Coastal Wetland Refugia Study: Central Coast, NSW

WRL Research Report 275, SEPTEMBER 2023

By Katrina Waddington, William Glamore, Valentin Heimhuber

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Project details

Report title	Coastal Wetland Refugia Study, Central Coast NSW
Authors(s)	K Waddington, W C Glamore, V Heimhuber
Report no.	WRL RR275
Report status	FINAL
Date of issue	September 2023
WRL project no.	2023-001
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Client reference	CPA/4274

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This report should be cited as: Waddington, K., Glamore, W. C. and Heimhuber, V. (2023) Coastal Wetland Refugia Study. Research Report for Central Coast Council. WRL Research Report 275. September **2023**.

Summary of recommendations

This study has developed and applied a geospatial approach to estimate how intertidal and supratidal ecosystems in Brisbane Water and Tuggerah Lakes, on the NSW's Central Coast, may transition under the effects of sea level rise. The study builds on existing mapping of the existing wetland vegetation, the local topography, and predictions of existing and future tidal water levels.

Each estuary will have a unique response to sea level rise, with changes to estuarine geomorphology and tidal dynamics resulting in site specific outcomes for coastal wetlands. In Brisbane Water, wetland communities on low-lying islands are vulnerable to inundation if local accretion rates cannot match rising sea levels. Along the foreshores, upslope accommodation space is typically limited by either residential housing, infrastructure or topography. Conversely, Tuggerah Lakes appears to have immediate refugia potential for tidal wetlands with connected areas of low-lying freshwater wetland and upland vegetation providing potential migration opportunities. Such migration would, however, have a significant impact on the extent and values of existing freshwater wetlands. Further, the future accommodation space available for both freshwater and tidal wetlands will be reduced by ongoing sea level rise. In both Tuggerah Lakes and Brisbane Water, ***the transition from fresh to brackish to saltwater wetlands will require careful management*****,** as will opportunities to ***transition existing environmental land-uses*** to either freshwater or tidal wetlands.

Within Brisbane Water, low-lying residential developments in Davistown, Woy Woy and Empire Bay will also be affected by sea level rise, highlighting that ***a transition plan is urgently needed*** for this catchment. Changes to land-use zonings in this area should ***consider opportunities for wetland migration that could enhance environmental values and ecosystem services within the estuary, while complementing future requirements for flood mitigation***.

Similarly, future management approaches to The Entrance will impact the potential tidal inundation regime and influence wetland migration opportunities throughout Tuggerah Lakes. Both ***freshwater and tidal wetland communities should be considered within the broader context of a transition study for the whole Tuggerah Lakes catchment***. This should include ***management of existing intertidal wetland vegetation along the foreshores*** of Tuggerah Lakes. These wetland areas provide nutrient abatement and a range of other ecosystem services to the lakes and are particularly vulnerable to sea level rise.

While this analysis has not allowed for vertical accretion, the foreshores of Brisbane Water and Tuggerah Lakes accommodate a number of expansive intertidal flats that may sustain or even increase future wetland extents under favourable conditions. These include areas such as Cockle Bay, Rileys and Pelican Islands, Saratoga and Erina Creek in Brisbane Water, or Tuggerah Swamp, Toukley and Calongra wetlands in Tuggerah Lakes. Various fringing wetlands and islands with Brisbane Water may also persist under suitable conditions. Accretion could be enhanced via ***proactive adaptation measures*** such as freshwater flow diversion, the installation of energy dissipation structures, or the diversion of dredging spoils. ***Monitoring and further investigations to better understand the accretion potential at key sites is recommended***.

Emerging methods of managing and mitigating tidal inundation and understandings of the mechanisms by which wetland vegetation migrates and adapts under changing environmental conditions should also be considered to ensure best management practices are applied throughout both estuaries.

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1 Introduction

Over the past millennium, sea levels worldwide have remained largely stable. This stability has led to mature intertidal ecosystems that are typically demarcated by tidal dynamics (Brophy et al., 2019). As these ecosystems mature, they provide a range of ecosystem services, including flood reduction, fish nursery, biodiversity, carbon sequestration, erosion mitigation, etc (Xu *et al.*, 2020). These services are being increasingly recognised, with several global initiatives underway to restore and protect these ecosystems (e.g., UN Decade of Ecosystem Restoration, Ramsar Convention, etc).

In New South Wales (NSW), the foreshore fringe of our estuaries is characterised by a transition from subtidal to intertidal to supratidal vegetation communities. As per Figure 1a, subtidal ecosystems are often characterised by seagrass in deeper waters, to mud/sand flats in shallower waters. Intertidal ecosystems are typically characterised by mangroves (in lower elevations) and saltmarshes (in upper elevations). Finally, the supratidal system is often dominated by casuarina or melaleuca forests. The distribution and extent of these ecosystems is commonly linked to the local tidal dynamics, where tidal inundation (or hydroperiod) can directly influence the vegetation community.

Sea level rise, and especially the annual rate of sea level rise, has the potential to negatively influence the established intertidal ecosystem zonation. In some circumstances, sea levels may rise faster than intertidal ecosystems can maintain accretion or biophysically adapt, resulting in drowned ecosystems with widespread morbidity. However, if the ecosystems can transgress upslope it may be possible for mangroves to overtake saltmarsh habitat (Figure 1b). This upslope process is commonly referred to as ‘coastal squeeze’ as it has the potential for saltmarsh or upland forests to be squeezed into smaller and smaller zones with limited room for upslope migration due to natural (e.g. rock slopes) or artificial (e.g. levees and dykes) barriers (Sadat-Noori *et al*., 2021). Without interventions, these ecosystems and their associated services may be severely degraded or reduced.

Ecosystem transition plans can be developed to forecast the upslope migration of intertidal vegetation and identify areas at risk of coastal squeeze. Analysing coastal squeeze impacts across an estuary can:

- Reveal potential wetland refugia locations that, if planned carefully, could provide upslope migration opportunities.
- Denote areas under threat from sea level rise, including risks to different habitat zones.
- Highlight the existing upland areas that may become intertidal (noting the potential loss of freshwater habitats and groundwater salinisation).
- Provide land-use zoning, policy, and planning opportunities to assist in future decision making, including retreat, defend and adapt practices.
- Draw attention to research and monitoring actions that may assist in estimating future impacts.

Based on our current understanding of rising sea level trends, this study examines potential intertidal wetland refugia in the Tuggerah Lakes and Brisbane Water estuaries on the Central Coast of NSW. The aim of the study is to trial an approach that can forecast shifts in intertidal vegetation due to sea level rise. The approach relies on existing intertidal vegetation mapping, high quality topographic data and long-term tidal water level data to develop existing and future (under sea level rise) mapping outputs. Results are then used to highlight regions where coastal squeeze may impact existing intertidal ecosystems, potential wetland refugia opportunities, and implications on ecosystem services.

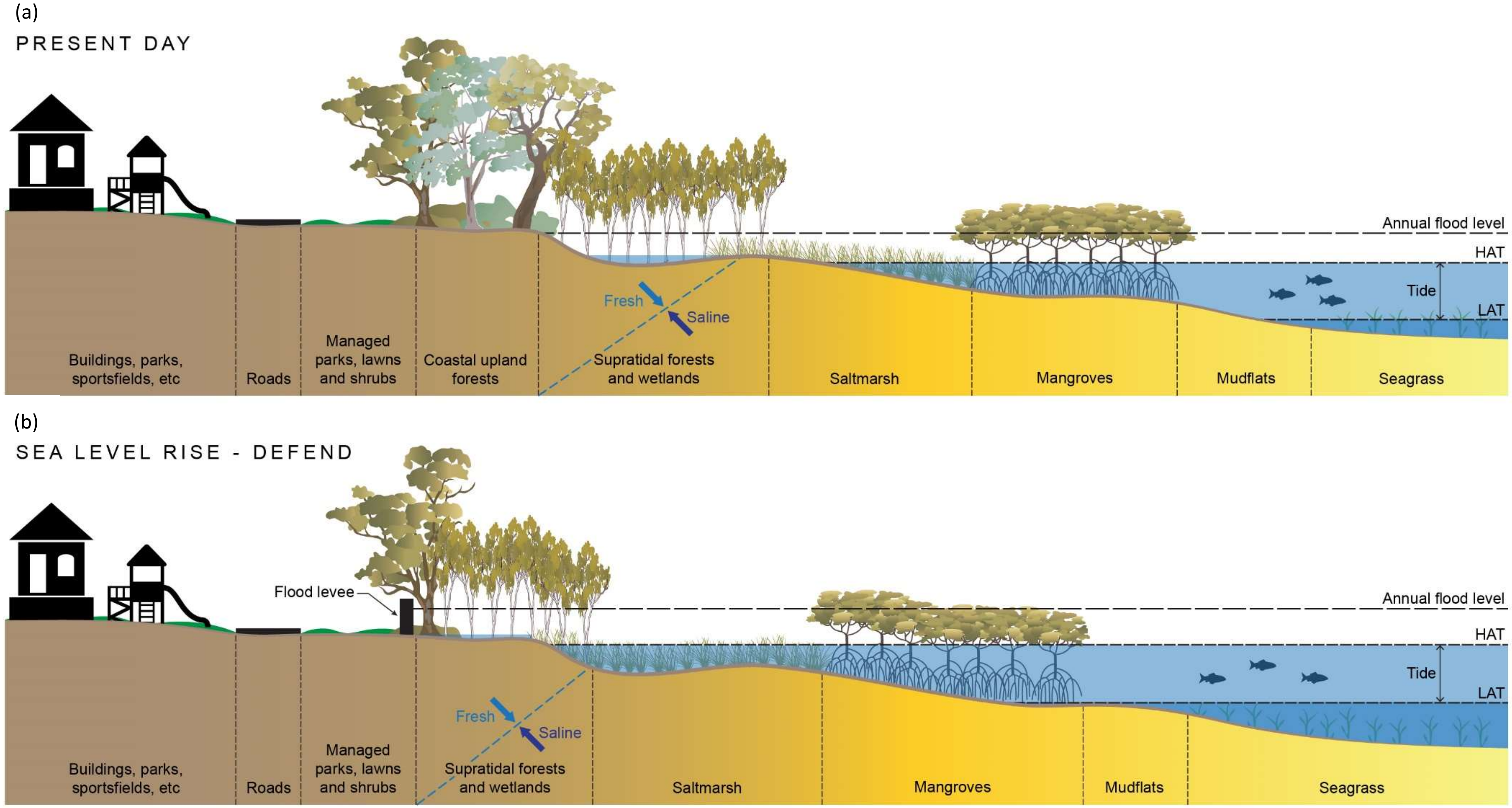

Figure 1 Existing intertidal vegetation zonation (a) and potential future implications of coastal squeeze (b) due to rising sea levels. Note that this figure denotes conditions similar to Brisbane Water. Tuggerah Lakes does not contain mangroves in the lower intertidal zone.

2 Methodology

2.1 Introduction

The existing habitat range of coastal wetlands is commonly thought to be determined by local hydrologic characteristics (tidal hydroperiod and dominance of fresh or saline waters) and the relationship between tidal inundation and topography (assuming beneficial soil type, climate, and connectivity variables). For this study, geospatial techniques were used to analyse these characteristics under present conditions to determine the preferred elevations for intertidal wetland habitats. This approach was then used to assess the potential effects of rising sea levels on vegetation extents at two future time periods.

2.2 Study Area

This study assesses the potential intertidal wetland refugia in the Brisbane Water and Tuggerah Lake estuaries within the Central Coast Council Local Government Area (LGA). Coastal wetlands within the study area have been mapped according to their dominant type, as presented in Table 1 (ELA, 2020; ELA, 2022).

Table 1 Wetland type, formation and class (from ELA, 2020; ELA, 2022)

Wetland type	Formation	Class
Intertidal	Saline Wetlands	Mangrove Swamps Saltmarshes
Supratidal or Freshwater	Forested Wetland	Coastal Floodplain Wetlands Coastal Heath Swamps Coastal Swamp Forests
Freshwater	Freshwater Wetlands	Coastal Freshwater Lagoons

Within Brisbane Water, wetlands are predominantly intertidal with mangrove communities dominated by *Avicennia marina* (Grey Mangrove) and *Aegiceras corniculatum* (River Mangrove) transitioning to saltmarsh along the foreshores and islands. These intertidal wetlands typically gradate through sedge/reed-lands to supratidal wetlands featuring a mosaic of Eucalyptus robusta (Swamp Mahogany) and/or Casuarina glauca (Swamp Oak) with myrtaceous shrublands, sedgelands and freshwater lagoons dominated by reeds (ELA, 2022).

Entrance conditions have a strong influence on the tidal range in Tuggerah Lakes, restricting the extent of intertidal vegetation such as saltmarsh and mangroves. Wetland communities are dominated by *Eucalyptus robusta* (Swamp Mahogany), *Melaleuca quinquenervia* (Broad-leaved Paperbark) and/or *Casuarina glauca* (Swamp Oak) mixed with shrubs and sedges and grading to sedge/reed-lands adjacent to the water edge (ELA, 2020).

2.2.1 Digital elevation models

Digital elevation models (DEM) depicting the topography of the study area were downloaded from NSW Spatial Services (DFSI Spatial Services, 2020) between 31 October and 4 November 2022. The dataset includes DEM coverage of the Gosford, Lake Macquarie, and Sydney regions derived from LiDAR surveys undertaken in 2011, 2017 and 2020. The DEMs have a 1 m grid resolution and were created using data with an accuracy of ±0.3 m vertical and ±0.8 m horizontal.

2.3 Existing wetland coverage

The existing wetland coverage and the elevation data were analysed to determine the conditions that best depict the intertidal and supratidal vegetation communities. The assessment of existing wetland coverage was based on four major studies recently undertaken:

1. Bell (2019) compiled an interim classification and maps of vegetation communities throughout the Central Coast Local Government Area (LGA). This was based on numerical classification of systematic plot data presented in previous compilations undertaken between 2002 and 2009 for the former Gosford and Wyong LGAs. Across the LGA, estuarine saltmarsh and grasslands were determined to cover approximately 167.35 ha and found to occur in close association with mangrove scrub, which covers approximately 780.46 ha of the LGA. Estuarine sedgelands were more limited in extent, covering approximately 24.68 ha. GIS shapefiles delineating intertidal, supratidal and upland vegetation communities were developed based on this data.
2. ELA (2020) mapped freshwater and tidal wetland boundaries within the Tuggerah Lakes estuary, using a combination of previous surveys, mapping, aerial imagery, digital elevation models, drone transects, and targeted field surveys. A total of 3,671 hectares of wetlands were mapped, including 1,470 hectares of wetlands not previously mapped in the Coastal Management State Environmental Planning Policy 2018 coastal wetlands area. Approximately 65% of the newly mapped areas were ground truthed, providing a high level of concurrence with the preliminary mapping. GIS shapefiles delineated intertidal, supratidal, and upland wetland types with a minimum polygon size of 0.01ha and a width of 10m. The final mapped product was considered accurate at a 1:5,000 scale.
3. ELA (2022) mapped freshwater and tidal wetland boundaries within the Brisbane Water estuary, using a combination of previous surveys, mapping, aerial imagery (2012), digital elevation models, drone transects, and targeted field surveys. A total of 2,567 hectares of wetlands were mapped, including 487 hectares of wetlands not reported in Bell (2019) and 2,011 hectares of wetlands not mapped in the Coastal Management State Environmental Planning Policy 2018 coastal wetlands areas. Approximately 42% of the newly mapped areas were ground truthed, indicating a high level of concurrence with the preliminary mapping. GIS shapefiles delineate intertidal, supratidal, and upland wetland types.
4. The NSW Department of Primary Industries (DPI) Fisheries maintains a Spatial Data Portal that includes detailed mapping of seagrass, mangrove and saltmarsh habitats within the estuaries of NSW, with the most recent dated 2020. Multispectral drone and satellite imagery photographs were used to identify and produce GIS shapefiles delineating the extent of mangrove, saltmarsh, and seagrass communities.

The existing vegetation extents determined by each of these sources are presented in Appendix A for Brisbane Water and Appendix B for Tuggerah Lakes. While all data was used to assess existing wetland extents, the ELA (2020, 2022) mapping was adopted to quantify potential tidal wetland loss and expansion as it is the most recent information and was extensively ground-truthed.

2.3.1 Existing upslope and downslope habitat limits

The elevation range representing the habitat of each estuarine wetland vegetation community was determined by intersecting the boundaries of each mapped community with the DEM. Vegetation boundaries that did not clearly represent natural upslope or downslope habitat limits, such as those adjacent to private property or roads, or otherwise influenced by anthropogenic infrastructure or activities were removed from the dataset. The downslope elevation limit of intertidal and the upslope limit of supratidal vegetation communities are presented in Figure 2 for Brisbane Water and Figure 3 for Tuggerah Lake.

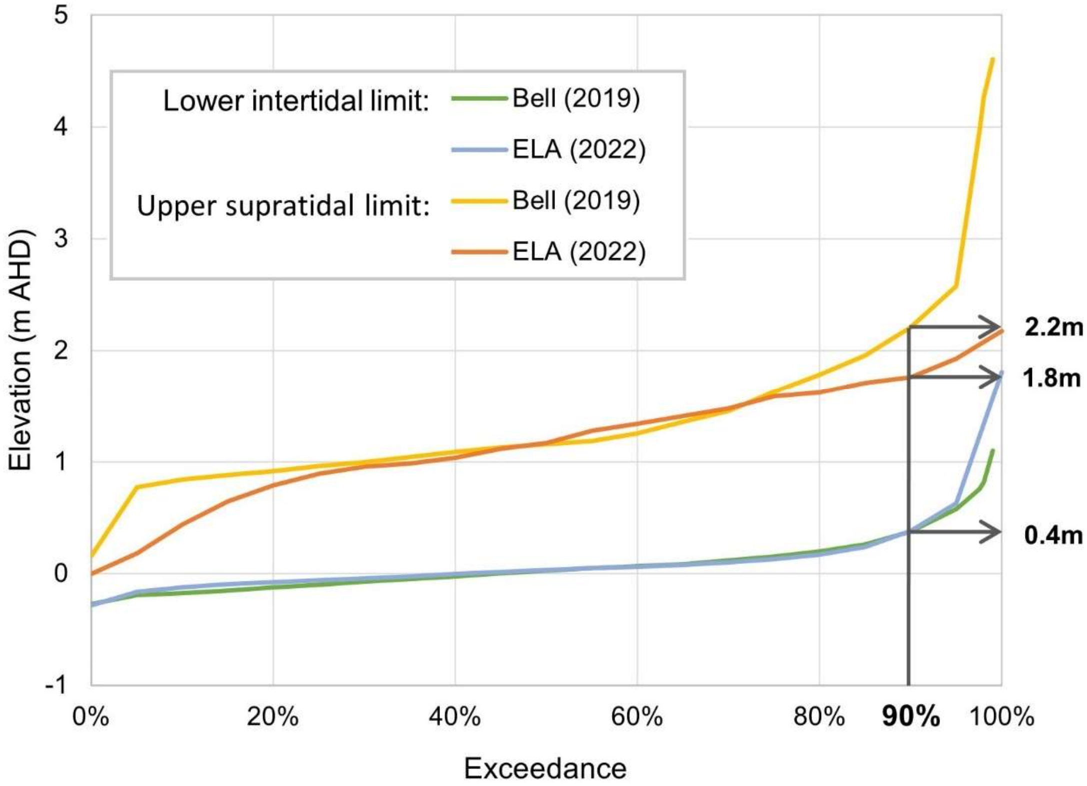

Figure 2 Elevation distribution for intertidal vegetation – Brisbane Water

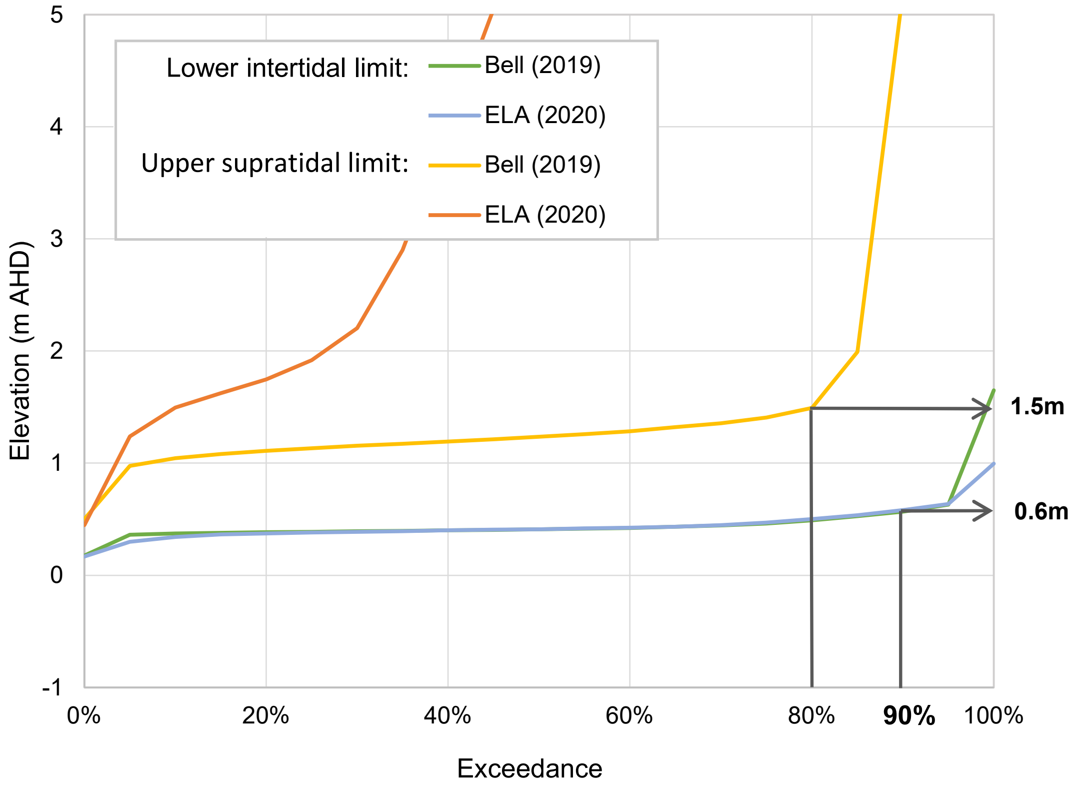

Figure 3 Elevation distribution for intertidal vegetation - Tuggerah Lake

Based on the data analysis, and with reference to the ground truthing of vegetation extents (Section 2.4), downslope and upslope limits were calculated for each vegetation class. An intertidal vegetation downslope limit of 0.4 m AHD (representing 90% of the data obtained from both mapping sets) and a supratidal vegetation upslope limit of 2.2 m AHD (representing 90% of the data obtained from the ELA (2022) maps and the upper limit of the Bell (2019) dataset) was adopted to define the current extent of tidal wetlands within the Brisbane Water estuary. For Tuggerah Lakes, 0.6 m AHD was adopted for the downslope limit of intertidal vegetation (representing 90% of the data obtained from both mapping sets) and 1.5 m AHD for the upper limit of the supratidal vegetation (representing 80% of the data obtained from the Bell (2109) mapping). These limits represent the higher end of the mapped vegetation extents, providing a conservative assessment of wetland loss and highlighting potential migration opportunities.

In general, the upslope supratidal wetland boundaries are not as clearly defined as the downslope intertidal boundaries because the mosaic of tidal and freshwater vegetation communities is increasingly complex as the tidal influence wanes. Additionally, the delineation of vegetation boundaries is complicated where heavy tree cover predominates, creating a wider transition zone at the upslope boundary, reducing DEM accuracy (refer to Section 2.4) and preventing extensive ground-truthing of the data. In particular, the elevation range of supratidal wetlands within Tuggerah Lakes was not as well defined as that for Brisbane Water leading to lower concurrence in the adopted elevation limit, ELA (2020) noted that wetland mapping in the northern Tuggerah Lakes catchment was complicated by highly variable topography and changes in elevation. For the Bells (2019) and ELA (2020) mapping, the median elevation of the upper supratidal limit for vegetation within the Lake Munmorah and Colongra Lake catchments exceeded 5m AHD. As this exceeds existing and potential future tidal limits, this data was excluded from the analysis. It is also noted that the downslope intertidal boundaries for Tuggerah Lakes, which is relatively high compared to those determined for Brisbane Water, may have been influenced by the La Nina weather patterns that brought wetter than average conditions to NSW between 2019 and 2022.

The adopted vegetation extents within the mapped vegetation boundaries are presented in Figure 4 and Figure 5. Figure 4 indicates a strong correlation between upslope and downslope intertidal vegetation limits within Brisbane Water where deviation from the upslope boundary is typically a result of residential or industrial development. Within the Tuggerah Lakes catchment (Figure 5), the downslope intertidal boundary is similarly well defined, but the upslope supratidal boundary frequently intrudes into areas that have been mapped as predominantly freshwater wetlands. This effect is most pronounced in Lake Munmorah, as discussed above, and in areas with reduced tidal influence, such as the Porter's Creek and Wyong Racecourse Wetlands. This suggests that the spatial distribution of the vegetation elevation curves could be refined with additional data. However, given the limited tidal range and future uncertainty regarding the effect of sea level rise on the entrance conditions for Tuggerah Lake, a conservative estimate of the upslope supratidal limit has been adopted for this study.

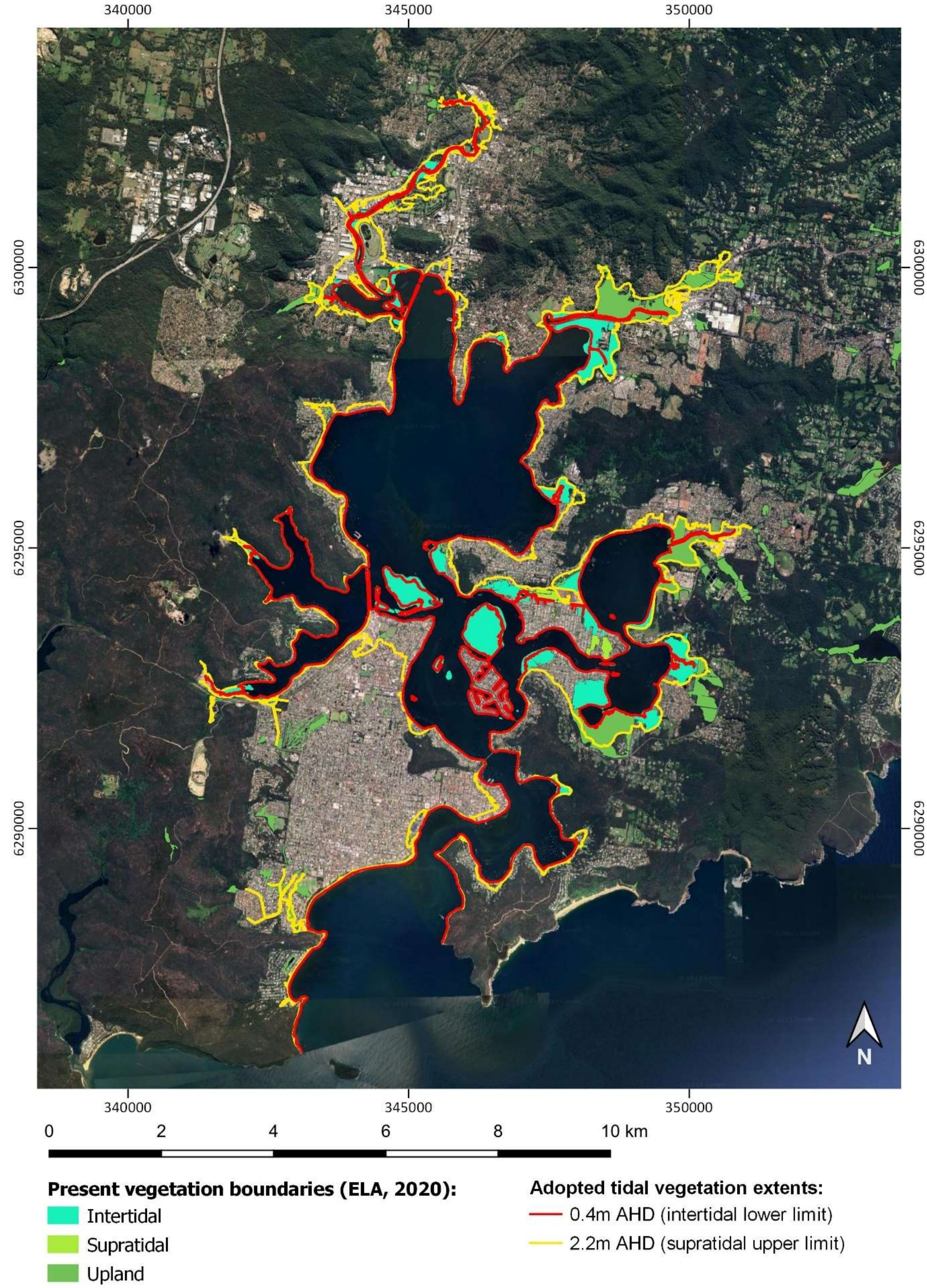

Figure 4 Adopted wetland extents for Brisbane Water compared to ELA (2022) mapping.

