TWEED RIVER ESTUARY

ESTUARINE VEGETATION MONITORING PROGRAM

FINAL REPORT

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ON BEHALF OF THE
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Executive Summary

A trend of increasing mangrove extent (2.66%) and decreasing saltmarsh extent (4.08%) was identified in the raw figures for the period 2000-2002, and the changes were deemed to be marginally higher than the error range of the methodology. The trend for both vegetation communities is consistent with longer-term trends on the Tweed River, and similar systems on the Australiana east coast. On the basis of these results, and the absence of any change in mangrove structural characteristics identified from on-ground surveys on Ukerebagh Island, we have concluded that mangrove and saltmarsh distributional and structural trends have not departed significantly from broader trends following the initiation of the sand bypassing project.

Seagrass was found to have increased in extent in the period 2000-2002 by approximately 9.05%, a figure well in excess of the estimated error of mapping in relation to seagrass in this survey. Such an increase is indicative of stable climatic, hydrological and geomorphic conditions.

The proliferation of mangroves in the Tweed River has been documented by Saintilan (1997, 1998), and forms the background against which results of this survey are to be interpreted. Saintilan (1997) found, in contrast to other sites in NSW, little evidence of upslope encroachment of mangrove upon saltmarsh. However, local occurrences of this trend are evident on the Tweed. Wilton (2002) found from aerial photographs of Ukerebagh Island dating from 1948 to 1998, which indicate between 1961 and1998 a trend of mangrove encroachment of saltmarsh, with saltmarsh declining by 20% and mangrove increasing extent by 20% over the same period.

Analysis of vegetation structure from quadrats located within the mangrove and saltmarsh zone between 2000 and 2002 indicate that there was no significant change in height, crown foliage diameter and number of stems for mangrove individuals. The cover of the saltmarsh species *Sporobolus virginicus* declined in 2001, possibly as a consequence of drought, and had recovered by December 2002.

SET's and feldspar marker horizons were installed in 2000 in the mangrove and saltmarsh zone to measure rates of subsidence and sedimentation. Surface elevation increased by mean of 1.55mm in the mangrove zone and 0.21mm in the saltmarsh zone. Sedimentation rates corresponded to tidal inundation frequency, from a mean of 9.57mm in the mangrove zone to 3.22mm in the saltmarsh zone. A decline in saltmarsh sedimentation rate in the period 2001-2002 is attributed to wind erosion corresponding to a decline in the cover of *S. virginicus*.

Within the mangrove and saltmarsh zones the rate of sedimentation exceeded the rate of surface elevation increase. Shallow compaction was measured at 8mm in the mangrove zone and 3mm in the saltmarsh zone. Given the current surface elevation, rate of shallow compaction and a mean sea level rise at Brisbane of –0.22mm per year the saltmarsh plain has increased elevation by 0.43mm per year relative to sea level, while the mangrove forest has increased elevation by 1.77mm per year relative to sea level. The results indicate conditions associated with wetland stability.

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1 Introduction

An Environmental Management System - Operations (EMS - Operations) was developed for the Tweed River Sand Bypassing Project to address environmental management issues associated with the ongoing operation of the system. This system contains a range of Environmental Management Plans (EMPs) that address key environmental performance issues. The EMS - Operations is currently being implemented by the NSW Department of Infrastructure Planning and Natural Resources, Queensland Environment Protection Agency and the Tweed River Entrance Sand Bypassing Company Pty Limited.

The EMS - Operations Sub-Plan B16, Tweed River Entrance and Lower Estuary Management Plan, has identified a number of monitoring requirements for the lower Tweed estuary including monitoring the distribution and health of wetlands in the lower estuary through the use of aerial photography mapping and periodic quadrant sampling, if required. The monitoring result will be compared to baseline data collected prior to the bypassing system operation. As part of the monitoring program, aerial photography of the lower Tweed estuary was captured every six months.

Pacific Wetlands were commissioned by the Tweed River Entrance Sand Bypass Project to undertake mapping of mangroves, saltmarsh and seagrass communities within the lower Tweed estuary using aerial photographs. The following report by *Pacific Wetlands* describes the methods by which these photographs have been utilised in determining the rates of change in mangrove, saltmarsh and seagrass vegetation cover, and comparisons of these rates to those determined in previous decades by Saintilan (1997). Further, the proposal describes high-resolution on-ground measurements of vegetation structure and wetland sedimentological process established on Ukerebagh Island in 2000, and continuing during the time of the establishment of the sand bypassing system. The Ukerebagh site is one of a network of sites monitored over the same time period in NSW and Victoria.

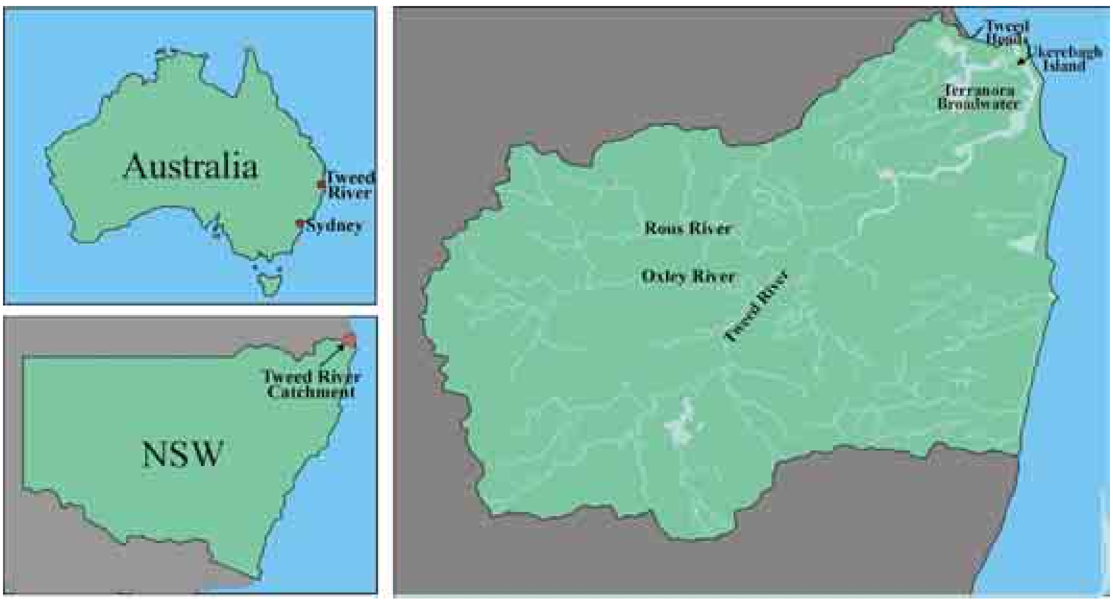

Figure 1: Location of the Tweed River and Ukerebagh Island.

Aerial photograph interpretation is a relatively coarse tool for the assessment of vegetation change in mangrove and saltmarsh, particularly at the temporal scale of months to years. An advantage of quadrat vegetation sampling over, or in addition to, aerial photo interpretation is the capacity of on-ground measures to assess seedling and juvenile recruitment. This is of particular interest in the present situation, as successful recruitment of mangroves in the saltmarsh environment might be an early indicator of changes to the vegetation structure following alterations in tidal conditions in the estuary. These changes are not detected on the spatial scale at which aerial photograph interpretation is made.

For this reason, the consultants established a series of six vegetation plots in the mangrove and saltmarsh environments of Ukerebagh Island in November 2000. Each plot contained a series of 6 randomly selected vegetation quadrats of 5 × 5 metres square. These plots were revisited in November 2001 and December 2002 during which times replicate measures were taken of species composition, mangrove height, girth and crown foliage diameter, the number of mangrove seedlings and the percent cover of each saltmarsh species in each quadrat.

Similar quadrats have been installed in the estuaries cited in Table 1. Rates of vegetation change on Ukerebagh Island can therefore be compared to 12 other sites in NSW and Victoria over the same period, providing a comprehensive context for the interpretation of the Ukerebagh Island data. The cost of this work was supported by Environment Australia under the Coasts and Clean Seas Initiative, and Tweed Shire Council, and results haven been incorporated into this report.

Region	Study Sites
Northern NSW	Ukerebagh Island, Tweed River
Central NSW	Kooragang Island, Hunter River Black Ned's Bay, Lake Macquarie Tilligerry Creek, Port Stephens
Sydney	Homebush Bay, Parramatta River, Towra Point, Botany Bay
Southern NSW	Currambene Creek, Jervis Bay Minnamurra River Cararma Inlet, Jervis Bay
Victoria	Kooweerup, Westernport Bay Rhyll, Westernport Bay Quaill Island, Westernport Bay French Island, Westernport Bay

Table 1: Study sites incorporated in the wider monitoring program undertaken by *Pacific Wetlands*

2 Methods

The primary method undertaken as part of this study is photogrammetric mapping. Methods used in the wider monitoring program, undertaken by Pacific Wetlands, were also incorporated into this study and include vegetation sampling using a series of plots and quadrats and measures of surface elevation and sedimentation using surface-elevation table (SET) techniques.

2.1 Photogrammetric Mapping

The consultants used the protocols established in Wilton and Saintilan (2000) for the mapping of mangrove and saltmarsh communities in eastern Australia. The following procedures were applied:

1. Aerial photographs covering the area to be mapped were loaned to the consultants for the duration of the project. This area includes all mangrove, saltmarsh and seagrass areas on the Tweed River north of Barneys Point Bridge, for the 13 May 2000 and 19 April 2002 series. These air photographs were scanned and imported into the ArcView Geographic Information System (*ESRI Inc.*) at a resolution of 360 dpi.

2. Aerial photographs were georectified to correct distortions of scale caused by the varying distances of photographed objects from the camera lens. A minimum of 6 ground control points per photograph were used, all derived from recognisable fixed points on the CMA topographic maps of the region.

3. The on-screen digitising functions of ArcView (*ESRI Inc.*) were used to create polygons of discrete mangrove, saltmarsh and seagrass areas. The following criteria were used when mapping vegetation communities

   - Mangrove, saltmarsh, mixed mangrove and saltmarsh, and seagrass were differentiated on the basis of colour, texture, and the geomorphic and geographical context of the vegetation, as described at length in Wilton and Saintilan (2000).

   - Interpretations were cross-checked with the earlier surveys of West *et al.* (1985), Saintilan (1997) and by comparison of the 2000 and 2002 series.

   - Saltmarsh was defined as intertidal vegetation where a gap of greater than 30 metres exists between mangrove crowns. Higher crown densities were classified as mangrove.

2.1.1 Ground-truthing of intertidal vegetation communities

Ground-truthing is the process of determining the accuracy of mapped vegetation units by comparison with field observation. This is particularly important if different vegetation units present similar textures and colours in the air photograph, and the geomorphic context does not allow easy differentiation.

Along the intertidal gradient, it is often difficult to distinguish between saltmarsh and adjacent pasture grasses. Similarly, it is at times difficult to distinguish from air photographic evidence alone the similar textures of mangrove, Casuarina and Eucalypt forests. These problems were noted in my previous (1998) report on distribution of Tweed River intertidal wetlands.

Visiting pre-determined sites following the production of draft maps is a simple and cost-effective way of ensuring the accuracy of the boundaries and, therefore, the validity of conclusions drawn concerning the rates of change in the vegetation. For this reason, ground-truthing was considered an essential part of the mapping exercise.

Two days were spent checking interpretations of vegetation communities at approximately 30 points at four key locations on the Tweed River. These points were determined following production of draft maps of the wetland vegetation.

2.1.2 Methods of Analysis

The total area of mangrove, saltmarsh and seagrass were calculated for each of the geomorphic divisions of the Tweed River described in Saintilan (1997) (Figure 2), including the Cobaki Broadwater, Tweed Channel, Terranora Broadwater and the Lower Tweed River and Terranora Channel. These analyses were performed digitally using the Spatial Analyst application in ARCView. Paired T-tests were applied to the area values for each vegetation unit to determine whether the variation between 13 May 2000 and 19 April 2002 were significant.

Trend lines were drawn for 2000-2002 in comparison with the results of Saintilan (1997) for the five decades preceding 1995 for the Lower Tweed River and Terranora Channel, and the combined broadwater areas of Cobaki Broadwater and Terranora Broadwater. Since the Tweed Channel was not mapped to the same extent at Saintilan (1997), comparisons were not made.

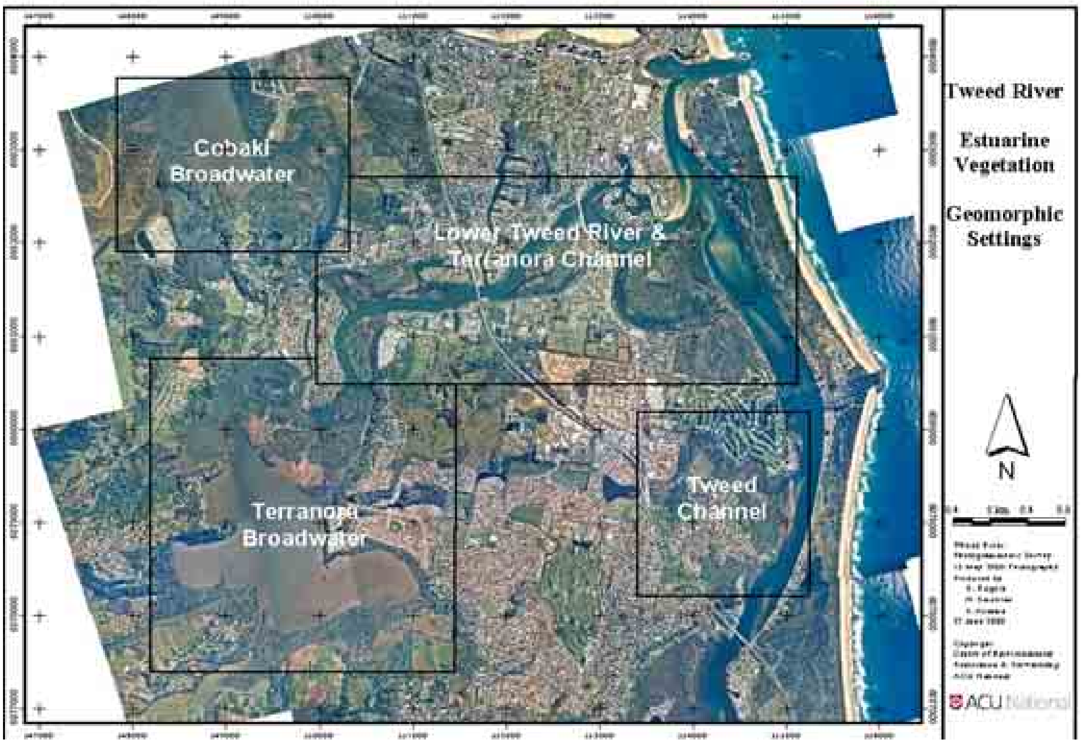

Figure 2: Geomorphic settings used for mapping comparisons, adapted from Saintilan (1997).

