Saltmarsh of the Parramatta River-Sydney Harbour: determination of cover and species composition including comparison of API and pedestrian survey

R.J. Williams[1], C.B. Allen[2] and J. Kelleway[1]

[1]Industry and Investment NSW, Cronulla Fisheries Centre, PO Box 21, Cronulla, NSW 2230 AUSTRALIA;
[2]Royal Botanic Gardens, Sydney, NSW, 2000 AUSTRALIA

***Abstract*:** In 2004 coastal saltmarsh was listed as an Endangered Ecological Community under the New South Wales *Threatened Species Conservation Act*, but more information on the ecology of saltmarsh species as well as accurate maps of the cover of saltmarsh are needed. Large scale maps produced in the early 1980s and the mid 2000s were based on air photo interpretation with follow-up field checks, but to determine the ability of air photos to detect small patches of coastal saltmarsh, a pedestrian survey along the foreshore of the Parramatta River-Sydney Harbour estuary (33° 53'S; 151° 13'E) was commissioned. Ground-truth activity was partitioned into three levels of intensity. At the greatest level of intensity, many small patches obscured in the air photos by (mainly mangrove) canopy cover were resolved and joined to reveal larger patches of saltmarsh. Compared to the earlier maps these areas are considered to increase the total area of existing saltmarsh, but they also may in fact be areas of saltmarsh that have been recently invaded by mangroves, and ultimately, through shading and competition result in the loss of the saltmarsh species at these sites. Another 609 patches not seen on the air photos were located.

The pedestrian survey located 757 saltmarsh patches (70% of these were less than 100 m^2 in area) with a total area of 37.3 ha. Parramatta River, relative to the Lane Cove River, Middle Harbour Creek and Sydney Harbour, supports the most numerous and extensive patches: 461 patches (61% by number), 29 ha (78% by area). Most of the patches of saltmarsh (60%), as well as most of their area (76%), are located in the most upstream Riverine Channel geomorphic zone of the Parramatta River, followed by downstream zones Fluvial Delta and Central Mud Basin. The fewest patches (14) and smallest area (0.04ha) were in the Marine Tidal Delta. The 'conservation 'sensitive' species as well as some of the weed species also appeared to be restricted to the upper and middle parts of the estuary.

API is useful for broad assessments of estuarine saltmarsh, but pedestrian survey is needed to provide the finer scale detail necessary to locate small patches and to identify species composition especially for rare or weed species.

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Introduction

Coastal saltmarsh is defined as an intertidal community dominated by halophytic herbs and low shrubs growing along the edge of the Australian continent (Adam 1990). The area of tropical saltmarsh exceeds that in temperate regions, but saltmarsh along the southeast coast is increasingly subject to human disturbance (Bridgewater & Cresswell 1999). At the structural and floristic levels there is some similarity between Australian saltmarshes and those elsewhere in the southern hemisphere, but less similarity with those in the northern hemisphere (Adam 1990).

The ecological role of Australian saltmarsh as a habitat for invertebrates, a foraging ground for fish, or a contributor to estuarine food chains has only recently been investigated (Laegdsgaard 2006). Some studies have focused on the subtropical saltmarshes of east coast Australia (e.g., Connolly 2003, Melville and Connolly 2003, Guest and Connolly 2004) while others have examined temperate saltmarshes further to the south (e.g., Connolly *et al*. 1997, Mazumder *et al*. 2006a, 2006b, Platell & Freewater 2009). Many species of non-vascular plants are found in saltmarsh, including epiphytic algae and diatoms, but the role of these in coastal ecology is also poorly understood (Adam 2002). Saintilan (2008) provides a review of many aspects of Australian saltmarshes. In 2004, because of threats to its long-term survival, Coastal Saltmarsh was listed as an Endangered Ecological Community (EEC) under the New South Wales *Threatened Species Conservation Act* 1995 (*TSC Act*).

Threats to saltmarsh

The main threat to saltmarsh globally has been the reclamation of tidal lands for agricultural, urban or industrial purposes (Adam 2002), but the invasion of terrestrial plant species, and rises in sea level are now issues of concern for surviving remnants. A significant threat in Australia is from expansion of mangrove forest (Mitchell & Adam 1989, Saintilan & Williams 1999, 2000). Encroachment of mangroves into saltmarsh habitat may mean less area for saltmarsh. For the Parramatta River evidence from the 19th and early 20th centuries indicates that there was less mangrove cover relative to saltmarsh than at present (McLoughlin 2000). West *et al*. (2004) estimated that the cover of mangrove in the Parramatta River at 185 ha, a substantial increase from the 148 ha of West *et al*. (1985). This difference was not thought to be an increase in area but an enhancement in detection methods.