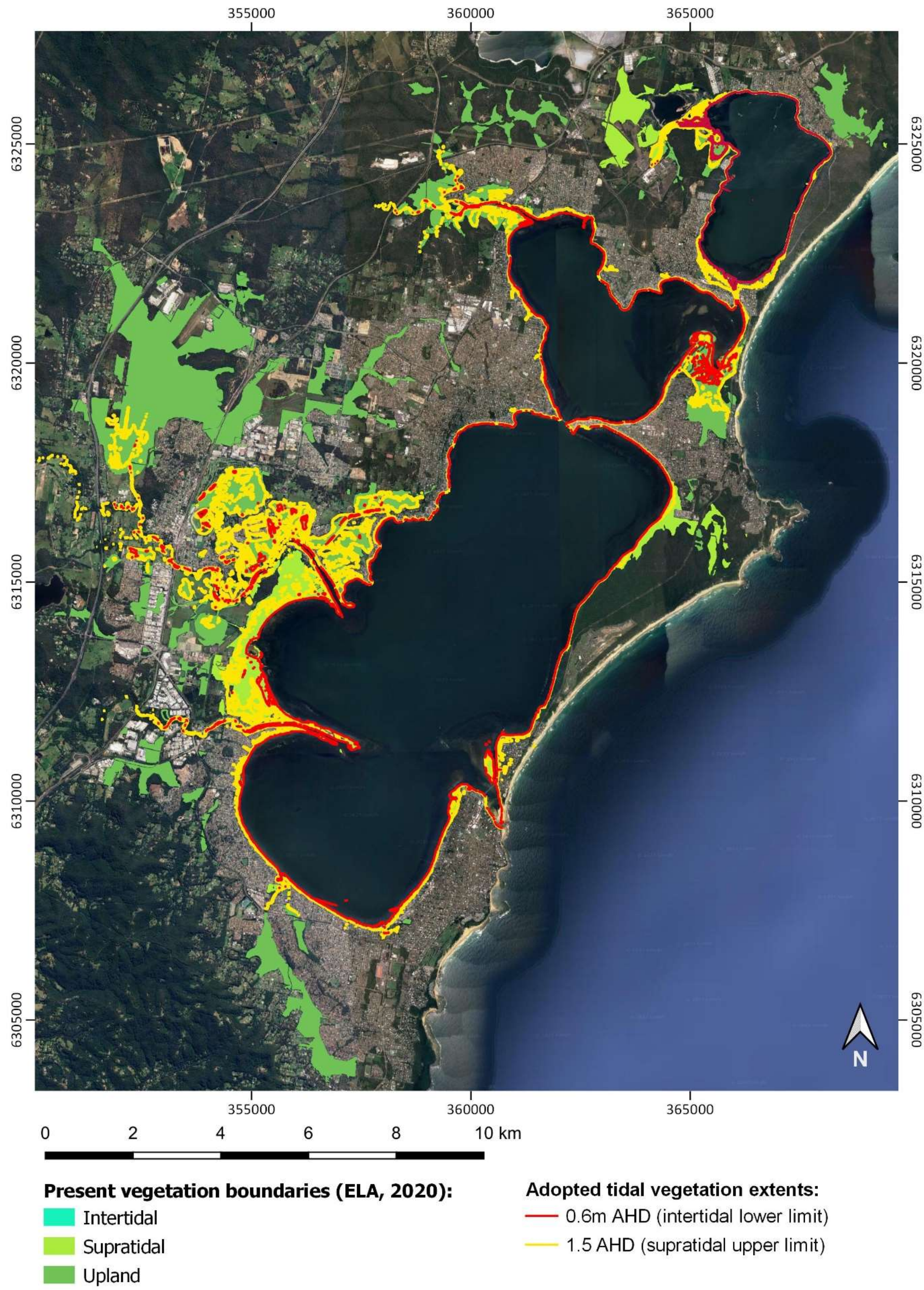

Figure 5 Adopted wetland extents for Tuggerah Lakes, compared to ELA (2020) mapping.

2.4 Ground truthing of vegetation extents

A ground-truthing field survey of key intertidal wetland sites was undertaken in December 2022 using a Trimble RTK-GPS with a CORSnet-NSW base station link providing an accuracy of ±8 mm horizontal and ±15 mm vertical. An additional ±0.5 mm of uncertainty applies for every 1 km of distance from the closest base station. CORSnet NSW stations located at Kincumber South and Wyong are within 10 km of the surveyed locations, providing a typical accuracy within ±10 cm. A comparison of levels surveyed and extracted from the DEM at each of the survey locations is presented in Figures 6 and 7. The DEM was found to provide a closer representation of the surveyed ground levels in areas vegetated by saltmarsh species, with higher canopy cover resulting in reduced DEM accuracy and contributing to uncertainty in quantifying the upper limit of the intertidal vegetation zone.

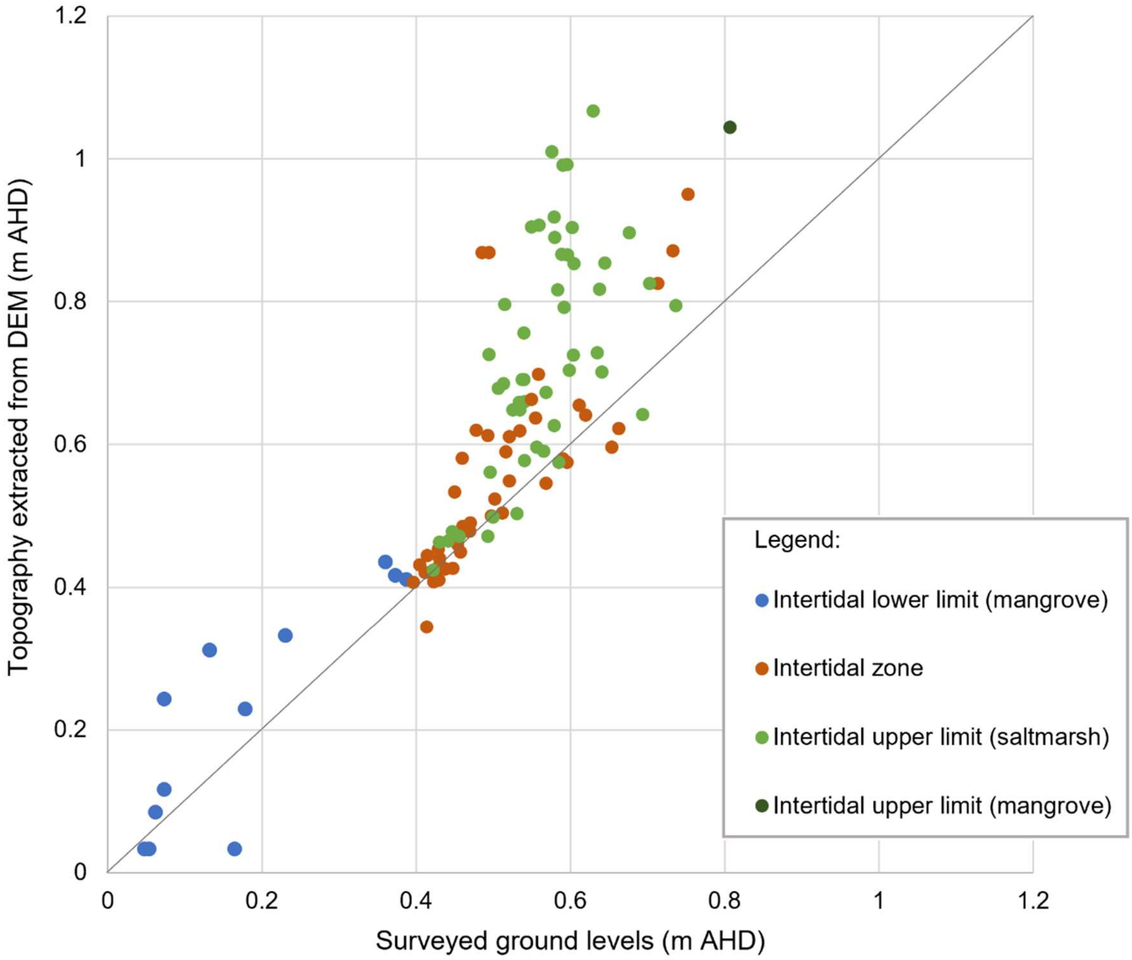

Figure 6 Comparison of DEM and surveyed levels for vegetation extents in Brisbane Water

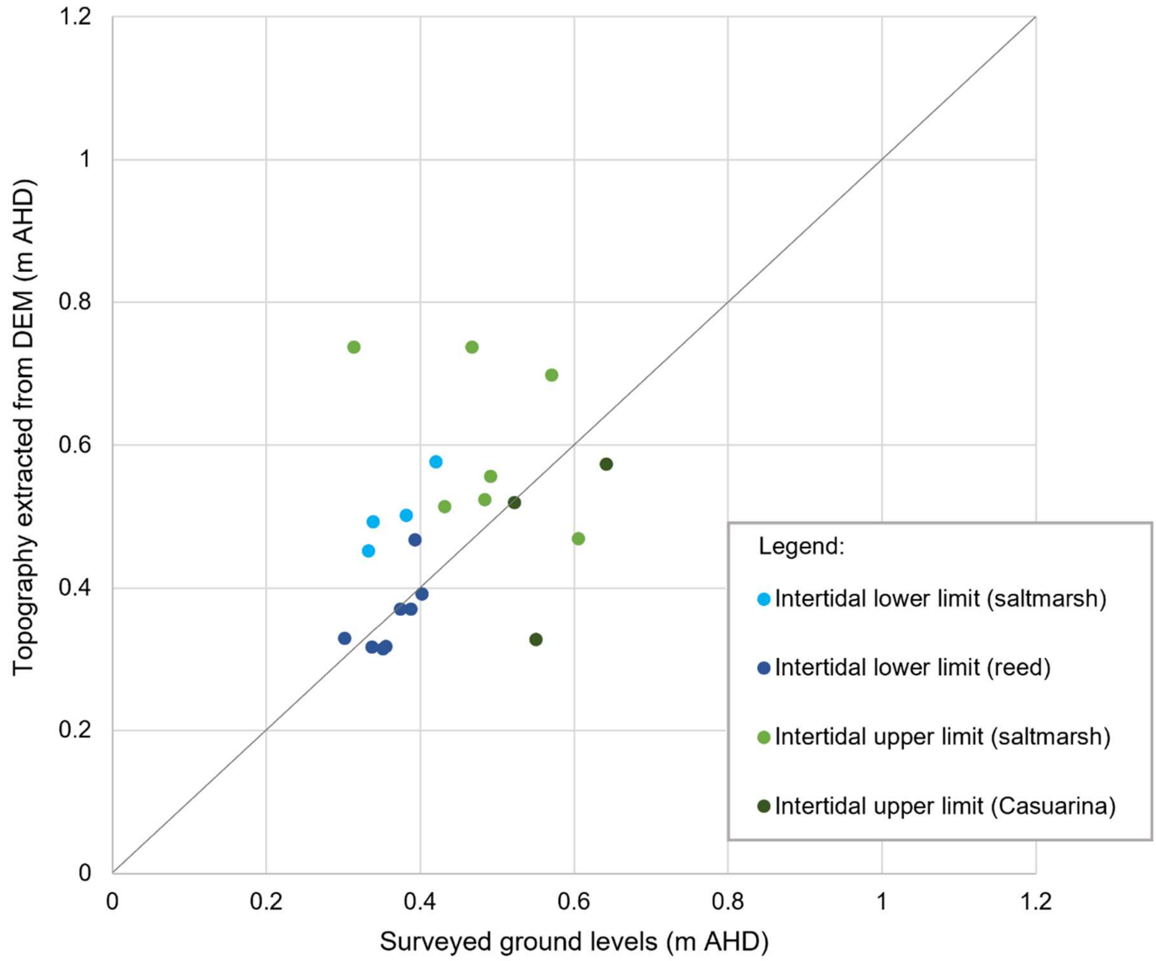

Figure 7 Comparison of DEM and surveyed levels for vegetation extents in Tuggerah Lake

2.5 Water levels and sea level rise

In this study, sea level rise is an important variable influencing the vertical distribution of intertidal vegetation and accurate forecasts are required to effectively map the project inundation regime. To this aim, the Intergovernmental Panel on Climate Change (IPCC) recently released its Sixth Assessment Report (AR6), identifying a 0.20 m increase in the global mean sea level between 1901 and 2018, with the rate of rise increasing to 3.7 mm/year over the period 2006 to 2018. Relative to the average sea level recorded between 1995 and 2014, the global mean sea level is projected to increase by between 0.63 m and 1.01 m by 2100 under the SSP5 (RCP 8.5) scenario. This is an increase from the likely range of 0.45 m to 0.82 m presented in the Fifth Assessment Report of 2014.

Mean sea levels can vary significantly on global and regional scales due to the relative influence of varying astronomical and atmospheric effects, oceanic temperature, density and changes to the land surface. Further variations occur due to the distortion of tidal waves as they interact with the coastal shelf, with tidal ranges along the NSW coast varying by up to ±0.2 m (MHL, 2011). These effects are exacerbated as the tide is propagated along an estuary. Local data is thereby critical in obtaining representative observations and projected tidal ranges, and consequently the actual and potential extent of local wetland vegetation under both existing and future tidal conditions.

Predictions of SLR for NSW (Glamore *et al*, 2016) are presented in Table 2. Under the RCP 8.5 (SSP5) scenario, these indicate a median increase of 0.27 m by 2050 and 0.78 m by 2100, relative to the mean sea level of 1996. For the period 1993 to 2009, White *et al*. (2014) determined an average trend in the relative sea level rise of 4.5 mm/year (± 0.2) around the Australian coastline, which is consistent with the global mean. Applying this trend to the intervening years since 1996, the remaining increase in MSL from 2022 to 2050 would be 0.17 m, and 0.67 m by 2100. These values are consistent with those adopted under various flood studies prepared for Central Coast Council.

Table 2 Projected median sea level rise averaged for the coast of NSW

Scenario	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
1996-2050	0.22 m	0.24 m	0.22 m	0.27 m
2022-2050	0.10 m	0.12 m	0.10 m	0.17 m
1996-2100	0.42 m	0.53 m	0.56 m	0.78 m
2022-2100	0.30 m	0.41 m	0.44 m	0.67 m

NSW Department of Planning and Environment's Manly Hydraulics Laboratory (MHL) operate multiple water level gauges within the foreshore areas and tributaries of Brisbane Waters and Tuggerah Lakes. MHL also operates a gauge in the outer harbour of Broken Bay at Patonga, which has recorded a lowest astronomical tide (LAT) level of -0.88 m AHD and a highest astronomical tide (HAT) level of 1.17 m AHD during the period 2001 to 2020. When measured as an annual average, the mean sea level (MSL) at Patonga has increased by 0.012 m between the periods 1990-2010 and 2001-2020, although these monitoring periods are too short to establish meaningful trends with respect to long-term sea level anomalies, including El Nino – Southern Oscillation and the Inter-decadal Pacific Oscillation.

Over these monitoring periods, the annual average tidal range at Patonga, measured as the difference between High High Water Solstice Springs (HHWSS), or 'king tide' and Indian Spring Low Water (ISLW), has only varied by 1 mm, from 1.85 m to 1.849 m, suggesting that there is minimal local hydrodynamic distortion of the open ocean tidal range. As the entrances to Brisbane Water and Tuggerah Lakes are located adjacent to the open ocean, there is minimal opportunity for the tidal signal to be further distorted by SLR. As such, the SLR predictions presented in Table 2 are deemed suitable to represent future water levels outside the entrance of both waterbodies.

2.5.1 Brisbane Water

NSW Department of Planning and Environment's Manly Hydraulics Laboratory (MHL) operates three water level gauges within the foreshore area of Brisbane Water and additional gauges approximately 5.9 km upstream within Narara Creek, and 3.8 km upstream within Erina Creek. The locations of these gauges are presented in Figure 8, with long-term tidal planes detailed in Table 3 and the trend in tidal levels in Table 4.

Figure 8 Brisbane Water tidal gauge locations

Table 3 Brisbane Water tidal planes (source: MHL, 2023)

Tidal planes	Patonga	Ettalong	Koolewong	Punt Bridge	Manns Road	Erina
HAT	1.17	0.99	0.78	0.78	0.81	0.82
LAT	-0.88	-0.43	-0.25	-0.27	-0.21	-0.27
HHWSS	1.032	0.826	0.661	0.661	0.643	0.692
MHWS	0.691	0.551	0.418	0.416	0.412	0.441
MHW	0.567	0.471	0.37	0.367	0.366	0.391
MHWN	0.442	0.39	0.322	0.319	0.319	0.34
MSL	0.059	0.11	0.118	0.112	0.127	0.131
MLWN	-0.324	-0.17	-0.087	-0.095	-0.064	-0.078
MLW	-0.449	-0.251	-0.135	-0.143	-0.111	-0.129
MLWS	-0.574	-0.332	-0.183	-0.192	-0.157	-0.179
ISLW	-0.817	-0.528	-0.356	-0.367	-0.322	-0.358
RANGE	**1.849**	**1.354**	**1.017**	**1.028**	**0.965**	**1.05**

Table 4 Long-term changes in tidal planes for Brisbane Water

Tidal planes	Patonga	Ettalong	Koolewong	Punt Bridge	Manns Road
1990-2010					
MLW	0.0038	0.1406	+0.076	+0.0779	+0.0874
MSL	-0.0011	0.152	+0.0646	+0.0646	+0.057
MHW	0.0057	0.1615	+0.0532	+0.0494	+0.0247
2001-2020					
MLW		0.018	+0.0396	0.0378	0.0378
MSL		0.0324	+0.0486	0.0468	0.0288
MHW		0.045	+0.0576	0.0558	0.0216

As per Table 3, historical water level data indicates that tidal energy is lost between the entrance to Brisbane Water (tidal range is reduced by 495 mm, from 2.05 m measured at the open ocean gauge at Patonga to 1.555 m at Ettalong). There is a further 337 mm attenuation from Ettalong to Koolewong, however there is a negligible (1%) difference in water levels or tidal planes further upstream within Brisbane Waters or along Narara Creek to Manns Road. There is some minor (approximately 3%, but less than 0.05 m) amplification of the tidal range along Erina Creek to the water level gauge at Narrawa Avenue (Erina gauge 212436). Exceedance probability curves for each station are presented in Figure 9.

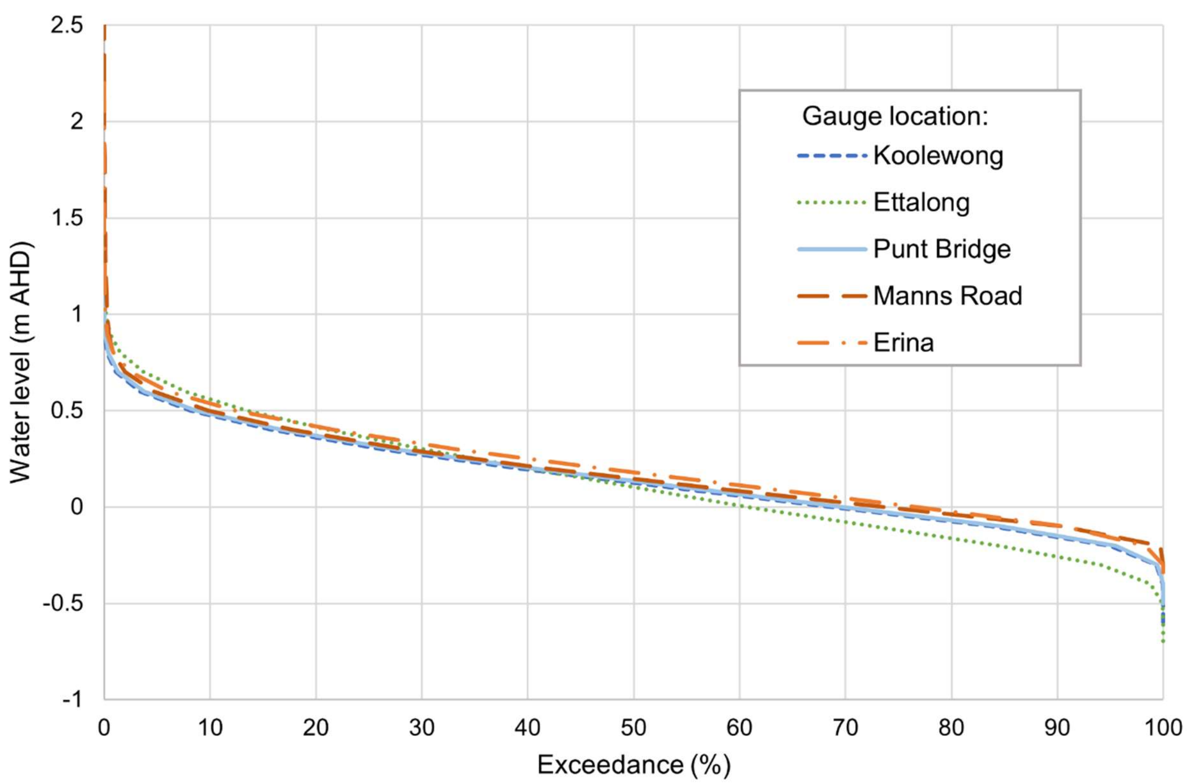

Figure 9 Water level exceedance curves for Brisbane Water

Using data obtained from the Koolewong gauge, the average annual tidal range is 1.02 m, measured from 2001 to 2020, with a mean sea level (MSL) of 0.118 m AHD. This has increased by 0.034 m over the long-term average measured from 1990 to 2010, with greater increases in water levels observed at low tides than at high tides indicating that the tidal range has been progressively attenuated by sea level rise. Similarly, the long-term average tidal range at Ettalong has decreased by 0.021 m with a corresponding increase in the mean sea level of 0.044 m over the same time period. The increases in mean sea level are consistent with local and global measurements, suggesting that global SLR projections can be reasonably applied to Brisbane Water, although future changes to the tidal range may impact how sea level rise is experienced throughout the estuary. A continued reduction in the tidal range is more likely to be experienced if inundation is permitted over additional low-lying ground. Conversely, if future works include hardening of the existing shoreline, reduced frictional losses, and a contraction in the flow area may amplify the tidal range and increase the potential habitat available for intertidal vegetation communities.

2.5.2 Tuggerah Lake

Tuggerah Lake is a coastal lake system that experiences limited tidal exchange (Roberts and Dickinson, 2005). MHL operates two water level gauges within the foreshore area of Tuggerah Lakes and additional gauges approximately 1.2 km upstream within Tumbi Umbi Creek, 3.7 km upstream within Ourimbah Creek and 0.7 km upstream within Wallarah Creek (Figure 10). The daily tidal range is typically less than 100 mm. Long-term exceedance probability curves for each station are presented in Figure 11.

Figure 10 Tuggerah Lakes tidal gauge locations

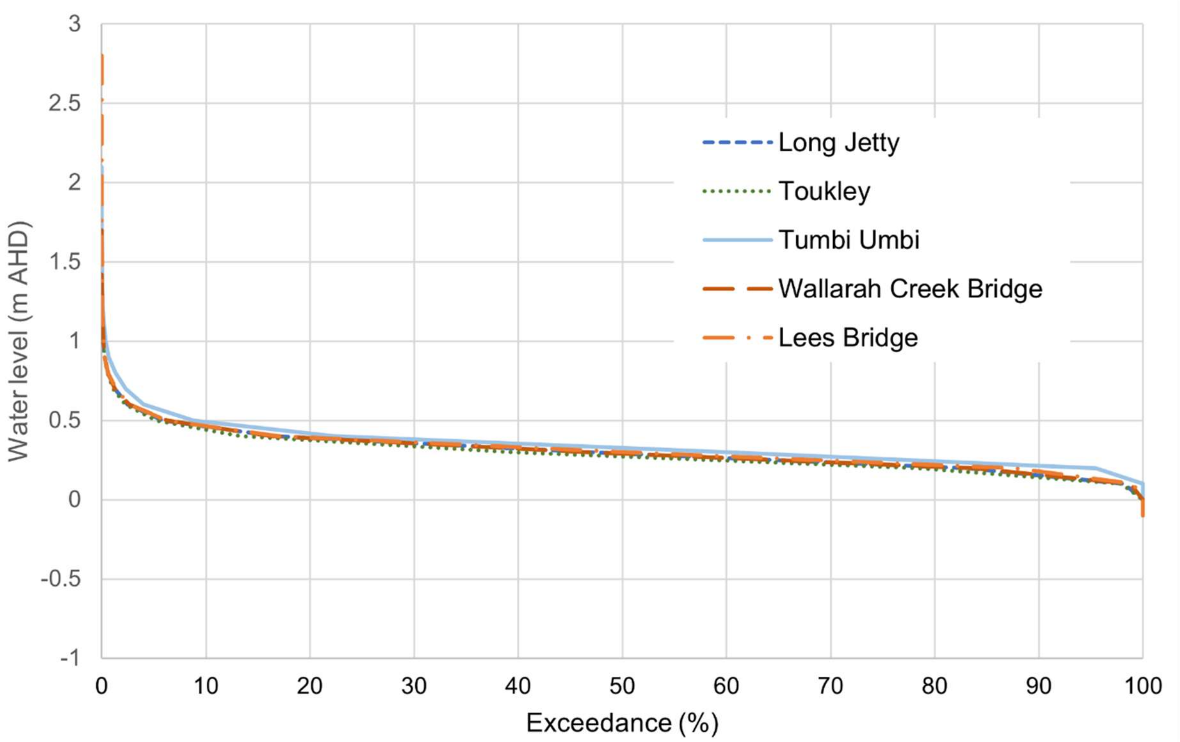

Figure 11 Water level exceedance curves for Tuggerah Lakes

There is no significant difference in water levels or tidal planes within Tuggerah Lakes or along the downstream reaches of the gauged tributaries.

Sea level rise will have significant implications on the management of the entrance to Tuggerah Lake. If present entrance restrictions are not maintained, the tidal range throughout the estuary is likely to increase. As these interactions are complex and require detailed analysis, this study assumed the status quo is maintained and tidal inundation remains limited in the near to far future.

2.6 Future wetland migration opportunities

In addition to changes in existing vegetation communities, sea level rise may facilitate the migration of intertidal vegetation into areas that currently maintain other land uses. Land uses identified in the Central Coast Council Local Environment Plan (LEP 2022) were assessed to identify opportunities for the expansion of tidal wetland habitats into areas that currently maintain Environmental land uses as nominated in Appendix A. Expansion of wetland habitats into other land uses may have significant social and economic implications and have not been considered herein.

2.7 Future tidal wetland vegetation extents

Neither Brisbane Water nor Tuggerah Lakes display a significant variation in the tidal range across the estuary. As such, a static extrapolation of sea level rise is considered reasonable for predicting future tidal conditions. The potential extent of future tidal wetland habitats were determined by adding 0.2 m (near future scenario, nominally 2050) and 0.7 m (far future scenario, nominally 2100) to the existing vegetation downslope and upslope limits, as outlined in Table 5. Future research on tidal inundation patterns may be useful in further confirming this hypothesis.

Table 5 Current and future intertidal wetland vegetation levels (m AHD)

Scenario	Brisbane Water		Tuggerah Lake	
	Downslope intertidal limit	Upslope supratidal limit	Downslope intertidal limit	Upslope supratidal limit
Present day	0.4	2.2	0.6	1.5
Near future (+0.2m)	0.6	2.4	0.8	1.7
Far future (+0.7m)	1.1	2.9	1.3	2.2

Existing wetland extents were based on mapping undertaken by ELA (2020, 2022). As discussed previously, this mapping has the most extensive ground-truthing in the region. GIS analysis was undertaken to establish the potential future extent of a suitable habitat range. Subject to suitable hydraulic connectivity, areas of potential wetland migration were identified as either from the expansion of existing wetland into (i) existing upland vegetation communities or (ii) into present environmental land uses.

3 Results

Future wetland extents were determined based on the area available between the intertidal lower and supratidal upper vegetation limits identified in Table 5 (Section 2.7). The projected change in existing versus potential future tidal wetland vegetation is illustrated in Figure 12 based on the existing and potential future tidal wetland extents for Brisbane Water and Tuggerah Lake that are summarised in Table 6 and Table 7. The spatial distribution of potential losses and gains in tidal wetlands mapped in Figures 13 to 16. More detailed results are presented in Appendices B and C, with tidal wetland losses and gains distributed between the wetland communities as identified by ELA (2020 and 2022). Local suburb and street names are used where further descriptions are required.