2.2 Vegetation Sampling

Prior to the commissioning of this study the consultants were engaged in monitoring vegetation and surface elevation characteristics of Ukerebagh Island for Environment Australia and the Tweed Shire Council. This study commenced in 2000 prior to the establishment of the Tweed River Entrance Sand Bypassing System. Results from this study bear directly upon the interpretation of data in this report, and so the methodology employed in this on-site monitoring is reproduced here.

Changes in estuarine wetland vegetation health are best assessed using plots and quadrats in a stratified manner to measure species composition and structural properties (Watkinson 1998). Based on the methods of Clarke (1993), plots were established in a stratified manner within the mangrove and saltmarsh vegetation at each study site. Six plots of 20m x 50m were established in November 2000 beside the SET monitoring stations. Within each plot, six random 5m x 5m quadrats were established.

Within the mangrove plots the number of mangrove seedlings and the height, diameter at breast height (DBH), number of basal stems and crown foliage diameter of mangrove individuals was recorded for each quadrat. Since DBH is typically measured at a height of 1.3m on the main trunk, DBH was not recorded for those individuals less than 1.3m tall and when the trunk had coppiced below this height. Power analysis has demonstrated that at least 50% change is discernible for most mangrove structural measures using re-randomised quadrats (Watkinson 1998).

Within the saltmarsh plots, species presence and the percentage cover of all saltmarsh species was recorded.

2.3 Surface Elevation

To analyse surface elevation, sedimentation-erosion table techniques were employed on Ukerebagh Island by Rogers *et al.* (2002). The sedimentation-erosion table (SET) is an instrument originally created by Boumans and Day (1993) for the United States Geological Survey (USGS) to make high precision measurements of change in the surface elevation of intertidal and shallow sub-tidal environments. The confidence interval of the SET is ±1.5m. The SET acts as a benchmark in space from which relative changes in the surface elevation can be determined (Figure 3).

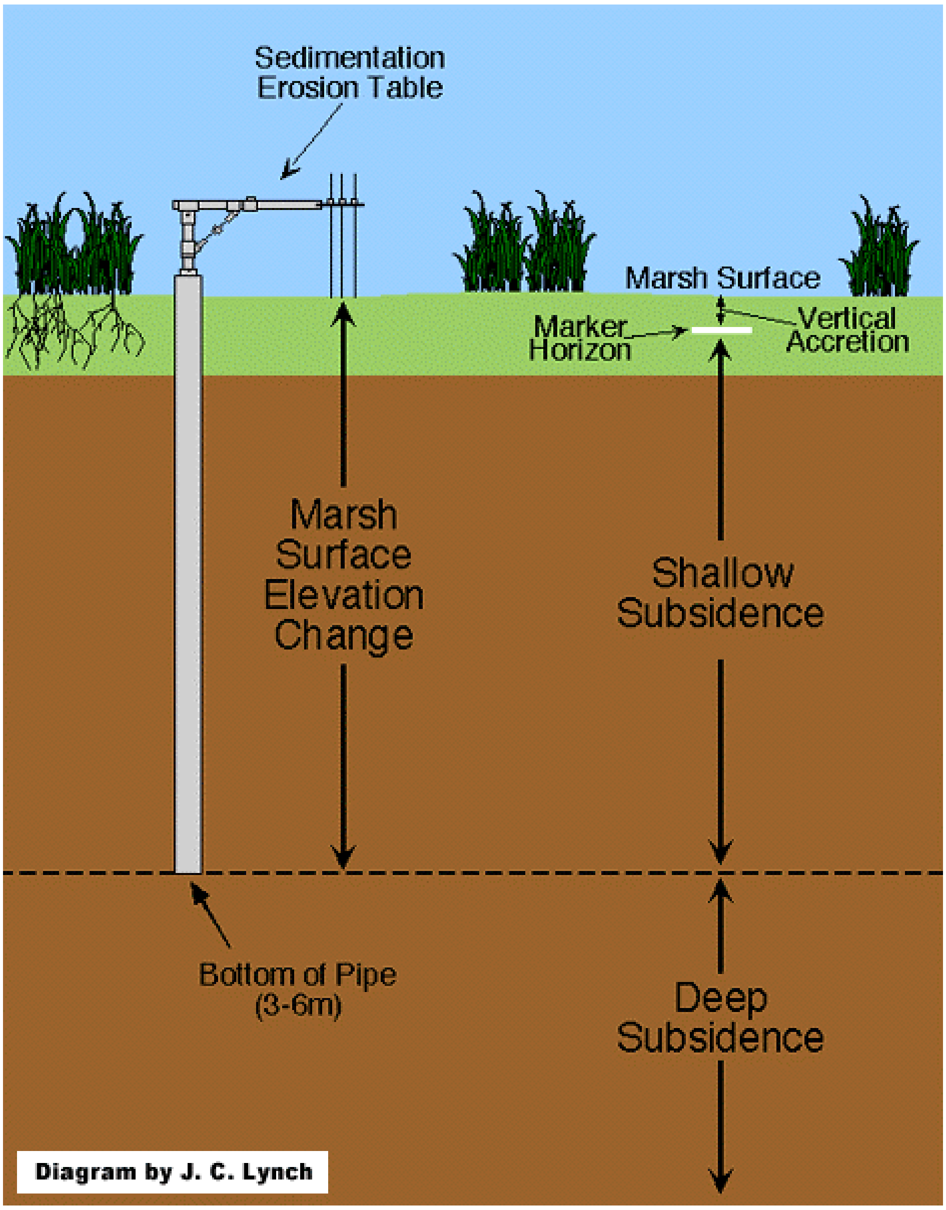

Figure 3: Overview of the Sedimentation-Erosion Table.

Before installation, the site was prepared so that disturbance of the marsh surface was minimised. A platform of treated pine was built from which installation was performed and all subsequent measurements taken. A six-metre aluminium pole was driven into the marsh surface to the point of refusal, to act as a permanent benchmark from which measurements of surface elevation are taken (Figure 4). The pole extends approximately 25cm from the wetland surface and an insert pipe is cemented at the top to provide a junction for the vertical arm of the SET. The SET fits onto the insert pipe at fixed positions so that at least four replicate sets of readings can be taken (Figure 5).

Figure 4: SET installation.

Figure 5: SET readings.

The SET was positioned on the insert pipe and the horizontal arm was levelled. The compass direction of the horizontal arm of the SET was recorded. Nine pins were lowered to the marsh surface and the length of each pin above the horizontal table was measured to the nearest millimetre using a ruler. This procedure was repeated for the nine pins and in four directions to yield a maximum of 36 elevation measurements per SET.

SET monitoring stations were employed in replicated sets of three to characterise the sedimentation and elevation properties of both the mangrove and saltmarsh vegetation of the Tweed River. A total of 6 SET’s were installed on Ukerebagh Island, with 3 being established within the mangrove vegetation and three in the saltmarsh vegetation.

2.4 Sedimentation

In conjunction with the SET installation, feldspar marker horizons were sprinkled on the wetlands surface at the perimeter of each SET. These horizons serve as a sedimentation marker against which vertical accretion in measured. Subsidence or uplift was then determined based on the difference between the degree of vertical accretion measured from the feldspar markers and the extent of surface elevation change measured with the SET.

Three 0.25 square metre feldspar marker horizons were sprinkled on the wetland surface at the perimeter of each SET at the time of installation (Figure 6). Mini-cores were removed from each feldspar marker horizon in December 2001 and the degree of sedimentation was measured using a ruler (Figure 7).

Figure 6: Feldspar marker horizon application.

Figure 7: Mini-core removal and measurement.

3 Results

3.1 Photogrammetric Mapping

3.1.1 Changes in Extent

Changes in extent within the entire mapped area is shown in Figures 8 and 9 and within the four geomorphic settings in Figures 10 to 17 (See Appendix 2 for larger versions).

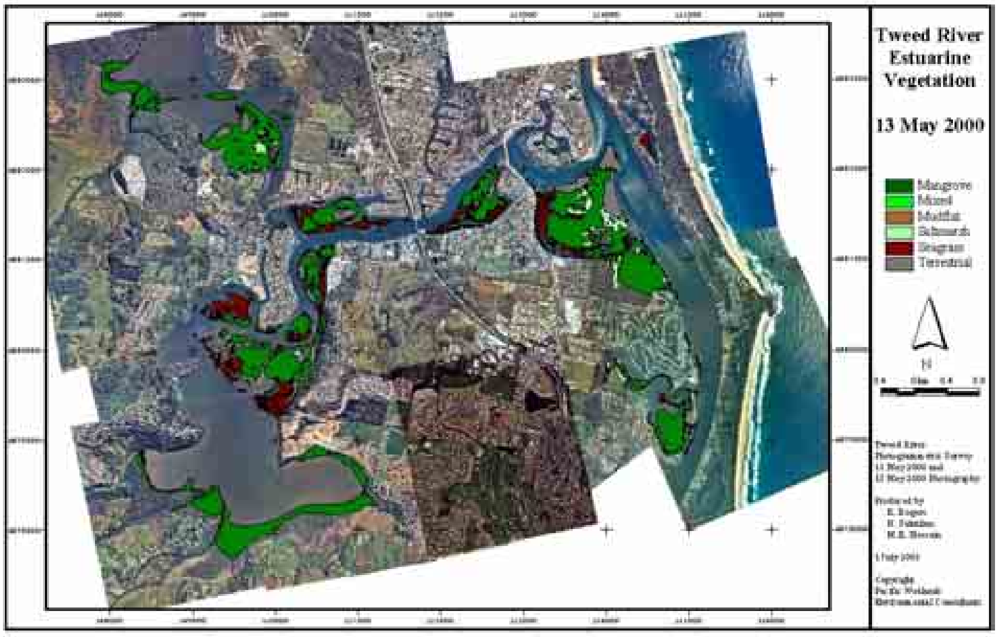

Figure 8: Tweed River estuarine vegetation extent on 13 May 2000.

Figure 9: Tweed River estuarine vegetation extent on 19 April 2002.

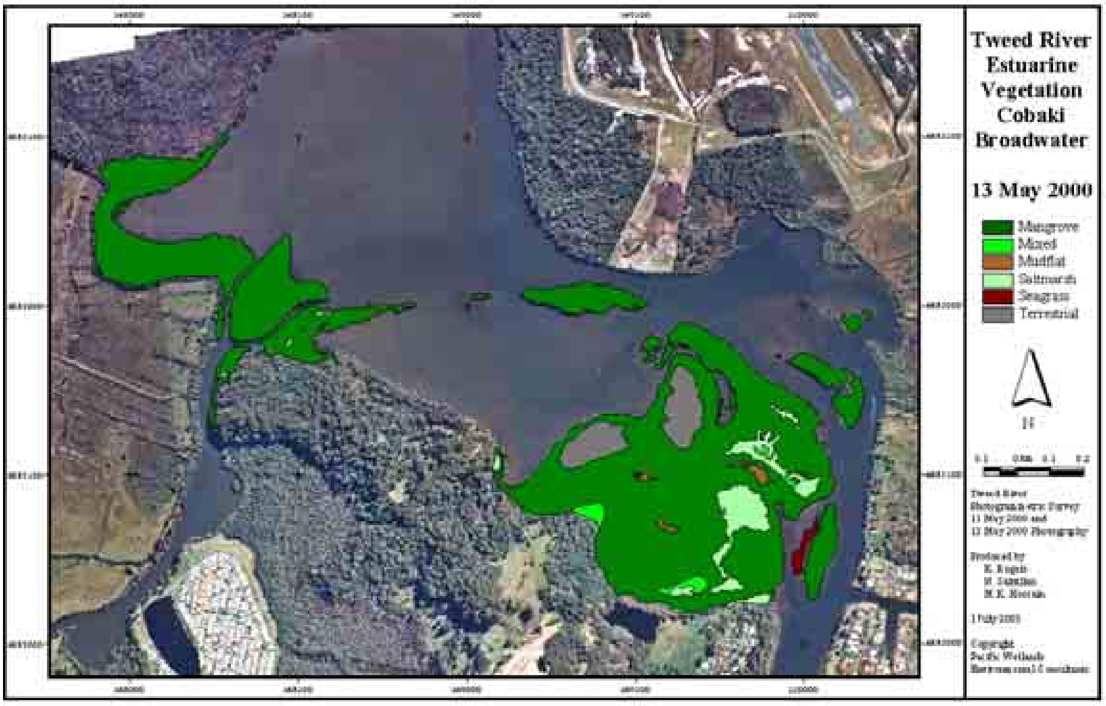

Figure 10: Cobaki Broadwater estuarine vegetation extent on 13 May 2000.

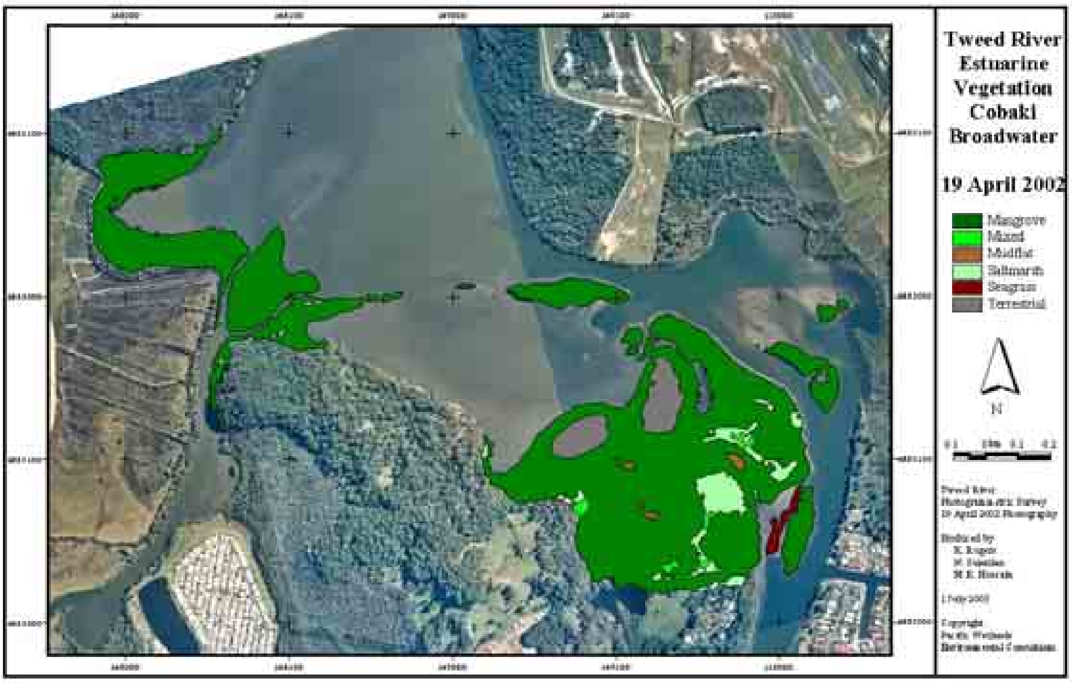

Figure 11: Cobaki Broadwater estuarine vegetation extent on 19 April 2002.

