Characterising channel degradation in low-energy floodplain wetlands, Gum Cowal, Macquarie Marshes, NSW

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Key points

- Channel degradation in Gum Cowal is characterised by bed incision and reduced vegetation cover in otherwise broad, vegetated, low-energy floodplain wetland channels.
- Degraded channels have sandier, less cohesive soils and show evidence of active erosion and sediment reworking compared with intact channels.
- Interactions between erosion, vegetation loss and exposure of dispersive subsoils appear to drive ongoing channel adjustment.
- Understanding degradation processes in low-energy floodplain wetlands can support conservation and management of land, water and wetlands.

Abstract

Channel degradation – in geomorphic terms, lowering of a channel bed over time due to erosion – can affect flow and inundation in alluvial rivers which may have negative geomorphic and ecological impacts. However, it is difficult to define and characterise channel degradation in low-energy, floodplain wetlands where channels vary in size, shape, and dominant hydrogeomorphic processes. Similarly, it is difficult to link channel erosion to other factors, such as ecological degradation in a river, which typically refers to a decline in structure, function, and/or resilience of aquatic and riparian ecosystems. We examined geomorphic factors related to channel degradation in Gum Cowal, Macquarie Marshes. Gum Cowal is a reoccupied palaeochannel with a broad macro-channel hosting shallow lagoons and multiple reticulate thalwegs in its bed. Channel mapping, field surveys, cross-section analysis, and surface soil and vegetation parameters were conducted at paired sites. Channels in the study area ranged from 8 to 20 m wide, and from 0.1 to 0.85 m deep. Degraded channels were deeper, had less vegetation ground cover, and showed evidence of incision (e.g., exposed tree roots) when compared to nearby intact channels. Degraded channels also had sandier, less cohesive topsoils than intact channels. It appears that a positive feedback occurs between channel erosion, loss of vegetative cover, exposure of dispersive subsoils, and reworking of sand from upstream to downstream. These findings are relevant to water, river, wetland, and agricultural management in semiarid landscapes, and for conservation and restoration of floodplain wetlands to maintain critical ecosystem services.

Keywords

Erosion, sedimentation, geomorphology, aquatic processes, wetlands in drylands

Introduction

Channel degradation can be considered in terms of ecology and/or geomorphology. Ecological degradation typically refers to a decline in structure, function, and/or resilience of aquatic and riparian ecosystems (Fu et al., 2015). In geomorphology, channel degradation is largely underpinned by process-landform relationships, such as mechanisms of erosion and deposition that alter the physical structure of a system (Lisenby et al., 2019). Specifically, geomorphic degradation involves the lowering or incision of a channel bed over time due to erosional processes, which can shift a system past its natural range of variability (Graves et al., 2024). This erosion frequently removes vital vegetation ground cover, cuts through cohesive topsoils, and leaves behind deeply incised channels with exposed tree roots and sandy thalwegs.

Geomorphic channel degradation can significantly affect flow and inundation in alluvial rivers, as altered geomorphology drives changes in longitudinal and lateral connectivity between channels and their surrounding floodplains (Fryirs et al., 2025). This disconnectivity disrupts the natural distribution of water and sediment, which directly impacts the physicochemical properties of the wetland, including carbon and nutrient cycling and microbial processes (Ralph and Kobayashi, 2025). In lowland rivers in NSW, healthy wetland soils are typically rich in clay and are capable of retaining soil organic matter, carbon, nitrogen, and phosphorus. However, as channels erode and incise, changes to the structure and function of these soils are altered rendering them unable to effectively retain these essential nutrients and organic matter.

Floodplain wetlands are critical landscape features and concentrated hotspots for biodiversity, ecosystem services, and climate mitigation in dryland environments (Grenfell et al., 2022). In Australia, where much of the landmass consists of arid and semi-arid regions, wetlands are providers of moisture and resources in climatically variable and moisture-stressed environments. They hold immense socio-economic and cultural importance, supporting primary industries such as agriculture and pastoralism, contributing significantly to regional food security and providing essential water resources (Shanafield et al., 2024).