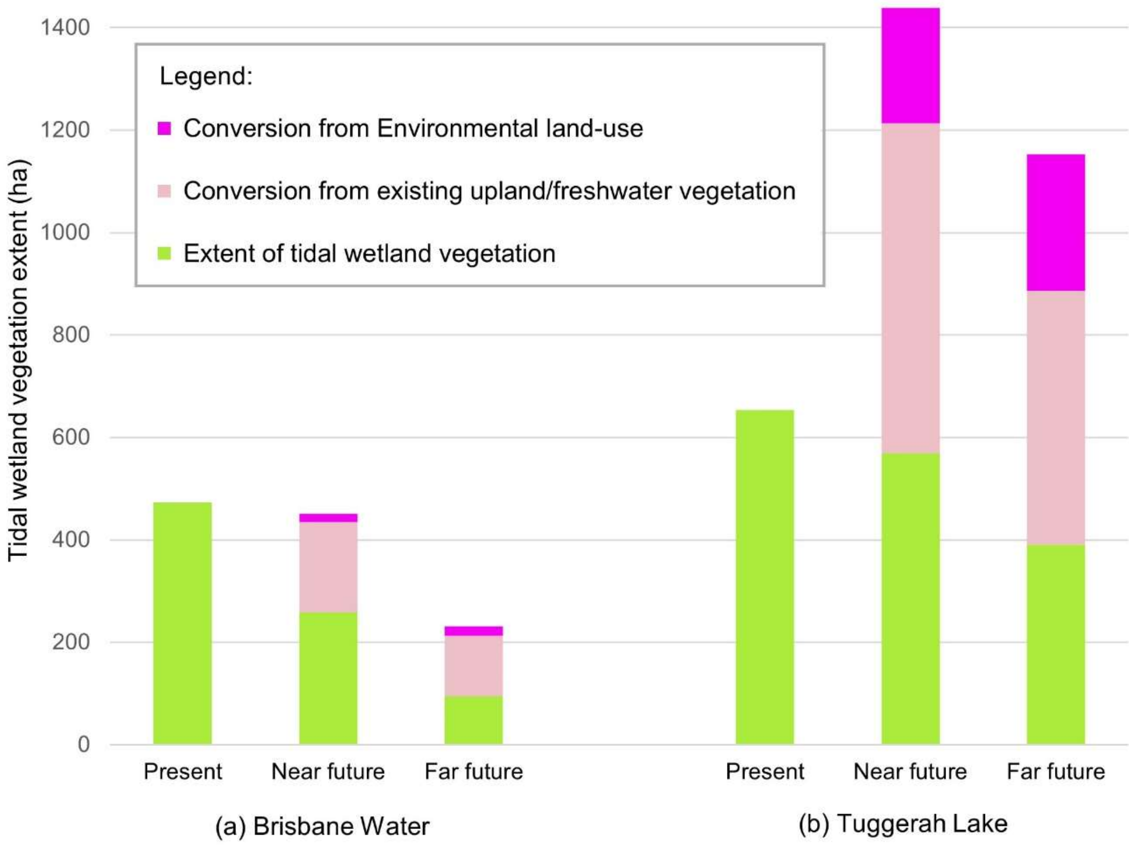

Figure 12 Area of existing and potential future tidal wetland vegetation around (a) Brisbane Water and (b) Tuggerah Lake

Table 6 Existing and potential future vegetation extents for Brisbane Water (ha)

Vegetation extent	Present	Near future	Far future
Intertidal	423.2	222.1	78.9
Supratidal	49.2	35.6	15.5
Total tidal	**472.4**	**257.8**	**94.4**
Upland	306.1	281.8	217.3
Total vegetation	**778.6**	**539.6**	**311.8**
Upland conversion to tidal	-	177.4	118.7
Potential land use change	-	16.0	17.6
Total potential tidal vegetation	-	**451.2**	**230.7**
Net change in tidal vegetation	-	**-21.3**	**-241.8**

Table 7 Existing and potential future vegetation extents for Tuggerah Lakes (ha)

Vegetation extent	Present	Near future	Far future
Intertidal	13.1	2.8	0.8
Supratidal	640.3	566.8	389.4
Total tidal	**653.4**	**569.6**	**390.2**
Upland	2,519.8	2,416.0	2,047.5
Total vegetation	**3245.2**	**2,985.6**	**2,437.7**
Upland conversion to tidal	-	643.4	496.6
Potential land use change	-	225.3	265.6
Total potential tidal vegetation	-	**1,438.3**	**1,152.4**
Net change in tidal vegetation	-	**+ 784.9**	**+ 499.1**

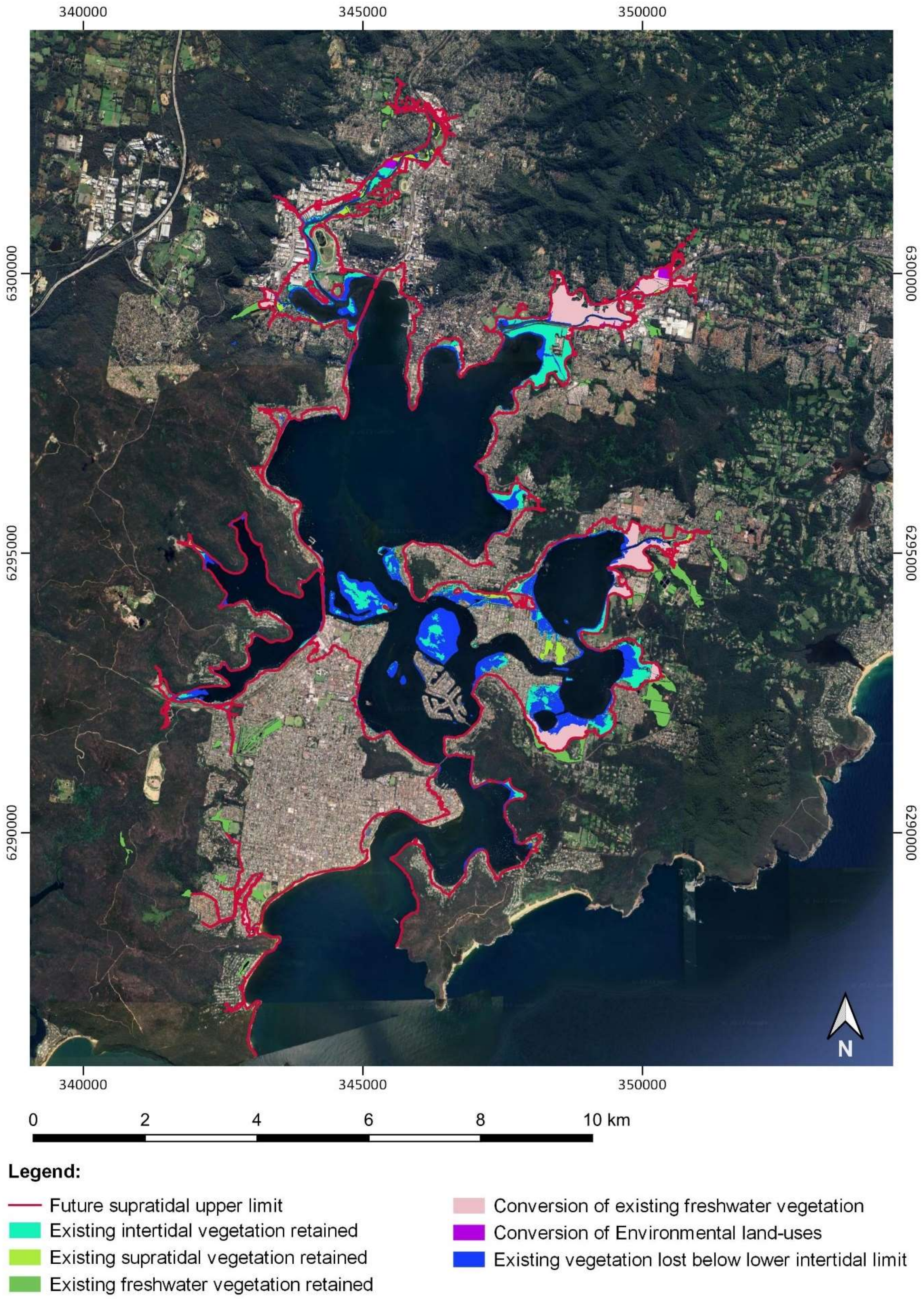

Figure 13 Potential near future (+0.2m sea level rise) changes to tidal wetland vegetation within Brisbane Water

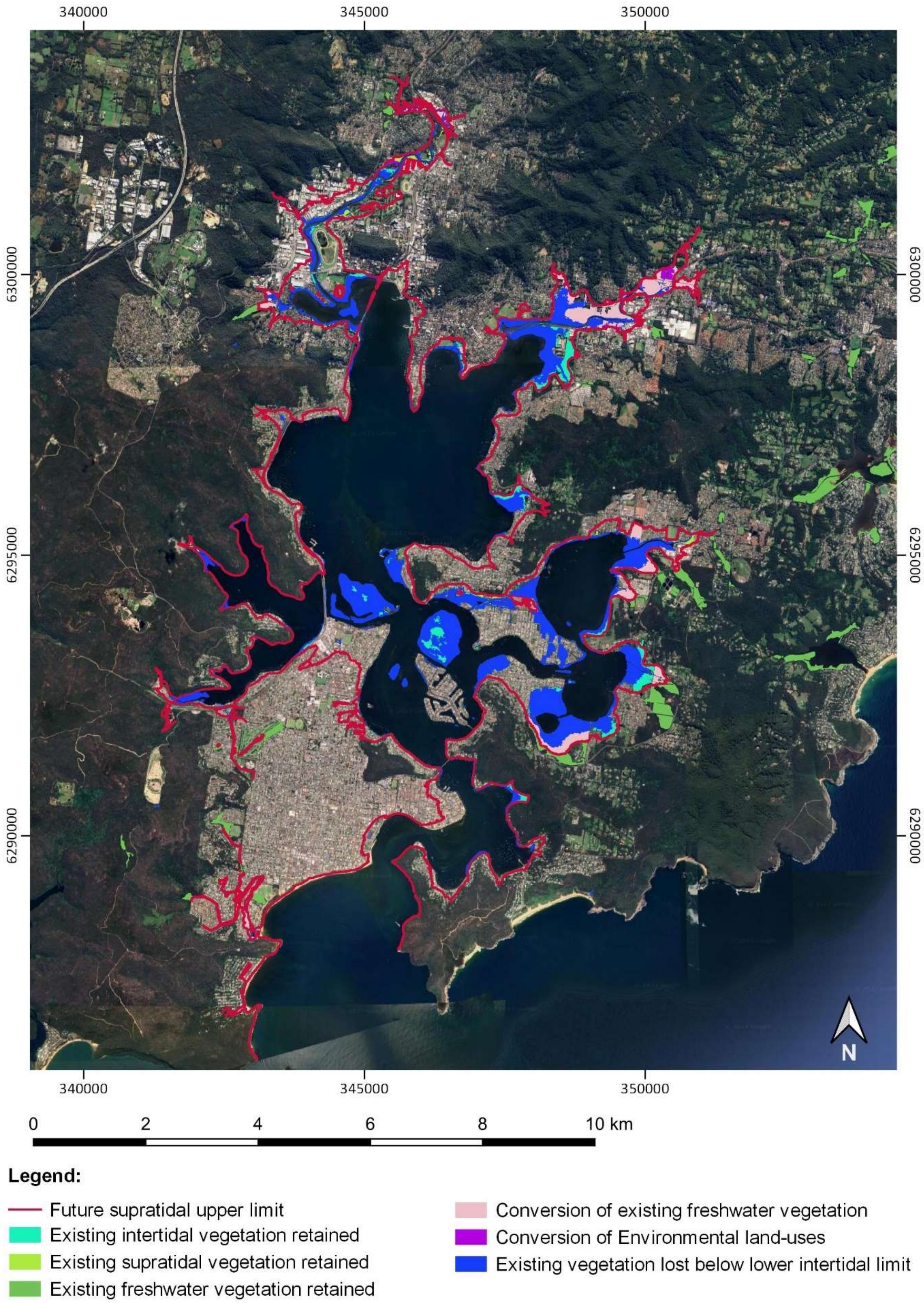

Figure 14 Potential far future (+0.7m sea level rise) changes to tidal wetland vegetation within Brisbane Water

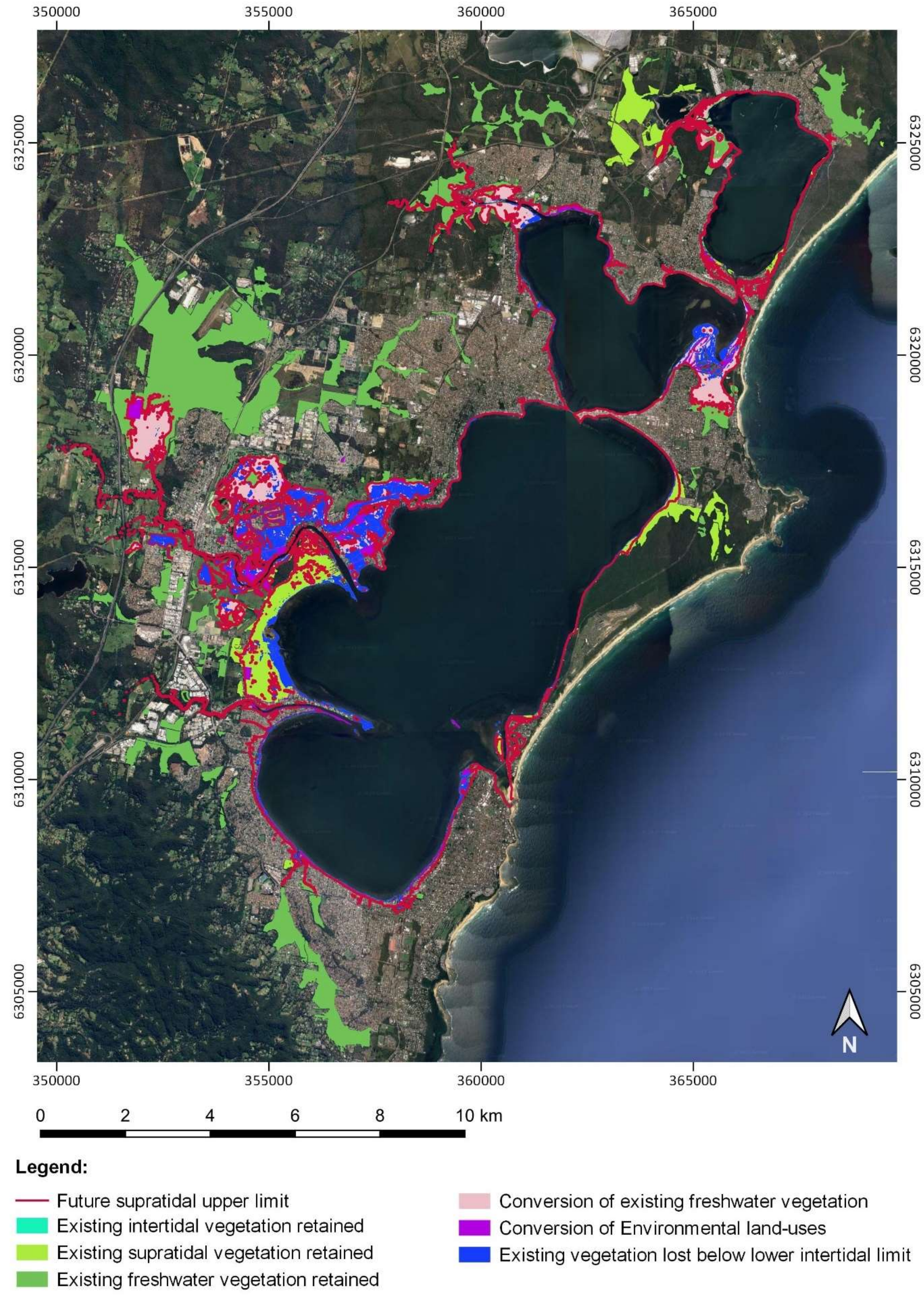

Figure 15 Potential near future (+0.2m sea level rise) changes to tidal wetland vegetation within Tuggerah Lakes

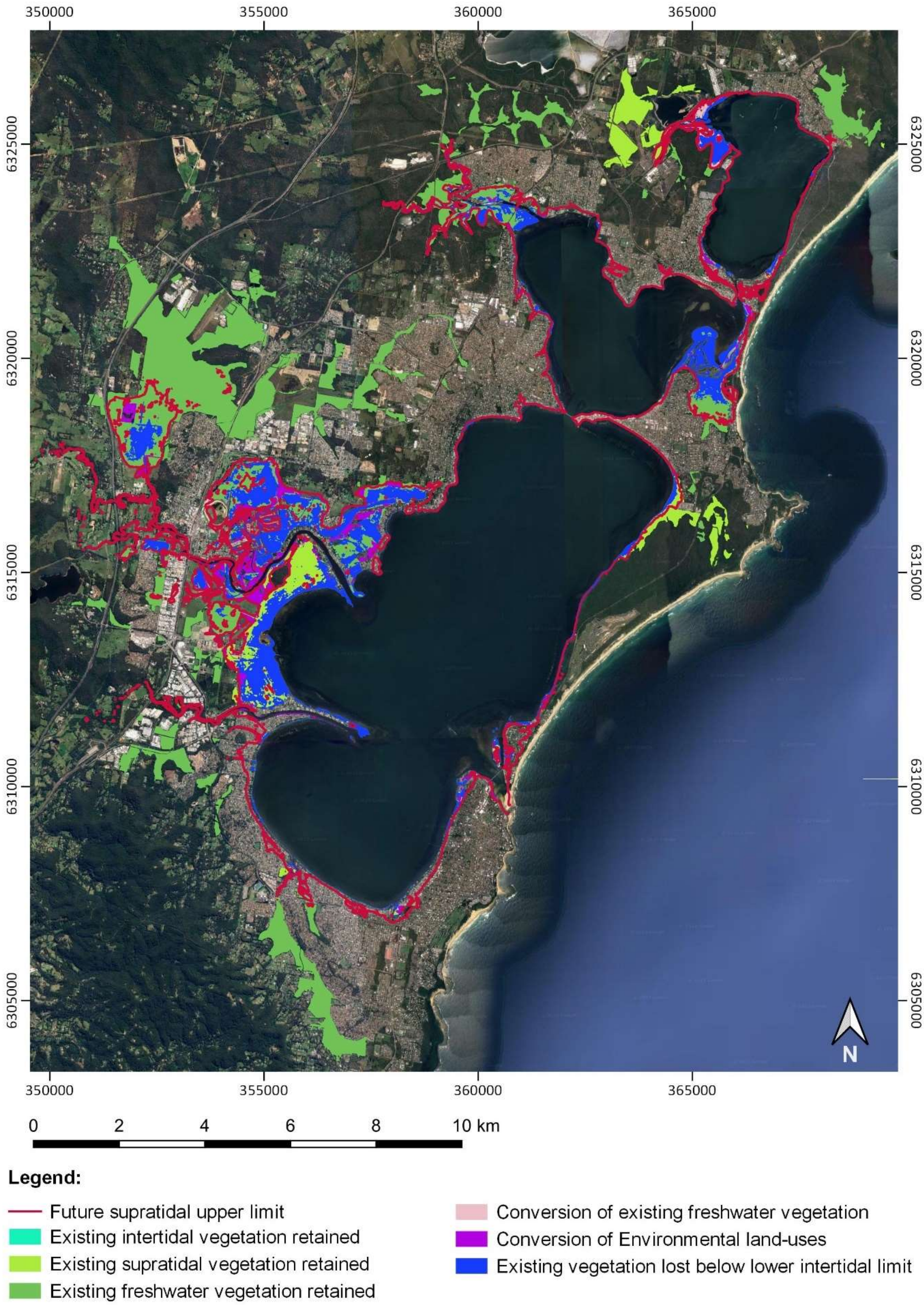

Figure 16 Potential far future (+0.7m sea level rise) changes to tidal wetland vegetation within Tuggerah Lakes

Within Brisbane Water, potential migration pathways for tidal wetlands are limited as they would occur within the residential areas of Woy Woy, Davistown, Empire Bay and Booker Bay (Figure 17). Both Empire Bay and Davistown could provide a connectivity link to existing wetland communities. However, if rising sea levels are precluded from these areas, the most significant future migration opportunities are limited to the riparian zones along Erina Creek. It is worth noting that any potential future increase in intertidal coastal areas would likely come at the loss of upland vegetation in these locations. Additionally, the most significant encroachment of the lower intertidal limit would occur around the existing tidal wetland communities of Cockle Bay, Erina Creek, and Pelican/Riley's Islands, resulting in a net loss of wetland area.

In contrast to Brisbane Water, geospatial mapping indicates refugia areas associated with Tuggerah Lake. Due largely to the limited tidal range, much of the existing tidal vegetation is interspersed within the dominant freshwater wetland species. As indicated in Figure 12, tidal wetland migration upslope would predominantly occur at the expense of freshwater wetlands, which, in turn, will increase coastal squeeze pressures.

For the purposes of this assessment, no allowance has been made for vertical accretion, which will be affected by numerous factors, including local rates of sea level rise, sediment supply and energy conditions. Nevertheless, the foreshores of Brisbane Water and Tuggerah Lakes accommodate numerous small, localised fringing wetland communities with limited horizontal accommodation space. Both waterbodies also contain a number of expansive intertidal flats that may sustain or even increase future wetland extents under favourable conditions. These include areas such as Cockle Bay, Rileys and Pelican Islands, Saratoga and Erina Creek in Brisbane Water, or Tuggerah Swamp and Toukley Wetlands in Tuggerah Lakes. These zones of accretion potential are typified at Tuggerah Swamp, where the complexity of the topography (Figure 19) and vegetation (Figure 20) within the intertidal zone may shelter a relatively low energy accretion environment that provides an opportunity for extensive ponding and sediment deposition. In these locations, accretive conditions could be enhanced by proactive adaptation measures such as freshwater flow diversion, the installation of energy dissipation structures, or the diversion of dredging spoils. Further investigations are required to better understand and monitor the accretion potential at key sites.

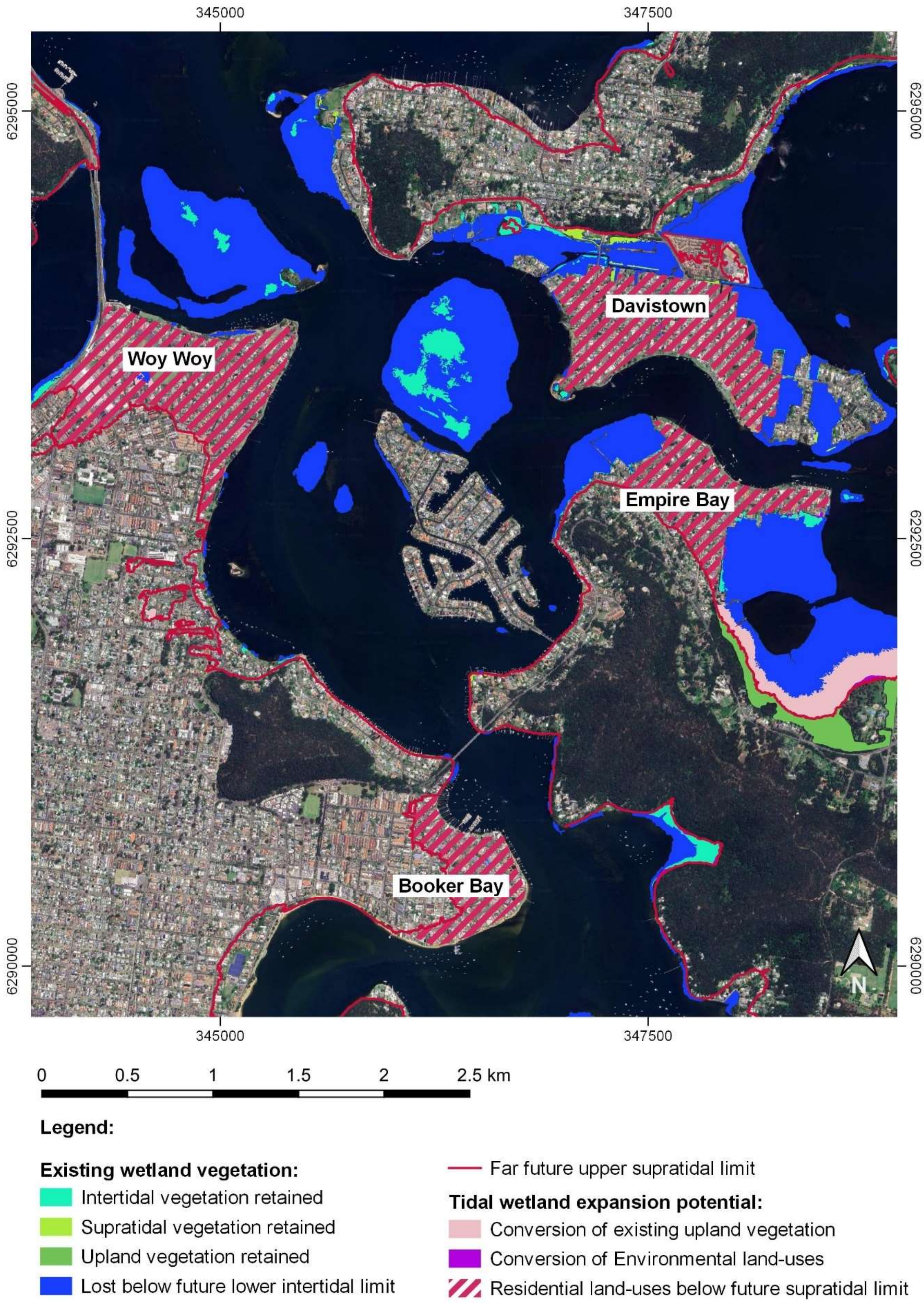

Figure 17 Potential far future tidal wetland migration areas in Brisbane Water is limited by existing residential land use

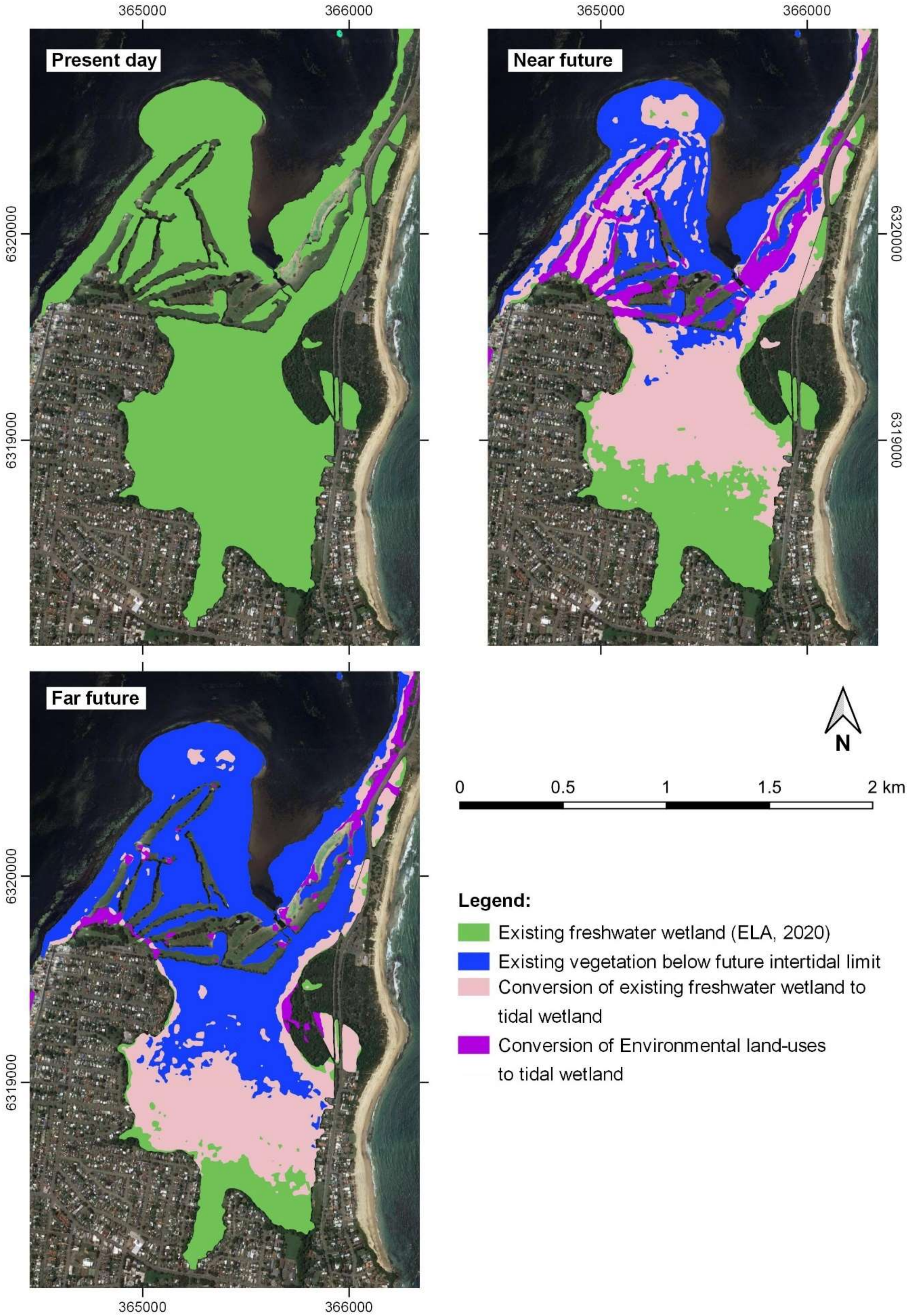

Figure 18 Toukley wetlands in Budgewoi Lake provide an example of potential future tidal wetland migration into existing freshwater wetland landscapes.

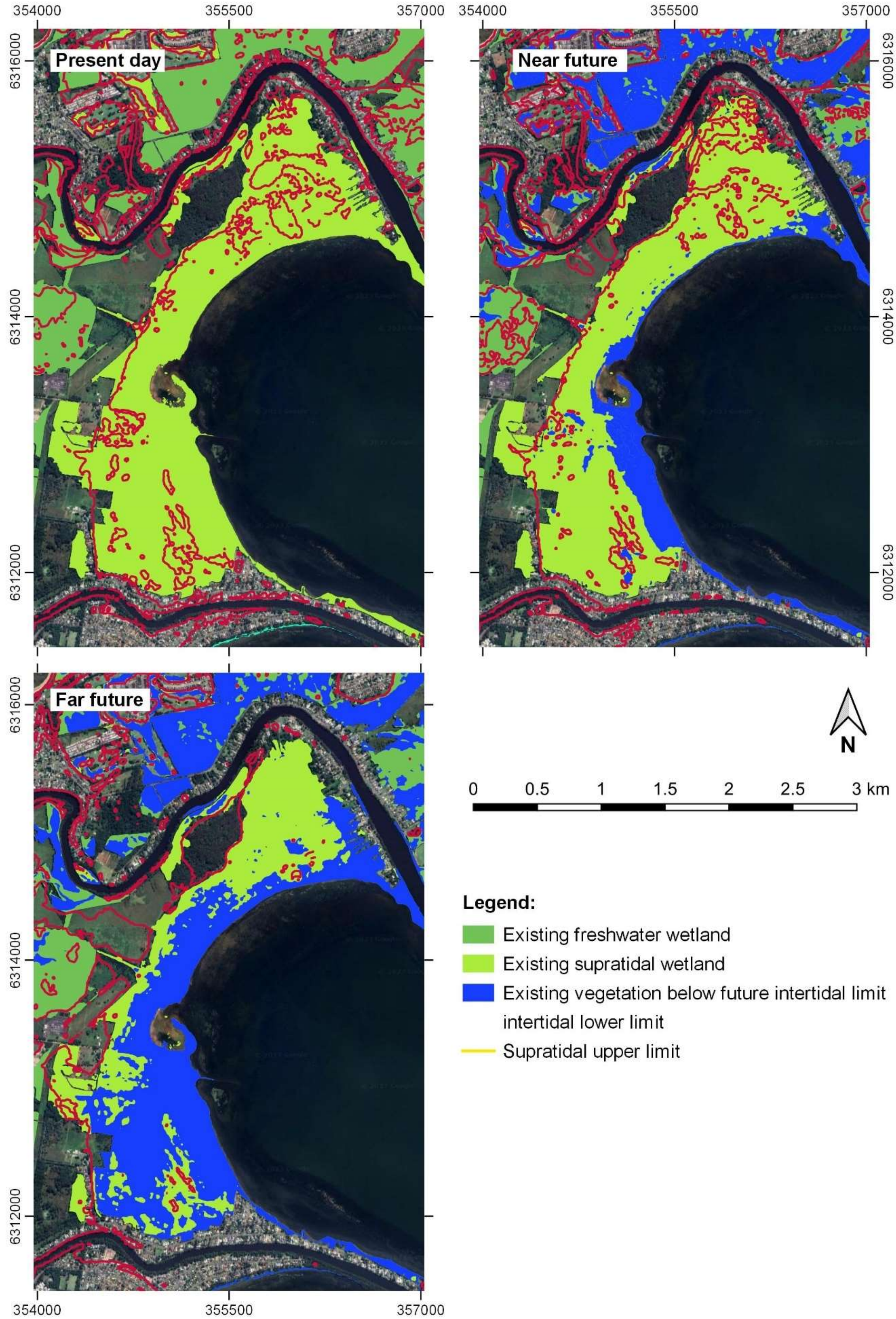

Figure 19 Tuggerah Swamp typifies areas where complex topography may increase ecosystem resilience and provide opportunity for vertical accretion.

