Riverbank mass failure and enhanced sediment supply after fires and floods in the Tuross River, NSW

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Key points

- Coupled fire–flood events from 2019-2022 increased sediment delivery to the Tuross River.
- Loss of riparian vegetation due to wildfire, subsequent high river levels, and saturated floodplain conditions promoted riverbank mass failure and rapid channel adjustment.
- A ~200 m long bank collapse released ~6,600 m^3 of sediment, representing a substantial local and catchment-wide increase in sediment supply.
- Local river conditions were affected and downstream transport of sediment has implications for water quality, aquatic processes and estuary condition.

Abstract

Patterns and processes of catchment disturbance, connectivity, and transfer of sediment to waterways from hillslopes and floodplains following bushfires and floods are poorly understood in eastern Australia. Fires cause biophysical alterations to vegetation and soils, leading to changes in infiltration, runoff, and erosion potential when heavy rainfall occurs. These factors may compound at the scale of a river reach due to the interaction of broader, catchment-scale processes with local fire and flood impacts. Saturated floodplain conditions, loss of riparian vegetation and associated roughness, and rapidly changing river levels can lead to bank erosion and slumping which may be key modes of geomorphic adjustment. This was documented using satellite imagery, photogrammetry and field observations in a partly-confined reach of the Tuross River on the south coast of NSW following the 2019/20 Australian 'Black Summer' bushfires and subsequent 2020 and 2021 floods. Mass failure of a ~200 m section of riverbank and subsequent bank retreat and floodplain erosion liberated an estimated ~6,600 m^3 (~9,950 t) of sediment directly to the river. This represents a significant enhancement in sediment supply to this reach, and also to the lower Tuross River sediment budget overall. Subsequent revetment works largely stabilised the bank, limiting channel expansion. While the fate of the eroded sediment is unknown, it likely contributed to deleterious impacts on downstream water quality, aquatic processes and habitats in the system, which are important considerations for river and estuary management.

Keywords

Bushfire, erosion, sediment budget, riparian conditions, aquatic ecosystem impacts

Introduction

The 2019/2020 'Black Summer' bushfires in southeastern Australia burnt 12.6 million hectares of land. Much of this was situated within NSW's coastal catchments, where fires were so extreme that they extended into riparian environments typically resistant to high-severity burning. In the 19 main coastal catchments of NSW, ~55,000 km^2 of land and ~ 23,300 km of stream length was burnt, approximately 30 % of the total surface area and the total stream length of these catchments (Fryirs et al., 2022). The fires were followed by heavy rainfall and major floods in 2020 and 2021, triggering hillslope erosion and pronounced declines in estuarine water quality (NSW DCCEEW, 2024). These impacts did not occur in isolation but were part of a larger cascade of hazards with compounding impacts on the NSW coast (Kemter et al., 2021). Drought conditions dried the environment for fires, and fires cleared the way for floods.

By clearing vegetation that would otherwise stabilise soils, fire increases the risk of hillslope erosion. Burning in riparian zones can also reduce the vegetative component of hydraulic roughness which serves to dissipate flow energy and decrease the erosive force exerted on riverbeds and banks during high-flow periods. Additionally, fire increases the water repellency of soils leading to reduced infiltration and greater flood risk during periods of high rainfall. Post-fire rainfall can produce several erosion types in both small and large watersheds which can lead to elevated sedimentation rates, poor water quality, and altered aquatic habitats (McGuire et al., 2024). In upper catchments and smaller watersheds, the influence of fire on erosion risk and the effects of post-fire sediment mobilisation have been well studied as sediment sources can be distinguished, transport pathways are short and direct, and the depositional fate is mostly defined by elevation (Smith et al., 2012). However, in larger watersheds the transfer and fate of fire-derived sediment is mediated by catchment (dis)connectivity. Geomorphic features like valley constrictions, floodplains, and intact riparian corridors can store and mix sediment for months to millennia which decouples sediments sinks from sources (Fryirs, 2013). As such, the influence of disturbances like wildfires on sediment flux is largely unknown (Ielpi and Lapotre, 2023). In particular, the way catchment-scale increases in runoff interact with local fire and flood impacts to mobilise sediment is not fully understood.

This paper describes a riverbank mass failure on the lower Tuross River that was triggered in July 2020 and uses unmanned aerial vehicle (UAV) photogrammetry to estimate the volume of sediment mobilised from this site over the following years. Then we assess the significance of the sediment exported from this site to the overall sediment budget of the river. We discuss how the extreme fire-flood event sequence resulted in catchment-scale and local effects that likely interacted to destabilise the bank and cause the slumping, as well as the consequences and management implications of the event for downstream aquatic ecosystems.