Downslope migration of *Phragmites australis* and freshwater reeds has also been observed (Wilton *et al*. 2003, Pickthall *et al*. 2004) and may threaten saltmarsh from its terrestrial side. The spread of *Phragmites* has been widely recorded in North America in recent decades where research has shown that the invading *Phragmites* is a foreign genotype and invasion is related to changed environmental conditions (Mitsch 2000, Stevenson *et al*. 2000, Weinstein *et al*. 2000). There is no evidence of exotic genotypes of *Phragmites* in Australia (although there has not been a proper survey) but at least in some cases, spread of *Phragmites* is clearly due to habitat alteration, such stormwater discharge.

Rise of sea level will have a significant impact on the distribution of plants living in and around estuaries (Vanderzee 1988, Williams 1990, Hughes 2003). Terrestrial vegetation, such as *Casuarina glauca* (Swamp She-oak) and *Melaleuca* species (Paperbarks) will be forced further upstream and upslope by the rise in mean sea-level. Mangrove and saltmarsh will also move further upslope from their present locations, as well as extend further upriver. Expansion of saltmarsh will be limited by topography and the presence of structures such as roads and buildings.

Human trampling can cause significant reductions in the number and cover of saltmarsh plants (Andersen 1995). In the Sydney region, recreational vehicles (4WD, trail bikes, BMX bikes) have been responsible for the loss of over 2.1 ha of saltmarsh along the Georges River (Kelleway 2004, 2005). Damage from unauthorised access has also been reported from the Parramatta River (K. Sommerville, pers. comm., 2006).

Mapping studies of New South Wales saltmarsh

An issue that has complicated wetland mapping at the whole-of-coast scale has been a lack of consensus on the number of species embraced within the term "saltmarsh". This is due, in part, to the definitional problem of what are "true" saltmarsh species relative to other species found in close association with saltmarsh. Saenger *et al*. (1977) identified 15 species in eastern Australia, Specht (1981) recorded 30 taxa and Adam *et al*. (1988) listed 120 possible taxa. Most saltmarshes are species poor (Adam *et al*. 1988), with richness increasing in the more southerly latitudes of Australia (Adam 1990).

Broad-scale mapping of vegetation has used remote sensing techniques based on air photos and satellite images, but the resolution of satellite images has not, until recently, been fine enough to differentiate small patches of estuarine macrophytes (Anstee *et al*. 2009). Mapping of saltmarsh for the whole of the NSW coast has used aerial photographic interpretation (API) in four general steps: obtain relevant aerial photos, extract boundary data to prepare presumptive maps, check the patch boundaries (polygons) in the field, and edit the presumptive maps to produce a final map.

West *et al.* (1985) produced the first maps of estuarine macrophyte cover for southeast Australia using API of photos taken in the late 1970s and early 1980s. They generated an atlas that showed cover of saltmarsh, mangrove and seagrass along the NSW coastline. The prime motive for the atlas was to assess the cover of seagrass within the context of the legislated responsiblities of the then NSW Department of Agriculture, but the extent of mangrove and saltmarsh were also denoted. The atlas revealed 58 km^2 of saltmarsh in 101 estuaries, but was not designed to provide details on species composition. The need to assess seagrass mandated the use of a boat for field checks but boat access through mangrove to saltmarsh to confirm presumptive locations would have been problematic at low tide and some patches assumed to saltmarsh may have been other types of vegetation. In circumstances where saltmarsh was hidden under mangrove canopy in aerial photos there may have been underestimations of area. In effect, both false positive and false negative observations may have ensued. In spite of these limitations the West *et al.* (1985) maps had wide use as planning and management documents by state and local government agencies.

API has been used to map the extent of saltmarsh in Sydney region estuaries including the Hawkesbury River (Williams & Watford 1997, Williams & Watford 1999, Williams & Thiebaud 2007); Parramatta River (West *et al*. 2004); Hacking River (Williams & Meehan 2004); and Careel Bay, Pittwater (Wilton 1998). Some non-urban locations have also been mapped (Wilton *et al*. 2003), and an updated atlas for the entire coast of NSW is currently being prepared (West *et al*. in prep.). These studies were complemented by ground-truthing, but the intensity of field inspections varied and none of these studies show details of the occurrence of individual plant species.