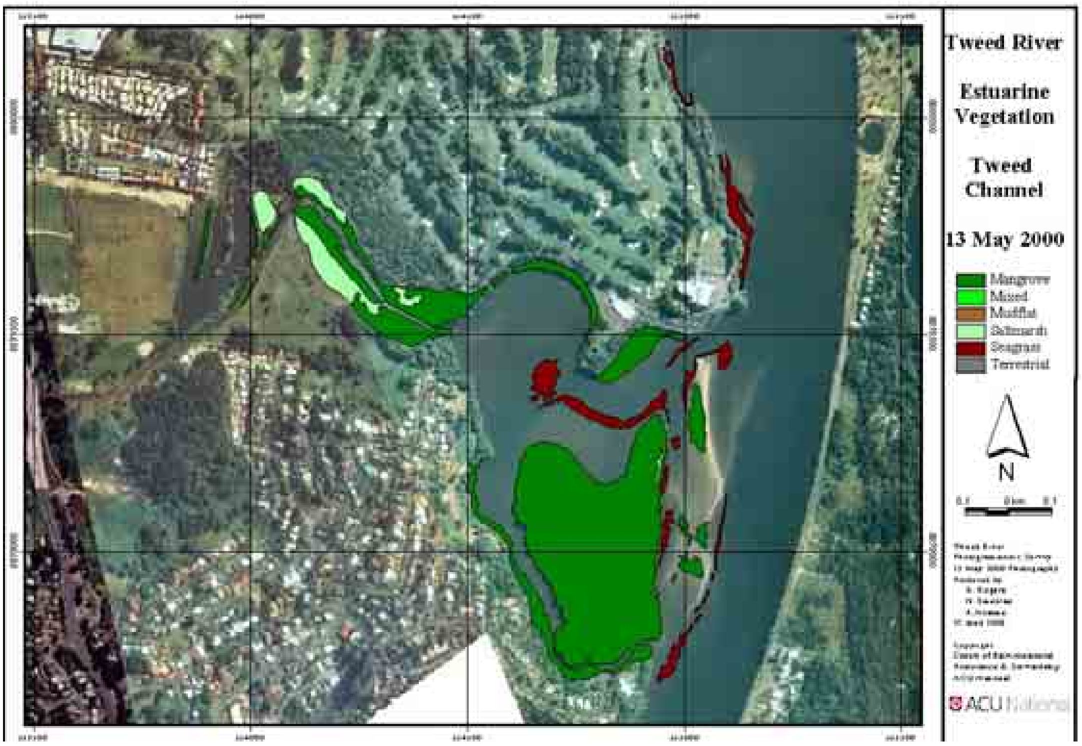

Figure 12: Tweed Channel estuarine vegetation extent on 13 May 2000.

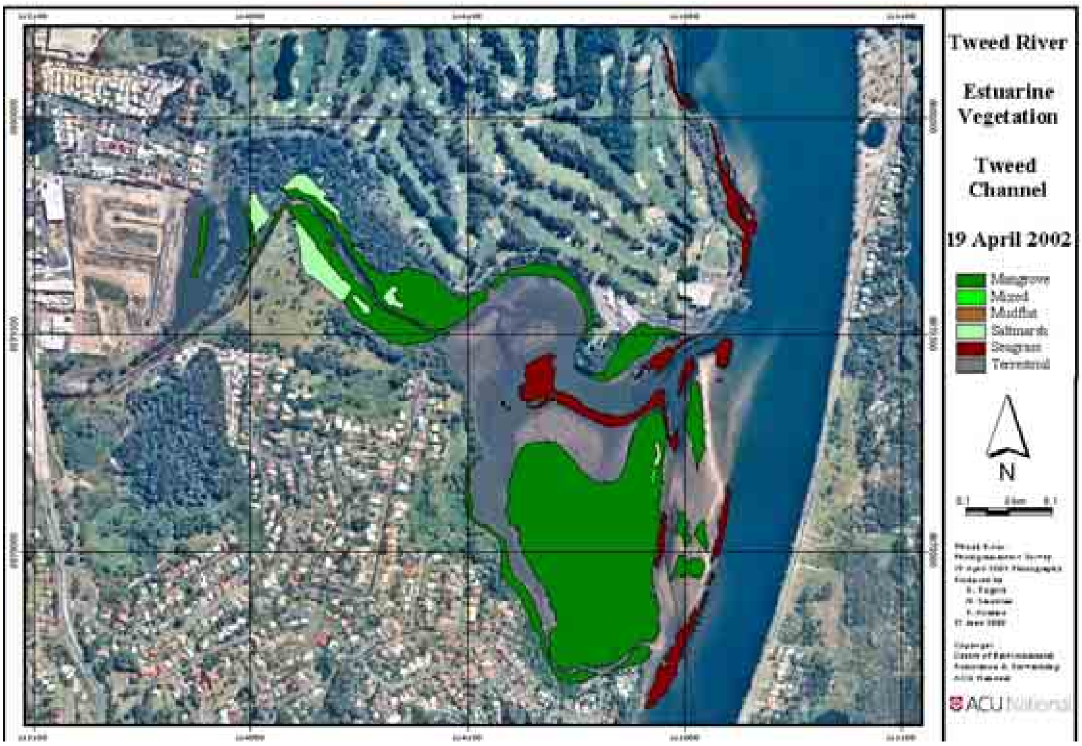

Figure 13: Tweed Channel estuarine vegetation extent on 19 April 2002.

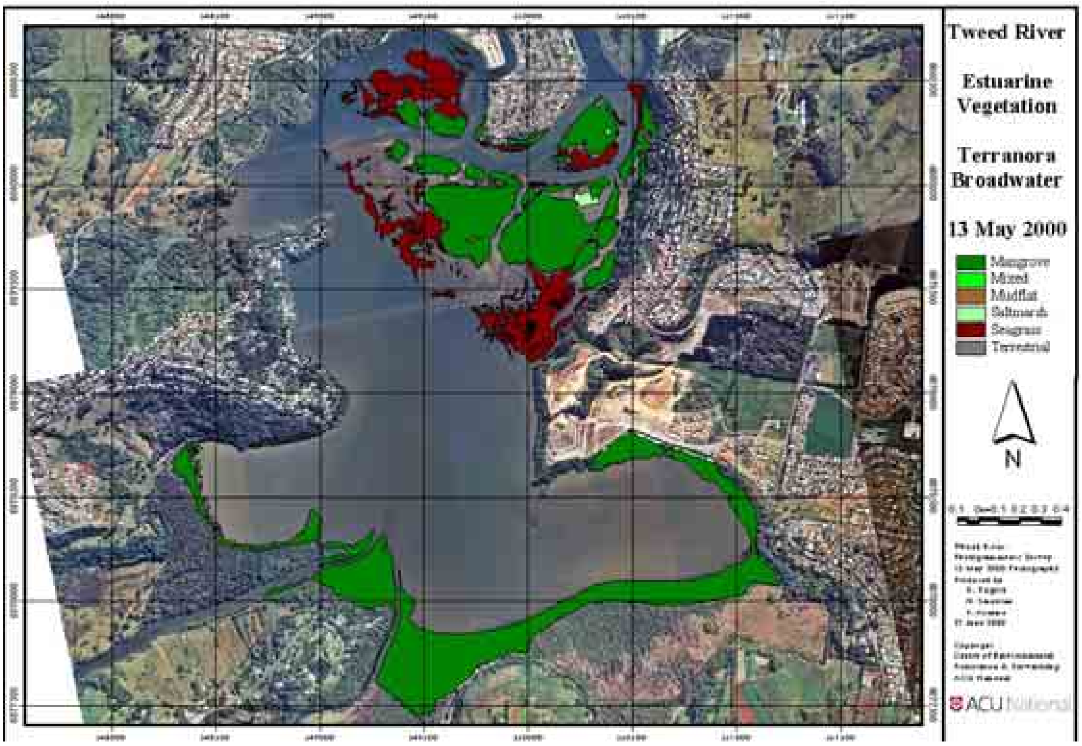

Figure 14: Terranora Broadwater estuarine vegetation extent on 13 May 2000.

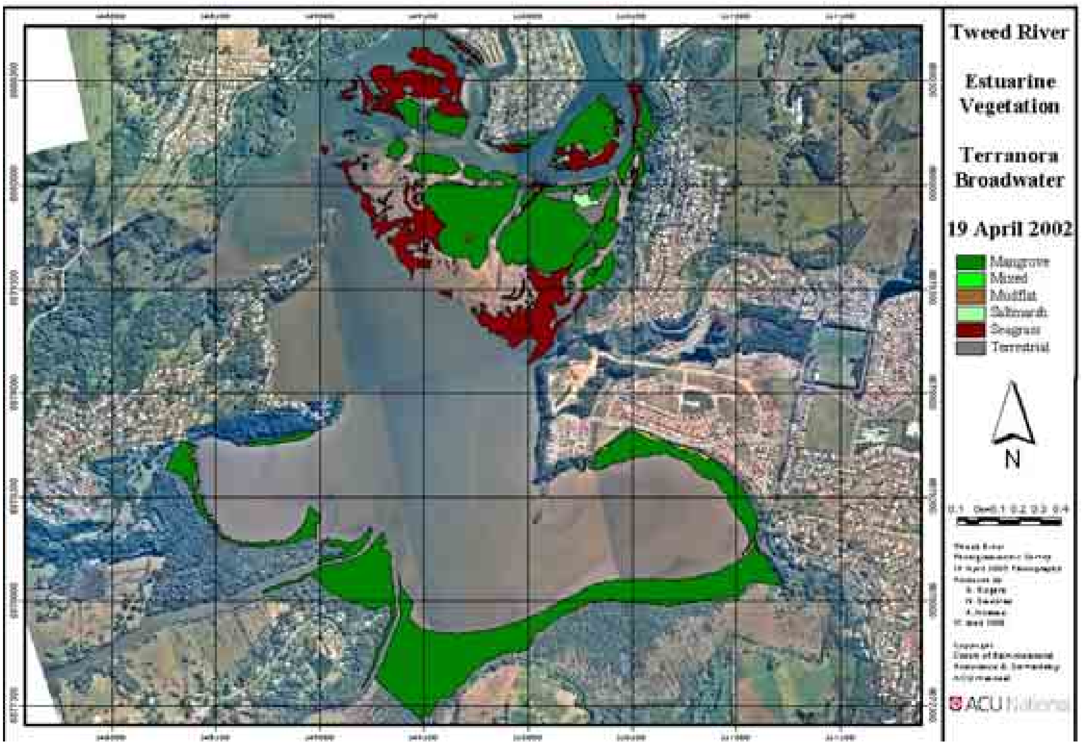

Figure 15: Terranora Broadwater estuarine vegetation extent on 19 April 2002.

Figure 16: Lower Tweed River and Terranora Channel estuarine vegetation extent on 13 May 2000.

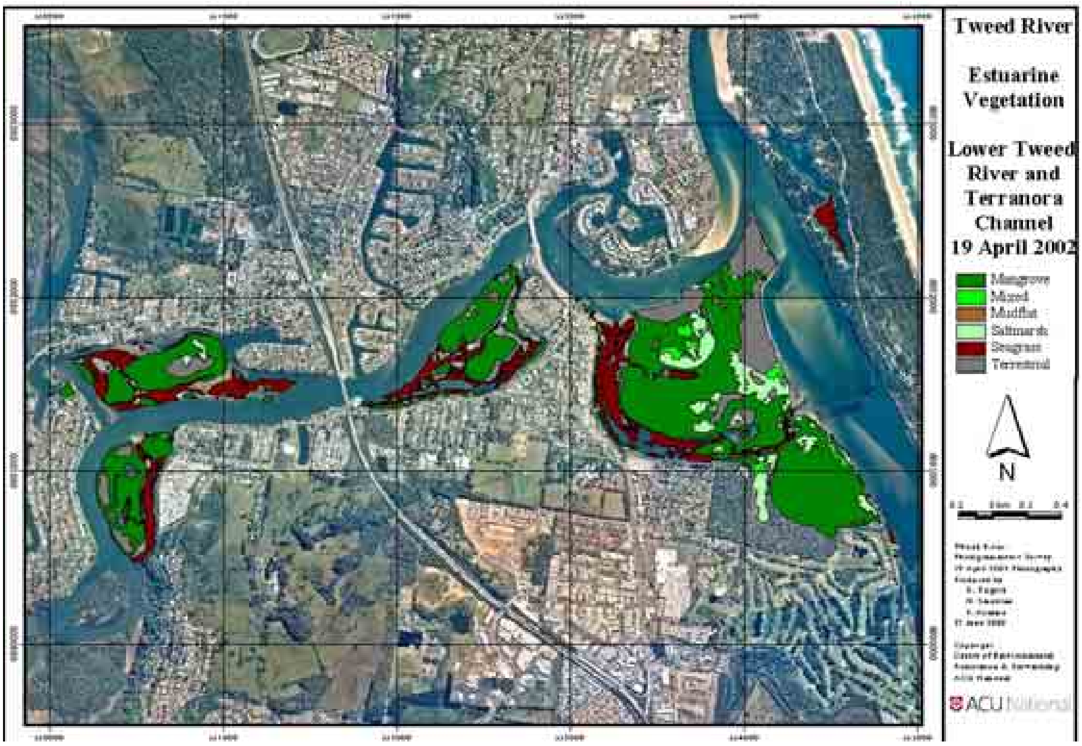

Figure 17: Lower Tweed River and Terranora Channel estuarine vegetation extent on 19 April 2002.

3.1.2 Changes in Area

Mangrove area increased by approximately 2.66% and seagrass area increased by approximately 9.05% between 13 May 2000 and 19 April 2002 within the entire mapped area (Figure 18). Both of these increases were higher than the estimated digitising mapping errors shown in Table 4. However, the percentage change due to georectification errors may bring the mangrove increase within the total estimated error, and the result may not be statistically significant. The increase in seagrass area is likely to be significant, given the small error in the digitising process. The decrease in saltmarsh area of 4.08% over the same period is consistent with historic trends, though cannot be demonstrated to be a significant change given the high errors associated with saltmarsh identification.

