Distribution of Estuarine Vegetation in the Parramatta River and Sydney Harbour, 2000

G. West, R.J. Williams and R. Laird

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Final Report
for
NSW Maritime
and
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ACKNOWLEDGEMENTS

Orthorectified images of the Parramatta River were obtained via a consortium of state and local government agencies. The consortium was co-ordinated by the Office of Sydney Harbour Manager. Brett Louden and Alan Genders assisted in digitising the vegetation boundaries. Jack Hannan, Brian Hill and Brett Louden, Andrew Morison and Bill Rooney provided ground truth data. Andrew Morison and Robert Lea commented on the final draft of this report.

Funding for the project was provided by the Australian Maritime Safety Authority (AMSA) under the National Plan to Combat Pollution of the Sea by Oil and Other Noxious and Hazardous Substances, and by NSW Maritime.

NON TECHNICAL SUMMARY

Distribution of Estuarine Vegetation in the Parramatta River and Sydney Harbour, 2000

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OBJECTIVES:

(1) To provide an up-to-date map of the estuarine macrophytes of Sydney Harbour and the upper and middle portions of the Parramatta River for NSW Maritime (previously NSW Waterways) in order to assist with foreshore planning and development decision making.

(2) To provide an up-to-date map of the estuarine macrophytes of Sydney Harbour and the upper and middle portions of the Parramatta River for NSW Maritime (previously NSW Transport) and the Australian Maritime Safety Authority (AMSA) in order to update the "Biological Resources – Habitats" theme for the NSW Oil Spill Response Atlas Version 4.

NON-TECHNICAL SUMMARY:

NSW Fisheries mapped the distribution of the large aquatic vegetation of the state's estuaries in the late 1970s and early 1980s to provide a baseline against which to assess change. Since that time there have been a number of reports of change in distribution of saltmarsh, mangrove and seagrass.

Change in distribution in the Parramatta and Lane Cove Rivers and in Middle Harbour is of particular interest to NSW Maritime due to conservation planning and management of the estuary and its foreshores as well as management of the spillage of oil and other hazardous materials. NSW Fisheries (now incorporated in the NSW Department of Primary Industries) was approached by NSW Maritime to remap the macrophytes of the estuary of the Parramatta River. The area of interest was from the most downstream weir at Parramatta to the heads, inclusive of that portion of the estuary known as Sydney Harbour. The Lane Cove River and Middle Harbour were also included. The study site is hereafter referred to as the Parramatta estuary.

Orthorectified images derived from 1:16,000 aerial photographs taken in January 2000 were analysed in a geographical information system (GIS) to delimit the boundaries of estuarine macrophytes. Areas of kelp, seagrass, mangrove and saltmarsh were identified and mapped from the images. The distribution of kelp had not been previously mapped in the estuary. Only a small amount of saltmarsh was seen and this was near Homebush Bay.

The estuary was divided into four geomorphic zones on the basis of criteria identified by Roy (1984). From the downstream end these zones are the Marine Tidal Delta, Central Mud Basin, Fluvial Delta and Riverine Channel. Most of the kelp (51 of 86 ha) was located in the Marine Tidal Delta. The Central Mud Basin was the largest geomorphic zone, extending from Sow and Pigs Reef to Kissing Point/Mortlake Point and had the largest amount of seagrass with 34 ha of the 52 ha of seagrass present. Another 17 ha of seagrass was present in the Marine Tidal Delta. Most of the

mangrove was located in the upstream reaches with 57 ha in the Fluvial Delta and 116 ha in the Riverine Channel.

When the maps produced in this study were compared to maps of seagrass, mangrove and saltmarsh created over 20 years ago (West *et al.* 1985), there would appear to have been a large net loss of seagrass from 129 ha to 52 ha. Large losses occurred at some sites (e.g., off Clontarf) and small gains occurred at others (e.g., Iron Cove). In contrast, the area of mangrove has increased from 148 ha to 185 ha. The area of saltmarsh appears to have remained steady at less than 10 ha.

The maps created by West *et al*. (1985) used the *camera lucida* principle, a less accurate method relative to GIS technique used in this study. Hence, there is some uncertainty about the amount of aquatic vegetation present 20 years ago. A more rigorous evaluation of change in distribution would be done with a GIS analysis of the photos used by West *et al*. (1985). A better resolution of historical trends would then be possible.

It is possible to model the future distribution of estuarine macrophytes in the Parramatta estuary on the basis of their historical and current distributions, on the historical and current bathymetry of the estuary and on water quality as it relates primarily to the transmission of light relative to photosynthesis.

The maps produced by this study will make an important contribution to the management of inter- and subtidal habitats and the control of spills of oil and other hazardous substances in the estuary of the Parramatta River.

1. INTRODUCTION

1.1. Background

Intertidal and subtidal vegetated communities contribute to estuarine food chains and offer shelter for juvenile and adult species of fishes, crustaceans and molluscs. The location and extent of these plants changes through time (e.g., Williams and Meehan in press), and their distribution needs to be regularly assessed in order to guide estuarine management decisions. In the Parramatta River estuary the management framework includes planning for landuse at or near estuarine foreshores, and response to oil spills. Until September 2003, NSW Transport was the state agency responsible for the latter, at which time the NSW Waterways assumed control. From 1 July 2004, the Waterways Authority became known as NSW Maritime.

NSW Maritime is the owner-manager of the bed of the Parramatta River and Sydney Harbour and has a number of approval roles relating to development in the waterway and on foreshore lands. Its strategic and day-to-day decisions require an understanding of the resources to be managed in a regional context.

The potential for oil and other hazardous substances to spill to the Parramatta River and Sydney Harbour is greater than for most other waterways in New South Wales. This is because of the considerable traffic of commercial, military and recreational vessels, the vehicular traffic adjacent to the water, and the existence of refinery and other industrial operations. Spills from vessels occurred at Berrys Bay in 1973 and 1995.

One key to protecting the natural, commercial and recreational resources of the river is the formal recognition of ecological, socio-economic and cultural resources. Another is the rapid response to oil spill incidents. Carter (1994) identified four categories of sensitivity for the aquatic resources of Parramatta River in relation to the spill of oil. His scheme categorised saltmarsh meadows, mangrove stands and intertidal seagrass beds as “extremely sensitive”. The next lower category, “highly sensitive”, included subtidal seagrass beds.

1.2. Need

The estuarine vegetation of NSW was first mapped in the late 1970s and early 1980s (West *et al.* 1985). Maps of over 130 estuaries were prepared and some were subsequently used for oil spill planning (e.g., Carter 1994). As change in the distribution of vegetation has taken place at many estuaries over the past 20 years (Williams *et al*. 2003), revision of the maps is necessary. Some of the change is due to natural phenomena, such as storms, whereas other change appears to have come about due to human activity such as dredging, reclamation, shoaling and shading from structures and increase in stormwater discharge. Creation of new maps will help define the extent of modification to the distribution of the estuarine vegetation.

Part of this project was initiated in 2001 with the then Marine Safety and Environment Group of NSW Transport in order to guide the response strategy for the spill of oil. That portion of Sydney Harbour east of the Harbour Bridge was selected as the site of investigation. The designated area was assessed and a draft report prepared. Subsequently, NSW Transport and NSW Maritime sought information on the portions of the estuary not included in the first study. NSW Maritime, as a major landholder along the river and harbour foreshores, needed information to assist in the decision making process for river and harbour land use. The draft report to NSW Transport was held in abeyance while the remaining portions of the estuary were assessed. Data derived from the

two projects are reported herein. At an even later stage the responsibility for oil spill management was transferred to NSW Maritime.

The intertidal and subtidal vegetated communities of interest included seagrass, mangrove and saltmarsh. In addition, kelp is prevalent in the outer portion of Sydney Harbour, but its distribution has rarely been mapped over the large areas it occurs in NSW estuaries. Kelp is recognised as providing shelter for a number of aquatic species (Dayton 1985, Kennelly 1991, Steinberg and Kendrick, 1999).

1.3. Objectives

This project provides a recent map of the estuarine macrophytes of Sydney Harbour and the upper and middle portions of the Parramatta River for NSW Maritime in order to assist with foreshore planning and the decision making process. It also updates the "Biological Resources – Habitats" theme for the NSW Oil Spill Response Atlas, Version 4.

To achieve the objectives, the aims of this investigation were to:

- collate existing data on the distribution of seagrass, mangrove and saltmarsh in the Parramatta River and Sydney Harbour;
- conduct PC-based GIS analysis of orthorectified aerial photographic images of the river and harbour taken in 2000;
- delimit the boundary of kelp, seagrass, mangrove and saltmarsh in the study area;
- conduct field checks (ground truth) to confirm vegetation boundaries;
- create ArcView shape files and associated data tables to indicate the area of cover for each vegetation type;
- provide a report to NSW Maritime.

2. METHODOLOGY

2.1. Study site

Under the terms of the initial arrangement, NSW Transport sought a map of the lower portion of Sydney Harbour, i.e., from the Sydney Harbour Bridge and the Spit Bridge downstream to the Harbour entrance. The eastern boundary was resolved as a line from North Head to South Head. In the second phase of the study, NSW Transport and NSW Maritime requested a map of the upper portion of the estuary, from the most downstream of the Parramatta weirs to the Harbour Bridge. NSW Maritime also sought to have Middle Harbour mapped above the Spit Bridge, as well as the Lane Cove River. It was our intent that the analysis would include the foreshore out to a line from North Head across to South Head but the quality of the aerial photos did not permit analysis east of Quarantine Head.