Figure 20 A broad mosaic of intertidal and supratidal vegetation at Tuggerah Swamp may help to increase ecosystem resilience.

4 Discussion

This study has developed and applied a geospatial approach to estimate how intertidal and supratidal ecosystems in Brisbane Water and Tuggerah Lakes, on the NSW's Central Coast, may transition under the effects of sea level rise. The study relies on accurate mapping of the existing wetland vegetation, the local topography, and predictions of existing and future tidal water levels. In combining these three primary data sources and estimating upper and lower vegetation slope limits under existing conditions, future intertidal and supratidal locations were overlaid on existing land-use maps. The results from the study should be viewed as approximate estimates of conditions suitable for intertidal ecosystems. The actual location may vary due to a range of onsite and environmental conditions.

This study has five (5) main outcomes:

- Substantial areas of existing coastal wetland habitat are likely to be affected by sea level rise;
- Upslope retreat options are spatially variable, with existing freshwater wetland habitat the most likely retreat scenario;
- Estuarine geomorphology is likely to influence sea level rise, resulting in site specific outcomes for coastal wetlands;
- Rising sea levels present a threat to various assets including housing and infrastructure. Climate change transition plans for the entire estuary are necessary to determine how these broader management decisions may influence tidal dynamics and/or land-use zonings.
- Predicted losses in coastal wetland area do not consider potential vertical accretion onsite. However, there are many unknowns related to vertical accretion (e.g. can it maintain pace with sea level rise, or is it spatially uniform across an estuary) requiring further investigation.

This section expands on these outcomes and provides recommendations for next steps.

4.1 Brisbane Water

Results from this study highlight that every estuary is likely to evolve in a unique fashion. In comparison to Tuggerah Lakes, Brisbane Water has limited coastal wetland refugia space and sea level rise is likely to result in reduced intertidal vegetation. Many of the existing coastal wetlands in Brisbane Waters are either located within a thin linear strip along the foreshore, with upslope accommodation space limited by residential housing, infrastructure and topography, or on low-lying islands or deltas. Figure 13 and Figure 14 highlight the projected losses in coastal wetlands, with approximately 50% of the existing coastal wetlands projected to remain in the far future scenario (Figure 12). While some of these losses may be offset by the transition of supratidal landscapes to intertidal landscapes, there is insufficient land available at this elevation to offset the loss. Further, it is likely that there will be additional impacts within the intertidal zone as mangrove forests encroach upon existing saltmarsh habitat.

The Brisbane Water analysis highlights the challenges associated with residential housing located on very low-lying lands. As depicted in Figure 17, several low-lying residential developments will face challenging circumstances under future sea level rise conditions with large parts of Davistown, Woy Woy and Empire Bay directly impacted. In addition to the potential for sunny day flooding, these areas will also have to manage elevated groundwater conditions (saturated substrate), reduced drainage, and salinisation. In combination, the predicted losses in coastal wetland area, the limited opportunities for upslope wetland refugia, and the broadacre threats to residential housing zones, suggest that a transition plan is urgently needed for the Brisbane Water's region.

4.2 Tuggerah Lakes

Broadly speaking, Tuggerah Lakes appears to have wetland refugia potential under rising sea levels. This refugia ensures that upslope areas are initially available for coastal wetland migration (near future scenario). However, as per Figure 16, if sea level rise continues this accommodation space will be affected and the overall area will decrease (far future scenario). Further, the existing ring of intertidal wetland vegetation near residential properties, especially on the southern foreshores of Tuggerah Lakes, is likely to be inundated and may be lost to sea level rise. These wetland areas are particularly important as they provide nutrient abatement services to the waterbody and a range of other ecosystem services.

It is worth noting that areas projected to foster new intertidal habitat are largely existing freshwater wetlands that are valued by the local community and provide freshwater wetland refugia ecosystem services. The conversion of these lands from freshwater to saltwater is likely to result in a transition period where freshwater species will decay/retreat and brackish/saltwater species encroach. Based on similar sites elsewhere, this transition period may last years, if not decades, and requires careful management. Other lands that may be converted for coastal wetland refugia include various environmental land zonings such as National Park, Conservation Lands or Environmental Conservation (see Appendix A for a full list). The management of these lands will also need to be considered under sea level rise.

One particularly challenging aspect in assessing Tuggerah Lakes is the potential future tidal dynamics at The Entrance. Changes to the oceanic entrance conditions may result in changes to the tidal dynamics within the waterbody, either via natural or artificial means. As such, the existing tidal dynamics may not be an effective indicator of the future circumstances. It is recommended that a broader transition study for the entirety of Tuggerah Lakes catchment is undertaken and a vision for the region developed. In consultation with the community, this overarching management plan can assist in setting an approach to the estuary entrance and tidal dynamics over the next 30-50 years. Outcomes from this study could be subsequently used to determine the potential future tidal inundation regime and the influence on upslope vegetation migration.

4.3 Accretion and natural adaptation potential

Based on the above analysis, the role of sediment accumulation is worth further analysis. In this study, a conservative approach has been taken that did not account for vertical accretion with time. This implies that as the sea level rises the landform will remain unchanged. However, there is ample evidence to suggest that both organic and inorganic sediment accumulation will occur. Saintilan et al. (2020) noted that the accumulation rate within coastal wetlands will maintain pace with sea level rise until the rate of change exceeds approximately 6 mm/annum (recent rates were shown to exceed 4.6 mm per year for the 2013-2022 period; rates beyond 6 mm/year are expected to occur in the next 30 years). Nonetheless, if estuarine accretion rates can be maintained in line with sea level rise there remains a chance that mature ecosystems could sustain higher sea levels.

At a local level, this analysis suggests that some of the larger islands in Brisbane Water that are covered in intertidal vegetation may persist beyond the predictions provided in this study. This is also the case in Tuggerah Lakes with areas such as Tuggerah Swamp (as illustrated in Figure 19), Colongra Swamp, Porters Creek, Toukley, Tacoma, Wyong Racecourse and Lower Pioneer Dairy Dam wetlands requiring ongoing accretion to avoid inundation in far future sea level rise scenarios. Monitoring and regular analyses of the accretion potential may be useful to understand the potential threats posed by tidal inundation.

In addition to accretion, natural biophysical adaptations may also ensure that coastal wetlands can persist for longer than predicted in this study. For instance, grey mangroves (*Avicennia marina*) have a range of biophysical adaptation measures, such as extending lateral roots or elongating pneumatophores, that may help the trees adapt to the local climate pressures. These adaptive mechanisms are likely to be greater in mature trees, such as those that already exist in the region, than in recently established trees. However, limited information is currently available on these adaptive mechanisms and how they can play a role in adapting to chronic and acute stressors.

Based on the results from this study, a transition plan may be required to determine how different interventions may artificially preserve sites while others are abandoned to the tide. Interventions, such as the "Tidal Replicate Method" described by Sadat-Noori *et al*. (2021), have been used elsewhere to ensure that low-lying areas are protected from being lost to the tide. This may be particularly important along tributaries such as Porter's, Erina and Narara Creeks. In other sediment-starved locations worldwide, dredged sediments have been applied to low-lying landscapes to foster accretion and ensure that existing tidal patterns are maintained. Based on the local circumstances and desires, these options may be required if natural mechanisms are insufficient.

Overall, the method used in this study applied a geospatial approach linking existing vegetation type and tidal data to sea level rise. However, geospatial approaches correlating multi-variables are static and fail to take into consideration dynamic factors, such as accretion or other short-term events that have deleterious effects on ecosystem health. As such, this type of analysis does not denote 'why' these variables are important or the influence of alternative stressors on the lifecycle of the plant. New alternative methods are emerging that focus on a broader lifecycle approach, examining the growth and morbidity of a plant throughout different lifecycle stages. This approach ensures that critical events that influence extent and distribution are considered to explain why a certain species flourishes or dies. To this aim, it is recommended that future studies examining vegetation migration patterns under sea level rise consider new emerging approaches aligned with best practice.

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Appendix A Assigned land uses

Land uses identified in the Central Coast Council Local Environment Plan (LEP 2022) were grouped into land value categories (Table A-1) to simplify the assessment and presentation of opportunities for the expansion of tidal wetland habitats into areas that currently maintain environmental values. Council owned land was similarly classified (Table A-2).

Table A-1 Categorisation of land uses under Central Coast LEP 2022 land zoning map

LEP 2022 land zone	Land value category
Business Development	Commercial/Industrial
Business Park	Commercial/Industrial
Commercial Core	Commercial/Industrial
Deferred Matter	Other
Enterprise Corridor	Commercial/Industrial
Environmental Conservation	Environmental
Environmental Living	Residential
Environmental Management	Environmental
Forestry	Environmental
General Industrial	Commercial/Industrial
General Residential	Residential
Infrastructure	Commercial/Industrial
Large Lot Residential	Residential
Light Industrial	Commercial/Industrial
Local Centre	Commercial/Industrial
Low Density Residential	Residential
Medium Density Residential	Residential
Mixed Use	Commercial/Industrial
National Parks and Nature Reserves	Environmental

Table A-1 (cont'd) Categorisation of land uses under Central Coast LEP 2022 land zoning map

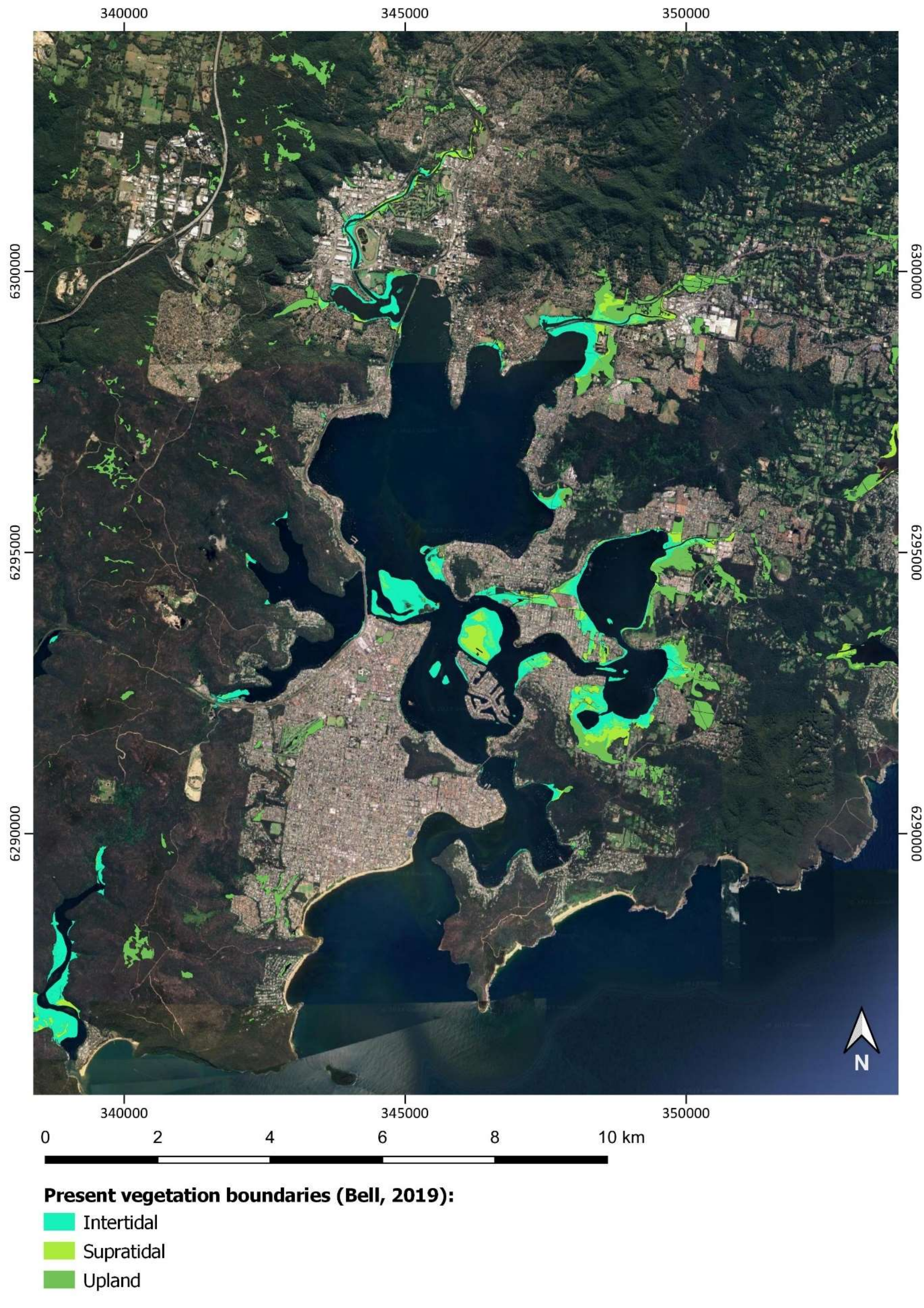
LEP 2022 land zone	Land value category
Natural Waterways	Waterways
Neighbourhood Centre	Commercial/Industrial
Primary Production	Rural/Agricultural
Private Recreation	Recreation
Public Recreation	Recreation
Recreational Waterways	Waterways
Rural Landscape	Rural/Agricultural
Special Activities	Commercial/Industrial
Tourist	Commercial/Industrial
Transition	Environmental
Unzoned Land	Other
Village	Commercial/Industrial
Working Waterfront	Commercial/Industrial
Other	Other

Table A-2 Categorisation of council owned land uses

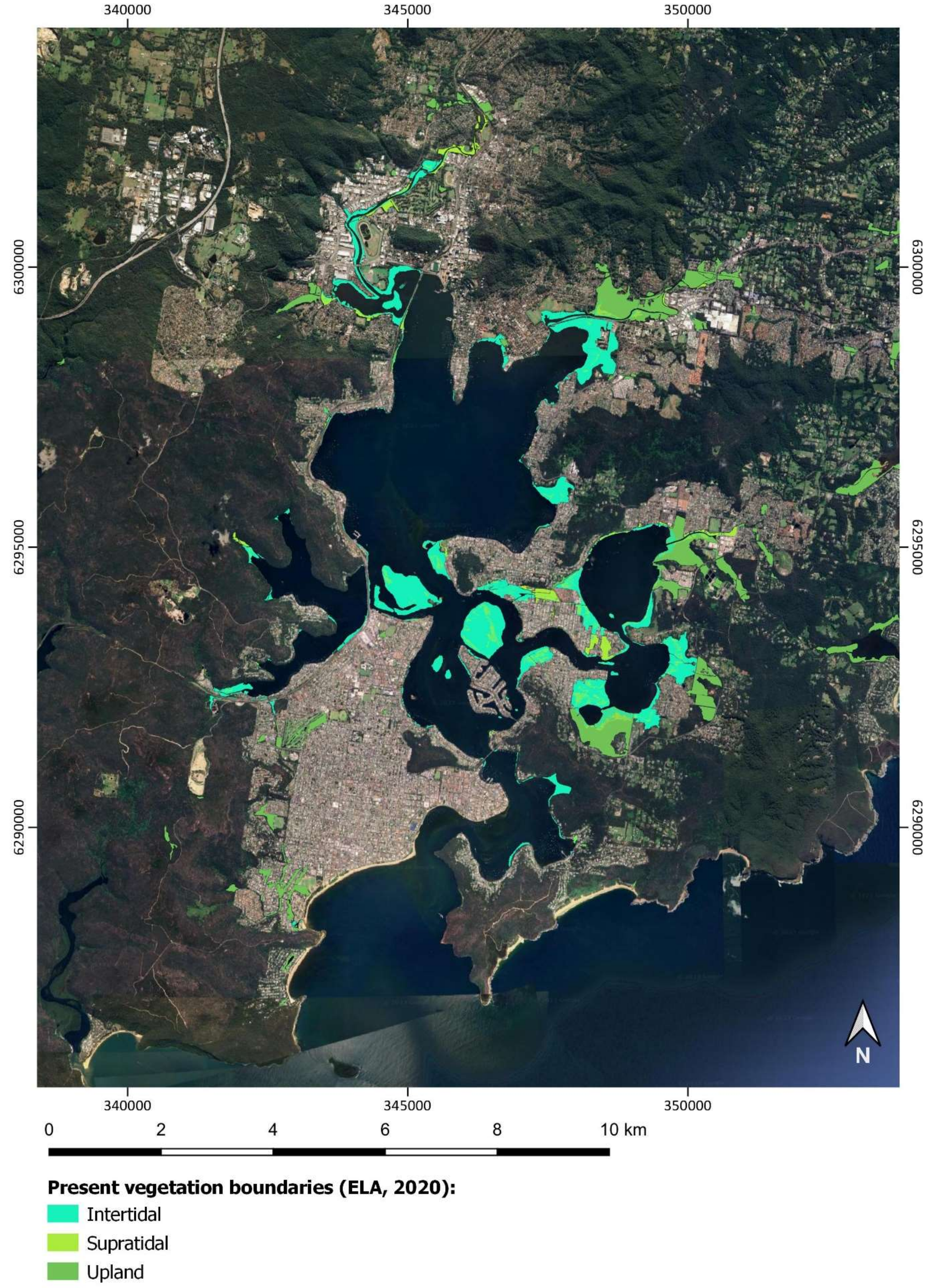
Council owned land use	Land value category
Operational	Commercial/Industrial
Community	Recreation
Crown Reserve Trusts	Environmental
Crown	Environmental
Other	Other

Appendix B Existing and potential future tidal wetland extents within Brisbane Water

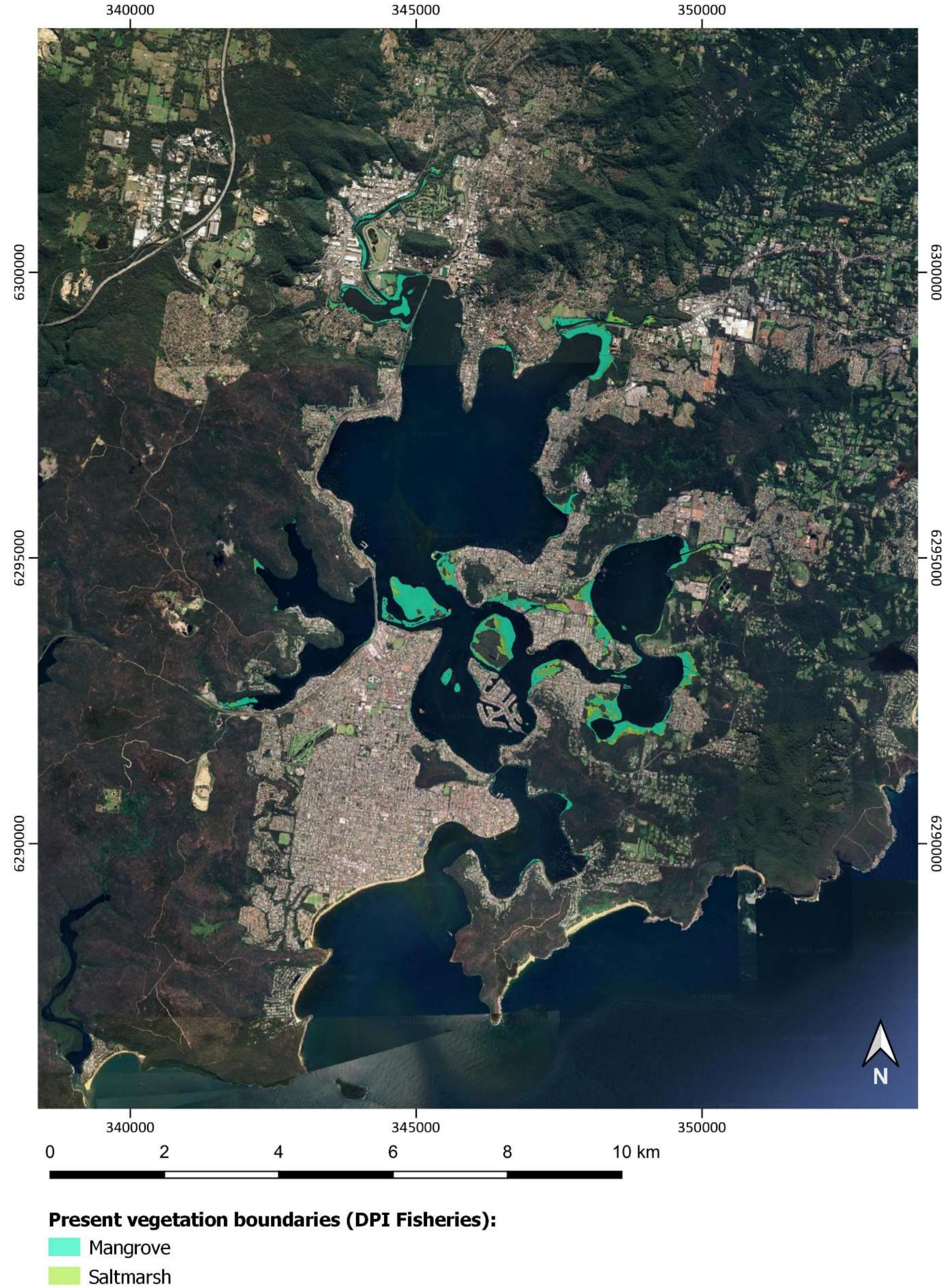
Existing and potential future vegetation extents within Brisbane Water were summarised in Table 6 and are mapped in Figures B-1 to B-15. Digital copies of these maps are supplied in the Compendium accompanying this report. A detailed listing of existing and predicted vegetation extents within each vegetation precinct identified by ELA (2022) is included in Table B-1 for the near future climate scenario and Table B-2 for the far future climate scenario.



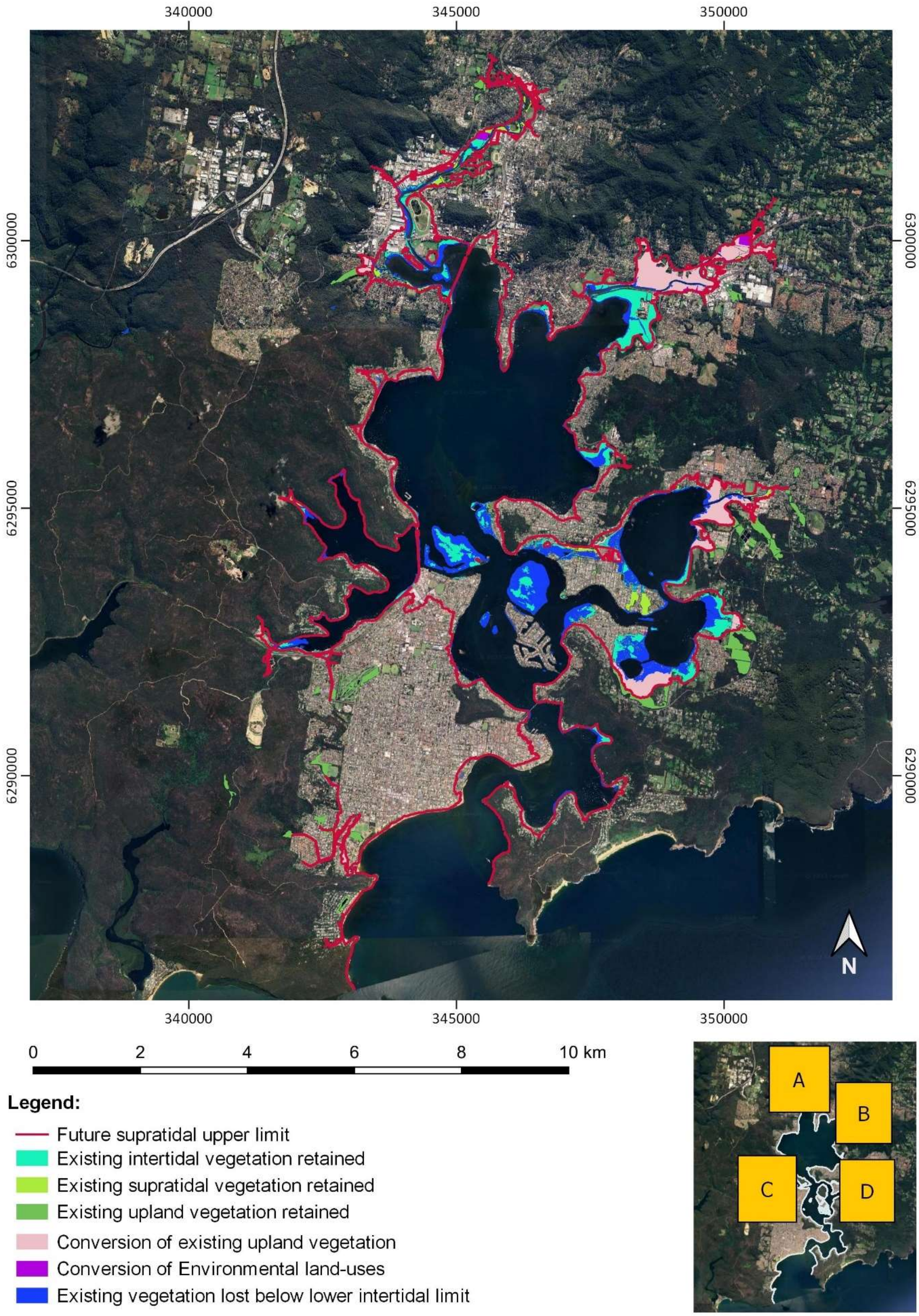
B-1 Existing vegetation extents mapped by Bell (2019)



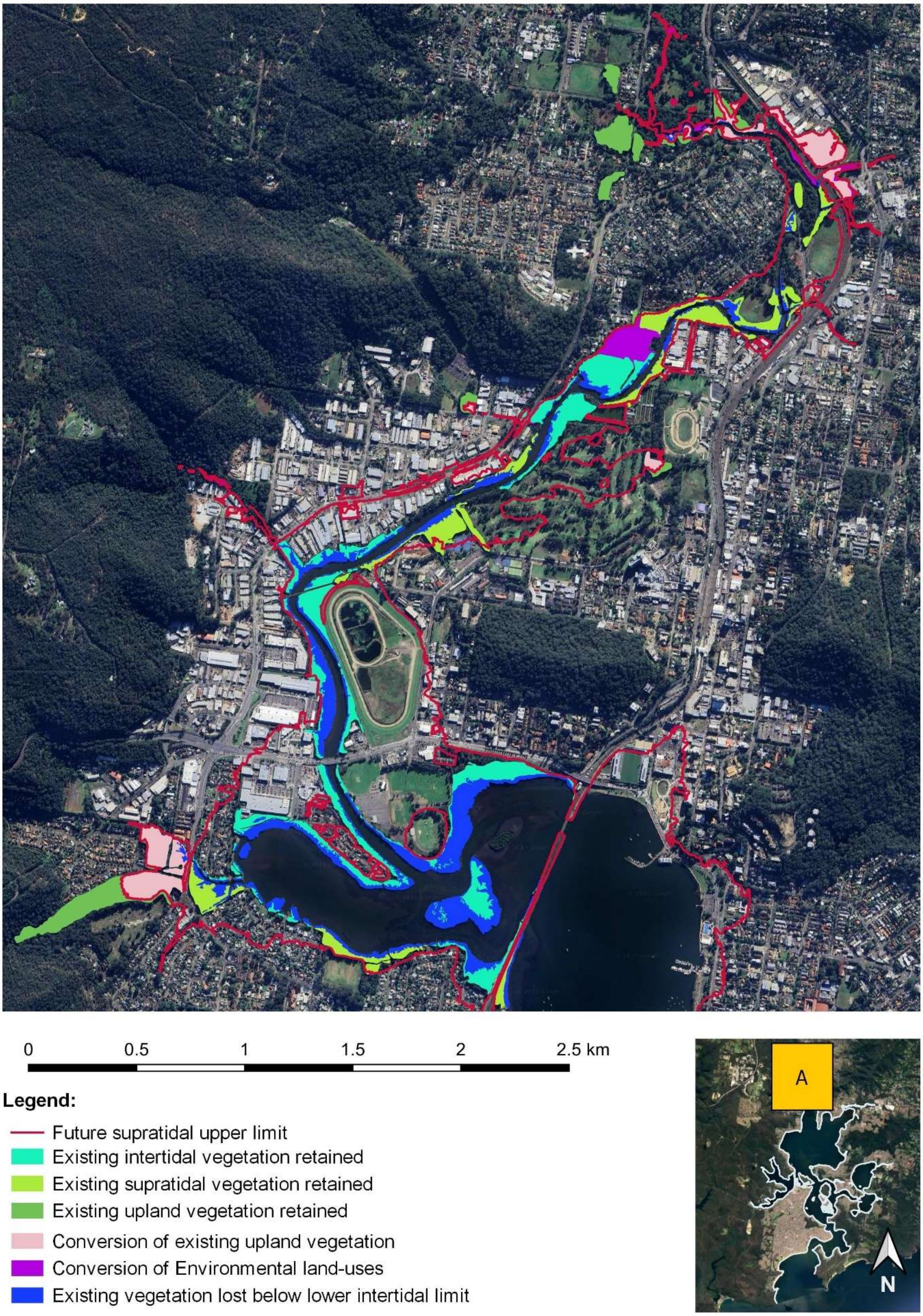
B-2 Existing vegetation extents mapped by ELA (2022)



