Linking catchment processes to coastal management program (CMP) outcomes: A strategic prioritisation approach for the Richmond River NSW

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Key points

- Managing water quality in estuaries and coastal waterways can only be achieved with a full understanding of the sources of sediment and other pollutants at the catchment scale
- In the Richmond catchment, like many east coast catchments, channel erosion is the dominant source of sediment.
- The annualised channel erosion yield of ~734,000 t/yr dwarfs all other assessed sources, confirming that management strategies focused primarily on within-estuary actions or hillslope farmland erosion — without addressing channel erosion — will have limited catchment-scale efficacy.
- For the first time, this project quantifies the cost of achieving a fully revegetated riparian zone across the entire Richmond catchment ($336M).
- Geo-Economic prioritisation highlights that 20% of the channel erosion can be targeted at a cost of ~ $2M pa over 10 years – a significant proportion of which involves working in reaches in relatively good condition, where optimising the health and extent of riparian vegetation is most cost effective.
- An FPC threshold of ~30–40% represents a effective minima for effective riparian erosion management.
- The current Estuary Health Risk Assessment (EHRA) framework is not fit for purpose in the Richmond - and likely most coastal catchments due to an over-emphasis on hillslope processes.

Abstract

The Richmond River estuary receives runoff from a 6,850 km^2 catchment in northern New South Wales (NSW) and is subject to serious sediment-driven water quality degradation. This study presents the first catchment-scale, high-resolution analysis of sediment sources and a geo-economic rehabilitation prioritisation framework developed for the Richmond River Estuary Coastal Management Program (CMP) Stage 2.1. Using multi-temporal airborne LiDAR differencing (DoD), satellite-derived foliage projected cover (FPC) mapping, 35-year Landsat persistent green time series, and camphor laurel weed mapping, the study characterises erosion and vegetation condition across 2,884 individual 500-metre reaches encompassing 1,442 km of the 3rd-order and higher channel network. Total channel erosion detected was 3.28 million m^3 (~734,000 t/yr). Strong inverse relationships between reach-scale woody riparian FPC and erosion volume confirm that maximising native woody vegetation is the primary management lever. A Marxan-based geo-economic optimisation demonstrates pronounced cost-efficiency: addressing 10% of total erosion requires only 6.1% of reaches at 1.9% of the full $336 million rehabilitation cost. Priority reaches are concentrated in Kyogle and Richmond Valley LGAs, with 80–90% falling outside the NSW coastal zone — underscoring the imperative for whole-of-catchment governance. Channel erosion dominates over all other assessed sediment sources. A 20% erosion reduction target over 10 years at ~$2 million/yr is recommended, and the existing Estuary Health Risk Assessment framework is identified as no longer fit for purpose in this context.

Keywords

Erosion prioritisation, Marxan modelling, riparian management, coastal water quality

Introduction

The Richmond River drains a 6,850 km^2 catchment in the Northern Rivers region of NSW into a comparatively small estuary (~19 km^2 water surface) supporting RAMSAR-listed wetlands, regionally important fisheries, and sensitive seagrass meadows. The disproportionate catchment-to-estuary ratio creates acute sensitivity to upstream land management. Extensive post-European-settlement riparian clearing, stock access, drainage works, and floodplain modification have severely degraded water quality. Despite decades of localised management actions, no integrated catchment-scale assessment of sediment sources existed prior to this study. CMP Stage 2.1 was commissioned to fill that gap — characterising the magnitude and spatial distribution of sediment sources across the full channel network, and developing a geo-economic framework to guide cost-effective rehabilitation prioritisation and investment.

The study is predicated on the well-established hypothesis for sub-tropical eastern Australian catchments (Wallbrink, 2004; Olley et al., 2013) that bank erosion from the 3rd-order and higher channel network is the dominant ongoing sediment source to the estuary, and that maximising native riparian woody vegetation is the most effective mitigation strategy. Confirming and quantifying this provides the empirical basis for strategic investment.

Methods

Channel network delineation and reach segmentation

Third-order and higher stream channels were delineated using a geomorphically informed approach accounting for channel dimensions, producing 2,884 reaches of 500 m length across 1,442 km of network. Each reach was assigned a variable-width riparian buffer determined by channel width, forming the spatial unit for all subsequent analysis.

