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Bellinger-Kalang River Estuary NEAP Bank Erosion and Riparian Condition Assessment Report

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Acknowledgement of Country
Fruition Environmental acknowledges the traditional custodians of the Gumbaynggirr lands upon which this assessment was undertaken. We recognise the continuing connection to lands, waters and communities. We pay our respect to Aboriginal and Torres Strait Islander cultures; and to Elders past and present.

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Executive Summary

This report presents the findings of the Bellinger and Kalang River Estuaries NEAP Bank and Riparian Condition Assessment. This report has been commissioned under the NSW Estuary Asset Protection Program (NEAP Program), part of the Riparian Stabilisation Package, co-funded by the Australian and NSW Governments under Disaster Recovery Funding Arrangements, managed by the NSW Department of Primary Industries and Regional Development – Fisheries.

The data and analyses from this assessment are to be used to inform future management actions to improve flood resilience, estuary asset protection, and estuary health including water quality, bank stability and riparian vegetation condition.

This project updates the existing bank erosion and riparian vegetation dataset collected by the Bellinger and Kalang Estuary Erosion Study undertaken by Telfer and Cohen in 2009. The updated dataset uses the DPIRD Fisheries Decision Support Tool for Bank Erosion Management in NSW Estuaries (the "DST"; Hydrosphere, 2020) as the basis of the assessment with additional criteria related to erosion processes and riparian vegetation attributes. In total approximately 115.1km of estuary bank were surveyed, including 748 individual reaches. This covered the navigable sections of the Bellinger River estuary to Lavenders Bridge at Bellingen, Back Creek, and the Kalang River estuary to approximately 470m below Brierfield Road bridge. Data was collected using a field mapping application developed by Fruition Environmental Pty Ltd. The data is stored online through an ESRI ArcGIS web portal and can be viewed and analysed using a simple web-based interface or exported to desktop GIS for further, more detailed analyses.

The updated mapping dataset and the identification of priorities for estuary bank and riparian vegetation management contained within this report directly address Action E6 in the Draft Bellingen Shire Coastal Management Plan (Exhibition Draft, Salients, April 2024).

Estuary bank and riparian condition

The field investigations showed that just over 8% of surveyed estuary banks were considered to have High to Extreme severity erosion, meaning that the rate and scale of erosion was considered significantly accelerated. These reaches of High to Extreme erosion severity are generally concentrated in the fluvial dominated reaches in the mid to upper Bellinger river estuary, and to a lesser extent in the upper estuary of the Kalang River. High to Extreme erosion was also prevalent in the Fluvial Transition Process Zone around Newry Island in the Kalang River estuary and in the Marine Tidal Delta Process Zone of the Bellinger on the eastern side of Urunga Island. Many of these areas have been recorded as eroding in previous assessments indicating that the issues are persistent at many of these locations.

A further 36.5% were considered to have Moderate erosion severity, which is at a rate beyond what could be considered a natural rate of channel change and where at least some estuarine values are impacted. Negligible to no erosion was recorded in almost a third of the reaches surveyed although some areas are recorded as having Negligible erosion because of bank protection works, particularly in the lower estuary around public foreshores, parks and infrastructure. With just under half of estuary banks surveyed exhibiting above natural rates of erosion it is clear that bank erosion continues to be a significant issue in the Bellinger and Kalang River estuaries.

Riparian Vegetation Condition was assessed using a multi-metric index of riparian condition which considered vegetation width, continuity, structure, diversity and weed presence/cover. Almost half of the banks surveyed had riparian vegetation in Very Good condition (22.1%) to Good condition (25.1%). A considerable portion of assessed reaches were recorded as having Moderate condition (28.8%) suggesting that over a quarter of banks could be considered in a transitional state where condition could either improve or decline depending on management.

When looking at individual estuary systems, the Bellinger River shows the highest level of riparian degradation, with 32.7% of its length in Very Poor to Poor condition, compared to 34.1% in Good to Very Good condition. In contrast, the Kalang River has 17% in the lower condition categories and 56.3% of its length in Good to Very Good condition. As with the erosion severity ratings, the higher proportion of riparian vegetation in Good to Very Good condition reflects the degree of valley confinement, reduced floodplain development, extensive mangrove forests of the lower estuary, limitations on land use that have resulted in reduced historical clearing of the riparian zone.

In reaches with Very Poor to Moderate condition vegetation, a major factor in the rating is narrow riparian width. More than half of the surveyed estuary length (57%) had average riparian widths recorded as less than 5 m wide. Factors that resulted in reduced riparian vegetation condition ratings (Very Poor to Poor condition) were generally impacted by a number of factors including:

- Clearing associated with infrastructure (due to road proximity or other infrastructure such as sea walls) or along areas of residential foreshore for amenity and access such as in Urunga, Raleigh, around Newry Island and opposite Mylestom.
- loss due to erosion processes including undermining of mangroves due to persistent wind or boat wave effects and post flood bank slumping particularly where only a narrow fringe of vegetation exists on the bank.
- stock access which suppresses vegetation regeneration including mangroves, particularly evident in the mid to upper Bellinger estuary, upper Kalang, and the around the non-residential areas of Newry Island.
- weed incursion, which although in most reaches is not significant, has resulted in some reaches of the upper Kalang and Bellinger estuaries becoming dominated by camphor laurel and small-leaved privet and, in some locations, vine weeds including cats claw creeper and madeira vine.

The presence, method and observed effectiveness of existing bank protection works was also recorded. Of the total length of bank field surveyed in the Bellinger and Kalang River estuaries (115.1 km), 19.8 km or 17% of estuary bank had some form of existing bank protection recorded across 231 individual reaches. Two thirds (66.4%; 12.9 km) of the existing bank protection measures observed were recorded as completely effective. Just under a third (27.8%: 5.4 km) of all works were described as only partially effective either because of poor condition (resulting in some erosion continuing) or poor design (resulting in the works being compromised or only partially suitable). Maintenance or retrofitting of the partially effective works, particularly around Newry Island, would likely improve the erosion control effectiveness. However, given the 5.4 km of works identified in this condition, some prioritisation would be required.

The most prevalent form of bank protection observed was rock revetment with over half (53.2%: 10.5 km) of all works recorded utilising this method and representing 9.2% of the total surveyed length of estuary bank in the study area (*Table 10*). These works are primarily focused around urban centres, particularly Urunga, Repton, Raleigh and Mylestom. The next most prevalent works types were entrance training walls/sea walls in the lower estuary (~2 km), concrete slab, blocks or walls along the bank (~1.4 km), revegetation (~1km), and rock fillets (~0.9 km). Just under one fifth of all identified protection works (18.1%) utilise inappropriate materials including rubble, building waste including broken concrete, and/or old tyres. A large majority of these works are concentrated around Newry Island and adjacent to Burrawong Parade in Urunga and lower Bellinger River at Raleigh and Repton.

Rates of erosion analyses

In addition to comprehensive mapping of bank and riparian condition in the Bellinger and Kalang River estuary systems, an analysis of erosion rates in the estuary was undertaken. A Digital Elevation Model of Difference (DEMoD) methodology was utilised to compare 2009/2010 LiDAR derived Digital Elevation Models (DEM) to the 2024 LiDAR derived DEM at fifteen reaches of observed High to Extreme severity erosion to quantify erosion volume over the observation period. The gross volume for each site was then annualised and converted to fractions of suspended sediment (<20um) and bedload sediment (>20um) based on soil samples collected from the sites. The results were then used to model the net annual suspended sediment load from High to Extreme severity bank erosion in the estuary.

Using this methodology, the annual estimated volume of erosion from the 15 analysed sites was 7,010m^3 per year. On the basis of soil sampling which included particle size differentiation and bulk density measurement, the annual fine sediment input to the estuary from the 15 sites was estimated at 2585 tonnes/year. Extrapolation of these results to all areas recorded as High or Extreme severity erosion within the study areas indicates an estimated 4,400 tonnes (~3,480m^3) of fine suspended sediment and 13,900 tonnes (~11,000m^3) of bedload sediment is inputted annually from High to Extreme erosion sites within the Bellinger and Kalang River estuaries. These quantities do not account for the subaqueous portion of the erosion of estuary bank and so are likely conservative. Further, cumulative sediment losses from Low and Moderate erosion areas across the estuaries could substantially increase the total sediment loads, suggesting that the actual figures may be considerably higher than those presented here.

At five sites where data on erosion rates were collected during the 2009 assessment (Telfer and Cohen), the contemporary rates between 2009/2010 and 2024 were compared to determine whether erosion was accelerating at those sites or otherwise. The comparison found that erosion rates are within the ranges of previously reported estimates of retreat, but generally show a minor increase in both the mean and minimum rate across all sites. This increase may be somewhat expected given the recent 2009 – 2024 period has been a flood-dominated period, with several high magnitude flood events. However, the pattern of erosion does not demonstrate a clear acceleration in the recent period, with mixed observations of both the mean and maximum retreat. While there is some uncertainty in these results, it is clear at all sites that the rates of erosion are not slowing. This is consistent with the comparison of the 2009 and 2024 surveys that demonstrate increased degradation of the estuary, with persistence in sites of High or Extreme erosion severity.

Future works

On the basis of the field collected data, a number of recommendations for works have been made by the DPIRD Fisheries DST. These include recommendations for a range of works types including large woody debris works, rock fillets, rock revetment, cobble beaching, sandbag installation, and maintenance of existing works depending upon the estuary location. Approximately 19.6km of estuary bank attracted a DST primary recommendation for works, including about 4.8km of existing works identified as requiring maintenance. In many cases the maintenance required is minimal and may involve simple steps to increase the bank/works resilience of the works at that location. More than 83% of estuary length attracted no primary recommendations but may have a final DST prescription of improving riparian vegetation width or introducing management controls such as boating restrictions or formalising public access. The online web portal data can be reviewed and filtered to see the full range of DST recommendations over the full Bellinger River estuary study area.

Importantly, whilst the recommendations are considered a best practice starting point for consideration there may be reasons why the DST recommendation may not be the most suitable option for the bank segment and these reasons may not be captured by the input data. Hydrosphere, in its documentation on the tool explicitly states that "*It is crucial that the DST recommendations are further investigated…to assess whether they are indeed applicable or if other techniques could be more suitable*" (Hydrosphere, 2020, p.18). Additionally, the fact that a surveyed reach attracts a recommendation for works or maintenance within the DST does not infer that the reach is a priority for management action. This is because the DST does not include any consideration of overall objectives for estuary management beyond bank erosion control using best practice. However, where a reach is separately assessed to be a priority for intervention, the DST provides a reasonably objective and standardised approach to determining which treatment options should be first considered.

Priorities for bank and riparian vegetation management

In terms of where activities may be directed to improve estuary bank and riparian vegetation condition in the Bellinger and Kalang River estuary, the report outlines a priority system for determining future action and investment. A set of criteria, drawn from the objectives of a number of foundational documents relevant to the management of the estuary (including the NSW Coastal Management Act 2016, the Marine Estate Management Strategy 2018-2028, the Bellingen Shire Coastal Management Program, the Bellinger Kalang Water Quality Management Plan, and the Bellingen Shire Biodiversity Strategy 2020) were used to create a "pool" of priority reaches drawn from the 2024 field data which could then be ranked using multicriteria analyses.

Of the 748 reaches field surveyed, 83 were included in the pool of priority reaches for action and management using the above system, this was reduced to 70 after adjacent reaches with similar issues and processes where combined. These are presented in the report (pages 99-107) along with a breakdown of reaches which are considered a priority for defined sets of typical estuary management objectives (lower ranked reaches for ongoing monitoring are included in *Appendix B*). These include a subset of priorities that address public asset protection and/or maintenance, water quality improvement, and riparian vegetation protection and enhancement.

The high priority reaches for management intervention are heavily weighted towards the protection of estuary assets and increasing flood resilience by directing works towards vulnerable areas of the estuary. This is a key objective of the NEAP program. The term "estuary assets" has been interpreted broadly and includes both infrastructure (such as roads and public foreshore) and natural assets such high conservation vegetation types, important estuarine habitats, and water quality. The 19 highest priority reaches are listed in *Table 20* in Part 5 of the Report and shown in *Figures 26* and *27* on pages 100-101. Addressing the issues identified at these locations will lead to lasting improvements in flood resilience, estuarine health, and public amenity. The proposed timeframe for implementation is the next 10 years to 2035.

In addition to the prioritisation tables based on the multicriteria analyses, three potential projects are proposed that were identified during engagement activities with the Yurruungga Aboriginal Corporation. These include a significant cultural site restoration project in Reach 165 on the Bellinger River at Raleigh, a project to remove tyres from failed bank remediation works on Urunga Island and in parts of the Kalang River where more appropriate works could be constructed, and a continuation of shorebird protection activities on the southern tip of Urunga Island.

Introduction

This report has been commissioned under the NSW Estuary Asset Protection Program (NEAP Program), part of the Riparian Stabilisation Package, co-funded by the Australian and NSW Governments under Disaster Recovery Funding Arrangements, managed by the NSW Department of Primary Industries and Regional Development – Fisheries. The aims of the NSW Estuary Asset Protection program are to:

- Assess the severity of flood impacts on estuarine and floodplain assets
- Identify priority areas for asset protection and increased resilience
- Implement actions that will provide increased resilience for estuarine and floodplain assets from flooding events.

This report presents the findings of the Bellinger-Kalang River Estuary Bank and Riparian Condition Assessment undertaken by Fruition Environmental Pty Ltd. The field assessment component was undertaken in July – August 2024.

The study area encompasses the navigable tidal reaches of the Bellinger River and Kalang River estuaries including Back Creek (*Figure 1*). 118km of estuary bank was delineated through digitising of the estuary bank using 2024 Nearmap® imagery (under subscription) at a reference scale of 1:2000. Approximately 115.1km of this bank length was field surveyed recording more than 748 individual reaches. Areas not surveyed (~3.1km) were not accessible by powered watercraft. Further detail of the estuary characteristics including climate, geology, land use, and broader management context are available in the Bellinger and Kalang River Estuaries Erosion Study (Telfer and Cohen, 2010) and in Appendix A of the Bellingen Shire CMP – Stage 2 Report (Salients, 2022).

The mapping from this assessment is to be used to inform future management actions to improve the stability, resilience, and ecological condition of the estuary. In addition to an updated and comprehensive understanding of the distribution of estuary bank erosion and riparian vegetation condition, the report:

- Reviews the existing knowledge and data relating to estuary bank erosion, erosion processes, riparian vegetation distribution and condition, sediment sources and loads, existing bank protection works, and bank and riparian management priorities.
- Describes the process zones existing in the estuary in terms of the estuary character and behaviour.
- Maps bank condition and riparian vegetation condition as at the time of field assessment (July 2024).
- Maps existing bank protection works as at the time of field assessment (July 2024) including methods used and current effectiveness.
- Reports the recommendations of the NSW *Decision Support Tool for Bank Erosion Management*, developed by DPIRD Fisheries as part of the Marine Estate Management Strategy Initiative 2, for each surveyed segment.
- Presents a prioritisation system based on the objectives of the Coastal Management Act, NSW Marine Estate Management Strategy and other relevant plans covering the study area.
- Lists management priorities for improving bank and riparian condition in the estuary framed around the main objectives of increasing resilience to flooding, improving asset protection, water quality improvement, and riparian vegetation protection and enhancement.

The report draws on existing information and data provided by Bellingen Shire Council staff including local knowledge of bank erosion and vegetation management issues affecting the Bellinger and Kalang River estuaries. The Council has also played a valuable role in reviewing the field dataset, review and feedback on the data portal, and review and feedback on the drafts of this report, all of which is gratefully acknowledged.

This report summarises the findings of the field and desktop assessments of bank and riparian condition.

Requests for access to the full online mapping dataset, which includes up to 106 individual attributes per reach, should be addressed to NSW Department of Primary Industries and Regional Development - Fisheries.

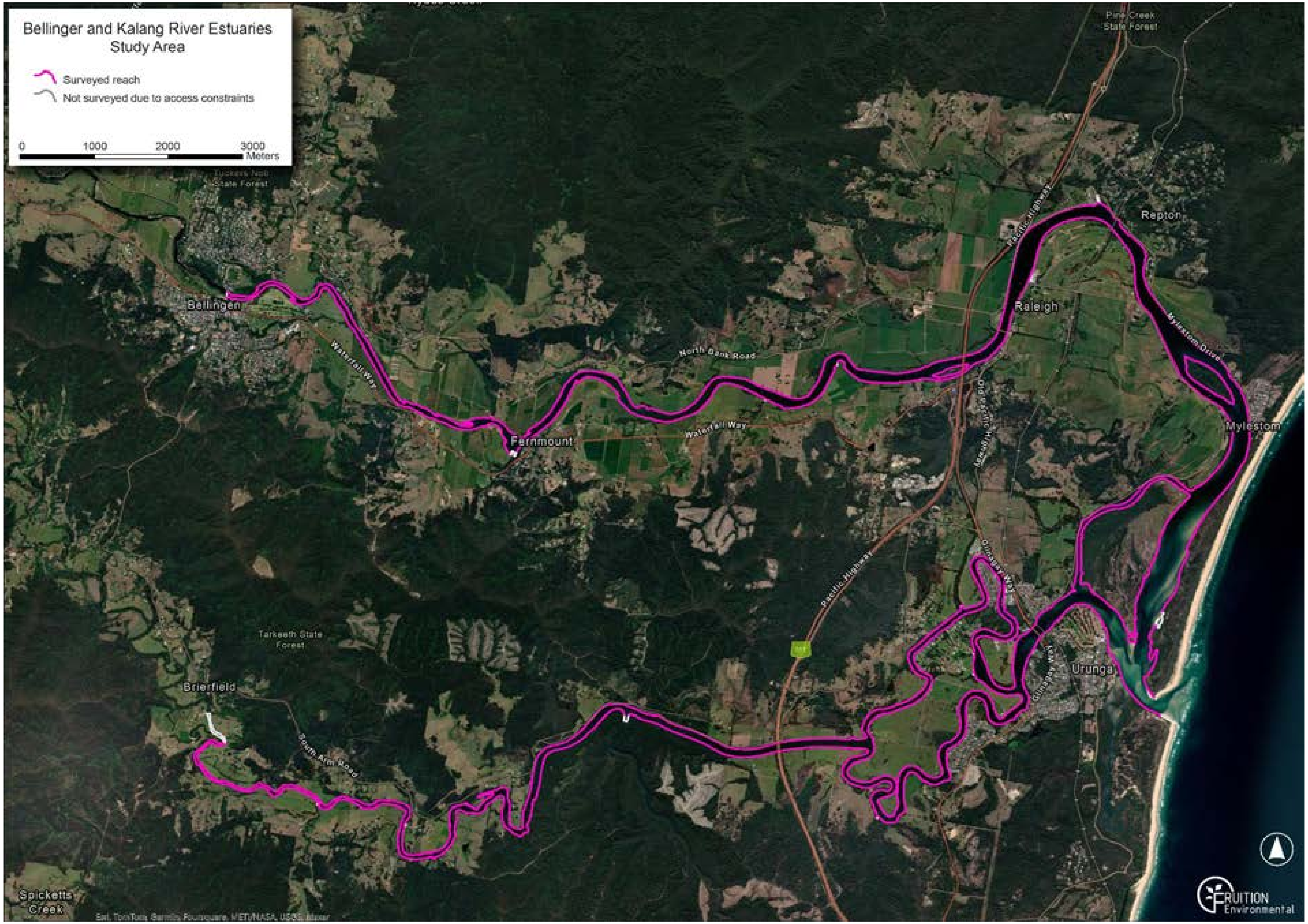

Figure 1 Bellinger-Kalang River Estuary Bank and Riparian Condition Assessment Study Area, July-August 2024

PART 1 - Existing Knowledge and Data

Literature Review

This section reviews the existing information and data that relate to the Bellinger and Kalang River estuaries physical processes and condition. There have been a number of studies and reports that have assessed to varying levels of detail the estuary processes, bank erosion distribution, estuarine vegetation, and potential estuary management strategies covering the study area. These include:

- Bellinger-Kalang Estuary Erosion Study (Telfer and Cohen, 2010)
- Bellingen Shire Coastal Management Program (Salients, 2024)
- Bellinger River Estuary Action Reach Plan (NRCMA, 2011)
- Bellingen Water Quality Management Plan (JBP, 2022)
- Bellinger Shire Biodiversity Strategy (Eco Logical Australia, 2019)

A number of additional documents were identified that provide useful background and overview information for the Bellinger-Kalang River Estuary study area. Most of these sources do not provide specific information or datasets of relevance to the NEAP Bank and Riparian Condition assessments but are nevertheless identified here for completeness. These include:

- Bellingen Coastal Zone Management Plan, 2014 (BMT WBM, 2014)
- Bellinger and Kalang Rivers Estuary Processes Study (Lawson and Treloar Pty, 2003)
- Bellinger-Kalang Rivers Ecohealth Project (Ryder et al., 2011)
- Bellinger Estuary Riverbank Erosion Assessments (Tallowwood, 2023-24)
- Burrawong Parade Riverbank Stabilisation Report (Elder Enviro, 2021)
- River Styles® assessment and mapping in the Northern Rivers CMA area (Alluvium, 2012)
- Lower Bellinger and Kalang Rivers Floodplain Risk Management Plan (WMA, Water, 2021)
- Bellinger River Estuary revegetation guide (Landcare)

Much of the background information presented in these documents are still relevant to managing the estuary in 2024 including information pertaining to the prevailing climate (rainfall, temperature, wind environments), historical river flow records, estuary sedimentation and erosion processes, bed sediment distribution, and estuary hydrodynamics. It is not intended to repeat the information presented in the documents here, except to summarise some of the information that is specifically relevant to the current 2024-2025 assessment of bank and riparian condition.

In this context, the focus of the review will be on identifying existing information relevant to the determination of estuary geomorphic process zones, estuary erosion processes, historic bank erosion mapping, historic riparian vegetation mapping, sediment sources and processes, existing bank protection works, and bank erosion and riparian vegetation management priorities in the Bellinger and Kalang River estuaries.

Where relevant and appropriate, the information presented in this review will be compared to the contemporary bank and riparian condition assessment results in later sections of this report.

Estuary Process Zones

Estuary process zones are a useful way to describe estuarine geomorphic attributes, estuarine character, estuarine sedimentary and erosion processes and to some extent riparian and estuarine vegetation associations occurring in a specific estuary system.

Estuary process zones have been mapped and described for the Bellinger-Kalang estuary by Telfer and Cohen (2010), using bathymetric data, satellite imagery and historical cross-sectional data (*Figure 2*). The process zones reflect underlying geomorphic characteristics including relative tidal fluvial energy dynamics, floodplain and channel morphology, sedimentary features, and vegetation attributes. The study provides a key reference to determining the baseline geomorphological context and estuary condition for successive documents.

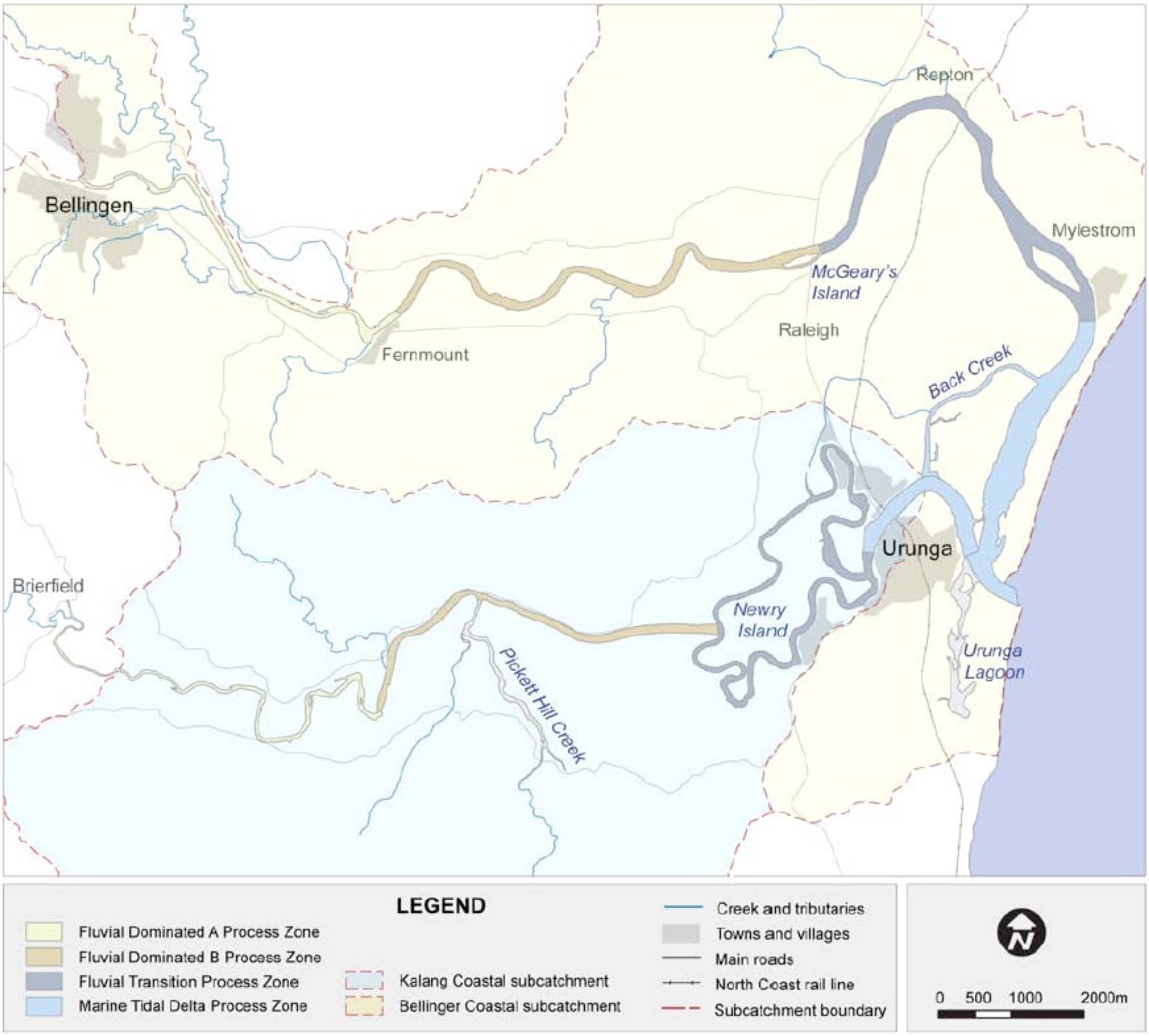

Figure 2 Distribution of estuary process zones in the Bellinger and Kalang River estuaries. (Source: Telfer and Cohen, 2010)

Bellinger-Kalang Estuary Erosion Study, 2010

As a precursor to this study, the 2010 Estuary Erosion Study collected detailed field data of bank erosion, riparian vegetation conditions and bank protection works, integrating detailed geomorphological data on the long-term landscape context and history with current processes and issues (Telfer and Cohen, 2010).

The Bellinger-Kalang estuary is classified as a "Mature Barrier (Wave Dominated)" estuary (Roy, 1984), influenced by historical sea-level rise and ongoing fluvial processes. The present system is river dominated by infilled mud basins west of Urunga to Raleigh and Repton. The geological development of the estuary began with post-glacial sea-level rise around 8000 years ago, which inundated previously exposed areas and led to the formation of a large embayment which progressively filled with sediment. Floodplain development on the lower estuary initiated approximately 4000 years ago, further shaping the estuarine environment.

Sediment distribution varies significantly across different sections in the estuary. The system is largely fluvially dominated, in that its present character and behaviour is controlled mostly by riverine erosion and deposition processes rather than tidal or marine processes, with an extensive floodplain with natural levees and backwater wetlands. The Bellinger River estuary then runs along a large coastal barrier system, which is replenished by sand drifting along the coast, before its confluence with the Kalang at the estuary mouth. While the estuary is tidal for >20 km upstream, only this lowermost extent is dominated by well sorted marine sediments. Mixed marine-fluvial sediments extend up to the entrance to Back Creek and east of Newry Island, reflecting the diminishing marine influence and increasing importance of riverine processes. Upstream areas are dominated by moderately sorted sub-angular fluvially derived sediment

Geomorphologically, the estuary system is divided into four distinct process zones along both the Bellinger River and Kalang River;

- Two Fluvial Dominated process zones
- Fluvial Transition process zone
- Marine tidal delta process zone.

The first zone, the Fluvial-Dominated A Process Zone, extends from the tidal limit at Bellingen to Fernmount on the Bellinger River and from Brierfield Bridge to Pine Creek on the Kalang River. This section is marked by a mixed sediment load, gravel bar formation, and a meandering belt with high-energy overbank flow. The zone has variable floodplain topography, with a compound channel exhibiting floodplain formation set within an older terrace margin. The Kalang River shows similar characteristics but within a more confined valley resulting in discontinuous floodplain pockets. Downstream, the Fluvial-Dominated B Process Zone on the Bellinger River shows finer sediment (sand) and lower floodplain elevations, while the Kalang River exhibits a change in valley bedrock morphology.

The Fluvial Transition Process Zone reflects a combination of fluvial and marine influences, with reduced floodplain elevations and increased low-velocity overbank flow. It is associated with the infilled mud basins, influenced by localised, remnant Pleistocene terrace sediments, which control channel positions and migration rates. On the Kalang River, this zone is characterized by an anabranching channel form.

The Marine-Tidal Process Zone, dominated by marine sediment transport processes, experiences a constant influx of marine sand, which is periodically flushed by large flood events but re-forms soon after due to flood and ebb-tide sediment transport. An estimated 40,000 m^3 net influx of marine sand is transported landward each year as a function of flood tide transport (based on 1981 data). The low floodplain height and low stream gradients results in tidal inundation of the salt marsh and mangrove flats, but only small areas of these communities exist in the estuary.

Human activities have substantially influenced sediment dynamics in the estuary. Dredging for navigation and construction material, the decrease in riparian and floodplain vegetation, along with the historical accounts of downstream aggradation suggest that the Bellinger River underwent a rapid shift in the nature of sediment supply shortly after colonial settlement. Extensive clearing of dense vegetation in the catchment, including lowland rainforest from the floodplains, for agricultural production resulted in major impacts to the Bellinger and Kalang Rivers, with undoubted but undocumented impacts to the estuaries. An estimated annual 150,000 m³ was dredged from the estuary entrance in the early 20th century. Currently, limited dredging continues, primarily for construction sand for development in the region.

Present erosion dynamics within the Bellinger-Kalang estuary differ significantly between the two rivers. The Bellinger River erodes at a faster rate than the Kalang River, largely due to less cohesive bank material and reduced riparian vegetation. Substantial channel width increases of 6–33% have occurred in the upper reaches since 1942, with associated channel capacity increases of 2–75% at various sites. By contrast, the Kalang River experiences slower erosion rates, attributed to more cohesive bank materials and a higher proportion of naturally stable banks. A 2009 survey of bank erosion revealed that the occurrence of major erosion sites had reduced along the estuaries over the preceding 25 years but a significant increase in minor erosion was observed, possibly related to a recent flood event. In the Bellinger River estuary, 54% of banks were stable, while 32% experience minor erosion and the remainder moderate to severe erosion. Many stable banks are maintained through erosion control works or natural bedrock features. In the Kalang River, 68% of banks were stable, with minor erosion recorded along 21% of banks. Bedrock plays a more prominent role in stabilizing the Kalang River compared to the Bellinger River.

Estuary Bank Erosion Mapping and Estuary Bank Erosion Processes

Several studies of erosion in the Bellinger-Kalang River Estuary have been undertaken over the last 30 years that have incorporated estuary bank erosion mapping and discussion of processes. The most recent and relevant of these studies were bank erosion surveys undertaken in 2009 (Telfer and Cohen, 2010), which provided detailed erosion mapping throughout the extent of the Bellinger-Kalang estuaries. Earlier mapping efforts were broadscale across the estuary (Cameron McNamara, 1985; Waner and Paterson, 1987) but have been superseded and subsequently used for comparative analyses in more recent studies. The studies involved detailed mapping of bank erosion and cross-sectional analyses of changes in bank profiles. Given, the age and current quality of access to these data they have not been further reviewed below.

Other studies that have focussed on limited extents of bank erosion processes occurring in the estuary, mostly focused on specific locations related to detailed site inspection and remediation plans. However, no further detailed mapping has been undertaken at the time of review.

Bellinger-Kalang Estuary Erosion Study, 2010

The study provides the most recent and comprehensive assessment of bank erosion and bank condition of the Bellinger and Kalang River estuaries prior to the 2024 NEAP Assessment (*Figure 3*). Field surveys were conducted in 2009 along the length of the main arm estuaries, including Back Creek, to document the extent and severity of bank erosion in conjunction with data on riparian vegetation condition and bank protection and access infrastructure. Survey results were mapped to a spatial dataset of the estuary margin and classified as;

- ***0** = **No erosion*** occurring in the reach
- ***1** = **Minor erosion***, being erosion of a minor nature considered to not warrant any action/intervention, not likely to be accelerating and possibly not continuing (flood impacted in 2009), and having moderate to high recovery potential at the time of assessment

- ***2*** = ***Moderate erosion***, being erosion that may warrant intervention depending upon the level of impact to values in the reach, which may accelerate depending upon the nature of the erosion processes (episodic or ongoing), and have low natural recovery potential
- ***3*** = ***Severe erosion***, being erosion which was affecting the entire bank profile and was likely impacting values in the reach and potentially beyond the reach (eg. water quality impacts) and which was unlikely to arrest without action/intervention

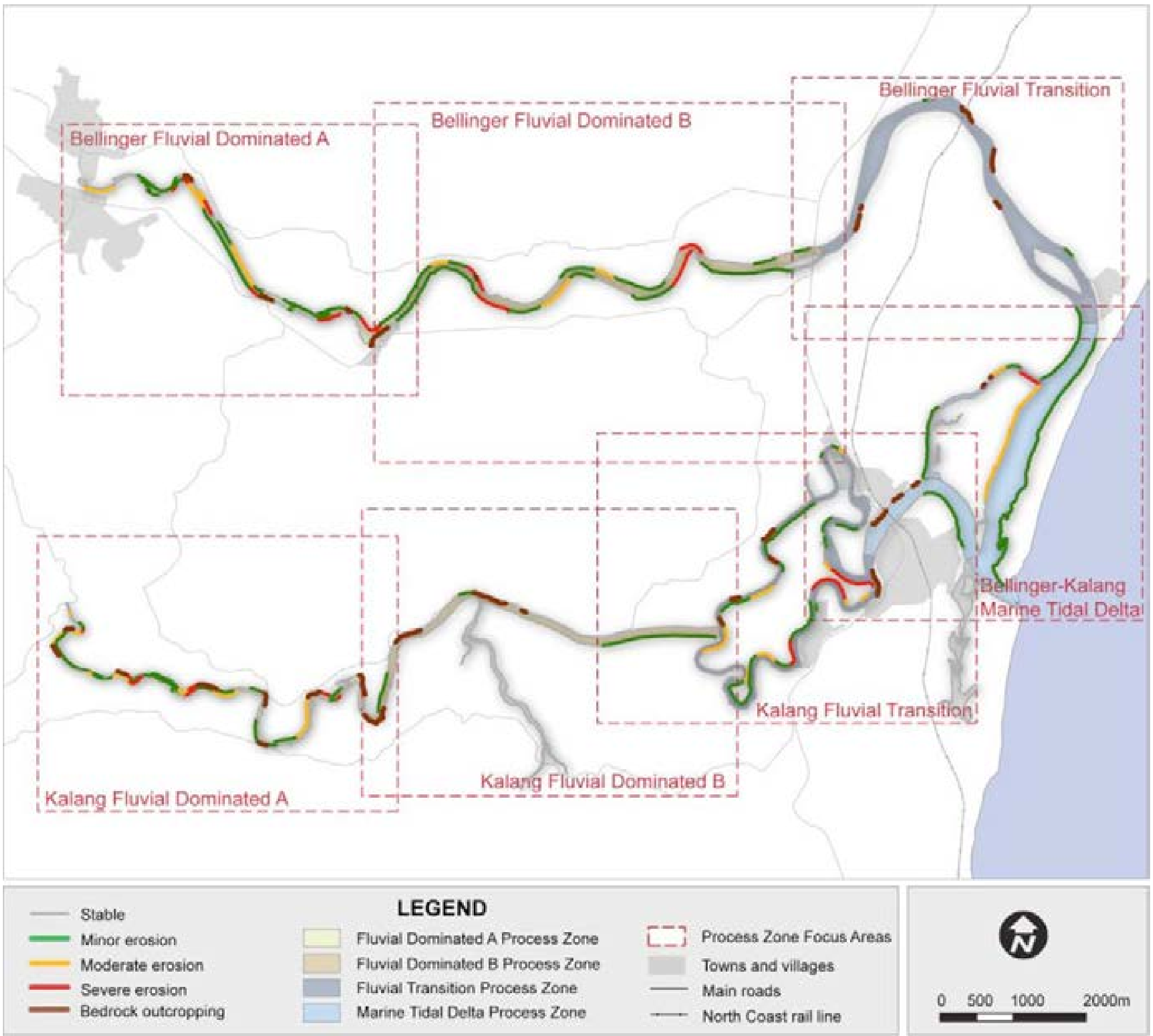

Figure 3 Bank erosion severity mapping In the Bellinger and Kalang River estuaries. 2009, undertaken by Telfer and Cohen (2010)

Banks were described as continuous reaches, where a consistent set of bank erosion or vegetation condition attributes existed. Types of erosion (e.g. scour, wave action, slumping) and factors affecting erosion (e.g. bedrock outcropping, foreshore protection works) were also documented. The nature of the erosion process was factored into the categorisation during the survey, assessing whether erosion was dormant, episodic or a progressive, ongoing process.

In addition to field mapping, desktop assessments of photogrammetry and historical reconstruction from aerial imagery (1942 – 2003) were used to investigate eight previously-identified major erosion sites (in

Cameron McNamara, 1985: see *Figure 4*) to determine ongoing erosion rates and volumes. The report noted that much of the erosion was the result of fluvial processes associated with flooding, but that erosion was exacerbated by clearing of riparian vegetation, as well as stock access in a number of locations.

The reasonable consistency of the methodology used in 2009 with the approach used in the 2024 NEAP Assessment means that the results allow a comparative assessment of changes in the distribution and severity of erosion since the 2009 survey. A similar exercise was undertaken by Telfer and Cohen (2010) with bank erosion data collected between 1984 – 2009, providing the ability for a detailed assessment of changes in bank erosion over the last 30 years.

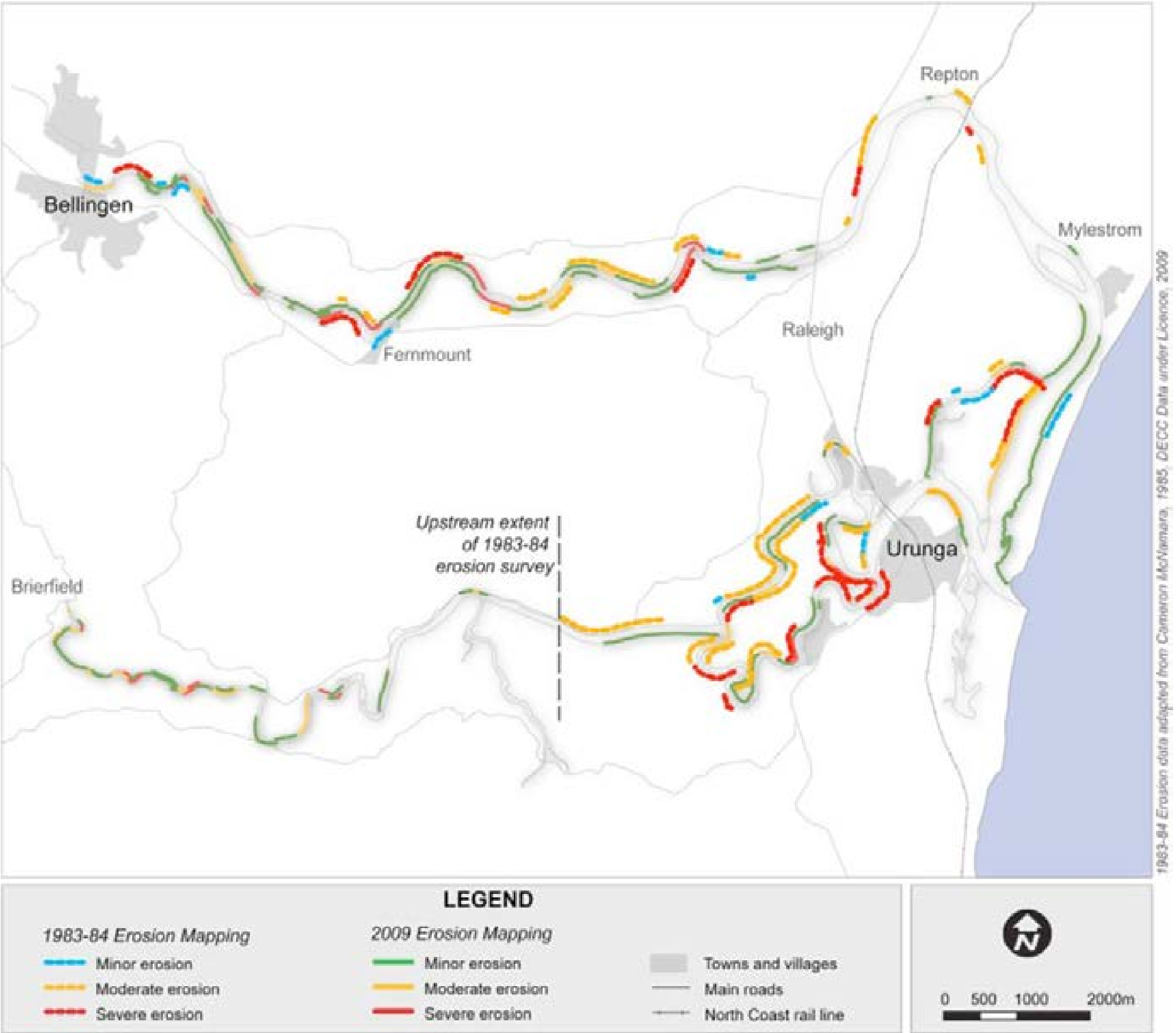

Figure 4 *Comparison of active bank erosion in 1981-84 (by Cameron McNamara, 1984) and 2009 (source: Telfer and Cohen, 2010)*

Bellinger River Estuary Action Reach Plan, 2011

Riparian condition assessments were undertaken at approximately 180 apparent locations across 53 sites in late August 2010 (Bellingen Shire Council, 2011) along three reaches of the Bellinger River that approximate the process zones of Telfer and Cohen (2010). Field surveys were predominantly focused on riparian vegetation, but observations of active bank erosion were recorded at each site as binary presence/absence, as well as grazing activity in the riparian zone.