Saltmarsh species in New South Wales estuaries

There is limited information about the distribution of saltmarsh species within individual NSW estuaries. In the Sydney region Clarke & Hannon (1967, 1969, 1970, 1971) identified seven species in a very detailed study at Towra Point, Clarke & Benson (1987) found the same seven species along the Lane Cove River, Clarke & Benson (1988) listed 25 species at Homebush Bay, and Pickthall *et al*. (2004) found 30 species along the Georges River. For Lake Illawarra, Yassini (985) listed 40 species, and for Jervis Bay Clarke (1993) listed 24 species. Clarke (1994) tabulated occurrences for other estuaries along the NSW south coast identifying up to six species at a number of locations. Characteristic saltmarsh species recognised by the NSW Scientific Committee (2004) in the Sydney region are listed in Table 1.

Except for the Georges River-Botany Bay study by Pickthall *et al*. (2004), no NSW studies have revealed species composition at the patch scale. To refine their study by overcoming locational vagaries such as "downstream" or "upper estuary", terms that, though in general use, have little ecological value due to the varying physical characteristics of estuaries, such as catchment size, surface area, water volume, tidal prism and sediment type, Pickthall *et al*. (2004) used a geomorphic framework (applying definitions of Roy 1984) to delimit the estuary into four geomorphic zones (from upstream to downstream): Riverine Channel, Fluvial Delta, Central Mud Basin, and Marine Tidal Delta.

Table 1. Characteristic saltmarsh species along the central coast of New South Wales (after the NSW Scientific Committee (2004). Six species (#) are considered of conservation significance due to their limited distribution in the Sydney metropolitan area. *TSC Act* = NSW *Threatened Species Conservation Act* 1995.

Scientific name	Family	Status in Sydney Region
Monocotyledons		
Baumea juncea	Cyperaceae	common
Gahnia filum	Cyperaceae	#rare
Juncus kraussii	Juncaceae	common
Triglochin striata	Juncaginaceae	common
Sporobolus virginicus	Poaceae	common
Zoysia macrantha	Poaceae	common
Juncus acutus	Juncaceae	common, introduced weed
Dicotyledons		
Lampranthus tegens	Aizoaceae	#rare
Halosarcia pergranulata subsp. *pergranulata*	Chenopodiaceae	#rare
Sarcocornia quinqueflora	Chenopodiaceae	common
Suaeda australis	Chenopodiaceae	common
Wilsonia backhousei	Convolvulaceae	#rare (listed as 'Vulnerable' in the *TSC Act*)
Selliera radicans	Goodeniaceae	#rare
Samolus repens	Primulaceae	common
Bacopa monniera	Scrophulariaceae	#rare

In each zone Pickthall *et al*. (2004) calculated the extent fof cover. *Sarcocornia quinqueflora* and *Sporobolus virginicus* were found throughout the estuary, but other species, such as *Gahnia filum*, *Selliera radicans* and *Wilsonia backhousei*, were found almost exclusively within the Fluvial Delta. That some species of saltmarsh were only found in the Fluvial Delta and not closer to the entrance was not thought to be due to human disturbance, but due to the natural distribution of particular ecological habitat conditions within the estuary. Pickthall *et al*. (2004) concluded that *Wilsonia backhousei*, *Selliera radicans* and *Gahnia filum* should be considered "sensitive" in conservation terms due to their limited presence relative to the other saltmarsh plants within the Georges River estuary.

These three species are also rare in the broader Sydney metropolitan region (*Australian Virtual Herbarium*, online) and the reduction in the distribution of *Wilsonia backhousei,* a prostrate mat-forming species, is such that it is now listed as "Vulnerable" under Schedule 2 of the NSW *TSC Act*. *Wilsonia backhousei* occurs at the northern end of its range in the Sydney region. In the 19th century it was extensive along the Sydney Harbour embayments (Hamilton 1919) but many of these areas were subsequently reclaimed. The historical record shows that *Selliera radicans*, another prostrate, mat-forming species, has also suffered a major decline in Parramatta River (Hamilton 1919, Adam *et al*. 1988).

Gahnia filum, a tall tussock sedge characteristic of the upper marsh fringe is at its most northern limit on the Georges River (Pickthall *et al*. 2004) and is markedly disjunct from the next nearest population further south in Jervis Bay (Clarke 1994). It is possible that *Gahnia filum* may have once been present along the foreshores of the Parramatta River, but there are no historical records to support this. Alternately, it may be spreading. P. Adam (pers. comm. (2007) has recently reported a small patch at Towra Point in Botany Bay that that has not been previously noted.