The only other maps of estuarine vegetation for the Parramatta River (West *et al.* 1985) showed saltmarsh and mangrove to be present upstream of the bridges, but seagrass of various types was found in the lower-most portion of the estuary. Little seagrass was found upstream of the Harbour Bridge. An aquatic reserve was declared over a portion of North Harbour in 1982, with the justification of the reserve in part to protect the seagrass occurring along the foreshore of Sydney Harbour National Park.

Roy (1984) recognised four geomorphic zones in NSW estuaries and Mesley (2003) delineated these zones in the Parramatta estuary (Figure 1). Much of the Harbour entrance was defined as being within the Marine Tidal Delta. All four geomorphic zones were present in Middle Harbour. The Lane Cove River had a small portion of Central Mud Basin and a much larger Fluvial Delta. The major portion of the estuary, extending from the most downstream weir at Parramatta to past the central business district and out to Vaucluse, encompassed three geomorphic zones: Central Mud Basin, Fluvial Delta and Riverine Channel.

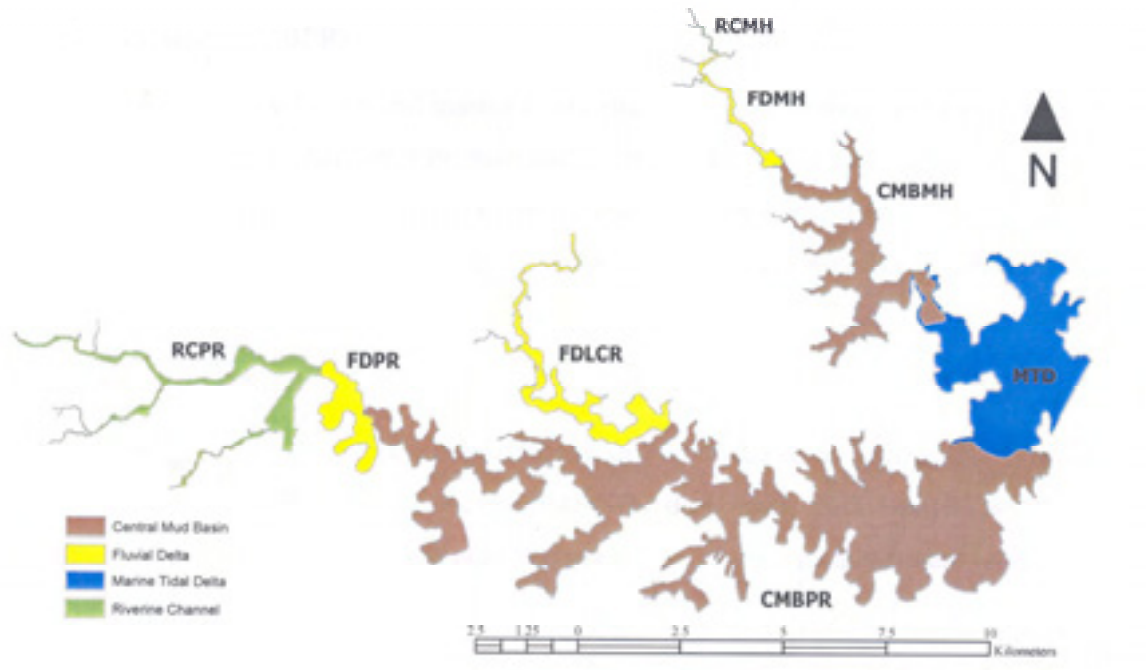

Figure 1. Sedimentary depositional zones in the Parramatta River and Sydney Harbour estuary from Mesley (2003).

2.2. Methods

In 1997 the Office of Sydney Harbour Manager created a consortium of over 15 state and local agencies to purchase aerial photographs of Sydney Harbour. In early 2000 the Spatial Division of Sinclair Knight Merz undertook aerial photography of the Sydney Basin, concentrating on the catchment of the Parramatta River. The extent of aerial photography is shown in Figure 2.

Over 700 aerial photos were orthorectified, processed to create contiguous imagery of the catchment, and made available to members of the consortium as "tiles". A tile is an aggregation of photo-images. The images had a resolution and spatial accuracy of 0.2m and were georeferenced to MGA Zone 56. Tiles were supplied to members of the consortium as TIF images on magnetic tape.

Tiles received by NSW Fisheries were downloaded from the tape to a GIS data server at Port Stephens Fisheries Centre for analysis. An overview layer of the available images was created in ArcView GIS. This layer was then used in conjunction with the digital cadastal database produced by Land and Property Information (LPI) in 2000 to identify those tiles that covered the estuarine waterway. For the Sydney Harbour phase of the project, 58 tiles were selected and copied to a local workstation for analysis; 100 tiles were used for the analysis of the upper portion of the Parramatta River estuary and the upper portion of Middle Harbour.

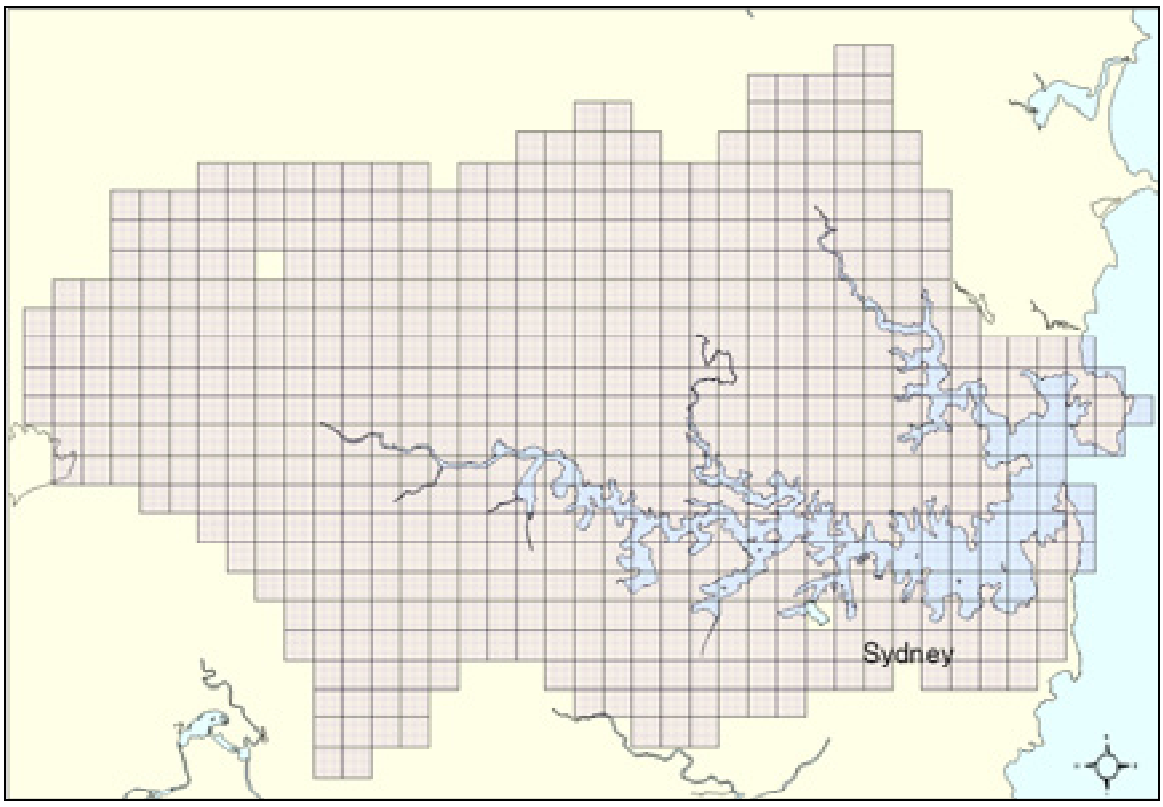

Figure 2. Aerial photos (tiles) of the Parramatta River produced for the Sydney Harbour LandData Consortium, January 2000.

To assist in the analysis, two "catalogue" maps were created for ready reference to the necessary tiles, one for Sydney Harbour and the other for the Parramatta River. All tiles were numbered on the respective catalogue maps, and the catalogues were printed to assist in the progress of the mapping (see Appendix 1 for an example of a catalogue map).

Delineation of kelp, seagrass, mangrove and saltmarsh was carried out using Erdas Imagine version 8.4 on a PC running the Windows 2000 operating system. Boundaries of vegetation were digitised on selected tiles. To ensure consistent spatial accuracy, all digitising was carried out at an onscreen scale of 1:1000. This scale provided optimal visual discrimination of the sub-aquatic features whilst maintaining a good spatial resolution. Each tile was individually mapped. Upon completion, a tile was marked as complete on the catalogue and the next adjacent tile was opened. This process was carried out until all tiles were analysed. In some instances the quality of the data on the tiles was problematic, due to poor contrast or brightness, and mapping of the subaquatic habitats was difficult. In these cases the images were "contrast adjusted" using either histogram equalisation or Gaussian contrast filters. In other situations where sun-glint was excessive, cover of subtidal vegetation was estimated from the map of Parramatta River/Sydney Harbour produced by West *et al*. (1985) and field studies done by NSW Fisheries. On the basis of colour and textural differences, two types of vegetation were observed in the images and delimited.