A key issue in low-energy floodplain wetlands is how to define and characterise channel degradation, because their channels typically vary in size, shape, and dominant hydrogeomorphic processes. Past research has oversimplified geomorphology as just a driver of wetland distribution, rather than a dynamic component that actively shapes wetland structure and function (Papas et al., 2008), making it difficult to link channel erosion to the ecological degradation of a riverine system. Relying on a single indicator of wetland function, such as hydrology or vegetation alone, fails to capture the complex, interconnected nature of these systems (Fu et al., 2015). Instead, process geomorphology, soil quality, nutrient cycling, and aquatic ecosystem function need to be understood together: without monitoring and interpreting these interactions, it is not possible to establish a normal ecosystem baseline or detect when a threshold has been crossed into a state of degradation. This is the knowledge gap addressed here: how to recognise and characterise channel degradation in low-energy floodplain wetlands.

The purpose of this paper is to examine geomorphic factors related to channel degradation in Gum Cowal, Macquarie Marshes. By assessing channel morphology alongside physical soil properties, this research aims to understand how internal geomorphic processes and soil characteristics interact to shape the physical condition of low-flow wetland channels.

Sites and methods

Study area and sites

The Macquarie Marshes are one of the largest and most important wetland systems in the Murray-Darling Basin, covering ~2,000 km^2 between Warren and Carinda in central NSW (Figure 1). The Macquarie Marshes occur in an area where the Macquarie Wambuul River experiences channel breakdown on the low relief mud-dominated floodplain; the single, meandering channel fans out into a network of anastomosing and distributary channels before breaking down into floodouts in the floodplain wetlands (Ralph and Hesse, 2010). The Eastern Macquarie Marshes is the least studied of the sub-systems, whereas the Southern and Northern Macquarie Marshes have been extensively studied.

Gum Cowal, in the Eastern Macquarie Marshes, is a reoccupied palaeochannel with a broad macro-channel hosting shallow lagoons and multiple reticulate thalwegs in its bed, surrounded by periodically inundated floodplain wetland habitats. Gum Cowal is a regulated system, with flows controlled by

Marebone Weir (Thomas et al., 2011), when it became a targeted flow area in 2005 to ensure that environmental flows reached Wilgara a Ramsar wetland site, and stock and domestic flows reached pastoralists (Driver and Knight, 2007). There are periods of time where Gum Cowal is completely dry, and periods where it is in flood.

Three pairs of sites were targeted for this study, each having two low-flow channels side by side within the Gum Cowal meander belt (Figure 1). Sites A and B were intact and degraded channels, sites C and D were both intact channels, and sites E and F were both degraded channels. Field reconnaissance of low-flow channels, combined with geomorphic and erosion assessments, helped in determining the sites in this study. Degraded channels showed signs of erosion which included sand exposed in the channel, an incised channel bed, exposed roots, scour marks, and a lack of in-channel ground cover, whereas intact channels did not possess these features.