LiDAR-based erosion quantification (DoD Analysis)

Channel erosion was quantified using multi-temporal LiDAR-derived DEM of Difference (DoD) analysis across datasets spanning 6–13 years (primarily 2010/2016/2017 to 2023). A conservative 2-sigma limit of detection was applied; areas with fewer than one ground point per 3 m^2 were excluded. Erosion estimates are therefore minima. Total erosion across the network was 3.28 million m^3 (~734,000 t/yr at 1.6 t/m^3 bulk density).

Vegetation condition mapping

Woody riparian vegetation was characterised using: (1) FPC derived from 2023 LiDAR canopy height data; (2) the Delta Green metric — the gradient of the regression through a 35-year quarterly Landsat persistent green time series (Pietsch et al., 2021); and (3) satellite-derived camphor laurel (*Cinnamomum camphora*) extent as a weed proxy, validated by ground-truthing which confirmed a 77% co-occurrence with other environmental weed species.

Geo-economic prioritisation via Marxan optimisation

The Marxan conservation planning tool was adapted to optimise riparian rehabilitation investment. Management scenarios — fencing (F), off-stream watering (OSW), revegetation (R), supplementary planting and weed maintenance (SW), assisted natural regeneration (Wanr), primary weed control and revegetation (RW), and monitoring (M) — were assigned to each reach via a decision tree (Figure 1) as a function of FPC, camphor laurel cover, land use, and Delta Green trend. Full network rehabilitation cost was calculated at $336 million. Marxan identified minimum-cost reach combinations achieving 10%, 20%, and 50% erosion reduction targets.

Key datasets underpinning the prioritisation

Figure 2 maps the four primary spatial datasets underpinning the prioritisation: (A) total reach erosion volume; (B) non-woody vegetation area; (C) camphor laurel cover; and (D) the 35-year Delta Green vegetation trend. High erosion, degraded cover, and weed infestation co-occur strongly in the upper catchment — particularly the Kyogle and Richmond Valley sub-catchments.