The erosion data is recorded as point data but the spatial dataset was not available at the time of review. The study mostly uses the Bellinger-Kalang Estuary Erosion Study (Telfer and Cohen, 2010) to reference the fluvial and geomorphological context and identify key threats. No comprehensive overview is provided, only the individual site reports (see example in *Figure 5*), with erosion being indicated in attached figures. Currently, it would require considerable qualitative investigation to extract relatively limited data. As such, the data has limited practical application.

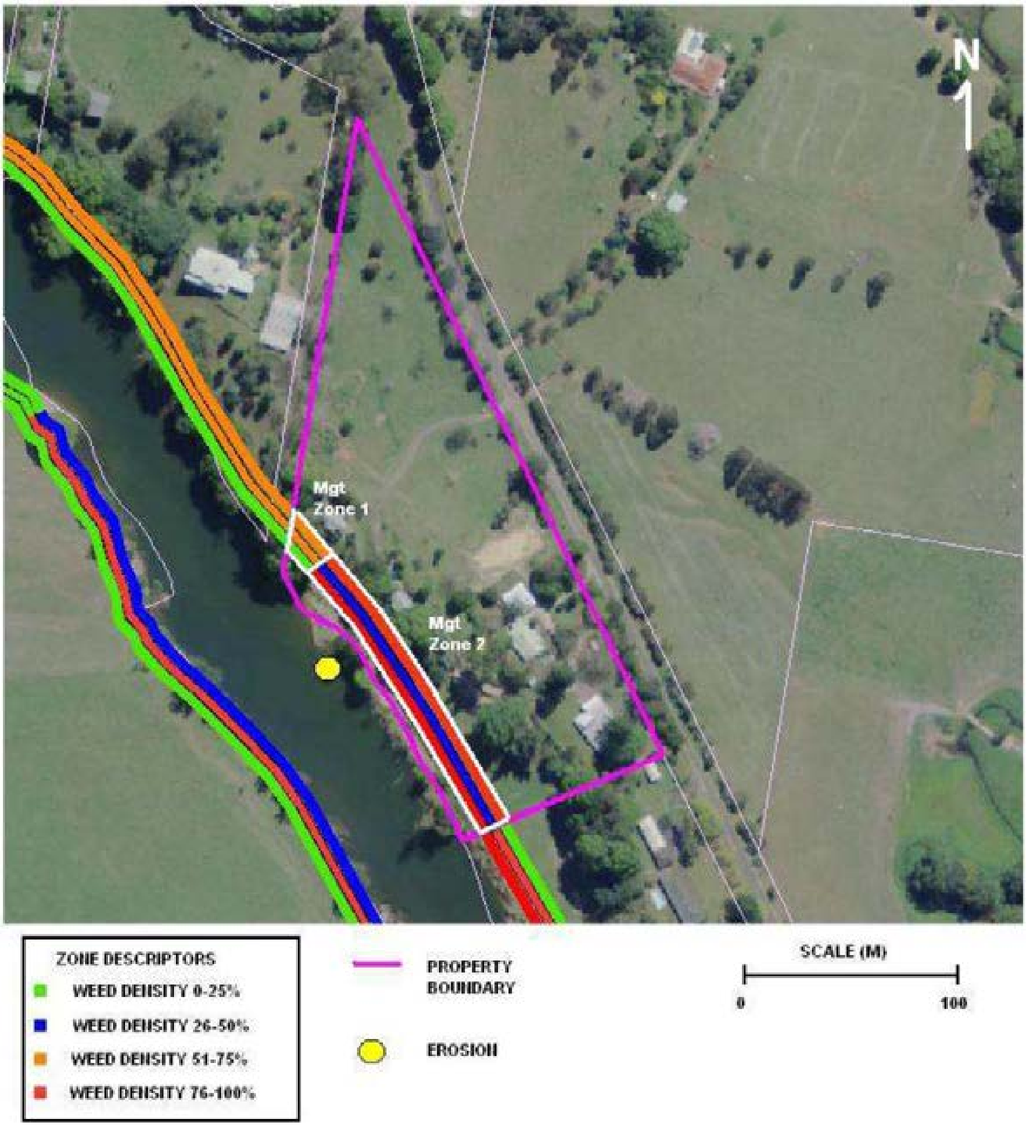

Figure 5 Example of mapping of bank erosion sites and weed density in canopy, mid story and ground cover at Site 9 (source: BSC, 2011).

Burrawong Parade, 2021

Bank stability assessments were undertaken at 43 sites along an 840 m length of riverbank along the Kalang River in Urunga along a narrow strip of Council Reserve (Elder Enviro, 2021). The majority of sites have had ad-hoc bank protection works installed, in varying states of disrepair. Sites were assessed as either actively eroding, susceptible to erosion or stable.

Tallowwood Riverbank Erosion Assessments, 2023-24

Riverbank assessments were undertaken at discrete sites in the Bellinger and Kalang Rivers, each approximately 200 – 300 m in length. Assessments were undertaken for the purpose of developing erosion remediation concept plans and included detailed inspection of erosion processes. The sites had previously been assessed as stable or featuring minor erosion (Telfer and Cohen, 2010). The sites offer limited value to a broadscale assessment of the estuary but highlight ongoing issues within the estuary system since the 2009 survey. Two sites demonstrate erosion scarps on low floodplain associated with wave erosion, likely induced by recreational boat activity. Clearing of vegetation up to the bank remains an issue, with erosion associated with cleared areas of bank at two sites.

Riverstyles® Assessment 2011

Alluvium Consulting was engaged by Northern Rivers Local Land Services to undertake a Riverstyles® assessment and mapping in the Northern Rivers CMA region (reported in Alluvium, 2012). The Alluvium assessment describes the entire Bellinger-Kalang River estuary study reach as a Tidal Laterally Unconfined, Low Sinuosity, Continuous Channel. The river style is in contrast to detailed geomorphic investigations undertaken by Telfer and Cohen (2010), which noted valley confinements, bedrock restrictions and differing sediment distributions. The entire estuary is described as being in either Poor or Moderate geomorphic condition, with Low to Moderate recovery potential. Only the fluvial dominated reaches of the Kalang River are considered a high priority for rehabilitation. There are no reasons for the classifications or specific management implications provided and so the ratings have limited practical management application.

Riparian Vegetation Condition Mapping

Several studies have investigated riparian vegetation condition within the Bellinger-Kalang River Estuary study area. Riparian vegetation condition mapping was completed for the extent of the main arms of estuary in 2009 as part of the Bellinger-Kalang Estuary Erosion Study (Telfer and Cohen, 2010), based on field surveys along the length of the estuary. Further assessments were undertaken in 2010

Bellinger-Kalang Estuary Erosion Study, 2010

Field surveys were conducted along the length of the Bellinger and Kalang River Estuaries in conjunction with bank erosion assessments described above. Vegetation width, structure, integrity and diversity were scored from 1 – 5 (indicating a scale of Very Poor to Very Good) during field surveys and inspections. The presence of major environmental weeds was also recorded and the degree of infestation on a scale of 1 – 3 (low - dominant). These scores were then combined to provide an overall vegetation condition rating (*Figure 6*).

The initial survey results were then mapped to a spatial dataset of the estuary margin, providing broadscale data on riparian vegetation condition with the following codes used within the GIS dataset:

- ***0*** = Not surveyed
- ***1*** = Very poor condition
- ***2*** = Poor condition
- ***3*** = Moderate condition
- ***4*** = Good condition
- ***5*** = Very good condition

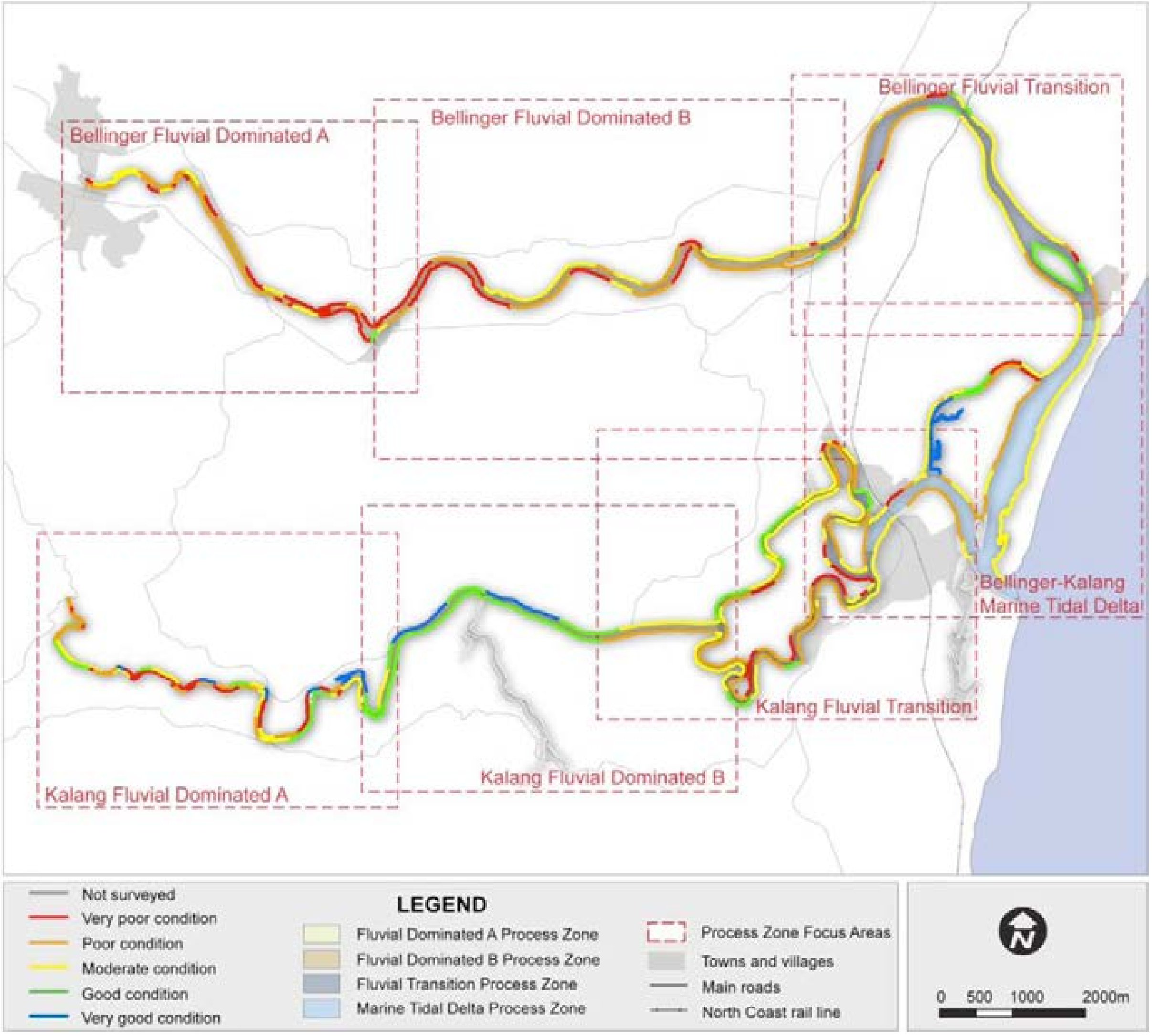

Figure 6 Mapping of riparian vegetation condition in 2009 (source: Telfer and Cohen, 2010)

Bellinger-Kalang Rivers Ecohealth Project, 2011

The Bellinger-Kalang Rivers Ecohealth Project Assessment of River and Estuarine Condition (UNE, 2011) undertook riparian condition assessments at ten sites throughout the catchment using the sub-tropical rapid appraisal for riparian condition (STRARC) method. STRARC is a multi-metric index of riparian condition, which has been modified from the original Rapid Appraisal for Riparian Condition (RARC) (Jansen et al. 2007a) and the adapted Tropical Rapid Appraisal of Riparian Condition (TRARC) (Dixon et al. 2006). The STRARC is comprised of 24 indicators to characterise vegetation condition, habitat, bank stability and amount of disturbance to the riparian zone. Data were collected along a representative 200 m reach and at 3, 25 m^2 quadrats within each study site.

Only one site was located in the estuary study area, on the Kalang River at Brierfield, at the upstream extent of estuary. As such, detailed comparison is not required.

Kalang River at Brierfield (upstream extent of estuary) was identified as a priority area for remediation. Recommended actions include weed management, improving riparian habitat in the form of organic litter and woody debris, and undertaking bank remediation.

Bellinger River Estuary Action Reach Plan, 2011

Riparian condition assessments were undertaken at approximately 180 apparent locations (called management zones) across 53 sites in late August 2010 (NRCMA, 2011) along three reaches of the Bellinger River that approximate the process zones of Telfer and Cohen (2010). The study provides a strong focus on weed issues in riparian zones, documenting detailed assessment of the severity of weed infestation. While aspects of the survey methodology are unclear, at each location information was collected on:

- Canopy, mid story and ground cover
- Presence of target weed species (12 identified)
- Proportion of weed infestation within the canopy, mid story and groundcover zones.
- Weed species densities
- Areas of significant erosion
- Stock access
- Riparian regrowth
- Riparian width and suitability

Vegetation and weed cover densities were recorded in four categories (0-25% up to 76-100%). Densities were recorded for each identified weed at each site. Other categories were binary. This data was used to establish baseline condition assessments and provided information to determine the level of intervention required and the prospective target condition rating for the reach. No comprehensive overview is provided of the data, with detailed information available for individual site descriptions, which may provide a benchmark for comparison with 2024 weed presence. However, the spatial dataset was not available at the time of review and would require considerable qualitative investigation to extract comparison data. Further, land-based assessment data and weed presence data observed from boat surveys the 2024 NEAP assessment may not be directly comparable.

Existing Bank Protection Works

Broadscale information is available detailing the extent and range of bank protection works within the estuary. Some of this data is now 15 years old and a consistent inventory of more recent works are not available.

The most extensive dataset is included in the 2009 field surveys (Telfer and Cohen, 2010) undertaken in conjunction with bank erosion and riparian condition assessments described above, recording the location and type of erosion protection works in the Bellinger and Kalang River Estuaries. Eleven different types of protection works were documented as well as a limited assessment of effectiveness at the time of survey. Entrance training walls were excluded from the assessment. Figure 7 shows an example of the location and types of works mapped in the estuary. The dataset provides a robust benchmark for comparison to the 2024 NEAP assessment of existing works.

Other studies have provided assessments on individual bank protection works, providing limited but updated information on asset condition and effectiveness (Elder Enviro, 2021; Tallowwood, 2024). The Bellinger WQMP (JBP, 2022) provided updates on 27 high and moderate priority sites identified by Telfer and Cohen (2010) and the status of protection works that have been undertaken in the intervening period. Only three sites have had remediation works undertaken.

Structural condition of bank protection works was more recently assessed at 43 sites along an 840 m length of riverbank along the Kalang River (Elder Enviro, 2021). Many sites were considered to be in varying states of disrepair and ineffective at addressing ongoing erosion issues.

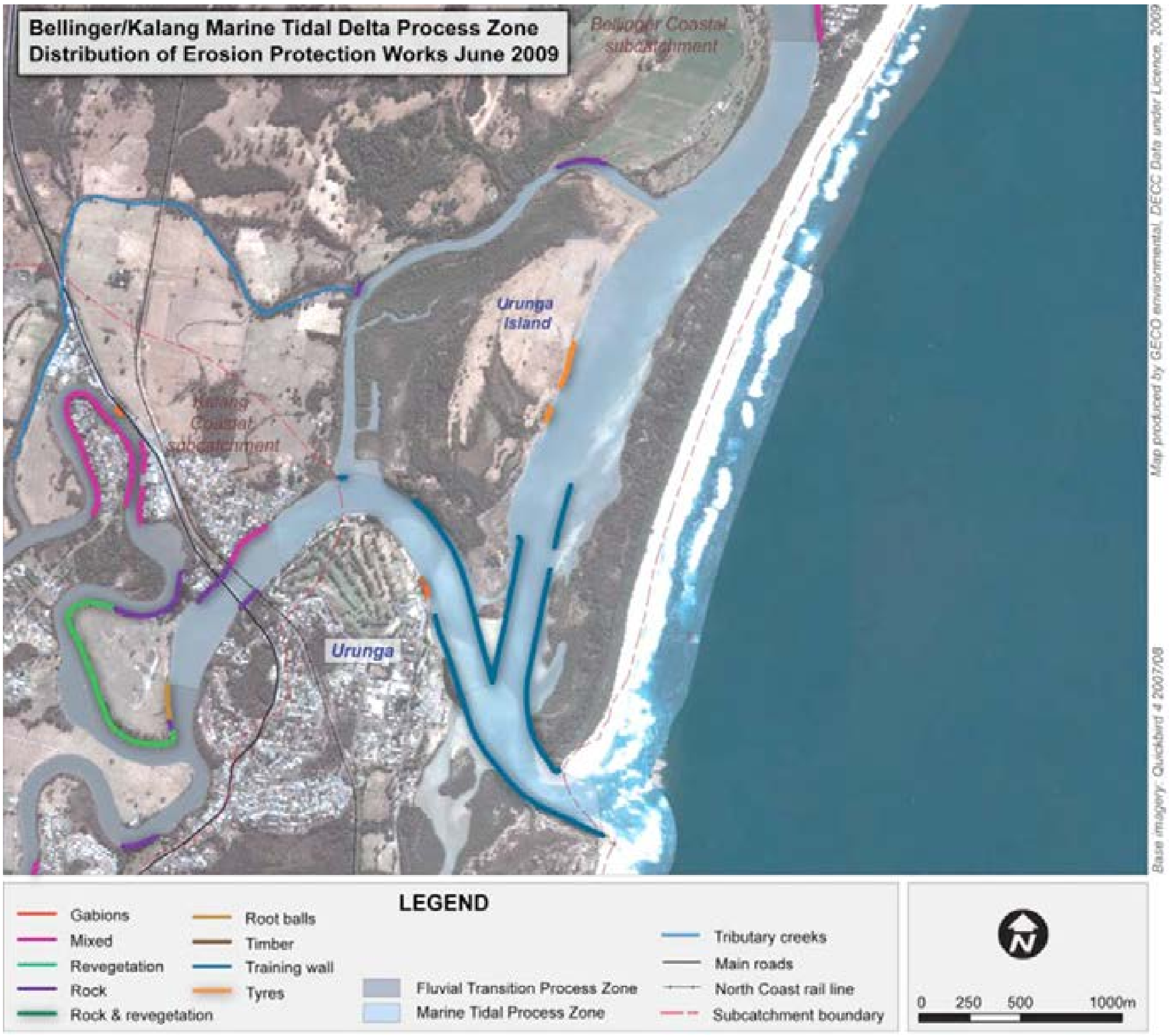

Figure 7 Distribution and type of existing bank protection and remediation works in the lower Bellinger and Kalang estuaries – Marine Tidal Delta Process Zone, 2009 (source: Telfer and Cohen, 2010).

Bank Erosion and Riparian Vegetation Management Priorities

The primary documents which provide recommendations and strategic prioritisation for future coastal and estuary management are the Bellingen CZMP (BSC, 2014), the Bellinger-Kalang WQMP (JBP; 2022) and Bellingen Shire Coastal Management Program (BSC, 2024). The Bellingen CZMP is focused primarily on the open coast and provides little insight into management priorities and actions within the Bellinger and Kalang estuaries, other than inundation. However, the latter two documents identify similar issues and impacts affecting the Bellinger-Kalang estuary study area. The strategies and actions contained within these documents will be used later in Part 5 of this report to assist in the ranking and prioritising sites. The Bellinger and Kalang Estuaries Erosion Study (Telfer and Cohen, 2010) also detailed a series of priority sites for management intervention.

Bellinger-Kalang Estuary Erosion Study, 2010

On the basis of the detailed field surveys of bank erosion, riparian vegetation condition and existing bank protection works, the 2009 study recommends high priority sites for on-ground works actions including bank stabilisation works, targeted revegetation, and maintenance of existing protection works.

Twenty-eight (28) sites were prioritised and ranked based on the significance of erosion and the protection of important community assets and estuarine values. A review of the current status of the priority sites identified in 2009 is provided in Part 3 of this NEAP Assessment Report.

Bellingen Shire Biodiversity Strategy (2020)

The broad key focus areas, programs and actions identified in this Strategy are aligned with the Bellingen Community Strategic Plan (CSP) 2027. They include the following programs and strategies relevant to the estuaries:

Vegetation

- **Program 2.1:** Endeavour to protect 100% of native vegetation in Council Reserves
- **Program 2.2:** Improve vegetation within core habitat areas that are considered to have opportunities for connectivity
- **Program 2.5:** Maintain and improve the condition of vegetation in Council reserves

Waterways

- **Program 3.1**: Measurable improvement in water quality across Bellingen waterways
  - Continue to reduce sediment inputs through bank stabilisation revegetation works in estuary tributaries
  - Minimise impacts of boating and recreation on seagrass through ‘no wash zones, buoy markers, education and other controls
  - Manage public access at environmentally sensitive foreshore locations. Priority areas may include key habitat and vegetation communities located in areas that are frequented by the public and require detailed design to achieve biodiversity protection
  - Reduce the unauthorised clearing of riparian and estuarine vegetation, impacts of agricultural runoff and use of unsuitable materials for bank stabilisation
  - Work with agencies and corporations, private landholders and Landcare groups to encourage and assist in the revegetation of riparian areas, and the protection, management and conservation of existing riparian vegetation and catchment headwaters. As a priority, target landholders with ecologically significant vegetation present on their land.
- **Program 3.2** Protect foreshores, coastal lagoons, significant wetlands and Coastal Saltmarsh
  - Includes wetlands, mangroves, saltmarsh, seagrasses and migratory and wader bird habitat (e.g. inclusion of core habitats, wetlands, priority areas and validated mapped HEVs as W2, E2, E3, E4 or Natural Resources Sensitivity in the LEP, and update clauses, maps or overlays within LEP and DCP)
  - Prepare a Council policy to conserve mangroves, mudflats, seagrass, coastal lagoons and shorebird habitat.
  - Identify site specific threats and implement appropriate management options in accordance with the Bellinger and Kalang Rivers Estuary Management Plan and the Bellingen Coastal Zone Management Plan

- Ensure that foreshore infrastructure masterplans and implementation protect wetlands, lagoons, saltmarsh, mangroves, seagrasses and migratory bird habitat
- Ensure that public and private projects protect foreshore vegetation, mudflats, and where rock revetment/ seawalls are required ensure they are designed as being biodiversity friendly.

- **Program 3.3:** Restore the ecological function of core habitat, waterways and wetlands
  - Protect and restore Council managed land where Key Fish Habitat is mapped
  - Prioritise and protect areas of intertidal saltmarsh, lagoons, coastal foreshore and mangrove to provide habitat for migratory waders

Habitat

- **Program 6.3**: Ensure weed density is managed in core habitat areas to ensure protection of significant areas in Council reserves

Bellinger-Kalang WQMP, 2022

The WQMP provides water quality updates for the entire Bellinger-Kalang catchment and provides broadscale catchment management actions (*Figures 8* and *9*). The Plan builds upon existing land management actions identified in prior plans and highlights the considerable and broadscale adverse effects to a range of catchment values from poor bank conditions, reflected in the recommendations of the Bellingen Shire Biodiversity Strategy (Eco Logical Australia, 2020). The goals and actions that relate to bank erosion and riparian vegetation are quite broad but were all factored as high priority for management and include:

Goal 3: Increase biodiversity and ecosystem services

- **BIO1:** Managing grazing/stock exclusion on riparian land.

  The management of riparian grazing through stock exclusion and fencing aligns with the Bellingen Shire Biodiversity Strategy and Bellinger Landcare Manual, aiming to improve water quality, reduce erosion, and restore ecological function. Council should advocate for riparian management on private land, focusing on priority areas for stock exclusion, revegetation, and erosion control.

- **BIO2:** Reinstatement and reforestation of riparian buffers.

  Restoration of riparian zones through vegetation reinstatement for bank stabilisation, water quality improvement, and biodiversity aligns with the Bellingen Shire Biodiversity Strategy. Council should implement this on Council managed lands and advocate for similar actions on private lands, particularly in areas where stock exclusion is achieved.

- **BIO4:** Protect and restore areas of intertidal saltmarsh, lagoons, and mangroves on Council managed land.

  A Council policy and action plan should be undertaken to identify steps to conserve ecologically important wetlands from future development, changes in land use, pollution, and degradation. This would involve identification of wetland areas, mapping of adjacent threats, and development of management actions.

Goal 4: Mitigate erosion and improve bank stability

- **ERO1:** Site-specific erosion investigations.

  A range of areas with erosion problems have been identified in previous reports. This action would aim to rehabilitate two sites to serve as demonstration projects, requiring preliminary assessments and designs to then undertaken by Council works teams or externally by contractors. The report specifically identifies two priority sites for remediation within the catchment, one within the estuary at Mylestom Reserve (Reach 145), where ongoing erosion has impacted and degraded existing protection works. These works appear to have been completed.

- **ERO2:** Advocate and educate for private land restoration and erosion protection works.

  Advocating for erosion management on private property should focus on collaboration with landholders and government agencies, prioritising moderate to severe erosion areas. This aligns with the Bellingen Shire Biodiversity Strategy, aiming to reduce threats to water quality through riparian revegetation and stock exclusion. Efforts should target landholders with ecologically significant vegetation, with potential funding from the NSW Environmental Trust's environmental education program.

- **ERO3:** Bank stabilisation and revegetation works on Council managed land.

  Council should continue to reduce sediment inputs through bank stabilisation and revegetation works on Council-managed land. Mitigation should begin using nature-based approaches including those with engineering-influenced designs such as pool and riffle restoration, habitat-creating pile logs and rock fillets.

- **ERO4:** Minimise impacts of boating.

  Undertake actions to reduce water quality risks from boat wash, including enforcing speed limits, defining "no wash zones," and installing buoy markers. Reducing boat speeds can help minimise bank erosion, seagrass loss, and impacts on aquatic biodiversity, particularly in areas like Newry Island and Back Creek. Signage should be used to educate boaters on the environmental impacts of boat wash.

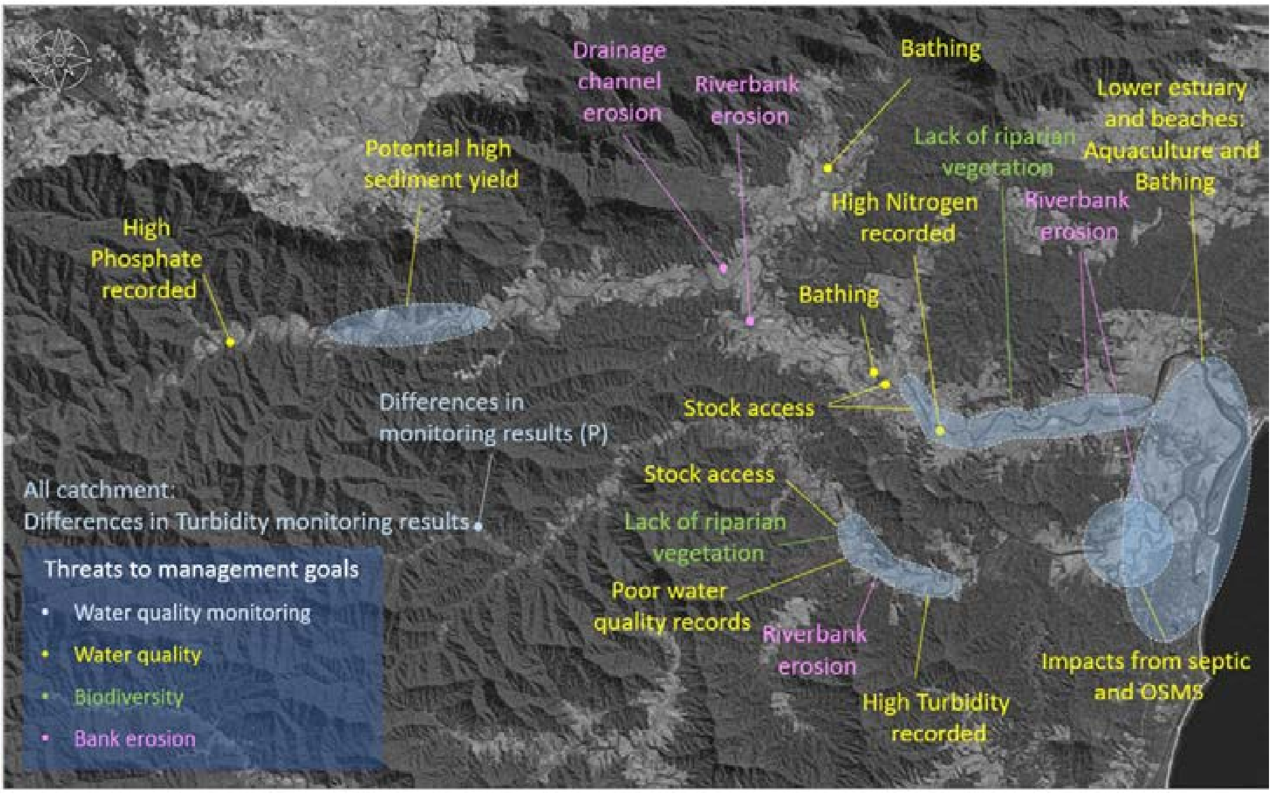

Figure 8 Snapshot of key threats and issues to water quality within the Bellinger-Kalang catchment, noting highlighted areas in the estuary study area (source: JBP, 2022).

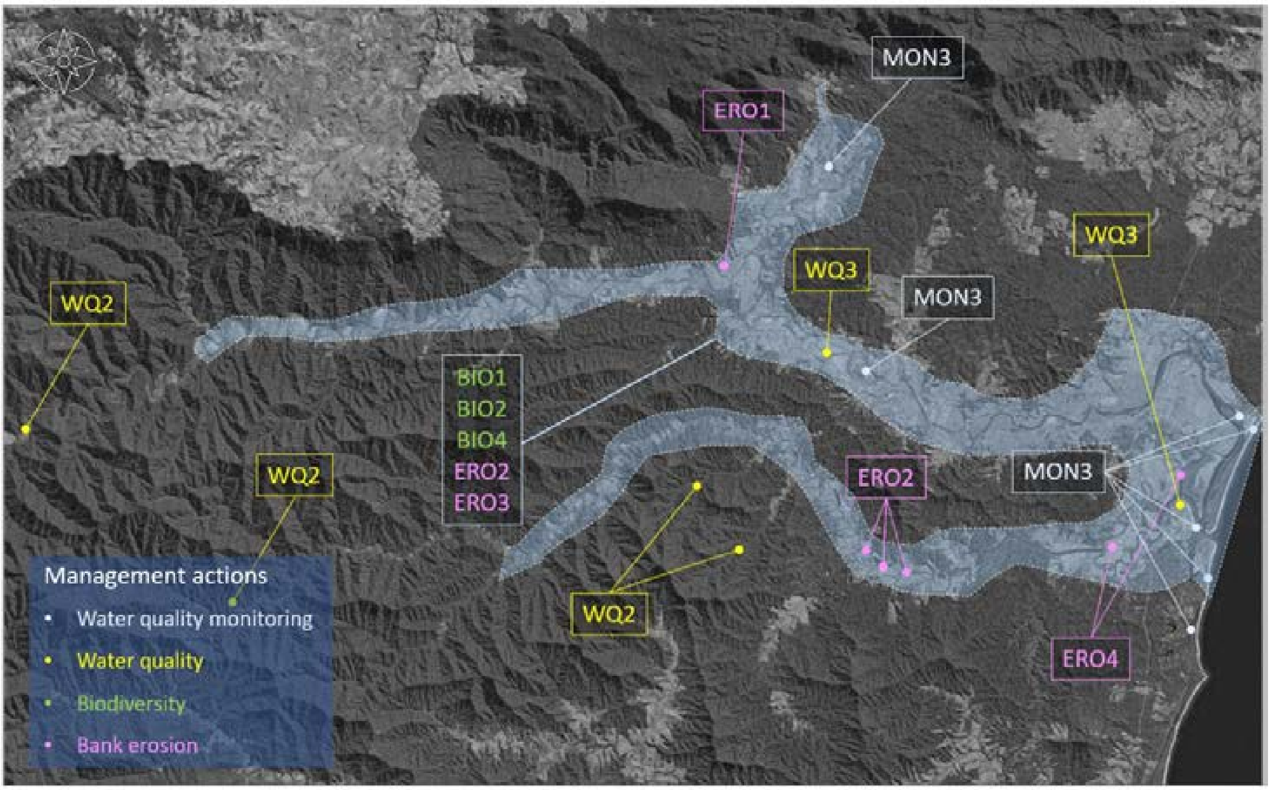

Figure 9 Map of water quality management action sites in the Bellinger-Kalang catchment (source: JBP, 2022).

Bellingen Draft CMP, 2024

The Bellingen Shire Coastal Management Program recognised threats to coastal ecological, cultural heritage and infrastructure values as key issues and challenges for ongoing land management within Bellingen Shire. The report contains broad priorities for long-term strategic land management in the coastal zone. It highlights ongoing issues and the high risk of bank erosion on rural and residential land, as well as the degraded state of riparian vegetation and issues with some existing bank protection works. The Draft Plan involved identifying generalised locations of the estuary and floodplain where these issues occur, but no detailed site identification was involved. Actions that relate to estuary bank and erosion and riparian management include:

- **Action E1:** Review Coastal Wetlands and Littoral Rainforest SEPP Mapping

  Coastal Wetland and Littoral Rainforest SEPP mapping, including the identification and mapping of weed presence, requires updating to accurately reflect vegetation extent, and to allow appropriate implementation of relevant planning controls.

- **Action E2:** Control Weeds in Coastal Wetlands and Littoral Rainforest

  Sites to be identified through Action E1 to undertake weed management works with priority given to sites on public land, where active Landcare, Dunecare, or custodian groups are present. Where possible, a weed containment buffer to the vegetation community would be established, as well as ongoing inspection and maintenance works.

- **Action E5:** Protect and Enhance Ecological Values at Urunga Island and Yellow Rock Road, Dalhousie Creek, along the Kalang River

  Urunga Island and the area adjoining Yellow Rock Road is of high biodiversity and cultural value and is under threat from bank stability, vegetation and future climate change impacts. Potential funding opportunities to be investigated, including Blue Carbon projects, public acquisition and engagement of private owner to undertake grant-funded works.

- **Action E6:** Undertake an Estuarine Bank Condition Assessment

  The bank condition mapping for the Bellinger and Kalang Rivers is over 10 years old and warrants a review and update. A comparative bank condition assessment is recommended to provide a consistent base to access permits and funding and, could use the Decision Support tool developed under MEMA.

- **Action W4:** Promote Programs and Grants for Stock Management on Riparian Land

  This action would reduce the high-risk to water quality of stock grazing of riparian and aquatic vegetation. Council should advocate for the riparian management on freehold, private land, supporting any opportunities to work with landholders or other government departments. Support should be given for any area where stock have direct access to the waterway.

- **Action U1 –** Upgrade foreshore stabilisation and recreational facilities at Mylestom Foreshore Reserve

  Design and construction of replacement stabilisation works that are fit for purpose. Key tasks for this action include:

  - Prioritisation of failing foreshore protection structures adjoining infrastructure assets (such as stormwater pipes, access stairs / ramps) for repair.
  - Refurbishment of the Mylestom Boat Ramp
  - Refurbishment of the Mylestom Tidal Pool
  - Construction of a new kayak launch facility

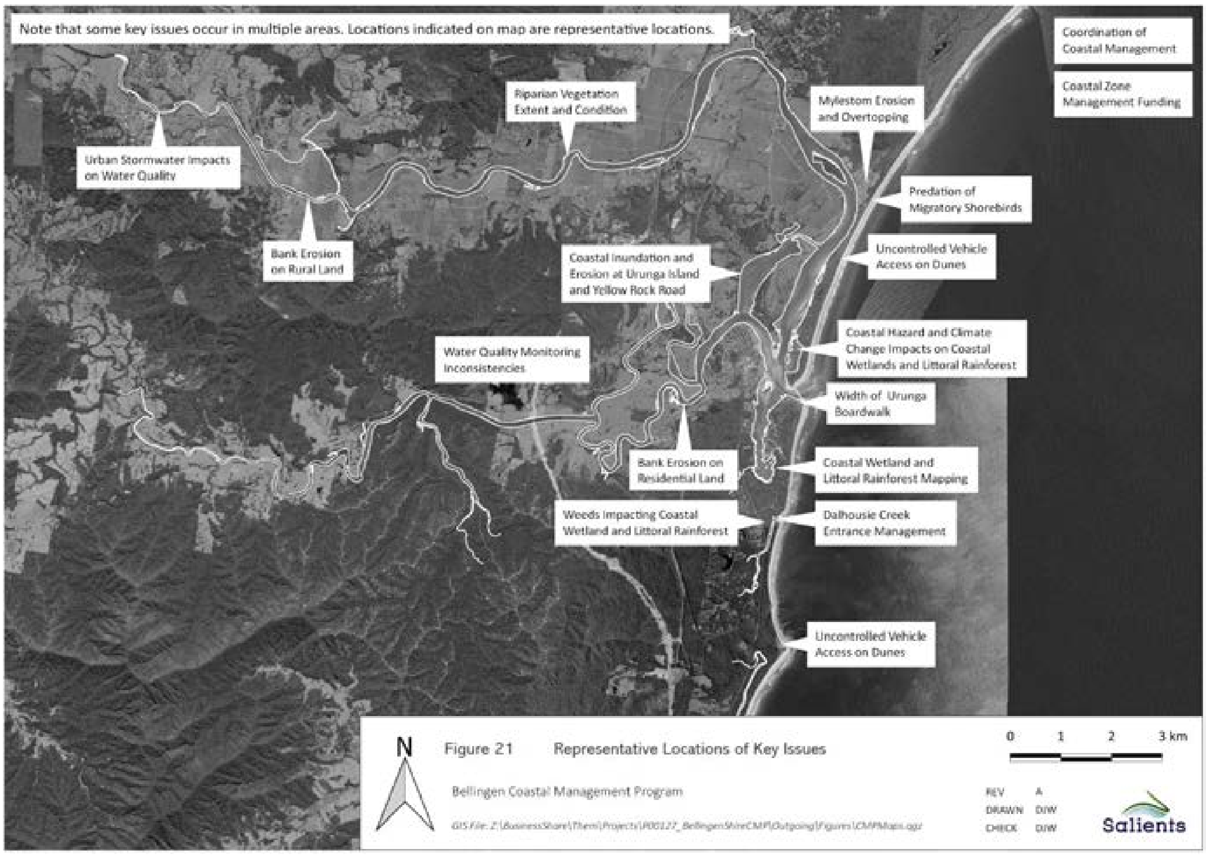

Figure 10 Representative areas of key issues and threats in the Draft Bellingen CMP (Source: Salients, 2024)

Existing and Derived GIS Datasets used in this Assessment

Existing spatial datasets

The following existing spatial datasets have been used in this assessment:

- *NSW Crown Lands Parcels* accessed via the NSW Spatial Data portal at https://www.spatial.nsw.gov.au/products_and_services/spatial_data which allowed for the identification of Crown owned land during the field survey and later during the priority setting process
- *NSW State Forest Parcels*, *NSW National Parks Estate Parcels, and Local Government Authority areas* accessed via the NSW Spatial Data portal at https://www.spatial.nsw.gov.au/products_and_services/spatial_data which was used during the field survey and later during the priority setting process
- *Council Owned Land Parcels* and Council Managed Land Parcels accessed under licence from Bellingen Shire Council which allowed for the identification of Council owned land during the field survey and later during the priority setting process
- *SEPP (Resilience and Hazards) 2021 Coastal Wetland Area, Coastal Wetland Proximity Area, Littoral Rainforest Area, and Littoral Rainforest Proximity Area* mapping accessed via the Seed Portal at https://www.seed.nsw.gov.au which was used as one of a variety of criteria which informed the determination of priorities for action relevant to the Coastal Management Act 2016
- *Estuarine Macrophytes* accessed via the Seed Portal at https://www.seed.nsw.gov.au which was used during the priority setting process
- *Aquaculture Lease Areas, Priority Oyster Aquaculture Area* and *NSW Oyster Reefs* datasets accessed via the NSW DPIRD Fisheries portal at https://www.dpi.nsw.gov.au/fishing/fisheries-research/spatial-data-portal which was utilised during the field survey and later during the priority setting process
- *Bellingen Shire Council and Office of Environment and Heritage 2013 Vegetation* mapping dataset including likely NSW Endangered Ecological Communities mapping accessed under licence from Bellingen Shire Council which allowed for the identification of areas of high ecological value (HEV) vegetation during the field survey and also informed the priority setting process for riparian management actions.
- *Bellinger and Kalang River Estuaries Erosion Study 2009 bank erosion dataset* created by Telfer (GECO Environmental) and Cohen (IRM Consulting) which was utilised in the literature review section of this report and for comparisons of the 2009 data with the results of the survey undertaken for this NEAP Assessment project

Spatial datasets derived from existing sources for the field survey

The following spatial datasets were created to facilitate the field survey component of this assessment:

- *Bellinger and Kalang River Estuaries Bank Reference Layer* was onscreen digitised at 1:2000 scale off June 2024 Nearmap® imagery accessed via subscription. This line feature allowed for increased accuracy of the mapping with field surveyed reaches “snapped” to the current 2024 bank location.