B-3 Existing intertidal vegetation extents mapped by DPI Fisheries

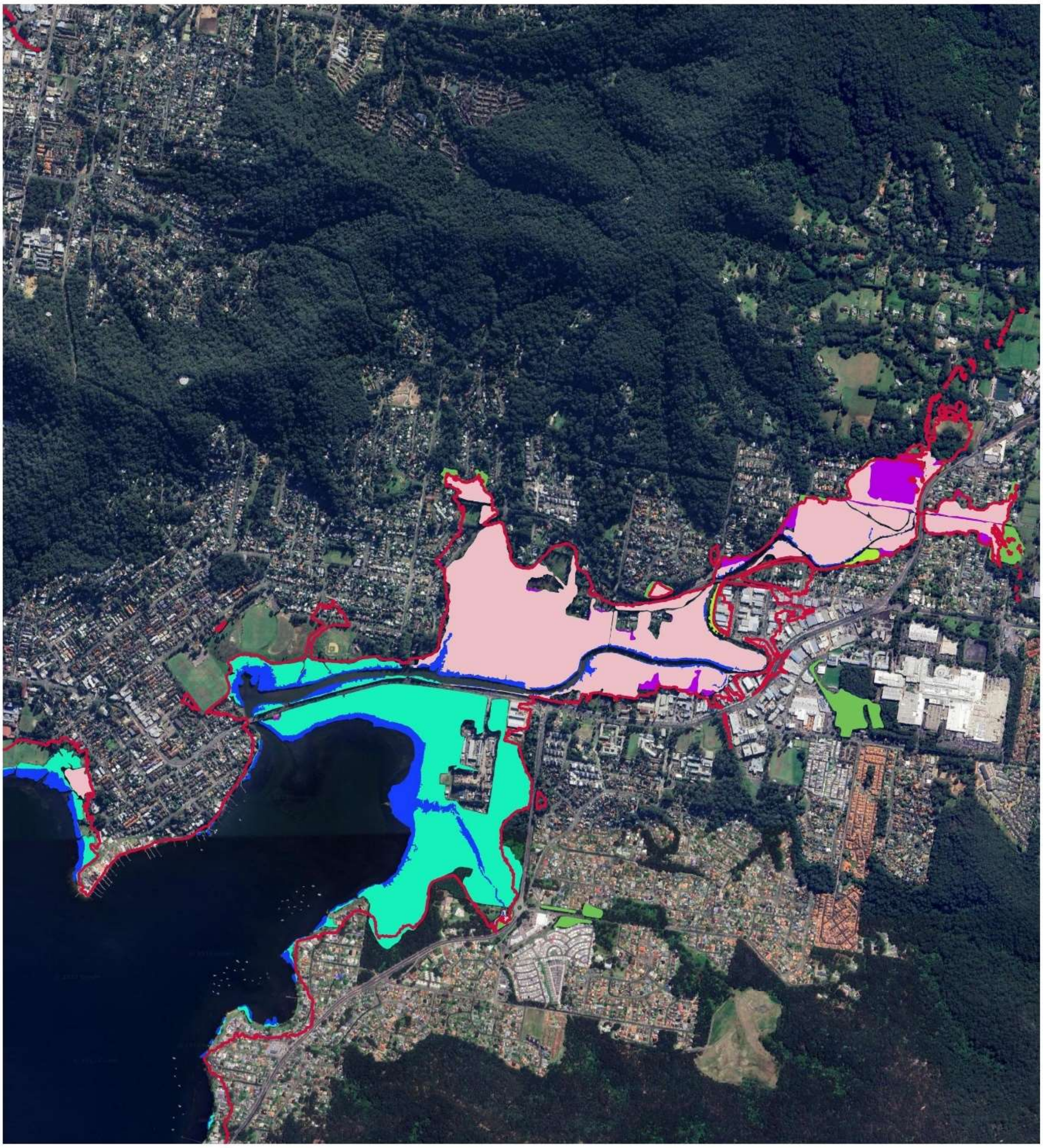


B-4 Near future (+0.2m SLR) intertidal vegetation potential for Brisbane Waters – overview



B-5 Near future (+0.2m SLR) intertidal vegetation potential for Brisbane Waters – Map A

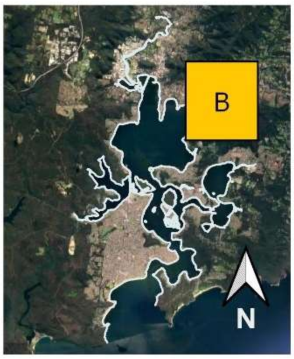
Narara Creek



0 0.5 1 1.5 2 2.5 km

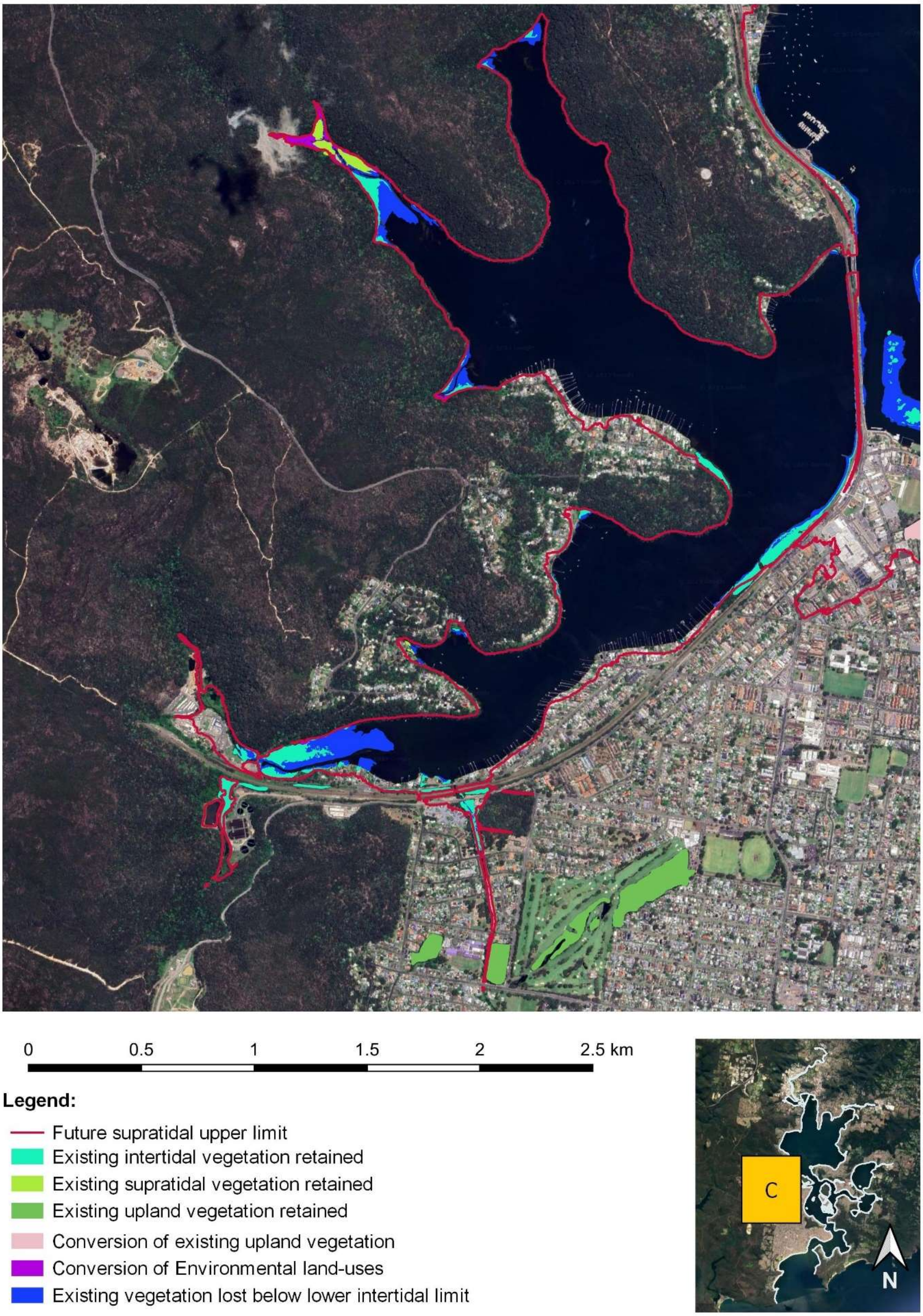
Legend:

- Future supratidal upper limit
- Existing intertidal vegetation retained
- Existing supratidal vegetation retained
- Existing upland vegetation retained
- Conversion of existing upland vegetation
- Conversion of Environmental land-uses
- Existing vegetation lost below lower intertidal limit



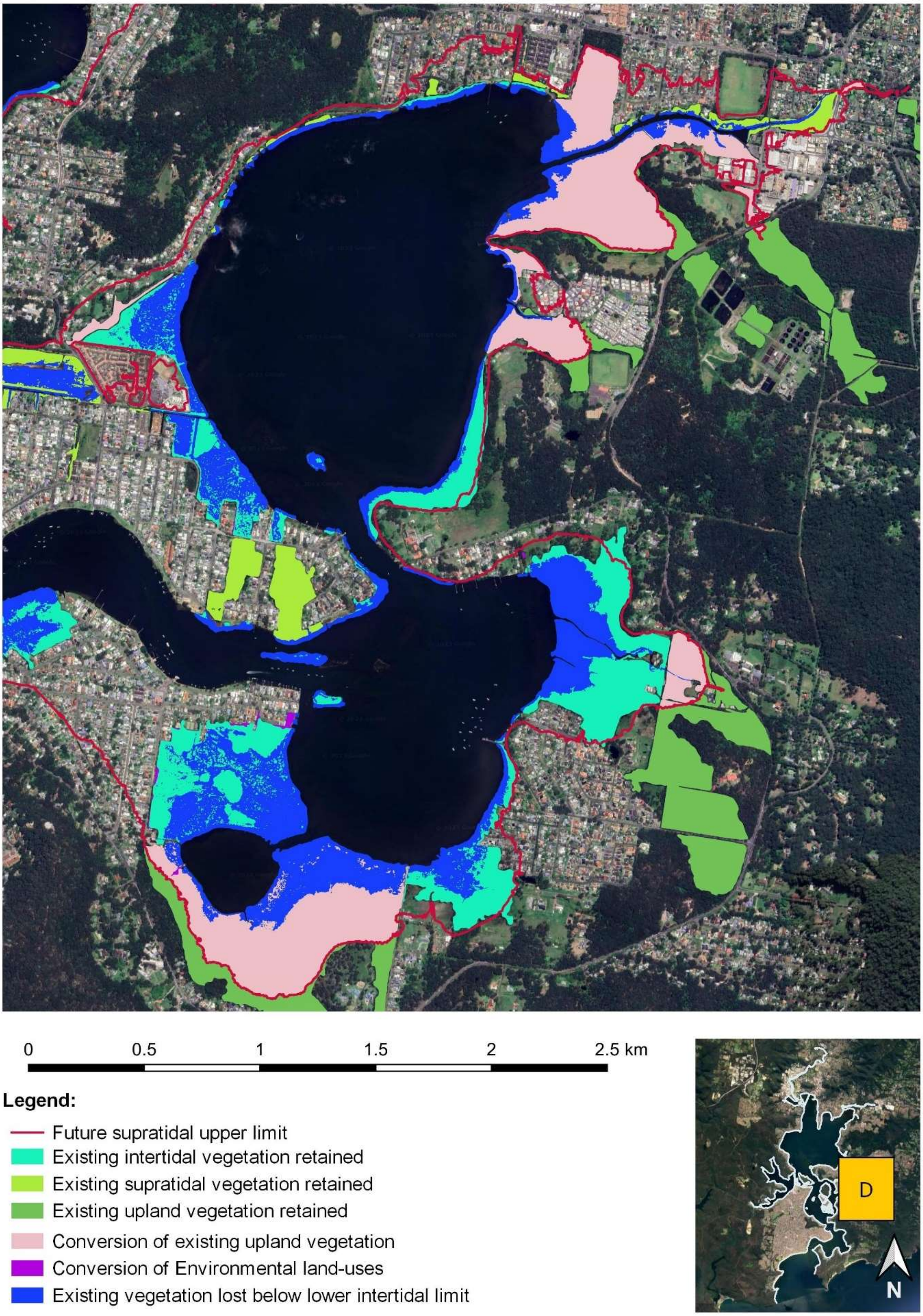
B-6 Near future (+0.2m SLR) intertidal vegetation potential for Brisbane Waters – Map B

Erina Creek



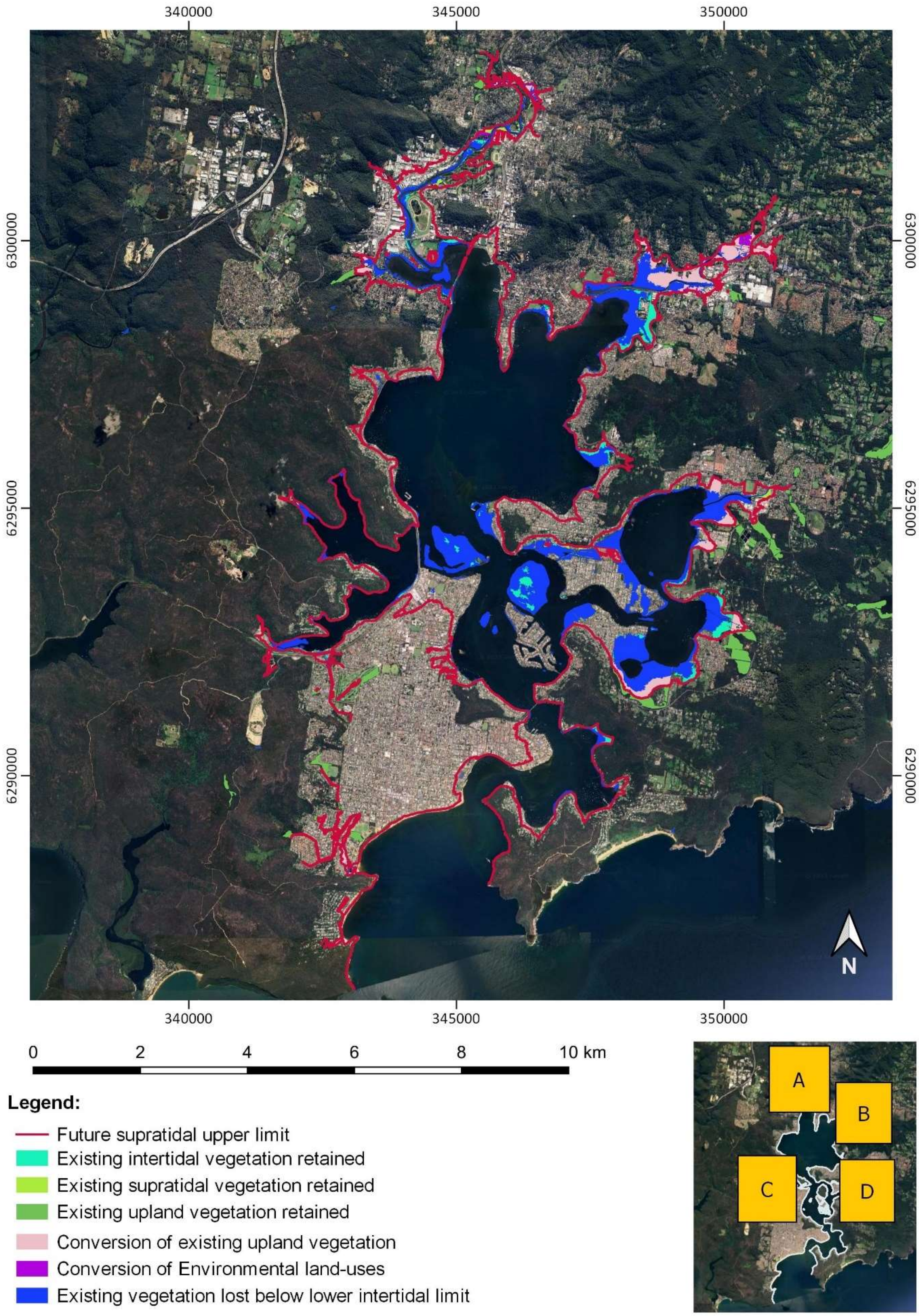
B-7 Near future (+0.2m SLR) intertidal vegetation potential for Brisbane Waters – Map C

Woy Woy Bay

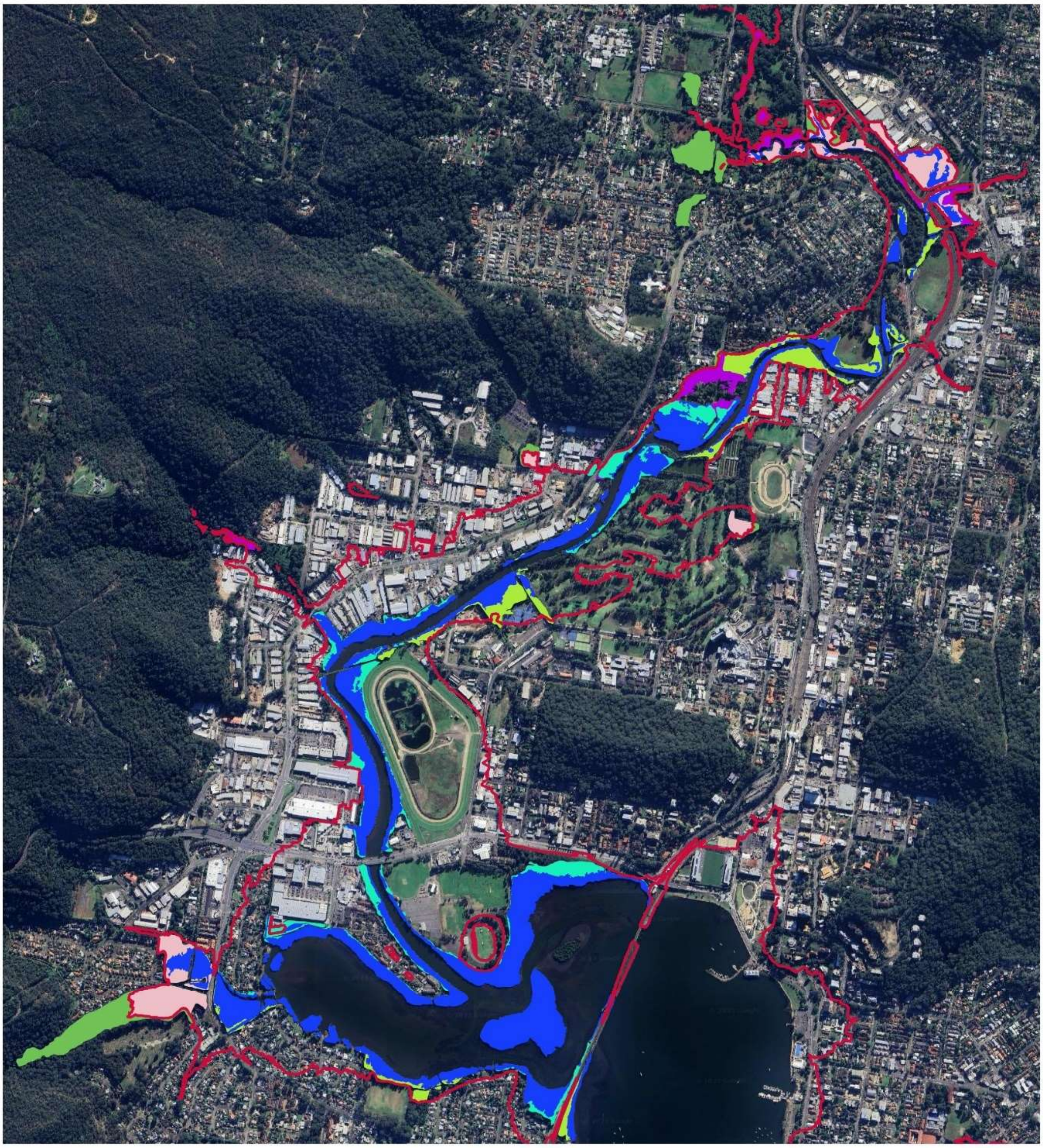


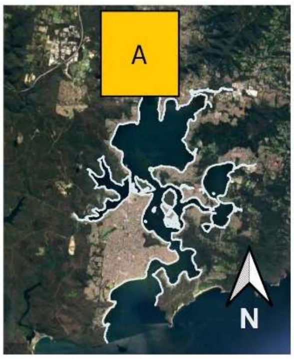
B-8 Near future (+0.2m SLR) intertidal vegetation potential for Brisbane Waters – Map D

Kincumber Broadwater and Cockle Bay



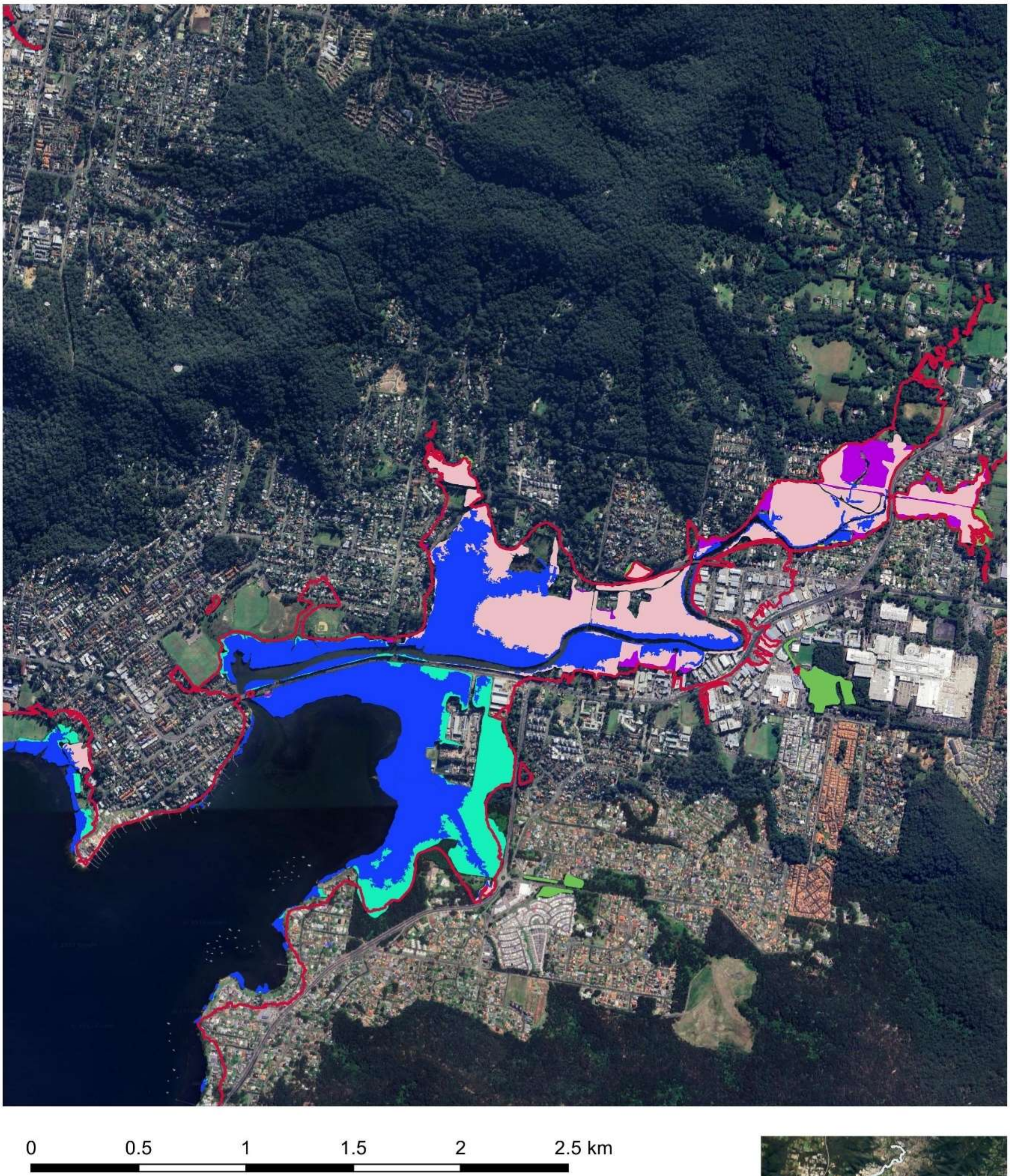
B-9 Far future (+0.7m SLR) intertidal vegetation potential for Brisbane Waters – overview

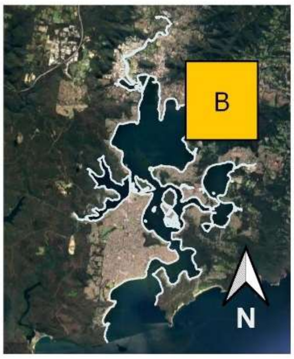




B-10 Far future (+0.7m SLR) intertidal vegetation potential for Brisbane Waters – Map A

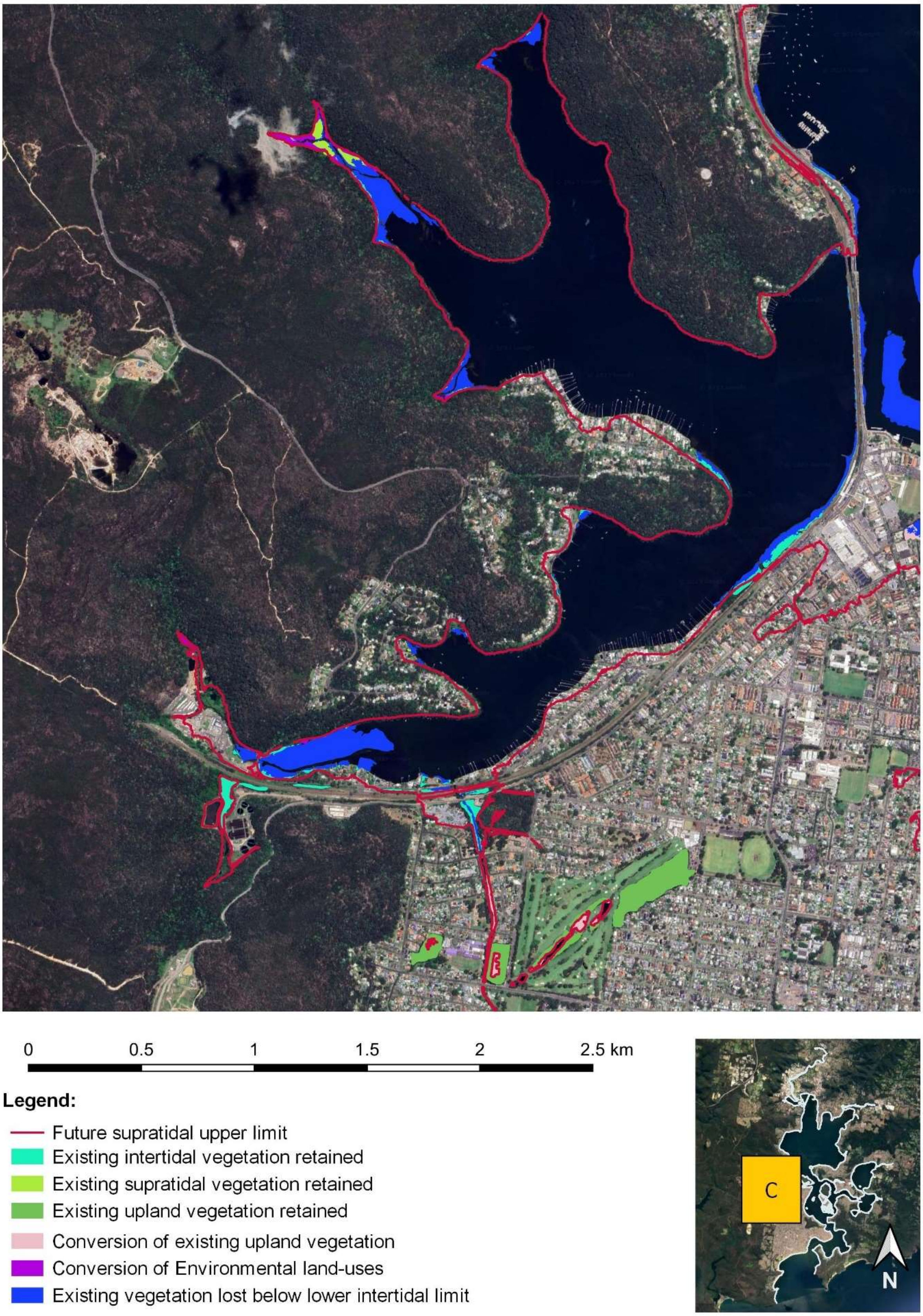
Narara Creek





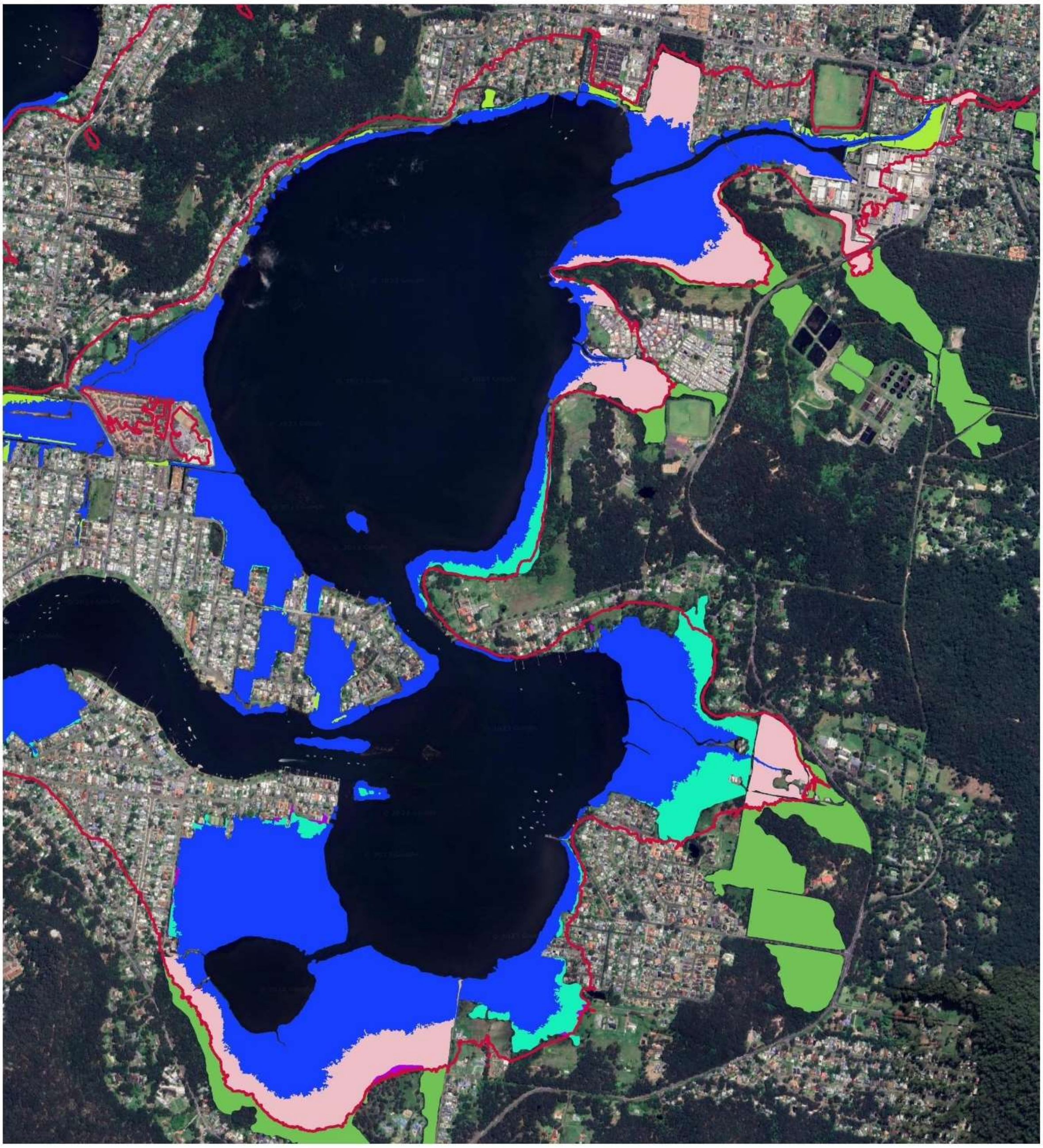
B-11 Far future (+0.7m SLR) intertidal vegetation potential for Brisbane Waters – Map B