Catchment setting and site location

The Tuross River drains a ~2,200 km^2 catchment, rising on the eastern slopes of the Kyebyan Range, part of the Great Dividing Range, and flowing approximately 140 km to Tuross Lake, a wave-dominated barrier estuary, where it discharges to the Tasman Sea (Figure 1). Rainfall varies from 700-1100 mm with the maximum annual rainfall occurring at the northern and southern bounds of the catchments. The geology of the catchment consists of Palaeozoic metasedimentary and granitic lithologies in the upper and middle reaches and Quaternary alluvium in the lower river and estuary. Land-use in the catchment is mixed; other than national parks, reserves and forestry, livestock grazing accounts for ~10 % of the total catchment area and irrigated land associated with dairy farms occur on the lower floodplain, accounting for ~1 % of the catchment (DPI, 2016). Urban development is limited to the small towns of Tuross Head and Bodalla, as well as several small villages scattered across the catchment. Tuross Lake, however, supports a notable oyster industry whose productivity is highly sensitive to fluctuations in nutrient levels and overall water quality.

The study reach of the lower Tuross River has a moderately sinuous meandering channel with discontinuous floodplain pockets set within a partly-confined valley (Figure 1). Floodplain and bank stratigraphy in the lower Tuross is characterised by sand and silty-sand layers of alluvium, associated with overbank deposition during the Holocene, although episodic floodplain erosion and stripping has occurred (Ferguson and Brierley, 1999).

The Tuross River was one of the most severely impacted catchments by the 2019/2020 Black Summer bushfires, with 74 % of the total catchment and 70 % of the total stream length burned (Fryirs et al., 2022). At the site of the Tuross bank mass failure, fire extended across the whole the channel, fully consuming or scorching mature riparian vegetation (Figure 1C). Following the fires, several high-rainfall periods occurred that progressively destabilised burnt areas. The first, in February 2020, triggered debris flows in upper-catchment tributaries and delivered a significant pulse of fire-derived sediment to the estuary, elevating turbidity and nutrient loads (NSW DCCEEW, 2024). Further heavy rainfall in July/August 2020 and again in March 2021 saturated floodplains and drove sustained high flows through the partly-confined lower reaches.

Methods

Historical imagery and hydrology

Repeat satellite imagery was sourced from Google Earth for the period 2018-2024 to establish a timeline for the bank mass failure event. Hydrology data was sourced from NSW Water Insights (WaterNSW, 2026).