Flora surveys of Homebush Bay in Parramatta River (Clarke & Benson 1988; Adam 1996) have identified other species of conservation significance. *Lampranthus tegens*, a spreading, prostrate shrub is only found around the ports of NSW, appears to have been introduced from South Africa in the 19th Century, but has since become extinct in that country (S.W.J. Jacobs, pers. comm., 2007). Regardless of its history, attention should be given to all occurrences of this species in the Parramatta River-Sydney Harbour due to its extreme rarity.

Halosarcia pergranulata subspecies *pergranulata* is a native halophyte that grows in saline habitats including salt lakes in inland NSW. It has not been recorded in coastal saltmarshes outside of the Parramatta River and may possibly have been inadvertently transported to the Sydney area with livestock (the Homebush saleyards and abattoirs operated nearby in the 20th Century) or may have been naturally dispersed there. As an interesting disjunct occurrence it has conservation significance.

Due to their extreme conditions of salinity and waterlogging, saltmarshes are generally less prone to invasion by terrestrial weeds than other habitats. However the introduced Sharp Rush *Juncus acutus* is of concern along the NSW coast from the Macleay River to the Moruya River (*Australian Virtual Herbarium*, online). It is difficult, although possible, to eradicate this species, as experience at Sydney Olympic Park (Paul & Young 2006) and the Kooragang Wetlands (P. Svoboda, pers. comm., 2005) have shown. The Endangered Ecological Community listing for NSW coastal saltmarsh (NSW Scientific Committee 2004) identifies *Juncus acutus* as well as *Baccharis halimifolia* (Groundsel Bush)*, Cortaderia selloana* (Pampas Grass) and *Hydrocotyle bonariensis* (Kurnell Curse) as weeds of particular consequence to saltmarsh.

Objectives

Investigations of saltmarsh cover in NSW have tended to fall into two categories: high-intensity investigations of single estuaries (e.g., Mitchell & Adam 1989), or low intensity investigations of all estuaries (e.g., West *et al*. 1985). Given the environmental sensitivity of coastal saltmarsh in NSW and possibly all of southeast Australia, accurate assessments of cover and species composition are needed. As a first step the methodology by which cover is determined needs to be resolved. While it is universally accepted that API must be complemented by field checking (ground-truth), there are no data to devise operating principles for such in-field observations. There are three likely pathways for field work. The cheapest of these is to inspect all presumptive polygons identified at the first stage of API and remove the incorrect ones. This approach will overlook small patches not captured in air photos and/or may ignore continuity, where canopy cover suggests several small patches but in fact a large contiguous patch may be present. A more intensive pathway is to enlarge the scope of the fieldwork (and hence the time-scale and budget) to locate all patches encountered. The third approach is to set a minimum size at which patches are to be mapped. In light of these alternatives, two major objectives were set for this study.

The first objective was to investigate ground-truth procedures that could be used to enhance presumptive API observations of saltmarsh. One subcomponent of this task was to determine the smallest patch size that could be detected with the current API tools; a second subcomponent was to determine the relative abundance of saltmarsh patches that might be hidden under the canopy of mangrove or other vegetation. At present, there is no remote sensing technology specifically adapted to locate hidden patches, but future application of spectral imaging systems might help to fill this gap. It was anticipated that field checks would reveal patches of vegetation incorrectly identified as saltmarsh (false positives) as well as add small patches not recognisable or resolvable in air photos (false negatives). The relative contribution of the two types of field survey to the total number as well as total area of patches could be assessed.

The second objective was to use pedestrian survey to identify the plant species composition, including weeds, within patches of saltmarsh. The size of patches in which the "sensitive" species occurred could then be determined.

A number of null hypotheses were tested:

- enhanced levels of pedestrian survey would not increase output
- species of native saltmarsh would be uniformly located throughout the estuary
- the degree of weed invasion of saltmarsh would be uniform throughout the estuary.

Methods

Study Site

The estuarine foreshore of Parramatta River-Sydney Harbour (33° 53'S; 151° 13'E) sits within a drowned river valley (Roy *et al*. 2001). Its catchment is small (347 km^2), with a total waterway area of 62 km^2 (NSW Dept of Natural Resources, online). We measured the length of the shoreline of the estuary as 361 km, but this length has changed considerably over the past 100 years, notably at Homebush Bay due to reclamation (Thorogood 1985, Rogers *et al*. 2005). Much of the estuary's northern foreshore is comprised of dissected Middle Triassic Hawkesbury Sandstone, whereas the western and southern shores are primarily alluvial material, being derived from Quaternary sands near the entrance, and shales and muds further upstream (Chapman & Murphy 1989).