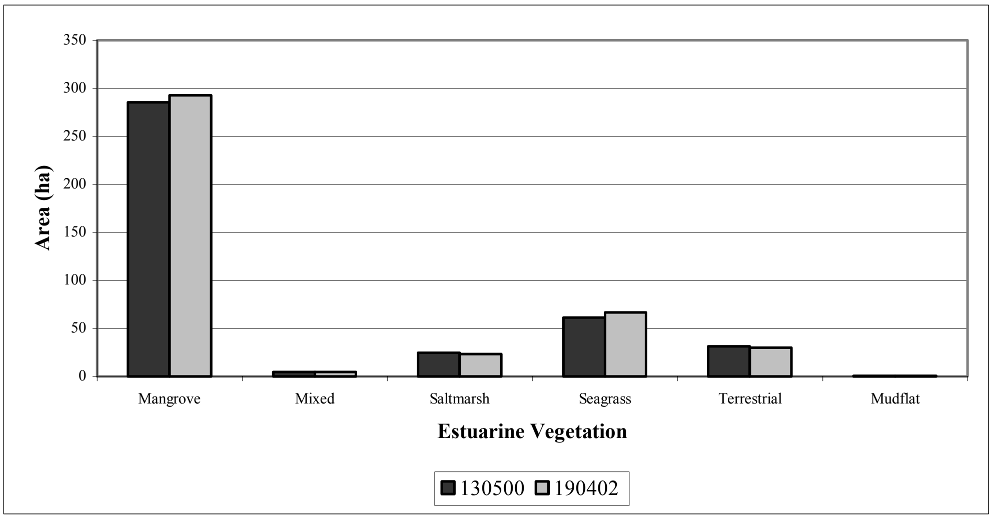

Figure 18: Area of estuarine vegetation within the mapped section of the Tweed River Estuary on 13 May 2000 and 19 April 2002.

The area of mangrove and seagrass in each geomorphic setting increased over the study period. Excluding the Lower Tweed River and Terranora Channel, saltmarsh area decreased in all geomorphic settings between 13 May 2000 and 19 April 2002 (Table 2, 3) (Figures 19 to 22).

Vegetation Type	Cobaki Broadwater	Tweed Channel	Terranora Broadwater	Lower Tweed River & Terranora Channel	Total
Mangrove	1.00	10.53	4.17	0.82	2.66
Saltmarsh	-5.78	-8.81	-55.33	1.41	-4.05
Seagrass	47.37	46.47	4.12	9.50	9.05

Table 2: Percentage change in the area of estuarine vegetation within the Cobaki Broadwater, Tweed Channel, Terranora Broadwater and Lower Tweed River and Terranora Channel on 13 May 2000 and 19 April 2002.

Zone	Cobaki Broadwater		Tweed Channel		Terranora Broadwater		Lower Tweed River & Terranora Channel	
Photography	**2000 (ha)**	**2002 (ha)**	**2000 (ha)**	**2002 (ha)**	**2000 (ha)**	**2002 (ha)**	**2000 (ha)**	**2002 (ha)**
Mangrove	60.30	60.90	20.61	22.78	93.97	97.89	110.26	111.16
Mixed	0.96	0.69	0.03	0.04		0.63	3.48	3.59
Saltmarsh	3.98	3.75	1.93	1.76	1.50	0.67	17.04	17.28
Seagrass	0.38	0.56	2.69	3.94	26.24	27.32	31.90	34.93
Terrestrial	3.83	3.66			2.39	2.44	25.24	24.22
Mudflat	0.44	0.33			0.10	0.09	0.24	0.44

Table 3: Area of estuarine vegetation within the Cobaki Broadwater, Tweed Channel, Terranora Broad water and Lower Tweed River and Terranora Channel on 13 May 2000 and 19 April 2002.

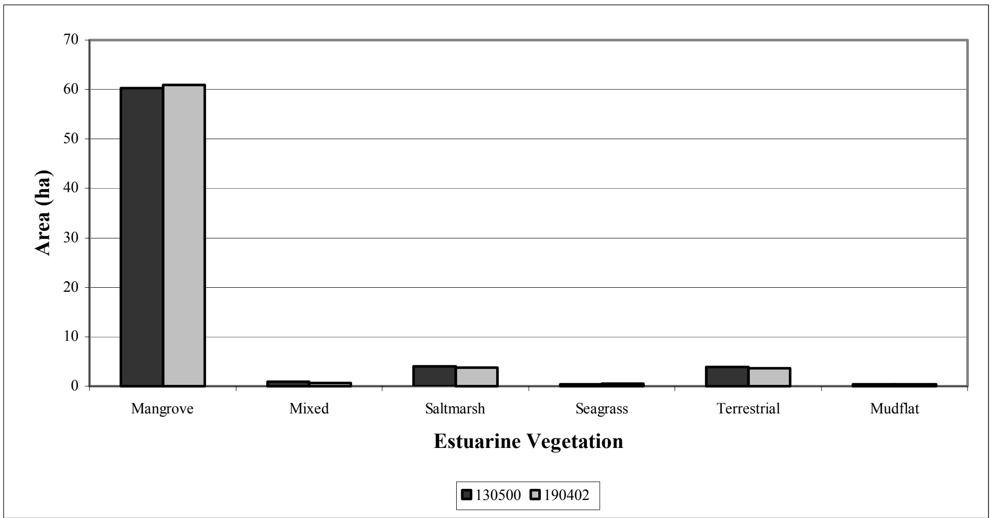

Figure 19: Area of estuarine vegetation within the Cobaki Broadwater
on 13 May 2000 and 19 April 2002.

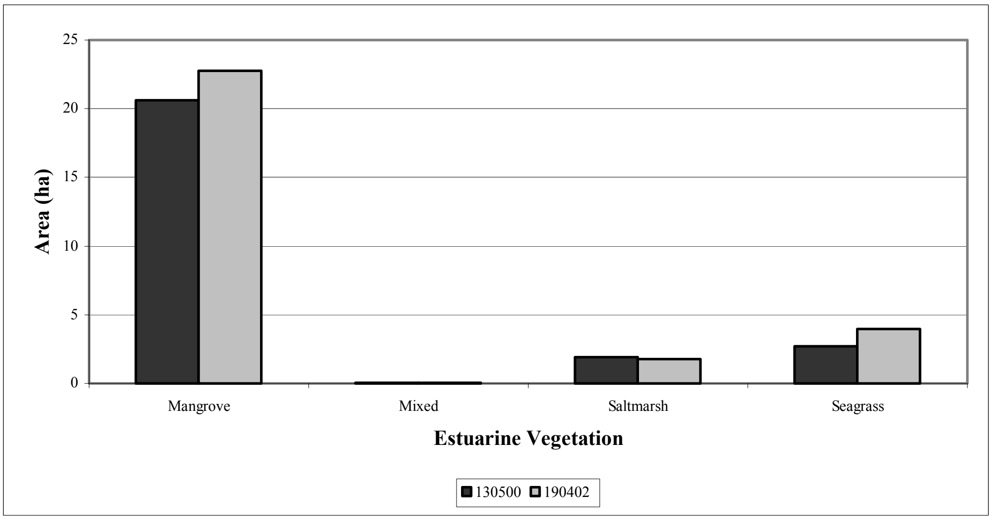

Figure 20: Area of estuarine vegetation within the Tweed Channel
on 13 May 2000 and 19 April 2002.

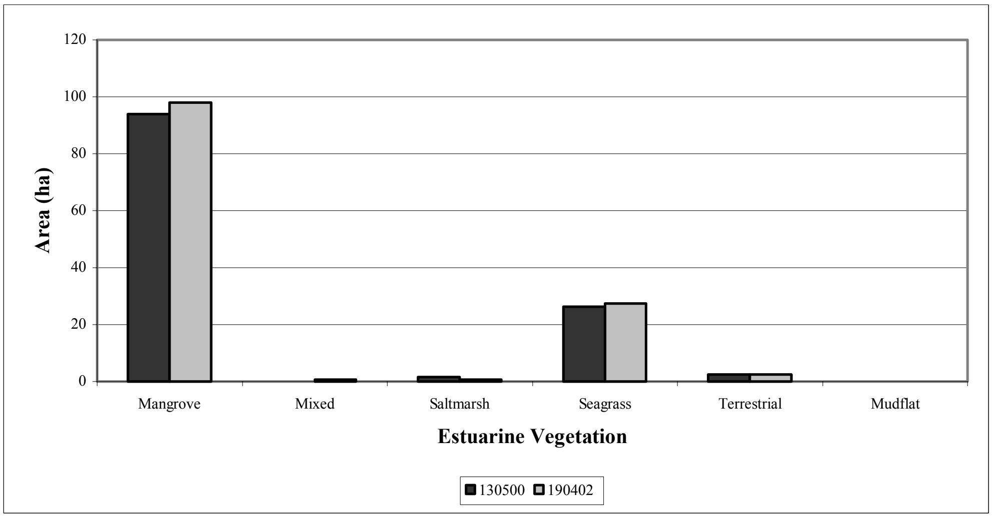

Figure 21: Area of estuarine vegetation within the Terranora Broadwater
on 13 May 2000 and 19 April 2002.

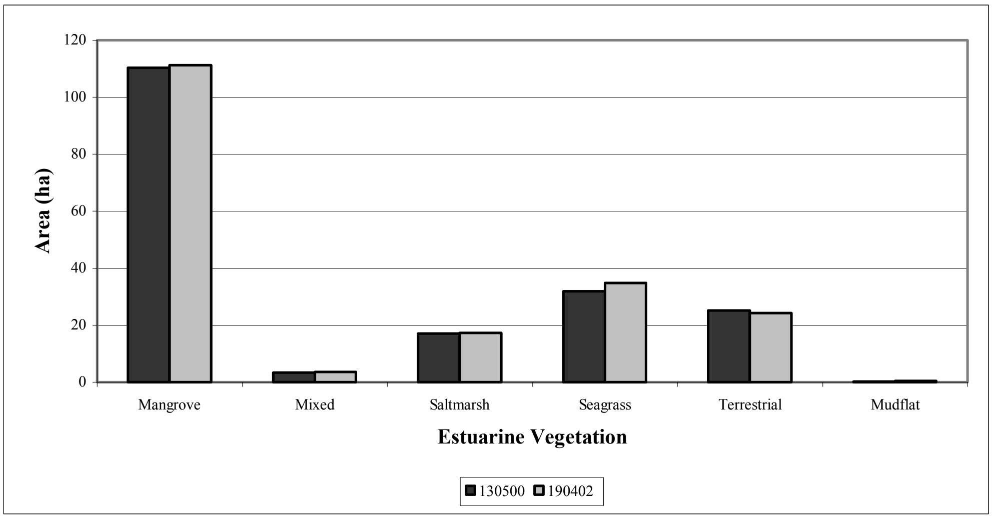

Figure 22: Area of estuarine vegetation within the Lower Tweed River and Terranora Channel on 13 May 2000 and 19 April 2002.

3.1.3 Mapping Errors

Some component of the estimated changes in the extent of mangrove, saltmarsh and seagrass will be due to variations in photograph quality between 13 May 2000 and 19 April 2002, inherent errors within aerial photograph images, georectification error and digitising error.

Variations always occur in photograph quality and image clarity leading to errors in aerial photography analysis and interpretation. In this survey, the 13 May 2000 mapping was based on images taken for the Tweed River Entrance Sand Bypass project on 11 and 13 May 2000. While taken close to the same date, due to differences in image resolution, air quality, weather conditions and tide levels, the images of 13 May 2000 have greater clarity and sharper boundaries. In a similar fashion the 19 April 2002 aerial photographs differ in photograph quality and image clarity from the 11 May 2000 and 13 May 2002 photographs.

Georectification is the process whereby the geometry of an image is made planimetric based on the co-ordinates on a map (Jensen, 1996). In doing so a root mean square (RMS) error is produced for each ground control point and is then averaged for each image. Based on the protocols of Wilton and Saintilan (2000) an RMS error of 5 metres or less was considered appropriate. Due to the topographic variability within the areas surrounding the broadwaters, it is expected that the error is greater in areas with a high elevation (>20m). Since estuarine vegetation is not located within high elevation areas, the need for correction within these regions was not necessary. RMS errors are contained in appendix 1 and average 1.5m for the 13 May 2000 map and 2.44m for the 19 April 2002 map.

The Tweed Heads and Currumbin topographic maps were used as the base maps for georectification. Topographic maps are produced based on aerial photography and therefore produce an error. This error should be accounted for in the calculation of mapping error based on these maps. The Tweed Heads map is based on 2002 aerial photography and on the horizontal axis, "90% of well defined areas is within 12.5 metres of true position". The Currumbin topographic map is based on 1972 imagery and was revised in 1983. On the horizontal axis the map error is 10 metres.

Human error is unavoidable in any manual procedure. To estimate the human error, each individual involved in the mapping process remapped a small section and the variability was determined based on differences in vegetation area. This variability is represented as a percentage error for each vegetation category in Table 4.

Vegetation Type	Area 1	Area 2	Percentage error
Mangrove	109996	111772	1.59
Saltmarsh	82361	83433	1.28
Seagrass	94693	92729	2.07
Terrestrial	25004	28138	11.138

Table 4: Percentage errors associated with interpretation of vegetation polygons, by vegetation category, for the 2002 photo series.

3.2 Vegetation Sampling

The mangroves of Ukerebagh Island are typically characterised by single stemmed individuals of *Avicennia marina* and *Rhizophora stylosa* with an approximate height of 4.5m and crown foliage diameter of 2.5m. Statistical analysis indicates that there was no significant difference between the density (p=0.884), height (p=0.710), CFD (p=0.642) and number of stems (p=0.896) of individuals over the study period (Figure 23).

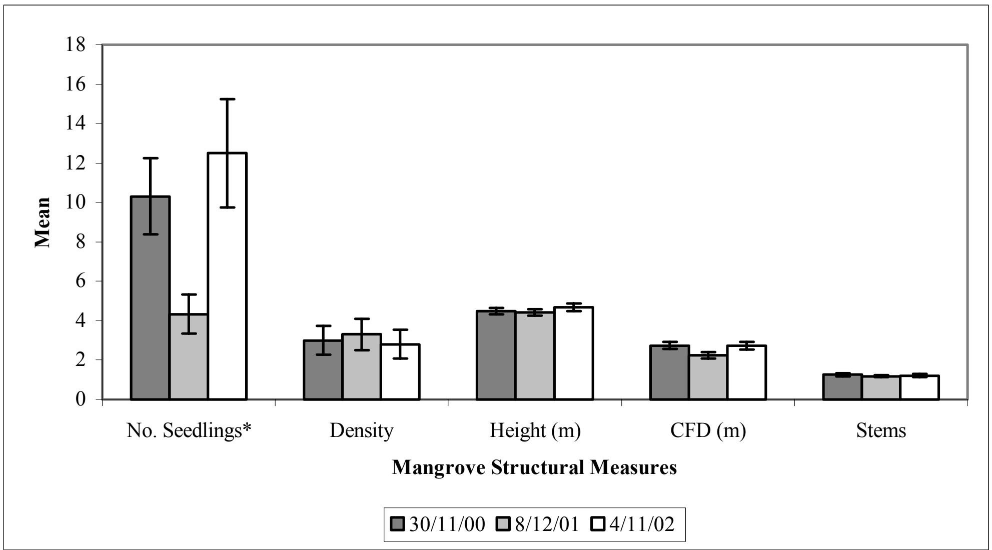

Figure 23: Mean results and standard error for different mangrove structural measures recorded in plots in October 2000, December 2001 and November 2002. * Mean number of seedlings per quadrat

The number of seedlings per quadrat varied significantly over time (p=0.002), but not between species (p=0.790). In particular, the number of seedlings recorded in December 2001 was significantly lower than November 2000 and November 2002.