Community, Industry and Stakeholder Consultation

A targeted community consultation process was undertaken to assist in identifying bank and riparian issues affecting the estuary from an industry and recreational use view point. The consultation was undertaken by telephone interview, targeting estuary users and land managers identified by early-stage consultation with local and state government stakeholders, during the interviews themselves and through online research. The consultation was supplemented by conversations with estuary users during the field mapping exercise.

Interviews were undertaken with:

- John Lindsay of Lindsays Oysters.
- Alacia Cockbain of Ozfish.
- Lynne Gordon of Mylestom Landcare.

Some other members of the community, including representatives from the Transport for NSW Maritime, the oyster industry, Bellingen Golf Club, and Urunga Anglers Club, were contacted but either did not wish to comment or did not respond to calls or emails.

Oyster Industry Comments

John Lindsay from Lindsays Oysters was interviewed by telephone to gain an appreciation of the oyster industry's views of bank erosion and riparian management issues in the Bellinger and Kalang Rivers estuary area. John has been operating for 37 years on the Kalang River. He has operational oyster leases on the south and north arms of the Kalang, covering approximately 10 acres. On the south arm of the Kalang River his leases extend approximately 4 km upstream of his shed and on the north arm they extend approximately 800 m upstream of the confluence.

Riverbank erosion impacts some of their oyster farming activities. John identified several areas of riverbank issues in the areas of the Kalang River that he is most familiar with:

- John noted the impact of increased sediment concentrations on young oysters in tumbler rails placed near the bank approximately 1800 m upstream of his shed. The area is across the river from the council reserve and the bank is eroding away in large chunks adjacent to his leases.
- On the north arm of the Kalang River along the first straight there are cattle accessing the mangroves on the eastern bank despite the fencing there, eating the young trees and defecating in the water adjacent to oyster leases.
- On the north arm of the river between his two lease areas there is a high wall of eroding riverbank approximately 4 – 5 m high.
- At the end of Burrawong Parade there is an area of approximately 100 m of severely eroding bank between the council reserve and the start of the mangroves.
- The riverbanks of the council reserve are mostly stable but the erosion control works are mostly *ad-hoc* in nature.
- Further upstream at the last of his large lease areas John noted that the bank is eroding on both sides of the river. The narrow peninsula to the west of that lease area has almost broken through. John was in support of the erosion control efforts on the upstream side of that peninsula and hopes the river does not break through in that location with subsequent creation of a

billabong/oxbow. John also noted that during the flood in 2009 the water overtopped this peninsula and washed away oyster farming equipment.

- Upstream of Newry Island where the river heads towards the highway bridge there is erosion on both sides.

When asked what he thought were the major factors contributing to erosion John responded that boat wash and wind waves were the major factors, with wind waves contributing to erosion as much as boat wash in some areas. He noted that many boats do not observe the speed limits, but among those that do sometimes the speed limits lead to greater wash by not allowing the boats to plane.

In discussing the effectiveness of existing works John noted that:

- The works on the Pemberton property have been very successful and were well done but that the area of inlets draining into the river upstream of the fillets could also have been stabilised as it is eroding.
- The rock fillets on the south and north arm are mostly capturing sediment and promoting mangrove growth.
- The rootstock works do not have the necessary longevity in most cases and in some cases, where they are incorporated into rock works, they may lead to failure of the works overall when they rot or are consumed by Cobra worm or Teredo.

Finally, John noted that there was some erosion monitoring infrastructure put in place on the South Arm of the Kalang approximately 30 years ago – being 4 inch poly pipe driven into the banks and filled with cement. It may be worth checking to see if any of it is still in place.

Figure 11 shows the areas identified by John Lindsay. They were assessed during the field survey to determine the severity of any bank erosion present and likely processes operating.

Ozfish Comments

Project Officer, Alacia Cockbain from Ozfish, was interviewed via telephone to record her perspective on bank erosion issues in the Bellinger and Kalang Rivers estuary. Ozfish have river rehabilitation projects ongoing throughout much of NSW. Alacia has been working as a project officer for Ozfish between the Clarence and Hastings Rivers since around 2020. They don't currently have many projects ongoing on the Bellinger/Kalang estuary but do have a project on the upper Kalang estuary near Hains Lane where they plan fencing, timber works and revegetation, funded by a Fisheries Flagship Grant.

Alacia believes there are many areas on the Bellinger Kalang system that are in need of attention. Her main concerns are cattle access to the banks and weed cover on the riverbanks, both of which are very evident on the Bellinger in particular. We discussed the areas of weeds between Fernmount and Bellingen, which she agrees are a particular issue.

The main barrier to riverbank restoration works in her experience is landholder resistance.

Most of her work is in freshwater reaches but with respect to the estuary she noted the golf course as an area where weed cover is pulling down large trees, worsening exiting erosion.

Figure 11 shows the areas identified by Alacia. They were all assessed during the filed survey to determine the severity of any bank erosion present and likely processes operating.

Mylestom Landcare

Lynne Gordon, a recent coordinator of Mylestom Landcare Group, was interviewed to gain an appreciation of their activities around the Bellinger and Kalang Rivers Estuary and their understanding of current bank erosion and riparian vegetation management issues.

Mylestom Landcare historically worked on the high sandy riverbank downstream of the netted swimming area at Alma Doepel reserve, removing Cockspur Coral Tree and planting Saltcouch, Lomandra and Tuckeroo etc. Mylestom Landcare don't have any current works on the riverbanks, instead focussing on beach dunes and littoral rainforest on the eastern margin of the peninsula.

Lynne found that deep-stem planting was the method that worked the best in the sandy riverbanks. She also found that Coastal Wattle grew too fast on the sand and would inhibit the growth of other plantings or fall and take the dune with it.

Lynne provided a cross-sectional vegetation and planting guide for the Mylestom peninsula that was prepared by Mylestom Landcare.

The area identified by Lynne has also been included in *Figure 11*.

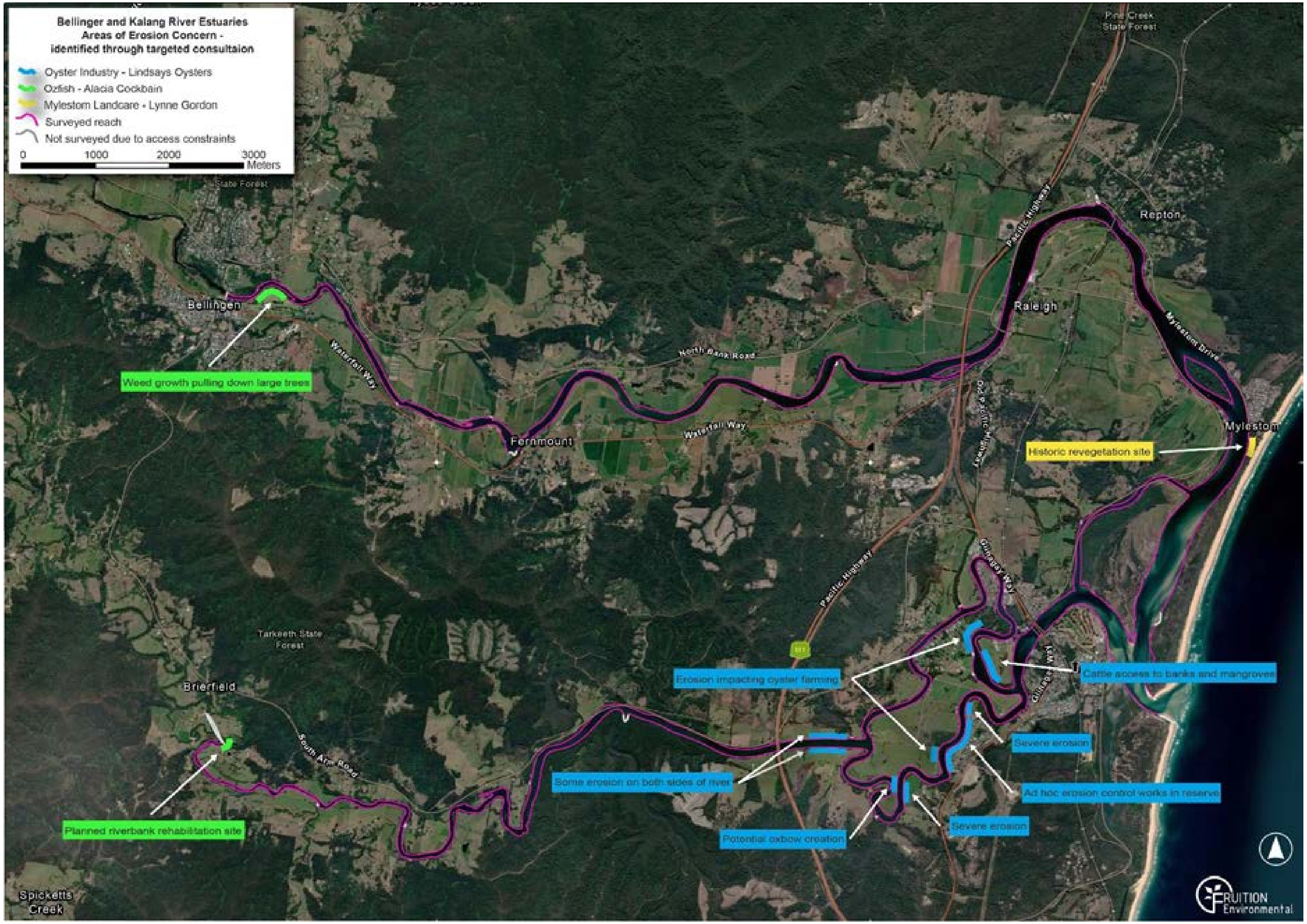

Figure 11 Areas of perceived bank erosion concern as identified by targeted consultation in the Bellinger and Kalang River estuary study area.

Cultural Engagement – Yurruungga Aboriginal Corporation

A cultural engagement activity was undertaken with members of the Yurruungga Aboriginal Corporation (YAC) and two elder representatives of the Gumbaynggir Nation over the 8-9th November 2024. The intent of the two days was to:

- gain an appreciation of areas of specific cultural importance within the estuary to the Gumbaynggir peoples, and
- understand indigenous cultural perceptions of the estuary and cultural management practices, and
- where possible and appropriate, identify linkages between the ongoing cultural caring for Country projects run or proposed by YAC and the NEAP assessment project outcomes.

The following descriptions summarises some of information shared over the two days and where appropriate identifies linkages to reaches assessed under the NEAP Bank and Riparian Condition Assessment. Areas and potential project ideas and sites are indicated in *Figure 12*[1].

- There are many important increase areas in the estuary, for mud oysters, shorebirds and stingrays amongst others (*Figure 12*).
- There were some significant areas identified for a number of reasons. Some of these were associated with important historical events and others with resources (ochre, etc). There are also numerous sites of great cultural significance to the Gumbaynggirr Peoples.
- There is a significant area that is currently impacted by old, dilapidated footings of an old wharf on the Bellinger (Reach 165). There is interest in remediating this site as it has cultural importance. This site has not been identified as an issue from an erosion perspective, but it is none-the-less still important from a cultural perspective.
- There is a strong desire to improve the health of the estuary stemming from the long connection to the land and the environments there.
- The group expressed more support for erosion mitigation structures like rock and log fillets that result in a living shoreline of mangroves when compared to for example rock armouring of the bank. There was some discussion of the prerequisite conditions for using these methods, ie. having an intertidal bench to build them on, and it was generally agreed that in some cases that may not be possible such as along the yellow rock road area where there is a deep-water profile and the road is at risk.
- There is an area on the northwestern side of back creek where there is some property held by Yurruungga elders where a leaking floodgate is causing a number of issues. There is neighbour dispute over this issue with the neighbour not wishing for the floodgate to be removed. There was interest in finding out what the legal situation is regarding this floodgate.

[1] It should be noted that the areas identified in *Figure 12* are a small subset of cultural areas and sites important to the Gumbayngir peoples. A duty of care remains for any projects proposed in the Bellinger or Kalang estuary with respect to ensuring any activities avoid or minimise harm to Aboriginal cultural heritage.

Potential cultural projects in the estuary

A number of potential indigenous-led projects were discussed with the YAC during the field trips on the Bellinger and Kalang estuaries. These projects have a number of objectives including looking after country, protecting areas of the estuary of specific cultural importance, and providing skill-building and work opportunities of local Gumbaynggir peoples on ountry. The following projects are put forward for further development and consultation and link to the NEAP objectives of building resilience of assets including cultural assets linked to the estuary banks and waterway:

- Removing old tyres from the waterway particularly at two sites in the upper Kalang (Reaches 425 and 689) and along the eastern side of Urunga Island (Reaches 279, 282 and 284). These sites are assessed later in the prioritization section of this Report – Part 5. This project has the capacity to provide ongoing employment and training opportunities for the local indigenous community whilst aligning with cultural protocols and responsibilities in relation to caring for country. Consultation with the current landowners and development of a plan for alternative remediation options for these sites are required to move this project forward.
- There is a significant area that is currently impacted by old, dilapidated footings of an old wharf on the Bellinger (Reach 165). There is interest in remediating this site as it has cultural importance. This site has not been identified as an issue from an erosion perspective, but it is none-the-less still important from a cultural perspective.
- Protecting shorebird habitat on the southern tip of Urunga Island (Reaches 259, 260 and 323). There is a nesting site for the critically endangered Beach Stone Curlew amongst other birdlife. This site is not identified in the NEAP assessment as a priority but addresses Action E4 – Protect threatened seabirds in the Bellingen Shire Coastal Management Program (2024 exhibition draft). The site was assessed as currently stable, but it is none-the-less and important site and an existing priority for the Yurruungga mob.

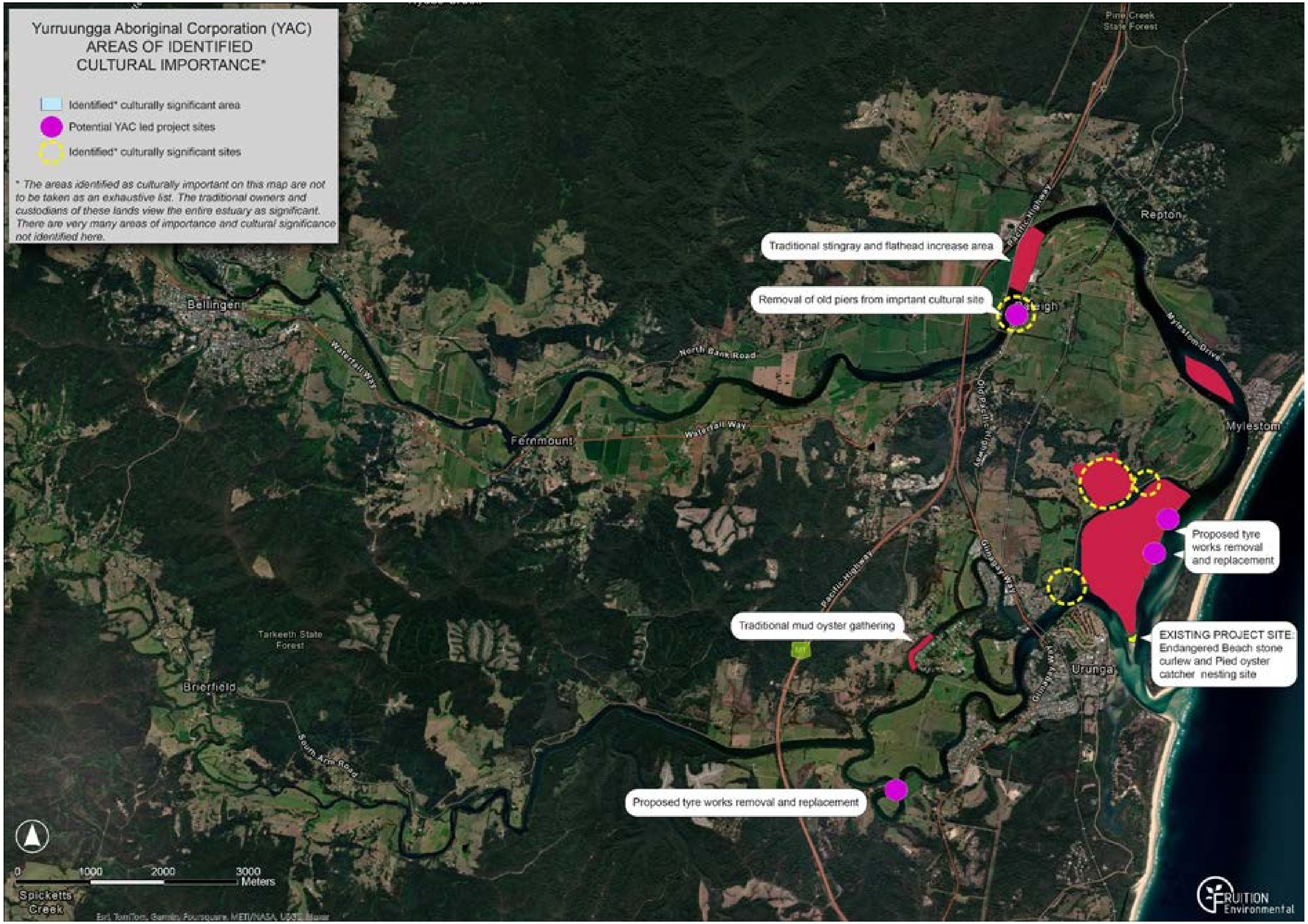

Figure 12 Yurruungga Aboriginal Corporation identified areas of cultural importance and project interest within the Bellinger and Kalang River estuary study area.

PART 2 – Bellinger and Kalang River Estuary Process Zones

The distribution of sedimentation within the estuary as well as the bank, channel and floodplain morphology characteristics allow for the identification of geomorphic process zones within the estuary.

The distribution of marine and fluvial sediment has been previously assessed in the Bellinger and Kalang Estuaries Erosion study (Telfer and Cohen, 2010) based on longitudinal elevation, depth, sediment distribution and bank morphology. The geomorphic process zones and descriptions have been adopted from that study to assist in understanding and discussing the primary factors influencing erosion processes within the estuary in 2024.

The distribution of the estuary process zones adopted for this study are shown in *Figure 13*.

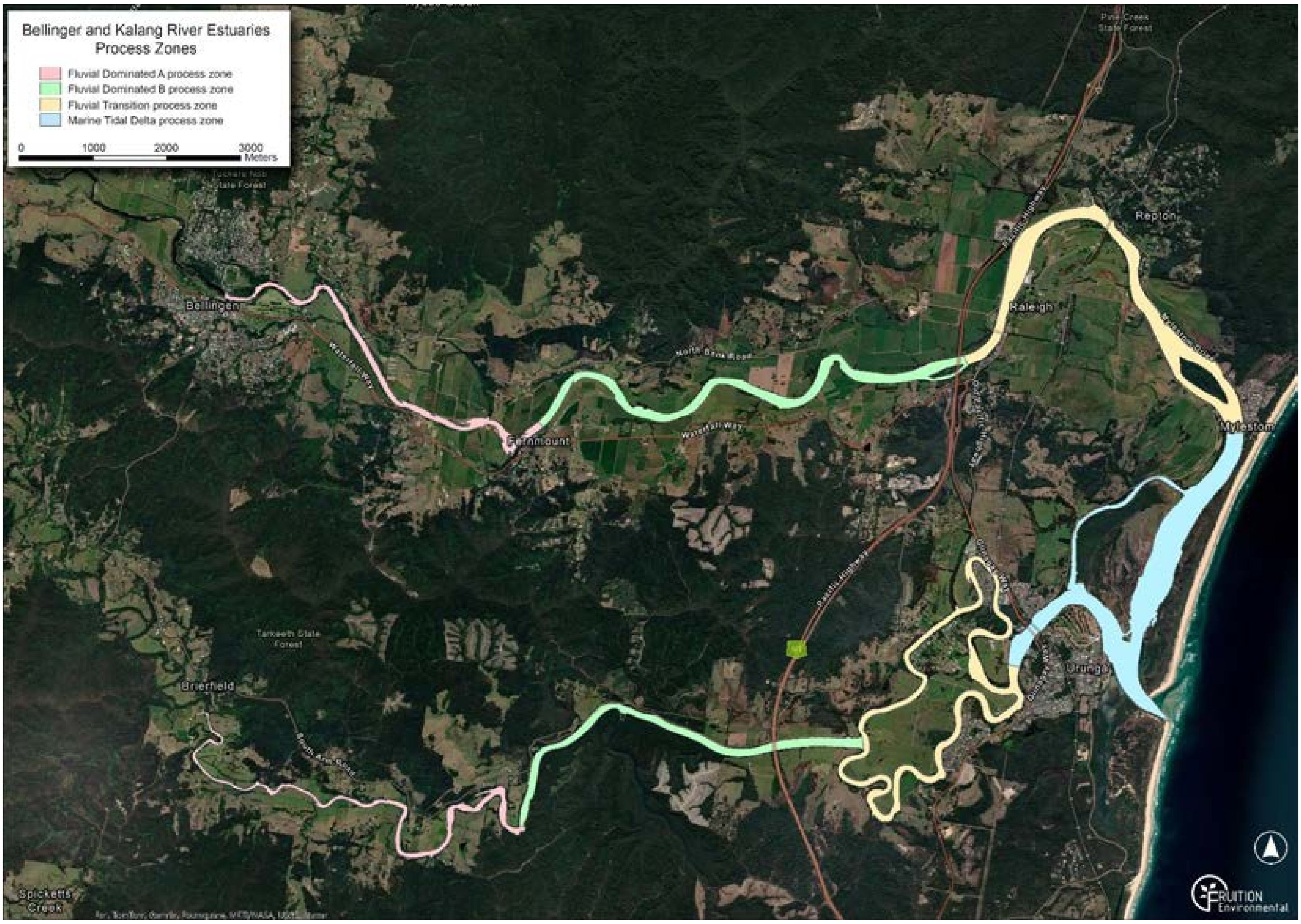

Figure 13 Distribution of geomorphic process zones in the Bellinger and Kalang River estuary study area (adapted from Telfer and Cohen, 2010).

Process Zone Descriptions

Fluvial-Dominated Process Zones

The Bellinger and Kalang River estuaries exhibit similar fluvial dynamics in their upper and middle reaches but differ in terms of valley confinement, sediment load, and flow energy. In both estuaries, the rivers are characterised by single thread meandering channels in low gradient floodplains up to 0.5-1 km wide, with irregular meanders. As inferred by the name, fluvial processes dominate erosion processes in this zone including bank scour during flooding and bank slumping/mass failure post flood (*Plate 1,* right image). Boat and wind waves related erosion are less significant issues in this process zone as boat traffic is limited and wind fetches are generally not sufficient to generate significant waves. The fluvial dominated process zone in both estuaries have been further separated into two sections based on differences in sedimentation and morphology.

In the most-upstream fluvially dominated reach of the Bellinger River from Bellingen to Fernmount (the Fluvial-Dominated A Zone in Telfer and Cohen, 2010), mixed sediment transport occurs, with gravel bedload and bar formation extending downstream through the reach to Fernmount Bluff. Floodplain morphology has a distinct compound form, with a well-defined macrochannel featuring inset floodplains and benches that are reworked (*Plate 1* left image). Floodplain topography is variable, with channel depth ranging to 8 to 10 m below the floodplain surface, with the floodplains themselves elevated 4 to 7 m above mean tide level. This reach experiences high-energy flows and pronounced morphological changes can occur during flood events, including channel widening, channel migration and floodplain stripping. The tendency for the Bellinger River to migrate has caused erosion of riverbanks on the outside of most bends (*Plate 1*, right image), exacerbated by historic clearing for grazing and agriculture.

Plate 1 *Inset benches and low floodplains on the Bellinger River estuary in the Fluvial Dominated A process zone are generally stable despite riparian vegetation clearing (left), whereas outside bends are commonly eroding with evidence of both fluvial scour and post flood slumping processes (right, Reach 120).*

Similar to the Bellinger, the Kalang River's Fluvial-Dominated A Zone (Brierfield Bridge to Pine Creek) shows varied floodplain topography with comparative range channel depth. However, the reach is more confined, with a valley less than 0.5 km wide. Bedrock outcrops at numerous locations along the channel banks and valley constriction drives pronounced bed scour and irregular discontinuous floodplain formation (*Plate 2*).

Plate 2 *Bedrock outcropping is common in the fluvial dominated reaches of the Kalang estuary (left) as is bank slumping post flood as a result of draw down processes (right, Reach 634).*

In the Fluvial-Dominated B Zones, both rivers are characterised by a significant reduction is sediment grain size, with finer sediment (sand) bedloads and lower-energy overbank flows. The Bellinger features reduced meander belt formation within a wider, lower floodplain 2.5 – 4 m above mean tide, although bed scour reaches depths of 10 m. Conversely, the Kalang has a shorter, straighter Fluvial-Dominated B Zone (3-4 km) with channel depths of up to 7 to 8 m. The confined valley maintains higher-energy flows compared to the broader, slower-flowing Bellinger. Boat wash is an issue in the lower reaches, particularly in the Kalang River, where a long straight reach creates an ideal area for recreational boating and skiing/wakeboarding.

Riparian vegetation in this zone becomes less tolerant of saline conditions towards the upstream extent of the estuary and there is an increased dominance of native freshwater riparian vegetation species including Weeping Lilly Pilly (*Waterhousea floribunda*), common reed (*Phragmites australis*), river lilies (*Crinum pedunculatum*), and Matt rush (*Lomandra hystrix*). In the Kalang River mangroves are recorded almost to the upstream extent of the estuary, while in the Bellinger River they only appear in Zone B downstream of around Fernmount. However, the predominant vegetation type of the riparian zone in this process zone was historically lowland rainforest which once dominated the floodplain of the Bellinger and Kalang Rivers, mixed with subtropical coastal floodplain forest and swamp sclerophyll forests on coastal floodplains depending on underlying soils, elevation and microclimate. Much of the original extent of these vegetation types has been significantly reduced because of clearing for agricultural and urban development. Remaining remnants are often heavily invaded by exotic weeds such as camphor laurel, small-leaved privet, lantana and coastal morning glory. Weeds present more of an issue in the Bellinger River, as well as the upper reaches of the Kalang River estuary, where the most reaches have high to very high exotic weed infestation.

Fluvial Transition Process Zone

The fluvial transition process zone reflects a section of the estuary study area which exhibit a pronounced marine influence whilst still exhibiting a fluvial form. The zone marks a progressive but critical shift in estuarine systems where sediment transport, floodplain and flow dynamics shift toward increased tidal or marine processes. On the Bellinger River this zone starts just downstream of McGeary's Island and continues to just upstream of Mylestom. On the Kalang River, it extends around Newry Island down both branches to their confluence at Urunga.

In both rivers, there is a considerable reduction in stream gradient, energy and floodplain elevation. These zones are inferred to be infilled mud basins, a common feature in estuarine systems along the NSW coast, where sediment deposition over time creates low-relief floodplains with reduced topographic variation. The Bellinger's floodplains sit at 1.5 – 2 m above mean tide level, while the Kalang's are slightly lower and more variable at 1 – 2 m. This lower elevation increases the frequency of overbank flow. However, while the Bellinger retains a more fluvially derived sediment load, the Kalang is dominated by finer, suspended sediments, reflecting a greater influence of slower, estuarine flow.

The Kalang River transitions into a broader valley 1 – 1.5 km wide, resulting in a low-relief floodplain and an anabranching channel system with smaller and simpler channel geometry. Planform and bend migration is constrained by the presence of localised late Pleistocene terraces and bedrock outcropping (*Plate 3*). In contrast, the Bellinger River retains more of its fluvial characteristics, with a more defined channel structure and increased channel width. Scroll bars evident in the floodplains indicate long-term meander migration in this zone.

Silts depositing in this zone are derived from the upstream catchment and fluvial dominated process zones and accumulate on intertidal benches and in backwaters. These deposits can be stabilised by estuarine macrophytes such as mangroves, may be eroded during episodic flood events by scour, or eroded by persistent wave attack between low and mid tide. Wave attack may be via wind waves where fetch and channel orientation are conducive, or by boat wash where the navigation channel is in close proximity to susceptible banks. Scouring and erosion processes also differ between the two rivers. In the Kalang River, bed scour and bend migration are the primary mechanisms for energy dissipation, with fewer and smaller bar formations. Boat wash impacts and mass failure erosion is particularly prevalent in the Kalang River, which is likely related to the proximity of Urunga and increased boat traffic near residential and recreational areas. While still a factor of erosion in this zone, these impacts are less prevalent along the Bellinger River.

Plate 3 *More recent floodplain deposition (chocolate layer in the top third of the bank profile) overlying the more resistant orange-yellow Pleistocene-aged terrace materials on Newry Island (left) and bedrock outcropping in the north branch of the Kalang River (right).*

Due to the low relief of the floodplains, they have been extensively cleared for agricultural purposes, often right to the streambank, with mostly isolated pockets of vegetation remaining. The riparian vegetation in this zone is highly variable in terms of vegetation community and predominantly degraded (narrow and discontinuous). Historically, the predominant riparian vegetation communities would have included swamp sclerophyll forests on coastal floodplains, swamp oak floodplain forests and likely patches of lowland rainforest. The species present are typical mid estuary vegetation communities on the North Coast NSW with fringing grey and river mangroves (*Avicennia marina*, *Aegiceras corniculatum*), swamp sheoak (*Casuarina glauca*) on intertidal flats and lower banks, and mid to upper banks commonly containing brushbox (*Lophestemon confertus*), blood wood (*Corymbia intermedia*) and other eucalypt species (*Eucalyptus spp.*), tuckeroo (*Cupaniopsis anacardioides*), wattle (*Acacia spp.*) pittosporum (*Pittosporum undulatum*), cheese tree (*Glochidion fernandii*), silkpod (*Parsonsia sp.*), blue flax lily (*Dianella caerulea*), and saw sedge (*Ghania clarkei*). Camphor laurel and lantana continue to be problematic weeds in this zone, especially in the upstream areas and particularly in the Bellinger system. Coastal morning glory is also widespread, while ground asparagus is present but poses a lesser issue.

Marine Tidal Delta Process Zone

The marine-tidal process zone reflects the component of the estuary dominated by marine processes (e.g flood and ebb-tide sediment transport). It extends from the east of Newry Island and downstream of Mylestom on the Bellinger River to the mouth at Urunga and includes Back Creek. The zone features depths of 3 to 4 meters with prominent shoals forming near the Back Creek confluence and upstream of the Pacific Highway Bridge on the Kalang River. Bed sediment mainly consists of reworked coastal sand, supplied by a net annual influx of 40,000 m^3 on the flood tide (PWD, 1983) and a direct supply from the adjacent coastal barrier dunes (*Plate 4*). While large flood events flush out shoals, low-frequency wave conditions quickly re-establish them, maintaining the dynamic sediment balance in the lower estuary.

Low floodplain of 1 – 1.5 meters consist of silts, clays, and fine sands over older estuarine clays. The low floodplain height and low stream gradients results in tidal inundation of the salt marsh and mangrove flats (*Plate 4*). Erosion is driven by tidal currents, episodic floods, and boat or wind-generated waves, though it is moderated by the extensive bank protection and entrance training works present in this zone.

Plate 4 The coastal barrier forms the eastern bank of the Bellinger below Mylestom (left) and low relief floodplains are generally dominated by swamp oak floodplain forest, mangroves and saltmarsh unless historically cleared (right).

Extensive areas of estuarine vegetation are found in the Marine Tidal Delta process zone including areas of intact saltmarsh, seagrass, and mangroves. Riparian vegetation on low intertidal benches consists of Swamp Oaks (*Casuarina glauca*), River mangrove (*Aegiceras corniculatum*), grey mangrove (*Avicennia marina*), and prickly-leaved paperbark (*Melaleuca styphelioides*) with Swamp Oak Floodplain Forest EECs on higher ground. In the lower reaches, coastal wattle (*Acacia longifolia*), white sally wattle (*Acacia floribunda*), Cheese tree (*Glochidion ferdinandii*), tuckeroo (*Cupaniopsis anacardioides*) and coastal banksia (*Banksia integrifolia*) are common. Littoral rainforest (identified in the OEH 2013 vegetation mapping dataset) only occurs at the southern extent of Mylestom along the eastern bank of the Bellinger River (Reach 151 – 152). Exotic weeds appear to be less of an issue in this zone and are typically observed to be in lower percentage cover compared with upstream. The main weeds present are ground asparagus, coastal morning glory and and bitou bush.

PART 3 – 2024 Bank and Riparian Condition Survey

Bellinger and Kalang Estuary NEAP Online Estuary Condition Mapping Database

Approximately 115.1 km of estuary bank was field surveyed in the Bellinger and Kalang River estuaries via boat in July/August 2024. The survey area included the full length of Back Creek. The Kalang River was surveyed from its confluence with the Bellinger to an upstream limit approximately 470m downstream of the Brierfield Bridge. The Bellinger River estuary was surveyed from the entrance training walls at the mouth to Lavenders Bridge at Bellingen. Urunga Lagoon was not surveyed due to poor navigability.

Data was entered directly into the field maps app, which allowed for survey segments (reaches) to be drawn as a line feature along the bank based on current location in the field. Reaches were defined based on a change in either erosion severity, riparian vegetation condition, or existing controls. Each new reach segment was snapped onto the previous line segment and the survey was repeated.

Except where survey bank length was very small, a minimum of two photos were taken of each segment: one downstream looking upstream, and one upstream looking downstream. Any features of interest within the section were also photographed (i.e., existing controls, erosion, etc.).

Seven hundred and forty-six (746) reaches were surveyed. Each reach had up to one hundred and six (106) attributes recorded. The recorded attributes primarily focussed upon:

- Bank erosion severity
- Riparian vegetation continuity, width, structure, diversity and weed presence (used to generate the riparian vegetation condition ratings)
- Presence of existing erosion control works, proportion of segment with works, style of works and works effectiveness.
- Criteria relevant to the NSW Fisheries Decision Support Tool for Bank Erosion Management, 2024 version (the "DST"; developed by Hydrosphere Consulting for DPIRD Fisheries under the Marine Estate Management Strategy Initiative 2, see Hydrosphere Consulting, 2020 and 2020b).

Appendix A and the methodology descriptions in the following section provide further detail on the criteria assessed.

The Fruition Environmental Web App

The Fruition Environmental Web App holds the full database of survey records including all attributes for each segment surveyed and any photographs taken of the reach. The records are current as of 20 September 2024 but are able to be updated in the field using ESRI Field Maps and an appropriate login if required.

How to access the online bank and riparian condition database

The custodian for the estuary condition survey database is Department of Primary Industries and Regional Development - Fisheries. Requests to use the database should be made directly to the Senior Fisheries Manager - NEAP.

Bellinger and Kalang River Estuaries Bank Condition

Method

Attributes related to bank condition were mapped directly into ESRI Field Maps via the Fruition Environmental online mapping tool. This ensured a standardised collection methodology across all areas of the estuary surveyed and also between survey personnel.

A component of the project scope was to allow for the bank condition dataset to be compatible with the 2024 version of the DPIRD Fisheries DST for bank erosion management in NSW estuaries. Accordingly, the methodology for recording bank condition incorporated the data attributes and definitions used in the DST manual (Hydrosphere Consulting, 2020b) in addition to other project attributes specific to this project.

Bank erosion severity was the primary attribute for the differentiation of bank segments for the bank condition assessment. The bank segments represent relatively homogenous reaches of similar attributes so where bank erosion severity was homogenous but riparian vegetation condition changed the segment was broken to allow the different vegetation condition to be represented despite the erosion severity being recorded as the same. The degree of bank erosion present in the segment was recorded as either Negligible, Low, Moderate, High or Extreme.

The definition for each erosion severity category were adopted from the DPIRD Fisheries DST (see Hydrosphere, 2020b) and as follows:

- NEGLIGIBLE: currently aggrading or stable – no erosion
- LOW: some erosion occurring but considered within natural parameters
- MODERATE: rate or scale of erosion is considered more than natural
- HIGH: rate and scale of erosion is significant
- EXTREME: erosion occurring with significantly accelerated rate and scale

Examples of reaches with Extreme to Low erosion severity are shown in *Plates 5* to *8*.

In addition to the severity of erosion, a number of other attributes were recorded to maintain compatibility with the DST and provide additional factors relevant to bank condition at the site.

The following additional information were recorded for all segments surveyed (see *Appendix A* for category definitions):

- Presence or absence of **bedrock** in the segment (Yes/No).
- The **estimated future trajectory** of erosion being either *not occurring not likely*, *not occurring but likely*, *occurring and continuing,* or *occurring and accelerating* (only one selected).
- **Water depth** (measured by a staff at 5m from the mean high tide mark on the bank), being a surrogate measurement for the question of what types of erosion control works could potentially be practical at the site if required: *shallow* (less than 0.8m), *moderate* (0.8 to 1.5m), *deep* (>1.5m).
- A subjective assessment of the **impact of erosion** upon perceived environmental, infrastructure/commercial, and amenity/safety values of the segment or broader estuary (see Hydrosphere Consulting, 2020b for more detail). Ratings of *negligible*, *low*, *medium*, or *high* could be assigned (one to be selected for each of the three values category). To assist this assessment, a number of existing datasets were available within the Field Maps app to help inform the surveyor

of known issues in the reach. These included NSW Endangered Ecological Vegetation Community mapping, aquatic vegetation mapping, and crown/council/NPWS land parcels.

- The **location** of any erosion occurring was recorded as either one or a combination of: *top of bank*, *upper bank*, and/or *lower bank* (refer to *Appendix B* for definitions).

- The c**ontributing causes** of erosion for each segment were documented with one or more causes selected from: *ocean waves*, *public access*, *river flood or tidal flows*, *sediment extraction*, *stock access*, *vessel waves*, and/or *wind waves* (Yes/No required for each cause for DST compatibility).