To resolve distributional differences within the estuary, the geomorphic scheme devised by Roy (1984) and applied by Mesley (2003) to Sydney Harbour was used. In this scheme there are four types of geomorphic zone (from upstream to downstream): Riverine Channel, Fluvial Delta, Central Mud Basin, and Marine Tidal Delta (Figure 1). One zone, the Marine Tidal Delta, occurs only at the entrance to the estuary but there are multiple occurrences of the other zones. For mapping purposes the tidal barriers of Middle Harbour Creek, Lane Cove River and the Parramatta River were used as upstream margins.

Parramatta River-Sydney Harbour was chosen as the study site for a number of reasons. The river drains the centre of Australia's oldest (200 years) and largest city (Sydney, pop. 4,000,000 people) and expansion of waterfront accommodation has resulted in the destruction of many saltmarsh areas. Contemporary scientific collections (Hamilton 1919) and historical studies based on diaries, reports and artworks (McLoughlin 1987, 2000, 2002) indicate that saltmarshes were extensive in many of the embayments, creeks and intertidal flats of the estuary, particularly the upper

Parramatta River in the 19th Century. Mangroves appear to have been relatively restricted in abundance until the late 1880s but have expanded in response to land-use practices that enhanced sedimentation and provided new substrates (McLoughlin 2000). Recently saltmarsh sites have also been damaged by trail bikes (K. Sommerville, pers. comm., 2006).

The major conservation initiative associated with the Sydney 2000 Olympic Games dedicated extensive areas of tidal (and freshwater) wetlands as part of Newington Nature Reserve for conservation purposes. These wetlands can serve as reference sites to study future growth patterns of saltmarsh in the Parramatta River and elsewhere.

There are many current disturbances to the saltmarsh of Parramatta River-Sydney Harbour and an up-to-date map of saltmarsh, including the best possible depiction of small patches is needed. Two sets of API-derived maps have already been produced for Sydney Harbour to show the distribution of its estuarine macrophytes. West *et al*. (1985) found three patches of saltmarsh with a total area of 7.3 ha. West *et al*. (2004) identified 30 patches with an area of 9.6 ha. The objective of the former was to produce an indication of cover of saltmarsh for the whole of NSW, rather than a finely detailed description of distribution. Field checks were conducted in each study by boat, but otherwise there were major differences in approach. West *et al*. (1985) used the *camera lucida* technique, an analogue method in which a series of optics facilitated the tracing of a vegetation boundary from a black and white contact print of an aerial photograph to a 1: 25,000 scale reference map that poorly represents medium and small sized patches (see Williams *et al.* 2003 for further details). Additional refinements to the API technique became available to West *et al*. (2004) who used higher quality colour aerial photos, digitized, spatially referenced and analysed in geographic information system (GIS).

That individual patches of saltmarsh expanded over the ensuing years is unlikely, even though little is known about the growth patterns of saltmarsh species along southeast Australia. For instance Streever and Genders (1997) found competitive interaction between characteristic saltmarsh dominant shrub *Sarcocornia quinqueflora* and the exotic terrestrial grass *Stenotaphrum secundatum* to the former's detriment, while ongoing land-fill, vehicular and pedestrian damage and invasion by mangroves argue against any large-scale spread of saltmarsh. It is more likely the larger area determined by West *et al*. (2004) arose from the enhancement of the API methodology.