The saltmarsh plain of Ukerebagh Island is characterised by *Sporobolus virginicus.* A number of *Avicennia marina* seedlings and juveniles have begun to encroach on the saltmarsh plain. The cover of saltmarsh showed significant differences over time (p=0.000). In particular the cover recorded in December 2001 averaged 58.61%, which was significantly less than the cover recorded in November 2000 (68.47%) and November 2002 (72.78%). There was no change in the density of *Avicennia marina* individuals in saltmarsh plots.

3.3 Surface Elevation

Surface elevation from the six SET's established in October 2000 showed an increase to November 2002 (Figure 24), with the majority of change occurring between December 2001 and November 2002. Surface elevation varied significantly between zones (p=0.000) and over time (p=0.000), increasing by a mean (standard error) of 7.0 mm (0.40) in the mangrove zone and 1.51 mm (0.10) in the saltmarsh zone between October 2000 and November 2002.

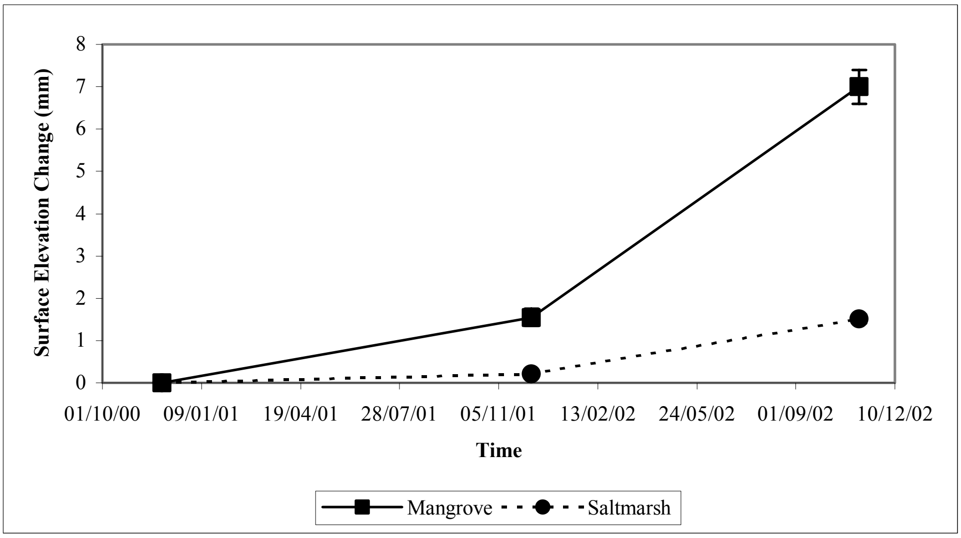

Figure 24: Change in surface elevation in the mangrove and saltmarsh zones between 2000 and 2002.

3.4 Vertical Accretion

Vertical accretion declined in a landward direction from mangrove to saltmarsh from a mean (standard error) of 8.88 mm (1.51) in the mangrove zone to 1.25 mm (0.59) in the saltmarsh zone between October 2000 and November 2002 (Figure 25). The majority of accretion occurred between October 2000 and December 2001, with an accretion deficit between December 2001 and November 2002. Vertical accretion was significantly different between mangrove and saltmarsh zones (p=0.000), but was not significantly different over time (p=0.174).

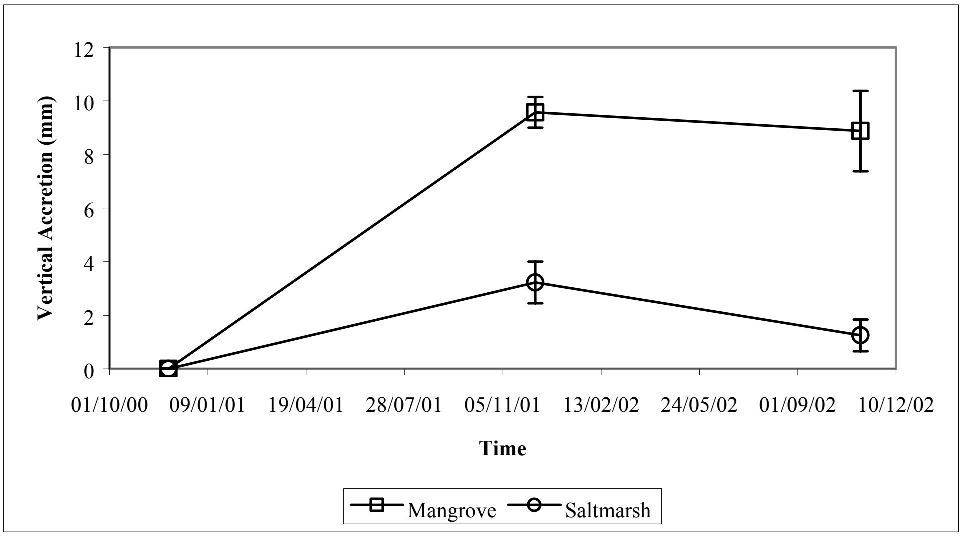

Figure 25: Change in sedimentation in the mangrove and saltmarsh zones between 2000 and 2002.

Measures of surface elevation and vertical accretion between October 2000 and November 2002 were significantly different (p=0.035). This was particularly evident within the mangrove zone (p=0.029) where vertical accretion exceeded surface elevation change by 8.02 mm by December 2001, decreasing to a difference of 1.88 mm by November 2002. Surface elevation and vertical accretion was not significantly different within the saltmarsh zone (p=0.487).

Based on the tidal inundation survey conducted as part of this study (Figure 13), it is estimated that the SET's located in the mangrove zone are inundated by 1.3m to 1.4m tides, corresponding to between 69.5% and 82.0% of tides per year. Similarly, the SET's in the saltmarsh zone are inundated by 1.7m tides, corresponding to 21.1% of tides per year. A simple arithmetic relationship was derived showing a high correlation between sedimentation rate and inundation frequency (r^2=0.623) (Figure 26). Sedimentation rates average at 0.006mm per tide.

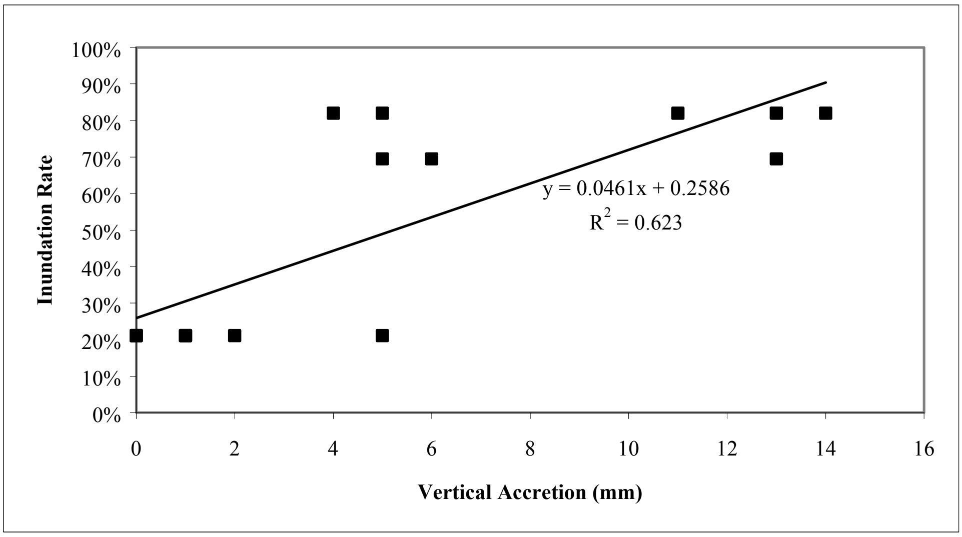

Figure 26: Simple arithmetic relationship between inundation frequency and sedimentation rate.

4 Discussion

4.1 Trends in Wetland Vegetation 1948- 1998- the historical context

The proliferation of mangroves in the estuaries of southeastern Australia since the time of European settlement over 200 years ago is now a well established trend (McLoughlin 2000, Saintilan and Williams 2000). Historical records point to a continuous increase in mangroves along estuarine shorelines (McLoughlin 2000) and historical air photographs extending back to the early 1950's show the landward encroachment of mangroves onto saltmarsh plains in numerous estuaries (Saintilan and Williams 1999). Many hypotheses have been advanced explaining this trend, including elevated sea level (Wilton 1997, Saintilan and Hashimoto 1999), marsh subsidence (Burton 1982, Vanderzee 1988, Saintilan 1998), increased sedimentation rates (Wilton 1997, McLoughlin 2000) and elevated nutrient levels (McLoughlin 1987, Wilton 1997, McLoughlin 2000). A network of monitoring sites is established in 11 locations throughout southeastern Australia to examine vegetation change in the context of the above hypotheses.

One estuary particularly affected is the Tweed River (Figure 1). The area of both mangrove and saltmarsh increased in the period 1939-1994 (Saintilan 1997). The increase in saltmarsh area in this period is atypical of estuaries in New South Wales, which are characterised by saltmarsh decline (Saintilan and Williams 1999). The increase in saltmarsh area was not significant in the final decade of this survey (1984-1994). A more recent survey (Wilton 2002) has demonstrated a decline in saltmarsh on Ukerebagh Island of 16% in the period 1948-1998, and this rate of decline corresponds to the rate of saltmarsh decline documented for the entire estuary in this survey.

A study was implemented in November 2001 in response to the proliferation of mangroves in estuaries in southeast Australia (Rogers, Saintilan and Wilton 2002). Detailed photogrammetric mapping in this report and the study of *Avicennia marina* community structure at the landward mangrove boundary indicate a trend of mangrove colonisation of saltmarsh. Saltmarsh area declined from 13.8ha in 1961 to 11.1ha in 1998 (20% decline), while mangrove area increased from 37.7ha to 45.2ha (20% increase) over the same period. Juveniles were observed spreading out over the saltmarsh plain in areas perceived by Saintilan (1998) to be relatively stable.

4.2 Vegetation trends in the period 2000-2002

The overall rate of mangrove area increase observed in this study was 1.33% per year and the rate of saltmarsh area decrease estimated 2.04 % per year. These rates of change are consistent with the historical trends described above, as well as changes in the extent of similar communities in estuaries within New South Wales and Victoria (Saintilan and Williams 2000). Even so, it is difficult to state unequivocally whether this change is due to actual vegetation change or mapping error, given that the figures are close to the error range of the methodology. There is no indication, on the basis of the mapping conducted, that trends in the distribution of mangrove and saltmarsh have been impacted by the very small change in monitored tidal hydrological conditions that may be associated with the Tweed River Entrance Sand Bypass Project (See Section 4.5).

Seagrass showed a consistent increase in the period 2000-2002, in all geomorphic settings. The overall increase in seagrass of 9.05 % is significantly higher than can be attributed to georectification and digitising errors. Factors which promote the increase of seagrass area include water clarity and salinity (which may be associated with drought conditions), and geomorphic stability. There is no indication that the small change in tidal hydrological conditions within the Tweed estuary are having a detrimental impact on seagrass beds.

4.3 Vegetation quadrats

Since measures of vegetation structural changes within the mangrove zone of Ukerebagh Island showed insignificant change, it is apparent that observed changes in extent are not accompanied by structural changes within the mangrove zone. Changes in seedling density is variable within and between years, depending on seedlings viability, tide conditions and the viability of the parent tree to produce propagules.

The precentage cover of the saltmarsh plant Sporobolus virginicus has declined in December 2001, possibly due to the onset of drought. By November 2002 there has been considerable recovery, with groundcover exceeding the 2000 levels. There was no indication of increased mangrove encroachment in the permanent saltmarsh vegetation plots.

4.4 Surface Processes

Sedimentation rates within the mangrove and saltmarsh zones correspond to inundation frequencies and were significantly higher than the estimated rate of sea level rise. The decline in the sedimentation rate in the saltmarsh zone in the period 2001-2002 is attributed to the drought, and corresponds to a decrease in the protective cover provided by *Sporobolus virginicus*, and the greater incidence of wind erosion.

Within the mangrove and saltmarsh zones the rate of sedimentation exceeded the rate of surface elevation increase. Shallow compaction, which is the deficit between surface elevation and accretion, was measured at 8mm in the mangrove zone and 3mm in the saltmarsh zone.

Mean surface elevation increase in the mangrove and saltmarsh zones averages 1.55mm and 0.21mm, respectively. Since sea-level rise in Brisbane is estimated at – 0.22mm per year, it is apparent that the degree of sedimentation is high enough to compensate for the shallow compaction that is occurring to enable the saltmarsh plain on Ukerebagh Island to keep pace with sea level rise and remain relatively stable. Given the current rate of shallow compaction and sea level rise the saltmarsh plain has increased elevation by 0.43mm per year relative to sea level, while the mangrove forest has increased elevation by 1.77mm per year relative to sea level. Unlike most other sites studied in NSW and Victoria, the Tweed River mangrove and saltmarsh surface elevation appeared not to decline during the drought. This may reflect regional climatic differences in the timing of the onset and breaking of the drought.

Care should be taken when interpreting this report since it is based on early results (Cahoon *et al.* 1999). This study is part of a wider network of monitoring sites established throughout southeast Australia. It is anticipated that with further results from Ukerebagh Island and other monitoring sites we will be in a better position to model the affect of mangrove encroachment.

4.5 Tidal Changes

4.5.1 Predicted Changes

The Tweed River Entrance Sand Bypassing Project, Environmental Impact Statement/Impact Assessment Study (EIS/IAS) predicts very small tidal changes directly attributed to entrance improvements as a result of the operation of the Tweed River Entrance Sand Bypass Project (Hyder 1997). The EIS/IAS predicts that a deeper river entrance condition would result in a slight increase in spring tidal range of about 5cm at the Letitia 2A tide gauge near the confluence of the Tweed River and Terranora Inlet (Figure 27). This predicted change would reduce with distance upstream of the Letitia 2A gauge and be less for non-spring tides.

The lower estuary marine shoals (Figure 27) are a control on the propagation of tides into the river estuary. These shoals have gradually infilled and reduced tidal exchange that has adversely impacted on tidal flushing and water quality since the mid 1970's. The EIS/IAS predicts that the operation of the sand bypassing system will reduce the net infeed of marine sand into the river estuary. Operation of the system has the beneficial impact of reducing growth of the lower estuary shoals and lessening their adverse impact on tidal flushing and water quality.

