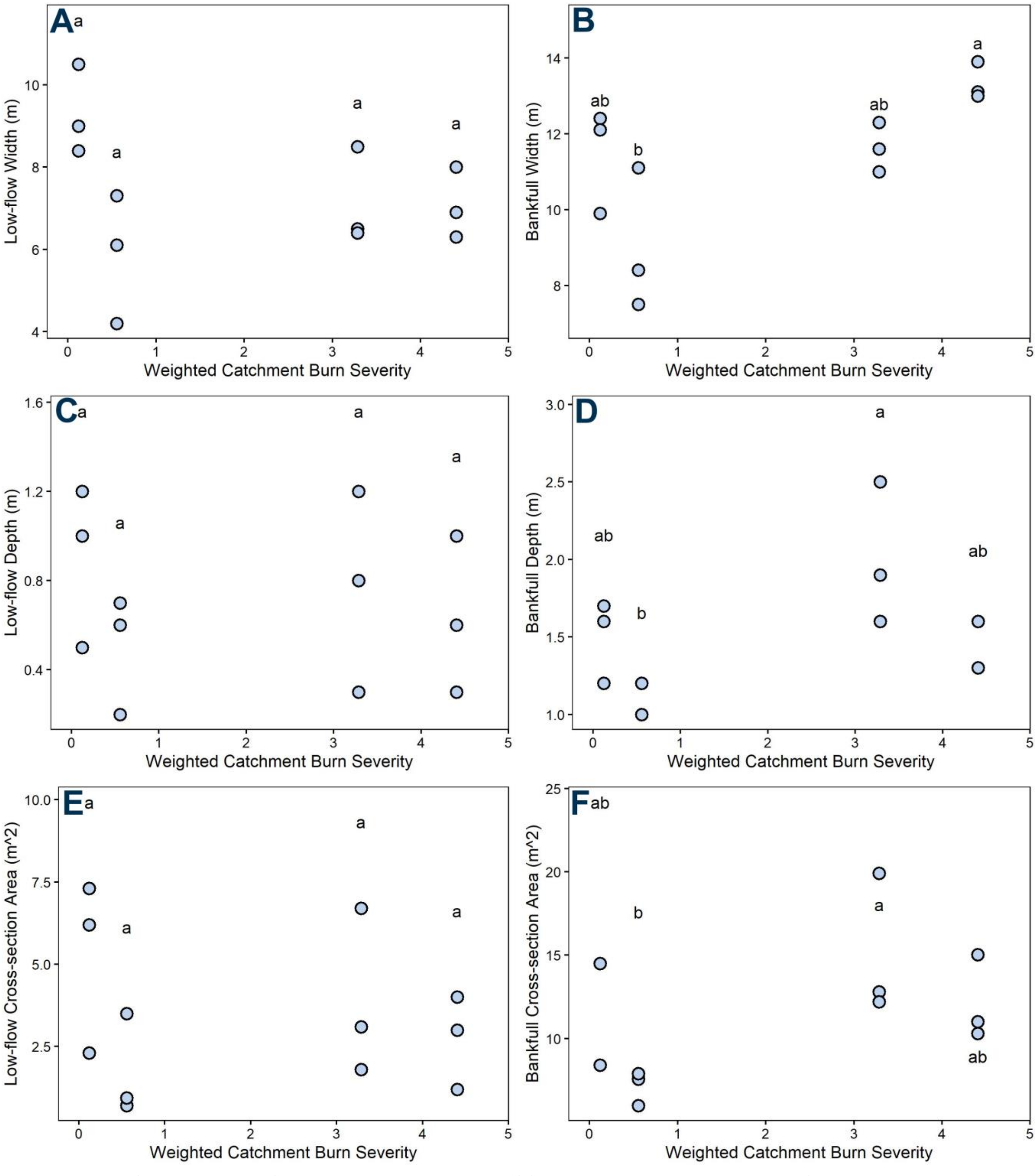

Figure 4 . Low-flow and bankfull channel dimensions of four study sites and results of Kruskal-Wallis rank sum tests. Sites with shared letters are not significantly different.

Discussion

Overall, there were few significant differences in the physical characteristics of the sites. Because of the long timeframes of geomorphic recovery (Nyman et al., 2011, 2019; Shakesby, 2011; Shakesby & Doerr, 2006), the sites' overall similarity three years post-disturbance likely means that they were relatively unaffected. The metrics which significantly differ at this point may take years to recover if directly related to bushfire impacts, or they may be due to underlying catchment differences and pre-fire conditions.

Channel geomorphology responses post-bushfire are highly variable (Leonard et al., 2017; Shakesby & Doerr, 2006). Sediment transport is unpredictable. Some literature suggests that changes in sediment supply are linked strongly to riparian zone burn intensity and weakly to upland burn intensity (Sheridan et al., 2007). Others find no difference in sediment flux between sites with burned and unburned riparian zones (Cooper et al., 2015), or seemingly uncorrelated responses with fire (Leonard et al., 2017). Among the more severely burned tributaries of Dignam's Creek, we have documented a potential decrease in fine sediment transport, but not a statistically significant one (Figure 2).

The most apparent difference in geomorphic units is the greater proportion of riffles in the most severely burned site (Figure 3a). Flow has not been sufficient in these reaches to transport and rework the additional coarse sediment inputs. As that site is confined by its valley within and upstream of the sample reach, the sediment will likely remain in place for years or decades, slowly migrating downstream during peak flows, and may be reworked into bars and benches as the channel narrows (Fryirs & Brierley, 2012; Leonard et al., 2017; Lyon & O'Connor, 2008). The second-most burned site, however, had a greater proportion of bars compared to the other three sites (Figure 3d). As with the most-burned site, this may indicate an influx and deposition of significant loads of sediment resulting from changes in the catchment. However, the second-most burned site has been able to rework the sediment flux into bars. This may be because it received less sediment input or because it had greater stream power with which to do geomorphic work compared to the most-burned site.

The differences noted in bankfull width, depth, and cross-section area (Figure 4b, 4d, 4f) may be attributable to changes post-fire. However, these were estimates based on cross-section profiles taken during base flow conditions, which may have introduced error; alternatively, they may have resulted from underlying differences in the catchments and not from recent disturbance.

This study is limited by the lack of data from before the 2019-2020 bushfires. It is difficult to determine whether any geomorphic differences are the result of the fires or of underlying differences between the sites.

Conclusion

This study added to the body of evidence regarding bushfire impacts on fluvial geomorphology. We used field-based methods to compare the geomorphology of four low-order gravel-bed rivers in southern New South Wales, three years after the 2019-2020 Black Summer fires burned the rivers' catchments. The rivers' geomorphic attributes were not significantly different, with the exceptions of bankfull channel dimensions, in-channel proportion of riffles, and in-channel proportion of bars. Overall, we found that catchment burn severity was not a strong predictor of geomorphic change.

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