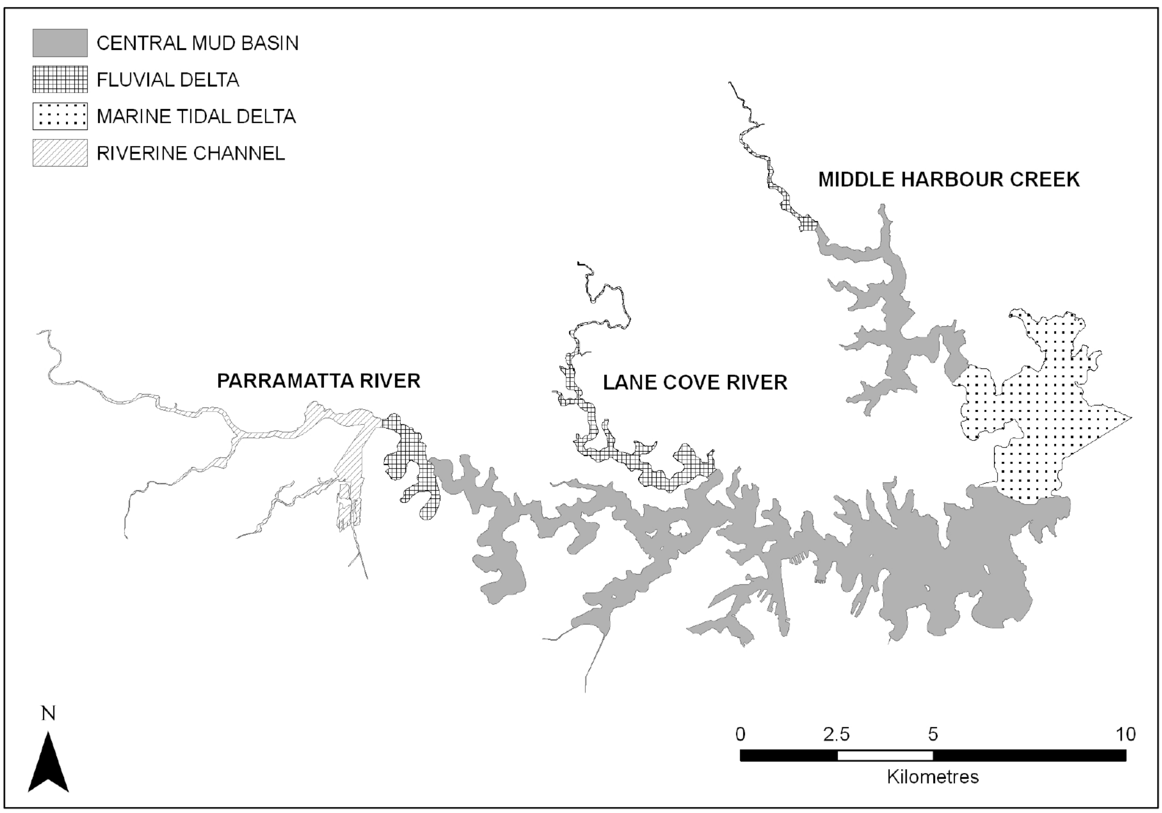

Fig. 1. Geomorphic zones in the estuary of the Parramatta River (after Mesley 2003).

Field survey

Coastal saltmarsh was defined as an intertidal community containing at least one or more of the 'Characteristic Species' listed by the NSW Scientific Committee (2004; Table 1) and/or species listed by Saintilan (2008, Appendix 2.1). Affiliated species observed growing in the intertidal region were also recorded. Elevation in terms of two vertical gradients was estimated.

Lower to middle marsh – growing below to within the tidal debris line (where present), with lowest areas often under the mangrove canopy.

Upper marsh – growing above the tidal debris line (where present), the highest elevation at which saltmarsh plants were observed growing.

It is likely that, particularly in the upper marsh fringe, *Zoysia macrantha* occurs intermingled with *Sporobolus virginicus* at some localities. It is possible, therefore, that some of the records for *Sporobolus virginicus* include *Zoyzia macrantha*, which because of the difficulty in distinguishing it from *Sporobolus virginicus* for most of the year is probably under-recorded in the Sydney region (P. Adam, pers. comm., 2007). Vegetatively the two grasses are very similar and hard to separate except when flowering. Field observations were carried out during the non-flowering season.

A pilot study in mid 2004 on the southwestern side of the estuary refined the method to be used in the pedestrian survey. The foreshore was traversed and each patch of saltmarsh was visited and its shape recorded on a 1: 25 000 topographic map and the approximate dimensions noted. Latitude and longitude were estimated from the topographic maps. Each patch was labeled with an alpha-numeric code in relation to the part of the estuary in which the patch was located. A condition assessment of each patch was made based on visual observation in relation to size, potential for tidal flushing and weediness, and a rating of poor, medium, good or excellent was given. Details on condition are reported in Kelleway *et al*. (2007).

The pilot study located 50 small patches along a 20 km section of foreshore (~6% of total shoreline length – 361 km). West *et al.* (2004) showed 30 patches of saltmarsh for the whole of the estuary; clearly, the pedestrian survey provided a greater level of detail.