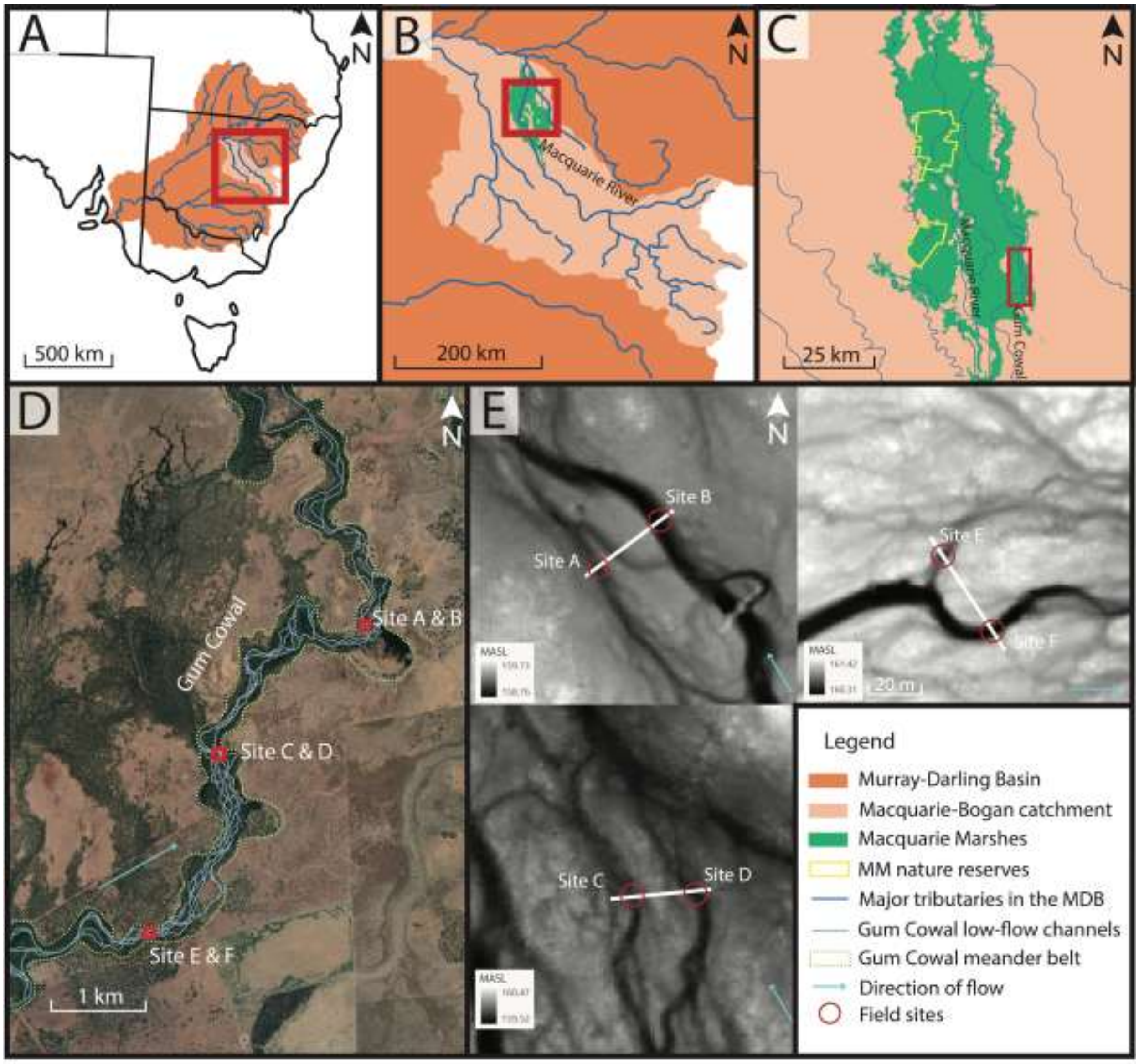

Figure 1 Location of Gum Cowal and field sites in the Macquarie Marshes, NSW. A) The Macquarie Wambuul River Catchment in the Murray-Darling Basin. B) The Macquarie Marshes. C) Gum Cowal in the Eastern Macquarie Marshes. D) The field sites in Gum Cowal. E) DEM of the field sites with survey transects and sampling locations marked

Desktop and field methods

Mapping of the Gum Cowal macro-channel and inset low-flow paths was conducted in ArcGIS Pro (version 3.0.3) using ESRI high-resolution basemap satellite imagery and a LiDAR-derived digital elevation model (DEM) with 1 m horizontal and 15 cm vertical resolution (DCCEEW, 2014). This DEM was also used to extract elevation data along the site transects and to plot channel cross-sections. Low-flow channel metrics including width, depth, and cross-sectional area were calculated from the cross-sections and validated from field data using on-ground surveys and drone photography.