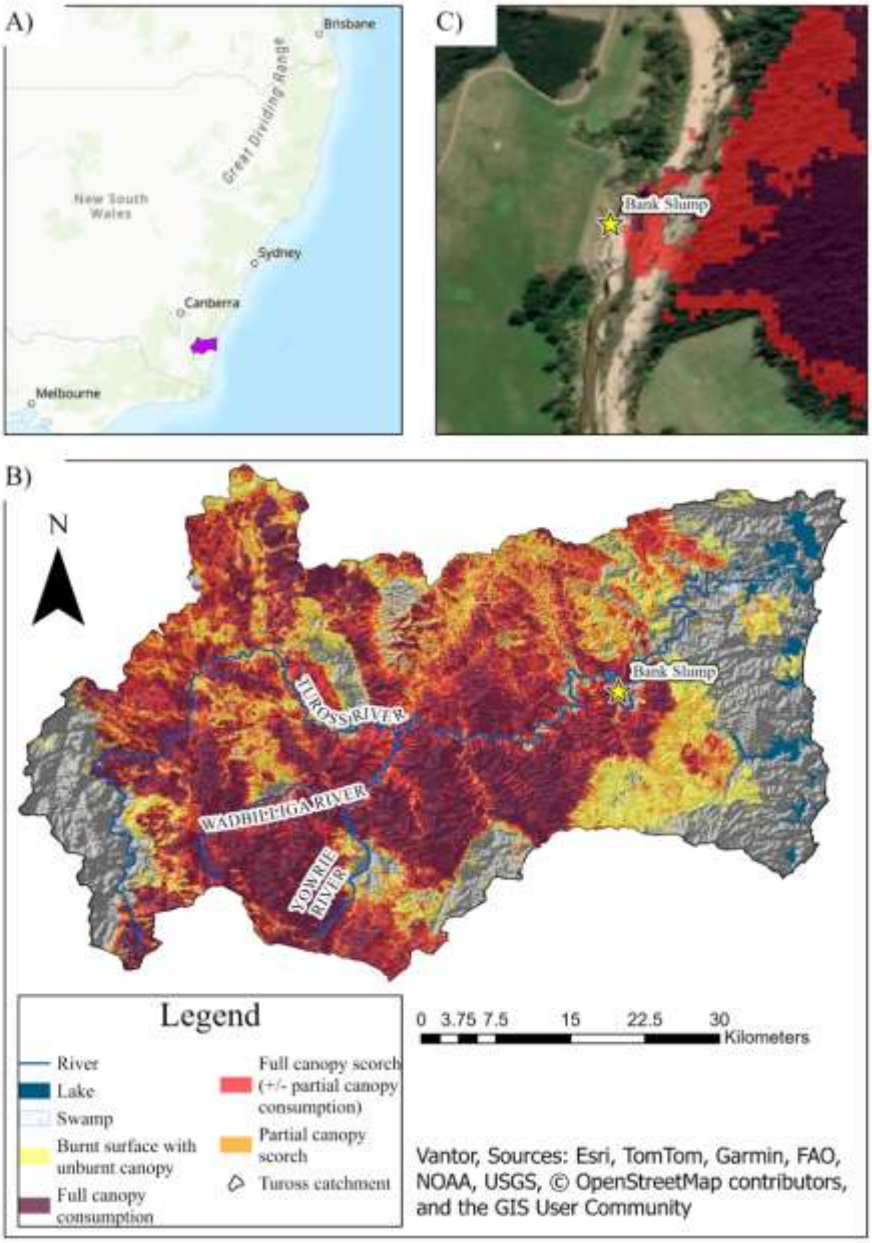

Figure 1 Map of the Tuross catchment and the fire extent and severity model (FESM) for the 2019/2020 Black Summer bushfires. A) Location of the Tuross catchment in relation to NSW. B) The Tuross catchment, and the Tuross River and major tributaries overlain with 2019/2020 FESM. C) Site of the riverbank mass failure where fire extended into the river channel. Data sources:

FESM from SEED (https://www.seed.nsw.gov.au/, last accessed 13/5/2026) and surface hydrology from Geoscience Australia (https://www.ga.gov.au/, last accessed 13/5/2026)

UAV photogrammetry

Three repeat UAV photogrammetry surveys were undertaken at the bank slump site in June and November 2021 and March 2023. The photos were processed using ODX version 3.7.3 and Pix4D version 4.10.1. An orthomosaic of the site photos were compiled in addition to developing a dense point cloud and digital terrain model (DTM) of the bank slump site for each of the surveys (Figure 2). The dense point clouds had an average sampling distance between 2.0-2.1 cm, covering an average extent of 0.11 km^2.