Erina Creek



B-12 Far future (+0.7m SLR) intertidal vegetation potential for Brisbane Waters – Map C

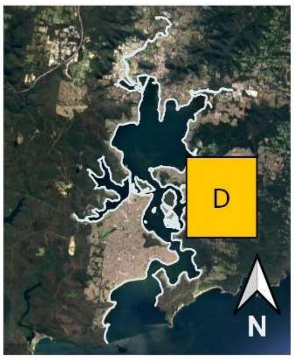
Woy Woy Bay



0 0.5 1 1.5 2 2.5 km

Legend:

- Future supratidal upper limit
- Existing intertidal vegetation retained
- Existing supratidal vegetation retained
- Existing upland vegetation retained
- Conversion of existing upland vegetation
- Conversion of Environmental land-uses
- Existing vegetation lost below lower intertidal limit



B-13 Far future (+0.7m SLR) intertidal vegetation potential for Brisbane Waters – Map D

Kincumber Broadwater and Cockle Bay

B-1 Existing and potential (near future) extents for vegetation precincts within Brisbane Water (ha)

	Existing vegetation			Vegetation retained in near future						
Vegetation precinct	intertidal	supratidal	upland	intertidal	supratidal	upland	Converted upland	Land use change	Potential tidal vegetation	Net change
TOTAL	**423.2**	**49.2**	**306.1**	**222.1**	**35.7**	**281.0**	**177.4**	**16.0**	**451.2**	**-21.3**
Araluen Drive wetlands (Stanley St Reserve)	0.1	0.6		0.1	0.2				0.3	-0.5
Austin Butler Oval Wetland			0.8			0.8	0.8		0.8	0.8
Barinya Lane Wetland			12.0			11.3	11.3	0.1	11.4	11.4
Bayside Drive Reserve Wetlands	1.1			0.5					0.5	-0.6
Blyth Street Cemetary	1.7		0.3	0.4		0.3	0.0		0.5	-1.3
Bonnal Road Reserve Wetland		0.6			0.4				0.4	-0.2
Brick Wharf Road Waterfront	0.5			0.4					0.4	-0.1
Brisbane Water Wetlands	5.9			2.0					2.0	-3.9
Broadwater Drive Wetland	10.1	0.1	1.3	3.7	0.1	1.3	1.3		5.1	-5.1
Burdett Place			1.6			1.6	0.0		0.0	0.0
Captain Cook Memorial Reserve Wetlands	0.4			0.2					0.2	-0.2
Carawah Reserve Wetland	9.3			3.5					3.5	-5.8
Caroline Bay Reserve Wetlands	5.2		1.1	2.7		1.1	1.1		3.8	-1.4
Carrington/Pandala Sports Ground Wetland			0.7			0.7	0.0		0.0	0.0
Cochrone Street Bush Reserve Wetland		2.1			1.8				1.8	-0.3
Cockle Bay Nature Reserve	28.6		54.1	13.0		41.3	27.5	0.6	41.0	12.5
Cockle Bay Wetlands	11.7	2.6	49.7	7.6	1.2	43.1	36.4		45.1	30.8
Cockle Channel Wetland	1.1			0.0					0.0	-1.1
Correa Bay Reserve	0.2			0.1					0.1	-0.1
Davistown Memorial Oval		0.3			0.3				0.3	0.0
Davistown Road Wetland		6.7			2.8				2.8	-3.8
Dell Road	0.1		0.6	0.1		0.6	0.2		0.3	0.2
Dulkara Road Reserve			0.4			0.4	0.2		0.2	0.2
Elaroo Road Reserve Wetlands	0.6			0.6					0.6	-0.1
Elfin Hill Road Reserve Wetland	0.1			0.0					0.0	-0.1
Emma Street Wetlands	13.6			8.6				0.0	8.6	-5.1
Empire Bay Drive Wetlands			11.9			11.9	8.2		8.2	8.2
Erina Creek Wetlands Complex	1.8	0.6	32.5	1.0	0.6	31.4	28.6	7.0	37.1	34.8
Frost Reserve Wetland		1.6			1.0				1.0	-0.6
Goodaywang Reserve Wetland		1.0	1.4		0.6	0.6	0.6		1.1	0.1
Gosford Golf Course Wetlands			0.7			0.7	0.4		0.4	0.4
Hardys Bay Parade wetlands	7.5			4.7				0.4	5.1	-2.5

B-1 (cont'd) Existing and potential (near future) extents for vegetation precincts within Brisbane Water (ha)

	Existing vegetation			Vegetation retained in near future						
Vegetation precinct	intertidal	supratidal	upland	intertidal	supratidal	upland	Converted upland	Land use change	Potential tidal vegetation	Net change
Hastings Wharf Reserve Wetlands	0.6			0.5					0.5	**-0.1**
Hawke Street Wetland		0.2			0.1				0.1	**-0.1**
Henry Kendall Street Reserve Wetland			3.1			2.9	2.8		2.8	2.8
Hillview Street Bush Reserve	0.8			0.8					0.8	**-0.1**
Horsefield Bay Wetlands	7.3	0.1		2.7	0.1			0.2	2.9	**-4.6**
Humphreys Road Wetland	0.3			0.0					0.0	**-0.3**
Hylton Moore Wetland	6.6			4.3				0.0	4.3	**-2.3**
Illoura Reserve Wetlands	13.1	3.5		4.2	3.5			0.0	7.8	**-8.9**
Iluka/Kahiba Creek Wetlands	0.6		21.1	0.6		21.1	6.9	0.2	7.7	7.1
Ilumba/Kincumber Cresent Wetlands		6.1			5.6				5.6	**-0.5**
Judy Anne Close Reserve			0.4			0.4	0.0		0.0	0.0
Jumbuck Close Reserve			0.4			0.4	0.0		0.0	0.0
Karalta Road Wetland			3.3			3.3	0.0		0.0	0.0
Kenmare Road Wetland	52.8		0.4	45.8		0.4	0.2	0.1	46.0	**-6.8**
Kinarra Ave			4.3			4.3	3.7	0.4	4.1	4.1
Kincumber Creek Wetland			4.5			4.7	0.3		0.3	0.3
Kincumber Crescent Wetland	0.8			0.5					0.5	**-0.4**
Kincumber Sewage Treatment Plant Wetlands			1.6			1.6	0.0		0.0	0.0
Kylie Close Wetlands	30.4		27.6	17.6		27.6	4.1	0.0	21.8	**-8.6**
Long Arm Parade Reserve	0.1			0.0					0.0	**-0.1**
Maliwa Road Reserve Wetland			0.1			0.1	0.0		0.0	0.0
Manuka Road Bush Reserve Wetland			7.5			7.5	2.7		2.7	2.7
McEvoy Oval Wetland			4.8			4.8	0.0		0.0	0.0
Milperra Road Bush Reserve Wetland			0.5			0.5	0.0		0.0	0.0
Morton Crescent Wetland	17.4	0.8		6.8	0.0				6.8	**-11.4**
Murrumbooee Place Wetland			0.6			0.3	0.3		0.3	0.3
Narara Creek Wetlands Complex	23.0	15.0	3.0	15.8	12.1	2.9	1.5	4.7	34.1	**-4.0**
Nicholii Close Reserve Wetland			0.7			0.7	0.4		0.4	0.4
Other - Killcare	0.9			0.2					0.2	**-0.7**
Pearl Beach Lagoon			2.0			2.0	0.0		0.0	0.0
Pearl Beach Wetland			0.6			0.6	0.5		0.5	0.5
Pelican Island Wetlands	50.4			17.6				0.2	17.8	**-32.7**
Pioneer Park Wetland	0.2			0.0					0.0	**-0.2**
Pixie Avenue Wetland	17.2			10.3				0.2	10.6	**-6.7**

B-1 (cont'd) Existing and potential (near future) extents for vegetation precincts within Brisbane Water (ha)

	Existing vegetation			Vegetation retained in near future						
Vegetation precinct	intertidal	supratidal	upland	intertidal	supratidal	upland	Converted upland	Land use change	Potential tidal vegetation	Net change
Point Clare Waterfront Wetlands	3.6	5.3		1.9	3.7				5.6	**-3.3**
Point Federick East	0.2			0.0					0.0	**-0.2**
Reeves Street Bush Reserve Wetlands			3.2			3.2	0.0		0.0	0.0
Rickard Road Wetland	15.1			4.2					4.2	**-10.9**
Rileys Island Wetland	55.6			28.8					28.8	**-26.7**
Saratoga Wetland	13.7	0.2		4.9	0.2				5.1	**-8.7**
Springfield Road Reserve Wetlands			2.5			2.5	1.8		1.8	1.8
St Huberts Narrows Wetlands	0.7			0.1					0.1	**-0.7**
The Everglades Wetlands			4.4			4.4	0.0		0.0	0.0
Uratta Street Playground Wetlands	5.0			2.5					2.5	**-2.4**
Veron Rd Bush Reserve Wetland			1.1			1.1	0.0		0.0	0.0
Veron Rd/Hillview St Wetland			1.5			0.5	1.5		1.5	1.5
Warrana Road Reserve Wetland		0.3			0.2				0.2	**-0.1**
Waterfall Bay	4.8	1.6		1.5	1.3			1.8	4.6	**-1.7**
Wells/Morella Close Wetland			35.9			34.3	34.3	0.1	34.4	34.4
Wharf Reserve	0.3			0.1					0.1	**-0.2**
Woy Woy Golf Course Wetlands			1.9			1.9	0.0		0.0	0.0
Woy Woy Water Treatment Facility Wetland	1.1			1.1					1.1	0.0
Woy Woy Waterfront	1.0			0.3					0.3	**-0.6**

B-2 Existing and potential (far future) extents for vegetation precincts within Brisbane Water (ha)

	Existing vegetation			Vegetation retained in far future				Land	Potential	
							Converted	use	tidal	Net
Vegetation precinct	intertidal	supratidal	upland	intertidal	supratidal	upland	upland	change	vegetation	change
TOTAL	**423.2**	**49.2**	**306.1**	**78.9**	**15.5**	**217.3**	**118.7**	**17.6**	**230.6**	**-241.8**
Araluen Drive wetlands (Stanley St Reserve)	0.1	0.6		0.1	0.0				0.1	**-0.7**
Austin Butler Oval Wetland			0.8			0.5	0.5		0.5	0.5
Barinya Lane Wetland			12.0			9.6	9.6	0.1	9.8	9.8
Bayside Drive Reserve Wetlands	1.1			0.2					0.2	**-1.0**
Blyth Street Cemetary	1.7		0.3	0.3		0.3	0.1		0.4	**-1.3**
Bonnal Road Reserve Wetland		0.6			0.1				0.1	**-0.5**
Brick Wharf Road Waterfront	0.5			0.0					0.0	**-0.5**
Brisbane Water Wetlands	5.9			0.0					0.0	**-5.9**
Broadwater Drive Wetland	10.1	0.1	1.3	0.3	0.1	0.1	0.0		0.4	**-9.8**
Burdett Place			1.6			1.6	0.0		0.0	0.0
Captain Cook Memorial Reserve Wetlands	0.4			0.0					0.0	**-0.4**
Carawah Reserve Wetland	9.3			1.7					1.7	**-7.6**
Caroline Bay Reserve Wetlands	5.2		1.1	1.5		0.9	0.9		2.4	**-2.8**
Carrington/Pandala Sports Ground Wetland			0.7			0.7	0.0		0.0	0.0
Cochrone Street Bush Reserve Wetland		2.1			1.6				1.6	**-0.5**
Cockle Bay Nature Reserve	28.6		54.1	1.3		28.1	16.1	0.8	18.2	**-10.4**
Cockle Bay Wetlands	11.7	2.6	49.7	3.9	0.9	22.6	17.3		22.1	7.8
Cockle Channel Wetland	1.1			0.0					0.0	**-1.1**
Correa Bay Reserve	0.2			0.1					0.1	**-0.1**
Davistown Memorial Oval		0.3			0.1				0.1	**-0.2**
Davistown Road Wetland		6.7			0.8				0.8	**-5.9**
Dell Road	0.1		0.6	0.1		0.6	0.3		0.5	0.3
Dulkara Road Reserve			0.4			0.4	0.3		0.3	0.3
Elaroo Road Reserve Wetlands	0.6			0.3					0.3	**-0.4**
Elfin Hill Road Reserve Wetland	0.1			0.0					0.0	**-0.1**
Emma Street Wetlands	13.6			3.9				0.1	4.1	**-9.6**
Empire Bay Drive Wetlands			11.9			11.9	1.3		1.3	1.3
Erina Creek Wetlands Complex	1.8	0.6	32.5	0.3	0.2	25.5	24.1	7.8	32.3	30.0
Frost Reserve Wetland		1.6			0.4				0.4	**-1.2**
Goodaywang Reserve Wetland		1.0	1.4		0.4	0.5	0.5		0.9	-0.2
Gosford Golf Course Wetlands			0.7			0.7	0.6		0.6	0.6

B-2 (cont'd) Existing and potential (far future) extents for vegetation precincts within Brisbane Water (ha)

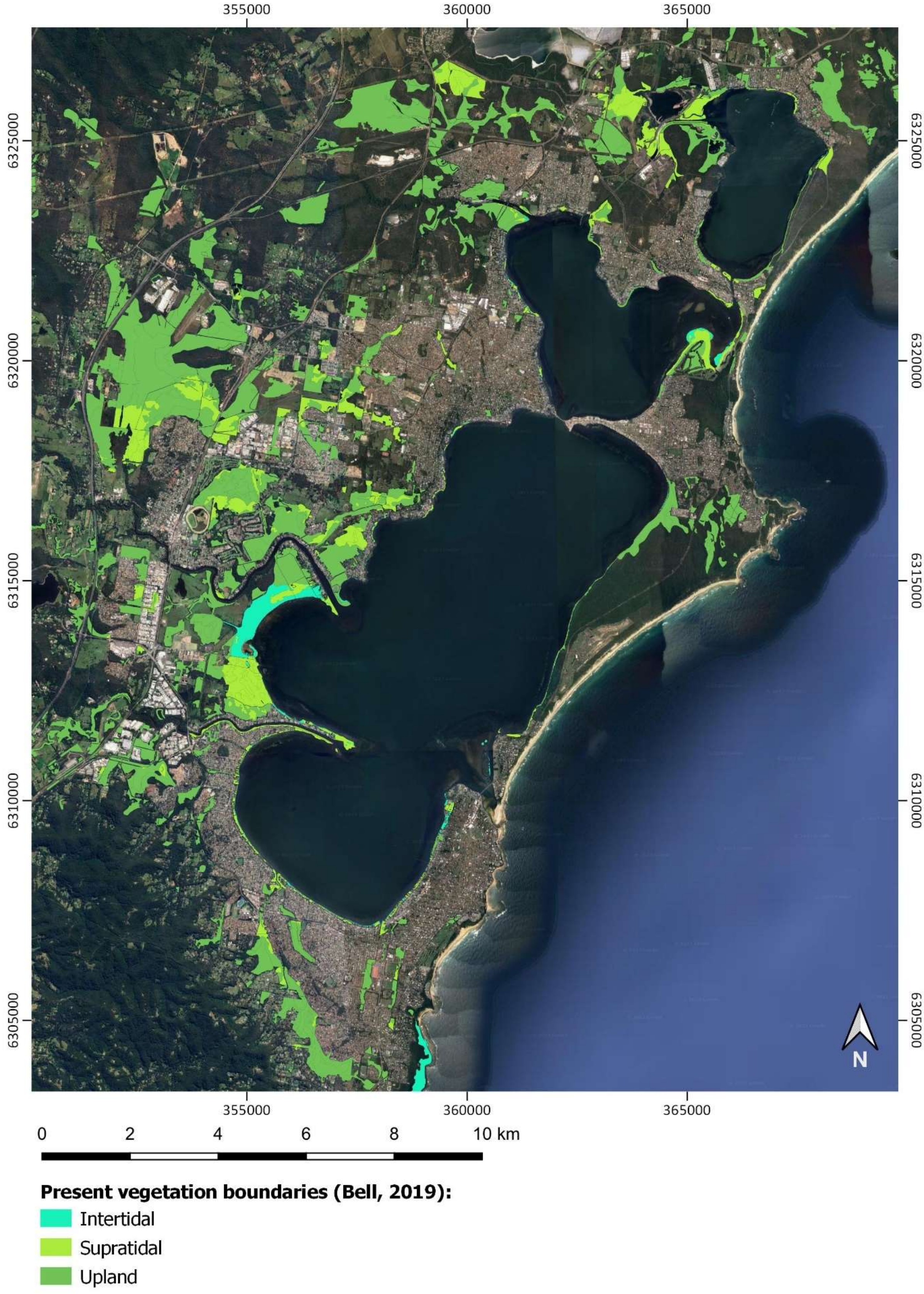
	Existing vegetation			Vegetation retained in far future						
Vegetation precinct	intertidal	supratidal	upland	intertidal	supratidal	upland	Converted upland	Land use change	Potential tidal vegetation	Net change
Hardys Bay Parade wetlands	7.5			3.4				0.7	4.2	**-3.3**
Hastings Wharf Reserve Wetlands	0.6			0.2					0.2	**-0.3**
Hawke Street Wetland		0.2			0.1				0.1	**-0.1**
Henry Kendall Street Reserve Wetland			3.1			1.6	1.5		1.5	1.5
Hillview Street Bush Reserve	0.8			0.6					0.6	**-0.2**
Horsefield Bay Wetlands	7.3	0.1		0.5	0.0			0.3	0.8	**-6.6**
Humphreys Road Wetland	0.3			0.0					0.0	**-0.3**
Hylton Moore Wetland	6.6			0.6				0.1	0.7	**-6.0**
Illoura Reserve Wetlands	13.1	3.5		0.2	0.1			0.0	0.3	**-16.4**
Iluka/Kahiba Creek Wetlands	0.6		21.1	0.6		20.8	10.3	0.2	11.0	10.4
Ilumba/Kincumber Cresent Wetlands		6.1			0.2				0.2	**-5.8**
Judy Anne Close Reserve			0.4			0.4	0.0		0.0	0.0
Jumbuck Close Reserve			0.4			0.4	0.3		0.3	0.3
Karalta Road Wetland			3.3			3.3	0.0		0.0	0.0
Kenmare Road Wetland	52.8		0.4	18.0		0.4	0.3	0.1	18.4	**-34.4**
Kinarra Ave			4.3			3.0	2.8	0.7	3.5	3.5
Kincumber Creek Wetland			4.5			4.7	0.3		0.3	0.3
Kincumber Crescent Wetland	0.8			0.1					0.1	**-0.8**
Kincumber Sewage Treatment Plant Wetlands			1.6			1.6	0.0		0.0	0.0
Kylie Close Wetlands	30.4		27.6	10.6		27.6	5.1	0.0	15.7	**-14.7**
Long Arm Parade Reserve	0.1			0.0					0.0	**-0.1**
Maliwa Road Reserve Wetland			0.1			0.1	0.0		0.0	0.0
Manuka Road Bush Reserve Wetland			7.5			7.5	3.2		3.2	3.2
McEvoy Oval Wetland			4.8			4.8	0.1		0.1	0.1
Milperra Road Bush Reserve Wetland			0.5			0.5	0.0		0.0	0.0
Morton Crescent Wetland	17.4	0.8		2.2	0.7				3.0	**-15.2**
Murrumbooee Place Wetland			0.6			0.6	0.0		0.0	0.0
Narara Creek Wetlands Complex	23.0	15.0	3.0	6.8	7.7	2.7	1.9	4.4	20.8	**-17.2**
Nicholii Close Reserve Wetland			0.7			0.7	0.5		0.5	0.5
Other - Killcare	0.9			0.1					0.1	**-0.7**
Pearl Beach Lagoon			2.0			2.0	0.4		0.4	0.4
Pearl Beach Wetland			0.6			0.6	0.6		0.6	0.6
Pelican Island Wetlands	50.4			1.8					1.8	**-48.6**

B-2 (cont'd) Existing and potential (far future) extents for vegetation precincts within Brisbane Water (ha)

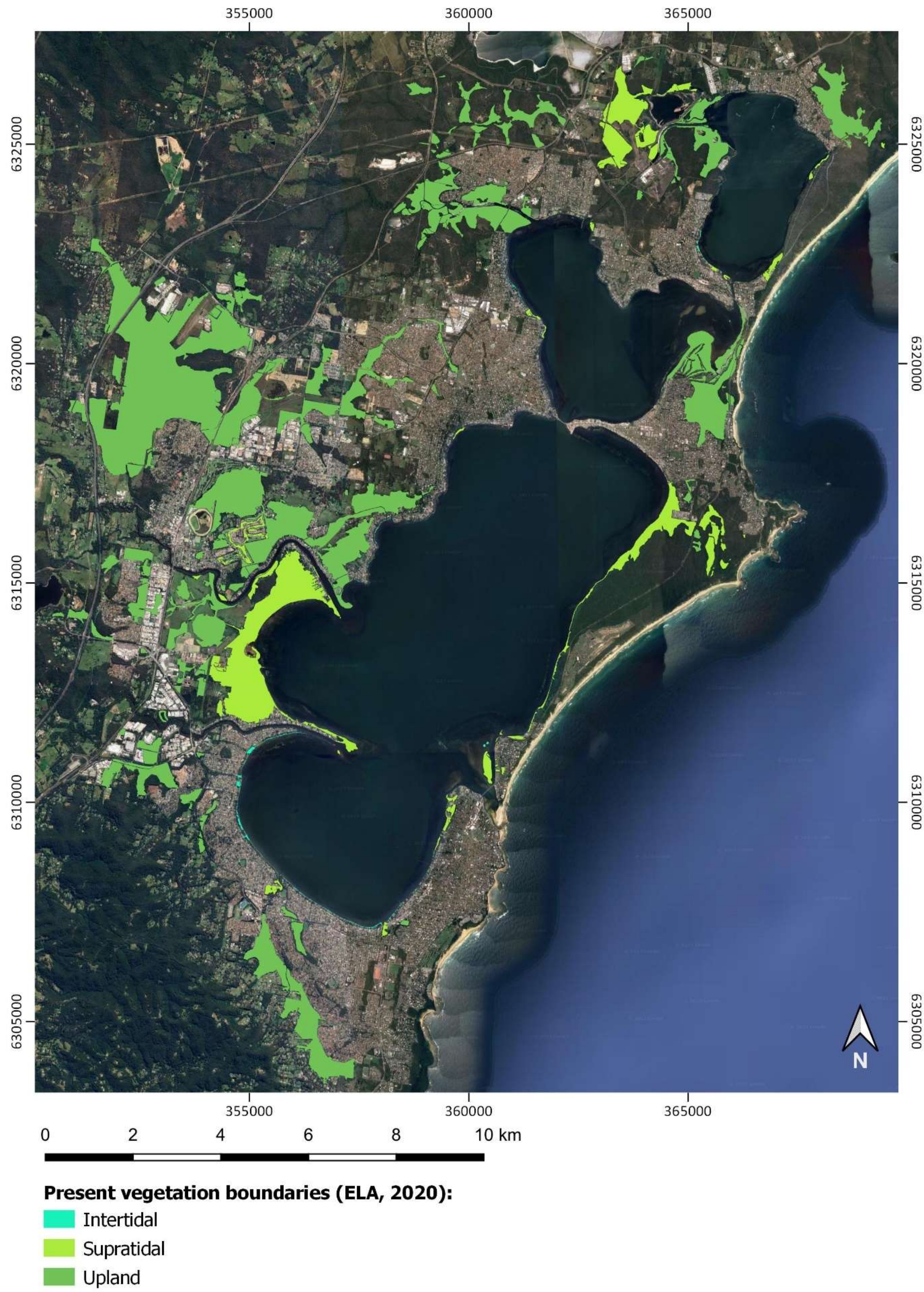
	Existing vegetation			Vegetation retained in far future						
Vegetation precinct	intertidal	supratidal	upland	intertidal	supratidal	upland	Converted upland	Land use change	Potential tidal vegetation	Net change
Pioneer Park Wetland	0.2			0.0					0.0	**-0.2**
Pixie Avenue Wetland	17.2			5.8				0.3	6.1	**-11.2**
Point Clare Waterfront Wetlands	3.6	5.3		0.6	1.1				1.7	**-7.2**
Point Federick East	0.2			0.0					0.0	**-0.2**
Reeves Street Bush Reserve Wetlands			3.2			3.2	1.2		1.2	1.2
Rickard Road Wetland	15.1			0.3					0.3	**-14.8**
Rileys Island Wetland	55.6			9.3					9.3	**-46.3**
Saratoga Wetland	13.7	0.2		0.6	0.1				0.6	**-13.2**
Springfield Road Reserve Wetlands			2.5			2.5	2.2		2.2	2.2
St Huberts Narrows Wetlands	0.7			0.0					0.0	**-0.7**
The Everglades Wetlands			4.4			4.4	0.0		0.0	0.0
Uratta Street Playground Wetlands	5.0			0.9					0.9	**-4.0**
Veron Rd Bush Reserve Wetland			1.1			1.1	0.1		0.1	0.1
Veron Rd/Hillview St Wetland			1.5			1.5	0.3		0.3	0.3
Warrana Road Reserve Wetland		0.3			0.0				0.0	**-0.3**
Waterfall Bay	4.8	1.6		0.3	0.9			1.9	3.1	**-3.3**
Wells/Morella Close Wetland			35.9			15.5	15.5	0.1	15.6	15.6
Wharf Reserve	0.3			0.0					0.0	**-0.2**
Woy Woy Golf Course Wetlands			1.9			1.9	0.6		0.6	0.6
Woy Woy Water Treatment Facility Wetland	1.1			1.1					1.1	0.0
Woy Woy Waterfront	1.0			0.2					0.2	**-0.8**

Appendix C Existing and potential future tidal wetland extents within Tuggerah Lake

Existing and potential future vegetation extents within Tuggerah Lake were summarised in Table 7 and are mapped in Figures C-1 to C-15. Digital copies of these maps are supplied in the Compendium accompanying this report. A detailed listing of existing and predicted vegetation extents within each vegetation precinct identified by ELA (2020) is included in Table C-1 for the near future climate scenario and Table C-2 for the far future climate scenario.