Topsoil samples were also collected and vegetation parameters measured at the field sites during a dry period when the river was not flowing. The sample collection strategy was the same for all sites, with 10 samples collected at even spacing across the full width of each channel (accounting for variations in channel width), and with 1 m^2 vegetation quadrats also spaced evenly across each transect (Figure 2). Individual soil samples and vegetation quadrats were treated as the unit of replication for statistical comparisons, pooled across the three sites within each condition (intact vs. degraded), giving 30 replicates per group for topsoil variables and vegetation ground cover. Sub-samples from 10 cm deep soil samples were analysed for basic physical properties including sand and mud content (by wet sieving at 63 μm and weighing), dry bulk density (DBD) and soil moisture content (by weighing and drying), and aggregate stability (slaking and dispersion tests via the Emerson method).

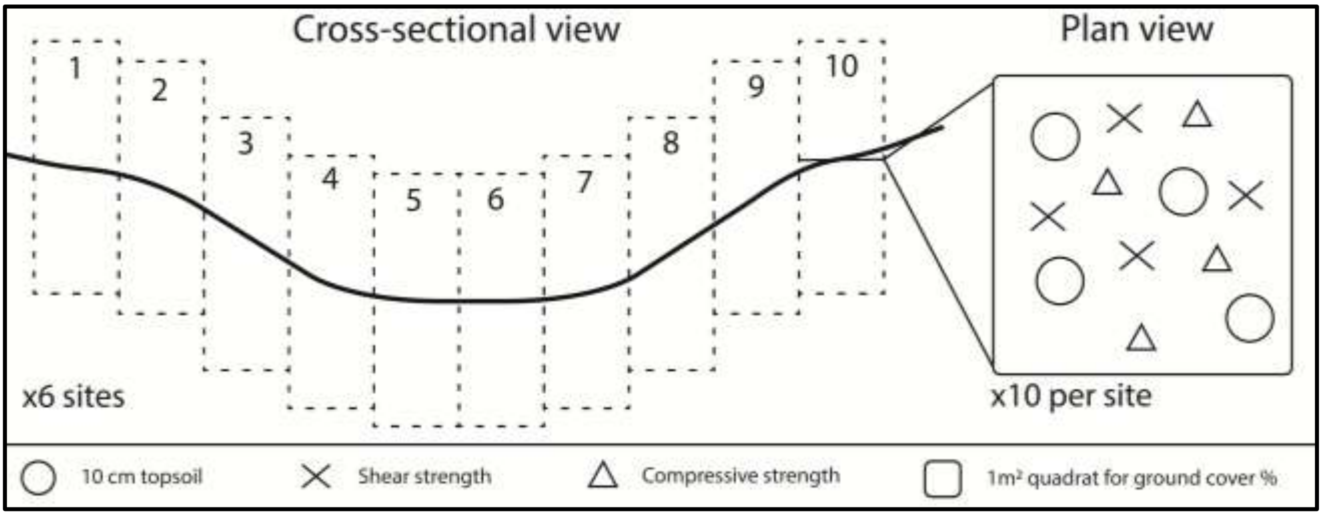

Figure 2 Schematic diagram showing sampling regime undertaken across the low flow channel at each site

Results and discussion

Channel morphology and soil characteristics

The low-flow channels in the study area ranged from 8 to 20 m wide, and from 0.1 to 0.85 m deep (Table 1; Figure 3). Intact channels had limited or no evidence of erosion, whereas degraded channels showed evidence of incision (e.g. exposed bed sediment and tree roots at bed and banks). Intact channels had shallow, gently sloping U-shaped morphology within the meander belt, with bankfull depths between 0.09 and 0.18 m, and channel areas generally <1 m^2. In contrast, degraded channels were more incised, featuring more steeply sloping banks or V-shaped notches in the thalweg, with bankfull depths up to 0.84 m and channel areas >2 m^2.