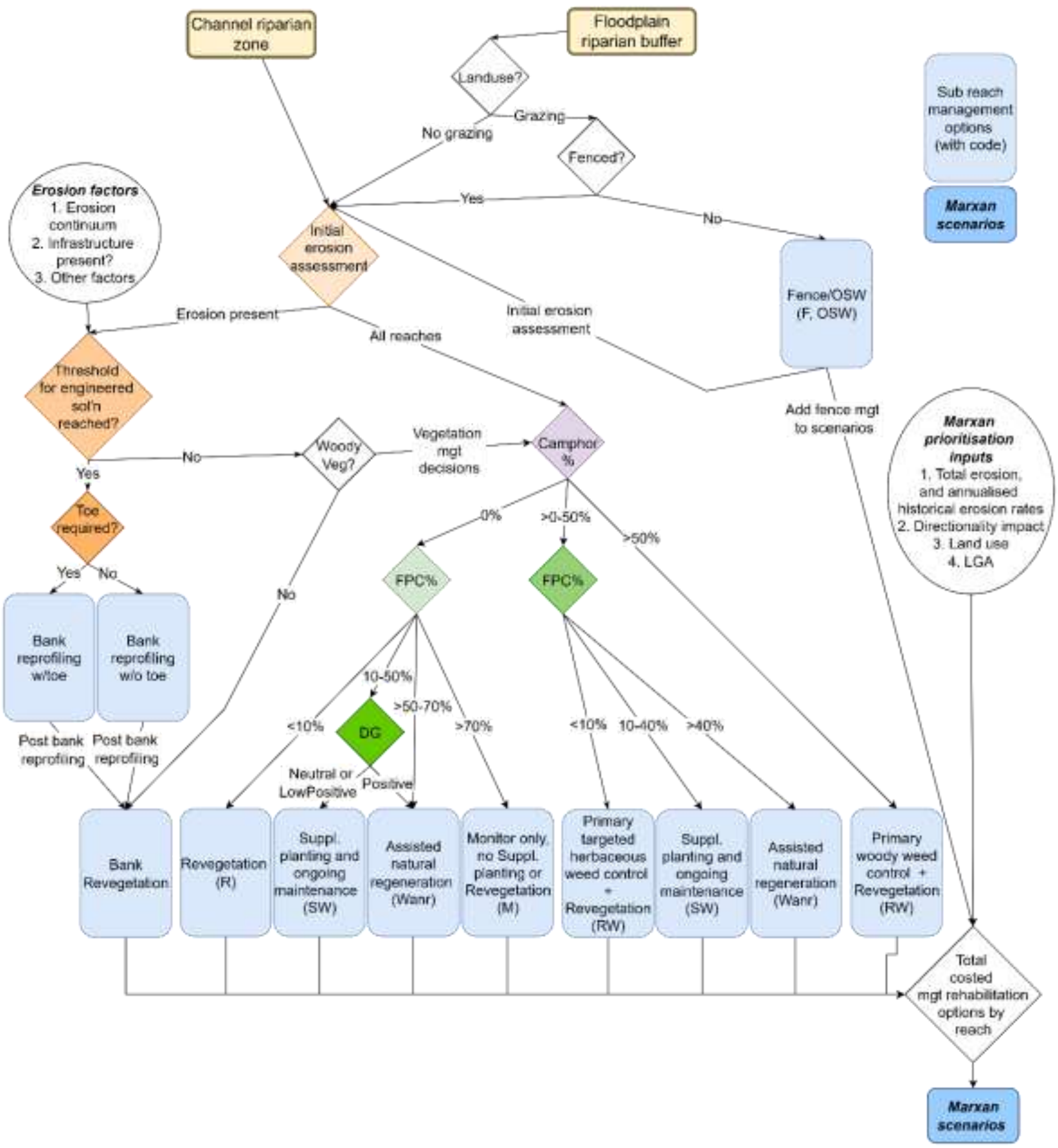

Figure 1 Marxan decision tree assigning management scenarios to sub-reach planning units based on vegetation condition, weed extent, and land use

Riparian vegetation and channel erosion: Empirical relationships

Figure 3 presents reach-scale scatter plots of erosion volume against riparian FPC for seven major tributary systems. Upper envelope curves consistently demonstrate that maximum potential erosion decreases substantially with increasing FPC. A threshold is apparent at approximately 30–40% FPC, below which minimum erosion rates also rise — indicating accelerating channel instability. Relationships vary between tributaries, reflecting differences in substrate erodibility and hydrology. For example, Ironpot Creek and Shannon Brook show steep power-law declines consistent with sandy, erodible banks, while Bungawalbin Creek exhibits a more gradual exponential response. The consistent direction of the relationship across all systems empirically justifies the focus on riparian revegetation as the primary catchment management intervention, while also cautioning that due to hysteresis, erosion reduction and vegetation recovery will not be linearly related.