Plate 5 *Examples of Extreme erosion severity: clockwise from top left, Kalang River Reach 687; Bellinger River Reach 131; Bellinger River Reach 120; Back Creek Reach 292.*

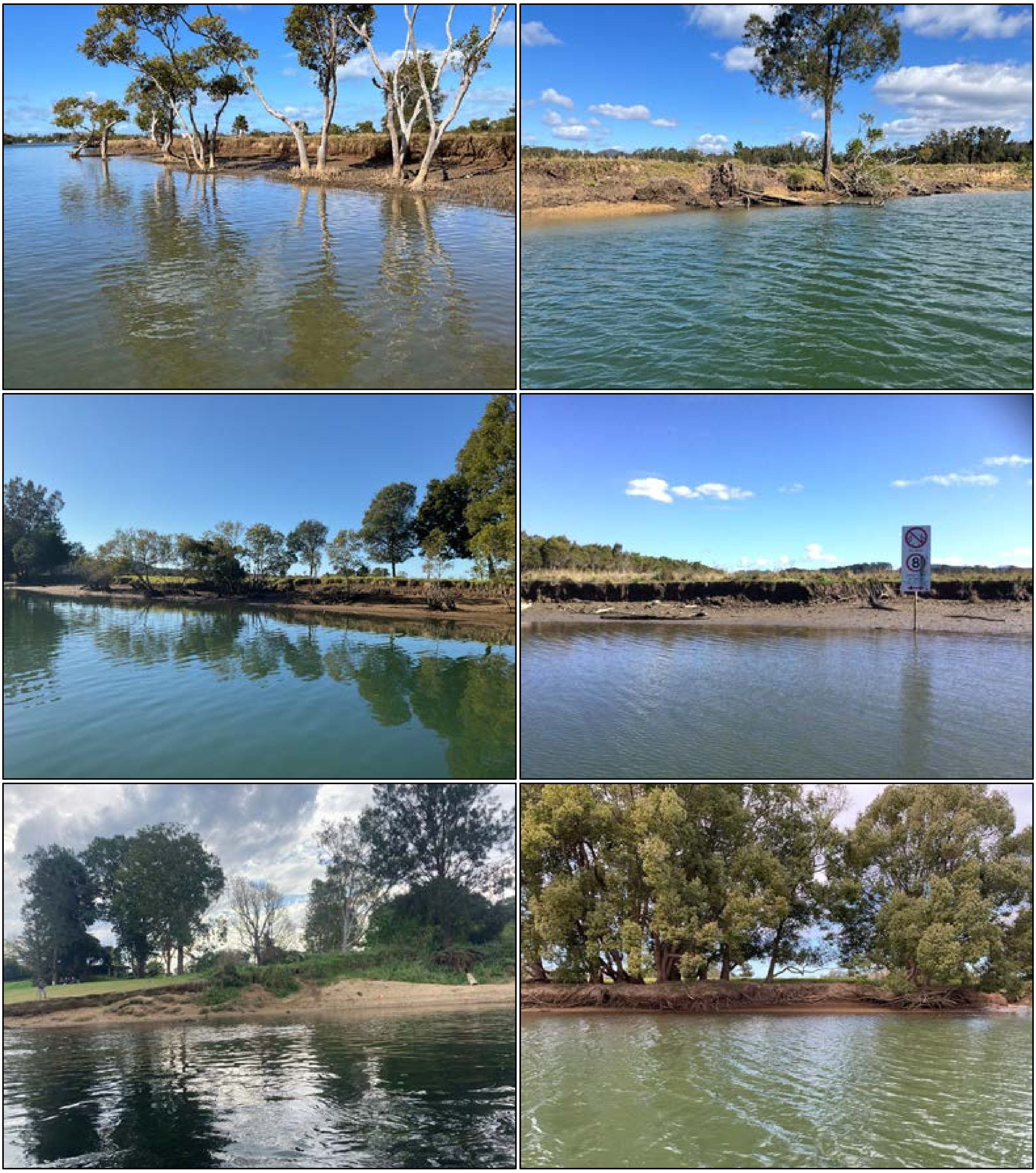

Plate 6 Examples of High erosion severity: clockwise from top left, Back Creek 296; Kalang River Reach 428; Kalang River Reach 669; Bellinger River Reach 118; Bellinger River Reach 752; and Bellinger River Reach 3.

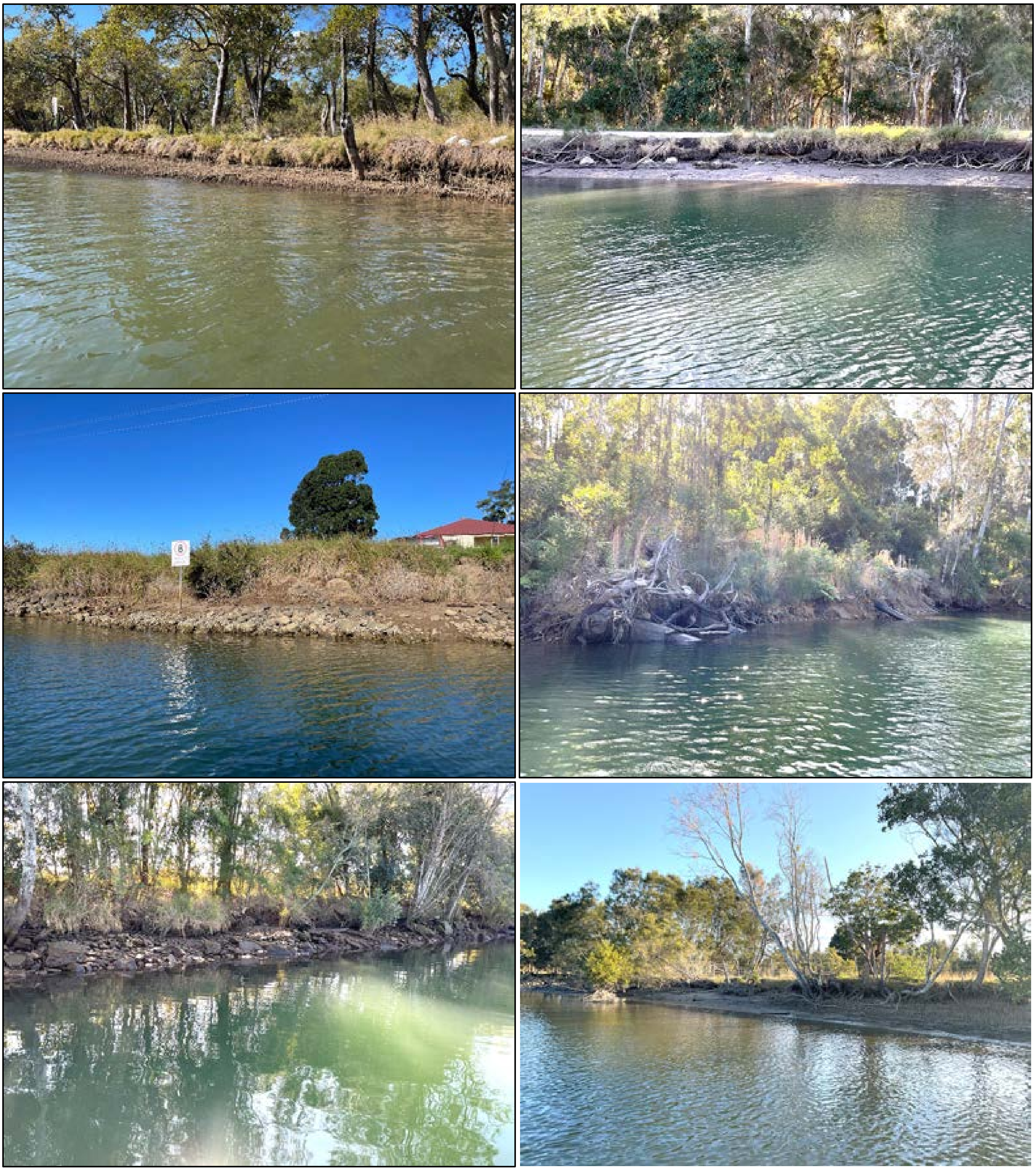

Plate 7 *Examples of Moderate erosion severity: Clockwise from upper left, Back Creek Reach 301; Back Creek Reach 347; Kalang River Reach 399; Kalang River Reach 737; Bellinger River Reach 13; and Bellinger River Reach 52.*

Plate 8 *Examples of Low erosion severity: Clockwise from left, Back Creek Reach 306; Kalang River Reach 704; Kalang River Reach 261; and Bellinger River Reach 4.*

Overview of Results

Figure 14 shows the spatial distribution of bank erosion severity within the Bellinger and Kalang River estuaries, while *Table 1* summarises the proportions of estuary bank of each category of erosion severity for the whole estuary study area (depicted graphically in *Figure 15*). This table shows that a little over half of the estuary banks in the study area have either Low or Negligible erosion (55.2%), and the remaining 44.8% of banks are experiencing erosion elevated above expected natural levels. The assessment of bank erosion severity across the estuary indicates that 1.6% (1,819 m) of the mapped banks are experiencing Extreme erosion, while 6.7% (7,759 m) show High erosion. This distribution suggests that while Moderate erosion is the most widespread erosion issue, Extreme and High erosion are less common but still significant in localised areas.

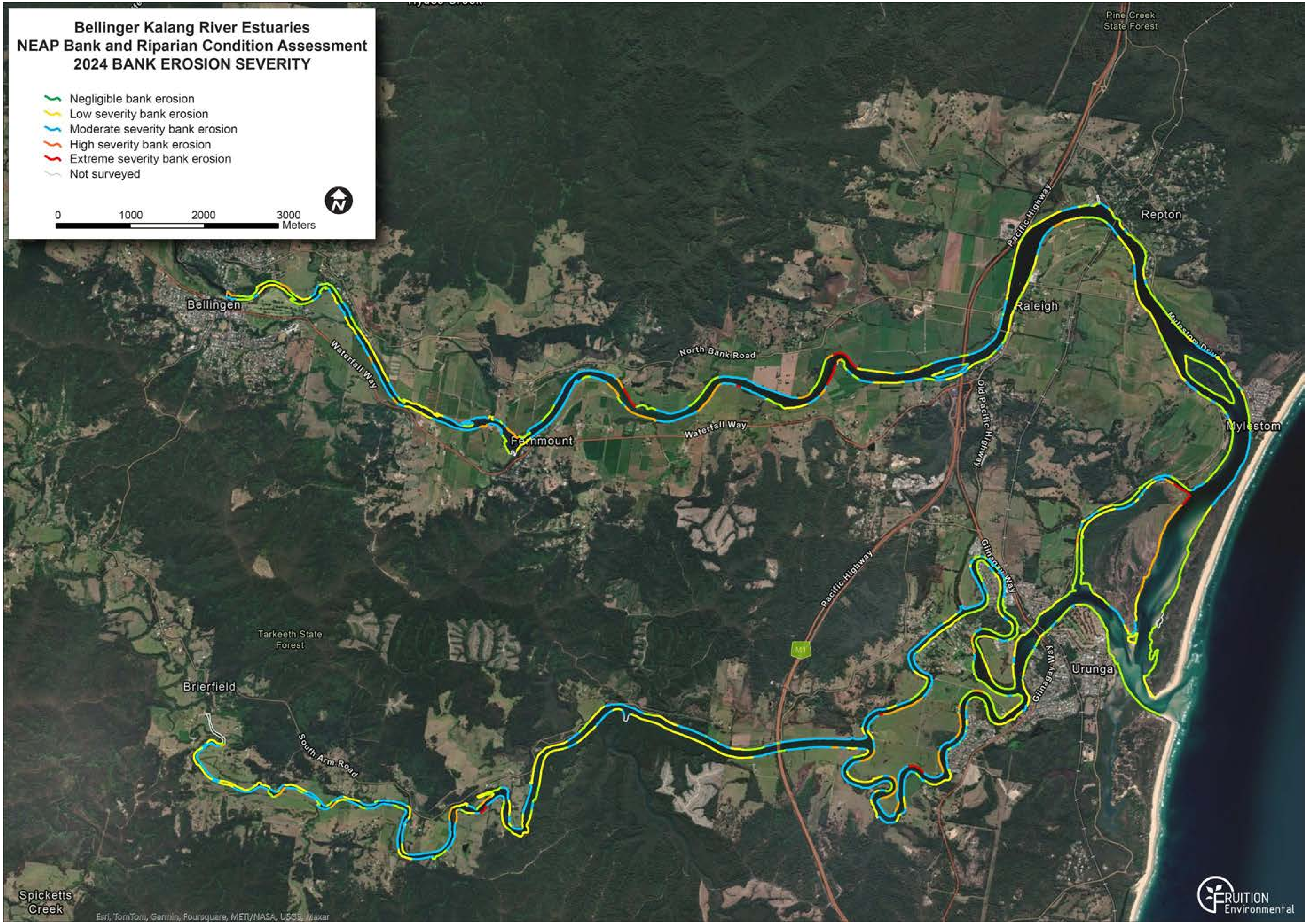

Figure 14 Distribution of mapped bank erosion severity across the Bellinger-Kalang *River Estuary Study Area*

Table 1 Bank erosion severity in the Bellinger and Kalang River estuaries study area

Bank erosion severity	Length of bank (m)	% of overall estuary bank mapped
Extreme erosion	1,819	1.6%
High erosion	7,759	6.7%
Moderate erosion	42,012	36.5%
Low erosion	27,278	23.7%
Negligible erosion	36,258	31.5%

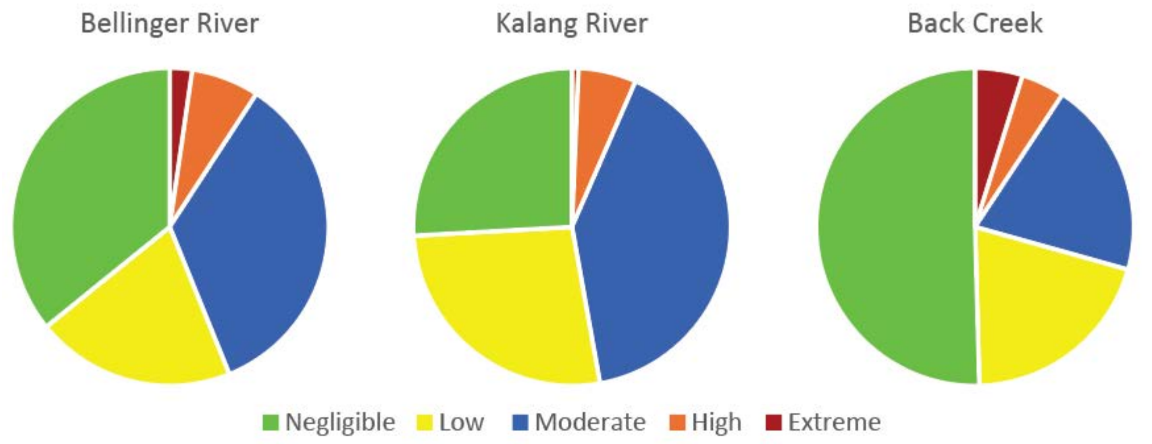

Figure 15 Proportional distribution of bank erosion severity within each estuary of the Bellinger-Kalang River study area.

Table 2 presents the proportions of estuary bank erosion severity across each river system and process zone. The distribution of bank erosion severity varies significantly across the different estuaries (*Figure 14*) and different estuary process zones. In the Fluvial Dominated Process Zones, both Zone A and Zone B show a similar trend in both the Bellinger and Kalang River estuaries. Moderate erosion is the most prevalent category, particularly in Zone A, where it affects over a third of the banks in both the Bellinger and Kalang Rivers. Negligible and Low erosion are also common recorded for ~35 – 55% of estuary banks in this zone. High and Extreme erosion are relatively less common, with no Extreme erosion in Zone A of the Bellinger River, although Zone B demonstrates a higher proportion of High and Extreme erosion. The majority of Extreme and High erosion throughout the study area is concentrated in this process zone. In the Kalang River, there is comparatively far less problematic erosion in this Fluvial Dominated Zone which reflects the lesser floodplain development and associated agricultural use and also the greater influence of bedrock and terrace control on the estuary bank margins.

The Fluvial Transition Process Zone exhibits greater differences between the two estuaries. The Bellinger River experiences predominantly Negligible and Low erosion, with only a small portion of the banks affected by Moderate or High erosion (22%) and no Extreme erosion. In part this is due to the extent of existing bank protection works in this part of the Bellinger estuary. The Kalang River in this zone sees a more even distribution, with Moderate erosion affecting a larger area (38.5%), and higher levels of High and Extreme erosion (10.7%) compared to other zones along this estuary. This reflects the comparatively intensive landuse and extensive clearing of the riparian zones around Newry Island.

The Marine Tidal Delta Process Zone stands out for its high proportion of Negligible and Low erosion, especially in the Kalang River where 87.8% of the banks show Negligible or Low erosion. Only 12.2% of the banks are experiencing Moderate erosion, and no High or Extreme erosion is recorded in this zone in the Kalang. This is also in large part to the high concentration of bank protection works in this zone. In the Bellinger River and Back Creek however, there is a notable presence of Moderate, High, and even Extreme erosion, indicating localized areas of concern, generally concentrated around Urunga Island (*Figure 14*).

Only three reaches (totalling 236 m) not identified as severe in the 2009 erosion study were identified as having Extreme erosion in 2024, indicating that most areas with Extreme erosion are experiencing long-term, persistent erosion issues. The primary reach featuring recently identified Extreme erosion is in the Marine Tidal Delta process zone of the Bellinger River, immediately downstream of the mouth of Back Creek. A more comprehensive comparison of the 2009 and 2024 survey data is presented in the next section of the report.

Table 2 Distribution of bank erosion severity by estuary process zone and location: summary statistics

	Negligible	Low erosion	Moderate erosion	High erosion	Extreme erosion
Fluvial Dominated A Process Zone Reaches					
Bellinger River	28.9%	26.1%	39.9%	5.1%	-
Kalang River	14%	28.4%	51.4%	5.3%	**0.8%**
Fluvial Dominated B Process Zone Reaches					
Bellinger River	21.9%	11.5%	48.2%	11.9%	**6.5%**
Kalang River	13%	42.4%	43.9%	0.9%	-
Fluvial Transition Process Zone Reaches					
Bellinger River	48.8%	29%	21.2%	1.0%	-
Kalang River	30.4%	20.4%	38.5%	9.7%	**1.0%**
Marine Tidal Delta Process Zone Reaches					
Bellinger River	48.8%	11.8%	19.7%	17.7%	**2.0%**
Kalang River	66.6%	21.2%	12.2%	**-**	-
Back Creek	50.4%	11.8%	26.1%	4.4%	**4.9%**

Comparison of 2009 and 2024 survey results

The Telfer and Cohen (2010) estuary condition survey data provides a useful baseline of erosion severity to compare against the current 2024 field survey results. Subject to three qualifications, such a comparison can provide an indication of changes in bank condition across the extent of the estuary study area over the last 15 years, and help identify key areas and persistent issues throughout the Bellinger and Kalang River estuaries, particularly regarding severe (High and Extreme) erosion. The three qualifications are that:

- There are key differences in the survey methods and erosion categories that limit direct comparison. These differences relate to the definitions for erosion categories between the 2009 data and the DST definitions. *Table 3* explains some of the primary differences in the descriptors of bank erosion severity used between the two assessment periods.

- The process of differentiation of homogenous reaches in the two assessments is essentially the same, although the accuracy of the 2009 dataset was described as plus or minus 20m whereas the 2024 dataset is expected to be accurate within 10m.

- Total length of survey was different, most likely related to differences in the resolution of mapping between surveys as similar estuary areas have been compared. Other factors include In 2009, the total survey length was 119.7 km, while the 2024 survey was 115.1 km. Picket Hill Creek and Urunga Lagoon, assessed in 2009, were excluded from the comparison.

Table 3 Descriptions of erosion severity categories used in 2009 and 2024 bank condition assessments of the Bellinger and Kalang River estuaries.

2009 Bank severity	Description	Comparable 2024 DST Erosion severity categories
No erosion	No erosion occurring in the reach	**Negligible**
Minor erosion	Erosion of a minor nature not warranting action or intervention, moderate to high natural recovery potential	**Low** erosion with negligible to moderate DST impacts recorded, OR **Moderate** erosion with low DST impacts recorded.
Moderate erosion	Erosion that may warrant intervention depending upon the level of impacts to reach values, possibly accelerating depending upon processes, low natural recovery potential	**Low** erosion with high DST impact recorded, OR **Moderate** erosion with moderate or above DST impact recorded.
Severe Erosion	Erosion affecting the entire bank profile, likely impacting reach values and values beyond the reach, unlikely to arrest without intervention	**High** or **Severe**

Bank erosion

The 2009 estuary survey was conducted several months after a major flood event that had significantly affected bank conditions throughout much of the Bellinger and Kalang estuaries. A key finding of the report was the notable increase in minor bank erosion, compared to erosion data from 1981 and 1984. This increase may be due to the timing of the survey, as insufficient time had likely passed for the banks to fully stabilise and recover. Comparative floods to the 2009 events occurred in February 2013 and again in March 2022. Given the relaxation time between the 2022 flood event and the 2024 bank condition survey, the same hypothesis of recovery times is less likely to be a factor and the results may indicate longer term impacts to streambanks.

Compared to the 2009 survey results, there has been a pronounced increase in the extent and severity in the study area. Considering the conclusions drawn by Telfer and Cohen (2010) regarding changes in erosion patterns from 1984, the Bellinger and Kalang estuaries show increasing degradation over the last 40 years. In both the Bellinger and Kalang, areas of negligible erosion have both decreased. Since 2009, the extent of streambanks experiencing some degree of erosion increased from 39.4% to 68.5% in 2024.

The majority of the apparent shift in both estuaries (including Back Creek) has been from negligible to minor erosion (*Table 4*). This is similar to the conclusions by Telfer and Cohen (2010), which identified a significant increase in minor erosion compared to the observations from 1984. In 2009, 52% of the Bellinger River had negligible erosion, while 33.7% had minor erosion. The 2024 survey suggests erosion is now affecting an even greater extent of streambanks along the Bellinger River estuary. In 2009, 52% of the Bellinger had negligible erosion, however that has now declined to 36%. This difference in negligible erosion is almost entirely accommodated by a 13.7% increase in minor erosion, which now accounts for 47.5% of streambanks in the Bellinger (*Table 4*). Similarly, the Kalang River estuary experienced a 42.3% reduction in streambanks with negligible erosion, associated with a 43% increase in minor erosion. Overall, the total extent of negligible to low erosion throughout the study area has remained relatively unchanged, covering between approximately 85 – 90% in both the Bellinger River and Kalang River. Only minor changes occurred in the extent of reaches observed with *moderate erosion*, with < 1% change in the Bellinger and Back Creek, and a 2.9% reduction in *moderate erosion* in the Kalang River which appears to be roughly equal with the increase in *severe erosion*.

Severe erosion (as either High or Extreme erosion in the 2024 survey) has increased in extent throughout the estuary study area by 63% since 2009. In the Bellinger River, the extent of severe erosion increased from 6% of streambanks in 2009 to 10.2% in 2024. Similarly, Back Creek increased from 6.6% in 2009 to 9.3% in 2024, while Kalang River had a 2.2% increase to 6.6% of all reaches in 2024 (*Table 4)*. However, while severe erosion has become more extensive throughout the estuary, many of the identified reaches have had erosion recorded persistently over several surveys. Within the areas identified as *severe* in 2009, 46.6% were found to still have either *extreme* or *high* erosion in the 2024 survey. Further, despite the increase in severe erosion, 30.6% of reaches with *high* or *extreme* erosion in 2024 were classed as *severe* in 2009, with 60.3% (1098 m) of the 2024 Extreme erosion reaches previously identified as such in 2009. Many of the reaches have not experienced any direct management intervention (see below).

Fewer reaches were observed to have undergone significant change in erosion severity. The areas that have increased from Negligible or Low erosion to High or Extreme erosion represent a smaller subset of the severe erosion sites, representing 338 m (18.5%) of *extreme erosion* reaches and 995 m (13.7%) of high erosion. Across the study area, these lengths are distributed across five sites that have increased in erosion severity from negligible or minor erosion in 2009 to Extreme erosion in 2024, and 12 sites that now feature High erosion (*Table 5*). Half of these sites reflect a downstream extension of existing severe erosion rather than a new source of erosion, while most of the other sites reflect discreet sections of degraded streambank.

Table 4 Comparison of bank erosion severity in each stream between 2009 and 2024 survey results, adjusting the 2024 results to match the 2009 erosion categories as per Table 3

Erosion Severity	2009 m	%	2024 m	%	09 – 24 % change
Bellinger River					
Negligible	28001	51.9	18483	35.8	-16.1
Minor	18180	33.7	24493	47.5	+13.7
Moderate	4508	8.4	3374	6.5	-1.8
Severe	3225	6.0	5265	10.2	+4.2
TOTAL	**53914**		**51615**		
Kalang River					
Negligible	41224	68.1	15054	25.9	-42.3
Minor	12807	21.2	37307	64.1	+43

Erosion Severity	2009 m	%	2024 m	%	09 – 24 % change
Moderate	3819	6.3	1997	3.4	-2.9
Severe	2657	4.4	3817	6.6	+2.2
TOTAL	**60506**		**58175**		
Back Creek					
Negligible	3367	63.7	2691	50.4	-13.3
Minor	1309	24.8	1836	34.4	+9.6
Moderate	262	5.0	313	5.9	+0.9
Severe	347	6.6	496	9.3	+2.7
TOTAL	**5285**		**5336**		

Table 5 Sites that have demonstrated a significant increase in erosion severity between 2009 – 2024 bank condition surveys

Survey ID	Location	2009 Severity	2024 Severity	Length	Site Notes
101	Bellinger R - mid estuary, outside bend	Negligible	Extreme	113	Downstream of existing severe erosion
131	Bellinger R - mid estuary, inside bend	Minor	Extreme	50	-
172	Bellinger R - mid estuary, outside bend	Negligible	Extreme	107	Downstream of existing severe erosion
555	Kalang R - upper estuary, outside bend	Negligible	Extreme	33	Downstream of existing severe erosion
716	Kalang R - mid estuary, inside bend	Minor	Extreme	35	-
3	Bellinger R - Mid estuary, Inside bend	Negligible	High	160	-
118	Bellinger R - Mid estuary, Inside bend	Negligible	High	25	Extension of existing erosion issue
173	Bellinger R - Mid estuary, Outside bend	Negligible	High	28	Extension of existing erosion issue
296	Back C - Lower estuary, Inside bend	Negligible	High	74	Downstream of existing severe erosion
313	Kalang R - Mid estuary, Outside bend	Negligible	High	97	-
330	Kalang R - Mid estuary, Inside bend	Negligible	High	33	Slumping
424	Kalang R - Mid estuary, Outside bend	Negligible	High	107	Extension of existing erosion issue
559	Kalang R - Upper estuary, Straight	Negligible	High	90	-
563	Kalang R - Upper estuary, Straight	Negligible	High	174	-
569	Kalang R - Upper estuary, Straight	Negligible	High	24	Extension of existing erosion issue
664	Kalang R - Mid estuary, Outside bend	Negligible	High	49	Erosion of outside bend with existing pressure
752	Bellinger R - Upper estuary, Inside bend	Negligible	High	135	New erosion downstream of bridge

Bellinger and Kalang River Estuaries Riparian Vegetation Condition

Method

Riparian Vegetation Condition was assessed using a multi-metric index of riparian condition. The index has been modified from previous methodologies utilised by Fruition Environmental in other estuarine assessments and studies (e.g. The Bellinger Kalang estuary study undertaken by Cohen and Telfer in 2010). The method has proved suitable for whole of estuary studies where each segment needs assessment (i.e. where the length of bank being assessed precludes more detailed assessments such as those undertaken under the Ecohealth Monitoring Project by Ryder et al, 2017).

Again, the attributes collected included those required to ensure compatibility with the DPIRD Fisheries DST methodologies. To this end the DST attributes of riparian vegetation continuity and width have been adopted with the criteria for assessment for these two attributes adopted from the DST assessment method (Hydrosphere Consulting, 2020b). Specifically:

- **Riparian Vegetation Continuity** was recorded as either *negligible*, *low*, *medium*, or *high*
- **Riparian Vegetation Average Width** was recorded as *<2m*, *<5m*, *<10m*, *<20m* and *>20m*.

In addition to the DST compatible attributes, three additional attributes were adopted to assist in determining riparian condition. The additional attributes adopted were:

- **Riparian Vegetation Structure** which was recorded as either *very poor*, *poor*, *medium*, *good* or *very good* (see Appendix A for descriptions of each category for this attribute). Again, a number of existing datasets were available within the Field Maps app to help inform field staff of what vegetation communities could be expected in the segment. These included NSW Endangered Ecological Vegetation Community mapping (derived from Byron Shire Council HEC vegetation mapping, 2023) and aquatic vegetation mapping (mangrove, saltmarsh and seagrass communities, as per the NSW DPIRD Estuarine Macrophyte data layer). For instance, where the riparian vegetation was a coastal saltmarsh community then the riparian vegetation structure value reflected what would be expected for a vegetation community of that type.
- **Riparian Vegetation Diversity** which was recorded as either *very poor*, *poor*, *medium*, *good* or *very good* (see *Appendix A* for detail). Again the value recorded was measured against the level of diversity expected for a vegetation community of the type that would naturally occur in that segment, informed by vegetation mapping layers loaded into field maps.
- **Exotic Weed Presence** which was recorded as either *nil observed*, *low* (<10% FPC), *moderate* (10-25% FPC), *high* (25-50% FPC), or *very high* (>50% FPC).

Upon completion of the field mapping exercise, the results of each segment's survey against the five sub-indices were used to compute a riparian condition index score using a simple algorithm (sum of attribute scores). The attribute scores used to convert the field records into the riparian vegetation condition score are shown in *Table 6*.

Table 6 Riparian Condition Index attributes and values used in calculation the Riparian Vegetation Condition Score for each field surveyed bank segment in the Bellinger and Kalang River Estuaries.

Attribute	Value	Score
Riparian Vegetation Continuity	Negligible	0
	Low	1
	Moderate	5
	High	9
Riparian Vegetation Average Width	Less than 2m	0
	Less than 5m	2
	Less than 10m	5
	Less than 20m	9
	Greater than 20m	12
Riparian Vegetation Structure	Very poor	0
	Poor	2
	Moderate	5
	Good	9
	Very Good	12
Riparian Vegetation Diversity	Very poor	0
	Poor	2
	Moderate	5
	Good	9
	Very Good	12
Weed Presence	Nil observed	5[2]
	Low (<10% FPC)	3
	Moderate (10-25% FPC)	1
	High (25-50% FPC)	0
	Very High (>50% FPC)	0
	Maximum Score	**50**

The condition score was then converted to a **Riparian Vegetation Condition** Rating which represents 5 condition bands ranging from *Very Poor*, *Poor*, *Moderate condition*, *Good condition* through to *Very Good condition*. The bands used to convert the condition score to the Riparian Condition Ratings are shown in *Table 7* with the definition for each category as follows:

- VERY POOR CONDITION: no to very little riparian vegetation.
- POOR CONDITION: discontinuous riparian vegetation of narrow width with poor diversity and structure, exotic weeds may be present.

[2] Note: if Riparian Vegetation Continuity <3 then weed presence score was set at 0 regardless of the weed presence entry. This was because if there was "no" to "low" vegetation continuity then there was likely also no weeds present so without this adjustment the condition score would be artificially high due to the 5 scored against "nil observed".

- MODERATE CONDITION: medium to high vegetation continuity, width greater than 2m and with variable structure and diversity, weeds may be present.
- GOOD CONDITION: medium to high vegetation continuity, width greater than 5m and with structure and diversity generally medium to good, weeds may be present but not dominant.
- VERY GOOD CONDITION: high vegetation continuity with width greater than 10m, Very Good vegetation structure and diversity, and low to no weed presence.

Table 7 Riparian Vegetation Condition Ratings derived from the Condition Index Scores used in the Bellinger-Kalang River Estuary assessment.

Riparian Vegetation Condition Rating	***Riparian Condition Index Score***
Very Poor Condition	*0-5*
Poor Condition	*6-10*
Moderate Condition	*11-25*
Good Condition	*26-40*
Very Good Condition	*41-50*

In addition to the five attributes which combine to form the Riparian Vegetation Condition rating, more detailed presence/absence of important individual **environmental weed species** were recorded. These included presence/absent within the segment of *Bitou bush*, *Broad-leaved privet*, *Camphor laurel*, *Coastal morning glory*, *Ground asparagus*, *Lantana*, and *Small-leaved privet*. The records of observations are available through the online mapping database.

Examples of reaches with Very Good Condition to Very Poor Condition riparian vegetation are shown in *Plates 9* to *13*.

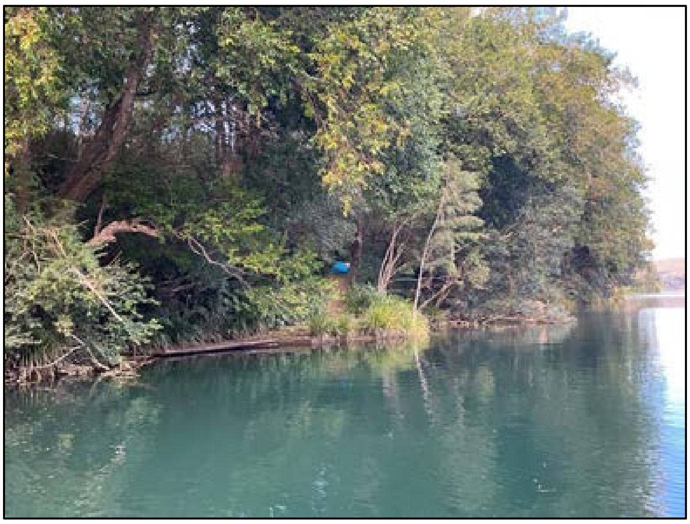


Plate 9 Examples of Very Good condition riparian vegetation: Left to right, Bellinger River Reach 234, Kalang River Reach 565.

Plate 10 Examples of Good condition riparian vegetation: Left to right, Kalang River Reach 367, Bellinger River Reach 87.

Plate 11 Examples of Moderate condition riparian vegetation: Clockwise from top left, Back Creek Reach 298; Kalang River Reach 711; Kalang River Reach 571; and Bellinger River Reach 245.

Plate 12 Examples of Poor condition riparian vegetation: Clockwise from top left, Kalang River Reach 331, Bellinger River Reach 125.

Plate 13 Examples of Very Poor condition riparian vegetation: Left to right, Back Creek Reach 723, Bellinger River Reach 190; Bellinger River Reach 117; and Kalang River Reach 717.

Overview of Results

Table 8 highlights the proportions of surveyed estuary bank which were mapped against each category of riparian vegetation condition. *Figure 15* shows the spatial distribution in the study area.

Table 8 Riparian Vegetation Condition in the Bellinger-Kalang River Estuary study area.

Riparian Vegetation Condition	Length of bank (m)	% of overall estuary bank mapped
Very Poor Condition	18882	16.4%
Poor Condition	8797	7.6%
Moderate Condition	33170	28.8%
Good Condition	28849	25.1%
Very Good Condition	25428	22.1%

The 2024 field survey results show that riparian condition varies across the Bellinger-Kalang estuary survey area, with 24% (27.7km) of estuary bank vegetation is in Very Poor to Poor condition, while nearly half (47.2% or 54.3 km) is in Good or Very Good condition.

A considerable portion of assessed reaches were recorded as having Moderate condition (28.8%) suggesting that almost a quarter of banks could be considered in a transitional state where condition could either improve or decline depending on management.

In reaches with Very Poor to Moderate condition vegetation a major factor in the rating is narrow riparian width. More than half of the surveyed estuary length (57%) having average riparian widths recorded as less than 5 m wide, almost two thirds (66%) recorded under 10 m wide.

Much of the bank length described with Poor to Very Poor riparian condition occurs in agricultural areas, along areas of residential foreshore development cleared for amenity and access such as in Urunga and Mylsetom, or are where intensive bank remediation works have been implemented in close proximity to infrastructure such as roads or entrance sea walls restricting riparian width.

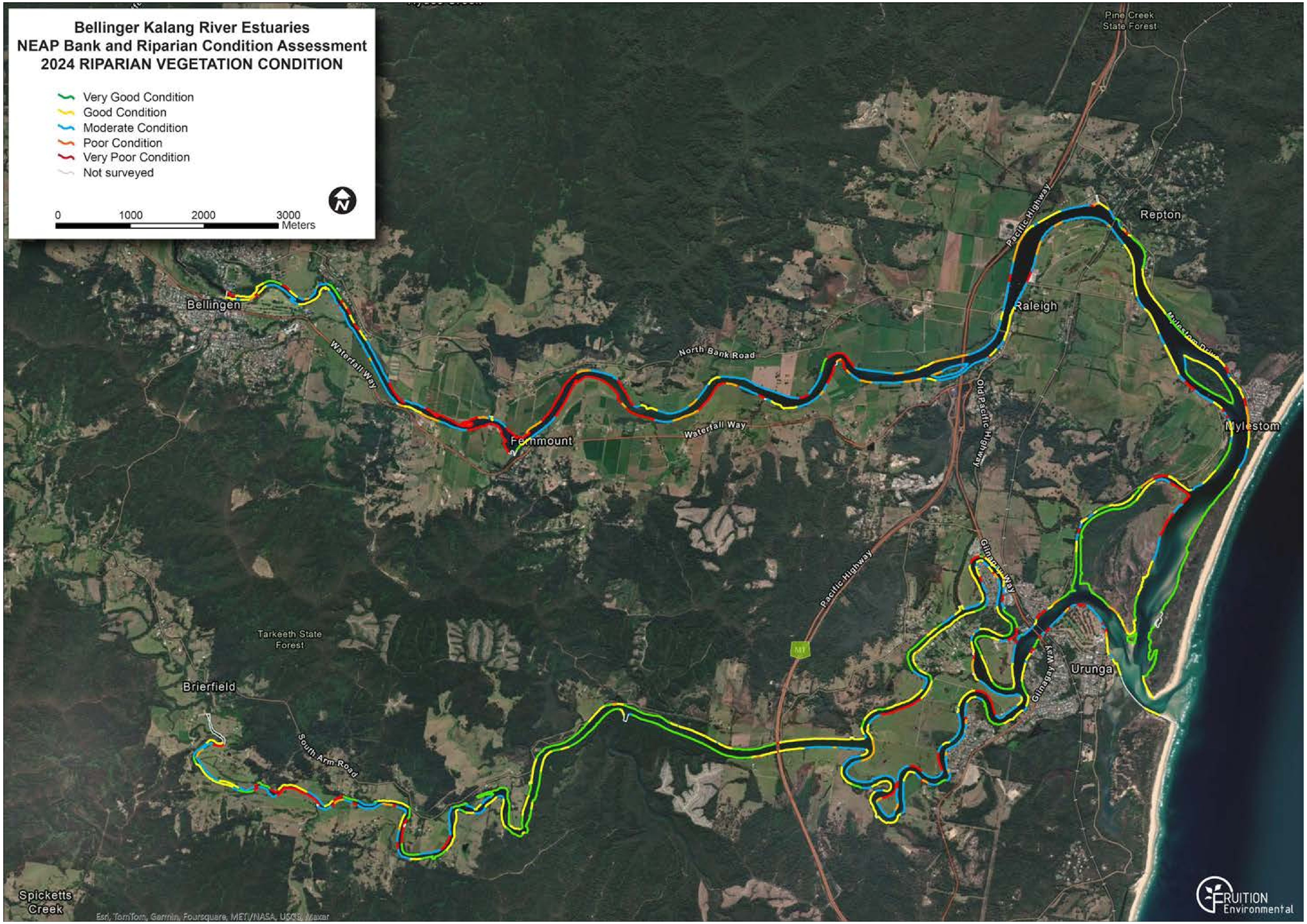

Figure 15 Distribution of riparian vegetation condition across the Bellinger and Kalang River Estuaries Study Area

Table 9 provides the distribution of riparian vegetation condition by process zone and estuary location. In the Fluvial Dominated process zones of the Bellinger River, there is a significant proportion of degraded vegetation, with little change in the proportion of Very Poor vegetation over the last 15 years. In these zones, over 30% of the riverbank is classified as being in Very Poor condition. Most reaches in the fluvial-dominated process zones also have high to very high weed cover including camphor laurel, small-leaved privet and lantana. However, there is also a marked improvement in Poor condition vegetation since 2009, which dropped from 40% to 9.6%, while Good and Very Good riparian vegetation increased from 1% to 22.6% in Zone A and 8.1% in Zone B.

Table 9 Distribution of riparian vegetation condition ratings in the Bellinger and Kalang River estuaries by estuary process zone and location: summary statistics.

	Very Poor Condition	Poor Condition	Moderate Condition	Good Condition	Very Good Condition
Fluvial Dominated A Process Zone Reaches					
Bellinger River	30.6	9.6	37.3	17.3	5.3
Kalang Creek	16.2	4.4	29.0	24.9	25.4
Fluvial Dominated B Process Zone Reaches					
Bellinger River	32.1	17.4	42.4	6.9	1.2
Kalang Creek	1.0	2.3	7.9	34.2	54.6
Fluvial Transition Process Zone Reaches					
Bellinger River	8.1	8.7	33.3	34.3	15.6
Kalang Creek	12.8	5.6	33.4	32.5	15.7
Marine Tidal Delta Process Zone Reaches					
Bellinger River	14.2	4.5	9.6	22.3	49.5
Kalang Creek	18.8	11.2	27.9	19.5	22.6
Back Creek	13.8	3.6	8.5	23.5	50.6

In contrast, the Kalang River demonstrates better overall condition in these zones, especially in the Fluvial Dominated B zone where 54.6% of its riverbank is classified as being Very Good, up from 18% in 2009, and degraded conditions have dramatically reduced to only minor areas of degradation. Similarly, the Fluvial-Dominated A zone recorded improved condition ratings, with a reduction in degraded areas and a 10% increase in Good and Very Good conditions.

In both rivers, the Fluvial Transition zone shows a relatively even distribution across the vegetation condition categories, with overall reduced areas of lower condition vegetation compared with upstream reaches/zones and significant increases in Good and Very Good condition vegetation reaches. In 2009, neither river featured Very Good vegetation while both now exceed 15% in this category.