Kelp species have no root system and are only found attached to hard substratum such as rock reef. As the images showed no observable colour and/or textural differences for rock, or kelp attached to rock, it was not possible to distinguish between these two entities at the time when the presumptive map was created. Consequently, on the basis that we assume all rock in shallow water is colonisable by kelp, we mapped and calculated the area of kelp and rock as a single unit.

Once all of the line work was complete, the GIS layer was cleaned, a process that searches and corrects for errors such as dangling nodes and poorly defined intersections. At the completion of the cleaning process the layer was redisplayed with errors highlighted. Errors were manually fixed and the cleaning process was reapplied. Remaining errors were corrected, and the layer was cleaned one final time before polygons of target vegetation were built.

The final process in the generation of data layers was the allocation of layer attributes. The polygon layer was imported into ArcView 3.1, polygons of known cover types were selected and the associated data table was updated to reflect the corresponding attribute. When all polygons had been labelled and verified, the area in hectares for each cover type was calculated and a presumptive map of the distribution of estuarine vegetation was produced (Appendix 2).

The presumptive map was taken into the field and checked against the actual vegetated communities through the use of a differential global positioning system (DGPS) that is accurate to 1m, and depth sounder, both instruments interfaced to an on-board laptop computer. It is possible to do field checks at various levels of intensity. Spot checks can be made of the sites of interest, or an entire shoreline can be navigated by boat. The speed at which the boat operates and the number of checks can vary depending on level of accuracy needed. For the Sydney Harbour phase of the study, checking was aligned with NSW Transport's need to locate major groups of plants, namely saltmarsh, mangrove, seagrass and kelp such that oil spill planning and response could be facilitated. Vegetation communities were visually inspected, using a bathyscope as necessary. In the second phase of the study, for NSW Maritime, it was necessary to distinguish between different types of seagrass, identifying to species level and determining density of cover wherever possible. Consequently, the Harbour was reinspected and a greater level of detail was placed in the final map. In the second phase, visual inspection was complemented with underwater video optics.

The presumptive maps were modified on the basis of field observations done for Sydney Harbour in 2002 and for the remainder of the study area in 2003 (Appendix 3). Additional field data were

provided by J. Hannan and A. Morison (NSW Maritime) and W. Rooney (Rooney and Associates). J. Hannan provided a valuable quality control function by inspecting draft and final maps.

Calculations of the areas of interest on the final maps were done by the computer software. Calculations are presented initially in relation to major geographic sectors of the estuary, and secondarily in relation to the four geomorphic zones that occurred in some or all of the sectors (Figure 1). A tertiary classification of area was made for vegetation found on the north or south side of the estuary.

The hardcopy maps presented at the back of the report showing macrophyte distribution are at an approximate scale of 1:60 000. Hence, the full set of details digitised at the 1:1 000 scale are not represented. In some cases, the boundaries of estuarine vegetation appear misplaced relevant to the shoreline boundaries. This is a result of variations in the way the shoreline and vegetation data sets were derived.

3. RESULTS

On the basis of aerial photos taken in January 2000, aquatic macrophytes were found to cover extensive portions of the bed of the Parramatta River estuary. Approximately 86 ha of kelp, 52 ha of seagrass, 185 ha of mangrove and 10 ha of saltmarsh were present (Table 1). Maps of these distributions are presented for each of the commonly recognised sectors of the estuary: Sydney Harbour Entrance (Figure 3), Middle Harbour (Figure 4), Lane Cove River (Figure 5) and the Parramatta River below the Parramatta weirs (Figures 5 and 6). Some vegetation occurrences, so small as to not be visible in the aerial photographs, but encountered in the field, are listed in a table so that their expansion or reduction can be examined at such time as another study is done (Appendix 4). In addition to setting out the results by sector, the distribution data are shown in relation to geomorphic zones, and then more detailed analysis is provided of the distribution of seagrass.

3.1. Harbour Entrance

Most of the kelp (35 ha) was found in this sector (Table 1, Figure 3), and most of that was on the north side. Some vegetation initially assumed to be seagrass was found on field inspection to be kelp, and these beds were relabelled accordingly. Field checks also indicated that the bulk of the kelp was *Ecklonia*. Three small patches of *Sargassum* spp. were found, two at Wudyong Point and another on the west side of Shell Cove. Small amounts of *Sargassum* were present at many other locations but in patches too small to map from aerial photographs.

Seagrass, in contrast to kelp, grows on soft substrata. Some seagrass initially assumed to be present was deleted from the final map as field inspection revealed the presence of detrital material. The largest of the detrital masses masquerading as seagrass were at Camp Cove and Watsons Bay. Almost all seagrass (13 ha) was found on the northern foreshore (Table 1).

Neither saltmarsh nor mangrove were found around the Harbour Entrance (Table 1).

3.2. Middle Harbour

The third largest amount of kelp (18 ha) was found in this sector (Table 1, Figure 4). Most of the kelp was in the Marine Tidal Delta.

Seagrass covered six hectares, two thirds of which was in the marine tidal delta, with most of the residual around the edge of the Central Mud Basin. No seagrass was found in the Riverine Channel. Material masquerading as seagrass was found at Balmoral Beach.

Fourteen hectares of mangrove were present, the major portion of which occurred in that part of the Central Mud Basin above the Spit Bridge, and Fluvial Delta. Downstream of the bridge only one small mangrove tree was located.

Saltmarsh was not located in this sector (Table 1).

Table 1. Cover (ha) of estuarine macrophytes in the Parramatta River estuary derived from aerial photographs taken 05/01/00 and field verification done in 2002 and 2003.

Sectors	Zone		Kelp	Seagrass	Mangrove	Saltmarsh
Harbour Entrance	Marine Tidal Delta	North	23.109	12.846		
		South	11.749	0.050		
		Subtotal	34.858	12.896		
Middle Harbour	Marine Tidal Delta	North	11.007	2.007		
		South	5.647	1.888		
	Central Mud Basin	North	0.615	0.774	2.457	
		South	0.761	1.400	6.027	
	Fluvial Delta	North	0.050	0.013	0.701	
		South	0.054	0.021	4.505	
	Riverine Channel	North			0.084	
		South			0.399	
		Subtotal	18.134	6.103	14.174	
Lane Cove River	Central Mud Basin	North	0.246	0.076		
		South	0.229	0.164		
	Fluvial Delta	North	0.681	0.930	12.168	
		South	0.566	0.328	23.738	
		Subtotal	1.722	1.498	35.906	
Parramatta River	Central Mud Basin	North	9.033	3.294	2.063	
		South	21.763	27.914	1.361	
	Fluvial Delta	North	0.029		1.868	
		South			14.137	
	Riverine Channel	North			26.915	
		South			88.280	9.565
		Subtotal	30.825	31.208	134.624	9.565
Grand Total			85.609	51.705	184.704	9.565

3.3. Lane Cover River

Mangrove was the dominant vegetation type, with 36 ha present, all of which was in the Fluvial Delta (Table 1, Figure 5). No saltmarsh was located along this waterway, but small amounts of seagrass and kelp were found.

3.4. Parramatta River

This is the largest sector, stretching nearly 30 km from the lowest of the Parramatta weirs to the sector we have identified as the Harbour Entrance (Figures 3, 4 and 5). More than 30 ha of kelp were present, almost all of which was in the Central Mud Basin (Table 1) and most of which was downstream of the Harbour Bridge (Figure 3). More than 31 ha of seagrass were found in this sector, the majority of this was on the south side. The largest patches occurred along the eastern side of Rose Bay. Some material masquerading as seagrass was found south of Middle Head.

By far the largest area of mangrove (135 ha) was found in this sector, with most located in the Riverine Channel, and most of that was on the south side. All of the saltmarsh (10ha) was found in the Riverine Channel on the south side of the river near or at Homebush Bay, and one small meadow was located on the southern side of Duck River.

3.5. Examination of seagrass distribution

Of the detailed analysis of the distribution of the 52 ha of seagrass found in the estuary, 38 ha were *Zostera,* of which 27 ha were in monospecific stands and 11 ha were of *Zostera* mixed with other species (Table 2). The balance was made up of 10 ha of *Posidonia* and 3 ha of *Halophila*. Only a small amount of *Posidonia* (2 ha) was in monospecific stands; most of it was mixed with other species (8 ha). More seagrass was located in the Parramatta River sector (31 ha) than in the three other sectors combined.

In terms of geomorphic zones, most seagrass was found in Central Mud Basin environments (34 ha), followed by the Marine Tidal Delta (17 ha) (Table 3). Small amounts were found in the Fluvial Deltas at Middle Harbour and Lane Cove River, but none was found in the analogous section of the Parramatta River. No seagrass was found in the Riverine Channel zones. The bulk of the *Posidonia* (8 ha) was found in the Marine Tidal Delta; the major cover of *Zostera* (28 ha) and all of the *Halophila* (3 ha) were found in the Central Mud Basin environments.