Table 1 Summary table of key geomorphic indicators including morphology, erosional evidence, soil type, and channel measurements

Group	Site code	Channel morphology	Erosion evidence	Topsoil type	Ground cover (%)	Channel width (m)	Channel bankfull depth (m)	Channel cross-sectional area (m²)
Intact	A	Gently sloping shallow U-shaped channel	None	Sandy clay	67	10.12	0.18	0.97
	C	Gently sloping shallow U-shaped channel	None	Medium light clay	100	15.38	0.16	0.77
	D	Gently sloping shallow U-shaped channel	None	Medium light clay	71	20.26	0.09	0.85
	Median				**71**	**15.38**	**0.16**	**0.77**
Degraded	B	Gently sloping banks with V notch in mid channel	Sandy mid channel, bare ground, incision in thalweg	Sandy loam	50	10.25	0.52	2.76
	E	Incised near vertical sloping channel	Exposed tree roots, bare ground, incision in thalweg	Sandy clay loam	3	8.39	0.69	2.06
	F	Incised near vertical sloping channel	Exposed tree roots, bare ground, incision in thalweg	Sandy clay loam	7	10.43	0.84	3.24
	Median				**7**	**10.25**	**0.69**	**2.06**

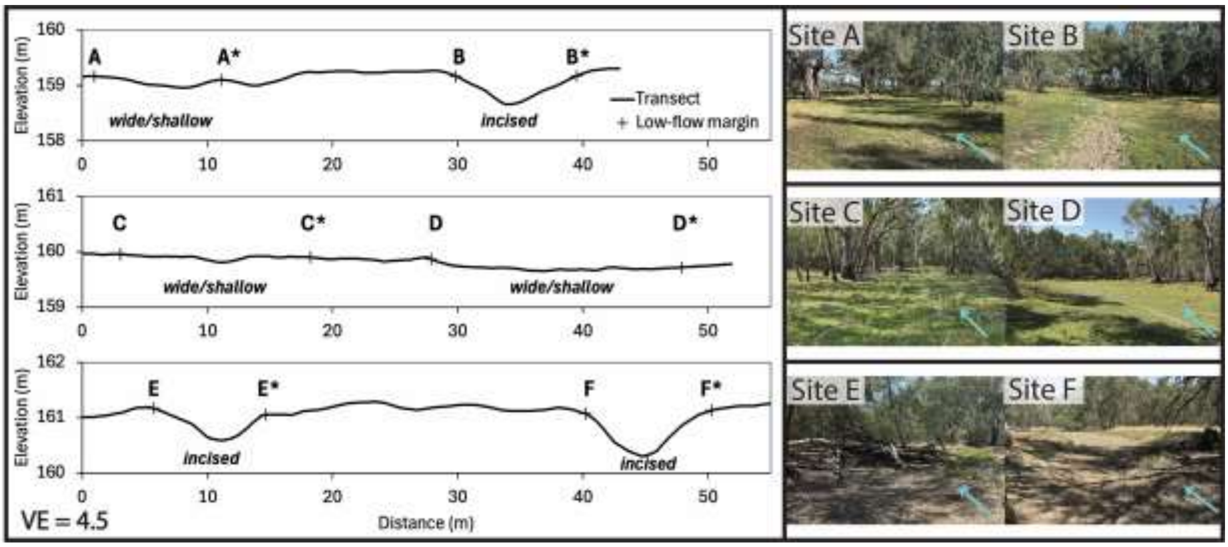

Figure 3 Cross-sections of sites and corresponding on ground site photos looking downstream