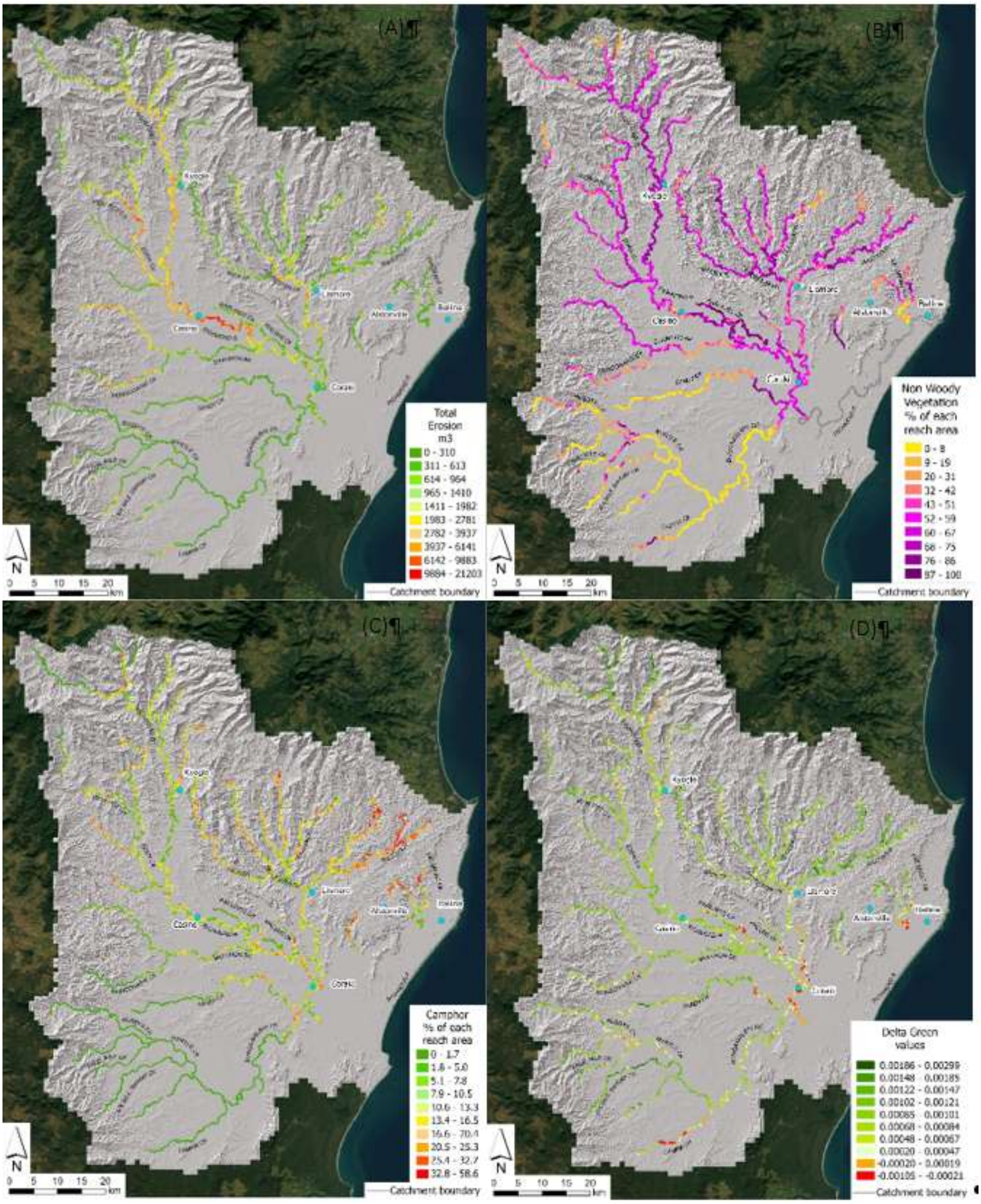

Figure 2 Spatial distribution of the four key input layers: A) Total reach erosion (m^3); B) Non-woody vegetation area (%); C) Camphor laurel cover (%); D) 35-year Delta Green vegetation trend. Priority areas cluster in the upper catchment