The survey was suspended until more detailed 2003 (~150 mm spatial resolution) colour electronic images were obtained. Boundaries of saltmarsh were mapped via onscreen digitising with Arcview version 3.2. To ensure consistent spatial accuracy, all digitising was carried out at an onscreen scale of 1: 700. A presumptive (draft) image was produced from which field maps were printed such that assumed locations could be confirmed in the field.

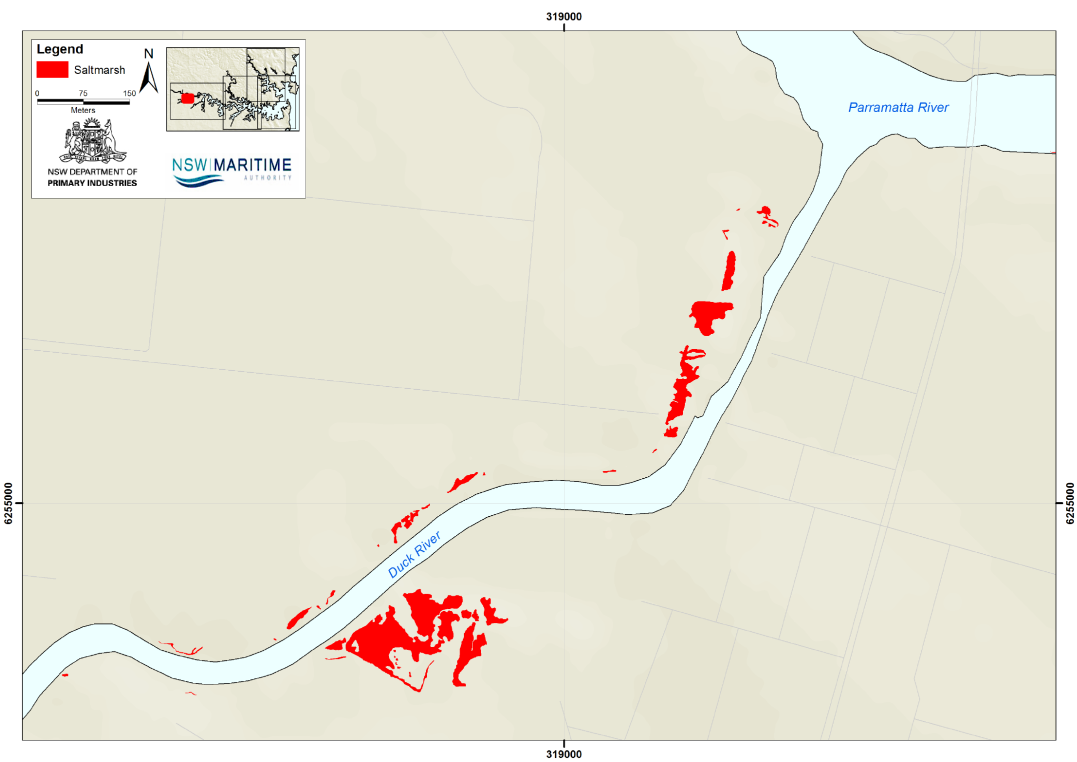

Fig.2. Saltmarsh of the estuary of the Parramatta River, 2005/06: magnification of a portion of the Duck River to provide an example of the detail available in the GIS shapefile generated for this project.

Field inspection was recommenced incorporating a global positioning system (GPS) to derive longitudes and latitudes. Other field observations were made as in the pilot study. Spurious patches were identified. Newly discovered patches too small to be identified in the images and omitted from the presumptive map were sketched to detail shape, size, orientation with GPS location, and proximity to landmarks, and were then digitised in GIS in relation to the 2003 colour imagery. In many cases canopy cover hid the true extent of the patch and so boundaries were modified on field maps as necessary. Twenty six sites were viewed tangentially due to access constraints (e.g. unexploded ordnance at Sydney Olympic Park). Fine-scale details (e.g., shape) were necessarily less well estimated at these locations. No island sites were visited. Edits to field maps were transferred to the presumptive digital image and all relevant data were assembled and cross checked in the GIS database. The area (in m^2) of each patch was calculated and tabulated.