Data was tested for normality using the Shapiro-Wilk test, and since almost all variables did not meet the assumption of normality, non-parametric statistical methods were applied to all data. Differences between intact and degraded sites were evaluated using the Wilcoxon rank-sum test. For each comparison, individual soil samples or vegetation quadrats from the three sites within a condition (intact or degraded) were pooled and used as the unit of replication, rather than site-level medians (see Methods). A significance threshold of $\alpha = 0.05$ was used for all analyses. Ground cover differed significantly between the two groups ($Z = 46$, $p < 0.001$), with degraded channels having lower values (median value 7%) than intact sites (median value 76%; Figure 4A). Degraded channels also had sandier, less cohesive topsoils than intact channels. While sand content values aggregated across the whole transects did not differ significantly between groups (Figure 4B), a deeper analysis specifically of the mid-channel bed sediment revealed a statistically significant difference in sand content ($Z = 112$, $p = 0.02$) between degraded mid-channels (median value 56%) compared to intact mid-channels (median value 36%). DBD was not significantly different between the groups (Figure 4C), but water content was significantly lower for degraded sites compared with intact sites ($Z = 256$, $p = 0.004$) (Figure 4D). Slaking and dispersion scores – indicative of soil aggregate stability – were significantly higher for degraded sites compared to intact sites ($Z = 741.5$, $p < 0.001$, $Z = 573$, $p = 0.044$ respectively) (Figure 4E and 4F).

Overall, degraded low-flow channels differed from intact low-flow channels in Gum Cowal in terms of their morphology (notched by incision, or steeper banks), ground cover (less vegetation) and soil character (sandier, less cohesive soils). We interpret this to be due to the presence of erosion in low-flow channels at the degraded sites, but not at the intact sites, which fits with field observations and landholder accounts. Erosional processes dictate the channel shape and topsoil properties across the study sites, differentiating intact from degraded channels. The distinctions between the groups were driven by the low ground cover and higher proportions of sand present in the beds of degraded low-flow channels, which influence other factors. Sandier soils natively possess larger but fewer pores, resulting in lower water retention capacities and higher dry bulk densities. Furthermore, the lack of mud (i.e. silt plus clay) limits soil particle adhesion, explaining the high slaking scores and structural instability observed at the degraded sites.