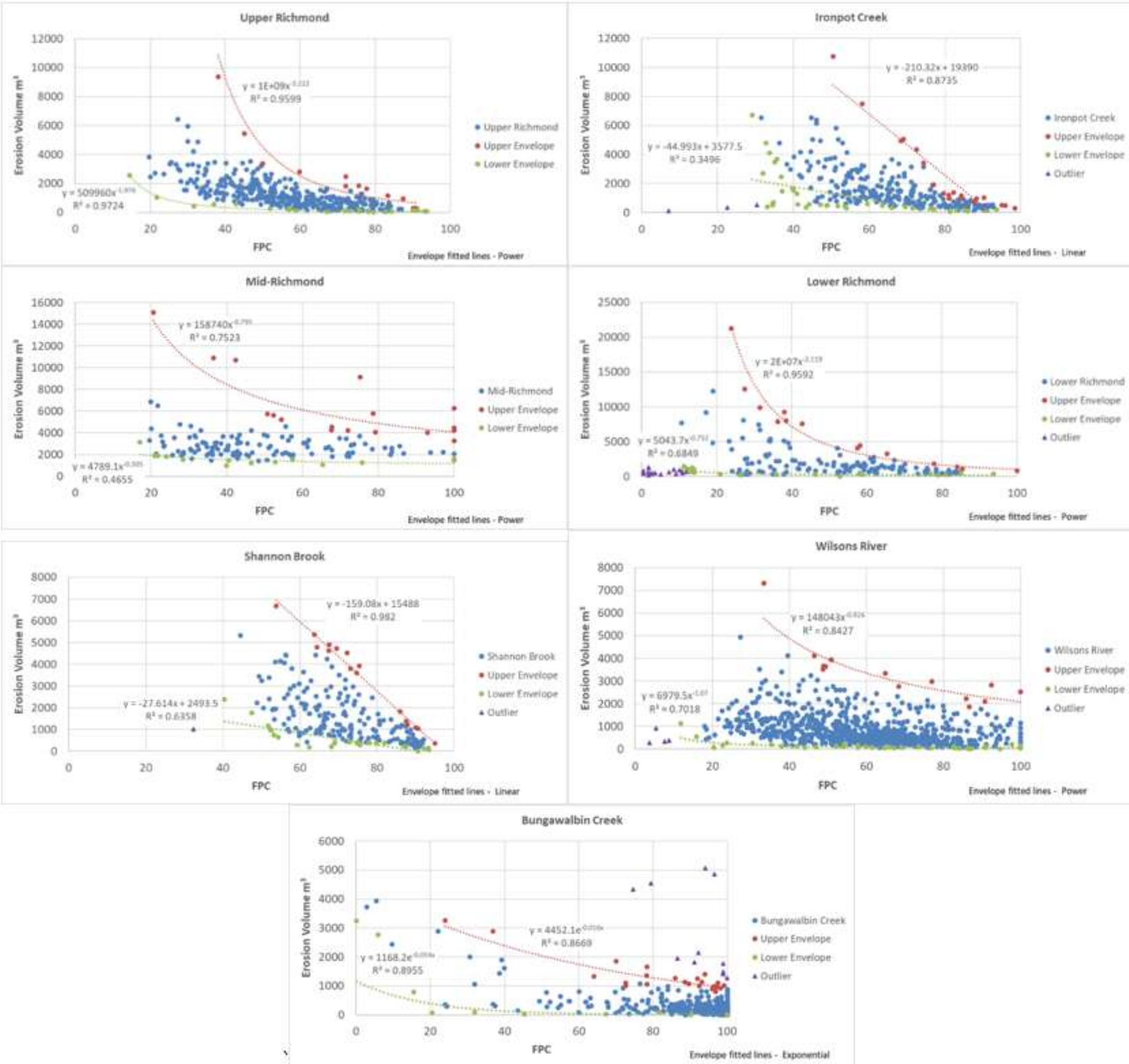

Figure 3 Relationships between reach erosion volume (m³) and riparian FPC (%) for seven tributary systems. Upper and lower envelope curves bound the erosion range as a function of woody riparian vegetation cover. Note that the pattern varies for each sub-catchment, but the general trends are clear. This highlights the need to account for variable vegetation/erosion relationships with geomorphic controls (river style)

Marxan prioritisation results

The Marxan optimisation reveals strongly non-linear cost-efficiency (Table 1). The 10% erosion target requires just 176 reaches (6.1%) at $6.4 million (1.9% of total cost; ~$19.5/m³), compared to a catchment average of $102/m³. The recommended 20% target requires 286 reaches at $17.9 million. Priority reaches cluster in the Kyogle and Richmond Valley LGAs (Figure 4), consistent with the upper-catchment concentration of high erosion and degraded riparian cover. This spatial pattern holds across all four Marxan scenario variants tested.

Table 1 Marxan scenario cost-efficiency summary

Scenario	Reaches	% Reaches	Cost ($M)	% Cost	$/m³
10% Erosion	176	6.1%	$6.4M	1.9%	~$19.5
20% Erosion	286	10.0%	$17.9M	5.3%	~$35
50% Erosion	728	25.2%	$73.7M	21.9%	~$64
Full catchment	2,884	100%	$336M	100%	$102