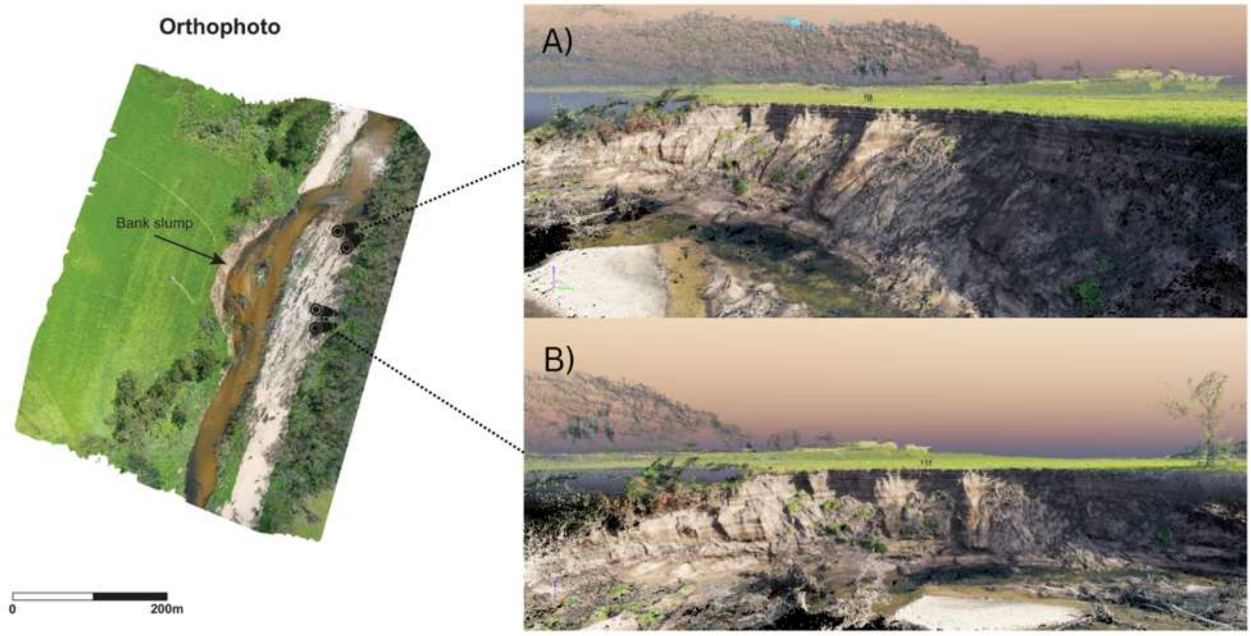

Figure 2 Example of an orthophoto and dense point cloud from the bank slump site (June 2023). Approximate viewpoints A) and B) of the point cloud indicated in the orthophoto

Cross-section analysis and sediment volume estimation

The Tuross River channel was digitised across the UAV survey area. Cross sections were derived using a vector line delineation tool in QGIS every 10 m from the centreline, with a horizontal distance of 200 m to cover the channel area (Figure 3). Sediment volume was estimated using pre-failure topography guided by available imagery from 2018 in addition to a representative transect immediately downstream. These dimensions were then used to estimate the volume of material mobilised. A sediment density of 1.5 tonnes/m^3 was applied to derive an estimate of the mass (in tonnes) of sediment eroded from the site.

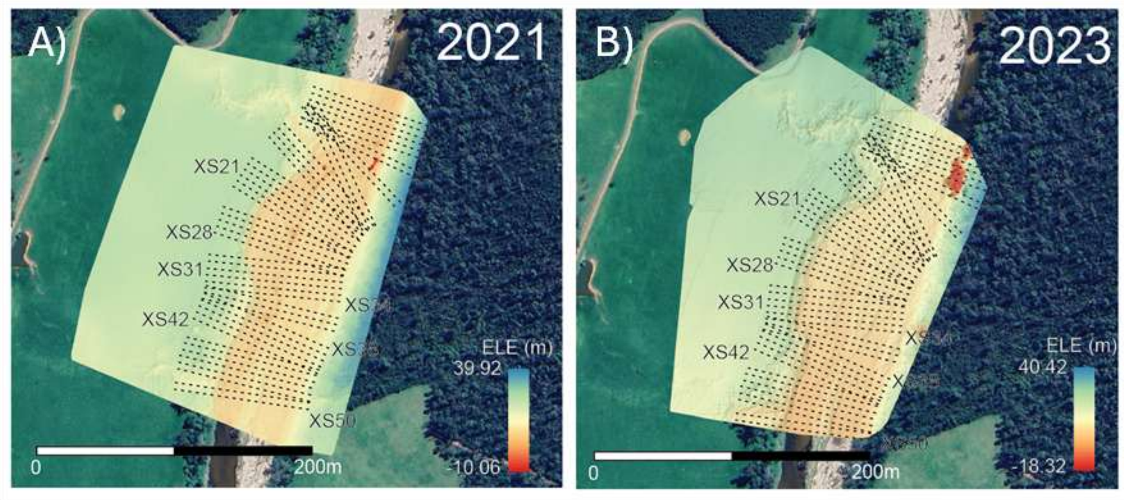

Figure 3 UAV-derived DEMs for the bank failure site in 2021 and 2023, with cross sections

An additional calculation of sediment volume was made using a DEM of Difference (DoD) created by subtracting one DTM from another for 2021-2023 using the Raster Calculator in QGIS. We produced new raster files where positive values represent material gained, and negative values represent material lost. The amount of material lost at the bank slump site was quantified using the Raster Surface Volume tool in QGIS which interprets DoD values as thicknesses. Using the method 'Volume above/below base level' and setting the base level to zero, the tool multiplies thicknesses by the pixel area to calculate total 'cut' (i.e. below zero) and 'fill' volumes (above zero). This method provides a simple approach to turn elevation change into a volumetric estimate.