Severe scouring of the lower estuary shoals by a major flood would lead to an increase in the river tide range. The increased tidal range would improve tidal mixing and flushing of the estuary, but would also impact on the ecology of the estuary. The reduction of the net infeed of marine sand into the river by the operation of the system would increase the period taken for post-flood recovery of the eroded shoals (Hyder 1997).

4.5.2 Monitored Changes

The Department of Commerce (formerly the Department of Public Works and Services), Manly Hydraulics Laboratory (MHL) has monitored tides within the Tweed River from 1971 to present. MHL analysed and reported on long-term tidal changes from analyses carried out for 1971, 1980 and yearly analyses from 1988 to 1997, on behalf of the Tweed River Entrance Sand Bypass Project. The NSW Department of Infrastructure, Planning and Natural Resources (formerly Department of Land and Water Conservation) has undertaken ongoing tidal analysis from 1997 to present. Tidal analysis is carried out using data from the Letitia 2A tidal gauge (Figure 27).

To date monitoring of the tidal data shows that there has been no significant change in tidal conditions that can be contributed to the operation of the sand bypassing system. The annual spring tidal ranges at Letitia 2A for June 2001 to June 2003 have not exceeded the EIS/IAS predictions (Floyd 2001, Floyd 2002 and *pers comm.*. 2003).

There have been no major floods in the Tweed River since the preparation of the EIS/IAS and no significant unexpected changes to date in the Tweed River lower estuary shoals. There have been minor net losses since 1994, but sand volumes are currently above EIS/IAS baseline conditions surveyed in 1989/1990.

Figure 27: Location of the Letitia 2A tide gauge and lower estuary shoals.

4.6 Recommendations concerning monitoring frequency

In determining an appropriate monitoring frequency, we have to take into account the wetland monitoring program for wetland distribution identified in section 8.5.1.5 of the TRESBP Stage 2 EIS/IAS and the relative influences of long term impacts associated with the project (i.e. tidal changes) compared to other influencing factors outside the control of the project such as climatic changes (example droughts and floods).

The survey for the period 2000-2002 showed that while the trend of mangrove increase and saltmarsh decrease fitted with the longer-term trends for the river, the magnitude of change recorded over this study was only marginally higher than error ranges associated with the methodology. For this reason, it is suggested that a 5-yearly survey of mangrove and saltmarsh distributions might be preferable to annual or biennial surveys.

Seagrass distribution was found to be more variable, and the increases measured in this survey clearly departed from the error range of the methodology. It is suggested that the seagrass communities be monitored at the same time as the mangrove and saltmarsh communities. Timing of the mapping would be revised in the event of a significant flood scour event or monitoring of significant unexpected tidal changes.

Under the projects Environmental Management System – Operations, the ongoing monitoring of tide and shoal conditions and in particular following a major flood event, additional shoal surveys would be undertaken to determine if the operation of the system have a significant impact on the condition or post-flood recovery of the shoals and tides. Unless monitoring identifies that the operation of the system has had a significant impact on the river tides, there does not appear to be a need for more frequent mapping to manage this potential impact on mangrove, saltmarsh and seagrass communities.

5 Acknowledgements

The authors would like to acknowledge the previous work of Kylee Wilton in mapping the vegetation extent of Ukerebagh Island between 1948 and 1998. The installation of SET's was supported by the Coast and Clean Seas Initiative, the Department of Infrastructure, Planning and Natural Resources and Tweed Shire Council.

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7 Appendix 1: Aerial Photographs

Date	Producer	Name	Scale	Run	Photo	RMS
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	3	85	2.51
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	3	84	2.29
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	3	83	1.26
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	3	82	2.40
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	3	81	1.44
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	3	80	1.72
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	3	79	1.29
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	3	78	2.48
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	3	77	2.26
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	4	67	3.85
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	4	68	1.65
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19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	4	70	1.72
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	4	71	1.42
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	4	72	3.84
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	4	73	2.61
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	4	74	3.56
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	4	75	3.49
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	5	65	2.91
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	5	64	2.89
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	5	63	3.15
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	5	62	3.02
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	5	61	3.14
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	5	60	2.41
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	5	59	3.79
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	6	47	1.13
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19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	6	51	2.82
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	6	52	2.79
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	6	53	3.51
19-Apr-02	Qld DNR	Tweed River Estuary	1:10000	6	54	2.23
Average RMS for April 2002						**2.44**

Date	Producer	Name	Scale	Run	Photo	RMS
13-May-00	QASCO Aust.	Tweed Project	1:10000	3	76	1.72
13-May-00	QASCO Aust.	Tweed Project	1:10000	3	77	1.46
13-May-00	QASCO Aust.	Tweed Project	1:10000	3	78	1.86
13-May-00	QASCO Aust.	Tweed Project	1:10000	3	79	1.88
13-May-00	QASCO Aust.	Tweed Project	1:10000	3	80	2.41
13-May-00	QASCO Aust.	Tweed Project	1:10000	4	75	0.93
13-May-00	QASCO Aust.	Tweed Project	1:10000	4	74	1.31
13-May-00	QASCO Aust.	Tweed Project	1:10000	4	73	1.76
13-May-00	QASCO Aust.	Tweed Project	1:10000	4	72	0.77
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13-May-00	QASCO Aust.	Tweed Project	1:10000	5	66	1.45
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13-May-00	QASCO Aust.	Tweed Project	1:10000	6	54	1.11
13-May-00	QASCO Aust.	Tweed Project	1:10000	6	53	0.64
11-May-00	Qld DNR	Tweed Heads-Currumbin	1:12000	1	150	1.49
11-May-00	Qld DNR	Tweed Heads-Currumbin	1:12000	1	151	2.32
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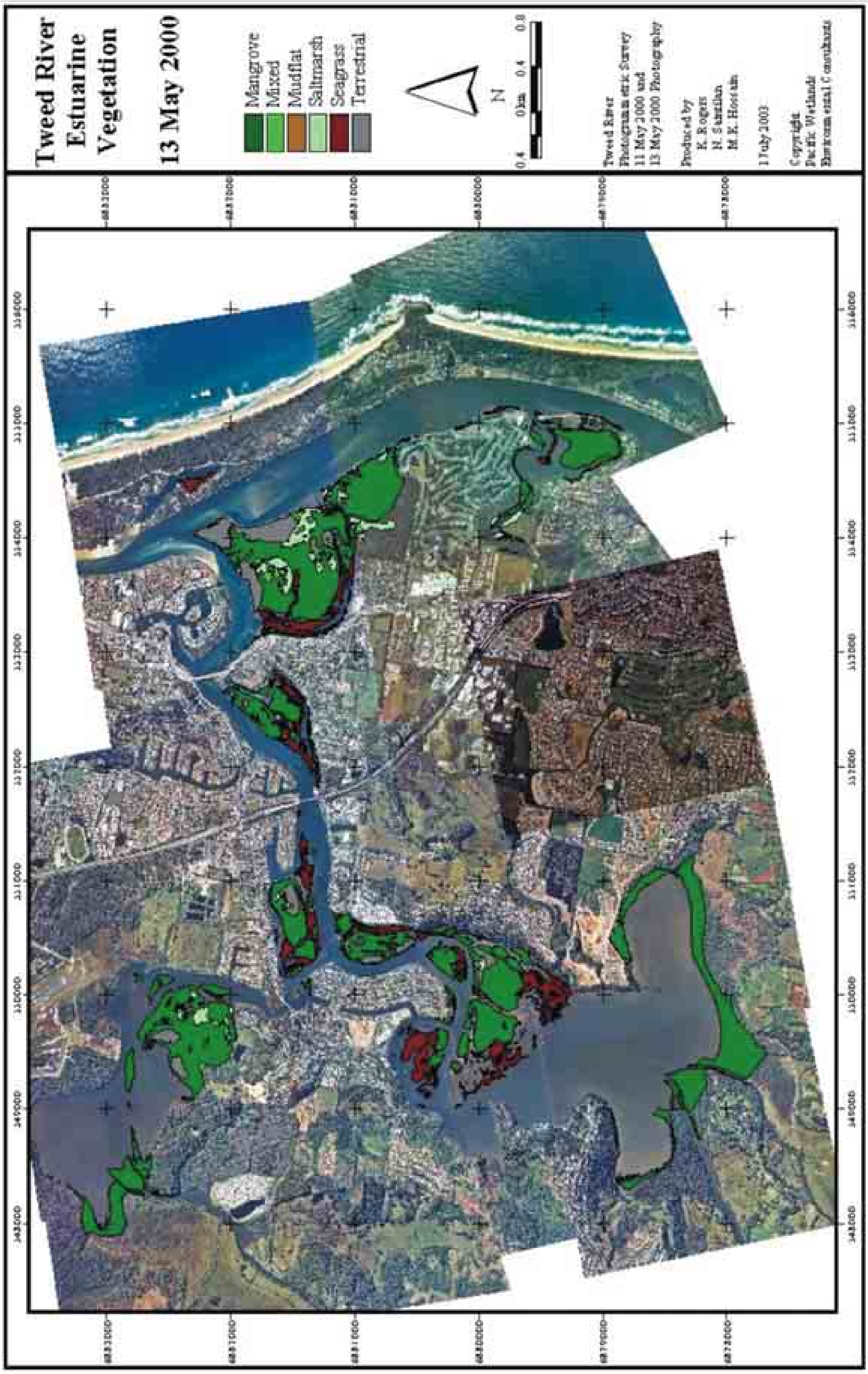
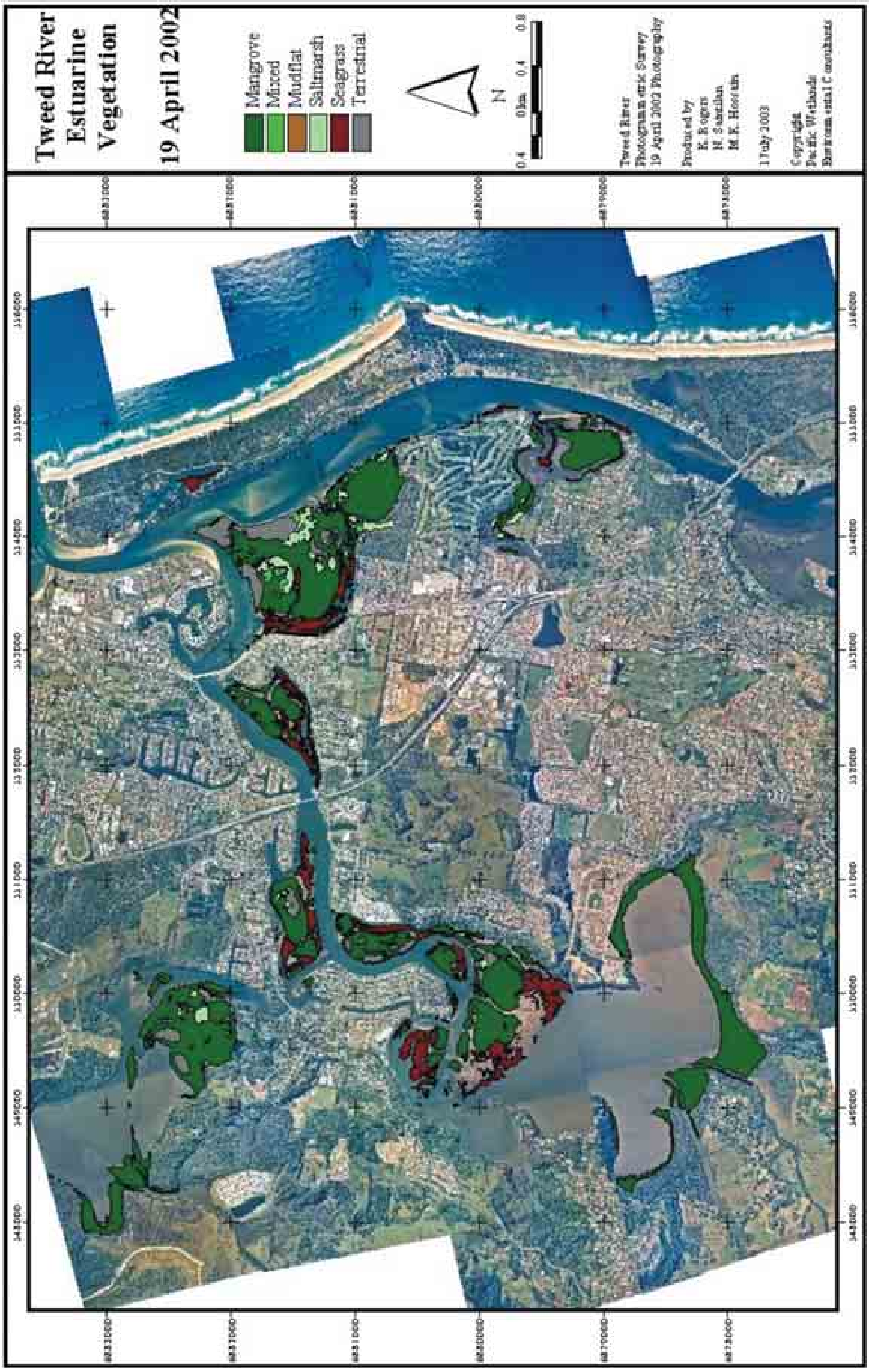
Average RMS error for May 2000						**1.50**