Except for *Posidonia*, more seagrass was found on the southern shorelines (32 ha) of the estuary than on the northern shorelines (20 ha) (Table 3). While about the same amount of *Posidonia* was found in monospecific stands on the north and south sides, the mixed *Posidonia* (8 ha) was much greater on the north side.

Table 2. Cover (ha) of seagrass in **sectors** of the Parramatta River estuary derived from aerial photographs taken 05/01/00. MTD = Marine Tidal Delta, CMB = Central Mud Basin, FD = Fluvial delta, RC = Riverine Channel, after Roy (1984).

			Posidonia	Mixed *Posidonia*	*Zostera*	Mixed *Zostera*	*Halophila*	Mixed *Halophila*	All seagrass
MTD	Harbour Entrance	North	1.113	6.624	3.555	1.554			12.846
		South			0.050				0.050
	Subtotal		**1.113**	**6.624**	**3.605**	**1.554**			**12.896**
MTD	Middle Harbour	North	0.056		0.857	1.094			2.007
		South			1.599	0.289			1.888
CMB		North	0.005	0.163	0.606				0.774
		South	0.070	0.368	0.939		0.023		1.400
FD		North			0.013				0.013
		South			0.021				0.021
RC		North							
		South							
	Subtotal		**0.131**	**0.531**	**4.035**	**1.383**	**0.023**		**6.103**
CMB	Lane Cove River	North				0.076			0.076
		South				0.164			0.164
FD		North			0.930				0.930
		South			0.316	0.012			0.328
	Subtotal				**1.246**	**0.252**			**1.498**
CMB	Parramatta River	North	0.007	0.025	1.408	1.854			3.294
		South	0.941	0.995	16.741	6.415	2.671	0.151	27.914
FD		North							
		South							
RC		North							
		South							
	Subtotal		**0.948**	**1.020**	**18.149**	**8.269**	**2.671**	**0.151**	**31.208**
	Total		**2.192**	**8.175**	**27.035**	**11.458**	**2.694**	**0.151**	**51.705**

Table 3. Cover (ha) of seagrass in **geomorphic zones** of the Parramatta River estuary derived from aerial photographs taken 05/01/00. MTD = Marine Tidal Delta, CMB = Central Mud Basin, FD = Fluvial delta, RC = Riverine Channel, after Roy (1984).

			Posidonia	Mixed *Posidonia*	*Zostera*	Mixed *Zostera*	*Halophila*	Mixed *Halophila*	All seagrass
MTD	Harbour Entrance	North	1.113	6.624	3.555	1.554			12.846
		South			0.050				0.050
	Middle Harbour	North	0.056		0.857	1.094			2.007
		South			1.599	0.289			1.888
	Subtotal		**1.169**	**6.624**	**6.061**	**2.937**	**0.000**	**0.000**	**16.791**
CMB	Middle Harbour	North	0.005	0.163	0.606				0.774
		South	0.070	0.368	0.939		0.023		1.400
	Lane Cove	North				0.076			0.076
		South				0.164			0.164
	Parramatta River	North	0.007	0.025	1.408	1.854			3.294
		South	0.941	0.995	16.741	6.415	2.671	0.151	27.914
	Subtotal		**1.023**	**1.551**	**19.694**	**8.509**	**2.694**	**0.151**	**33.622**
FD	Middle Harbour	North			0.013				0.013
		South			0.021				0.021
	Lane Cove River	North			0.930				0.930
		South			0.316	0.012			0.328
	Parramatta River	North							
		South							
	Subtotal		**0.000**	**0.000**	**1.280**	**0.012**	**0.000**	**0.000**	**1.292**
RC	Middle Harbour	North							
		South							
	Riverine Channel	North							
	Parramatta River	South							
	Subtotal		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

Table 3. Continued.

Total		2.192	8.175	27.035	11.458	2.694	0.151	51.705
	North side subtotal	1.181	6.812	7.369	4.578	0.000	0.000	19.940
	South side subtotal	1.011	1.363	19.666	6.880	2.694	0.151	31.765
Total		**2.192**	**8.175**	**27.035**	**11.458**	**2.694**	**0.151**	**51.705**

4. DISCUSSION

Mapping with remote sensing techniques offers advantages in relation to coverage of large areas in a timely fashion, albeit with a loss of resolution for fine scale features such as seagrass beds of the order of a metre in diameter or less. Where fine scale detail is needed, on-ground surveys are necessary. Nevertheless, there are certain procedures built into our assessment technique that provide a robust estimate of the area of estuarine macrophytes. These include: a spatial accuracy of 0.2m from the input tile data, on-screen digitising at a scale of 1: 1 000, processing techniques to optimise the boundaries of target features, post-processing techniques to eliminate errors arising in the construction of boundary lines for features of interest, field inspection of presumptive maps with the use of a DGPS with 1m accuracy, and inspection of final maps by experts familiar with current distributions of estuarine macrophytes.

Aquatic vegetation in the form of saltmarsh, mangrove, seagrass, kelp and other marine algae is present along much of the foreshore of the Parramatta River and Sydney Harbour. Saltmarsh, mangrove and some of the seagrass is present in intertidal (littoral) beds where it is considered "extremely sensitive" to oil spills (Carter 1994). The deeper parts of seagrass beds, as well as kelp and other marine algae, are found in the sublittoral zone where they are at less risk from oil but still considered "highly sensitive". When the water in the Harbour is clear, sublittoral beds are readily seen at the lowest of tides. Ideally, it would be possible to distinguish between the littoral and sublittoral beds to assist in prioritising oil spill response. More specifically, littoral vegetation is at greater risk as it is exposed during ebb tides, whereas sublittoral beds are never exposed to floating oil. Such a demarcation can be done with appropriate bathymetric data, but an analysis of this type was beyond the scope of the project. Saltmarsh is at the highest portion of the littoral zone (occasionally known as the supralittoral) and would be subject to oil spill damage only at the highest of tides.

Textural and colour differences between rock and kelp were not obvious in aerial images, and colour balance in some of the image tiles was notably different to others. These factors made it difficult to distinguish between rock and kelp. In this study all visible rocky reef was mapped and therefore the area of kelp (86 ha) may be an over-estimate. Over the long term, its distribution will vary naturally due to storm damage and cropping by fish and invertebrates, meaning a patch of bare rock in one year might be covered with a kelp forest the next. In this context, all subtidal rock (and possibly some low littoral rock) along the foreshore must be considered as potential kelp habitat.

Using the *camera lucida* technique, West *et al.* (1985) found 129 ha of seagrass (Table 3) in the estuary of the Parramatta River, mostly at the heads of bays and other sheltered locations. Multiple beds occurred in Middle Harbour, including above Spit Bridge as far as Bantry Bay. The reduction to 52 ha in the aerial image of 2000 is alarming and needs to be further investigated. It may be that the reduction is an artefact due to overestimation of the amount reported in 1985. Estuarine vegetation can be expected to change in distribution over time, but because of inherent inaccuracies in the *camera lucida* technique (Meehan *et al*. in prep.), any nominal change in cover needs to be thoroughly investigated. Extensive loss of seagrass has been reported for a number of NSW estuaries over the same timeframe as this study (Williams *et al*. 2003).

Table 4. Comparison of cover of seagrass, mangrove and saltmarsh between West *et al.* (1985) and this survey.

	West *et al.* (1985)	This study
Date of airphoto	1978	2000
All kelp/rock	Not measured	85.6 ha
All seagrass	128.6 ha	51.7 ha
Mangrove	147.5 ha	184.7 ha
Saltmarsh	7.3 ha	9.6 ha

Several substantive beds of seagrass present in the late 1970s (West *et al.* 1985) seem to have disappeared (Figures 3 and 6). The largest of these losses was in Middle Harbour along the western side of Grotto Point. Patches at Edwards Beach and the west side of Bradleys Head are now absent. In contrast, cover appears to have increased along the western shore of Vaucluse Bay. Of greater importance is the fact that West *et al.* (1985) did not show seagrass at upstream locations such as Iron Cove, Five Dock Bay, and Hen and Chicken Bay, but it was found at each of these locations during this study. Historic change at upstream sites are difficult to determine from aerial photographs given the highly turbid water that occurs at that part of the river. Should turbid water still persist, assessments of present and future distribution are possible with detailed underwater surveys (W. Rooney, pers. comm., 2003). If water quality has improved, change into the future could be monitored by analysing relevant photos with GIS facilities. Such investigations should be undertaken within the boundaries determined by Mesley (2003) to assess change a geomorphic context.

The detailed analysis of the distribution of seagrass (Tables 2 and 3) indicates variable cover in terms of species, sector, geomorphic zone and shoreline (north/south). These distributions imply that management response also needs to vary to conserve what seagrass remains, and to enhance the regrowth of seagrass where possible. The apparently extensive losses seen in our maps relative to what was depicted in the early 1980s (West *et al.* 1985) imply that further work is necessary to understand at a more precise scale exactly where losses and gains have occurred.