Results

River conditions and bank morphology

The site of bank failure occurred at a river reach with an area of thick sclerophyll forest on the eastward bank and up the valley slope; a section of intact riparian vegetation on the western bank bordering the agricultural floodplain; and well-developed in-channel vegetation (Figure 4A). In the build-up to the fires that spread through large areas of the NSW south coast, a major 'flash drought' had occurred where anomalously wet conditions in 2016 were immediately followed by three years of anomalously dry conditions. The limited water availability caused an uncharacteristically long period of low-flow conditions in the Tuross River and significantly elevated the region's fire risk (Figure 4B). When the fires occurred in December 2019 and January 2020, they spread into the channel, and unlike the burned terrestrial eucalypts, the in-channel vegetation has limited signs of recovery. Historical imagery suggests the bank failure likely occurred in late July 2020 during the second post-fire high-flow period. By January 2024, river works including perpendicular logjams had been laid to stabilise the bank and create a more favourable depositional zone for bank recovery.

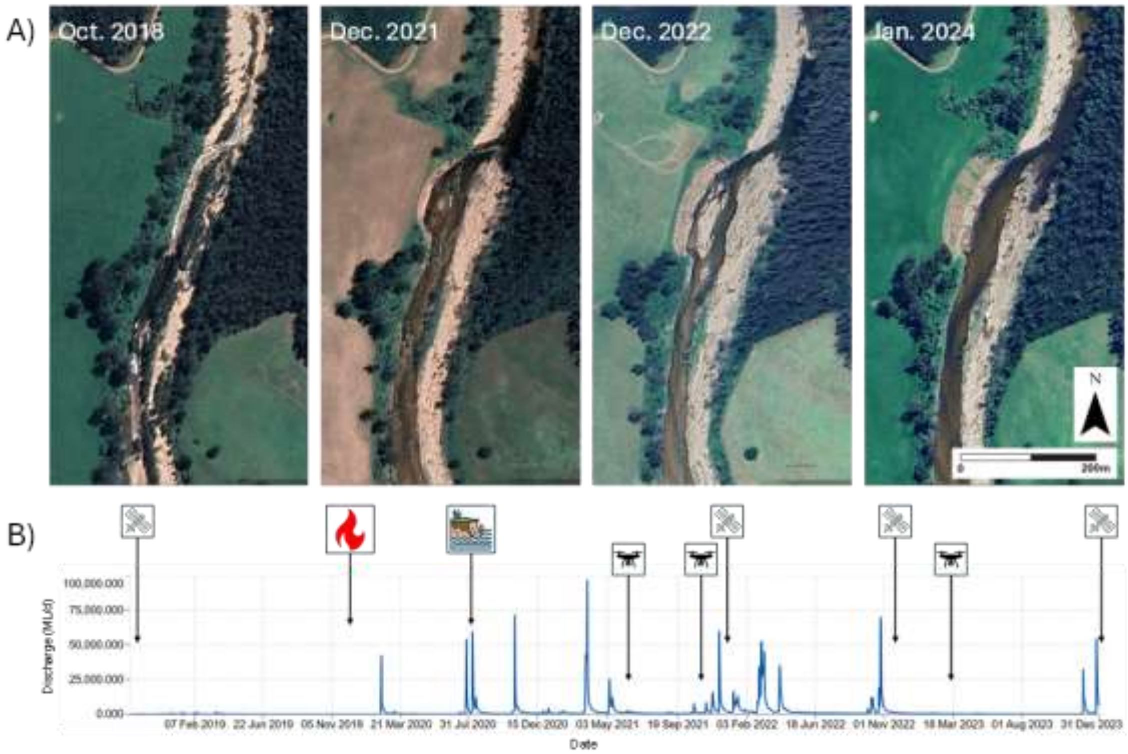

Figure 4 A) Satellite imagery showing the bank mass failure site on the Tuross River before (2018) and after (2021, 2022, 2024) the 2019-20 Black Summer bushfires and subsequent floods. B) Discharge record for the Tuross River at Eurobodalla (gauge 218008) showing the dry period leading up the bushfires (red flame), subsequent floods in 2020, 2021 and 2022, the bank failure, and the timing of satellite image acquisition (from part A) and UAV surveys. Imagery from Google Earth, and flow data from NSW WaterInsights (https://waterinsights.waternsw.com.au, last accessed 13/5/2026)

The river bank failure extended ~200 m along the channel. The bank profile changed from a convex form, stepping relatively smoothly down a series of benches from crest to toe, to a concave form with a markedly steepened face. The UAV-derived DEMs show an elevation change of ~15 m, equivalent to the loss of the total bank height. Transects from 2021 and 2023 show that the flooding in 2022 caused the bank to retreat a further ~20 m into the floodplain (Figure 5).