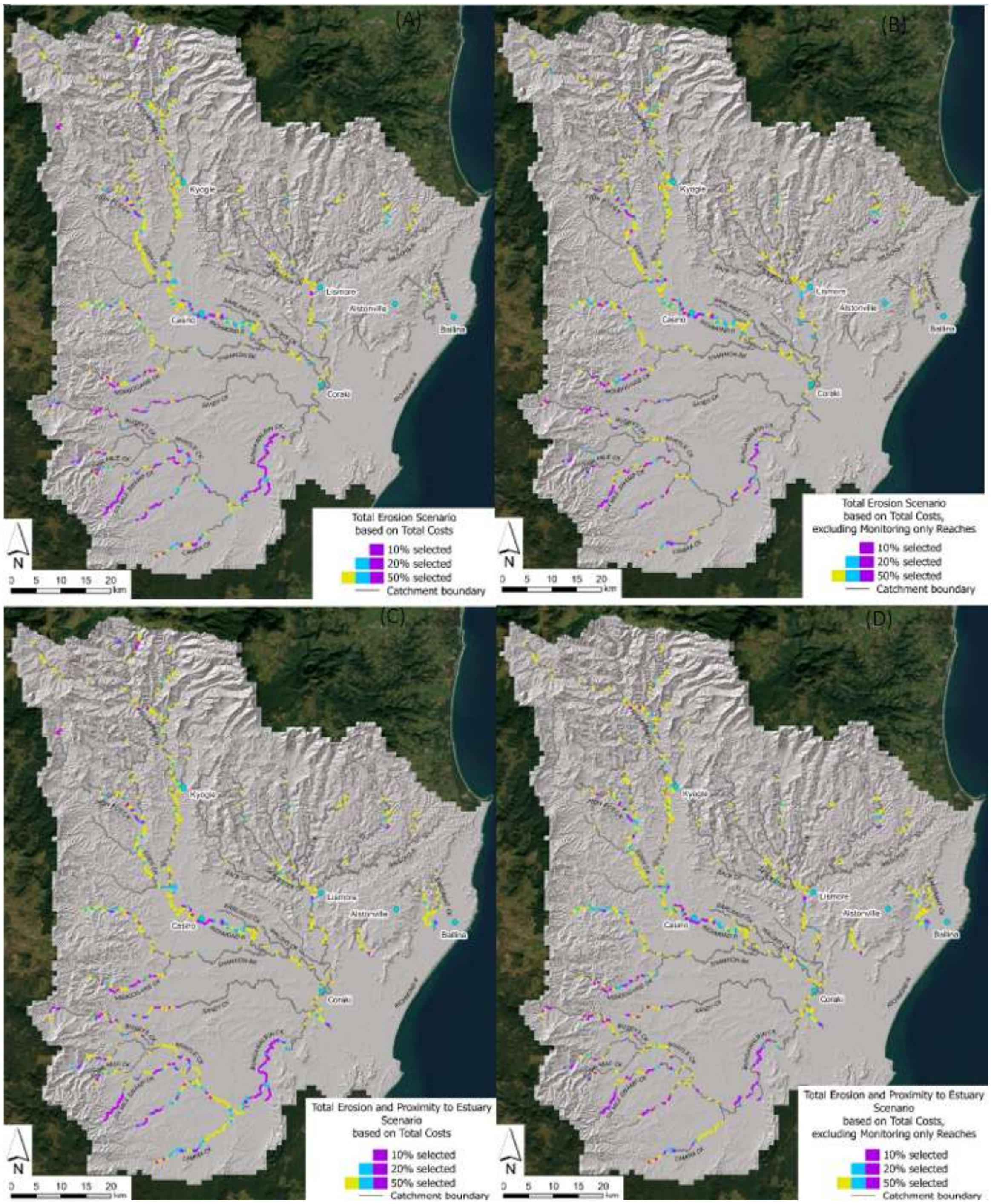

Figure 4 Spatial distribution of prioritised reaches for 10%, 20% and 50% erosion targets under four Marxan scenario variants. Priority reaches tend to cluster in the upper catchment outside the Coastal management Zone

Coastal zone governance: The upper catchment imperative

A critical finding is the spatial mismatch between priority rehabilitation reaches and the NSW-designated Coastal Management Zone (CMZ). Figure 5 shows that 80–90% of required investment falls outside the CMZ across all erosion scenarios. Even at the 50% target, CMZ reaches account for only ~20% of total cost. Current NSW coastal management legislation and associated funding mechanisms are oriented around the CMZ, yet the dominant sediment sources lie far upstream in Kyogle and Richmond Valley. Effective implementation demands cross-boundary coordination and whole-of-catchment investment frameworks unconstrained by CMZ boundaries.