As seagrass is only found on soft substrata, its growth is influenced by factors such water clarity. Wind and recreational use can stir up bottom sediments, reducing light intensity. Turbidity is also increased by stormwater discharge, meaning some seagrass may be stressed at stormwater pipelines. Recolonisation of seagrass will be dependent on these and potentially a number of other factors. Wind also has important implications in terms of the trajectory and containment of drifting oil.

In contrast to seagrass, most of the mangrove found by West *et al.* (1985) was in the upper portion of the Parramatta River. They found smaller amounts in the Lane Cover River and Middle Harbour above Spit Bridge as far as Roseville Bridge. None was mapped along the foreshores of Sydney Harbour. Subsequently, there has been a considerable expansion of area of mangrove over the past 20 years, from 148 ha to 185 ha (Table 4)[1]. Our finding updates that of Thorogood (1985) who showed a consistent cover of around 150 ha from 1970 to 1985. Thorogood (1985) also noted a much greater cover, of the order of 200 ha across the interval 1930-1961. A re-analysis of historical photos in the context of geomorphic zones is warranted.

[1] The area of 91.4 ha of mangrove published by West *et al.* (1985) was subsequently modified to 147.5 ha via a *corrigenda*.

No mangrove was located in the marine tidal delta, but one small stand was located downstream of the Spit Bridge on the northern side of the waterway. Another small group of trees was located in the Central Mud Basin environment of Rozelle Bay. Given this community's growth habit and the geomorphic characteristics of Sydney Harbour, other small stands or single trees might be growing on the soft substrata at the heads of bays. As it is difficult to access these shallow locations with a boat, foot surveys of bay heads are needed in order to locate any small mangrove stands. Recent reports (Saintilan and Williams 1999, Saintilan and Williams 2000) indicate that at a number of locations along southeast Australia, mangrove is increasing in area to the detriment of saltmarsh. Small stands can be expected to expand enough in the near future to be visible in aerial photos.

Only three meadows of saltmarsh were mapped in the Parramatta River by West *et al.* (1985); two of these occurred at Homebush Bay, and the other along the southern shore of Duck River. The meadows at Homebush were of the order of three to five hectares in size and were readily visible in aerial photos. Investigations of the species inhabiting these meadows have been conducted by the University of New South Wales, University of Technology and Sydney Olympic Park Authority. Two environmentally sensitive species, *Selleria radicans* and *Wilsonia backhousei* are present (P. Adam, pers. comm. 2001, S. Paul, pers. comm. 2002). Historical records show *Selleria* has suffered a major decline along the Parramatta River (Pickthall *et al*. in press). *Wilsonia* was once extensive along the Sydney Harbour embayments, but with the progressive reclamation of foreshore sites, it is now listed as a "Vulnerable" species on Schedule 2 in the Threatened Species Conservation Act (Pickthall *et al*. in press).

The three meadows of saltmarsh located by West *et al.* (1985) (two at Homebush Bay and one at Duck River) were still present in 2000. Given this community's growth habit, other small occurrences of species in this group of plants might grow on the flats at the heads of bays in the upper portion of the Central Mud Basin, in the Fluvial Delta, or in the Riverine Channel. Depending on topography, these plants might be growing alone or upslope of mangrove. A pedestrian survey would be needed to assess the presence of small amounts of saltmarsh. The presence of these meadows, with or without *Selleria* or *Wilsonia*, is currently uncertain.

As the distribution of estuarine vegetation can be expected to vary over time, recurrent surveys of its presence are warranted for a number of reasons, not the least of which is to adapt existing decision-making processes, but as well for the appropriate management of spills of oil and other hazardous substances.

5. CONCLUSIONS

The GIS method used in this study is repeatable and robust, and resulted in accurate estimates of the area of macrophytes in the estuary of the Parramatta River.

While saltmarsh, mangrove and seagrass might have a higher conservation profile than kelp, much of the rocky foreshore of Sydney Harbour is covered with the latter. The area of kelp in the Parramatta River/Sydney Harbour estuary in 2000 was approximately half again as much as seagrass. The distribution of kelp has been overlooked previously in oil-spill management planning.

In the maps of West *et al*. (1985), most seagrass in the estuary was downstream of the Harbour Bridge. The amount of seagrass in the 2000 photographs is less than one half what was shown in the late 1970s.

Seagrass is not evenly distributed across the estuary, with most *Posidonia* found at the entrance, and most *Zostera* found in the central portion of the estuary. What appear to be new occurrences of *Zostera* were found in Iron Cove.

Mangrove has increased in extent from 148 ha to 185 ha compared to 20 years ago. Some small patches of mangrove are present but not visible in airphotos of Sydney Harbour taken in 2000. Where not sighted in the photos, the cover of this community needs to be identified by ground survey. Mangrove may have existed previously in much greater amounts at the heads of bays, but was cleared as urban development proceeded.

Only a small amount of saltmarsh is present in the Parramatta estuary. Most of what is present is in Sydney Olympic Park, at foreshores that have been greatly modified by reclamation. Saltmarsh may have existed previously in much greater amounts, but was cleared as a consequence of urban development.

The type of substratum (mud, sand, rock) in combination with tidal range determine the potential for colonisation by estuarine vegetation. Orientation of the foreshore and prevailing wind may also play a role. Theoretically, it is possible to model past and future distributions of estuarine vegetation.

Wind is an important factor in determining the trajectory and containment of drifting oil in relation to protection of estuarine plant communities.

6. RECOMMENDATIONS AND IMPLICATIONS

6.1. Further development

The distribution of seagrass in the Parramatta River and Sydney Harbour has changed substantially over the past 20 years. These changes should be better quantified by analysing historical aerial photos within a GIS format and comparing the results to the data generated in this study.

Given the geomorphology of the estuary, mangrove and saltmarsh were almost certainly present in the pre-colonial era but confined to the tidal flats at the heads of bays. The historical distribution of these communities should be ascertained.

The distribution of estuarine vegetation will respond to natural forces such as storms, as well as to modifications of the river's foreshores and water quality. In future, maps of the vegetation of the Parramatta River and Sydney Harbour should be produced at regular (e.g., two year) intervals to assist with foreshore conservation and oil spill contingency planning.

6.2. Benefits

The project will directly benefit NSW Maritime in relation to asset management. It will also directly benefit NSW Maritime and the Commonwealth Department of Transport, as well as New South Wales Department of Environment and Conservation and the oil and transport industries for contingency planning for oil spill management.

6.3. Intellectual property

Property arrangements were negotiated with NSW Waterways (now known as NSW Maritime) as follows:

6.3.1. Acknowledgment of Mutual Understanding

NSW Maritime and the NSW Fisheries (now incorporated in the NSW Department of Primary Industries) agree that all information regarding the matters covered by, arising out of, or in connection with this Memorandum of Understanding is strictly confidential to them.

If the NSW Department of Primary Industries wish to disclose any such information to any other person or entity, the NSW Department of Primary Industries shall first obtain the written consent from NSW Maritime as to the terms of such disclosure.

The following disclosures will be permitted:

- any disclosure made to a professional adviser or to any officer or employee of the NSW Department of Primary Industries or NSW Maritime;
- any disclosure of information available in the public domain;
- any disclosure required by law; and
- any other disclosure to the extent that the disclosure is necessary to obtain the benefit of, and to carry out the obligations under, this agreement.

This Memorandum of Understanding is not a binding agreement. However, the Parties will act cooperatively, honestly and fairly with each other to fulfil their respective obligations contained within this document.

6.3.2. Use of the Data

The parties agree that:

- The data collected by NSW Fisheries (now incorporated in the NSW Department of Primary Industries) to prepare the shape files and associated data tables, remain the property of the NSW Department of Primary Industries;
- Data prepared by NSW Maritime (such as the simplified ArcView shape files and data tables) remain the property of NSW Maritime;
- NSW Maritime authorises the NSW Department of Primary Industries to use the simplified data collected in this study for normal non-commercial activities of the NSW Department of Primary Industries. The simplified data shall not be provided to a third party in any form without the permission of the Department; and
- NSW Department of Primary Industries shall acknowledge the source of the funding when the data collected as per this project are used in any publication.

6.4. Staff

6.4.1. Fisheries staff

Rob Williams negotiated the initial brief for the study of Sydney Harbour with Robert Lea of NSW Transport. The second brief for the study of upper Middle Harbour and the Parramatta River upstream of the Harbour Bridge as well as the Lane Cove River was negotiated with Robert Lea and Andrew Morison representing NSW Maritime. Greg West and Roger Laird undertook the primary analysis of images. Brett Louden and Alan Genders assisted with the manual digitising. Jack Hannan, Brian Hill and Brett Louden provided ground truth data. Comments on the draft report were provided by Bob Creese, Dan Breen and Claudia Jordan.

6.4.2. Volunteers

Edwina Mesley, BSc Honours student at the University of Sydney, helped with fieldwork.