The Marine Tidal Delta process zone shows the healthiest vegetation overall for the Bellinger River and for Back Creek. Around 50% of the vegetation in these systems is in Very Good condition in this zone. However, in both the Bellinger River and Kalang River there has been an approximate 10% increase in Very Poor vegetation condition in this zone since 2009. In the Bellinger Marine Tidal Delta process zone, the increase has mostly been associated with foreshore erosion along Urunga Island. The Kalang River shows a more mixed condition, with 18.8% of estuary banks in the Marine Tidal Delta Zone in Very Poor condition, mostly associated with bank protection works in foreshore areas adjacent to residential properties. Generally, vegetation has likely not been able to recover or establish in part for visual amenity purposes.

Figure 16 shows the proportions of each condition category by estuary system.

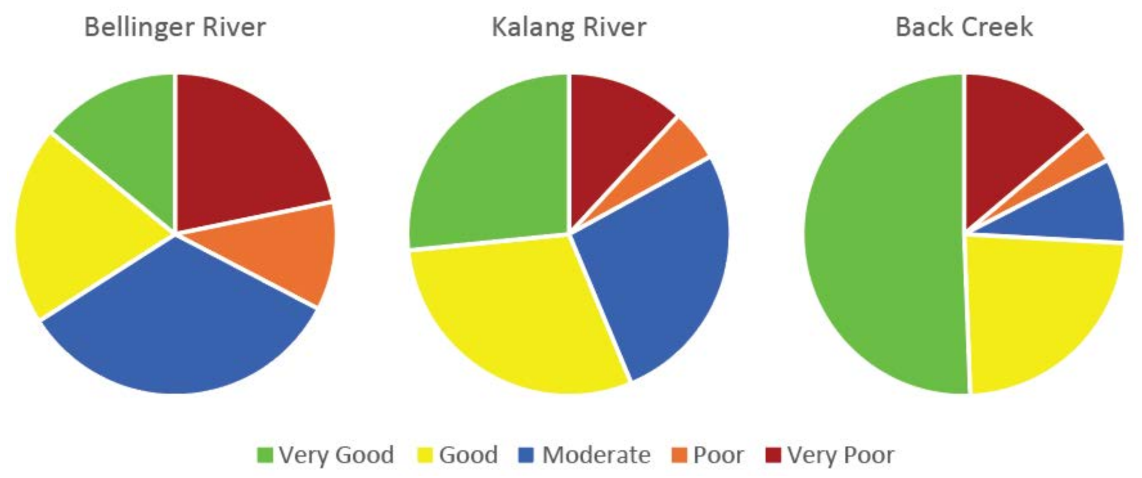

Figure 16 Proportional distribution of riparian vegetation condition within each estuary of the Bellinger-Kalang River study area.

When looking at individual estuary systems, the Bellinger River shows the highest level of riparian degradation, with 32.7% of its length in Very Poor to Poor condition, compared to 34.1% in Good to Very Good condition. In contrast, the Kalang River has 17% in the lower condition categories and 56.3% of its length in Good to Very Good condition. As with the erosion severity ratings, the higher proportion of riparian vegetation in Good to Very Good condition reflects the degree of valley confinement, reduced floodplain development, extensive mangrove forests of the lower estuary, limitations on land use that have resulted in reduced historical clearing of the riparian zone.

Back Creek shows the highest proportion of healthy vegetation (50.6% in Very Good condition) with over half its banks featuring riparian vegetation in Very Good condition. The poorer condition vegetation is generally found adjacent to Yellow Rock Road where the riparian strip is narrow or on the Northern tip of Urunga Island which has been cleared and impacted by stock for many years.

The major impacts on riparian vegetation condition observed during the field assessment included:

- Clearing, associated with agriculture in the upper and middle estuary and with infrastructure and urban development in the lower estuary in proximity to Urunga and Newry Island.
- Loss due to erosion processes including, in the lower estuary, stripping of intertidal benches under mangrove habitat due to persistent wind or boat wave effects, and in the upper estuary due to post flood bank slumping particularly where only a narrow fringe of vegetation exists on the bank.
- Weed incursion in the fluvial process reaches of the Bellinger River estuary and upper reaches of the Kalang River estuary where camphor laurel, small leaved privet and vine weed are particularly invasive.

Existing Estuary Erosion Control Works

Method

The presence or absence of existing erosion controls on the bank was recorded for each surveyed section. The methodology broadly followed the DPIRD Fisheries Draft Decision Support Tool methodology (Hydrosphere Consulting, 2020b) with some modification. Compatibility with the DST was maintained although extra information was recorded to assist in the more accurate determination of existing control statistics (percentage of bank treated with control) and a number of additional control types were added (eg. gabion baskets).

If existing erosion control works were present the following information were recorded:

- The type of control/s (i.e., rock revetment, revegetation, building rubble, etc.) were recorded using a yes/no data field against each potential control listed (multiple selections possible),
- the percentage of segment with an existing control/s was recorded to allow more accurate determination of length of works as the control length does not always correlate with the segment length as it is not the primary determinant of the segment. The options for this field were *nil existing*, *less than 10%*, *10-25%*, *25-50%*, *50-75%*, and *75-100%* of the segment length (only one selected).
- Finally, the effectiveness of the existing control/s was recorded. The options for this field were *Ineffective*, *Partial (Condition)*, *Partial (Design)*, *Completely*, *Under Construction*, *Trial works/untested*, or *Redundant*. The DST descriptions of the works effectiveness categories were adopted for this assessment (see Hydrosphere Consulting, 2020b; also *Appendix B*).

Types of works present

Of the total length of bank field surveyed in the Bellinger and Kalang River estuaries (115.1 km), 19.8 km or 17% of estuary bank had some form of existing bank protection recorded across 231 individual reaches. *Table 10* shows the total length of the different bank protection types recorded within the study area.

The most prevalent form of bank protection observed was rock revetment with over half (53.2%: 10.5 km) of all works recorded utilising this method and representing 9.2% of the total surveyed length of estuary bank in the study area (*Table 10*). These works are primarily focused around urban centres, particularly Urunga, Repton, Raleigh and Mylestom. The next most prevalent works types were:

- Entrance training walls/sea walls in the lower estuary (~2 km)
- Concrete slab, blocks or walls along the bank (~1.4 km),
- Building rubble including broken concrete (~1.2 km)
- Used tyres (960 m) primarily along residential foreshore in the lower Kalang River around Urunga and lower Bellinger River at Raleigh and Repton

Table 10 Total length of each existing bank protection works style, the percentage of each style of the overall total length of bank protection measures, and the percentage of each style of the total length of estuary bank surveyed in the Bellinger and Kalang River estuaries.

Control Type	Total length of bank (m)*	% of overall works	% of surveyed bank
Rock armouring	10545	53.2	9.2
Entrance training walls / seawalls	1957	9.9	1.7
Concrete	1445	7.3	1.3
Building rubble	1178	5.9	1.0
Tyres	958	4.8	0.8
Revegetation	967	4.6	0.8
Rock fillets	866	4.4	0.8
Timber wall	509	2.6	0.4
Natural logs on bench	426	2.2	0.4
Natural log wall	323	1.6	0.3
Cobble beaching	268	1.4	0.2
Gabion baskets	191	1.0	0.2
Geotextile sand bags	123	0.6	0.1
Timber or log piles	68	0.3	0.1
Oyster shells	22	0.1	0.0
Rock groynes	12	0.1	0.0
Trial	-	-	-
Total Bank Treated	**19808**	**100**	**17**

* *Note: the total length of works may exceed the length of bank treated where works types overlap, such as rock armouring of the bank toe and revegetation of the mid and upper bank.*

A lot of the works present throughout the estuary use multiple works types, with 40.7% of reaches using an integrated approach or multiple adjacent types. However, only seven reaches totalling ~970 m were identified as having active revegetation, despite active revegetation being a widely recommended practice for riverbank protection projects and the need for improved riparian condition and vegetation extent recognised within the Bellinger-Kalang estuary (Telfer and Cohen, 2010; Eco Logical Australia, 2019; JBP, 2022). Where revegetation was used it was typically undertaken in concert with other protection works, including rock armouring and rock fillets and stock management fencing.

Just under one fifth of all identified protection works (18.1%) utilise inappropriate materials including rubble, building waste including broken concrete, and/or old tyres. As mentioned, a large majority of these works are concentrated around Newry Island and adjacent to Burrawong Parade in Urunga.

Condition of works

Two thirds (66.4%; 12.9 km) of the existing bank protection measures observed were recorded as completely effective (*Table 11*). Just under a third (27.8%: 5.4 km) of all works were described as only partially effective either because of poor condition (resulting in some erosion continuing) or poor design (resulting in the works being compromised or only partially suitable). Maintenance or retrofitting of the partially effective works, particularly around Newry Island, would likely improve the erosion control effectiveness. However, given the 5.4 km of works identified in this condition, some prioritisation would be required. Only one reach (reach 660) shows partial failure with high erosion, where rock armouring has collapsed with mass failure of the adjacent bank. A further 23 reaches (1,793 m of works) have partially effective works and were recorded with Moderate erosion.

Table 11 Total length of each category of works effectiveness for bank erosion protection measures surveyed and percentage of each category of the total length of surveyed bank protection measures in the Bellinger and Kalang River estuaries.

Works Effectiveness	Total length of bank (m)	% of overall works
Completely	12,882	66.4%
Partial (Condition)	2,101	10.8%
Partial (Design)	3,298	17.0%
Ineffective	281	1.4%
Redundant	819	4.2%
Under construction	24	0.12%
TOTAL	**19,404**	**100%**

Few areas of ineffective works were recorded. Only 1.4% of works (281 m) were described as ineffective and 4.2% (819 m) described as redundant. The main differentiation is that redundant works are generally an inappropriate form of erosion control as well as being ineffective. Over 70% of ineffective or redundant works consist of inappropriate works including tyres, building rubble or concrete. This likely relates to the ad-hoc nature of such works, as opposed to other protection works involving design and assessment protocols. Six sites had ineffective or redundant rock armouring but in all cases these were issues with design, where a relatively minor amount (<10% of the bank) had rocks placed along it in an ad-hoc manner. Examples of the types of erosion protection works present in the Bellinger-Kalang River Estuary study area and their condition/effectiveness status are shown in *Plates 14* to *16*.

Figure 17 shows the distribution of works within the study area and the assessed effectiveness or otherwise of the structures/works types present in those reaches.

Inappropriate works generally demonstrated a high degree of failure, with 33.3% of these works (15.1% of the length) having completely failed or been ineffective at mitigating erosion, and a further 34.3% (38.3% of bank length) having partial failure. Examples of inappropriate works types are shown in *Plate 17*.

Plate 14 Examples of effective bank protection works in the study area, clockwise from top left: Cobble beaching in lower Kalang River Reach 268; Rock fillets at Newry Island, Kalang River Reach 662; Large woody debris/rootballs in the lower Kalang Reach 739; Rock armouring adjacent to Yellow Rock Road on Back Creek Reach 353; Rock armouring and logs at Mylestom on Bellingen River Reach 355; Gabion wall at Mylestom on the Bellinger River Reach 29.

Plate 15 Examples of partially effective bank protection (design) in the study area, from left to right: insufficient rock fillet height and subsequent erosion of the mid bank on the Kalang River Reach 654; failure of the bank toe and subsequent subsidence of rock armouring on the Kalang River Reach 660.

Plate 16 Examples of partially effective bank protection works (condition) in the study area, from left to right: erosion of the mid bank above slumped rock armouring in the lower Bellinger River Reach 57; subsiding rock works on Back Creek exposing upper bank to erosion, Reach 723.

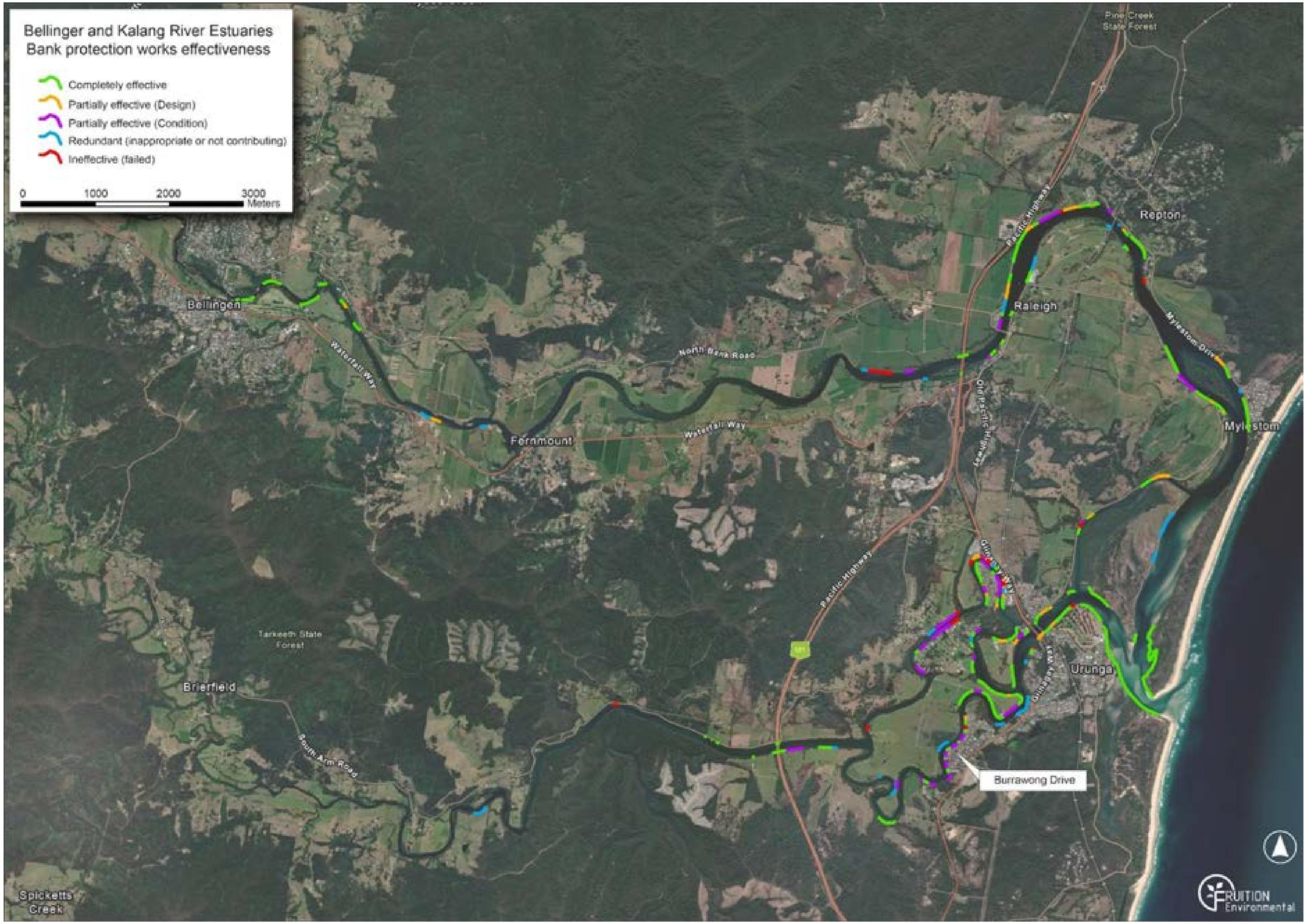

Figure 17 Distribution of bank protection works effectiveness within the Bellinger-Kalang River study area.

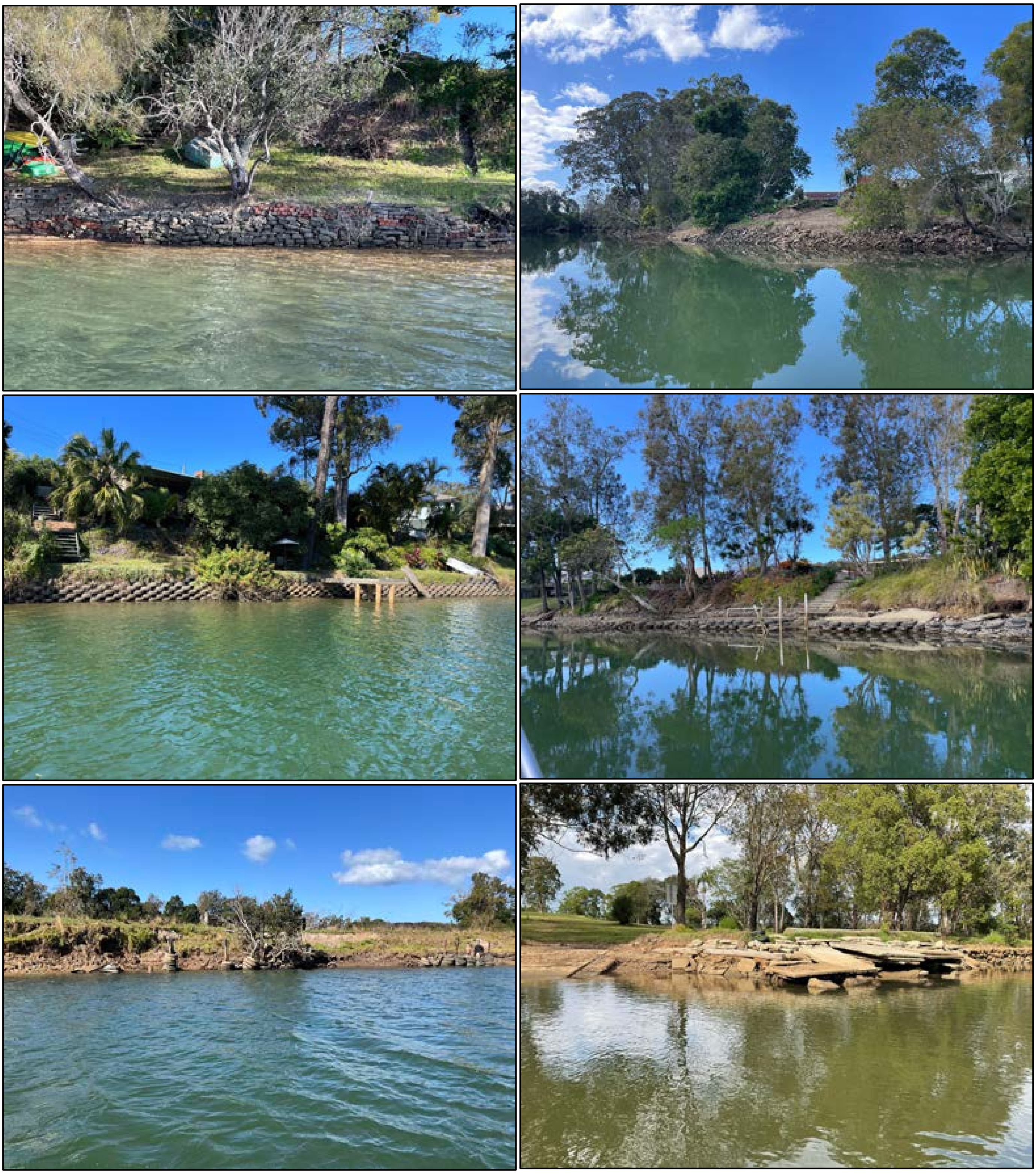

Plate 17 Examples of inappropriate bank protection works in the study area, clockwise from top left: building rubble dumped over the bank at Reach 261 Kalang River; building rubble pushed over the bank on the Council reserve at Reach 333 Kalang River; tyre wall in the Council reserve area behind Burrawong Pde Kalang River; Concrete debris and building waste on the Kalang River; deteriorating tyre wall Kalang River Reach 425; tyre wall on the Bellinger River at Raleigh Reach 77.

Comparison of 2009 Priorities to 2024 Works Assessment

Many of the priority sites identified in the 2009 erosion survey (Telfer and Cohen, 2010) have had no direct action to mitigate erosion or riparian vegetation degradation. A review in the 2022 Water Quality Management Strategy (JBP, 2022) identified that only three of the 20 priority sites from those listed in 2009 had been remediated since 2010 (see Table 4-5 in the WQMS).

An update of the status of these sites was undertaken as part of this NEAP assessment. *Table 12* shows the status of the priority sites identified in the 2009 erosion study updated based on the 2024 field assessment. The three sites identified in the WQMS are shown in red. Of these three, one site was considered highest priority, while the other two were moderate priority sites. These include Site 10 (2024 assessment Reach 720), along Yellow Rock Rd at the northern end of Back Creek, and Sites 22 and 24 at the downstream limits of the Kalang River on Newry Island. For the most part, these works have been effective at mitigating erosion, although some design issues have resulted in partial failure of small sections of the works. Notably, a segment of the rock wall at Site 22 (2024 assessment Reach 660) has failed and was assessed as high erosion severity in 2024 (*Table 12*).

Site 5 (2024 assessment Reaches 753/755/756) was not identified in the WQMS but had 2009 flood damage repaired after the 2009 erosion survey using rock armouring and partial revegetation on the upper bank. These works appear to have been successful at the site, although erosion was observed along the bank immediately downstream of this reach.

There are 13 additional reaches across eight sites in the estuary study area that featured moderate to severe erosion in 2009 but have existing controls. These are primarily focused around Bellingen, Urunga Island and Newry Island, and include a number of priority sites from Telfer and Cohen (2010) including Site 2 (Reach 231), Site 4 (Reach 763), Site 23 (Reach 425) and Site 26 (Reach 482). Some of these works were already in place and likely partially degraded at the time of that initial survey. During the 2024 survey, 32% of these works were identified as being partly or completely ineffective. These include tyres along the eastern margin of Urunga Island that have completely failed and are scattered across the intertidal bench. This reach featured only moderate erosion in 2009, so may have been partly effective at the time, but now appears to have completely failed.

Two sites on the Kalang River which were not identified as priority sites in the 2010 study appear to have had works undertaken between 2010 and 2024. Reach 555 at the lower limit of the Fluvial Dominated Zone A, located on an outside bend, appears to have been actively revegetated but ongoing severe erosion continues to impact the site, with several trees observed being undermined and collapsing into the river. This site is included in the rate of erosion assessment in Part 4. Reach 654 at Newry Island has also been remediated using rock armouring, rock fillets and revegetation. These works were assessed in 2024 as partially effective due to erosion persisting on the upper bank behind the works in some sections.

For sites identified as being implemented since the 2009 survey, only two sites featured active revegetation.

Table 12 2024 status of priority sites identified in the 2009 Bellinger Kalang Estuaries Erosion Study, entries highlighted in RED have been remediated since the 2009 erosion survey (Telfer and Cohen, 2010; modified from JBP 2022)

Priority	Site ID (2010)	Reach ID (2024)	River	Description	Status
Highest	Site 10	720	Back Ck	260m of erosion adjacent to Yellow Rock Road. Wave wash causing undermining and subsequent bank collapse.	Rock armouring has effectively treated erosion issues, excepting a minor (3-4 m) section that has failed
	Site 12/27	265, 267, 270, 273, 277, 279, 281, 282, 284, 286, 288	Bellinger	Ongoing disturbances associated with wave wash (primarily wind generated) and unmanaged stock access	No action
	Site 16	581 - 582	Kalang	The deep water profile limits potential bank stabilisation methods. Further site investigation is recommended to determine appropriate methods of stabilisation and approximate costs	No action
	Site 21	399, 401	Kalang	The deep water profile limits potential bank stabilisation methods. Further site investigation is recommended to determine appropriate methods of stabilisation and approximate costs	No action
	Site 26	482	Kalang	Erosion on the left bank (Pacific Highway side) upstream of the Newry Island bridge may threaten upstream eastern bridge abutment if not treated	Existing works are ineffective and inappropriate for mitigating erosion
High	Site 2	231 - 232	Bellinger	Flood damage to existing bank protection measures threatens the loss of a small alluvial flat	Existing works are redundant and not mitigating erosion issues
	Site 5	**753, 755, 756**	**Bellinger**	**Flood damage to existing protection works adjacent to the Bellingen Golf Club. The majority of works have survived the 2009 floods well, however, revegetation and weed control and some repair of mesh fencing on the site may assist in reducing scour at the site and on the adjacent golf course**	**Existing works appear to be completely effective, no apparent erosion**
	Site 17	627	Kalang	Flood damage to an existing riparian revegetation project should receive priority assistance to ensure the success of the works. Landholder commitment has already been demonstrated	No action

Priority	Site ID (2010)	Reach ID (2024)	River	Description	Status
	Site 23	425	Kalang	Works here should aim to stabilise the banks using best practice techniques, although the deep water profile adjacent to the site will complicate and increase the costs of construction. Remove of disturbance factors such as unmanaged stock access and wave wash (primarily from boats in this location) will also be important factors in long-term stability	Existing works are redundant and inappropriate for mitigating erosion
Moderate	Site 1	188, 192, 193	Bellinger	All adjacent sites listed here as Moderate Priority are in agricultural landscapes and would require a significant commitment from landholders, responsible government agencies, and funding bodies to actively remediate. All sites except Site 9 (which had fencing on the top bank) are subject to stock impacts with sites 7 and 11 also affected by wave wash	No action
	Site 3	209, 211, 212	Bellinger		No action
	Site 4	763	Bellinger		No action
	Site 6	172, 174	Bellinger		Nil
	Site 7	183	Bellinger		Nil
	Site 8	118, 120	Bellinger		Nil
	Site 9	101, 173	Bellinger		Nil
	Site 11	292	Bellinger		Nil
	Site 13	621	Kalang	All adjacent sites listed here as Moderate Priority are in agricultural landscapes and would require a significant commitment from landholders, responsible government agencies, and funding bodies to actively remediate. All sites except Site 20 are subject to stock impacts with sites 22, 23, 24 and 25 also affected by wave wash. Sites 24 and 25 may be suitable for rock embayment construction due to their relatively shallow water profiles and proximity to the lower estuary and therefore mangrove seed sources	Nil
	Site 14	634	Kalang		Nil
	Site 15	609	Kalang		Nil
	Site 18	613	Kalang		Nil
	Site 19	607	Kalang		Nil
	Site 20	561	Kalang		Nil
	Site 22	656, 658, 660, 662	Kalang		Bank restoration in 2017, and 2018/19. Partial failure along ~100 m section of works due to design issues
	Site 24	436, 437, 439, 442	Kalang		Bank restoration in 2017, and 2018/19. Partial failure along 50 m section of works
	Site 25	681	Kalang		Nil
	Site 28	672, 693, 695	Kalang	This site covers two separate remnant vegetation communities which occur on outside bends in the lower Kalang estuary opposite Newry Island. The condition of the remnants has not been established and erosion is not currently occurring adjacent to the remnants. Further assessment and monitoring is recommended	Nil

Future Works

The trend of increased erosion severity and extent highlights the need for management actions to build the resilience of riverbanks to erosion.

It is clear from the existing works statistics that the predominant forms of bank erosion protection used in the estuary to date rely on rock and building materials in varying forms of direct bank protection. Where adjacent to urban areas preference has been for full bank revetment, although many examples of ad hoc works adjacent to private properties, often on Crown/Council foreshore, and often using inappropriate materials also exist (e.g. building and construction waste). Areas adjacent to Burrawong Parade, around Newry Island, and at Raleigh are examples.

The preference for hard engineering solutions probably reflects the setting, that is, rock revetment is often used in high public use areas or where public infrastructure is to be protected. Additionally, where near-bank deep water channel profiles exist then rock revetment may be the only practical solution. However, in such situations remediation is generally expensive due to the volume of rock required.

Where inappropriate works types have been used and the land is Crown or Council owned, a potential future action could be the targeted removal of inappropriate works and replacement with more appropriate works types which contribute to bank stability and estuarine and riparian habitat in these reaches. There was broad support for this approach expressed during the targeted consultation phase of the project and some preliminary investigations have been initiated by Council in some parts of the study area.

Interestingly, there are several sites that utilise novel approaches such as hybrid rock and log/rootball/timber pins in the mid estuary, particularly in the Fluvial Transition Zones in both the Bellinger and Kalang Rivers, some with fish habitat modules integrated. These works, though generally successful, sometimes have partial failures of the timber elements due to marine borers and worms. Wood elements permanently in contact with mid-estuary waters are the most susceptible. Provided the finished heights of the wave dissipation/protection structures is sufficient, the slow decomposition of timber elements is not an issue. However, where the wood elements failure results in slumping of the crest height of the fillets, erosion is often observed of the mid to upper bank due to waves overtopping.

Where wave erosion is the dominant cause of erosion (either wind generated or boat wake) and rock fillet works without timber have been installed they have generally been very successful in both bank protection and mangrove recruitment. An exception is on the southern bank of Newry Island in the Kalang River estuary where the fillet height has either been constructed too low or subsidence has resulted in this effect. This reinforces that care is required in the construction of rock fillet works. Important considerations are ensuring the site has a suitable bench for construction that resists subsidence or settlement of the structure, that the finished level of the fillet crest equates to the Mean High Water Spring (MHWS) level (see *Figure 18*), and that some protection is provided on the bank face adjacent to the fillet opening that ensures wave erosion doesn't "funnel" into the bank at that location. Importantly, where deep water occurs adjacent to the eroding bank toe, rock fillets are difficult to construct and not usually cost effective and therefore are not an appropriate technique to use in this setting.

The erosion of peaty/mud deposits on intertidal benches is a key degradation process in many areas of the mid and lower estuaries including the Bellinger but particularly in the Kalang around Newry Island and Back Creek. Persistent wave wash (boat waves and wind waves) removes these muds resulting in stilting of the mangroves and eventual fall, even of mature mangroves. Uncontrolled grazing in some areas increases the impact. Regeneration of mangroves in areas where these processes are ongoing is significantly impeded. Natural recovery is generally inhibited in these areas without management intervention which includes improving management controls to address boat wake impacts but also stock management.

As has been noted in various previous assessments (e.g. Stockard et al., 1999; Taylor, 2017), in areas where bank erosion is caused by wave action (boat or wind) and an intertidal bench is available, an alternative and cheaper option to rock fillets which may be available depending on site condition is the use of cobble beaching or low rock revetments. These styles of works are less intrusive in the estuary, are a more commonly observed natural estuarine habitat type, do not impede bank to channel access in the same way as fillets, absorb rather than reflect wave energy, can suffer minor resettlement without losing structural integrity, can be repaired easily, and encourage both oyster and mangrove colonisation within the structure.

An additional action to address the persistent erosion of intertidal benches, which has been observed to be very successful in other areas on the mid-north coast (including within the Hastings River and Manning River estuaries: Fruition Environmental, 2023), is the use of cobble beaching on the intertidal bench as a technique on its own or in combination with LWD, oyster shell, or rock. The cobble beaching is resists persistent wave attack whilst still retaining sufficient space within the cobbles and contact with the mud sediments to promote mangrove regeneration.

The Primary DST Recommendations (covered in the following section of this report) suggests hybrid style works approaches in ~12% of reaches where a structural erosion control method is recommended by the tool (*Table 13* but see qualifications on the tool's use in that section).

Lastly, in the upper Bellinger River and in the upper Kalang and on Newry Island, stock fencing and riparian vegetation management is recommended due to the widespread impacts of stock and the generally thin linear strip of riparian vegetation. The need for widespread revegetation and stock management is consistent with previous assessments (Lawson Treloar, 2003; Telfer and Cohen, 2010; JBP, 2022). Management efforts to enhance and enlarge existing areas of Good condition riparian vegetation should also be prioritised, particularly the exclusion of stock from intertidal benches to encourage mangrove recruitment.

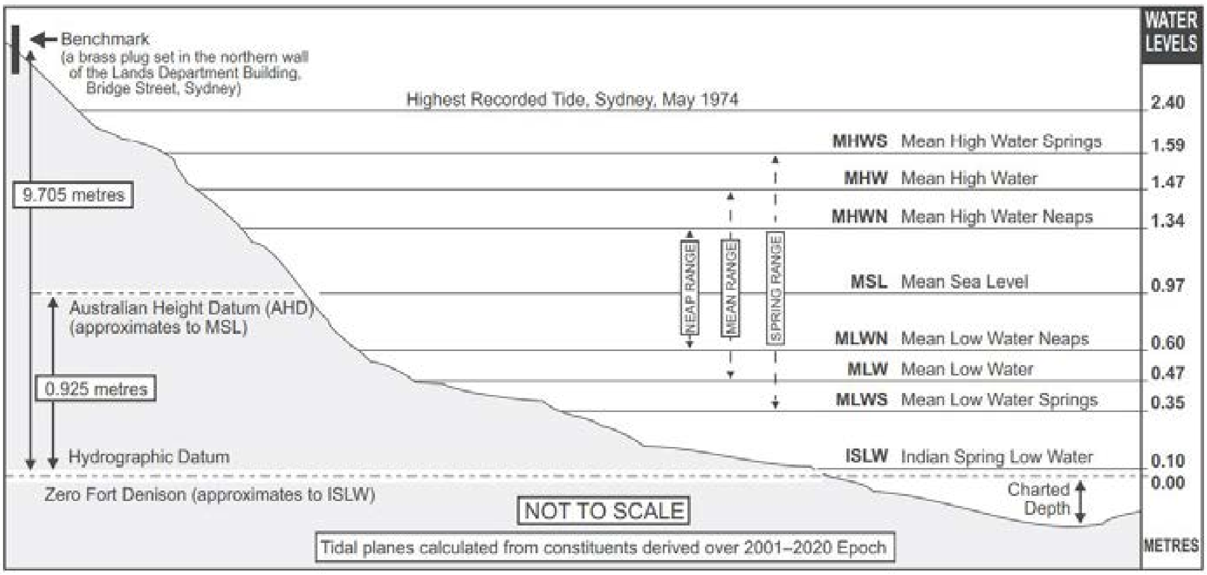

Figure 18 Tidal height definitions (Source: Manly Hydraulics Laboratory, NSW Tide Chart).

DST For Bank Erosion Management in NSW Estuaries – Summary of Recommendations

Method

The Decision Support Tool for Bank Erosion Management in NSW Estuaries (the "DST") is an excel-based tool developed by Hydrosphere Consulting for NSW Department of Primary Industries and Regional Development – Fisheries under the NSW Marine Estate Management Strategy. The tool is designed to contribute to the development of estuary bank management strategies which are consistent with best management practices.

The main output of the tool is the DST Recommendation. This recommendation is made up of the primary recommendation determined by the DST macros plus any additional recommendations related to riparian management, fencing, or other management actions (eg. boating controls). The primary recommendation may be a recommended treatment type where bank erosion and erosion impact thresholds are exceeded or may be a recommendation to undertake maintenance on existing controls. Shortlisted treatment types are also provided.

The method by which the DST determines bank erosion treatments and riparian/estuary management actions are detailed in the DST's supporting documentation (see Hydrosphere, 2020 and 2020b). It is important to review these documents before using the DST outputs as they provide important context and explanatory notes on the outputs. As examples:

- Fencing will be recommended where stock access or public access is identified as contributing to erosion in a specific reach.
- Riparian vegetation management will be recommended where the average width of riparian vegetation in a surveyed reach is less than 10 m, or where the vegetation is patchy (ie. "continuity" is negligible or low), unless there is a landward constraint such as a road or other infrastructure that would prevent improvement.
- Other management controls are recommended where vessel wave wash is identified as a contributing factor or public access is a consideration.

It is explicitly acknowledged in the DST documentation that social and economic impacts of the recommendations have not been considered at this stage and that consultation with relevant stakeholders would be required before implementation.

Importantly also, the primary recommendation and shortlisted options provided by the DST are based on the data collected during the field survey which due to the scale of assessment are not necessarily of the detail that would normally be required for developing site specific remediation recommendations. As such there may be reasons why the DST recommendation may not be the most suitable option for the bank segment and these reasons may not be captured by the input data. Hydrosphere, in its documentation on the tool explicitly states that "*It is crucial that the DST recommendations are further investigated…to assess whether they are indeed applicable or if other techniques could be more suitable*" (Hydrosphere, 2020, p.18).

Overview of Results

Figures 19 and *20* show the distribution of DST Primary Works Recommendations within the Bellinger-Kalang River estuary study area. The DST primary recommendation is either a main works type or a recommendation to maintain the existing controls present where appropriate. In some instances where options score equally, the DST has recommended multiple options as a primary recommendation. As bank protection works are typically recommended as a combination of different treatment types, this outcome of the primary recommendation is useful in considering the value of different options or combinations of control types. A summary of the range of DST Recommendations made for the Bellinger-Kalang River estuary study area is included in *Table 13.*

As mentioned previously, the DST recommendations are made on the basis of the field data in accordance with the tool's macros and are designed to give a first cut assessment of best practice works types suitable for the estuary location and the processes and impacts recorded during the field survey. Some of the primary recommendations of the DST will not be suitable for that location. Large Woody Debris works have been overwhelmingly recommended at 65% of eroding banks. Reviewing these sites, some are evidently unsuitable for such control types, such as where a deep water profile is eroding and outside bank. While rock armouring accounts for over half of current works, including recently constructed works, the DST has recommended this control type in >5% of recommended works.

It should be noted that the fact that a surveyed reach attracts a recommendation for works or maintenance within the DST does not infer that the reach is a priority for management action. This is because the DST does not include any consideration of overall objectives for estuary management beyond bank erosion control using best practice[3]. However, where a reach is separately assessed to be a priority for intervention, the DST provides a reasonably objective and standardised approach to determining which treatment options should be first considered.

It should be noted that the DST Final recommendation may also include management actions such as fencing, riparian vegetation management or other management controls. The complete NEAP Bellinger-Kalang River Estuary Condition Survey dataset should be reviewed to understand Final DST Recommendations within the study area.

Table 13 Summary of primary recommendations from the DPIRD Fisheries Decision Support Tool for Bank Erosion Management in NSW for the Bellinger and Kalang River estuaries.

Control Type	Total length of works recommended (m)	% of total surveyed bank
Large Woody Debris works	11,504	9.99
Maintenance on existing control	4841	4.20
Large Woody Debris / Rock Fillets	914	0.79
Rock Revetment	589	0.51
Cobble Beaching	555	0.48
Rock Fillets	547	0.48
Large Woody Debris / Rock Fillets / Oyster Reef	288	0.25
Oyster Reef	255	0.22
Rock Revetment / Geotextile Sandbag installation	115	0.10
Large Woody Debris / Cobble Beaching	18	0.02
Total	**19,626**	**17.0**
No recommendation	**95,500**	**83.0**

[3] The prioritisation of reaches for management intervention is covered separately in Part 5 of this assessment report.