8 Appendix 2: Maps

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Estuarine
Vegetation
19 April 2002
Mangrove
Mixed
Mudflat
Saltmarsh
Seagrass
Terrestrial
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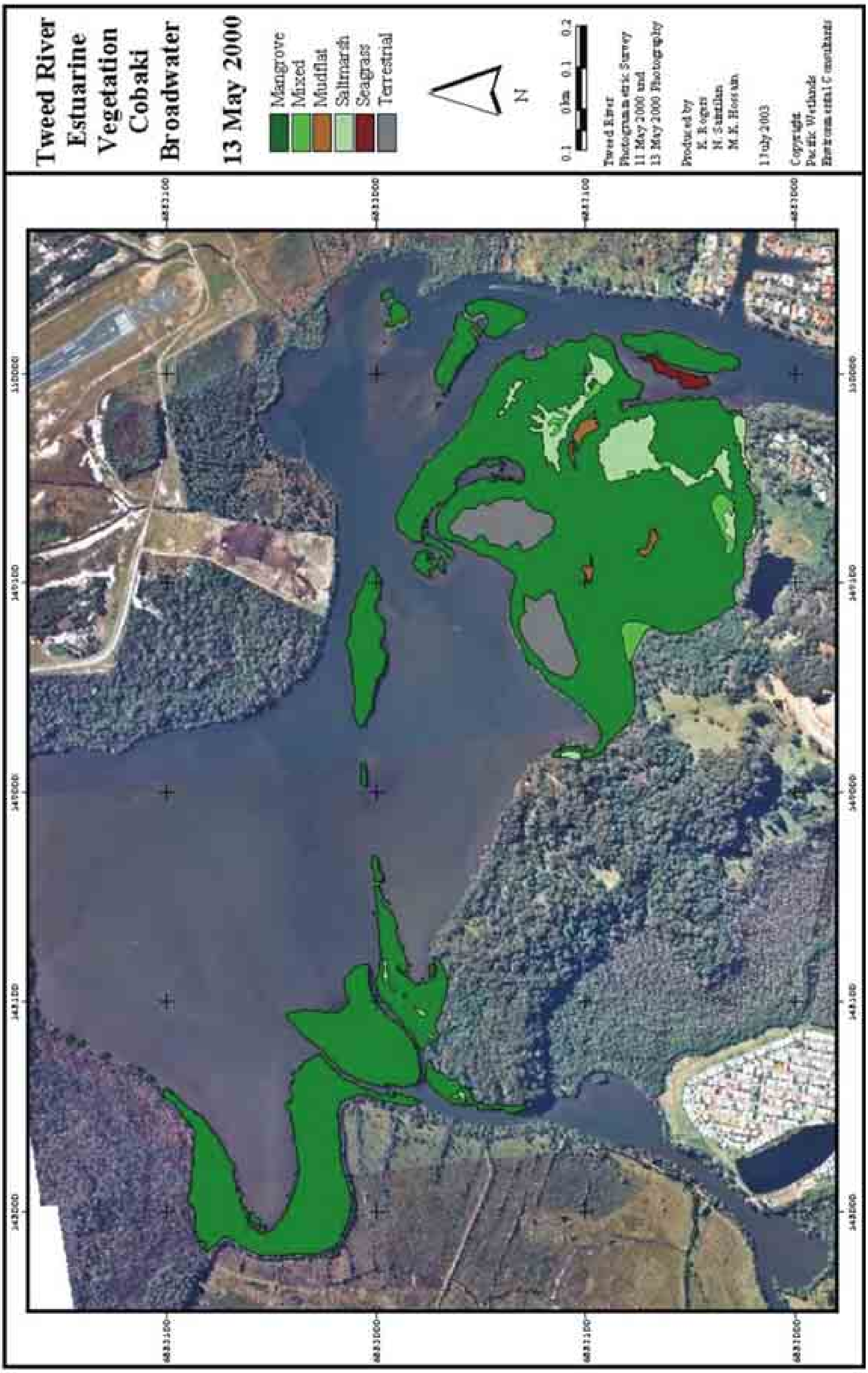
Tweed River
Photogrammetric Survey
19 April 2002 Photography
Produced by
K. Rogers
N. Saintilan
M.K. Hossain
1 July 2003
Copyright
Pacific Wetlands
Environmental Consultants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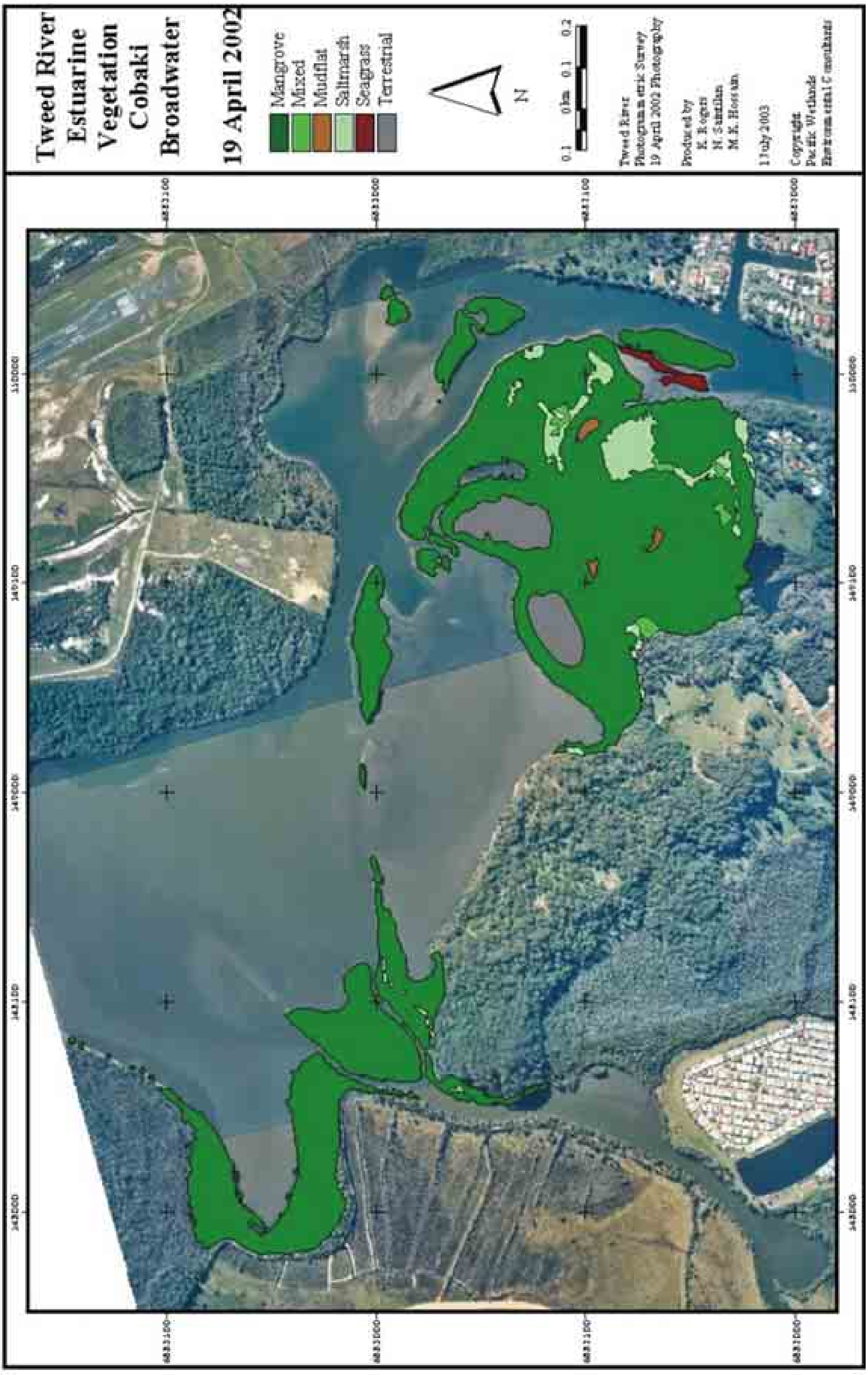
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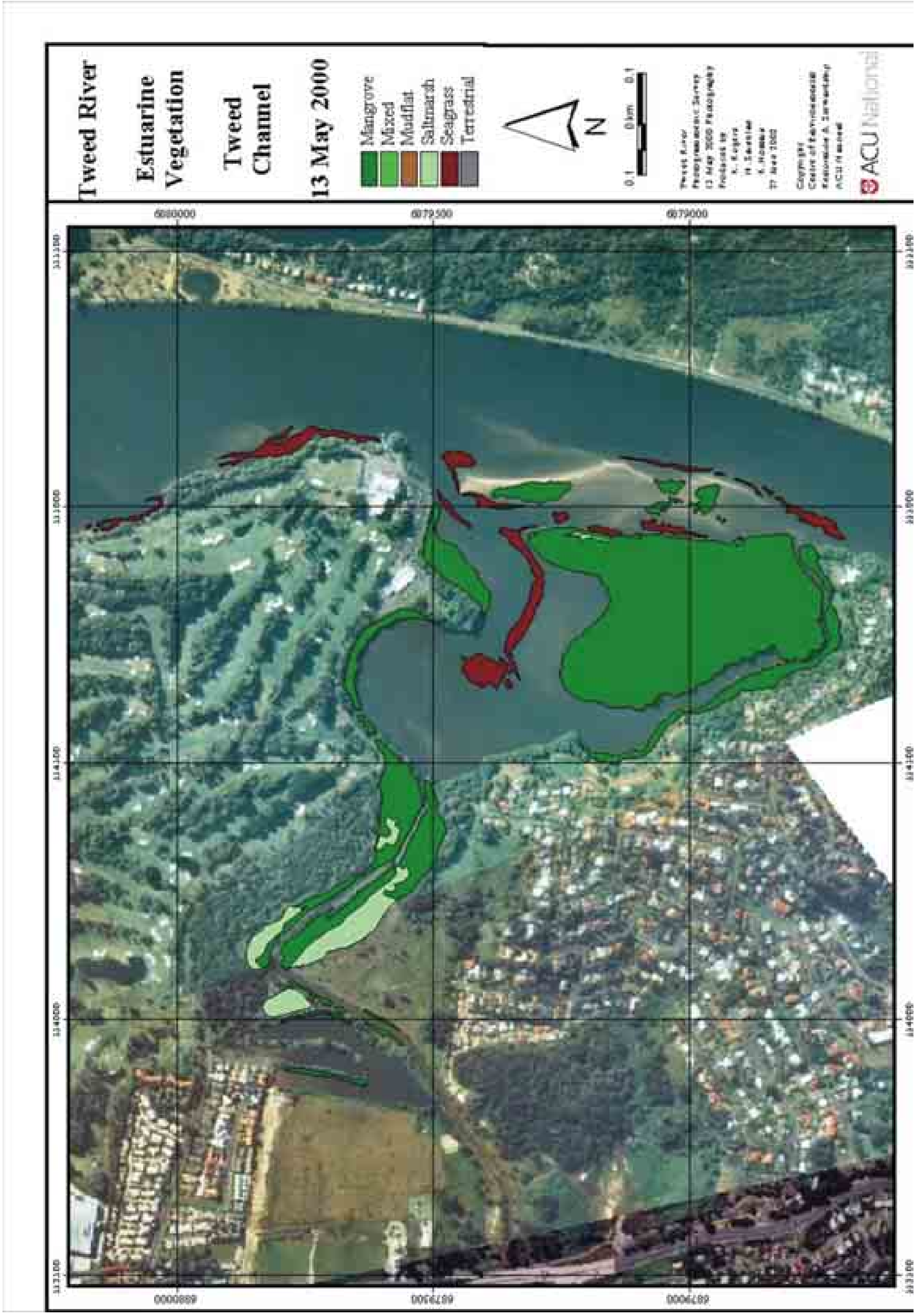
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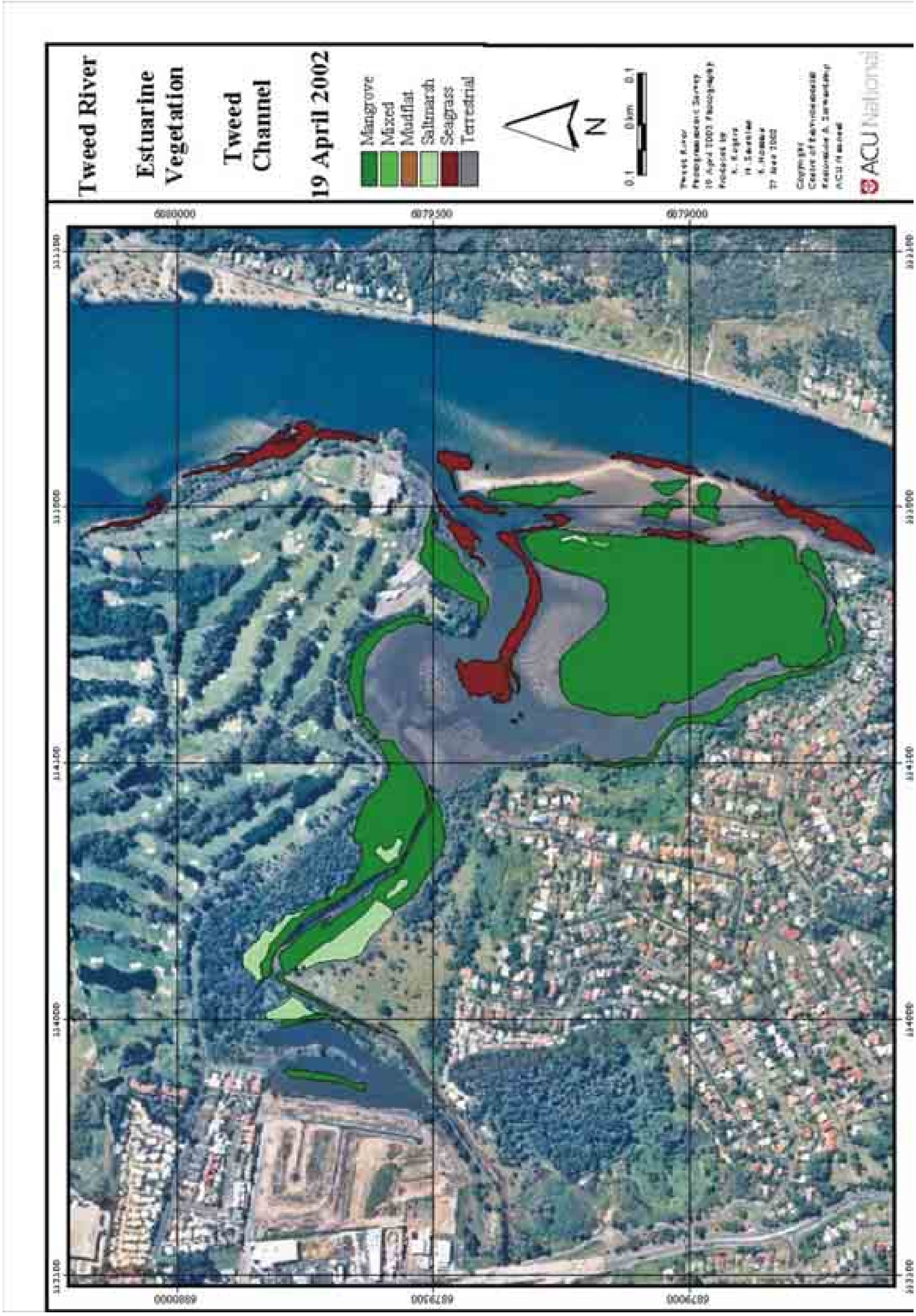