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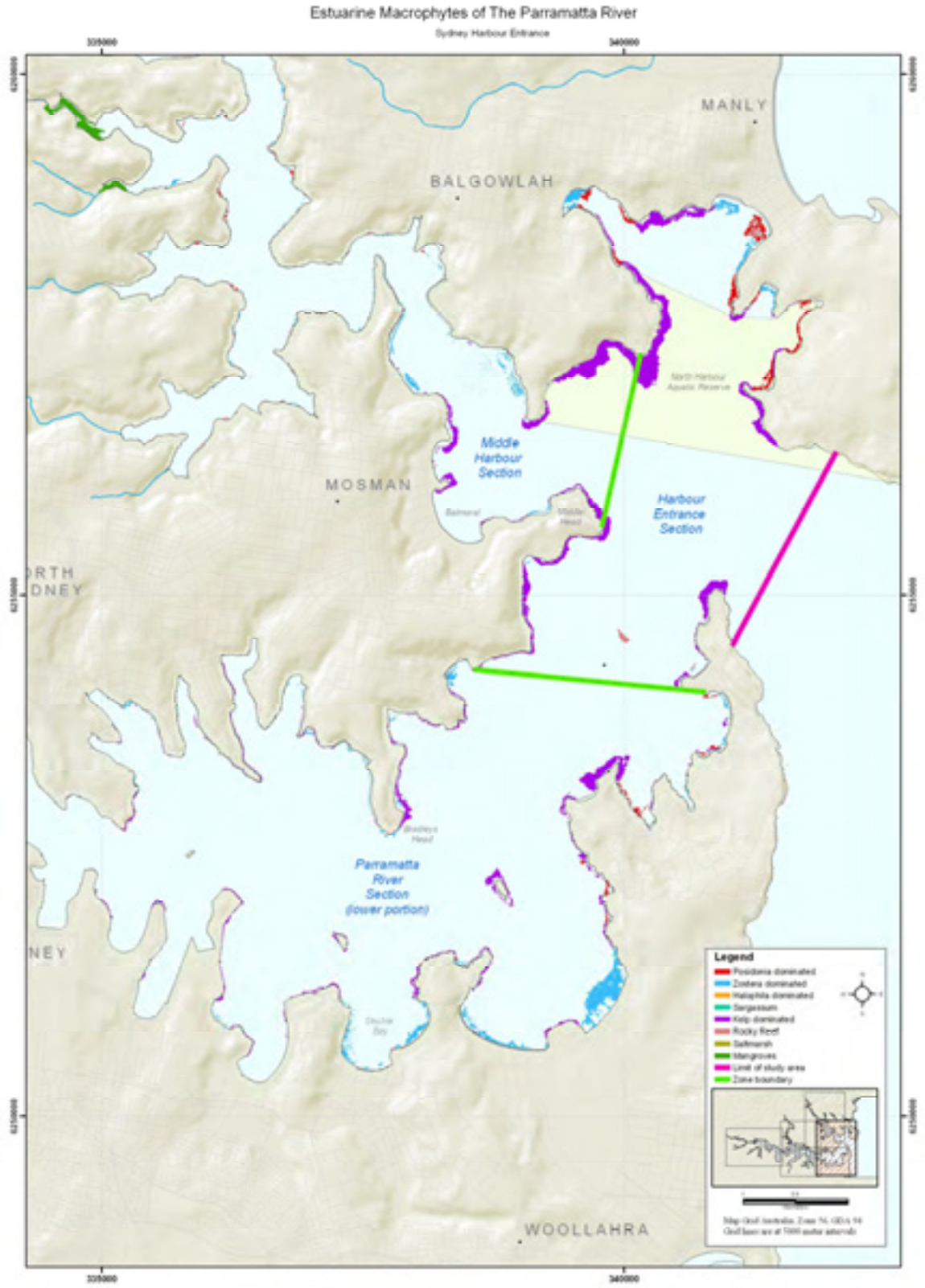


Figure 3. Estuarine macrophytes in the Harbour Entrance, 2000.

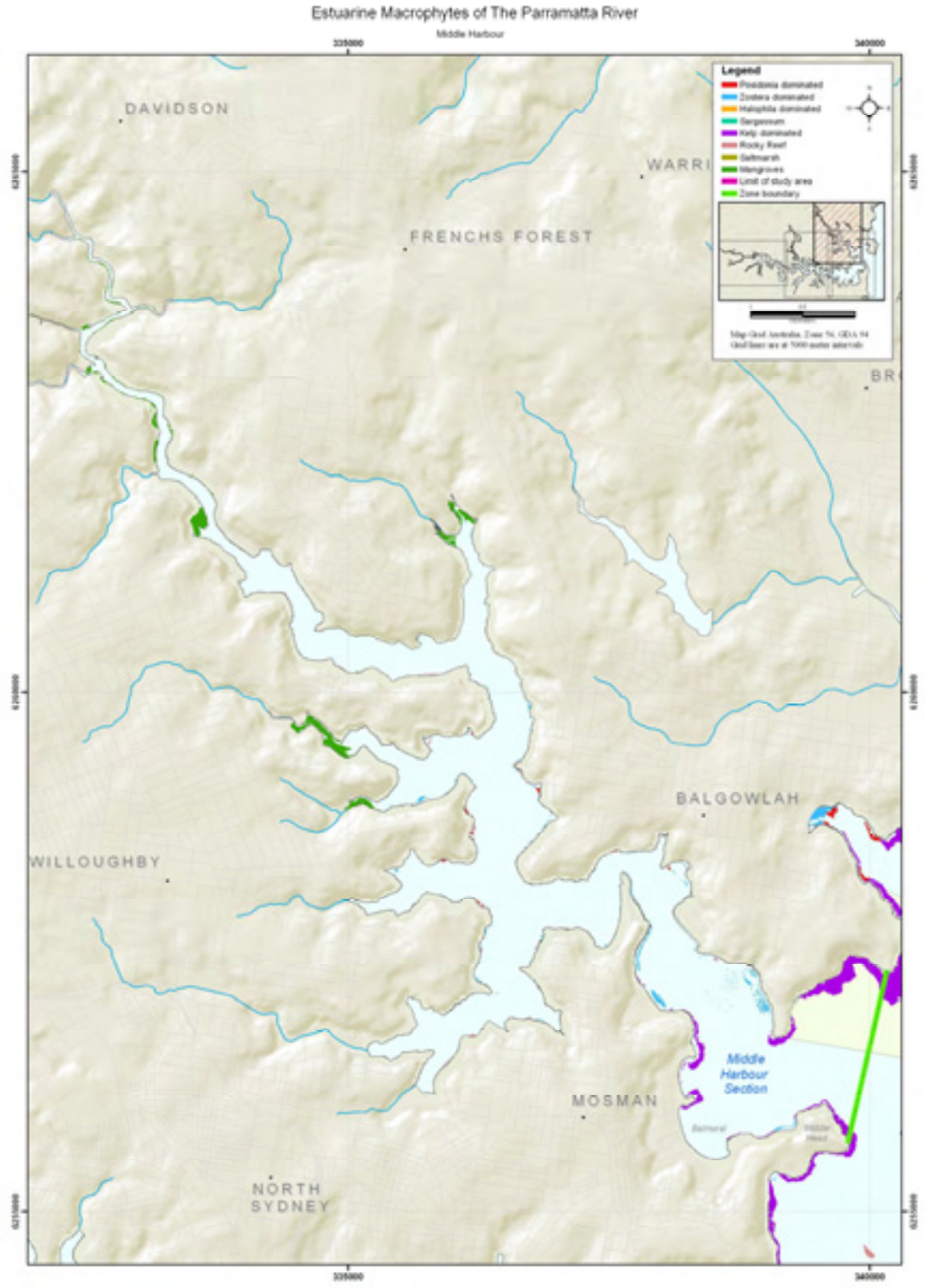


Figure 4. Estuarine macrophytes in Middle Harbour, 2000.