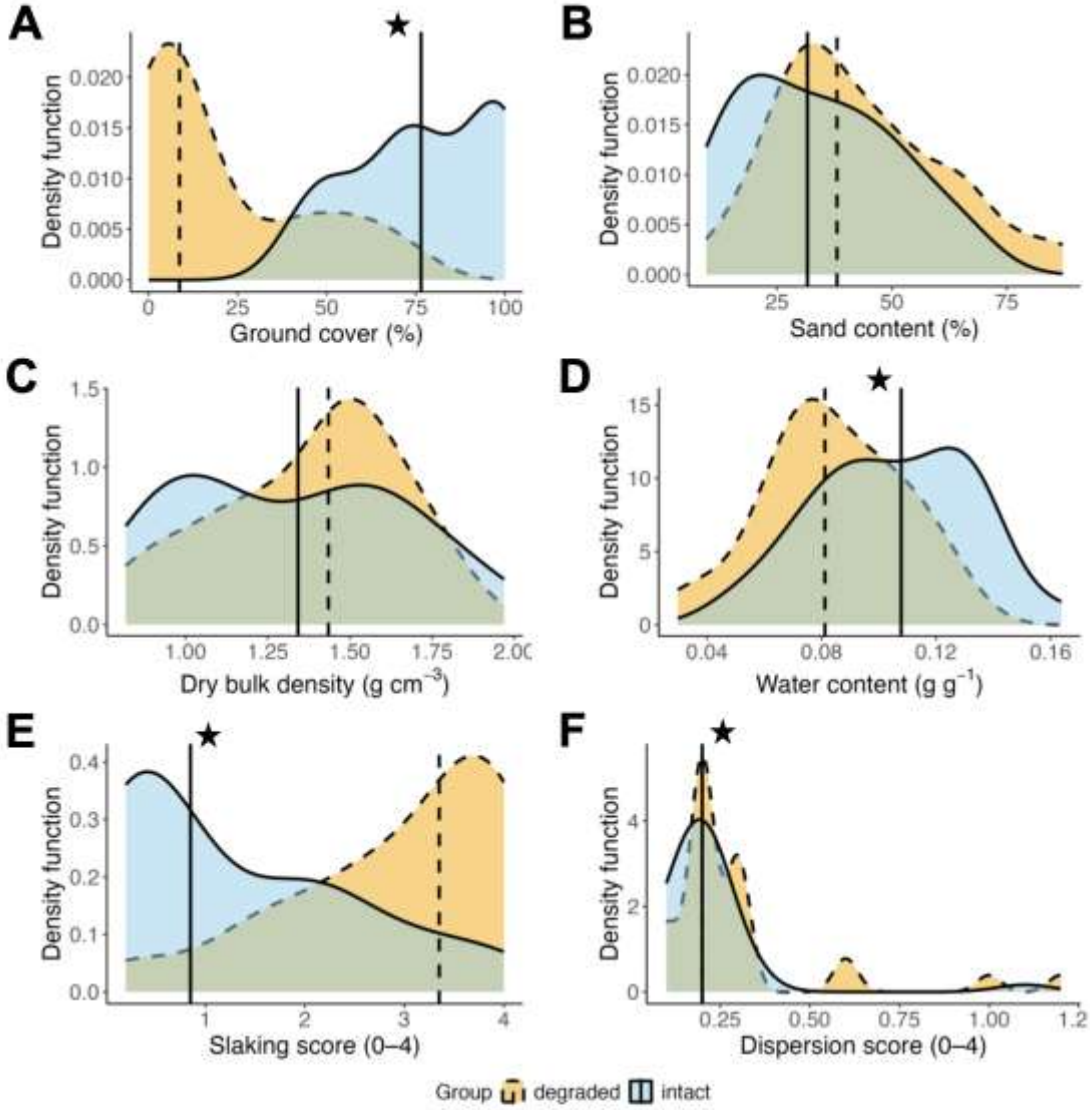

Figure 4 Physical soil properties for 0-10 cm for intact and degraded groups. (A) Ground cover. (B) Sand content. (C) Dry bulk density. (D) Water content. (E) Slaking score. (F) Dispersion score. Dashed and solid line indicates median. Black star indicates statistically significant difference

Interaction of biophysical processes in floodplain wetlands

The mechanism outlined below is a proposed process model rather than a directly measured result. It synthesises the observed contrasts in channel morphology, ground cover and soil properties between intact and degraded sites (see Results and Discussion, above) into a plausible explanation for how degradation may progress and self-reinforce over time; testing it directly would require repeat monitoring or process measurements (e.g., erosion pins, vegetation recovery tracking) at individual sites. We interpret that a positive feedback likely occurs between loss of vegetative cover, channel erosion, exposure of dispersive subsoils, and reworking of sand from upstream to downstream in Gum Cowal, which may be indicative of erosion and reworking processes in other at-risk floodplain wetland systems. As vegetation cover is lost from the channel bed (due to drought, or animal grazing, or fire, or removal by water – drowning or flooding) and erosion begins, it is harder for vegetation to reestablish or recolonise the areas of disturbed channel bed. This allows subsequent disturbance events to enhance the rate and/or extent of erosion processes. As erosion cuts into subsoils with less aggregate stability, erosion may accelerate, and the exposed soils are even less conducive to vegetation regrowth.

At extensively degraded locations, the low-flow channels may act as sand production zones within the river and wetlands. Sand is dislodged and transported when erosion cuts through the cohesive vertosol topsoils, exposing the highly erodible sandy paleochannel subsoils beneath. Further downstream, this reworked sand is deposited in localised sink zones, which may include previously intact low-flow channels that become swamped by sand. The deposition of loose sand in these previously intact areas smothers existing topsoils and vegetation, sometimes killing existing plants and preventing vegetation regrowth. By eliminating the vegetation and its roots which help to hold the bed and banks together, these deposition zones may then be easily eroded, and may become new production zones for sand which enables channel degradation to expand in the system.