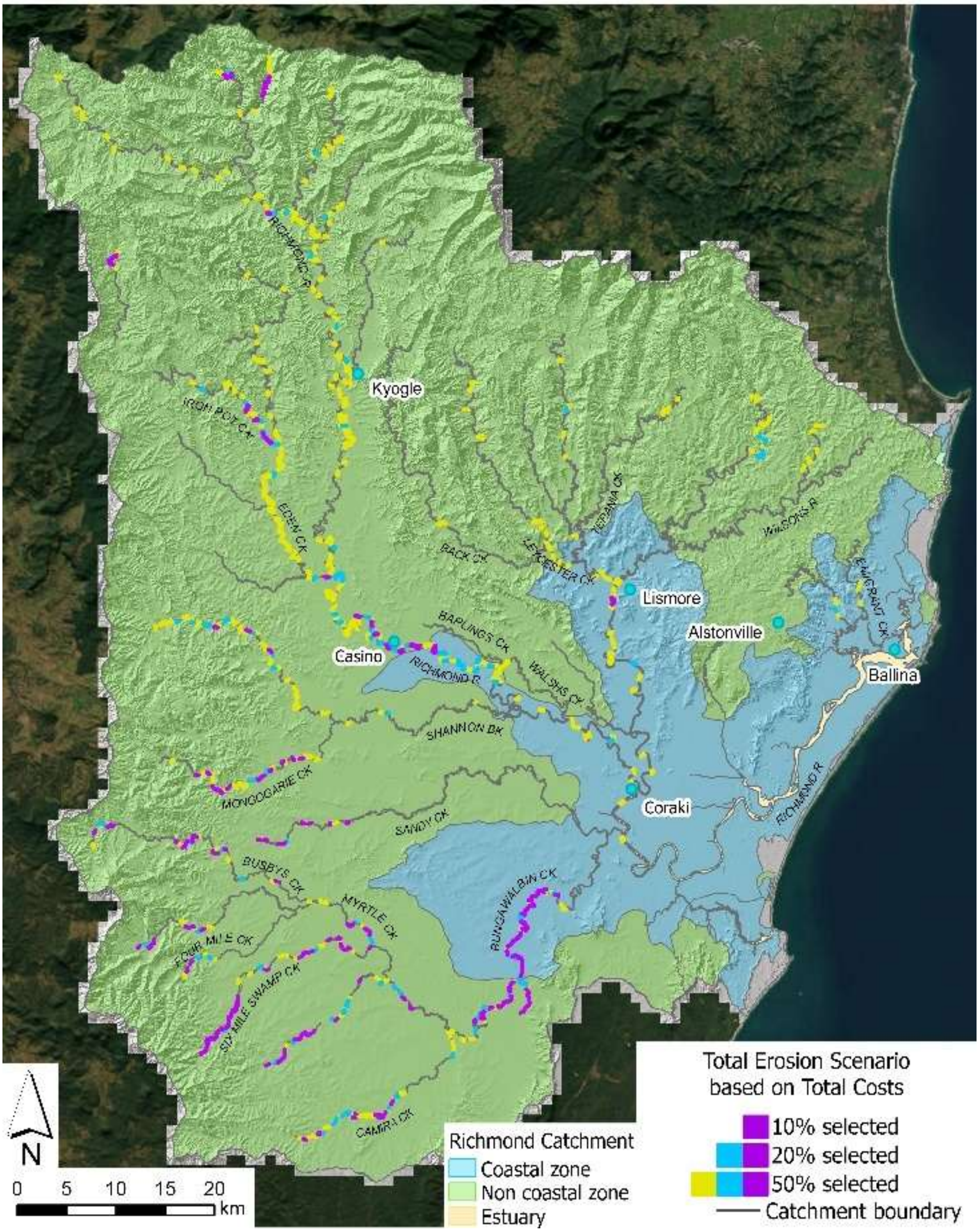

Figure 5 Distribution of prioritised reaches and investment between the Coastal Management Zone and non-coastal catchment for 10%, 20% and 50% erosion scenarios. 80–90% of investment falls outside the NSW-designated coastal zone

Alternative sediment sources: Preliminary assessment

Preliminary quantification of four additional sources contextualises the dominance of channel erosion. The February 2022 flood triggered ~1,630 landslides mobilising ~970,000 m^3, of which approximately 710,000 t reached the channel network contributing to elevated suspended sediment yields for several years as those sediments were reworked on the slopes and in the channel network The majority of landslides scarps have since stabilised, highlighting that this significant sediment input represents an episodic rather than a persistent or chronic source. While historically rare, it remains to be seen whether extreme events of this nature become more common. Macadamia farmlands (~12,000 ha) yield an upper-bound estimate of ~84,000 t/yr applying the highest measured orchard runoff rates (SCU, 2024), and unsealed roads (~5,750 ha) contribute an estimated ~17,500 t/yr based on data from southeast Qld (Forsyth et al., 2006).