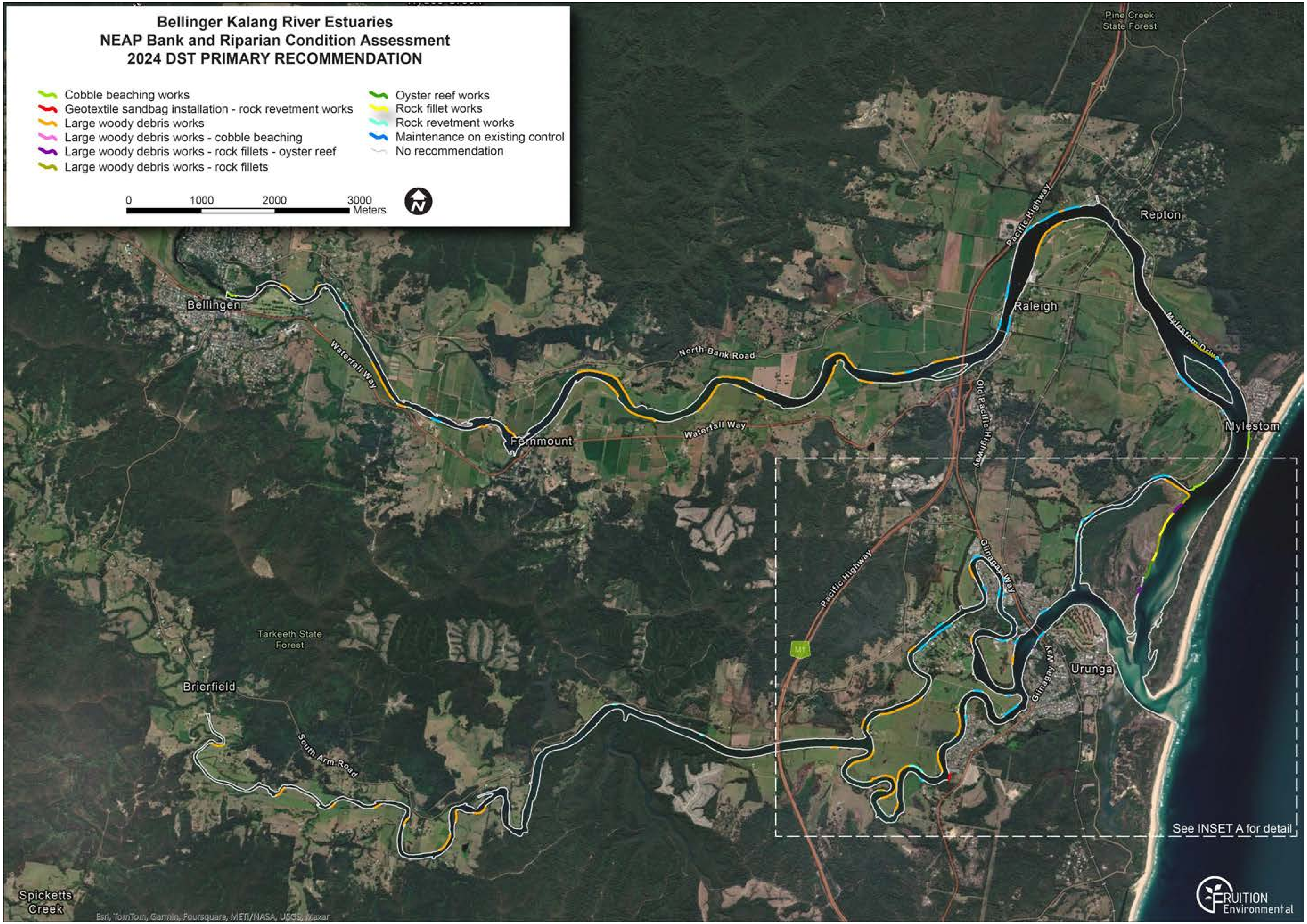

Figure 19 Primary DST Recommendations across the Bellinger and Kalang River Estuary Study Area

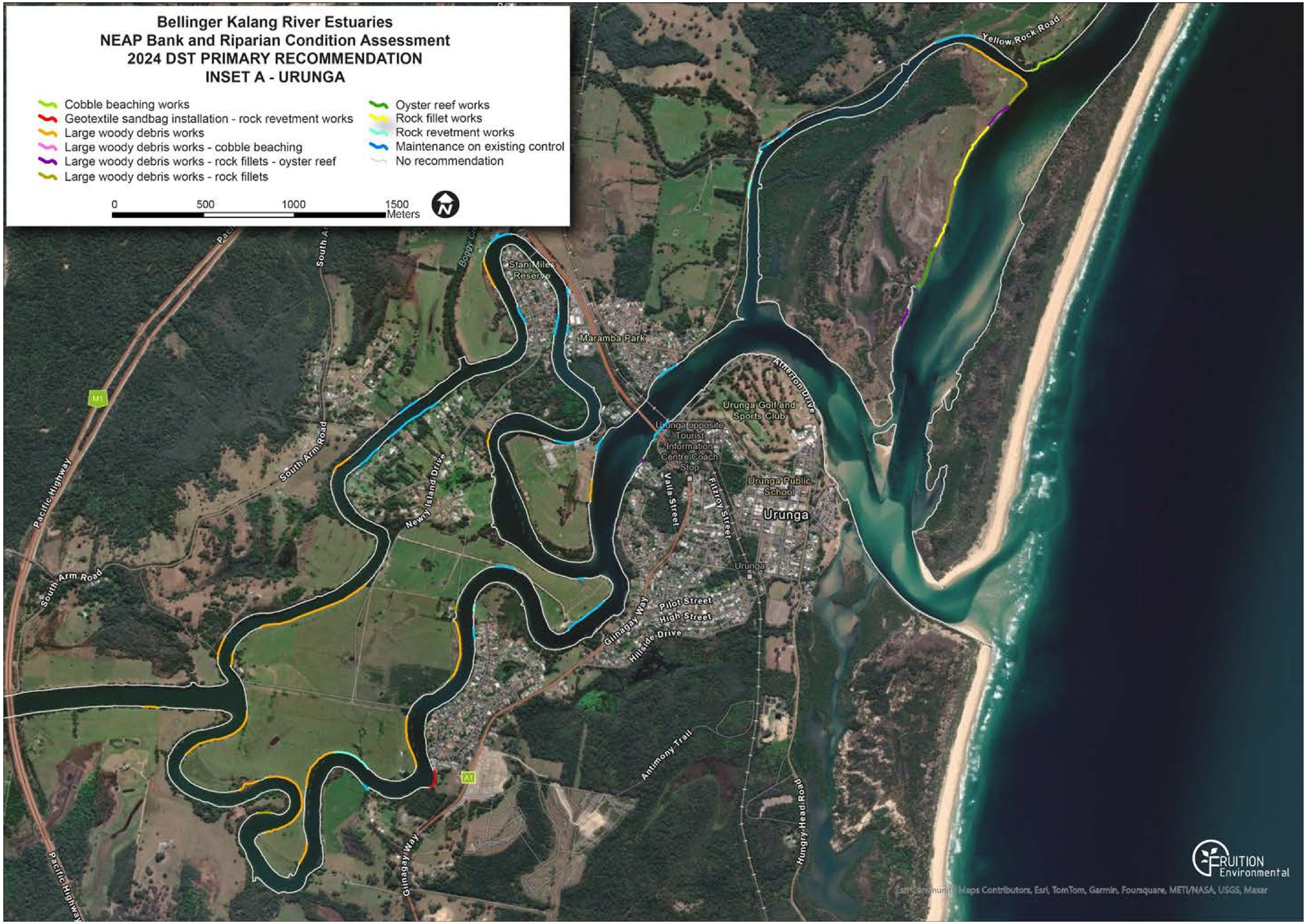

Figure 20 Primary DST Recommendations across the Bellinger and Kalang River Estuary Study Area

PART 4 – Erosion Rates in the Bellinger-Kalang Estuary

Bank erosion along the estuary contributes large volumes of sediments to the estuary (Owens, 2020; Rangel-Buitrago et al., 2023). Increased sediment loads in estuarine zones significantly impacts both geomorphological structures and ecological dynamics. The effects of suspended sediments and bedload sediments are distinct, each altering estuarine ecosystems in unique ways (Wilber and Clarke, 2001; Birch and Hutson, 2009; Kjelland et al., 2015; Rangel-Buitrago et al., 2023). These impacts include:

- Smothering aquatic and benthic habitats (leading to the loss of seagrass and macroalgae for example).
- Disrupting metabolic, physiological, and behavioural characteristics of fish, resulting in higher levels of stress and mortality.
- Changing fish assemblages and benthic invertebrate communities.
- Reducing light penetration as a result of the increased turbidity associated with fine suspended particles.
- Increasing contaminant concentrations in the form of nutrients, pesticides, heavy metals and other chemicals often associated with fine sediment particles can accumulate in estuarine environments. Nutrients may be released into the water column under certain conditions resulting in eutrophication, while bioaccumulation of other contaminants may pose risks to higher trophic levels such as fish and birds.
- Reducing oxygen levels by promoting water column stratification.
- Impacting estuary-dependent industry productivity (eg. oyster farming) due to poor water quality and access to lease areas.
- Causing navigation issues and exacerbating erosion at some locations due to shoaling.

Recent research into sediment plumes in the Great Barrier Reef region indicate that clay and silt materials (<63 µm in diameter) eroded from the catchment and riverbanks predominantly remain suspended until flocculation on contact with relatively low levels of salinity (<0.1 psu) resulting in deposition on estuary margins as mud flats or in near shore and lagoon areas. These materials are prone to resuspension via wind induced bed turbulence causing ongoing turbidity issues and also contributing to the estuary nutrient load. Very fine particles (<20 µm) have been shown to remain suspended beyond the initial low salinity zone and are transported into oceanic environments where their eventual flocculation into large floc aggregates via algae contribute to a muddy depositional film which coat and smoother seagrass and other benthic marine organisms (Bainbridge, 2015).

Coarser sediment fractions cause a different suite of issues for estuary environments and users. Excess bedload sediments can alter channel morphology, causing shifts in estuarine hydrodynamics. These changes may reduce habitat complexity, such as intertidal flats and tidal creeks, which are essential for a diverse array of species, including juvenile fish and migratory birds. Redistribution of coarse sediments during floods or dredging activities can bury estuarine habitats, particularly those supporting filter feeders such as mussels and oysters. Burial disrupts ecosystem services such as water filtration and nutrient cycling. Increased bedload delivery may exacerbate estuarine infill. This geomorphological shift diminishes aquatic habitats, impacting species reliant on estuarine connectivity. High bedload transport can lead to scouring of soft sediment habitats, destabilising important benthic communities and reducing the availability of organic-rich sediment layers crucial for nutrient cycling and carbon storage.

The combined effects of suspended and bedload sediment pollution intensify as these processes interact. Elevated sediment loads disrupt the balance between sediment deposition and resuspension, amplifying erosion of intertidal zones and diminishing the resilience of ecosystems to natural disturbances, such as storms or sea-level rise. For Australian estuaries, many of which are already under pressure from urbanisation and agricultural activities, these impacts pose significant threats to biodiversity, fisheries productivity, and cultural values.

The sections of this report below attempt to quantify the volumes of sediment being released into the estuary environment by contemporary bank erosion. Additionally, the analyses have been used to determine which sites were contributing the most sediment to the estuary per annum, and which sites were contributing the most in terms of bedload (fine sands and gravels) and suspended load (silts and clays).

Volumetric Analyses of Estuary Bank Erosion

In order to determine the annual rates of erosion in the estuary, 15 sites were analysed to quantify the gross volume of erosion for the period 2009 to 2024 (ie. over the last 15 years).

Sites were selected on the basis of the 2024 field survey of bank condition, with sites selected from the pool of 58 sites mapped as either having high or severe erosion within the Bellinger and Kalang River estuary study area. The sites selected were all from the mid to upper Bellinger River, upper Kalang River, Newry Island and Urunga Island (*Figure 21*).

Digital elevation models (DEMs) have been generated for each data acquisition period from LiDAR datasets. The primary datasets used for the volumetric assessment of erosion were:

- 2009 1 m lidar-derived DEM collected for NSW Spatial Services in December 2009, vertically adjusted to the 2024 surveyed controlled LiDAR data on a site-by-site basis.
- 2010 1 m lidar-derived DEM collected for NSW Spatial Services in February 2010, vertically adjusted to the 2024 surveyed controlled LiDAR data on a site-by-site basis
- 2024 0.5 m lidar-derived DEM lidar data collected by Fugro in September 2024 adjusted to ground control points collected by RTK survey prior to data capture and converted to a 1 m DEM to align with the latter datasets

Volumetric Assessment of Erosion 2009-2024

Repeat high-resolution elevation data, derived from lidar, are a valuable tool for detecting morphological changes in landscapes and for deriving sediment budgets at specific sites. This is achieved by assessing the volumes of erosion and deposition occurring between two surveys, using the above datasets. A DEM of Difference (DEMoD) approach was applied to quantify volumetric changes at 15 sites identified as having High or Extreme erosion severity within the Bellinger-Kalang estuary. The assessed sites, including soil sample locations, are shown in Figure 21.

Data Quality and adjustment

To ensure the reliability of the analysis, the DEMs were evaluated for alignment errors. Visual inspection and comparison of consistent fine-scale surface features in the 2009–2010 lidar-derived DEM and the higher-resolution 2024 DEM confirmed that no horizontal adjustments (x and y orientations) were necessary. However, vertical offsets were observed in the DEMoDs. These offsets were identified by analysing summary statistics of residual landscapes (areas where negligible changes were expected) within each survey area. A vertical shift (z adjustment) was subsequently applied to the earlier DEM to align it with the 2024 data, improving the precision of the volumetric calculations. *Table 14* summarizes the vertical offsets and corrections applied to each site.

Gross volumetric changes were calculated by subtracting the earlier DEM from the later DEM for each site. The resultant DEMoD values represent elevation changes between the two surveys, with positive values representing deposition/aggradation and negative values representing erosion. To account for analytical uncertainty and inherent noise in the data, a critical Limit of Detection (LoD) was applied to each DEMoD. This threshold ensures that only significant surface changes are measured, excluding changes within the uncertainty range.

The LoD was determined using a probabilistic error propagation method (Fuller et al., 2003; Brasington et al., 2003; Wheaton et al., 2010). DEM accuracy was validated by comparing elevations from the DEMs with elevations from 12 NSW survey marks located near the assessment sites. This yielded root mean square errors (RMSE) of 0.40 m and 0.21 m and standard deviations of error (SDE) of 0.13 m and 0.09 m for the 2009–2010 and 2024 DEMs, respectively. Using the SDE values as estimates of uncertainty and a 95% confidence interval ($t = 1.96$), a propagated error of 0.31 m in the DEMoD was calculated. This is equivalent to any change in the range of -0.31 to 0.31 m being within the limits of noise within the DEMoD. To ensure conservative and robust results, a higher LoD threshold of 0.4 m was adopted, discarding changes in elevation between -0.4 m and +0.4 m in the final sediment budget estimates.

It is also important to note that lidar data cannot capture changes beneath the water surface. Consequently, the volumetric estimates presented here do not account for subaqueous sediment loss (the portion eroded from the bank but below the estuary water surface level). Field surveys indicate that streambanks at several sites extend to depths greater than 1.5 m below the water surface, suggesting substantial unquantified sediment losses. Thus, the reported erosion and sediment loss volumes are conservative. Actual erosion volumes at each site may be considerably higher than the reported values.

Table 14 Adjustments made to the 2009 – 2010 LiDAR data to improve alignment against the 2024 ground survey-controlled LiDAR dataset

Site	Stream	Survey ID	Analysis period	Vertical adjustment (m)
B1a	Bellinger	211, 212	2009 - 2024	-0.08
B1b	Bellinger	209	2009 - 2024	-0.08
B2	Bellinger	192, 193	2009 - 2024	-0.08
B3	Bellinger	172	2009 - 2024	-0.08
B4	Bellinger	183	2009 - 2024	-0.08
B5	Bellinger	120	2009 - 2024	-0.08
B6	Bellinger	101	2009 - 2024	-0.08
U1a	Back Ck	292	2010 - 2024	nil
U1b	Bellinger	288	2010 - 2024	nil
U2	Bellinger	281, 282, 284, 286	2010 - 2024	nil
U3	Bellinger	270, 273, 277, 279	2010 - 2024	nil
K1	Kalang	621	2009 - 2024	-0.14
K2	Kalang	555	2009 - 2024	-0.14
K3	Kalang	424, 425, 428	2009 - 2024	-0.06
K4	Kalang	687	2009 - 2024	-0.06

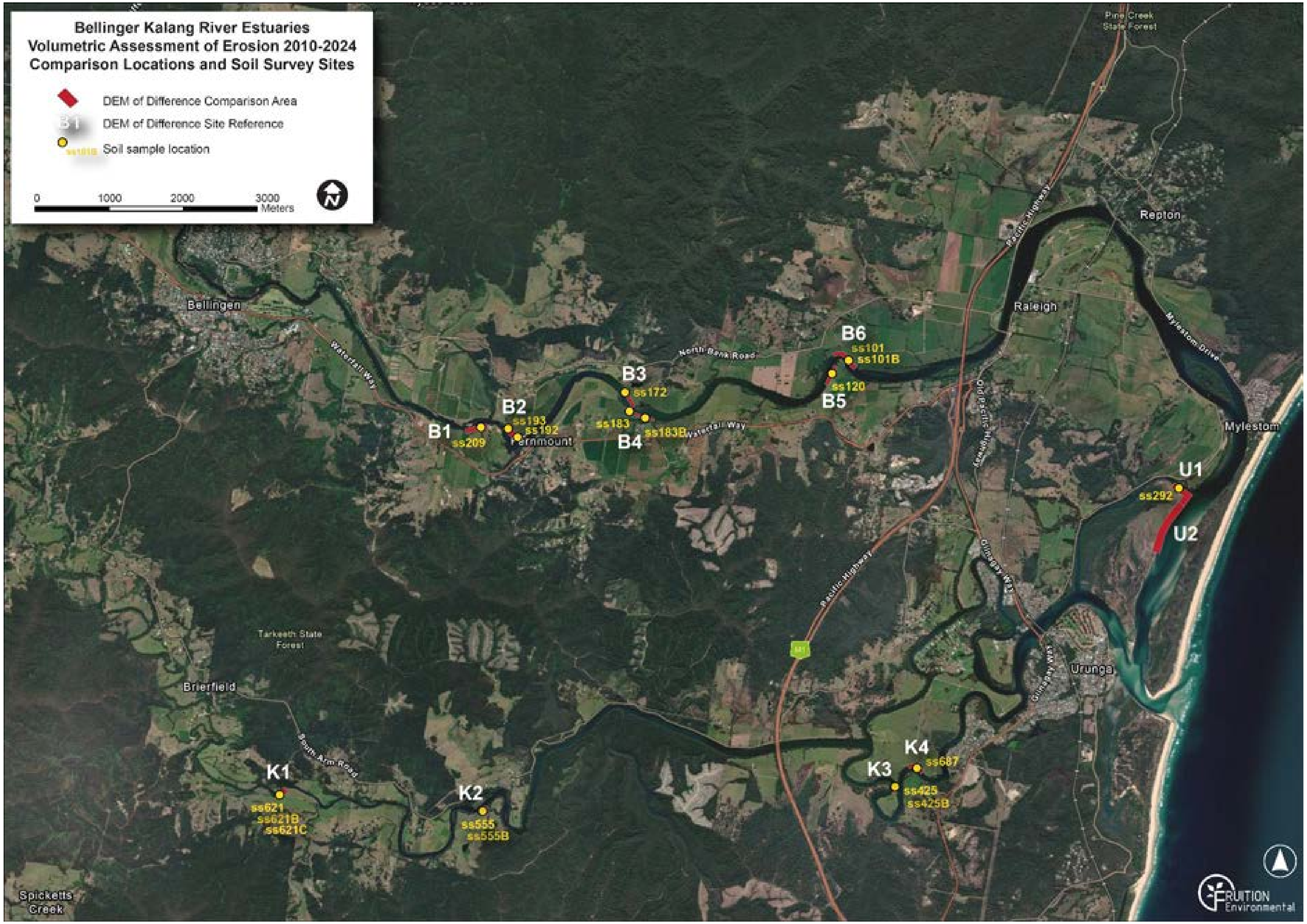

Figure 21 Sites of erosion identified through field assessment in 2024 which have been analysed to determine contemporary rates of erosion and contribution to fine sediment supply within the Bellinger and Kalang River estuary study area (2010-2024).

Although the primary focus of this assessment is erosion, the DEMoD approach quantifies net volumetric change as the balance of erosion and deposition within each site. Boundaries defining the analysis areas were established for each site, and changes within these areas were quantified. None of the sites exhibited deposition volumes exceeding the LoD threshold. Annualized volumetric changes were calculated by dividing total changes by the observation period (14–15 years), providing a crude estimate of average annual erosion rates. However, it is recognised that such changes are often episodic, driven by specific flow or flood events.

Volumetric changes

Erosion statistics, including both lateral erosion rates and volumetric estimates, are detailed in Table 15, with *Figures 22–25* providing illustrative examples of erosion volumes at selected sites. As discussed above, the presented erosion depths and volumes do not include the portion of eroded banks below the water surface and are inherently conservative estimates. The volumetric assessment shows that bank retreat rates across 15 analysis areas over the last 15 years (2009 – 2024) have been up to 2.2 m per year but on average 0.8 m per year (Table 15). Bank erosion across the sites exceeded 100,000 m^3 of sediment, or 7000 m^3 per year. Normalised to bank length, these volumes translate to an average of 22.2 m^3 of sediment per metre of eroding streambank over the 15 years.

The highest erosion volumes were found in the fluvial-dominated zones of the Bellinger River, with the highest rates observed at the most upstream analysed bends (*Figure 22*). Sites along Urunga Island in the marine tidal delta zone have also yielded a large volume of sediment to the estuary. While the normalised volume of sediment is lower at these sites compared with upstream, an extensive area of streambank is being impacted by this erosion process (*Figures 23–24*). Interestingly, while there are extensive lengths of High and Extreme erosion observed along Newry Island in the lower Kalang River, sites K3 and K4 both indicate lower erosion rates than other sites, with mean retreat rates of 0.1 – 0.2 m per year and annual volumes <75 m^3 per year (*Figure 25*).

Five sites selected for analysis overlap with the sites identified in the Estuary Erosion Study (Telfer and Cohen, 2010) and provide opportunity to compare the recent period (2009 – 2024) with long-term erosion rates (*Table 16*). Four sites are in the mid estuary of the Bellinger River and one site in the upper Kalang estuary. While erosion volumes have not previously been assessed for the Bellinger or Kalang rivers, the rates of bank retreat reported here are comparable with historical rates derived from photogrammetry analysis in the 2010 study.

Erosion rates are within the ranges of previously reported estimates of retreat, but generally show a minor increase in both the mean and minimum rate across all sites. This increase may be somewhat expected given the recent 2009 – 2024 period has been a flood-dominated period, with several high magnitude flood events. The present rates exceed erosion rates observed from 1942 – 2002 (e.g. Sites B2 and B5), including previous flood-dominated periods, or are at least consistent with those rates (e.g. Site B6). However, the pattern of erosion does not demonstrate a clear acceleration in the recent period, with mixed observations of both the mean and maximum retreat (*Table 16)*. For example, the maximum rate at Site B1 (2.1 m/yr) is lower than occurred in 2002 – 2009 (3.4 m/yr), although a significant increase in the average from 0.8 m – 1.7 m/yr may indicate a change in the erosion dynamics of the site, with a larger extent of the site eroding more significantly. However, while there is some uncertainty in these results, it is clear at all sites that the rates of erosion are not slowing. This is consistent with the comparison of the 2009 and 2024 surveys that demonstrate increased degradation of the estuary, with persistence in sites of High or Extreme erosion severity.

Table 15 Summary statistics of erosion for sites within the Bellinger-Kalang estuary, 2009 -2024, including gross and annualised volumes of erosion.

Site	Survey ID	Average width of erosion (m)	Max width of erosion (m)	Mean retreat rate (m/yr)	Average depth (m)	Max depth (m)	Total eroded volume (m³)	Bank length normalised erosion volume (m³/m)	Annualised erosion rate (m³/yr)
B1a	211, 212	21.4	24.6	1.4	3.52	5.95	**14,624**	**75.4**	975
B1b	209	28.0	30.8	1.9	3.04	5.9	**11,543**	**105.9**	770
B2	192, 193	33.2	43.4	2.2	3.26	5.53	**27,319**	**108.4**	1821
B3	172	7.1	13.2	0.5	2.26	3.19	4,462	16.0	297
B4	183	6.4	11.5	0.4	2.21	3.9	**6,795**	14.2	453
B5	120	10.0	11.8	0.7	2.12	3.86	6,140	21.1	409
B6	101	5.8	11.6	0.4	2.21	3.8	5,094	12.9	340
U1a	292	3.2	4.1	0.2	1.16	1.82	957	3.7	68
U1b	288	10.6	16	0.8	1.18	1.84	2,013	12.5	144
U2	281, 282, 284, 286	16.1	22.9	1.2	1.11	2.57	**11,210**	18	801
U3	270, 273, 277, 279	11.2	17.7	0.8	0.86	1.73	**6,410**	10	458
K1	621	9.4	17.9	0.6	2.28	5.56	3,402	21.5	227
K2	555	7.6	13.9	0.5	1.98	3.63	1,829	15.0	122
K3	424, 425, 428	2.1	2.8	0.1	0.81	1.89	766	1.7	51
K4	687	4.5	6.6	0.3	1.11	1.96	1,120	5.0	75
Total	-	**11.7**	**43.4**	**0.8**	**1.94**	**5.95**	**103,682**	**22.2**	**7,010**

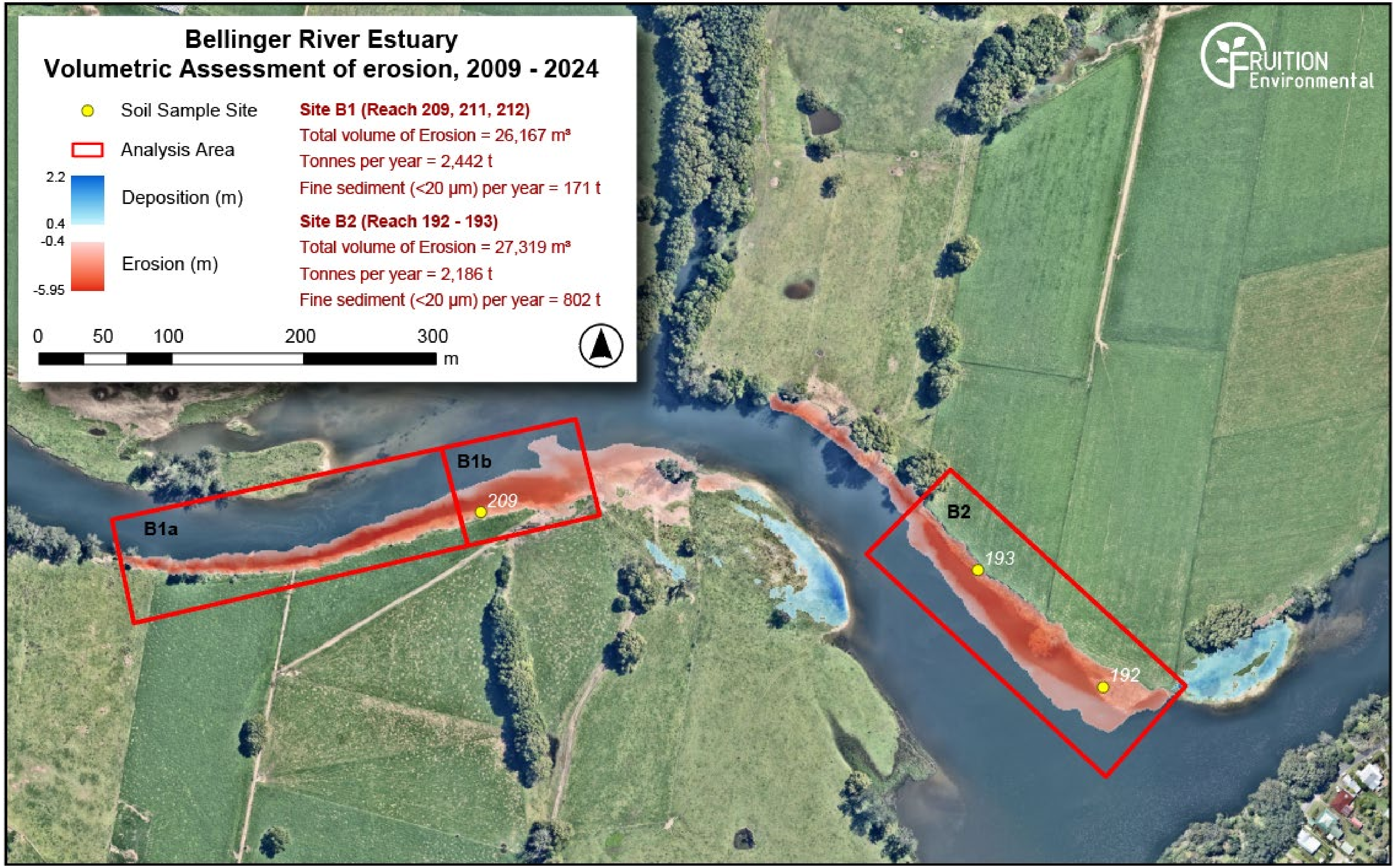

Figure 22 Erosion and deposition heatmap for Sites B1 and B2 in the upper estuary of the Bellinger River, based on lidar-derived DEM of Difference. Erosion rates and fine suspended sediment entrained into the estuary and marine environment also indicated.

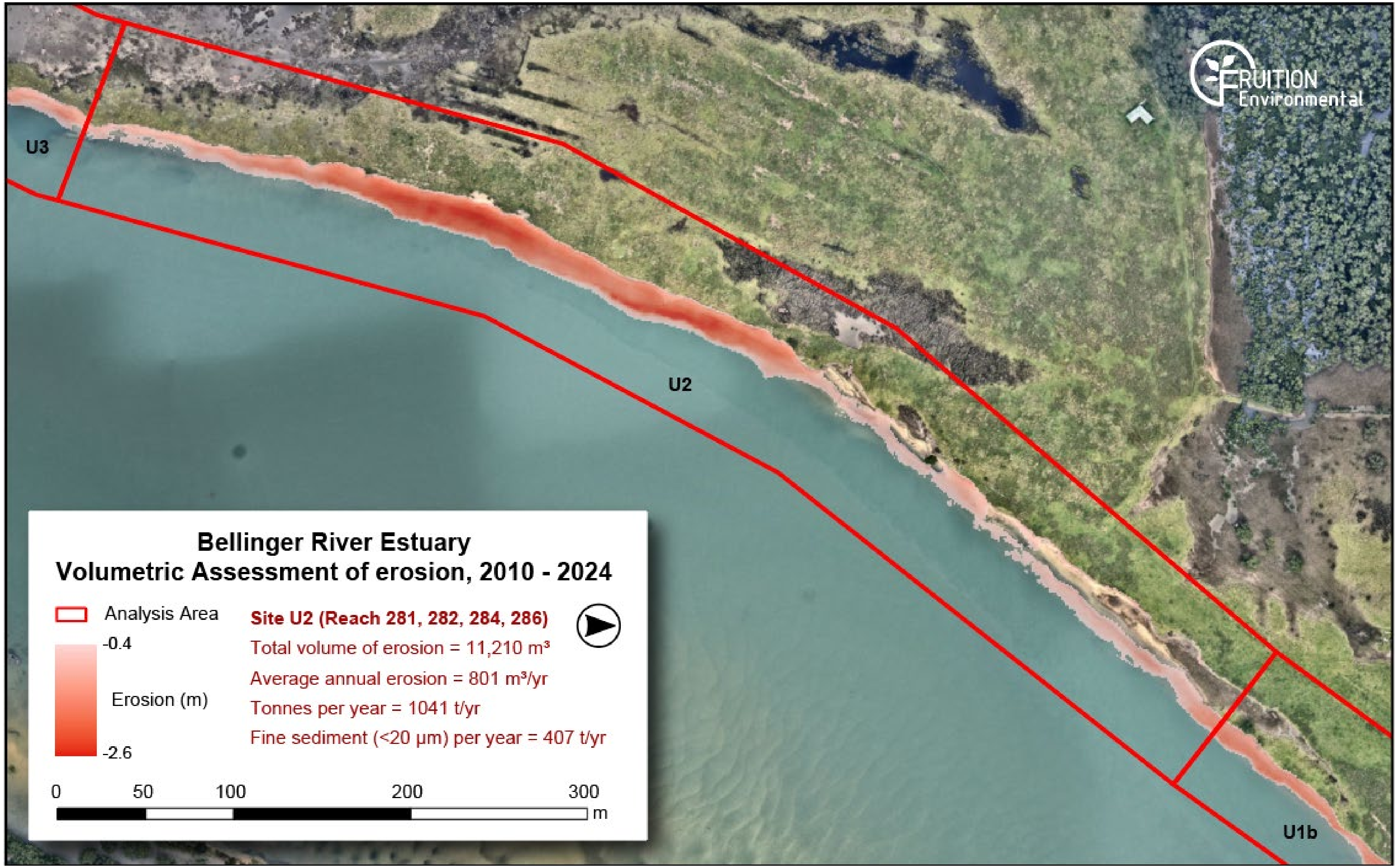

Figure 23 Erosion and deposition heatmap for Site U2 along Urunga Island on the Bellinger River, based on lidar-derived DEM of Difference. Erosion rates and fine suspended sediment entrained into the estuary and marine environment also indicated.

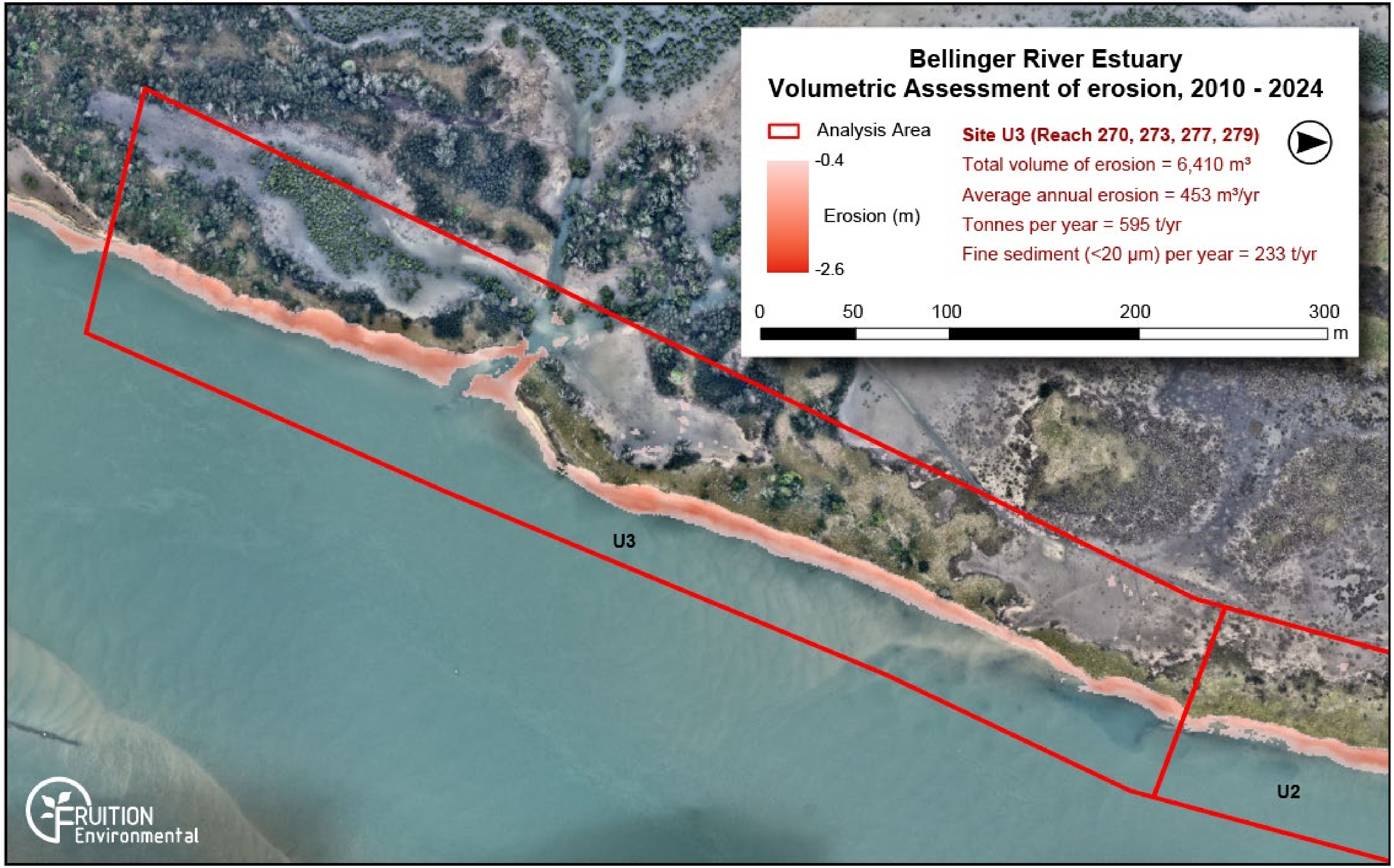

Figure 24 Erosion and deposition heatmap for Site U3 along Urunga Island on the Bellinger River, based on lidar-derived DEM of Difference. Erosion rates and fine suspended sediment entrained into the estuary and marine environment also indicated.

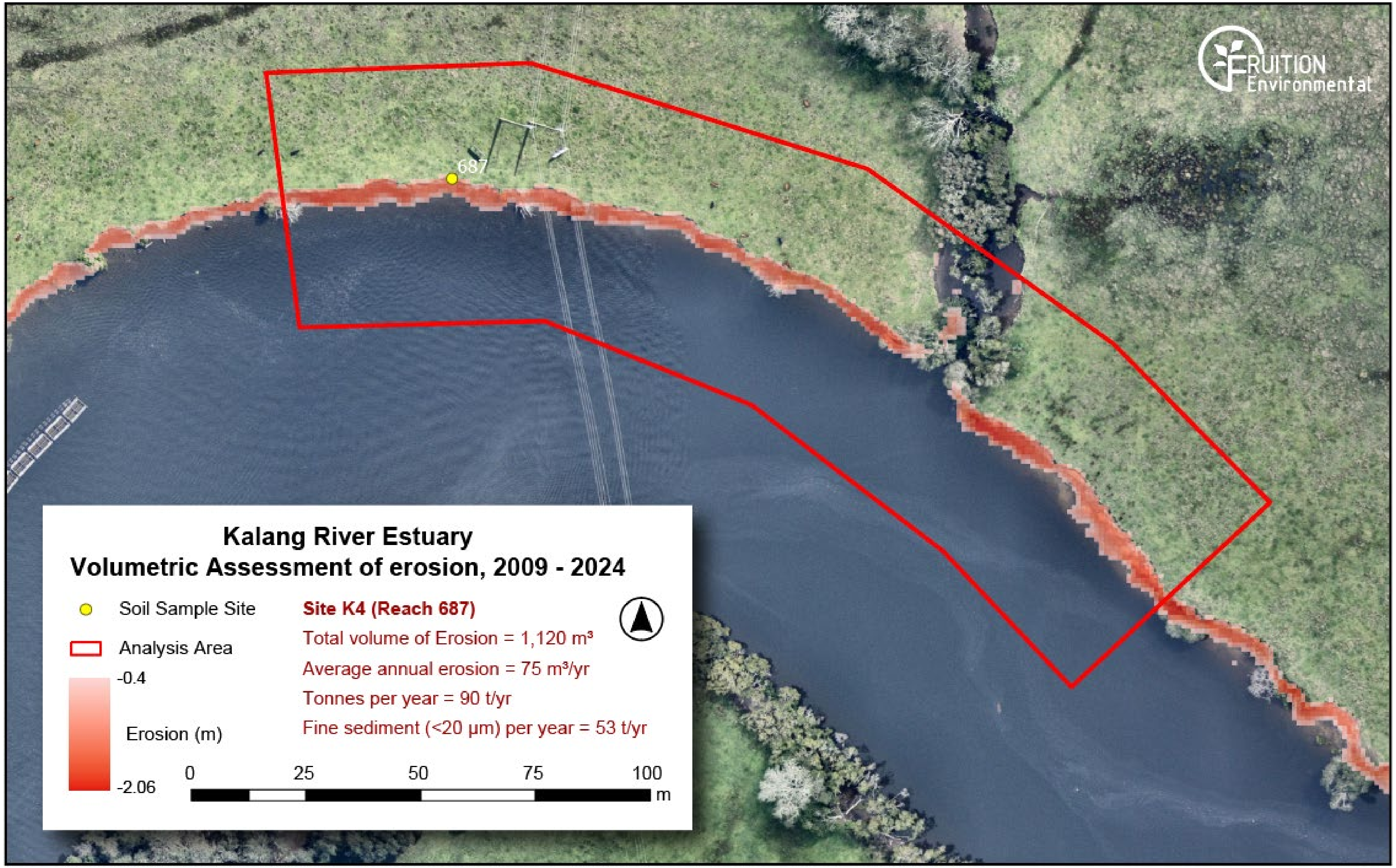

Figure 25 Erosion and deposition heatmap for K2 along Newry Island on the Kalang River, based on lidar-derived DEM of Difference. Erosion rates and fine suspended sediment entrained into the estuary and marine environment also indicated.

Suspended and Bedload Sediment Yields from Bank Erosion

Soil sample analyses were conducted to determine the proportions of fine sediment (suspended load, <20 µm) and bedload sediment (coarse silt, sands, and gravels) in the eroding banks assessed in the volumetric analyses. All soil samples were collected in August 2024 and analysed by EAL in Lismore, NSW, for bulk density and particle size distribution. The results of the particle size analyses are presented in *Table 18*. For this study, the fine sediment fraction comprising clay and fine silt particles <20 µm is classified as suspended load, while coarse silt, sand, and gravel are categorized as bedload. Sediment yield estimates for each site were derived by multiplying the annualized volume of erosion by a bulk density factor and the particle size fractions obtained from the soil sample analyses.

The results demonstrate considerable variability in soil characteristics across the estuary catchment. This variability underscores the importance of implementing a comprehensive sampling strategy to accurately assess sediment loss at individual sites. Bulk density ranged from 1.0 to 1.4 g/cm³, while the proportion of fine sediment varied from 7% in the Bellinger terrace to as high as 86% in the middle estuary. On average, fine sediment accounted for 39% of samples, with particularly high proportions (50–60%) observed in the mid-lower estuary, reflecting the long-term depositional characteristics of these zones. Some upstream sites also exhibited similar fine sediment proportions, whereas lower estuary samples occasionally showed lower fine sediment contents. Sampling at Urunga Island (Site 292) indicated 39% fine sediment and 48.5% fine sand, which may be influenced by its proximity to coastal barrier deposits. Fine sand, often including the coarse silt fraction (20–63 µm), was prevalent across most samples, especially in those with lower fine sediment content based on field texture assessments (*Table 18*). Coarse sand and gravel fractions were generally low across the samples.