We emphasise that this vegetation–erosion–sand reworking cycle is a proposed conceptual model, inferred from the paired comparison of intact and degraded sites at a single point in time, rather than a process directly observed to unfold through time at any one site. Geomorphically, this positive feedback loop resembles an erosion cell, where local erosion and downstream deposition of sediment alters channel bed conditions and the overall gradient as part of a channel adjustment cycle (Graves et al., 2024). Ecologically, channel degradation due to erosion can affect aquatic ecosystem function as different organisms require different flow conditions and may not adapt well to deeper, faster flowing water in incised channels. Also, certain soil types (with associated carbon and nutrients) provide the essential energy for microbial food webs in aquatic ecosystems (Kobayashi et al., 2013). Ultimately, if erosion forces a major shift toward degraded channel conditions, the geomorphology, ecology and soils may change to the point where erosion, sedimentation, aquatic metabolism, soil health, and other factors may decline to the point of threatening the biodiversity that the river and its wetland support.

Relevance to water, river and wetland management

These findings are relevant for water management because channel degradation alters the distribution, residence time and connectivity of water within floodplain wetlands. Incised and enlarged channels are likely to convey water more efficiently downstream, reducing overbank inundation and limiting the persistence and spatial extent of shallow wetland habitats during flows, including environmental flow events. This may decrease the effectiveness of environmental watering by reducing the ability of flows to spread across the floodplain and sustain wetlands, while also increasing sediment mobilisation and turbidity that can affect water quality.

Changes in channel form and inundation patterns are also likely to affect wetland ecological processes, including aquatic habitat availability, vegetation dynamics, carbon and nutrient cycling, and connectivity between channels, lagoons and floodplain wetlands. Very subtle changes in microbial communities can occur through changes in inundation that have flow-on effects up the food chain (Ralph and Kobayashi, 2023). Loss of vegetative cover and increased erosion may reduce water quality, as well as the habitat complexity and resilience of aquatic and riparian ecosystems in semiarid wetlands. Factors that underpin aquatic ecosystem metabolism, including gross primary productivity (GPP), planktonic respiration (PR), and carbon substrate utilisation by microbes (e.g., bacteria) may also be affected, as they depend on water clarity and the availability of nutrients and carbon sources (Kobayashi et al., 2013).

From an agricultural perspective, channel incision and associated erosion may reduce the water-holding capacity of floodplain environments and contribute to loss of productive soils through sediment mobilisation and bank retreat. Concentration of flows into deeper channels may also alter local groundwater, soil moisture conditions, and carbon retention, potentially reducing the productivity of adjacent grazing lands and floodplain pastures (Sharififar et al., 2023). Soft engineering that adds roughness and disperses the concentration of flow is preferable in controlling such issues.

For on-ground management, the geomorphic and soil indicators measured in this study double as practical, low cost early warning signs that managers and landholders can monitor at low-flow channels to detect the onset of degradation before it becomes advanced: declining vegetative ground cover; exposed tree roots and scour marks on the bed or banks; bed incision and channel deepening; increasing sand content and coarsening of bed material; and reduced topsoil cohesion (e.g., increased slaking and dispersion). Regular, low-effort monitoring of these indicators would allow managers to identify vulnerable low-flow channels and prioritise intervention, such as targeted environmental watering, exclusion of stock, or soft-engineering works that add roughness and disperse flow, before a channel transitions to a persistently degraded state.

Conclusions

This study demonstrates that geomorphic processes and soil characteristics are intimately linked and determine the physical condition of low-flow channels in floodplain wetlands of Gum Cowal, Macquarie Marshes. A self-reinforcing cycle of degradation exists wherein initial erosion removes cohesive topsoils, exposing sandy subsoils that are subsequently transported downstream with compounding negative effects on the low-flow channels and potentially the aquatic ecosystem. Understanding biogeomorphic interactions and feedback mechanisms is vital for the early detection of channel degradation, which can support water and wetland conservation and restoration actions.

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