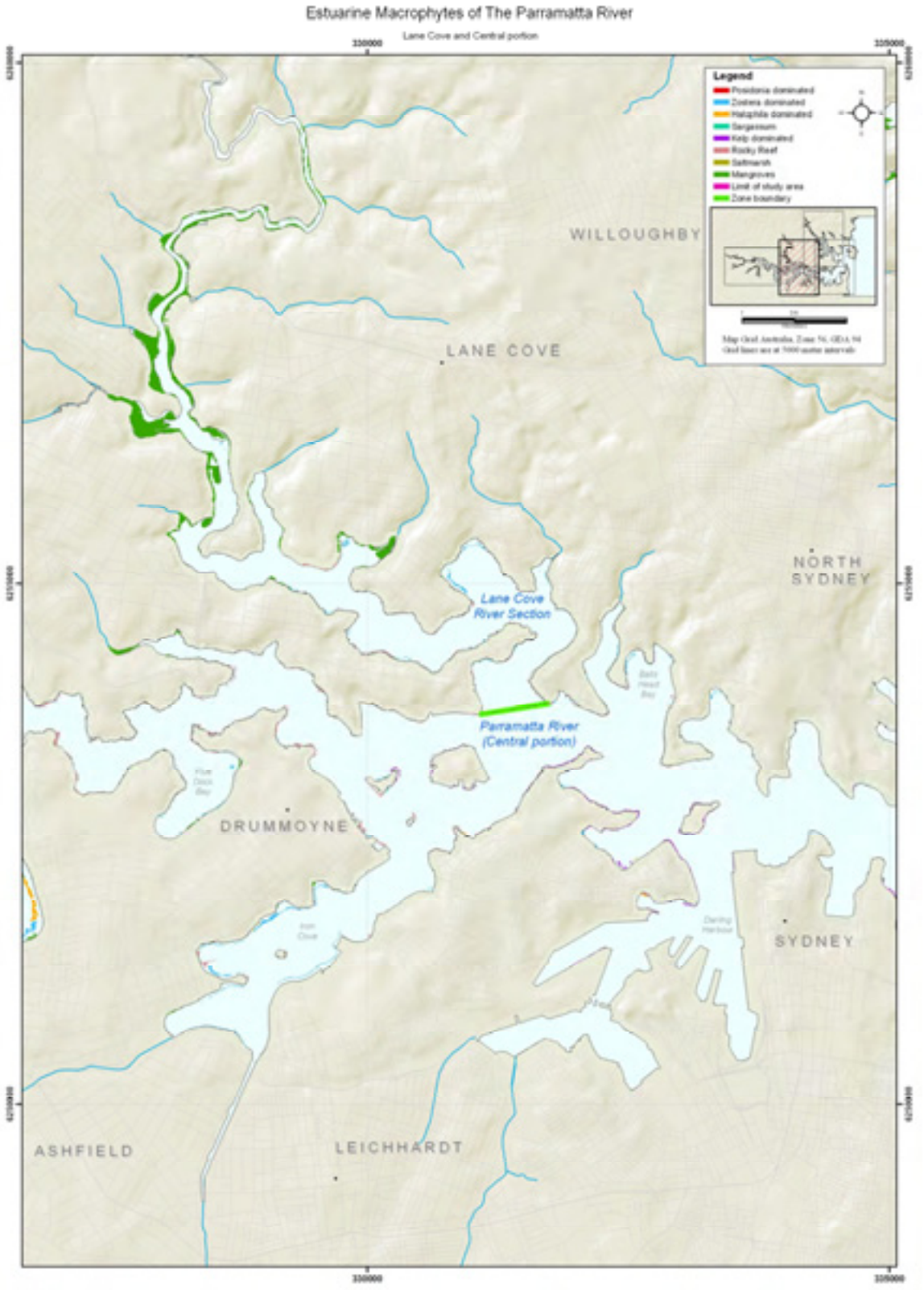


Figure 5. Estuarine macrophytes in the Lane Cove River, 2000.

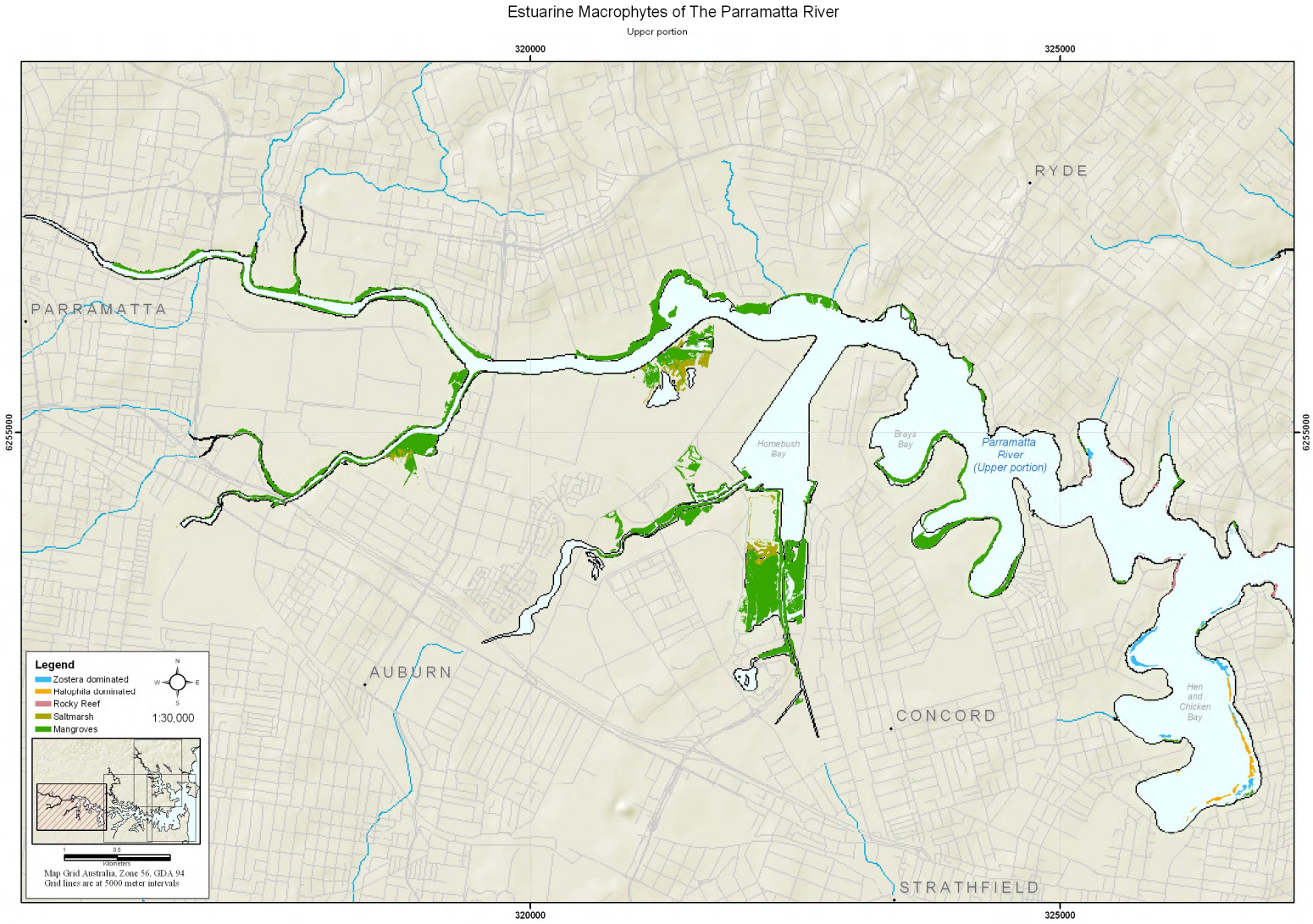
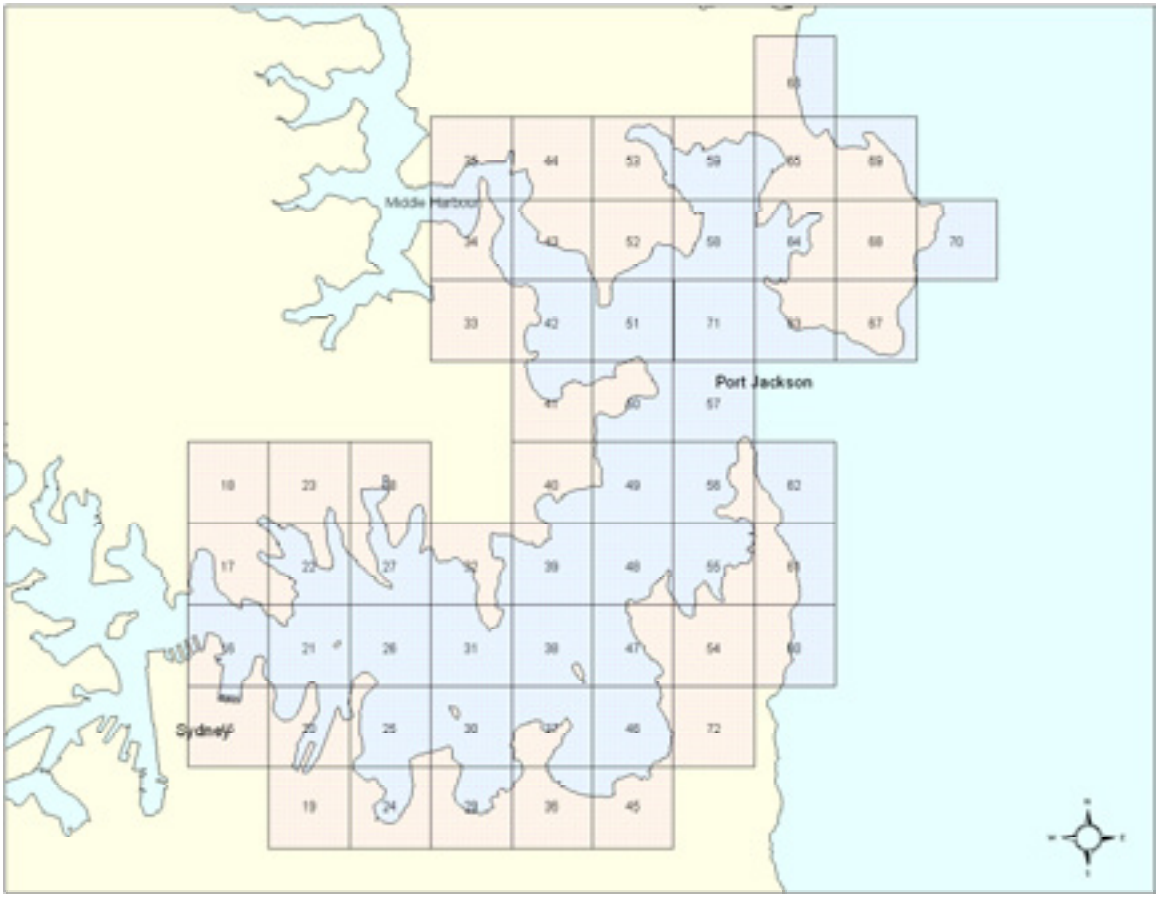