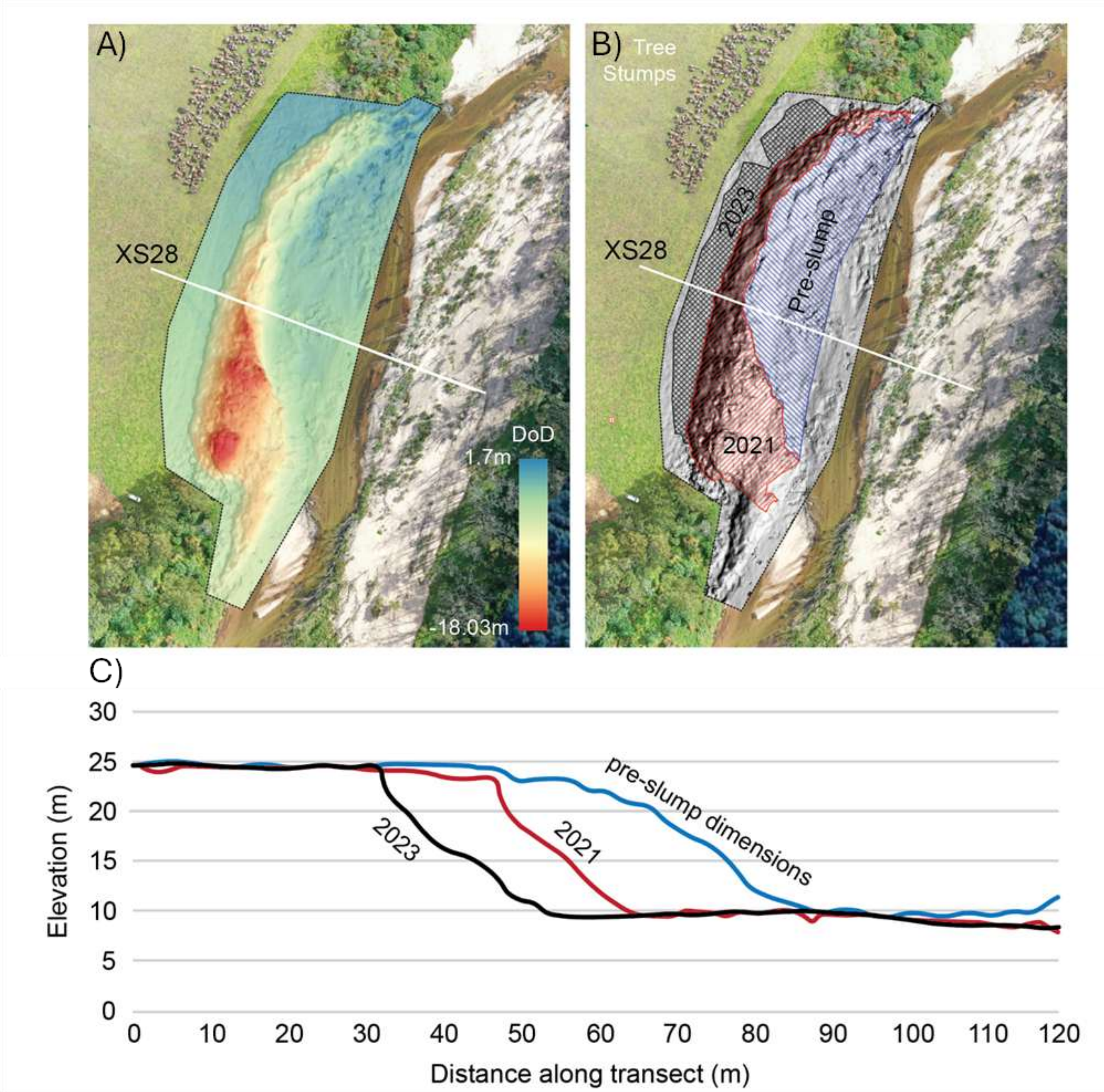

Figure 5 Morphology and topographic change at the bank failure site. A) DoD showing elevation change from 2021-2023. B) Approximate area lost in 2021 and 2023 compared with the pre-failure state in 2018. C) Post-failure bank profiles (XS28) compared with the estimated pre-failure bank morphology derived immediately downstream (XS50) to show representative bank dimensions