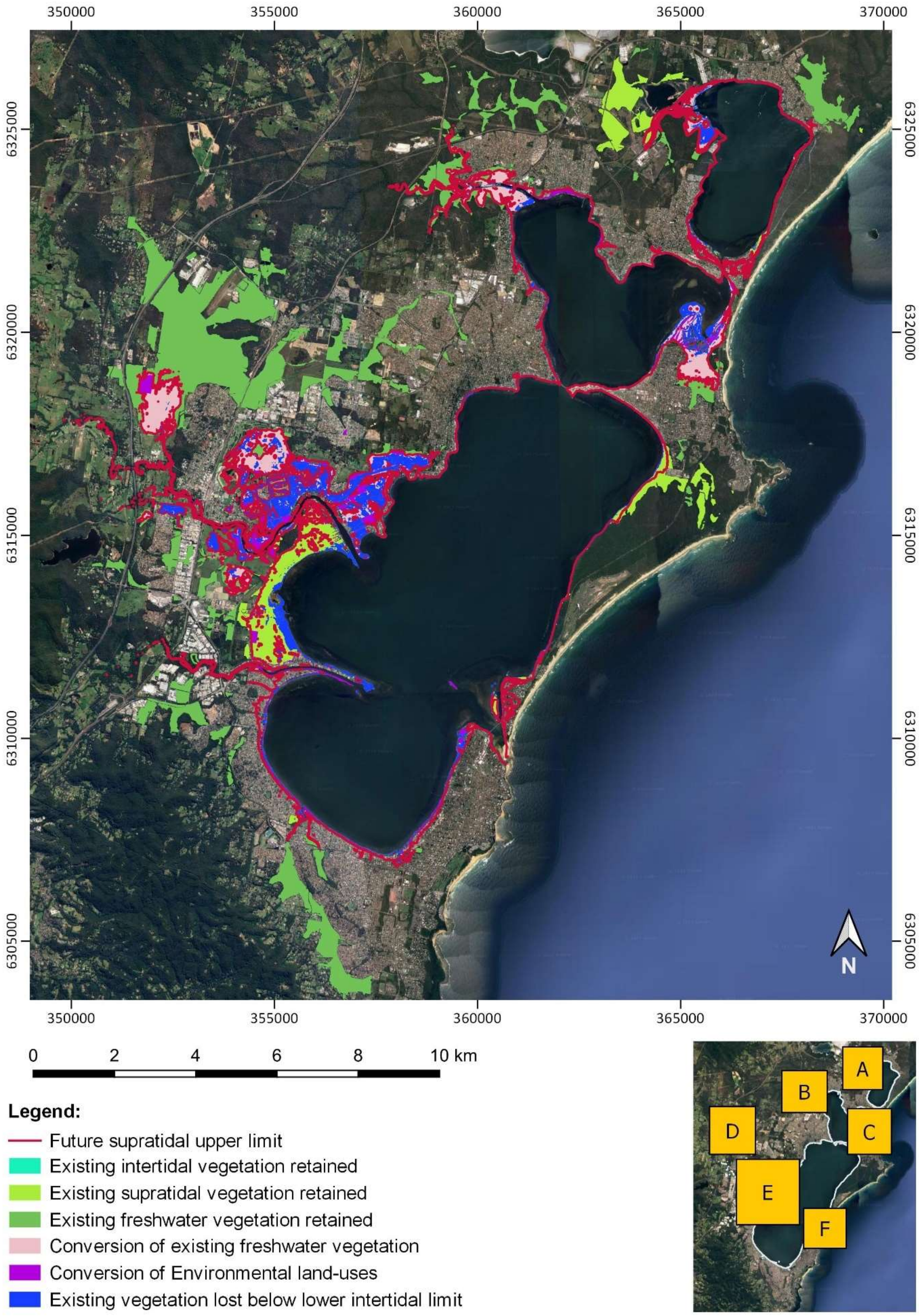


C-1 Existing vegetation extents mapped by Bell (2019)

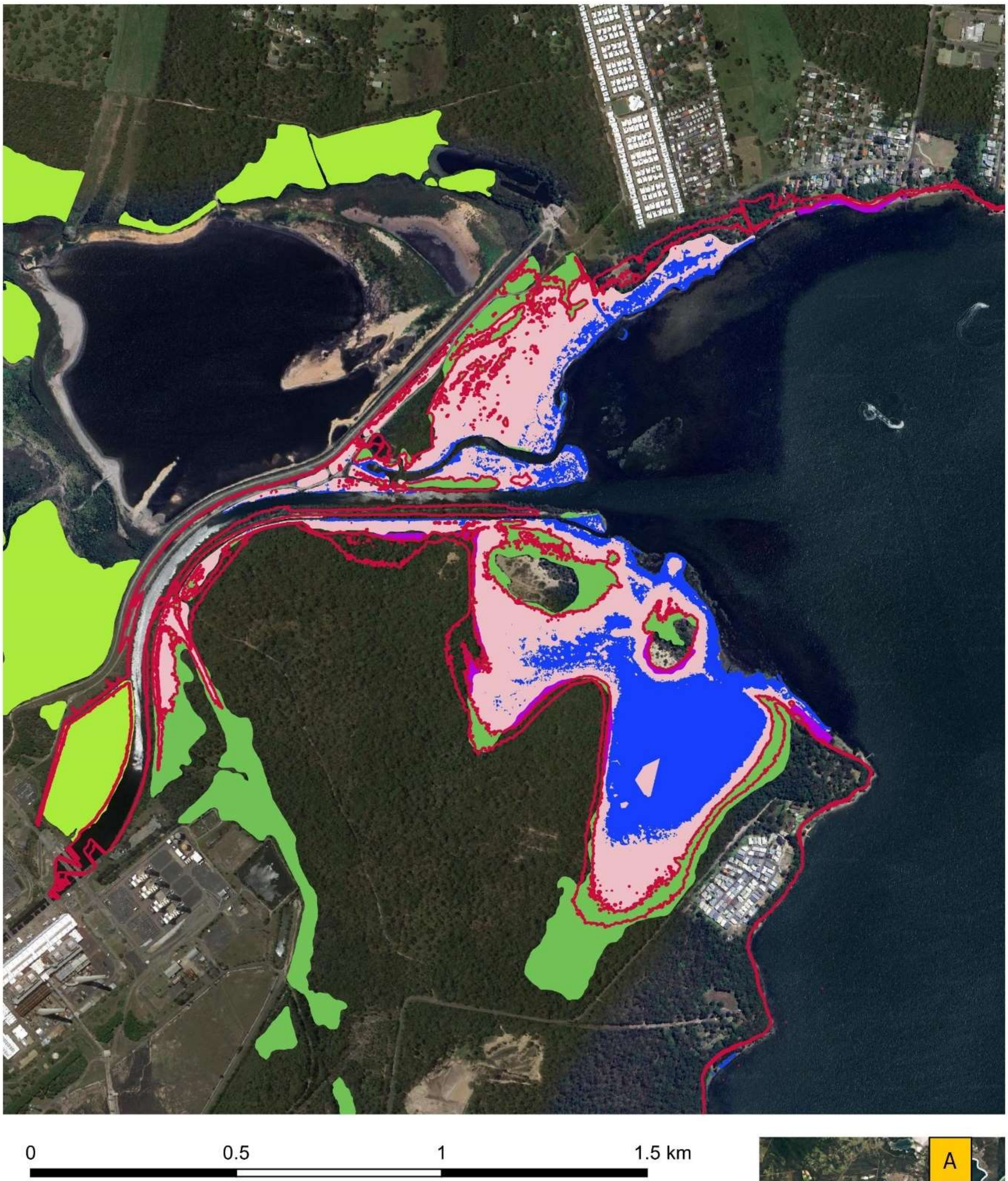


C-2 Existing vegetation extents mapped by ELA (2020)

C-3 Existing intertidal vegetation extents mapped by DPI Fisheries



C-4 Near future (+0.2m SLR) intertidal vegetation potential for Tuggerah Lake – overview

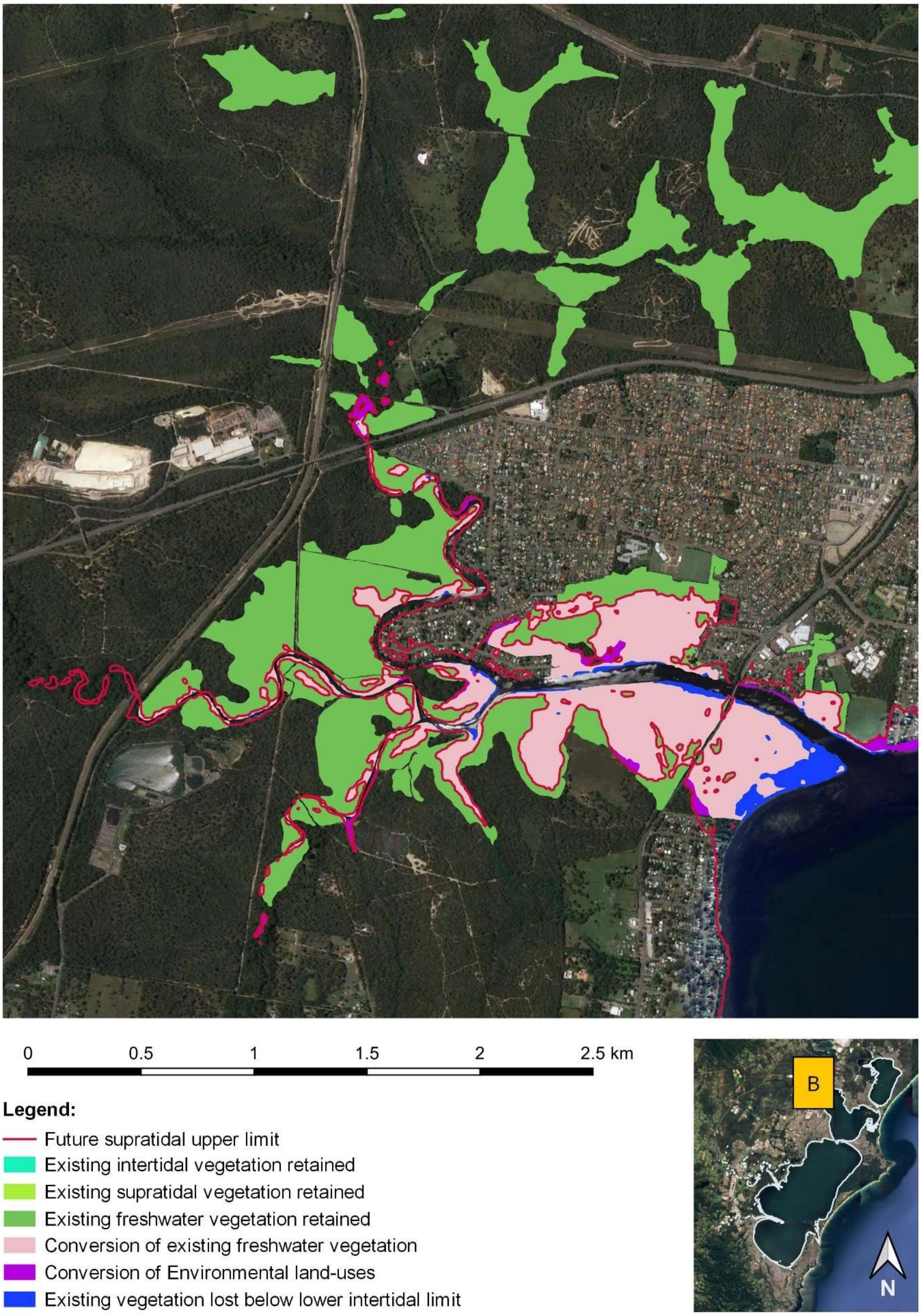


Legend:

- Future supratidal upper limit
- Existing intertidal vegetation retained
- Existing supratidal vegetation retained
- Existing freshwater vegetation retained
- Conversion of existing freshwater vegetation
- Conversion of Environmental land-uses
- Existing vegetation lost below lower intertidal limit

C-5 Near future (+0.2m SLR) intertidal vegetation potential for Tuggerah Lake – Map A

Colongra Creek



C-6 Near future (+0.2m SLR) intertidal vegetation potential for Tuggerah Lake – Map B Wallarah Creek

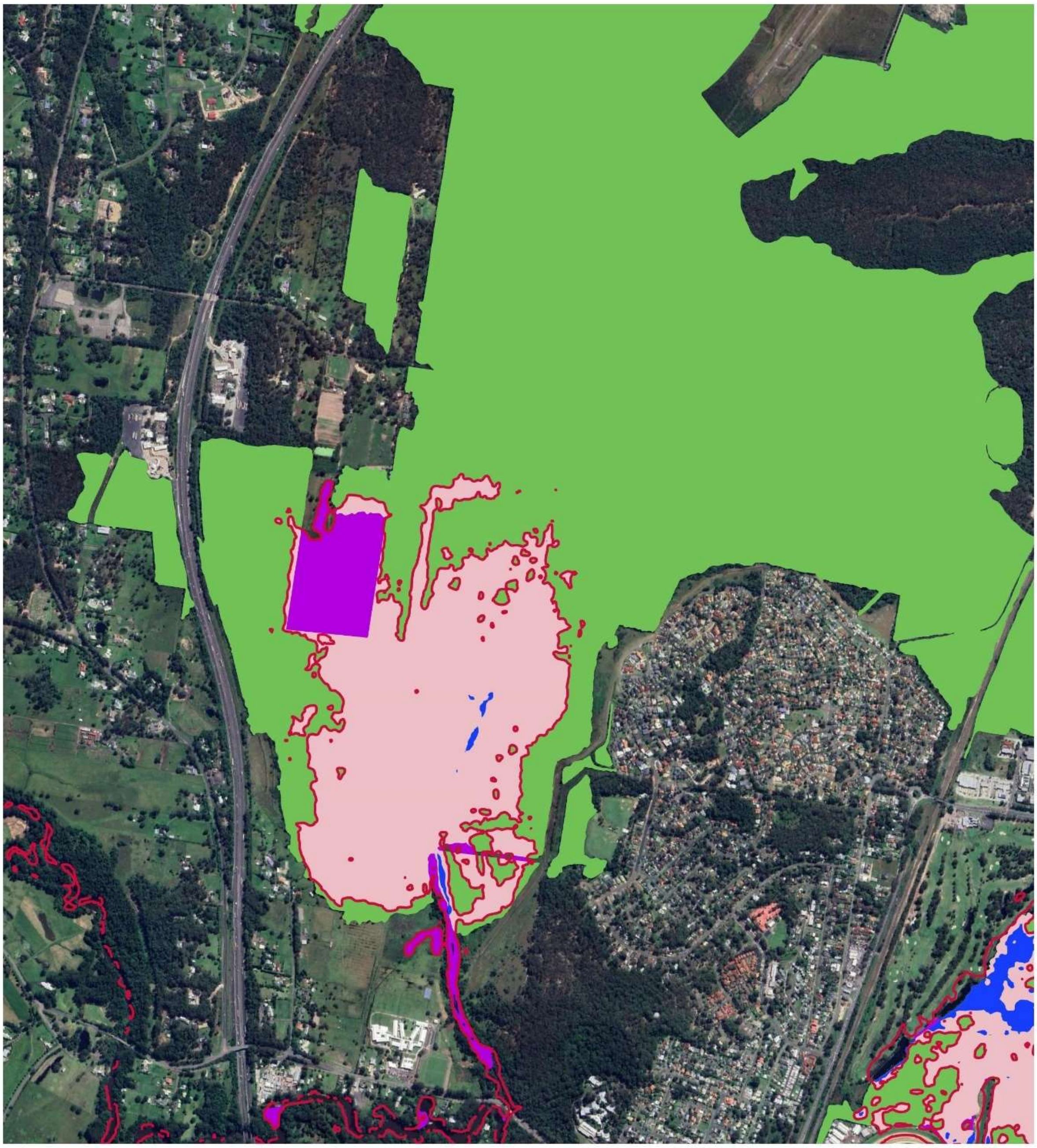
0 0.5 1 1.5 2 2.5 km

Legend:

- Future supratidal upper limit
- Existing intertidal vegetation retained
- Existing supratidal vegetation retained
- Existing freshwater vegetation retained
- Conversion of existing freshwater vegetation
- Conversion of Environmental land-uses
- Existing vegetation lost below lower intertidal limit

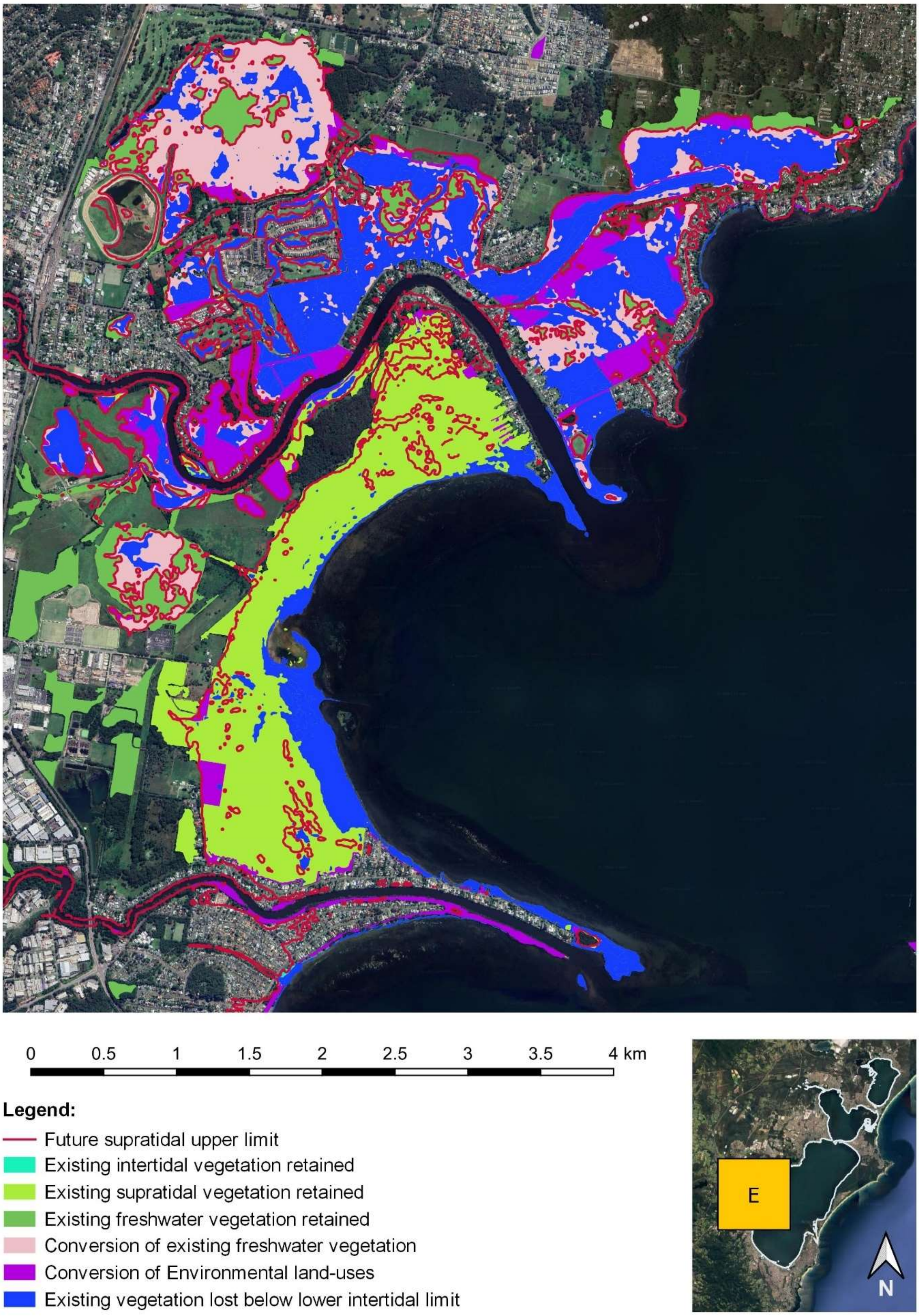
C-7 Near future (+0.2m SLR) intertidal vegetation potential for Tuggerah Lake – Map C

Toukley Wetland / Budgewoi Sandmass



Legend:
- Future supratidal upper limit
- Existing intertidal vegetation retained
- Existing supratidal vegetation retained
- Existing freshwater vegetation retained
- Conversion of existing freshwater vegetation
- Conversion of Environmental land-uses
- Existing vegetation lost below lower intertidal limit

C-8 Near future (+0.2m SLR) intertidal vegetation potential for Tuggerah Lake – Map D Porters Creek

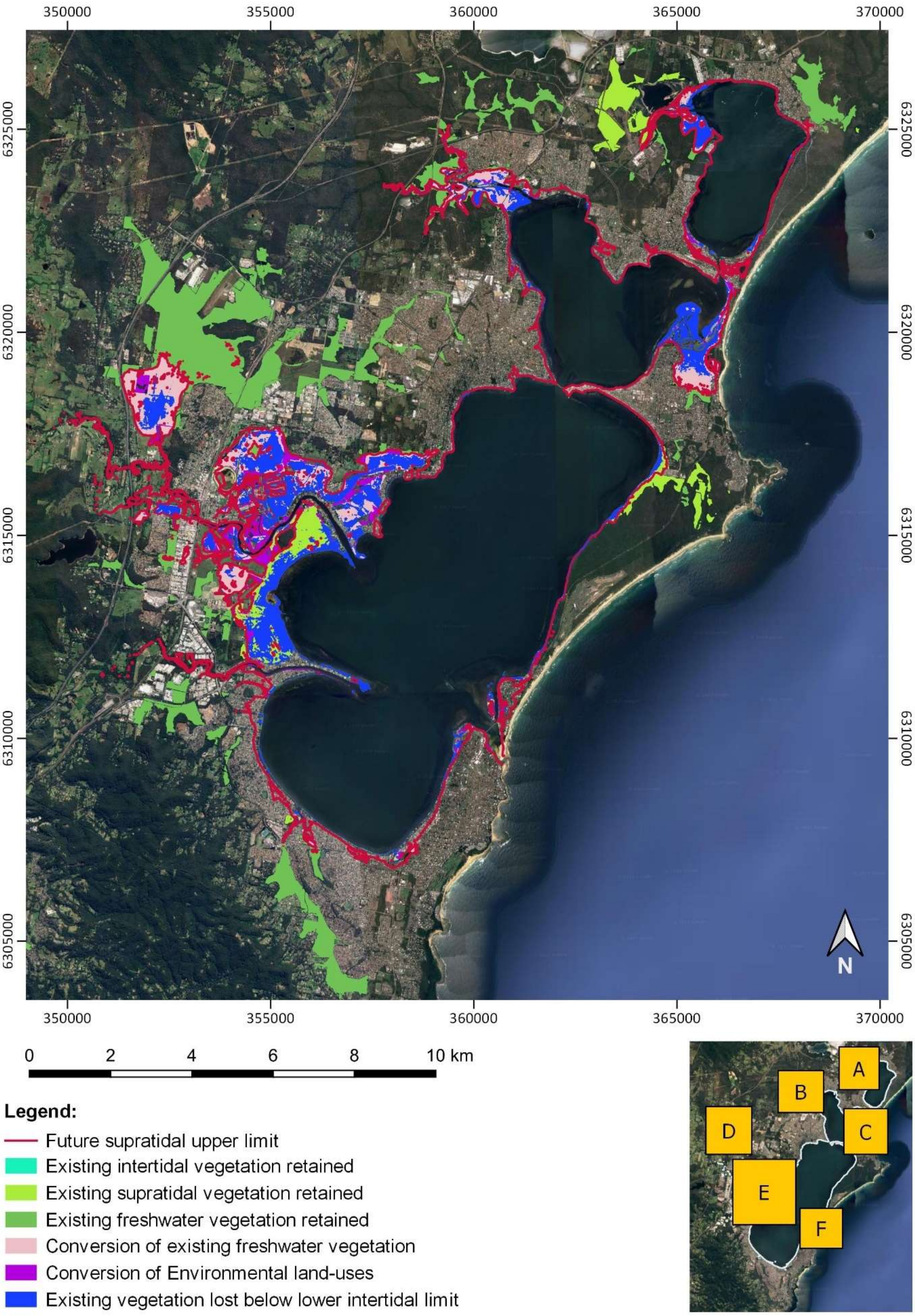


C-9 Near future (+0.2m SLR) intertidal vegetation potential for Tuggerah Lake – Map E

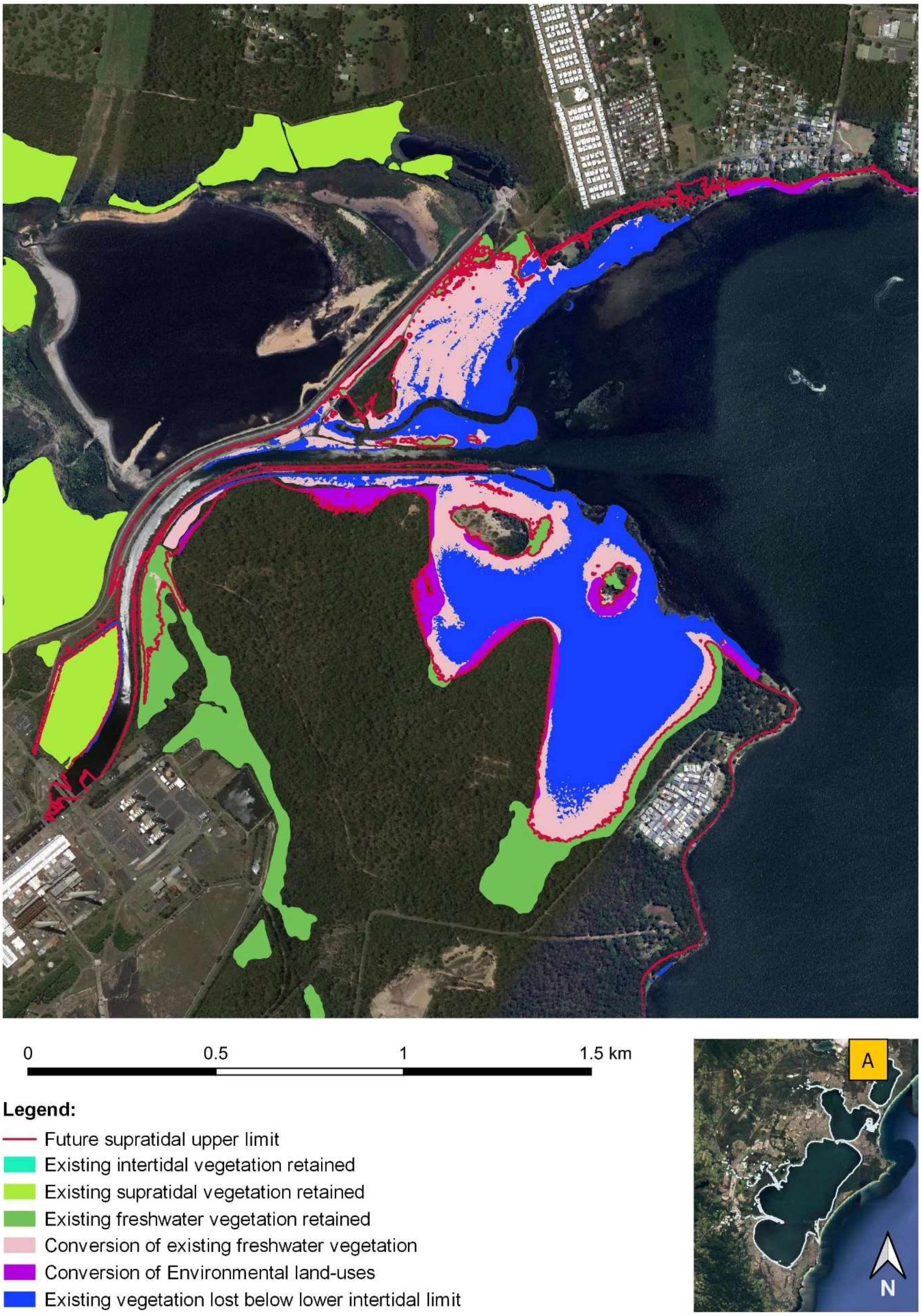
Tuggerah Swamp

C-10 Near future (+0.2m SLR) intertidal vegetation potential for Tuggerah Lake – Map F