An unvalidated preliminary analysis of first- and second-order headwater channels suggests yields potentially comparable in order of magnitude to the 3rd-order network — representing a significant knowledge gap requiring urgent targeted investigation. Together, these sources are substantially smaller than the annualised channel network contribution of ~734,000 t/yr, confirming channel erosion as the dominant, persistent and chronic sediment source.

Discussion

The annualised channel erosion yield of ~734,000 t/yr dwarfs all other assessed sources, confirming that management strategies focused primarily on within-estuary actions or hillslope farmland erosion — without addressing channel erosion — will have limited catchment-scale efficacy. The FPC-erosion threshold (~30–40%) is especially significant for riparian management. Even partial revegetation in the most degraded reaches can deliver disproportionate erosion reductions, and this non-linearity is directly reflected in the Marxan cost-efficiency results. The most erosion-productive reaches are frequently those on cleared private grazing land with minimal weed burden, and hence lowest rehabilitation cost.

The current Estuary Health Risk Assessment (EHRA) framework is not fit for purpose in the Richmond context. Its reliance on hillslope erosion modelling, which is highly sensitive to slope but blind to channel processes, produces spatial predictions that show minimal concordance with the LiDAR-derived channel erosion distribution (Figure 2). The EHRA should be replaced with a catchment scale channel-erosion-centric prioritisation approach informed by the datasets developed here. After all, estuaries are connected to catchments and whatever happens in the catchment affects the estuary. The preponderance of priority reaches on private land (~80% across all scenarios) underscores the need for landholder-focused delivery mechanisms — targeted stewardship payments, Landcare-facilitated works, and adopt-a-reach programs — alongside direct government investment.

Study limitations and qualifiers

- The current study assesses total erosion and does not weight sources according to sediment particle size, geochemistry or particulate nutrient loads.
- While the study focused on the most likely dominant sediment sources it is not possible to compare these data with all other potential sources. A full quantitative sediment budget is required to do this – which requires all sources are measured and the spatial and temporal variability of sources assessed. This would also require that sediment delivery ratios to the estuary for each source and sediment particle size fractions are also quantified.
- This study does not assess the fate of sediment and associated nutrients within the estuary and out to sea nor its ecological significance. A different study with these aims is required to answer these questions.
- All lidar DoD analyses have used a very conservative 2 sigma “Limit of Detection” (LoD) and all ground coverage with fewer than 1 ground pt per 3m^2 have been removed from the analysis. Hence the erosion data are extremely conservative.
- The analysis does not include erosion below the standing water level at the time of lidar data capture – hence once again the channel erosion data should be regarded as minima.

Conclusions

1. Channel erosion from the 3rd-order and higher network (~734,000 t/yr; 3.28 million m^3 total) is confirmed as the dominant ongoing sediment source to the Richmond estuary.
2. Woody riparian FPC is the primary determinant of channel erosion potential, with a critical threshold at ~30–40% FPC below which erosion accelerates across all tributary systems.
3. Marxan geo-economic optimisation demonstrates exceptional cost-efficiency: the 10% erosion target costs $6.4M (1.9% of total) by targeting just 6.1% of reaches. A 20% target at ~$2M/yr over 10 years is the recommended implementation goal.
4. 80–90% of priority rehabilitation reaches fall outside the NSW Coastal Management Zone, demanding whole-of-catchment governance frameworks that transcend CMZ funding and jurisdictional boundaries.
5. The existing Estuary Health Risk Assessment framework should be replaced with a channel-erosion-centric approach. Priority future research: quantification of 1st/2nd order channel yields; sediment tracing for source apportionment validation; and particle-size/nutrient characterisation.

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