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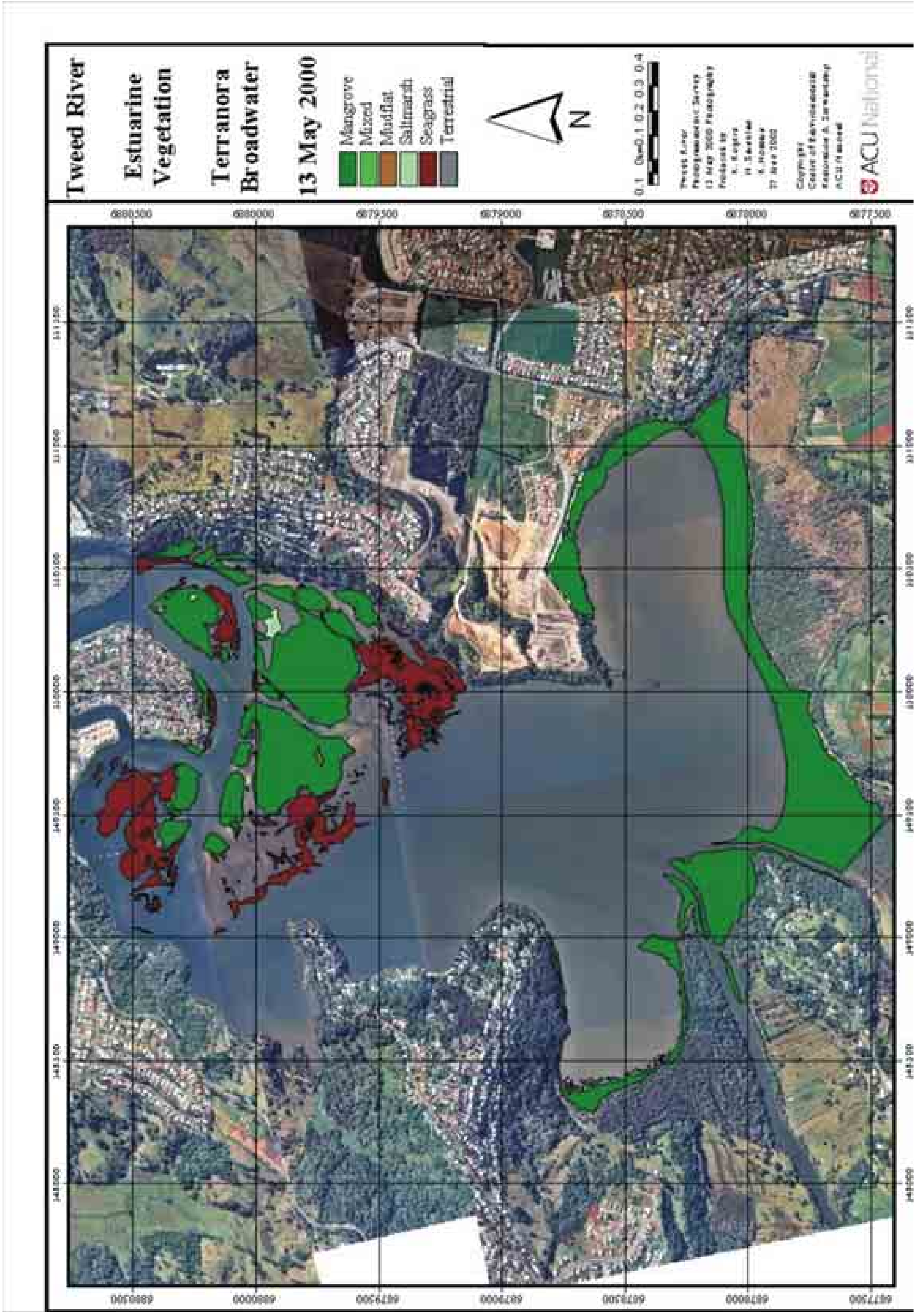
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Terranora Broadwater
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Mudflat
Saltmarsh
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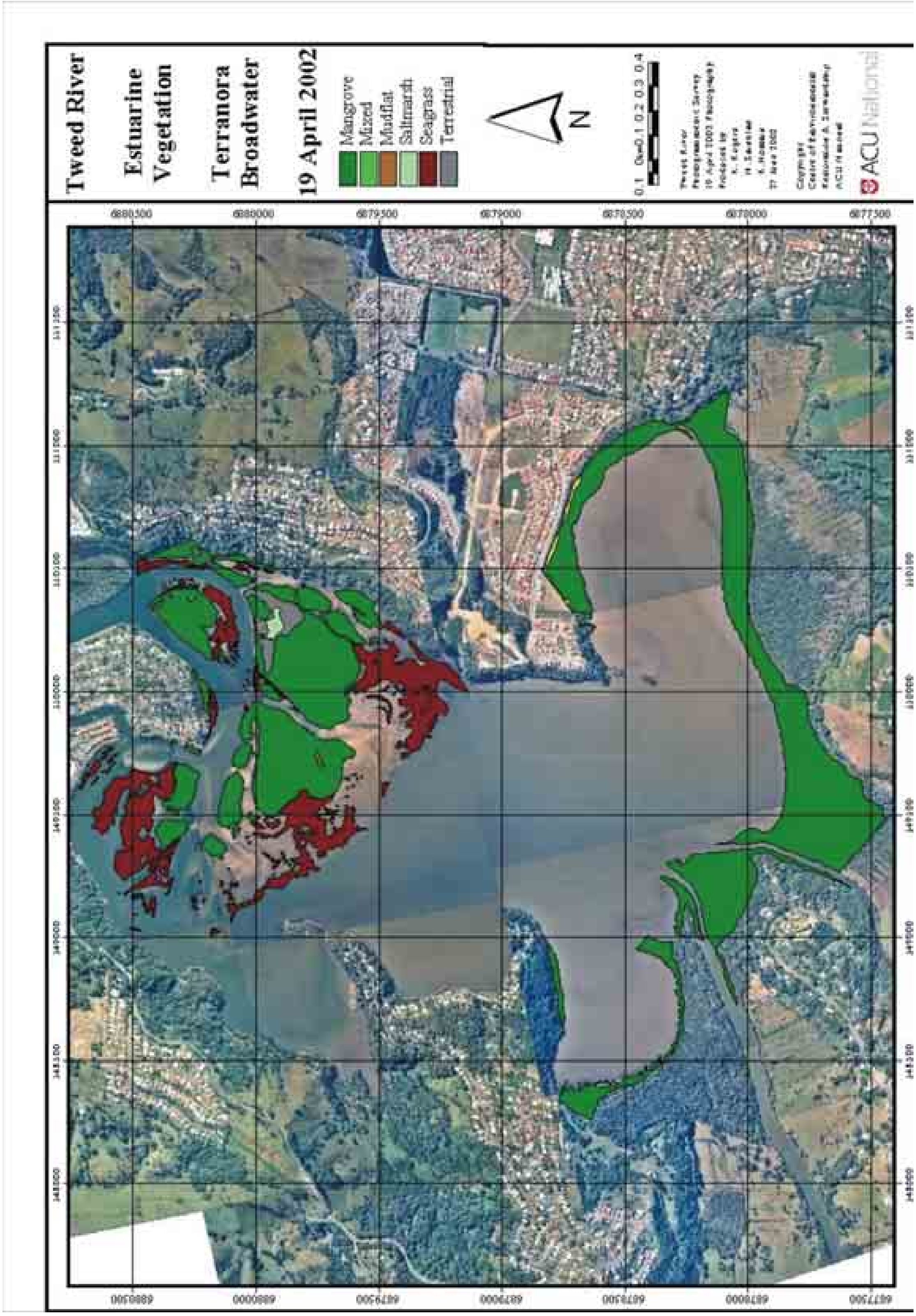
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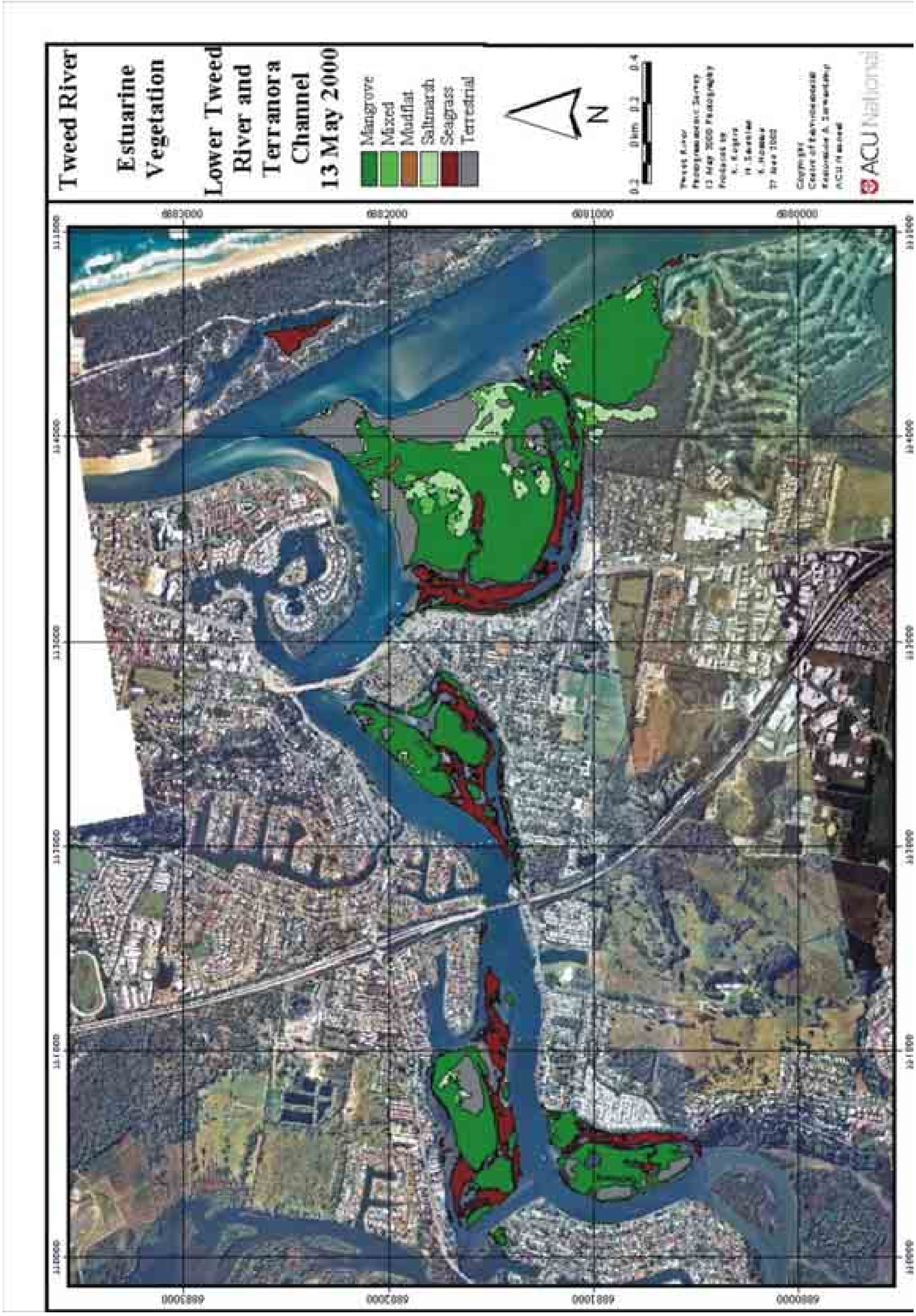
Tweed River
Estuarine Vegetation
Lower Tweed River and Terranora Channel
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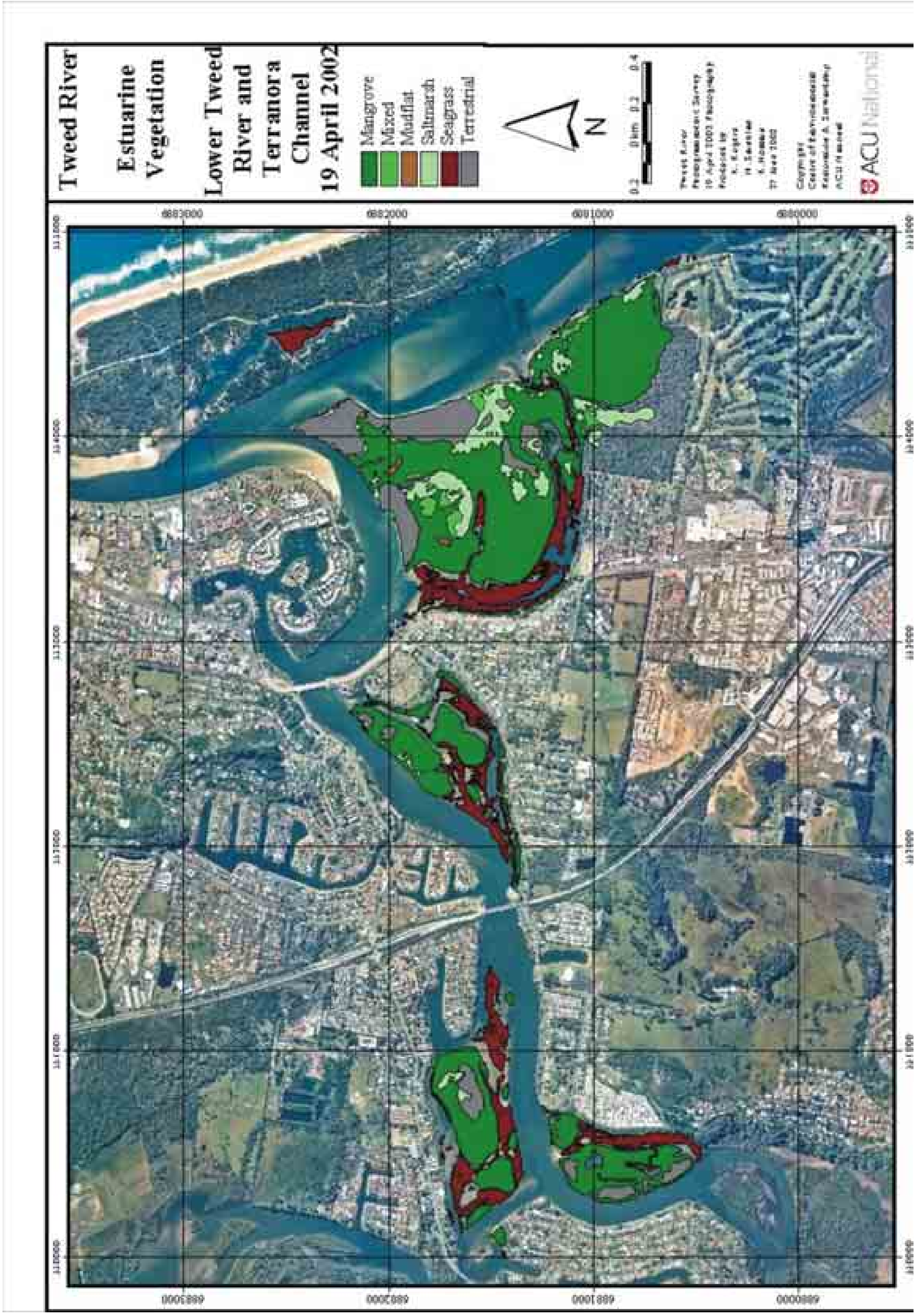
Mixed
Mudflat
Saltmarsh
Seagrass
Terrestrial
N
ACU National


Tweed River
Estuarine Vegetation
Lower Tweed River and Terranora Channel
19 April 2002
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