Proportional quantities of fine and bedload sediment loss associated with bank erosion for each site are detailed in *Table 19*, where sites are ranked by fine sediment yield (tonnes per annum). The total sediment load exported from the 15 assessed sites over the survey period was 104,000 m³, equivalent to 133,000 tonnes. Suspended sediment yield comprised 39,000 tonnes, or 2,585 t/yr, while bedload sediment accounted for a substantially higher proportion at 94,000 tonnes, or 6,288 t/yr. Average total sediment loss per site was 5,583 tonnes, with fine sediment loss averaging 1,663 tonnes (113 t/yr) and ranging from 486 to 12,031 tonnes of fine sediment (35–802 t/yr).

When proportional sediment loads are considered, the sites contributing the highest fine sediment yields differ from those with the largest total erosion volumes. For instance, Site B1 (*Figure 22*) exhibited some of the highest erosion volumes, yet fine sediment loss at this site was relatively low due to the lower proportion of fine sediment in the bank material. This re-ranking of sites by fine sediment yield highlights the need to consider sediment composition alongside erosion volumes when evaluating sediment export dynamics.

Using observations from the above analyses, erosion volumes and sediment loads have been extrapolated to other areas of High or Extreme erosion, offering an indicative sediment budget for the Bellinger and Kalang River estuary. Normalised erosion rates, as shown in *Table 15*, were extrapolated based on landscape unit and bend position, and multiplied by the length of each reach, while sediment characteristics were inferred by proximity to soil sampling sites. Further, the subaqueous volume of the streambank has been approximated using the minimum erosion depth from field surveyed categories of *Average Water Depth*. This analysis is inherently limited by the simplifications in the underlying assumptions, which do not fully account for the complexities of erosion dynamics or sediment variability within the system. The analysis also does not account for low or moderate erosion. As such, the results represent a first-order approximation of major estuary sediment losses and should be interpreted as indicative rather than exhaustive.

Extrapolated erosion rates from severe erosion sites indicate that approximately 164,300 m³ of sediment, equivalent to 207,800 tonnes, has been eroded from the streambanks of the Bellinger and Kalang Rivers between 2009 and 2024 (*Table 17)*. This represents an average annual total loss of 13,900 t/yr and a fine sediment loss of 4,400 t/yr. Within the Bellinger River, 184,000 tonnes of sediment were eroded, compared to 23,700 tonnes in the Kalang River. Of this, 54,300 tonnes and 11,800 tonnes of fine sediment (sub 20µm) were lost from the Bellinger and Kalang Rivers, respectively. When accounting for the subaqueous portion of the banks, total sediment loss across the 15-year period could reach 239,000 m³, corresponding to an average annual loss of 6,600 t/yr of fine sediment across the estuary catchment (*Table 17*). In reality, cumulative sediment losses from Low and Moderate erosion areas across the estuaries could substantially increase the total sediment loads, suggesting that the actual figures may be considerably higher than those presented here.

Table 16 Bend migration rates (bank erosion rates) for the Bellinger and Kalang Rivers, 1942 – 2009 based on photogrammetry analysis (Source: Telfer and Cohen, 2010) and 2009 – 2024 based on lidar-derived volumetric analysis

Site Name		1942-1964		1964-1982		1982-2002		2002-2009		2009-2024	
		Flood-dominated		Flood-dominated		Drought-dominated		Drought-dominated		Flood-dominated	
This study	2010 study	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
n/a	B1	0.6 ± 0.2	0.7	0.8 ± 0.2	2.4	1.5 ± 0.4	4.1	NC	NC	n/a	n/a
n/a	B2	0.4 ± 0.2	0.8	0.6 ± 0.2	1.4	1.1 ± 0.1	2.5	NC	NC	n/a	n/a
n/a	B3	0.4 ± 0.1	0.7	0.8 ± 0.2	1.7	0.4 ± 0.1	0.7	1.3 ± 0.3	1.8	n/a	n/a
n/a	B4	0.7 ± 0.2	1.1	0.4 ± 0.1	1	0.3 ± 0.1	0.6	1 ± 0.2	2	n/a	n/a
Site B1	B5	0.9 ± 0.2	1.5	0.8 ± 0.2	1.8	0.7 ± 0.2	1.2	0.8 ± 0.3	3.4	1.7	2.1
Site B2	B6	1.4 ± 0.2	1.9	0.7 ± 0.2	1.5	0.6 ± 0.1	1	1.1 ± 0.3	2.8	2.2	2.9
Site B5	B7	0.5 ± 0.1	0.9	0.3 ± 0.1	0.5	0.3 ± 0.1	0.8	0.6 ± 0.2	1.5	0.7	0.8
Site B6	B8	0.4 ± 0.1	1	0.3 ± 0.1	0.5	0.3 ± 0.1	0.5	0.6 ± 0.2	0.9	0.4	0.8
Site K1	K1	0.2 ± 0.1	0.3	0.4 ± 0.2	0.6	0.3 ± 0.1	0.5	0.4 ± 0.2	0.7	0.6	1.2
n/a	K2	0.3 ± 0.1	0.4	0.5 ± 0.2	0.8	0.3 ± 0.1	0.5	NC	NC	n/a	n/a
n/a	K3	0.2 ± 0.1	0.8	0.2 ± 0.1	0.5	0.2 ± 0.1	0.3	0.7 ± 0.2	0.9	n/a	n/a
n/a	K4	0.2 ± 0.1	0.8	0.3 ± 0.1	0.6	0.2 ± 0.1	0.4	0.3 ± 0.2	0.5	n/a	n/a

Table 17 Indicative sediment losses for the Bellinger and Kalang River estuaries derived from High and Extreme erosion sites

	Volume (m³)	Sediment load (tonnes)			Annualised load (t/yr)	
		Total	Fines	Bedload	Fines	Bedload
Sub-aerial erosion						
Bellinger	146,796	184,113	54,300	129,813	3,620	8,654
Kalang	17,541	23,687	11,752	11,935	783	796
Total	164,337	207,800	66,052	141,748	4,403	9,450
Sub-aqueous erosion						
Bellinger	58,185	71,717	22,154	49,563	1,477	3,304
Kalang	16,425	22,265	11,292	10,973	753	732
Total	74,610	93,982	33,446	60,536	2,230	4,036
Combined total	**238,947**	**301,782**	**99,497**	**202,284**	**6,633**	**13,486**

Table 18 Results of soil sample analyses undertaken on eroded bank samples collected on the Bellinger-Kalang River estuary (Analyses by EAL, hydrometer and sieving techniques: see Figure 21 for soil sample and site locations).

Stream	Survey ID	Unit	Depth	Sample ID	Lab Code	Moisture content (%)	Bulk Density	Gravel (2.00-4.75 mm)	Coarse Sand (0.2-2.0 mm)	Fine Sand (0.02-0.2 mm)	Silt (2-20 µm)	Clay (< 2 µm)	Total Fines (<20 µm)	Av Bulk Density	Av Fines	Av bedload
Bellinger R	101	Upper bank	0.3 m	1, 2	R7456/1, R7456/2	13.90	1.4	0.03%	32.4%	43.1%	13.0%	11.4%	24.4%			
Bellinger R	101B	Lower bank	0.8 m	3, 4	R7456/3, R7456/4	29.32	1.0	-	0.18%	13.7%	58.4%	27.7%	86.1%	1.2	79.6%	20.4%
Bellinger R	120		1 m	5, 6	R7456/5, R7456/6	11.60	1.2	0.05%	52.5%	30.5%	8.4%	8.5%	17.0%			
Bellinger R	172		1.5 m	7, 8	R7456/7, R7456/8	13.72	1.3	-	52.5%	35.6%	5.0%	6.9%	11.9%			
Bellinger R	183	High bank	0.8 m	9, 10	R7456/9, R7456/10	14.18	1.3	-	6.6%	63.4%	16.1%	13.9%	30.0%			
Bellinger R	183B	Bench	0.5 m	11, 12	R7456/11, R7456/12	21.35	1.1	0.12%	15.4%	54.5%	15.9%	14.1%	30.0%	1.2	30.0%	70.0%
Bellinger R	192	Lower bank	1.8 m	13, 14	R7456/13, R7456/14	29.11	1.0	-	1.7%	54.2%	22.9%	21.2%	44.1%			
Bellinger R	193	Upper bank	0.2m	15, 16	R7456/15, R7456/16	17.31	1.4	-	21.2%	49.4%	14.1%	15.2%	29.4%	1.2	36.7%	63.3%
Bellinger R	209	Terrace	3.5 m	17, 18	R7456/17, R7456/18	7.80	1.4	0.04%	77.3%	15.6%	2.5%	4.5%	7.0%			
Back Ck	292		0.6 m	19, 20	R7456/19, R7456/20	24.64	1.3	1.50%	10.9%	48.5%	21.3%	17.8%	39.1%			
Kalang R	425	Upper bank	1 m	21, 22	R7456/21, R7456/22	21.37	1.7	-	0.37%	41.9%	36.2%	21.5%	57.7%			
Kalang R	425B	Lower bank	1.8 m	23, 24	R7456/23, R7456/24	25.49	1.2	0.11%	1.3%	52.1%	29.1%	17.5%	46.5%	1.5	52.1%	47.9%
Kalang R	555	Upper bank	0.4 m	25, 26	R7456/25, R7456/26	24.98	1.4	-	0.04%	38.0%	39.1%	22.8%	61.9%			
Kalang R	555B	Lower bank	1 m	27, 28	R7456/27, R7456/28	21.67	1.4	0.03%	0.03%	44.3%	33.5%	22.1%	55.6%	1.4	58.8%	41.2%
Kalang R	621	Upper bank	0.3 m	29, 30	R7456/29, R7456/30	19.00	1.2	-	0.57%	49.3%	29.4%	20.7%	50.2%			
Kalang R	621B	Mid Bank	0.8 m	31, 32	R7456/31, R7456/32	20.39	1.5	0.83%	1.0%	64.4%	22.8%	11.0%	33.8%			
Kalang R	621C	Lower bank	1.2 m	33, 34	R7456/33, R7456/34	19.90	1.2	0.22%	7.0%	70.7%	12.7%	9.4%	22.0%	1.3	35.3%	64.7%
Kalang R	687		0.8 m	35, 36	R7456/36, R7456/35	26.56	1.2	0.15%	0.91%	40.2%	35.8%	23.0%	58.8%			

Table 19 Summary of sediment loads for erosion sites within the Bellinger-Kalang estuary, 2009 -2024. Fine sediment fraction includes <20µm particles (clay and fine silt), bedload fraction includes particles 20 – 4750 µm (coarse silt, sand, gravel). See Figure 21 for site locations.

Site	Survey ID	Total eroded volume (m^3)	Bulk Density	Sediment proportion (%)		Sediment load (t)			Annualised load (t/yr)	
				Fines (<20 µm)	Bedload (>20 µm)	Total	Fines	Bedload	Fines	Bedload
B2	192, 193	**27,319**	1.2	36.7%	63.3%	32783	12031	20752	**802**	**1383**
U2	281, 282, 284, 286	**11,210**	1.3	39.1%	60.9%	14573	5698	8875	**407**	**634**
B6	101	5,094	1.2	79.6%	20.4%	6112	4865	1247	**324**	**83**
U3	270, 273, 277, 279	6,410	1.3	39.1%	60.9%	8333	3258	5075	**233**	**362**
B4	183	**6,795**	1.2	30.0%	70.0%	8154	2446	5707	**163**	**380**
K1	621	3,402	1.3	35.3%	64.7%	4422	1561	2861	**104**	**191**
K2	555	1,829	1.4	58.8%	41.2%	2560	1505	1055	**100**	**70**
B1a	211, 212	**14,624**	1.4	7.0%	93.0%	20474	1433	19041	**96**	**1269**
B5	120	6140	1.2	17.0%	83.0%	7367	1252	6115	**83**	**408**
B1b	209	**11,543**	1.4	7.0%	93.0%	16160	1131	15028	**75**	**1002**
U1b	288	2013	1.3	39.1%	60.9%	2617	1023	1593	**73**	**114**
K4	687	1120	1.2	58.8%	41.2%	1344	790	554	**53**	**37**
B3	172	4462	1.3	11.9%	88.1%	5801	690	5111	**46**	**341**
K3	424, 425, 428	766	1.5	52.1%	47.9%	1149	599	551	**40**	**37**
U1a	292	957	1.3	39.1%	60.9%	1244	486	757	**35**	**54**
Total	-	**103,682**	**1.3**	**36.7%**	**63.3%**	**133093**	**38771**	**94322**	**2585**	**6288**

PART 5 – Priorities for Action and Investment

This part of the bank and riparian condition assessment report outlines a priority system designed to identify and rank priority reaches for management, remediation, protection and investment. The multicriteria analyses used to determine the priority reaches draws the criteria from the objectives of a number of foundational documents relevant the management of the estuary. These include the NSW Coastal Management Act 2016, the Marine Estate Management Strategy 2018-2028, the Coastal Crown Lands Guidelines 2023, the existing Bellingen Draft CMP (Salients, 2024), the Bellinger Kalang WQMP (JPB, 2022), and to a lesser extent the Bellingen Shire Biodiversity Strategy 2020 (Ecological Australia, 2019).

The Management Context

Coastal Management Act No 20 2016 (NSW)

The *Coastal Management Act 2016 No 20* NSW (CMA 2016) identifies the management objectives for coastal management areas in New South Wales. The objects of the CMA 2016 include (s3):

> *to manage the coastal environment of New South Wales in a manner consistent with the principles of ecologically sustainable development for the social, cultural and economic well-being of the people of the State*, and of particular relevance to this assessment:
>
> *(a) to protect and enhance natural coastal processes and coastal environmental values including natural character, scenic value, biological diversity and ecosystem integrity and resilience, and*
>
> *(b) to support the social and cultural values of the coastal zone and maintain public access, amenity, use and safety, and*
>
> *(c) to acknowledge Aboriginal peoples' spiritual, social, customary and economic use of the coastal zone, and*
>
> *(d) to recognise the coastal zone as a vital economic zone and to support sustainable coastal economies, and*
>
> *(f) to mitigate current and future risks from coastal hazards, taking into account the effects of climate change, and*
>
> *(h) to promote integrated and co-ordinated coastal planning, management and reporting, and*
>
> *(i) to encourage and promote plans and strategies to improve the resilience of coastal assets to the impacts of an uncertain climate future including impacts of extreme storm events, and*
>
> *(m) to support the objects of the Marine Estate Management Act 2014.*

The CMA 2016 breaks the coastal zone into management areas with identified management objectives. Under Part 2 Section 8 the management areas include *wetlands and littoral rainforest areas* and *coastal environment areas*. These areas are defined within the State Environmental Planning Policy (Resilience and Hazards) 2021 (SEPP(R&H) 2021) and associated mapping (SEPP(R&H) 2021, s2.4). Coastal environment areas are defined in the CMA 2016 as the coastal waters of the State, estuaries, coastal lakes, coastal lagoons and land adjoining those features, including headlands and rock platforms. Wetlands and littoral rainforest areas are defined as land which displays the hydrological and floristic characteristics of coastal wetlands or littoral rainforests and land adjoining those features.

The entire area of this assessment constitutes *coastal environment area*, however only a small proportion of the assessment area constitutes *wetland and littoral rainforest* areas. The CMA 2016 proscribes a hierarchy that operates where a parcel of land is mapped as more than one management area (s10(3)). In the context of this assessment that hierarchy operates to ensure that the management objectives for the wetland and littoral rainforest areas are given priority over the management objectives for coastal environment areas wherever an inconsistency arises. The management objectives for the two management areas are generally consistent. However, one practical outcome of this hierarchy is that in areas of the Bellinger and Kalang River estuary areas where wetlands or littoral rainforests occur, management efforts should include promoting the rehabilitation and restoration of degraded wetlands and littoral rainforests (CMA 2016 s6(b)).

In all other areas assessed in this study, the management objectives for *coastal environment areas* can be reasonably adopted and include (CMA 2016 s8(2)):

(a) to protect and enhance the coastal environmental values and natural processes of coastal waters, estuaries, coastal lakes and coastal lagoons, and enhance natural character, scenic value, biological diversity and ecosystem integrity,
(b) to reduce threats to and improve the resilience of coastal waters, estuaries, coastal lakes and coastal lagoons, including in response to climate change,
(c) to maintain and improve water quality and estuary health,
(d) to support the social and cultural values of coastal waters, estuaries, coastal lakes and coastal lagoons,
(e) to maintain the presence of beaches, dunes and the natural features of foreshores, taking into account the beach system operating at the relevant place,
(f) to maintain and, where practicable, improve public access, amenity and use of beaches, foreshores, headlands and rock platforms.

NSW Marine Estate Management Strategy 2018-2028

In terms of the State-wide perspective, the NSW Marine Estate Management Strategy 2018-2028 identifies a number of Management Initiatives relevant to this assessment including:

- Under *Management Action 1.3*: Facilitate and deliver on-ground activities that reduce diffuse source water pollution through investigation and provision of funding programs and financial incentives.
- Under *Management Action 2.3*: Develop marine vegetation management plans that maximise resilience…address key threats…facilitate rehabilitation opportunities. Also, to investigate estuary-wide bank protection options to inform the assessment of bank protection work proposals and facilitate rehabilitation opportunities.
- Under *Management Initiative 3*: Note that on-ground activities and habitat protection and rehabilitation that will help mitigate the impacts of climate change are to occur via actions under Initiative 1 and 2 and will include rehabilitating coastal wetlands, revegetating riparian areas, and protecting river banks.

Coastal Crown Lands Guidelines 2023

The Coastal Crown Lands Guidelines were released by the NSW Department of Planning and Environment in October 2023. The Guidelines apply generally to the administration of Crown land where that land occurs within the “coastal zone” within the meaning of section 5 of the Coastal Management Act 2016. This includes lands mapped under the SEPP (Resilience and Hazards) 2021 as coastal wetlands and littoral rainforest area, coastal vulnerability area, coastal environment area, and/or coastal use area.

The Guidelines focus on aligning decisions made under the Crown Land Management Act with the objects and principles of the Coastal Management Act and promote the integration of Crown land management with CMPs.

Of particular relevance to this report and its future use, where the preparation of a CMP is envisaged and actions stemming from this report are proposed to occur upon Crown Lands, it is a requirement that those actions are referred to Crown Lands before the CMP is adopted. If this process is followed and the CMP is then certified, then applications for dealings or authorisations under the Crown Land Management Act will be streamlined.

Bellingen DRAFT CMP, 2024

The Bellingen Draft Coastal Management Program has broadly general management principles for the Bellinger and Kalang estuaries but identifies several specific actions that relate to estuary bank erosion and riparian management. These have been summarised in the literature review above and include:

- **Action E1-E2** relate to prioritising protection and management works in Coastal Wetlands and Littoral Rainforest
- **Action E5:** Protect and enhance ecological values at Urunga Island, Yellow Rock Road (Back Creek) and along the Kalang River
- **Action U1:** Foreshore stabilisation and recreational facilities at Mylestom Foreshore Reserve

Bellinger-Kalang WQMP, 2022

The WQMP provides a number of goals and actions relevant to the prioritisation of actions to improve water quality, bank stability, riparian vegetation, and estuarine health in the Bellinger-Kalang River estuary study area. These strategies have been briefly outlined in the literature review section of this report. The WQMP identified sites recommended from previous reports where high priority on-ground works actions such as bank stabilisation works, targeted revegetation, and maintenance of existing protection works. The recommended strategies include:

Goal 3: Increase biodiversity and ecosystem services

- **BIO1:** Managing grazing/stock exclusion on riparian land
- **BIO2:** Reinstatement and reforestation of riparian buffers
- **BIO4:** Protect and restore areas of intertidal saltmarsh, lagoons, and mangroves on Council managed land

Goal 4: Mitigate erosion and improve bank stability

- **ERO1:** Site-specific erosion investigations
- **ERO2:** Advocate and educate for private land restoration and erosion protection works
- **ERO3:** Bank stabilisation and revegetation works on Council managed land
- **ERO4:** Minimise impacts of boating

Bellingen Shire Biodiversity Strategy, 2020

The Bellingen Shire Biodiversity Strategy contains a number of key focus areas, programs and actions to protect and improve bank stability, riparian vegetation and estuarine health in the Bellinger and Kalang estuaries. These are briefly outlined in the literature review of this report and include:

- **Program 2.1:** Endeavour to protect 100% of native vegetation (Threatened Ecological Communities; TECs) in Council Reserves
- **Program 2.2:** Improve vegetation within core habitat areas that are considered to have opportunities for connectivity
- **Program 2.3:** Retain the maximum amount of native vegetation (TECs, habitats and corridors) across development, infrastructure and high impact landuse zones
- **Program 2.5:** Maintain and improve the condition of vegetation in Council reserves
- **Program 3.1**: Measurable improvement in water quality across Bellingen waterways
- **Program 3.2** Protect foreshores, coastal lagoons, significant wetlands and Coastal Saltmarsh
- **Program 3.3:** Restore the ecological function of core habitat, waterways and wetlands
    - Key Fish Habitat
    - Saltmarsh, lagoons, coastal foreshore and mangrove
- **Program 6.3**: Ensure weed density is managed in core habitat areas to ensure protection of significant areas in Council reserves
- **Program 6.5:** Increase support of Landcare groups and community programs that educate about biodiversity

Priorities for Intervention

The priorities for intervention outlined below reflect the management objectives in the *Coastal Management Act 2016*, the management initiatives under the MEMS 2018-2028, the bank and riparian management strategies identified in the Bellinger Shire Draft CMP (Salients, 2024), the Bellinger-Kalang WQMP (JBP, 2022), and the estuary related objectives of the Bellingen Shire Biodiversity Strategy (Eco Logical Australia 2019).

Priority reaches and priority focus areas

As part of the Bellinger-Kalang River Estuary NEAP Bank Condition and Riparian Condition Assessment, a draft list of priority reaches for protection, enhancement and/or remedial intervention is to be produced.

In this context, an estuary "reach" refers to an individually mapped segment of bank which have been assessed during the field survey as being relatively homogenous in terms of either bank erosion severity and/or riparian vegetation condition. However, where appropriate, a number of adjacent reaches may be grouped and targeted as a priority on the basis that the same or similar strategies would be applied to address issues common to all the reaches in that grouping. To avoid confusion, where several reaches are combined to strategically address an identified issue, the combined reaches will be referred to as a "priority focus area".

Seven hundred and forty-eight (748) individual reaches were mapped during the field survey.

The bank erosion severity and riparian vegetation condition are the primary fields upon which the estuary banks have been segmented into reaches. However, each reach also has a number of additional data fields recorded. This allows reaches to be identified on the basis of other attributes besides erosion severity or riparian condition. These additional attributes may include for example physical features (e.g. presence of bedrock), vegetation characteristics (e.g. presence of priority weed species), and/or man-made influences (e.g. the presence of existing control works and their effectiveness/condition at the time of survey).

The recording of field data in this way allows the interrogation of the field data sets using multicriteria analyses which in turn allows reaches with certain sets of attributes to be extracted from the field dataset and supplemented with other existing datasets to produce subsets which form either potential priority reaches or potential priority focus areas for further assessment.

Table A describes the draft analyses adopted for this assessment to develop the subset of reaches where further investigation as to whether protection, enhancement, or remediation is warranted. The analyses have been separated into the four primary areas of interest to this assessment: bank condition, riparian vegetation condition, estuarine habitat and existing works condition.

Table A Reach analyses outcomes based on the field data collected and multi-criteria analyses, supported by existing GIS datasets as described. These reaches form the pool of mapped estuary reaches to which the priority ranking criteria are to be applied to determine priorities for estuary bank and riparian vegetation remediation/protection actions.

ID	Analyses	Description	Notes
Bank Condition			
BC1	Reach mapped as "High" or "Extreme" erosion severity and associated with "Good" or "Very Good" riparian vegetation condition.	These are reaches where bank remediation measures would protect existing riparian vegetation that has been mapped as being in Good to Very good condition.	MEMS Action 2.3. 2 reaches identified. (Reaches 454, 563)
BC2	Reach mapped as "High" or "Extreme" erosion severity and also containing existing bank protection works which have been identified as partially effective, ineffective, or redundant.	These are reaches where erosion severity was classified as "High" or "Extreme" based on field assessment and the DST criteria, but which landholder interest can be inferred by the presence of existing erosion protection works (which were not mapped as effective).	MEMS Action 1.3. 10 reaches identified. (Reaches 209, 279, 282, 284, 313, 425, 458, 555, 660, 707)

ID	Analyses	Description	Notes
BC3	Reaches mapped as "High" or "Extreme" erosion severity but also mapped as having "high" environmental, infrastructure/commercial, or Amenity/safety impact rating	These are reaches where High to Extreme erosion severity is causing medium to high level impacts to environmental, infrastructure, commercial, amenity or safety values as defined in DPIRD Fisheries Decision Support Tool for bank erosion management.	CMA 2016 s3(b). 11 reaches identified. (Reach 172, 192, 193, 288, 292, 330, 343, 621, 660, 669, 687)
BC4	Reaches mapped with at least "Moderate" erosion severity and also important for public access	These are reaches where public access is established but where bank erosion is potentially compromising public safety, or public access is contributing to bank erosion in the reach.	CMA 2016 s8(2)(f). 2 reaches identified. (Reach 151, 752)
BC5	Reach mapped as "High" or "Extreme" erosion severity and also containing riparian vegetation in Moderate condition	These are reaches where bank remediation measures would protect existing riparian vegetation that has been mapped in Moderate condition from High to Extreme bank erosion.	MEMS Action 2.3. 11 reaches identified. (Reaches 227, 286, 296, 313, 343, 424, 458, 559, 569, 664, 669)
Riparian Vegetation Condition			
RC1	Reach containing or immediately adjacent to a mapped littoral rainforest community and threatened by at least "Moderate" erosion severity.	These are reaches that correspond to the SEPP (Resilience and Hazards) 2021 Littoral Rainforest area mapping or the updated 2013 OEH Littoral Rainforest mapping and are threatened by erosion above natural levels.	CMA 2016 s6(b) promotion of rehabilitation and restoration of degraded littoral rainforests. Also Draft CMP Actions E1/E2, Biodiversity Strategy Program 2.2 & 2.3 One reaches identified: Reach 151
RC2	Reach containing or immediately adjacent to a mapped coastal wetland and threatened by at least "High" erosion severity.	These are reaches that correspond to the SEPP (Resilience and Hazards) 2021 Coastal Wetlands Area mapping and are threatened by High or Extreme severity erosion.	CMA 2016 s6(b) promotion of rehabilitation and restoration of degraded coastal wetlands. Also Biodiversity Strategy Program 3.1, 3.2 and 3.3 and WQMP Action BIO4 3 reaches identified (Reaches 183, 296, 669)

ID	Analyses	Description	Notes
RC3	Reach immediately adjacent to a candidate High Ecological Value riparian vegetation community (excluding estuarine macrophyte communities) and threatened by “High” or “Extreme” erosion (e.g. mapped EEC), with at least “Moderate” condition riparian vegetation.	These are reaches where the estuary bank vegetation forms part of a mapped candidate NSW Endangered Ecological Community which is threatened by erosion processes which are considered significantly above natural rates. NOTE: The riparian vegetation condition rating of at least “Good” filters out reaches mapped in 2024 with Very Poor to Moderate condition vegetation condition.	Biodiversity Strategy Program 2.2 17 reaches identified. (Reaches 24, 28, 30, 37, 68, 71, 76, 106, 107, 108, 156, 164, 232, 255, 261, 273, 302)
Estuarine Habitat			
EH1	Reach containing or immediately adjacent to a mapped coastal saltmarsh community and threatened by at least Moderate erosion severity.	These reaches are where coastal saltmarsh is threatened by erosion processes which are considered above natural rates.	MEMS Action 1.3. Also Biodiversity Strategy Program 3.1, 3.2 and 3.3 and WQMP Action BIO4 9 reaches identified. (Reaches 263, 495, 497, 669, 682, 692, 284, 286, 304)
EH2	Reach containing significant mapped mangrove habitat (at least half of reach containing mapped mangrove habitat) and threatened by “High” to “Extreme” erosion severity, or “Moderate” erosion severity with “Poor” vegetation condition	These reaches are where mangrove habitat is threatened by erosion processes which are considered above natural rates.	MEMS Action 1.3. Also Biodiversity Strategy Program 3.1, 3.2 and 3.3 and WQMP Action BIO4 6 reaches identified. (Reaches 3, 176, 296, 313, 659, 669)
Existing Works Condition			
EC1	Reach identified as having “medium” to “high infrastructure/commercial impacts or amenity/safety impacts and also have existing works in ineffective or partially effective condition.	Identifies reaches where failing works are contributing to impacts to infrastructure, commercial, amenity or safety values.	CMA 2016 s3(b). 13 reaches identified (Reaches 13, 14, 15, 17, 31, 53, 347, 350, 351, 355, 399, 714, 723)

ID	Analyses	Description	Notes
EC2	Reach mapped as at least "Moderate" erosion severity and also containing existing bank protection works adjacent to public land.	Public land is defined as Council owned land, crown reserves, or crown land parcels. This criterion identifies reaches that have existing works but where erosion is continuing and is affecting a public land asset/public foreshore area	CMA 2016 s3(b). 28 reaches identified. (Reaches 13, 27, 28, 47, 52, 53, 70, 209, 269, 285, 293, 313, 333, 335, 337, 340, 344, 347, 348, 355, 365, 399, 432, 462, 478, 676, 678, 723)

Rankings

A simple weighted scoring system has been adopted to rank the priority reaches and focus areas identified using the above analyses. Higher rankings are allocated to higher scoring reaches. Higher ranking indicates greater justification for investment to meet the objectives outlined in the sections above.

Table B outlines the criteria used.

Table B Criteria and associated weightings used to rank the list of priority reaches and focal areas for potential investment in remediation/enhancement/protection.

ID	Criteria	Description	Weighting	Notes
A	Public assets or infrastructure at risk	Primarily proximity to road, boating, or other public infrastructure. Applied where the DST infrastructure/commercial impact was recorded as medium or high and the asset has been recorded as a high value asset at risk.	+5	CMA 2016 Object 3(b) and (d). Reaches where works are currently being implemented will be excluded.
B	Intervention likely able to address suite of estuarine natural values including bank stability, estuarine and riparian vegetation, estuarine habitat, and water quality	Reaches which intervention is likely to address a suite of estuary values are ranked more highly than those which address only a single value (such as bank stability). The weighting is applied where the reach meets 3 or more of the analyses listed in *Table A*.	+5	CMA 2016 Object 3(a). MEMS Management Initiative 1,2 and 3.
C	Reach is an important public access location	Proximity to a public access location and requiring considerations of safe access	+5	CMA 2016 s8(2)(f).
D	Intervention likely to improve future flood resilience of built assets	Interventions likely to improve the resilience of coastal built assets (private or public) to the impacts of extreme events (e.g. Storm or flooding events) are given more weight.	+5	CMA 2016 Object 3(f) and (i). This criterion is primarily focussed on built assets as criteria B focusses on natural assets although the two are not mutually exclusive.

ID	Criteria	Description	Weighting	Notes
E	Reach is listed within a previous report as a priority area and has not yet been addressed through an appropriate management action	Reaches in the priority pool which are also identified in previous estuary management strategies and reports have already undergone assessment through an existing planning process and, if not already addressed, are ranked more highly in the priority system. The previous strategies and reports referenced are the Belinger Shire Draft CMP 2024, the WQMP 2022, and the Bellinger and Kalang Estuary Erosion study 2010.	+5	CMA 2016 s3(a), (h) and (i) The sites captured under this criterion include reaches at Mylestom, Urunga Island, the mid to upper Bellinger River estuary, and around Newry Island.
F	Indigenous Cultural Heritage values at the site	A consultation process has been initiated with the Yurruungga Aboriginal Corporation and the Coffs Harbour & District LALC to identify reaches of significance in terms of Indigenous cultural heritage and ongoing use. Where this process results in the identification of areas of particular importance/significance, the weighting will be applied either positively or negatively to reflect either support for remediation/intervention or a desire from the TO group for no disturbance to occur.	+5 or -5	CMA 2016 Object 3(c) and s8(2)(d) and MEMS Management Action 4.2.
G	Accelerated erosion rate verified by LiDAR DEM of Difference	Fifteen (15) reaches were assessed to quantify the annualised average width of erosion (m). Reaches which were eroding at a rate exceeding an average of 0.5m width over the reach length per year have been weighted as a higher priority.	+4	The DEM of Difference method allows for the quantification of erosion over the period 2009/2010 to 2024. The method allows reaches to be objectively compared using the calculated annualised average width of bank retreat.

ID	Criteria	Description	Weighting	Notes
H	Verified high source of fine sediments to the estuary	The fifteen (15) reaches and focus areas analysed using the DEMoD method have being assessed to quantify their annualised contribution to fine sediment and shoaling in the estuary. Reaches with significant on-going fine sediment yields over 100 tonnes per annum will be ranked more highly. Fine sediment has been defined as particles less than 20µm which are known to remain in suspension for long periods in estuaries and waterways.	+4	CMA 2016 s8(2)(c) and MEMS Management Action 1.3. This criterion uses particle size distributions of soil samples collected from the reaches analysed for volumetric change using the LiDAR DEM of Difference method. Volumetric erosion is converted to fine sediment yield based on the results of soil sample analyses.
I	Landholder support known or likely	Landholder support is generally crucial to the successful implementation of most interventions on estuary banks or in the riparian zone. Where landholder support is known or can be inferred from previous works or communications then potential interventions in those reaches will be scored more highly.	+4	Bellingen Shire Biodiversity Strategy Program 4.2 – 4.3 and WQMP Goal 4 Action ERO2 In the Bellinger-Kalang River Estuary study area, the likelihood of landholder support will be assessed through consultation with Bellingen Shire Council and Bellingen Landcare. Additionally, reaches adjacent to Crown Land, NPWS estate, Council owned or managed land, and road reserves are assumed to meet this criterion.
J	Intervention likely to have a high degree of success	Site factors, erosion processes, and recommended methods are considered to have a high probability of achieving and maintaining site stability over the medium term (~10 years).	+4	Based on expert opinion.
K	Access is straight forward and is via existing all-weather private road/track, Crown Land or Council owned land	Ease of access reduces intervention costs	+4	Straightforward access will reduce implementation costs.

ID	Criteria	Description	Weighting	Notes
L	Intervention likely to protect/enhance important natural or aesthetic values	Factors include proximity to Good to Very Good riparian vegetation, style of likely intervention, existence of redundant materials (tyres, building rubble), and location within the estuary.	+3	CMA 2016 Object 3(a).
M	Reach corresponds with or located within close proximity of a biodiversity priority action area (based on Bellingen Shire Biodiversity Strategy)	Interventions that support the existing biodiversity strategy for the Bellingen Shire are scored more highly, specifically maintaining/improving connectivity in the riparian landscape (Program 2.2) and improving vegetation condition in Council Reserves (Program 2.5).	+3	CMA 2016 Object 3(a). Biodiversity Strategy Programs 2.2 and 2.5.
N	Reach adjacent to the oyster harvest zone or aquaculture lease	The Oyster Industry is an important commercial end user group that contributes to the local economy. The industry is highly dependent on good water quality and is often the first to be impacted from nutrient, sediment and ASS runoff.	+3	CMA 2016 Object 3(d).
O	Reach immediately adjacent to mapped estuarine vegetation – Seagrass	Determined from existing Estuarine Macrophyte mapping or 2024 field observations, seagrass must be on the same side of the channel as the segment to receive the additional weighting.	+3	CMA 2016 Object 3(a). Seagrass has been allocated a high rating due to its limited distribution in the estuary.
P	Reach contains mapped estuarine vegetation – Coastal Saltmarsh	Based on the Byron Shire Council HEV mapping dataset and the NSW Estuarine Macrophytes mapping	+3	CMA 2016 Object 3(a) and (f). Coastal saltmarsh has been allocated a high rating due to its susceptibility to sea level rise and the limited opportunities for landward expansion of the community.

ID	Criteria	Description	Weighting	Notes
Q	Site factors facilitate lower cost interventions	Some site factors such as severity of erosion, scale of required works, type of intervention, and materials requirements can significantly influence the costs of interventions. Lower cost interventions are scored more highly as cheaper interventions can free resources up for other interventions elsewhere.	+2	Cost of intervention is relative to the value of the asset or issue being addressed.
R	Intervention likely to protect/enhance existing estuary remediation works	Interventions that protect existing investments in estuary health or stability are considered to add additional value provided that they are appropriate remediation types	+2	Recognises the importance of maintaining existing works which are contributing to estuary stability and health.
S	Reach contains estuarine vegetation - Mangroves	Determined from existing mapping and aerial or other imagery, or from 2024 field observations/records.	+2	CMA 2016 Object 3(a).
T	Reach located within a high use boating area	There is existing commercial boating use in the estuary (oyster growers, boat hire, etc.). Additionally, recreation boating is a very popular activity in some sections of the estuary, particularly the lower to mid Kalang River. High use boating areas have been identified through the targeted consultation process.	+2	CMA 2016 Object 3(b). Likely to increase costs of remediation due to specific issues related to boat wave wash management but consistent with addressing multiple objectives protecting the social values of estuarine waterways.
U	Reach complimentary to existing other NRM program	Interventions that support existing NRM programs in the estuary are scored more highly.	+1	CMA 2016 Object 3(h). E.g. Cultural heritage program, fish habitat program, etc.

ID	Criteria	Description	Weighting	Notes
V	Reach identified as a priority investment site in previous or ancillary studies	A small increase in weighting is given to any sites mapped as High or Extreme erosion in the 2024 field survey and which are also identified as having high erosion or bank instability in other documents such as reports from/to Council, DCCEEW, Landcare or other community organisations.	+1	CMA 2016 Object 3(h).
W	Reach has a complicated approvals pathway due to proximity to coastal wetlands, littoral rainforest, or marine parks estate.	Reaches that are likely to involve significant costs and delays associated with approvals/permitting/licencing reasons are discounted slightly.	-2	

Priority Reaches

The priority system outlined above has been applied to the 748 estuary reaches assessed during the NEAP field survey. Reaches were first reviewed against the objective criteria in *Table A* and if the reach satisfied any of the criteria it was added to the "pool" of priority reaches. The criteria resulted in 83 reaches being added to the priority pool. Each of the reaches in the "priority pool" were then assessed against the ranking criteria in *Table B*.

Overall Priority list

After accumulating adjacent reaches with similar processes and management issues into priority focus areas (for example reaches 14 and 15 on the Bellinger River at Repton; reaches 192 and 193 opposite Fernmount on the Bellinger River; reaches 270, 273, 277, and 279 on Urunga Island on the Bellinger River; reaches 281, 282, 284, 286, and 288 on Urunga Island on the Bellinger River; and reaches 333, 335, 337 and 340 adjacent to the Council Reserve at Burrawong Parade on the Kalang River; and 716 and 717 on the north arm of the Kalang River on Newry Island), a ranked list of 70 priority reaches/focus areas remained. *Figures 26 and 27* shows the distribution of the priority reaches assessed in the study area.

Table 20 lists the top 19 ranked reaches/focus areas within the Bellinger-Kalang River estuary study area. The main issues identified as affecting the reach and the objectives of management intervention are listed. These locations are considered higher priority for management interventions to improve flood resilience, protect public assets and infrastructure, improve water quality, improve estuary health, and protect or enhance important riparian vegetation communities. The locations of the higher priority reaches and focal areas are indicated in red in *Figures 26* and *27.*

Tables 20-23 identify the top ranked locations for targeted programs that aim to protect public assets and infrastructure, improve water quality, or protect or enhance riparian vegetation (specifically high conservation value vegetation types). These are subsets of the overall priority list and include locations outside of the high priority list.