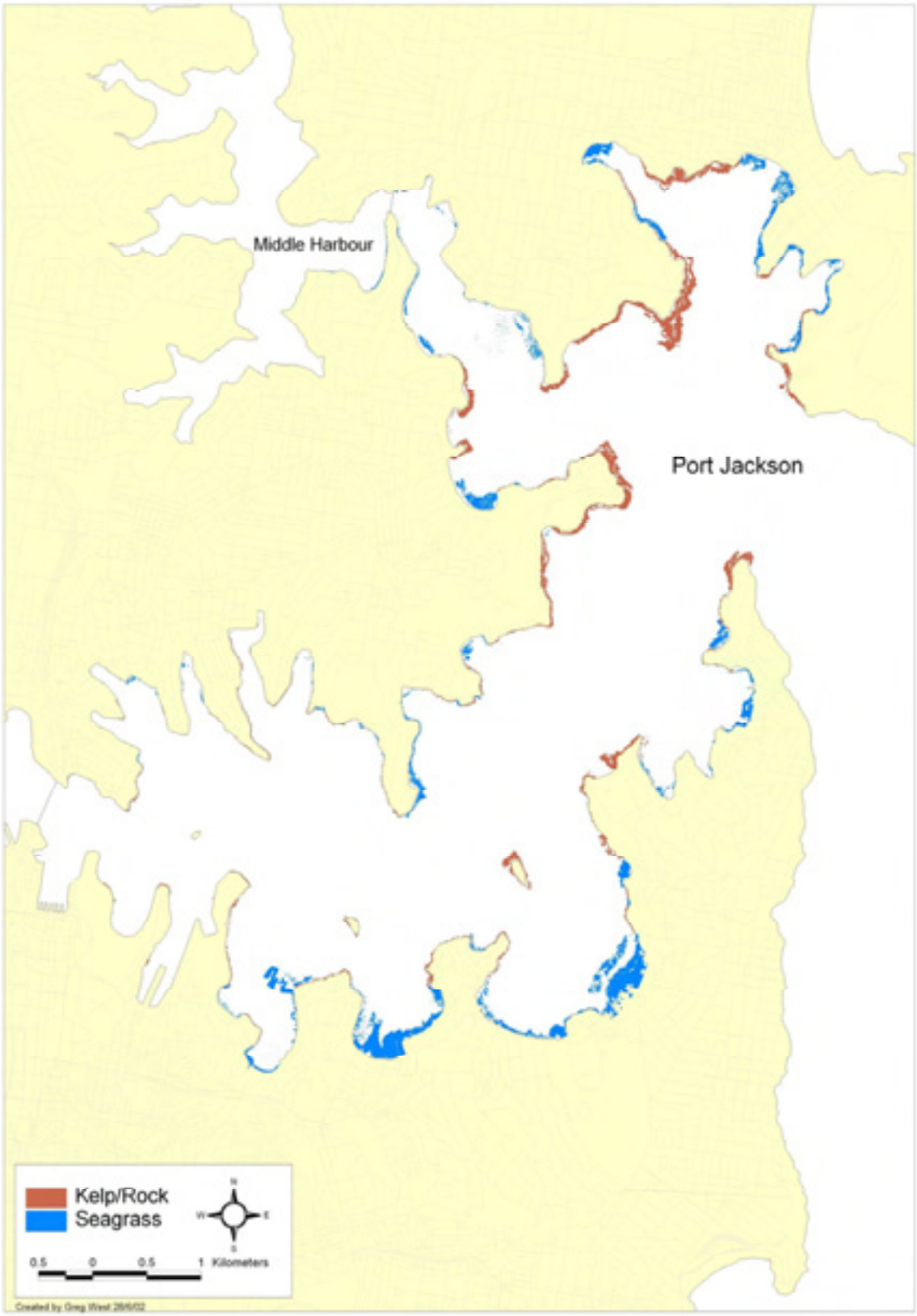
Figure 6. Estuarine macrophytes in the Parramatta River, 2000.

Figure 7. A portion of the estuary of the Parramatta River as mapped by West *et al*. (1985) from aerial photographs taken in 1982.

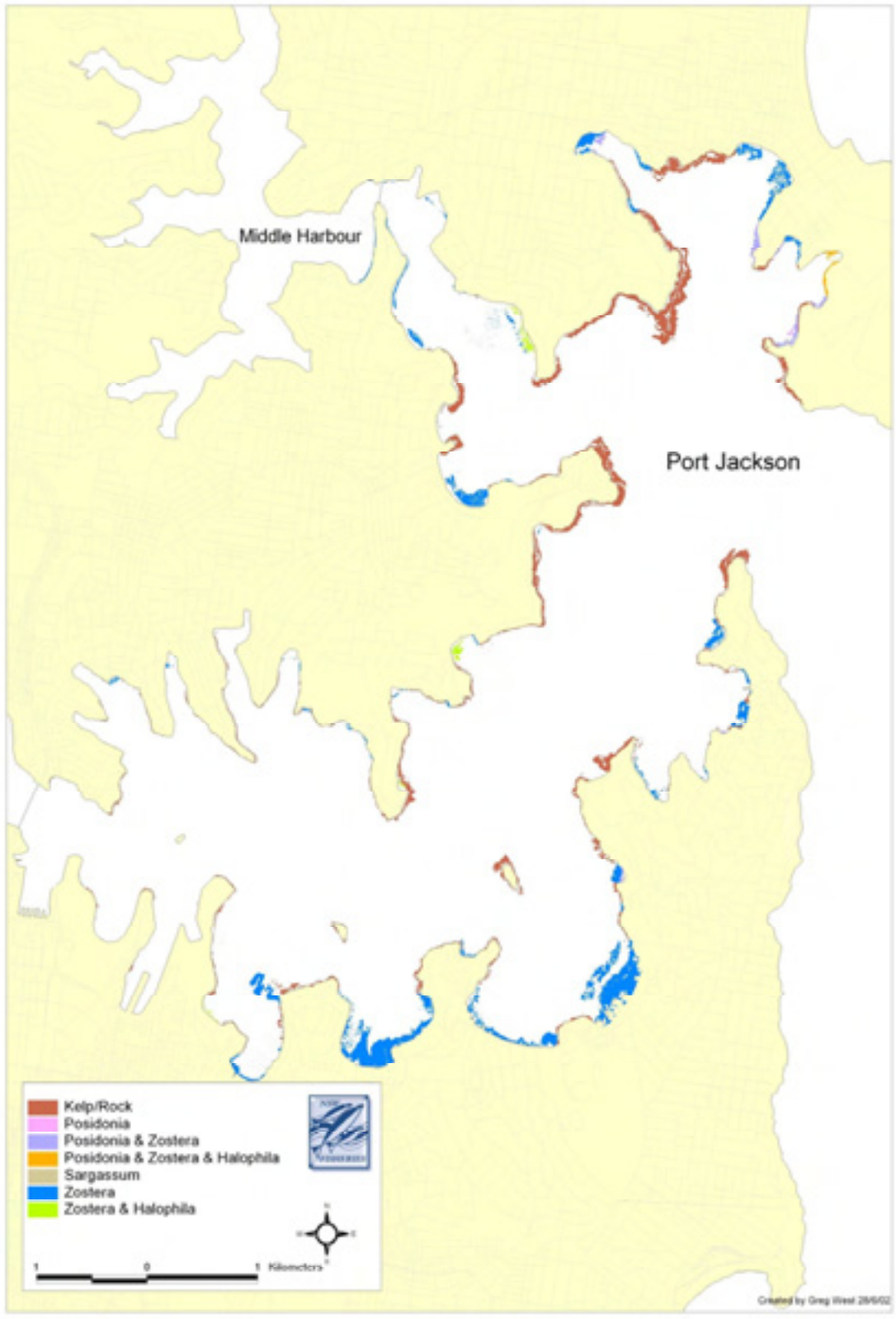
8. APPENDICES



Appendix 1. Aerial photos (tiles) used in the assessment of estuarine vegetation for the lower reaches of the Parramatta estuary.



Appendix 2. Presumptive map of the estuarine vegetation at the entrance to the Parramatta estuary, January 2000.



Appendix 3. Estuarine vegetation at the entrance to the Parramatta estuary, January 2000.

Appendix 4. Reports of estuarine macrophytes in the Parramatta estuary not encountered in this study. These sightings should be inspected during any future mapping exercises.

Sector	Location	Site	Species	Source
Middle Harbour	Castle Cove	Head of the cove	*Zostera* spp.	J. Hannan
Parramatta River	Little Sirius Cove	Half way along eastern side	*Zostera* spp.	J. Hannan
	Tarban Creek	Near Riverglade Reserve	*Zostera* spp.	J. Hannan
	Johnstons Creek	Southern end of Federal Park	*Sarcocornia quinqueflora*	G. Sainty
	Powells Creek	Northern side of Homebush Substation	*Wilsonia backhousei*	S. Paul

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