The Entrance

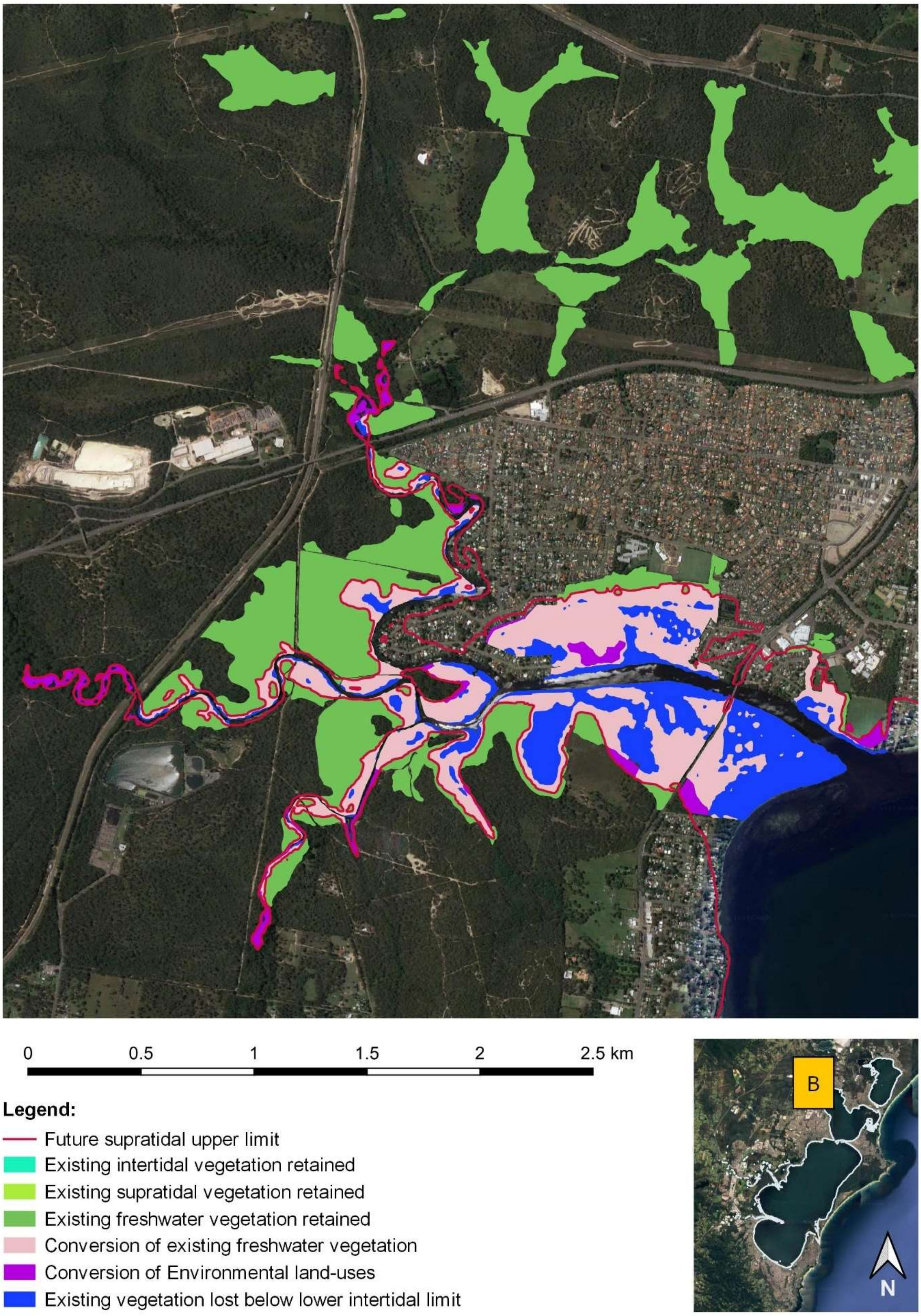


C-11 Far future (+0.7m SLR) intertidal vegetation potential for Tuggerah Lake – overview

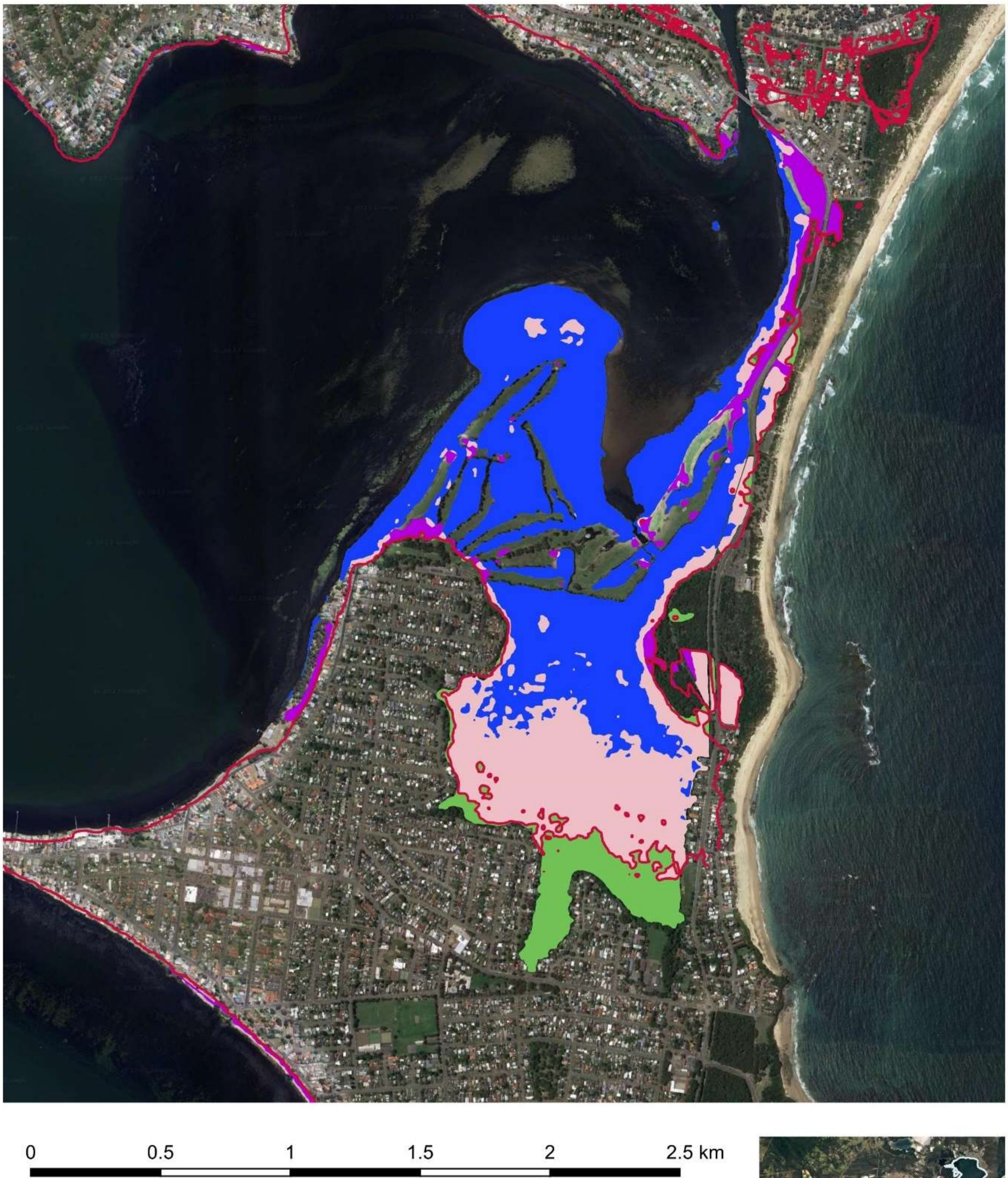


C-12 Far future (+0.7m SLR) intertidal vegetation potential for Tuggerah Lake – Map A

Colongra Creek



C-13 Far future (+0.7m SLR) intertidal vegetation potential for Tuggerah Lake – Map B Wallarah Creek

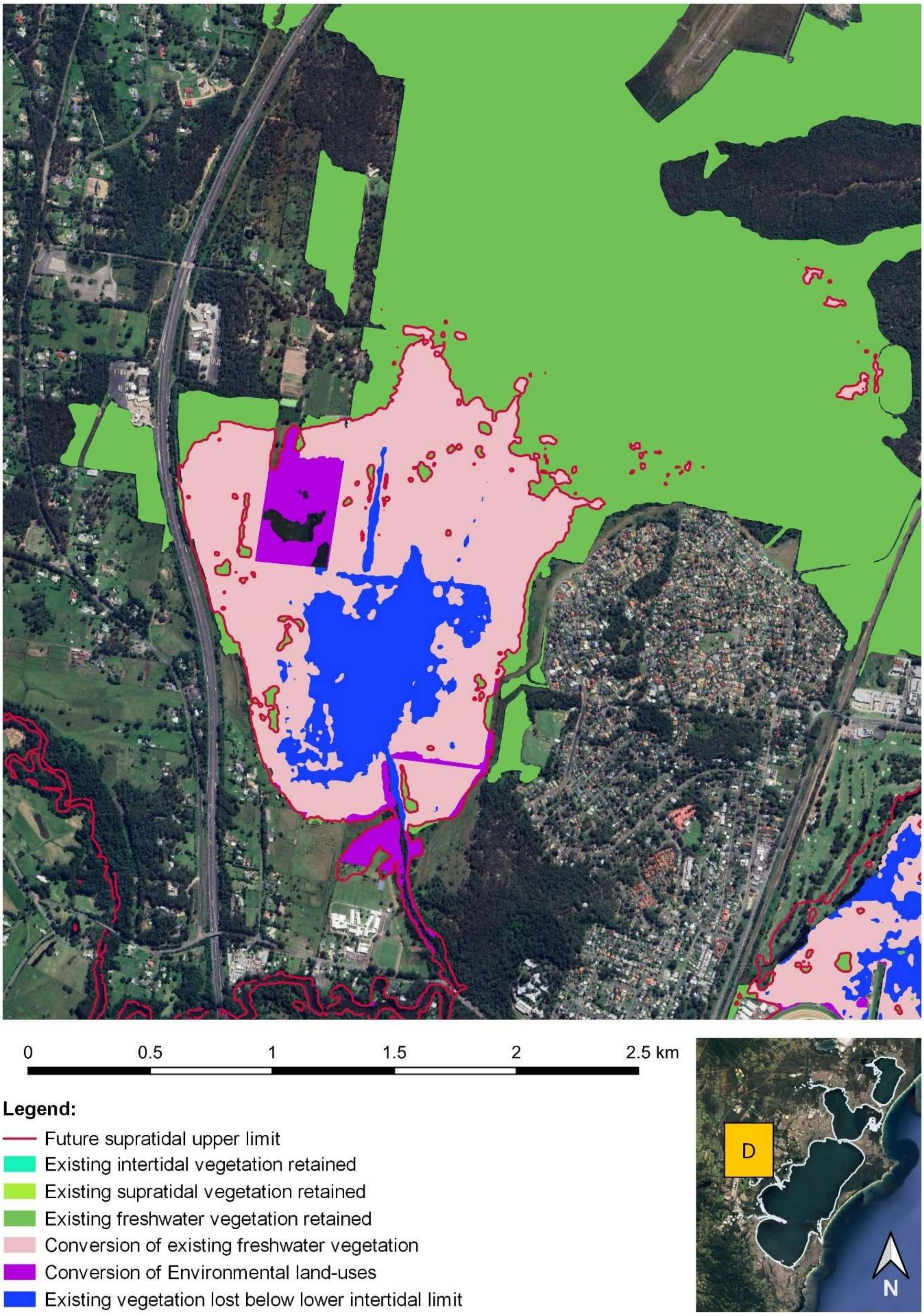


Legend:

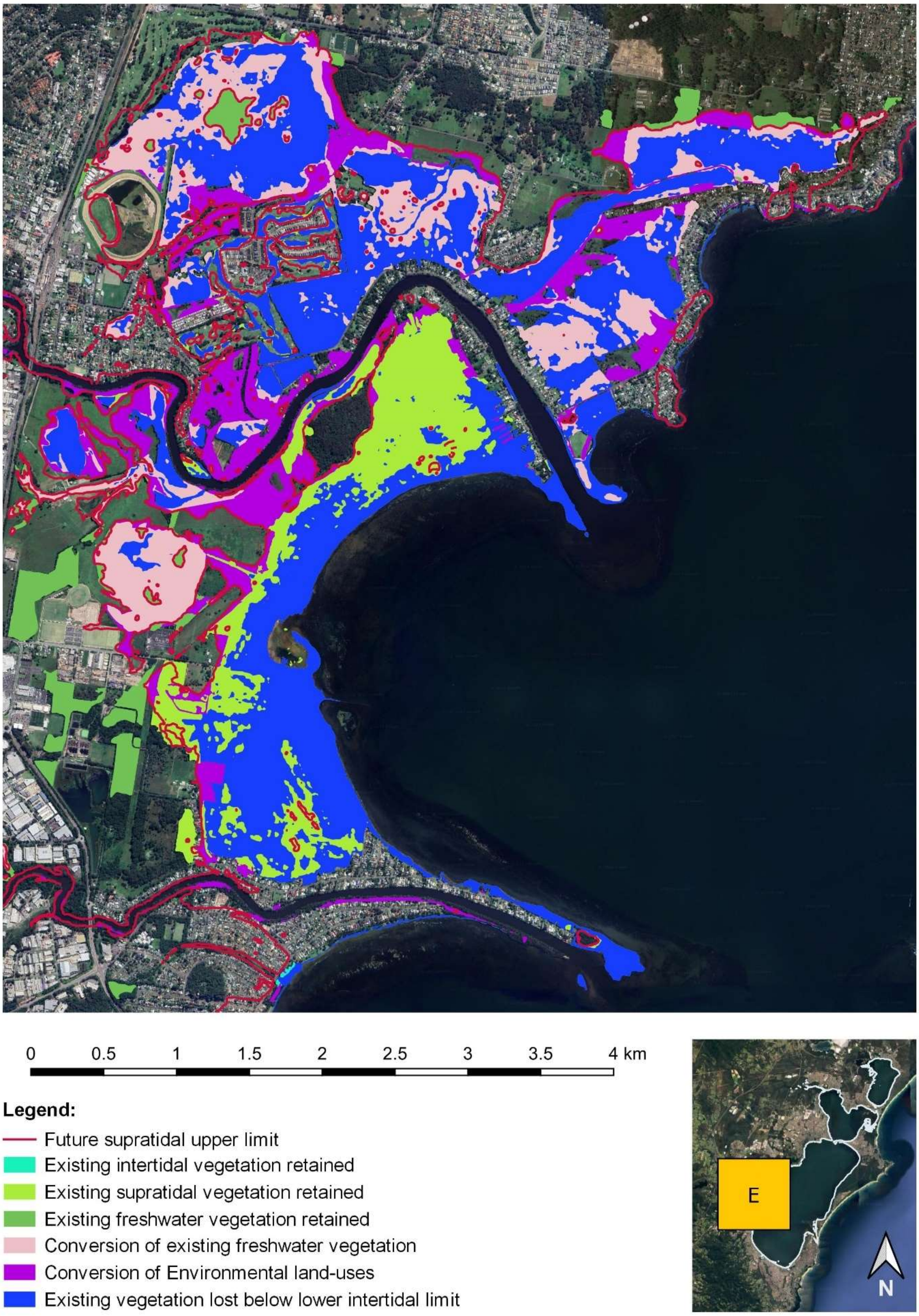
- Future supratidal upper limit
- Existing intertidal vegetation retained
- Existing supratidal vegetation retained
- Existing freshwater vegetation retained
- Conversion of existing freshwater vegetation
- Conversion of Environmental land-uses
- Existing vegetation lost below lower intertidal limit

C-14 Far future (+0.7m SLR) intertidal vegetation potential for Tuggerah Lake – Map C

Toukley Wetland / Budgewoi Sandmass

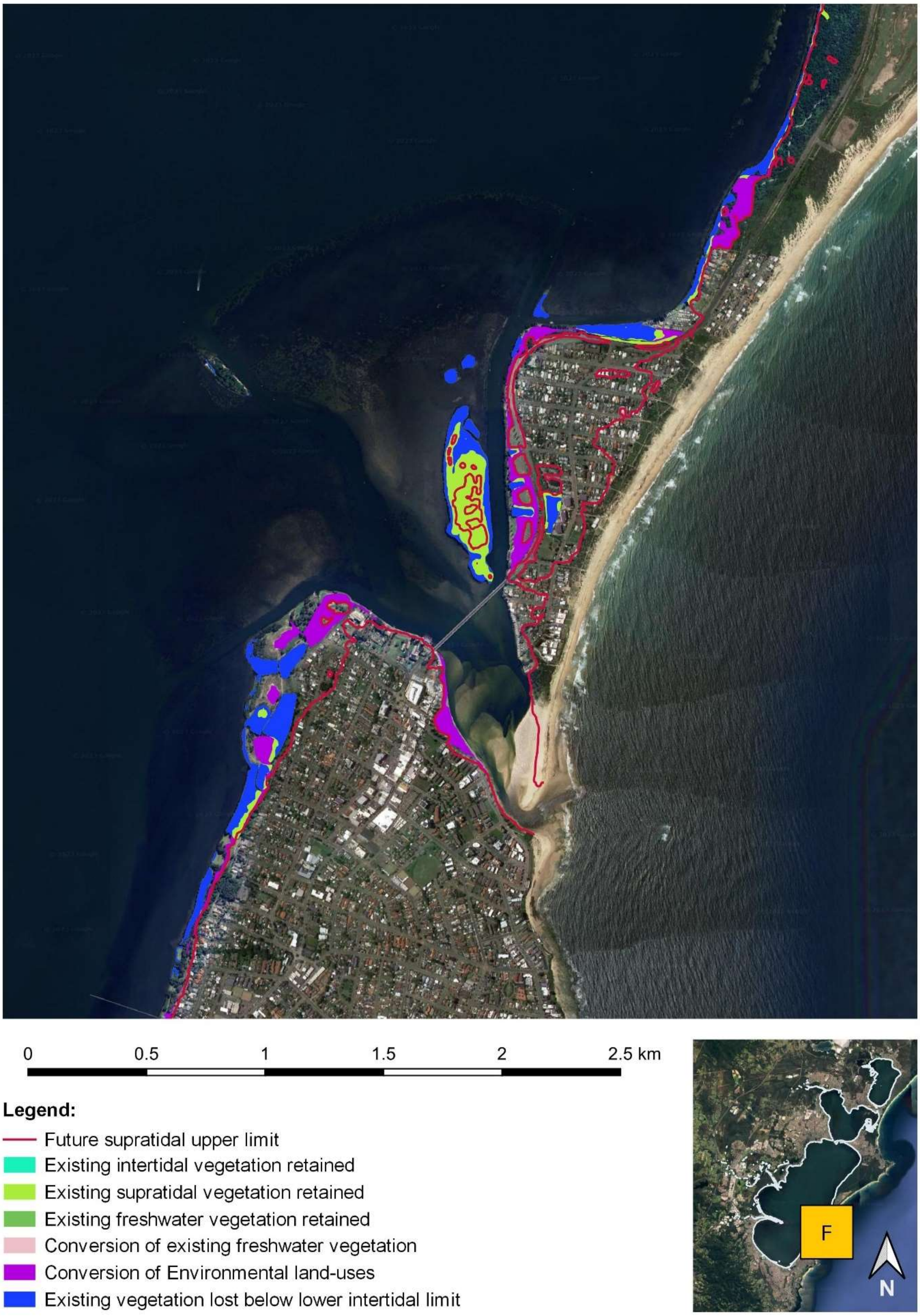


C-15 Far future (+0.7m SLR) intertidal vegetation potential for Tuggerah Lake – Map D Porters Creek



C-16 Far future (+0.7m SLR) intertidal vegetation potential for Tuggerah Lake – Map E

Tuggerah Swamp



C-17 Near future (+0.2m SLR) intertidal vegetation potential for Tuggerah Lake – Map F

The Entrance

C-1 Existing and potential (near future) extents for vegetation precincts within Tuggerah Lake (ha)

	Existing vegetation			Vegetation retained in near future						
Vegetation precinct	intertidal	supratidal	upland	intertidal	supratidal	upland	Converted upland	Land use change	Potential tidal vegetation	Net change
TOTAL	**12**	**493**	**2,414**	**3**	**426**	**2,294**	**611**	**219**	**1,258**	**753**
Berkeley Vale Wetland 1			53.7			53.7			0.0	0.0
Berkeley Vale Wetland 2			9.9			9.9			0.0	0.0
Berkely Vale upland			30.7			30.7			0.0	0.0
Bluehaven Wetland - Orooaloo			31.4			30.9	19.0	1.0	20.0	20.0
Budgewoi East Foreshore	0.2		0.2	0.1		0.2	0.0	2.4	2.5	2.3
Budgewoi Sand mass / Toukley Wetland, Budgewoi			175.5			129.6	84.3	21.9	106.1	106.1
Budgewoi West Foreshore	0.7	2.7		0.0	1.9				1.9	**-1.5**
Buff Point		1.3			1.1			3.0	4.1	2.8
Charmhaven Wetland - Orooaloo			72.5			65.8	45.7	1.1	46.8	46.8
Chittaway Bay Wetland		11.2			3.6			0.8	4.4	**-6.8**
Colongra Swamp	0.01	132.78	81.60	0.00	132.78	26.77	32.90	1.93	167.6	34.8
Constructed			27.3			27.3			0.0	0.0
Craigie Park		1.2			0.8				0.8	**-0.4**
Elizabeth Bay Drive Wetland	0.00	2.38	95.76	0.00	1.78	95.76	0.00	0.56	2.3	0.0
Gavenlock Road			49.3			47.0	11.0	4.9	15.9	15.9
Halekulani/Ashley Chapman Reserve	1.21	1.76	0.00	0.08	0.75	0.00	0.00	3.66	4.5	1.5
Jensen Road Wetland, Rocky Point			88.2			76.8	63.7	8.2	72.0	72.0
Karrangah Point Foreshore	0.1			0.1					0.1	0.0
Kooindah Waters Golf Course		17.0			16.0			0.3	16.3	**-0.8**
Lower Pioneer Dairy Dam, Tuggerah			81.2			79.4	32.4	6.5	38.9	38.9
Mardi			15.8			15.8			0.0	0.0
McDonagh Road North / McDonagh Road South			98.4			73.7	60.6	4.3	65.0	65.0
McPhersons Road			8.4			8.4	3.4	5.9	9.3	9.3
Oleander Street Wetland, Canton Beach		73.4			68.4				68.4	**-5.0**
Ourimbah Creek								3.5	3.5	3.5
Pipeclay Point Foreshore	0.0			0.0					0.0	0.0
Porters Creek Wetland			882.7			882.4	95.2	16.5	111.7	111.7
Reliance Drive Wetland			2.6			2.6			0.0	0.0
Rocky Point Foreshore	0.3			0.0				0.0	0.0	**-0.2**
San Remo	0.1		5.4			5.1	2.6	7.4	10.0	9.9
South Tuggerah Lake Foreshore	9.5	10.1	1.7	2.5	7.2	1.7	0.0	34.3	44.0	24.4
Spring Creek			7.7			7.7	0.2	1.0	1.2	1.2

C-1 (cont'd) Existing and potential (near future) extents for vegetation precincts within Tuggerah Lake (ha)

	Existing vegetation			Vegetation retained in near future						
Vegetation precinct	intertidal	supratidal	upland	intertidal	supratidal	upland	Converted upland	Land use change	Potential tidal vegetation	Net change
Tacoma Wetland			86.1			77.9	72.6	27.1	99.7	99.7
Terilbah Island	0.5	10.2		0.0	9.1			1.7	10.8	0.1
Terilbah Reserve		1.7			1.6			1.7	3.3	1.6
The Entrance North Foreshore		2.6			2.2			0.8	3.0	0.4
Top Dairy Dam			9.2			4.3	4.2	3.1	7.3	7.3
Toukley Sewerage Plant			4.4			4.4			0.0	0.0
Tuggerah			22.1			22.1			0.0	0.0
Tuggerah Swamp		318.9			272.0			10.8	282.8	**-36.1**
Tuggerawong Foreshore	0.6			0.0				2.1	2.1	1.6
Tumbi Creek Wetland			174.6			174.7			0.0	0.0
Tumbi Umbi Creek		5.9	16.0		5.6	16.0	0.0	3.0	8.6	2.7
Upstream of Porters Creek Wetland			27.0			27.0			0.0	0.0
Walker Park			1.3			1.6			0.0	0.0
Warner Avenue			9.9			8.6	7.1	3.7	10.7	10.7
Warnervale			113.4			113.5			0.0	0.0
Weemalah Wetlands	0.00	10.69	0.00	0.00	5.57	0.00	0.00	0.34	5.9	**-4.8**
Wetland B, Charmhaven STP			79.8			79.7	9.5	0.9	10.4	10.4
Wetland C, Bluehaven / Wetland E, Doyalson Ridge			13.4			13.4			0.0	0.0
Wetland D, Doyalson			5.8			5.8			0.0	0.0
Wetland F, Doyalson			37.9			38.0			0.0	0.0
Wyee Wetland			27.1			27.1			0.0	0.0
Wyong Racecourse Wetland			127.4			117.8	90.4		90.4	90.4
Wyong River Foreshore (D/S Pacific Hwy)		2.5	12.1		2.4	8.5	8.4	4.8	15.7	13.1
Wyong River, upstream of Pacific Hwy								0.6	0.6	0.6
Wyrrabalong National Park		34.1	4.5		34.1	4.5		35.4	69.5	35.4

C-2 Existing and potential (far future) extents for vegetation precincts within Tuggerah Lake (ha)

Vegetation precinct	Existing vegetation			Vegetation retained in far future			Converted upland	Land use change	Potential tidal vegetation	Net change
	intertidal	supratidal	upland	intertidal	supratidal	upland				
TOTAL	**13**	**640**	**2,592**	**1**	**389**	**2,048**	**497**	**266**	**1,152**	**499**
Berkeley Vale Wetland 1			53.7			53.7			0.0	0.0
Berkeley Vale Wetland 2			9.9			9.9			0.0	0.0
Berkely Vale upland			30.7			30.7			0.0	0.0
Bluehaven Wetland - Orooaloo			31.4			25.0	20.8	1.7	22.5	22.5
Budgewoi East Foreshore	0.2		0.2	0.0				2.7	2.7	2.5
Budgewoi Sand mass / Toukley Wetland, Budgewoi			175.5			74.9	56.7	11.6	68.3	68.3
Budgewoi West Foreshore	0.7	2.7		0.0	0.6			1.1	1.7	**-1.8**
Buff Point		1.3			0.6			1.0	1.6	0.3
Charmhaven Wetland - Orooaloo			72.5			39.5	28.7	2.4	31.2	31.2
Chittaway Bay Wetland		11.2			0.5			0.2	0.8	**-10.4**
Colongra Swamp	0.01	132.78	81.60	0.00	132.54	13.10	20.65	5.33	158.5	25.7
Constructed			27.3			27.3			0.0	0.0
Craigie Park		1.2			0.3				0.3	**-0.8**
Elizabeth Bay Drive Wetland	0.00	2.38	95.76	0.00	0.50	95.76	0.00	1.50	2.0	**-0.4**
Gavenlock Road			49.3			38.3	8.8	1.8	10.6	10.6
Halekulani/Ashley Chapman Reserve	1.21	1.76	0.00	0.00	0.01	0.00	0.00	3.83	3.8	0.9
Jensen Road Wetland, Rocky Point			88.2			28.8	19.7	11.9	31.6	31.6
Karrangah Point Foreshore	0.1			0.1					0.1	0.0
Kooindah Waters Golf Course		17.0			4.3				4.3	**-12.7**
Lower Pioneer Dairy Dam, Tuggerah			81.2			70.1	48.1	20.7	68.8	68.8
Mardi			15.8			15.8			0.0	0.0
McDonagh Road North / McDonagh Road South			98.4			31.5	30.7	2.6	33.3	33.3
McPhersons Road			8.4			8.2	6.0		6.0	6.0
Oleander Street Wetland, Canton Beach		73.4			53.8			4.3	58.1	**-15.3**
Ourimbah Creek								6.7	6.7	6.7
Pipeclay Point Foreshore	0.0			0.0				0.2	0.2	0.1
Porters Creek Wetland			882.7			839.4	138.9	18.6	157.5	157.5
Reliance Drive Wetland			2.6			2.6	0.9		0.9	0.9
Rocky Point Foreshore	0.3			0.0					0.0	-0.2
San Remo	0.1		5.4			4.1	2.8	1.7	4.4	4.4

C-2 (cont'd) Existing and potential (far future) extents for vegetation precincts within Tuggerah Lake (ha)

Vegetation precinct	Existing vegetation			Vegetation retained in far future			Converted upland	Land use change	Potential tidal vegetation	Net change
	intertidal	supratidal	upland	intertidal	supratidal	upland				
TOTAL	**13**	**640**	**2,592**	**1**	**389**	**2,048**	**497**	**266**	**1,152**	**499**
South Tuggerah Lake Foreshore	9.5	10.1	1.7	0.6	2.0	1.7	1.2	11.8	15.6	**-4.0**
Spring Creek			7.7			7.6	0.2	2.1	2.2	2.2
Tacoma Wetland			86.1			33.0	33.0	23.7	56.7	56.7
Terilbah Island	0.5	10.2		0.0	6.8			2.5	9.4	**-1.3**
Terilbah Reserve		1.7			0.9				0.9	**-0.8**
The Entrance North Foreshore		2.6			0.6			1.0	1.6	**-1.0**
Top Dairy Dam			9.2			1.4	1.4	7.6	9.0	9.0
Toukley Sewerage Plant			4.4			4.4			0.0	0.0
Tuggerah			22.1			22.1	0.1		0.1	0.1
Tuggerah Swamp		318.9			143.7			23.1	166.7	**-152.1**
Tuggerawong Foreshore	0.6			0.0				2.0	2.0	1.4
Tumbi Creek Wetland			174.6			174.7	0.0		0.0	0.0
Tumbi Umbi Creek		5.9	16.0		4.9	16.0	2.3	4.1	11.3	5.4
Upstream of Porters Creek Wetland			27.0			27.0			0.0	0.0
Walker Park			1.3			1.6			0.0	0.0
Warner Avenue			9.9			4.2	4.0	11.9	15.9	15.9
Warnervale			113.4			113.5			0.0	0.0
Weemalah Wetlands	0.00	10.69	0.00	0.00	2.03	0.00	0.00	0.99	3.0	-7.7
Wetland B, Charmhaven STP			79.8			76.2	16.6	4.1	20.7	20.7
Wetland C, Bluehaven / Wetland E, Doyalson Ridge			13.4			13.4			0.0	0.0
Wetland D, Doyalson			5.8			5.8			0.0	0.0
Wetland F, Doyalson			37.9			38.0			0.0	0.0
Wyee Wetland			27.1			27.1			0.0	0.0
Wyong Racecourse Wetland			127.4			63.4	51.8	18.8	70.6	70.6
Wyong River Foreshore (D/S Pacific Hwy)		2.5	12.1		1.4	3.2	3.2	46.9	51.5	49.0
Wyong River, upstream of Pacific Hwy								5.1	5.1	5.1
Wyrrabalong National Park		34.1	4.5		34.1	4.5			34.1	0.0