For the Bellinger Kalang Estuary NEAP Assessment, reaches outside the top 19 should be pro-actively monitored for any change, for example after flood events. These reaches are listed in *Appendix B* and their locations are indicated by yellow in *Figures 26* and *27.*

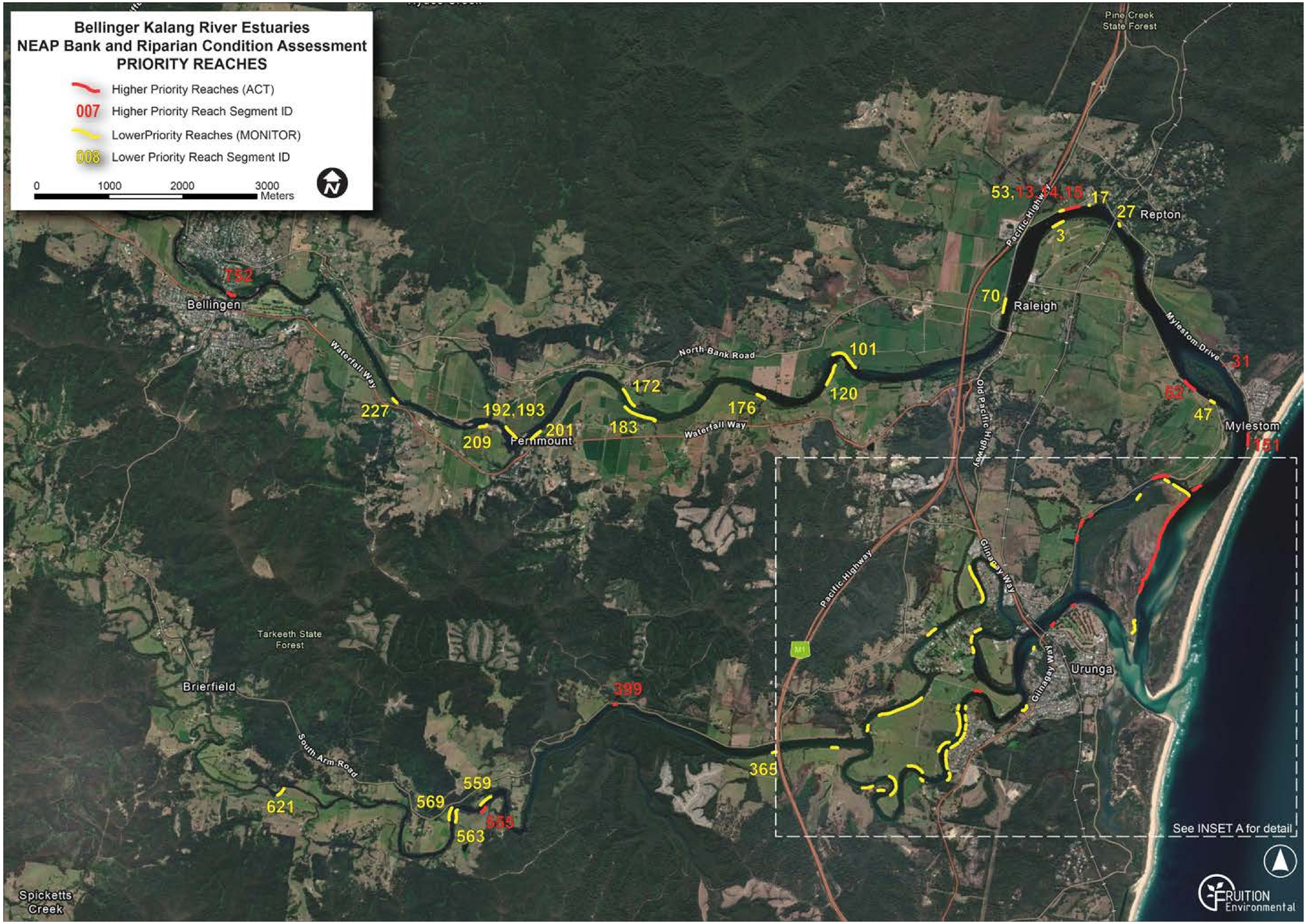

Figure 26 *Locations and Reach reference IDs for priority reaches for management intervention based on the Bellinger and Kalang River Estuaries NEAP Bank and Riparian Condition Assessment 2024 (INSET A provided in Figure 27 overleaf).*

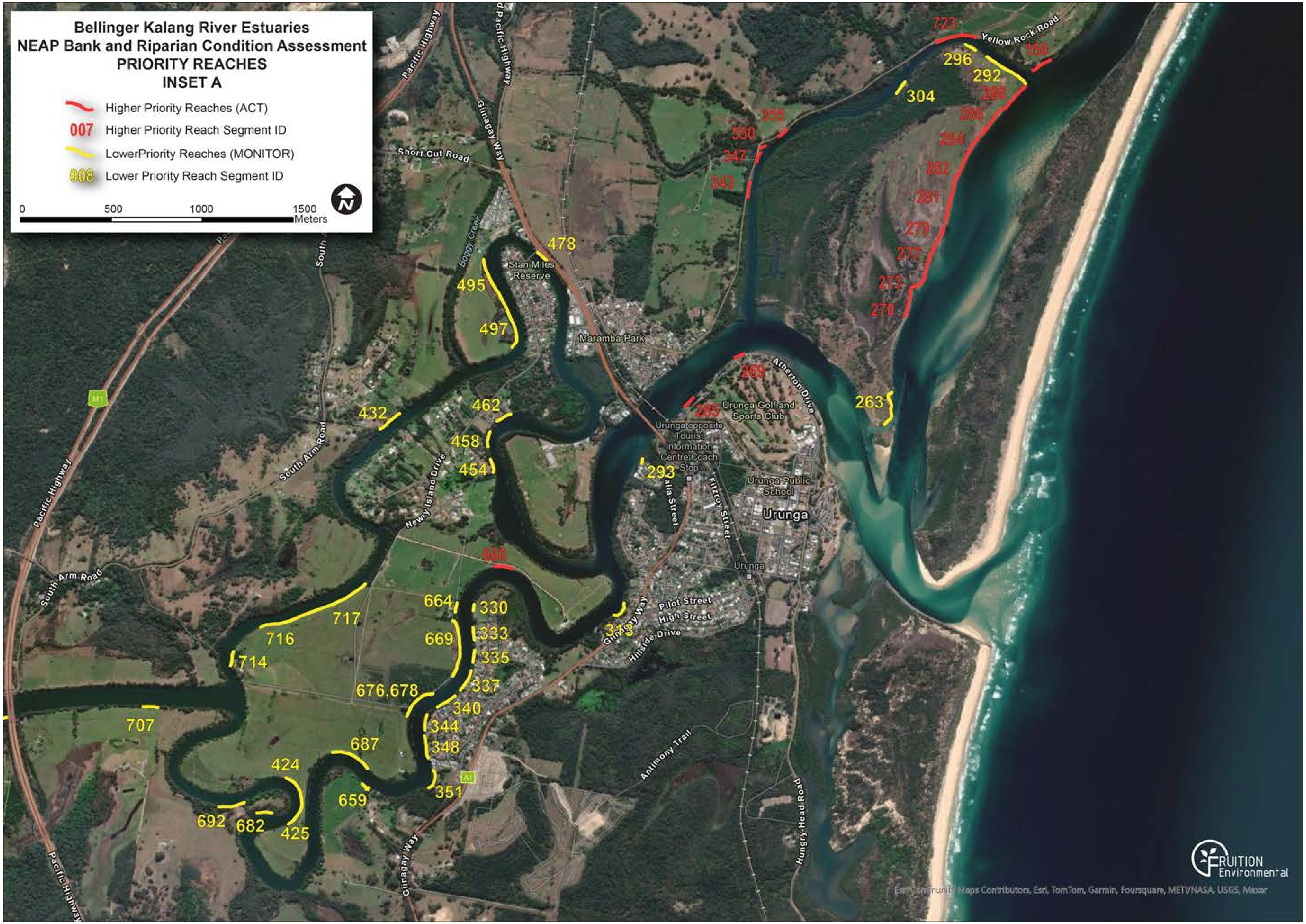

Figure 27 Locations and Reach reference IDs for priority reaches for management intervention in the Newry Island/Urunga/Back Creek area (INSET A) based on the Bellinger and Kalang River Estuaries NEAP Bank and Riparian Condition Assessment 2024

Table 20 Ranked list of highest priority reaches for management interventions to improve overall bank and riparian condition in the Bellinger Kalang River estuaries study area (Lower priority reaches which have been assessed as "monitor only" are included in Appendix B).

Rank	Reach	Location	Management Issues	Priority Score	Management Objectives
1	355	Back Creek	Existing rock armour works requiring maintenance for protection of public infrastructure (Yellow Rock Road)	40	Infrastructure protection, maintenance of existing works, protection of high value natural site, flood resilience
2	270/273/277	Urunga Island, Bellinger River	Persistent high severity erosion impacting Coastal Saltmarsh EEC and site of cultural significance at Urunga Island, contributing to poor estuarine water quality (confirmed source of fine suspended sediment and associated nutrients)	30 - 40	Protection of Coastal Saltmarsh, high value natural site and sites of cultural significance, improving estuarine water quality
3	723	Back Creek	Existing rock armour works requiring maintenance for protection of public infrastructure (Yellow Rock Road)	38	Infrastructure protection, maintenance of existing works on public land, flood resilience
4	279/281/282/284/286/288	Urunga Island, Bellinger River	Persistent high severity erosion impacting Coastal Saltmarsh EEC at Urunga Island, and also contributing to poor estuarine water quality (likely source of fine suspended sediment and associated nutrients).	28 - 35	Protection of Coastal Saltmarsh and high value natural site, improving estuarine water quality
5	151	Bellinger River, Mylestom	Moderate erosion impacting Candidate Littoral Rainforest EEC adjacent to public access and infrastructure	32	Protecting HCV vegetation, maintenance of public access
6	150	Bellinger River	Moderate severity erosion impacting foreshore and public access, adjacent to Urunga Island	31	Protection of public foreshore and high value natural site
7	343	Back Creek	High severity erosion from boat wash along road reserve (Yellow Rock Road)	31	Infrastructure protection, protection of high value natural site
8	347	Back Creek	Existing works use inappropriate design and ineffective at mitigating erosion, threat to public infrastructure (Yellow Rock Road)	30	Infrastructure protection, removal and replacement of inappropriate

Rank	Reach	Location	Management Issues	Priority Score	Management Objectives
					existing works, protection of high value natural site
9	31	Bellinger River, Mylestrom Drive	Existing rock armour works requiring maintenance for protection of public infrastructure (public road)	29	Infrastructure protection, maintenance of existing works on public land, flood resilience
10	399	Kalang River, South Arm Road	Existing rock armour works requiring maintenance for protection of public infrastructure (public road)	29	Infrastructure protection, maintenance of existing works on public land, flood resilience
11	350	Back Creek	Existing rock armour works requiring maintenance for protection of public infrastructure (Yellow Rock Road)	28	Infrastructure protection, maintenance of existing works, protection of high value natural site, flood resilience
12	555	Kalang River	Extreme severity and accelerated erosion contributing to poor estuarine water quality (source of fine sediment inputs into estuary), existing revegetation requires maintenance	28	Improving estuarine water quality, maintenance of existing works, flood resilience
13	14/15	Bellinger River, Repton	Existing rock armour works requiring maintenance in area of public use	22 - 28	Maintenance of existing works and public access, flood resilience
14	285	Kalang River, Urunga	Public access location with partly effective works, poor amenity	26	Improve public access, enhance vegetation and amenity
15	752	Bellinger River, Bellingen	High severity erosion impacting site of high public use	26	Maintaining safe access and amenity on public land
16	269	Kalang River, Urunga	Existing works (timber piles) ineffective at mitigating erosion, area if high public use	26	Maintenance of public access and amenity
17	13	Bellinger River, Repton	Existing rock fillets and rock armour works requiring maintenance for protection of public infrastructure (public road)	25	Infrastructure protection, maintenance of existing works on public land, flood resilience

Rank	Reach	Location	Management Issues	Priority Score	Management Objectives
18	52	Bellinger River, Repton	Existing rock armour works requiring maintenance for protection of public infrastructure (public road)	25	Infrastructure protection, maintenance of existing works, flood resilience
19	660	Newry Island, Kalang River	High severity erosion undermining existing rock armour works with potential public infrastructure considerations (powerline pole)	25	Maintenance of existing works, flood resilience

Priorities for asset protection and/or maintenance

The ranked priority list presented in *Table 21* is a subset of reaches where the management objectives are related to infrastructure and public asset protection or maintenance and include reaches where:

- protecting public assets and infrastructure (e.g. roads) is the primary objective
- maintenance of existing bank protection works is the primary objective (i.e. existing investment protection), and/or
- protecting and maintaining safe public access is the primary objective

Table 21 Ranked list of priority reaches for management intervention to improve or maintain public assets, infrastructure and public access in the Bellinger Kalang River estuaries study area.

Rank	Reach	Location	Management Issues	Priority Score	Management Objectives
1	355	Back Creek	Existing rock armour works requiring maintenance for protection of public infrastructure (Yellow Rock Road)	40	Infrastructure protection, maintenance of existing works, protection of high value natural site, flood resilience
3	723	Back Creek	Existing rock armour works requiring maintenance for protection of public infrastructure (Yellow Rock Road)	38	Infrastructure protection, maintenance of existing works on public land, flood resilience

Rank	Reach	Location	Management Issues	Priority Score	Management Objectives
5	151	Bellinger River, Mylestom	Moderate erosion impacting Candidate Littoral Rainforest EEC adjacent to public access and infrastructure	32	Protecting HCV vegetation, maintenance of public access
7	343	Back Creek	High severity erosion from boat wash along road reserve (Yellow Rock Road)	31	Infrastructure protection, protection of high value natural site
8	347	Back Creek	Existing works use inappropriate design and ineffective at mitigating erosion, threat to public infrastructure (Yellow Rock Road)	30	Infrastructure protection, removal and replacement of inappropriate existing works, protection of high value natural site
9	31	Bellinger River, Mylestrom Drive	Existing rock armour works requiring maintenance for protection of public infrastructure (public road)	29	Infrastructure protection, maintenance of existing works on public land, flood resilience
10	399	Kalang River, South Arm Road	Existing rock armour works requiring maintenance for protection of public infrastructure (public road)	29	Infrastructure protection, maintenance of existing works on public land, flood resilience
32	687	Newry Island, Kalang River	High value public asset (powerline) at risk	20	Infrastructure protection

Priorities for water quality improvement

The ranked priority list presented in *Table 22* is a subset of reaches where the management objectives are related to improving water quality, specifically reducing suspended sediment loads and associated nutrients. Many of these sites have the additional objective of protecting agricultural land and actions aimed at reducing high suspended sediment yields from these sites will also improve the resilience of these properties against flood damage. The five reaches/priority focus areas are the top five identified reaches for fine sediment export to the estuary waterway identified through the rate of erosion assessment in Part 4 of this report (see *Table 19* on page 84). The rankings for these site range for 2nd highest overall priority to lowest overall priority of all the reaches assessed.

Table 22 Ranked list of priority reaches for management intervention to improve water quality and in particular suspended sediment and associated nutrient loads in the Bellinger Kalang River estuaries study area.

Rank	Reach	Location	Management Issues	Priority Score	Management Objectives
49	192/193	Bellinger River, Fernmount	High severity and accelerated erosion contributing to poor estuarine water quality (source of fine sediment inputs into estuary)	13	Improving estuarine water quality
4	279/281/282/ 284/286/288	Urunga Island, Bellinger River	Persistent high severity erosion impacting Coastal Saltmarsh EEC at Urunga Island, and also contributing to poor estuarine water quality (confirmed source of fine suspended sediment and associated nutrients).	28-35	Protection of Coastal Saltmarsh and high value natural site, improving estuarine water quality
37	101	Bellinger River	Persistent Extreme severity erosion contributing to poor estuarine water quality (likely source of fine suspended sediment and associated nutrients)	18	Improving estuarine water quality
2	270/273/277	Urunga Island, Bellinger River	Persistent high severity erosion impacting Coastal Saltmarsh EEC and site of cultural significance at Urunga Island, contributing to poor estuarine water quality (confirmed source of fine suspended sediment and associated nutrients)	30 - 40	Protection of Coastal Saltmarsh, high value natural site and sites of cultural significance, improving estuarine water quality
70	183	Bellinger River	High severity erosion threatening mangrove habitat and contributing to poor estuarine water quality (source of fine sediment inputs into estuary)	2	Protection of mangrove habitat, improving estuarine water quality

Priorities for riparian vegetation protection and enhancement

Table 23 provides a ranked priority list of reaches where the management objectives are related to protecting or enhancing riparian vegetation, particularly High Conservation Value (HCV) vegetation communities (such as NSW Endangered Ecological Communities). Many of these sites have the additional objectives such as erosion protection, habitat protection or enhancement, and water quality improvement. Not all reaches contain riparian vegetation in Good or Very Good condition and in some cases the actions required will include weed control, assisted natural regeneration, or active revegetation.

Table 23 Ranked list of priority reaches for management intervention to protect and/or enhance riparian vegetation in the Bellinger Kalang River estuaries study area.

Rank	Reach	Location	Management Issues	Priority Score	Management Objectives
2	270/273/ 277	Urunga Island, Bellinger River	Persistent high severity erosion impacting Coastal Saltmarsh EEC and site of cultural significance at Urunga Island, contributing to poor estuarine water quality (confirmed source of fine suspended sediment and associated nutrients)	30 - 40	Protection of Coastal Saltmarsh, high value natural site and sites of cultural significance, improving estuarine water quality
4	279/281/ 282/284/ 286/288	Urunga Island, Bellinger River	Persistent high severity erosion impacting Coastal Saltmarsh EEC at Urunga Island, and also contributing to poor estuarine water quality (confirmed source of fine suspended sediment and associated nutrients).	28-35	Protection of Coastal Saltmarsh and high value natural site, improving estuarine water quality
26	263	Urunga Island, Bellinger River	Moderate erosion impacting mapped Coastal Saltmarsh (vegetation community requires verification as likely incorrect) at Urunga Island	22	Protection of high value natural site
34	296	Back Creek, Bellinger River	Persistent high severity erosion from boat wash impacting mangrove habitat at Urunga Island	19	Protection of mangrove habitat and high value natural site
39	563	Kalang River	High severity erosion impacting Candidate Lowland Rainforest on Floodplain ECC	18	Protecting HCV vegetation
40	669	Newry Island, Kalang River	High severity erosion impacting Coastal Saltmarsh EEC and mangrove habitat	18	Protection of Coastal Saltmarsh, mangrove habitat

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Appendix A – Bank and Riparian Condition Assessment Criteria

NEAP Estuary Bank and Riparian Condition Assessment Criteria

Notes:

Headings in BLUE are criteria required under the NSW DPIE Fisheries Decision Support Tool for Bank Erosion Management in NSW Estuaries (developed by Hydrosphere Consulting, 2020).

Headings in Red are criteria developed by Fruition Environmental for use in the 2024-25 NEAP Estuary Bank and Riparian Condition Assessment Project. These are criteria which are additional, or additional clarifications, to the requirements of the NSW Fisheries DST.

Bank Condition Assessment

BEDROCK PRESENT

Does bedrock outcropping influence the stability of the bank segment being surveyed?
YES/NO answer required.

EROSION SEVERITY

Enter one code only for bank segment erosion severity.

NEGLIGIBLE	**N**	currently aggrading or stable – no erosion
LOW	**L**	some erosion occurring but considered within natural parameters
MODERATE	**M**	rate or scale of erosion is considered more than natural
HIGH	**H**	rate and scale of erosion is significant
EXTREME	**E**	likely to be rare, represents largest scale of erosion occurring within the estuary with significantly accelerated rate and scale

EROSION TRAJECTORY

Select one only.

NOT OCCURRING, NOT LIKELY	Erosion ***not currently occurring and unlikely to occur***
NOT OCCURRING, BUT LIKELY	Erosion is ***not currently occurring but is likely in the foreseeable future*** due to inadequacy of stability/protection or future erosive factors
OCCURRING and CONTINUING	Erosion occurring and ***likely to continue at the same rate/scale/extent*** without significantly increasing, adequacy of existing stability/protection measures ***unlikely to further deteriorate***
OCCURRING and ACCELERATING	Rate/scale/extent of current erosion **likely to significantly increase**, existing stability/protection measures ***likely to further deteriorate***

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NEAP Estuary Bank and Riparian Condition Assessment Criteria

WATER DEPTH

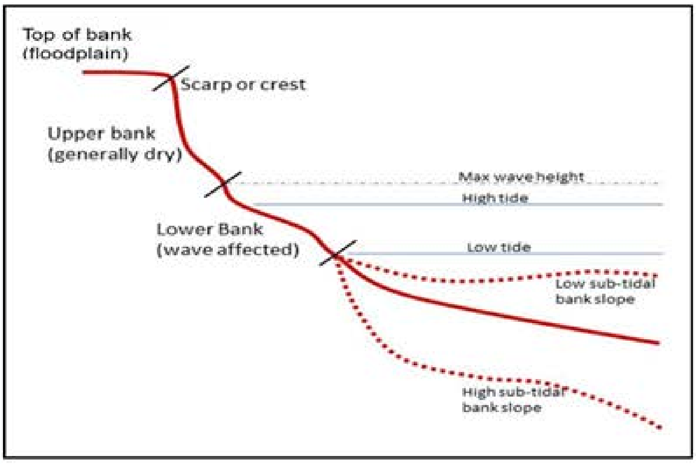
Select one only.

AS A GUIDE:

- select SHALLOW if there is an obvious intertidal bench extending out from the bank toe for at least 5m.
- Select DEEP if there is obvious deep water within 5m of the bank toe
- Select MODERATE if neither of the above apply.

SHALLOW	***Less the 0.8m deep*** on average at estimated mean high water, measured 5m from the bank toe
MODERATE	***Between 0.8m and 1.5m deep*** on average at estimated mean high water, measured 5m from the bank toe
DEEP	***More than 1.5m deep*** on average at estimated mean high water, measured 5m from the bank toe

LOCATION OF EROSION



NOTE:

Erosion on the top of the bank is rare.

Normally it will be Lower Bank or Upper Bank.

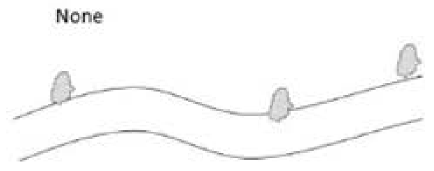
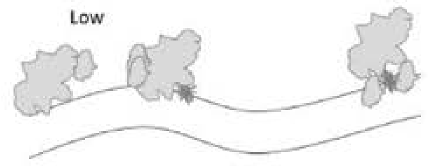
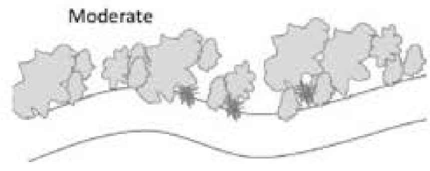
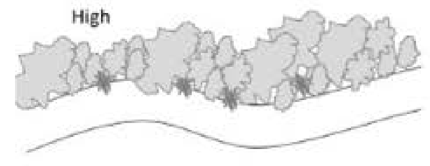
Toggle YES/NO for each location in the survey

NEAP Estuary Bank and Riparian Condition Assessment Criteria

Riparian Condition Assessment

RIPARIAN VEGETATION CONTINUITY

The longitudinal continuity along the bank of riparian vegetation (recorded for the maximum vegetation structure likely at the site (ie. usually woody vegetation but may be only sedges/rushes in saltmarsh areas)

NEGLIGIBLE	No vegetation, OR Isolated individual trees and shrubs	
LOW	Woody vegetation discontinuous with significant gaps. Gaps more dominant than vegetation.	
MODERATE	Woody vegetation almost continuous. Occasional small gaps but vegetation is dominant	
HIGH	Woody vegetation continuious. No significant gaps.	

RIPARAIN VEGETATION AVERAGE WIDTH

Enter one code only for ***average*** riparian vegetation width for the segment. ***Measured from the low bank***.

<2m	Less than 2m average width of riparian vegetation
<5m	Less than 5m average width of riparian vegetation
<10m	Less than 10m average width of riparian vegetation
<20m	Less than 20m average width of riparian vegetation
>20m	Greater than 20m average width of riparian vegetation

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NEAP Estuary Bank and Riparian Condition Assessment Criteria

RIPARAIN VEGETATION STRUCTURE

Riparian Vegetation Structure refers to the existence or otherwise of expected vegetation sub-strata (eg. canopy, shrub layer, ground layer, etc). ***This is a relative measure of structure based on what vegetation community would be expected to naturally occur at that location given the estuary location and context***.

Enter one code only for riparian vegetation structure for the segment.

VERY POOR	No riparian vegetation present in the segment OR only grass present
POOR	Riparian vegetation is mostly grass with sporadic canopy trees/shrubs
MEDIUM	Riparian vegetation is missing one or more sub-strata through entire segment (ie. no shrubs present but groundcover and canopy present through whole segment)
GOOD	Riparian vegetation structure has all of the expected elements for that location but has some areas of patchiness within the segment
VERY GOOD	Riparian vegetation structure has all expected elements for that location for the whole segment (eg. Intact riparian forest or intact saltmarsh or mangrove forest)

RIPARAIN VEGETATION DIVERSITY

Riparian Vegetation Diversity refers to what would be expected in a natural situation at that location, focussing on native riparian vegetation species. ***It is a relative measure of diversity based on what vegetation community would be expected to naturally occur at that location given the estuary location and context***.

Enter one code only for riparian vegetation diversity for the segment.

VERY POOR	No riparian vegetation present in the segment OR only grass present
POOR	Sporadic native shrubs and/or trees (unless mapped as saltmarsh) with a uniform grass understorey (often grazed, parklands or private foreshore areas)
MEDIUM	Moderately diverse native vegetation species but impacted by land use or clearing. May be regenerating but lower diversity of shrubs and groundcovers than would otherwise occur without disturbance.
GOOD	Disturbed remnant vegetation BUT with diverse ground cover species (ie. some grazing or clearing impacts)
VERY GOOD	Remnant riparian vegetation (eg. intact riparian forest, mangrove forest or Saltmarsh)

WEED PRESENCE

Enter one code only for ***presence of woody weeds and exotic vines***. Measured as **Estimated Foliage Projective Cover** (FPC) for weed species observed.

NIL OBSERVED	No woody or vine weed species observed
LOW	Less than 10% FPC for woody and vine weeds observed
MODERATE	10%-25% FPC for woody and vine weeds observed
HIGH	25%-50% FPC for woody and vine weeds observed
VERY HIGH	Greater than 50% FPC for woody and vine weeds observed

WEED SPECIES

Do any of the listed priority weed species occur in the segment? **YES/NO** answer required for each possibility.

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NEAP Estuary Bank and Riparian Condition Assessment Criteria

Existing Controls and Erosion Works

EXISTING CONTROLS PRESENT

Do any of the existing controls occur in the segment? Toggle **YES if any occur** and then select **PERCENTAGE of BANK** with any controls present then select **OVERALL EFFECTIVENESS** for all works present. Toggle **WORKS TYPES** present.

PERCENTAGE OF SEGMENT WITH EXISTING CONTROLS

Select one only.

<10%	Less than **1/10th** of the bank segment has existing works
10-25%	About **1/10th** to **1/4** of the bank segment has existing erosion works
25-50%	About ¼ to ½ of the bank segment has existing erosion works
50-75%	About ½ to ¾ of the bank segment has existing erosion works
75-100%	More than ¾ of the bank segment has existing erosion works

EFFECTIVENESS OF EXISTING CONTROLS

Select one only.

No Existing Control	DEFAULT OPTION, select another from list below
INEFFECTIVE	Existing control not effective and maintenance would not improve
PARTIALLY (CONDITION)	Existing acceptable controls that are only partially effective due to deterioration, maintenance may ameliorate.
PARTIALLY (DESIGN)	Existing acceptable controls that are only partially effectiveness due to a design flaw (ie.work doesn't address processes, etc)
COMPLETELY	Existing acceptable controls that are completely effective
REDUNDANT	Existing control unacceptable form or not contributing to bank stability
UNKNOWN / UNTESTED	The existing control is a demonstration or untested trial works type
UNDER CONSTRUCTION	Bank protection controls are currently under construction

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NEAP Estuary Bank and Riparian Condition Assessment Criteria

NSW FISHERIES DST CRITERIA

IMPACT RATINGS

Select one only for each of the three IMPACT CATEGORIES.

ENVIRONMENTAL IMPACTS

Select one category only for environmental impact.

NEGLIGIBLE	**N**	**Erosion at "natural rate"** (NEGLIGIBLE to MODERATE) **AND** No features of biodiversity or conservation value threatened **AND** No impacts of erosion likely to effect downstream environments. Examples: • No erosion present (either naturally or because of erosion mitigation) • If Low Erosion Severity must be minimal water quality impacts and no vegetation being lost • If Moderate Erosion Severity then must be no water quality impacts and no biodiversity/conservation value impacts (eg. Sandy sediments)
LOW	**L**	Erosion rate/scale elevated above natural rate (ie. MODERATE to EXTREME) **AND** No features of biodiversity or conservation value **<u>significantly</u>** threatened **AND** Impacts of erosion likely to have local effects on water quality only (NOTE CONSIDER LENGTH OF SEGMENT). Examples: • Localised water quality impacts (ie. localised turbidity within the bank segment) • Erosion threatening or small loss of "low value" vegetation
MEDIUM	**M**	Erosion rate/scale significantly greater than natural rate (MODERATE to EXTREME severity) **AND** Features of biodiversity or conservation value **<u>likely</u>** to be affected **<u>AND/OR</u>** Impacts of erosion likely to have water quality impacts beyond the segment surveyed. Examples: • Water quality impacts extending beyond the segment surveyed • Erosion threatening vegetation of biodiversity or conservation value
HIGH	**H**	Erosion rate/scale significantly greater than natural rate (HIGH to EXTREME severity) **AND** Features of **<u>listed</u>** biodiversity or conservation value directly affected **AND/OR** A known cultural heritage site is directly affected **AND/OR** Impacts of erosion having water quality impacts beyond the segment surveyed. Examples: • Erosion significantly impacting water quality beyond the segment surveyed (ongoing sedimentation, turbidity) • Erosion actively damaging vegetation of biodiversity or conservation value (Listed EEC or HCV vegetation type eg Mangroves/saltmarsh) • Erosion impacting a midden.

NEAP Estuary Bank and Riparian Condition Assessment Criteria

INFRASTRUCTURE/COMMERCIAL IMPACTS

Select one category only for infrastructure/commercial impact.

"THREAT" defined as impacted, use impaired, damaged or lost as a result of erosion in the next 10 years.

NEGLIGIBLE	No built or land assets under threat
LOW	Minor assets of low value under threat, **AND** Loss of land relatively minor and likely to be of low concern to landholder
MEDIUM	Assets of intermediate value threatened Examples: boat ramps, foot paths, park benches, access stairs.
HIGH	High value or important infrastructure under threat. Examples: power lines, water and sewerage infrastructure, public utilities, houses, buildings, roads, carparks, etc.

AMENITY/SAFETY IMPACTS

Select one category only for amenity/safety impact.

NEGLIGIBLE	No impact on visual amenity, **AND** Very low risk of injury associated with erosion.
LOW	Minor impact on visual amenity to a small number of people, **AND** Low risk of injury associated with erosion.
MEDIUM	Significant visual impact, **OR** Public access to foreshore impeded, **OR** Greater risk of injury related to higher use area.
HIGH	Significant visual impact to high number of users, **OR** Foreshore access significantly impeded, **OR** Public safety risks associated with public areas.

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NEAP Estuary Bank and Riparian Condition Assessment Criteria

CONSTRAINTS

Do any constraints effect the segment? Toggle **YES if any occur.**

Immediate Landward Constraint	Record YES if there is a feature located landward that may hinder or limit construction or effectiveness of an erosion treatment method. EXAMPLES • impossible access or roads, • footpaths • powerlines or other utilities or buildings
Offshore Constraint	Record YES if there is a sensitive estuarine habitat (seagrass, rocky reef, etc), a navigation channel, aquaculture lease or boat mooring immediately offshore an eroding bank.
Public Access	Record **YES if public access to the bank or foreshore is a major consideration** for the site. Select **NO** if the access is any of the following: • if it is private property • if it is likely UNAUTHORISED access example a private access point or an informal camping area • informal access areas and areas of unauthorised access. • If the access is only along the top of the bank, for example a public walkway above the foreshore.
High Value Asset at Risk	**High value assets** are generally built assets such as Public Roads, Public Buildings, Public Structures (such as boat ramps, jetties, car parks), Public Utilities, Flood mitigations structures (such as levees and floodgates), Cultural Heritage Sites. **Assets are considered at risk if within 5m of Moderate to Extreme erosion that is continuing and accelerating and not stabilised by some means.**

Appendix B – Lower priority reaches for ongoing monitoring

The table presented in this Appendix lists the reaches and focus areas from the priority pool which fall outside the highest 19 priorities after applying the ranking criteria. In general, these reaches should be monitored for any change that may affect the priority scores, for example after flooding.

Entries in RED are also listed in *Tables 21, 22 and 23* above which target specific management objectives such as protecting public assets and infrastructure, improving water quality or protecting and enhancing riparian vegetation in the Bellinger and Kalang River Estuaries.

Rank	Reach	Location	Management Issues	Priority Score	Management Objectives
20	716/717	Newry Island, Kalang River	High erosion severity impacting site of cultural significance and potential mangrove habitat	17 - 24	Protect sites of cultural significance and native vegetation
21	47	Bellinger River	Existing rock armour works requiring maintenance for protection of public infrastructure (public road)	24	Infrastructure protection, maintenance of existing works, flood resilience
22	425	Newry Island, Kalang River	Existing works are inappropriate and ineffective at mitigating erosion	24	Removal and replacement of inappropriate existing works, flood resilience
23	209	Bellinger River	High severity erosion from boat wash and public access in area of high public use	22	Maintenance of public access, flood resilience
24	351	South Arm Kalang River	Moderate erosion impacting existing works, public access and Candidate Swamp Oak Floodplain Forest EEC	22	Protecting HCV vegetation, maintenance of existing works and public access, removal and replacement of inappropriate existing works, flood resilience
25	17	Bellinger River, Repton	Existing concrete works requiring maintenance in area of public use	22	Maintenance of existing works and public access, flood resilience

Rank	Reach	Location	Management Issues	Priority Score	Management Objectives
26	263	Urunga Island, Bellinger River	Moderate erosion impacting mapped Coastal Saltmarsh (vegetation community requires verification as likely incorrect) at Urunga Island	22	Protection of high value natural site
27	707	Kalang River	High severity erosion from boat wash and grazing contributing to poor estuarine water quality (likely source of fine suspended sediment and associated nutrients), existing works are inappropriate and ineffective at mitigating erosion	21	Removal and replacement of inappropriate existing works, improving estuarine water quality
28	333/335/ 337/340	South Arm Kalang River	Existing works use inappropriate design and ineffective at mitigating erosion, Moderate erosion on public land	18 - 21	Removal and replacement of inappropriate existing works, improve public amenity, flood resilience
29	27	Bellinger River, Repton	Existing works (concrete blocks) completely failed in area of public use, areas of Moderate erosion recorded	20	Replacement of existing redundant works on public land, flood resilience
30	344	South Arm Kalang River	Existing works use inappropriate design and ineffective at mitigating erosion, Moderate erosion on public land	20	Removal and replacement of inappropriate existing works, improve public amenity, flood resilience
31	348	South Arm Kalang River	Existing works use inappropriate design and ineffective at mitigating erosion, Moderate erosion on public land	20	Removal and replacement of inappropriate existing works, improve public amenity, flood resilience
32	687	Newry Island, Kalang River	High value public asset (powerline) at risk	20	Infrastructure protection
33	292	Urunga Island, Back Creek	Persistent Extreme severity erosion from boat wash impacting Coastal Saltmarsh EEC at Urunga Island, and also contributing to poor estuarine water quality (likely source of fine suspended sediment and associated nutrients).	19	Protection of Coastal Saltmarsh and high value natural site, improving estuarine water quality

Rank	Reach	Location	Management Issues	Priority Score	Management Objectives
34	296	Urunga Island, Back Creek	Persistent high severity erosion from boat wash impacting mangrove habitat at Urunga Island	19	Protection of mangrove habitat and high value natural site
35	714	North Arm Kalang River	High value public asset (powerline) at risk from ongoing erosion, existing building rubble is not mitigating erosion	19	Infrastructure protection, replacement of inappropriate works
36	53	Bellinger River, Repton	Public infrastructure (public road) at risk, ineffective works cobble beaching, areas of Moderate erosion	18	Infrastructure protection, replacement of ineffective works
37	101	Bellinger River	Persistent Extreme severity erosion contributing to poor estuarine water quality (likely source of fine suspended sediment and associated nutrients)	18	Improving estuarine water quality
38	330	South Arm Kalang River	High value public asset (powerline) at risk from high severity erosion	18	Infrastructure protection
39	563	Kalang River	High severity erosion impacting Candidate Lowland Rainforest on Floodplain ECC	18	Protecting HCV vegetation
40	669	Newry Island, Kalang River	High severity erosion impacting Coastal Saltmarsh EEC and mangrove habitat	18	Protection of Coastal Saltmarsh, mangrove habitat
41	304	Urunga Island, Back Creek	EEC Coastal Saltmarsh EEC and mangrove habitat under threat from erosion (Urunga Island)	17	Protection of Coastal Saltmarsh, mangrove habitat and high value natural site
42	365	Kalang River	Moderate erosion impacting Candidate Swamp Oak Floodplain Forest EEC	17	Protecting HCV vegetation
43	621	Upper Kalang River	High severity and accelerated erosion contributing to poor estuarine water quality (source of fine sediment inputs into estuary)	17	Improving estuarine water quality
44	659	South Arm Kalang River	Erosion from boat wave wash is impacting mangrove habitat, existing timber bank protection works requires maintenance	17	Protection of mangrove habitat, maintenance of existing works
45	293	Kalang River, Urunga	Existing works (tyres) partially failed in area of public land, areas of Moderate erosion	16	Replacement of inappropriate works on public land

Rank	Reach	Location	Management Issues	Priority Score	Management Objectives
46	313	South Arm Kalang River	Moderate severity erosion are impacting mangrove habitat, existing works have failed and not mitigating erosion, public land	16	Protection of mangrove habitat, removal and replacement of inappropriate works, improve local water quality adjacent to oyster lease
47	3	Bellinger River	High severity erosion from boat wave wash and grazing are impacting mangrove habitat	14	Protection of mangrove habitat
48	120	Bellinger River	Persistent Extreme severity and accelerated erosion contributing to poor estuarine water quality	14	Improving estuarine water quality
49	192 /193	Bellinger River, Fernmount	High severity and accelerated erosion contributing to poor estuarine water quality (source of fine sediment inputs into estuary)	13	Improving estuarine water quality
50	201	Newry Island, Kalang River	Erosion concerns in area of private access	13	Maintenance of public access
51	692	South Arm Kalang River	Moderate erosion impacting on Coastal Saltmarsh EEC and Candidate Swamp Oak Forest EEC	13	Protecting Coastal Saltmarsh and HCV vegetation
52	70	Bellinger River, Raleigh	Existing building rubble is not mitigating erosion, threat to public infrastructure (public road), areas of Moderate erosion	12	Infrastructure protection, replacement of inappropriate works
53	432	North Arm Kalang River	Moderate erosion, existing works are inappropriate and ineffective at mitigating erosion	12	Removal and replacement of inappropriate existing works
54	462	Newry Island, Kalang River	Moderate erosion impacting Candidate Swamp Oak Floodplain Forest EEC, maintenance required for existing (rubble) works	12	Protecting HCV vegetation, removal and replacement of inappropriate existing works
55	495	North Arm Kalang River	Moderate erosion impacting Coastal Saltmarsh, mangrove habitat, mapped Swamp Oak Forest EEC under threat from erosion from boat wash and grazing	12	Protection of Coastal Saltmarsh, HCV vegetation, mangrove habitat
56	497	North Arm Kalang River	Candidate Swamp Oak Forest EEC and Swamp Sclerophyll Forest EEC under threat from erosion from boat wash and grazing	12	Protection of Coastal Saltmarsh, HCV vegetation, mangrove habitat

Rank	Reach	Location	Management Issues	Priority Score	Management Objectives
57	664	Newry Island, Kalang River	High severity erosion impacting mangrove habitat	12	Enhance native vegetation
58	682	South Arm Kalang River	Candidate Swamp Oak Forest EEC and mangrove habitat	11	Protecting HCV vegetation
59	676	Newry Island, Kalang River	Existing works are inappropriate and ineffective at mitigating erosion and Candidate Swamp Oak Forest EEC threatened by Moderate erosion	10	Removal and replacement of inappropriate existing works, protecting HCV vegetation, improve local water quality adjacent to oyster lease
60	176	Bellinger River	Erosion from boat wave wash and grazing are impacting mangrove habitat	8	Protection of mangrove habitat
61	458	Newry Island, Kalang River	High severity erosion impacting Candidate, existing works	8	Protecting HCV vegetation
62	559	Kalang River	High severity erosion impacting Candidate Lowland Rainforest on Floodplain ECC	8	Protecting HCV vegetation
63	569	Kalang River	High severity erosion impacting Candidate Lowland Rainforest on Floodplain ECC	8	Protecting HCV vegetation
64	678	Newry Island, Kalang River	Existing works are inappropriate and ineffective at mitigating erosion	8	Removal and replacement of inappropriate existing works, improve local water quality adjacent to oyster lease
65	424	Newry Island, Kalang River	High severity erosion impacting Candidate Swamp Oak Floodplain Forest EEC	7	Protecting HCV vegetation
66	478	North Arm Kalang River	Moderate erosion impacting Candidate Swamp Oak Floodplain Forest EEC, existing rock armour works requiring maintenance	7	Protecting HCV vegetation, maintenance of existing works on public land
67	172	Bellinger River	Persistent Extreme severity erosion contributing to poor estuarine habitat	5	Improving estuarine habitat

Rank	Reach	Location	Management Issues	Priority Score	Management Objectives
68	227	Bellinger River	High erosion severity impacting estuarine habitat	4	Protecting agricultural lands, enhancing vegetation
69	454	Newry Island, Kalang River	High severity erosion impacting Candidate Swamp Oak Floodplain Forest EEC	3	Protecting HCV vegetation
70	183	Bellinger River	High severity erosion threatening mangrove habitat and contributing to poor estuarine water quality (source of fine sediment inputs into estuary)	2	Protection of mangrove habitat, improving estuarine water quality