Sediment export estimates

By assuming that a wedge of sediment was lost, three sediment volumes were quantified from the cross-sectional areas (Figure 5): 28,718 m^3 (~43,077 t) from pre-failure to 2021; 24,233 m^3 (~36,350 t) from 2021-2023; and 13,042 m^3 (~19,563 t) from 2023-2024. The DoD method using the UAV-derived DEMs from 2021 and 2023 (Figure 4) produced a volumetric estimate of 6,634 m^3 (~9,950 t). These two independent approaches provide an upper and lower constraint for the sediment lost, with the cross-section approach likely overestimating the volume and the DoD likely underestimating the volume. To be conservative in our interpretation, we discuss the lower limit volume derived from the DoD method below.

Discussion

Significance for the Tuross River sediment budget

The DoD volumetric estimate of ~6,600 m^3 (~9,950 t) of sediment mobilised over the three-year period following our UAV survey in 2021 likely represents a considerable fraction of the sediment budget for the river reach, significantly elevating local sediment supply. The extent to which this contributes to the overall catchment sediment yield is determined by the degree of connectivity from source to sink, the amount of sediment delivered from other sources, and the proportion of mobilised sediment that became bedload, suspended load, or dissolved load. Drewry et al. (2009) found that the Tuross system is supply-limited in terms of the export of suspended sediment to the Tuross estuary, suggesting that when available, suspended sediment is readily transported downstream. These measurements were extrapolated to model the total suspended sediment yield in the river, and the annual export from the lower Tuross River ranged from 1,500 to 2,300 t, including >50 % contribution from river bank erosion, and also hillslopes, gullies, and roads (Fu et al., 2013). Assuming the average bulk density of the mobilised sediment was 1.5 t/m^3 and a modest estimate of 50 % conversion of mobilised sediment to suspended sediment with the remainder being dissolved or bedload, we find that the contribution of this bank failure to the Tuross's suspended sediment budget was ~1,650 t/yr. While both Fu et al. (2013) and our approach have limitations, this suggests that the single bank failure plausibly exported a comparable amount of suspended sediment over the 2021-2023 period as the entire Tuross catchment was modelled to deliver under typical conditions. Thus, given the vast amounts of sediment liberated from the upper catchment, tributaries and the trunk stream during the post-fire disturbance window, the cumulative post-fire sediment flux could exceed the modelled catchment-wide yield by an order of magnitude or more.

Ecosystem impacts and implications for management

Bank failures such as the one documented here generate ecological impacts both locally and downstream. Locally, the collapse altered in-channel conditions, widening the channel, steepening the bank profile, smothering the bed of the river, and removing riparian habitat which diminishes shading and allochthonous carbon input, and severely degrades or eliminates aquatic habitats and their associated biota over the affected reach. Downstream, the mobilised sediment elevates turbidity and may transport nutrients and contaminants toward the estuary, potentially resulting in the drowning of intertidal and estuarine vegetation with sediment, accelerating eutrophication (contributing to harmful algal blooms or red tides), and negative impacts to recreational fisheries and commercial oyster leases. When any flood occurs, DPI puts oyster harvesting on hold until water quality improves. Post-fire floods may extend this recovery period causing adverse economic impacts to oyster farmers each extra day of closure.

Even though riparian vegetation on the failed bank was mostly intact following the fire, the loss of in-channel vegetation, which would have slowed the flood peaks in 2020, 2021, and 2022, increased the hydraulic forcing exerted on the bank. This, combined with the catchment-scale increases in surface runoff and high rainfall events, likely caused the bank failure. Although NARCliM2.0 projections of future fire weather in NSW are not as severe on the Far South Coast as in the dry interior (AdaptNSW, n.d.), global increases in climatic variability under future emission scenarios could result in the increased cooccurrence and compounding of fires and floods. Therefore, instances when fire spreads from the valley-margin into riparian corridors warrant monitoring attention as it may systematically increase the erosion risk and possibility of bank failure during subsequent high-rainfall periods and floods. In NSW coastal rivers, where agricultural land clearing and settlement have left a legacy of bank destabilisation, channel widening, and persistent sediment slugs with some signs of recovery over the last 50-70 years, disturbances such as fires and floods have the potential to prolong reach-scale recovery trajectories and fundamentally alter their geomorphic condition. As such, management actions, such as stock exclusion, active revegetation, and broader floodplain restoration, could help to increase reach-scale resilience to the compounding effects of global climate change.

For landowners, riverbank mass failures directly reduce land available for grazing, lowering agricultural output. Although the land lost is minor relative to the floodplain as a whole, its significance may be greater at the scale of the individual holding where even a small reduction in productive grazing area can result in a disproportionate loss of net income. Yet, addressing such losses is not straightforward and while funding and expertise for stabilisation works may be available, it would need to be prioritised across a fire and flood impacted catchment. The geomorphologically sound preventative measure is to extend and revegetate the riparian zone which itself reduces arable land and places erosion mitigation in conflict with landholder interests. Going forward, greater collaborative effort between landholders and waterway managers could help to identify shared objectives that benefit both agricultural productivity and fluvial condition.

Conclusions

Repeat UAV photogrammetry, cross section analysis and volumetric calculations show that a single bank failure on the lower Tuross River mobilised upwards of ~6,600 m^3 of sediment after the Black Summer bushfires and 2020, 2021 and 2022 floods. According to our estimates, this localised erosion source represents a suspended sediment yield comparable to that of the entire catchment under typical conditions. The event sequence highlights the post-fire vulnerability of burnt riparian corridors which warrants further research and management prioritisation as fire and flood regimes intensify with climate change.

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References

AdaptNSW. (n.d.). *Interactive climate change projections map* [Interactive map]. NSW Government, Department of Climate Change, Energy, the Environment and Water. Retrieved July 12, 2026, from https://www.climatechange.environment.nsw.gov.au/projections-map

Department of Primary Industries (2016). *Water sharing plan for the Tuross River unregulated and alluvial water sources: Background document*. NSW Department of Industry, Skills and Regional Development. https://www.water.dcceew.nsw.gov.au/sites/default/files/2025-08/wsp-tuross-unreg-alluvial-background.pdf

Drewry, J.J., Newham, L.T.H., & Croke, B.F.W. (2009). Suspended sediment, nitrogen and phosphorus concentrations and exports during storm-events to the Tuross estuary, Australia. *Journal of Environmental Management, 90*(2), 879–887. https://doi.org/10.1016/j.jenvman.2008.02.004

Ferguson, R.J., & Brierley, G.J. (1999). Levee morphology and sedimentology along the lower Tuross River, south-eastern Australia. *Sedimentology*, *46*(4), 627–648. https://doi.org/10.1046/j.1365-3091.1999.00235.x

Fryirs, K. (2013). (Dis)Connectivity in catchment sediment cascades: A fresh look at the sediment delivery problem. *Earth Surface Processes and Landforms*, *38*(1), 30–46. https://doi.org/10.1002/esp.3242

Fryirs, K.A., Zhang, N., Duxbury, E., & Ralph, T. (2022). Rivers up in smoke: Impacts of Australia's 2019–2020 megafires on riparian systems. *International Journal of Wildland Fire, 31(7*), 720–727.

https://doi.org/10.1071/WF22046

Fu, B., Newham, L.T.H., Field, J.B., & Vigiak, O. (2013). A weight-of-evidence approach to integrate suspended sediment source information. *Journal of Environmental Management, 128*, 182–191. https://doi.org/10.1016/j.jenvman.2013.05.005

Ielpi, A., & Lapôtre, M.G.A. (2023). Modelling fire-induced perturbations in sediment flux based on stream widening and accelerated bank migration. *Catena*, *228*, Article 107173. https://doi.org/10.1016/j.catena.2023.107173

Kemter, M., Fischer, M., Luna, L.V., Schönfeldt, E., Vogel, J., Banerjee, A., Korup, O., & Thonicke, K. (2021). Cascading hazards in the aftermath of Australia's 2019/2020 Black Summer wildfires. *Earth's Future*, *9*(3), Article e2020EF001884. https://doi.org/10.1029/2020EF001884

McGuire, L.A., Ebel, B.A., Rengers, F.K., Vieira, D.C.S., & Nyman, P. (2024). Fire effects on geomorphic processes. *Nature Reviews Earth & Environment*, *5*(7), 486–503. https://doi.org/10.1038/s43017-024-00557-7

NSW Department of Climate Change, Energy, the Environment and Water. (2024). *Post-fire debris flows in New South Wales: Susceptibility modelling and implications for management* (Report No. EH20240101). NSW Government. https://www.environment.nsw.gov.au/research-and-publications/publications-search/post-fire-debris-flows-in-new-south-wales

WaterNSW (2026), WaterInsights, WaterNSW data. Available online at https://www.waternsw.com.au/water-services/water-data/water-insights, last accessed 22/05/2026.