Results

Comparison of API and pedestrian-derived maps

API of the 2003 digital image identified 411 patches of saltmarsh in Parramatta River-Sydney Harbour inclusive of Lane Cove River and Middle Harbour Creek (Table 2). The minimum size of patch in the API analysis was $1.33m^2$. Field inspection revealed 155 (nearly 40%) of the 411 presumptive sites were false positive polygons, being comprised of reedlands (*Phragmites australis* or *Typha* spp.), mud, water, algal mats, lawn or anthropogenic structures. Field inspection of the 256 true patches revealed many were smaller parts of larger patches hidden under mangrove (mainly *Avicennia marina*) canopy. When the appropriate mergers were made, a subtotal of 148 patches was identified. One of these new large patches was an amalgam of 23 smaller patches that had been hidden or appeared to be separated under mangrove canopy. An additional 609 patches were newly discovered, ranging in size from 0.2 m^2 to 0.57 ha. When the appropriate mergers and additions were made, 757 patches were located.

The area determined from the presumptive map was 29.24 ha. Of this, 5.28 ha was incorrect, being that spurious area arising from the false positive polygons. It was then necessary to add the area obscured under canopy, and a subtotal of 29.83 ha was obtained. The area of the 609 newly discovered polygons was 7.43 ha, making a total area of 37.26 ha (Table 2). The field survey not only made a substantial contribution to the number of patches and the total area by eliminating falsely identified saltmarsh patches, but also by amalgamating patches that appeared to be disjunct, and by discovering many new, mostly very small, patches. Hence, the first null hypothesis was rejected.

Intensive field survey also discovered saltmarsh growing in non-typical areas (i.e., other than creek flats and heads of embayments). More specifically, saltmarsh was found on intertidal rock platforms in the bays and headlands of the lower estuary, particularly North Harbour. It was on this rock habitat that three previously unknown occurrences of the Vulnerable *Wilsonia backhousei* were located.

Figure 2 is from the final map and provides an example of the distribution of patches of saltmarsh of various sizes. An analysis of patch size in relation to connectivity, the ability of different technologies and imagery to find saltmarsh, and sea level monitoring implications is being conducted separately (Allen & Williams in prep.).

Distribution of saltmarsh in geomorphic zones

Parramatta River, relative to the Lane Cove River, Middle Harbour Creek and Sydney Harbour, supports the most numerous and extensive patches of saltmarsh: 461 patches (61% by number), 29 ha (78% by area) (Table 3). Most of the patches (60%), as well as most of the area (76%), are located in the most upstream Riverine Channel geomorphic zone of the Parramatta River, followed by downstream zones Fluvial Delta and Central Mud Basin. The fewest patches

Table 2. Stage by stage output from the mapping process for Parramatta River-Sydney Harbour estuary (2005/06) beginning with the presumptive saltmarsh map (API) and subsequent maps derived from the pedestrian survey by removing spurious patches, merging obscured patches, and then adding newly found patches of saltmarsh.
= contiguous presumptive (256) polygons split by canopy cover merged into (148) whole polygons
* = additional 5.88 ha obscured (by canopy) in API

Stage of map production	Operation	Count of polygons	Area of polygons (ha)	Estimated analytical and field time (person days)
1st stage	Produce API presumptive map	411	29.24	5
2nd stage	Identify spurious polygons on presumptive map	-(155)	-(5.28)	15
3rd stage	Remove spurious polygons	256	23.95	1
4th stage	Merge polygons partially obscured	148#	29.83*	1
5th stage	Add new polygons observed during pedestrian survey	609	7.43	20
6th stage	Final map	757	37.26	42

Table 3. Number and area of saltmarsh patches in the Parramatta River-Sydney Harbour estuary by geomorphic zone, 2005/06.

Upstream → → → → Downstream

Geomorphic zone	**Riverine Channel**			**Fluvial Delta**				**Central Mud Basin**			**Marine Tidal Delta**	**Total (all zones)**
	Entire zone	Parramatta River Sub-catchment	Middle Harbour Creek Sub-catchment	Entire zone	Parramatta River Sub-catchment	Lane Cove River Sub-catchment	Middle Harbour Creek Sub-catchment	Entire zone	Parramatta River Sub-catchment	Middle Harbour Creek Sub-catchment	Entire zone	
Patch count (% of total count)	442 (60%)	442	0	201 (25%)	22	123	56	100 (14%)	78	22	14 (1.9%)	757 (100%)
Area (ha) (% of total area)	28.28 (76%)	28.73	0.00	7.34 (20%)	1.84	3.39	2.12	1.61 (4%)	0.62	0.99	0.04 (0.1%)	37.26 (100%)

(14) and smallest area (0.04ha) were found in the Marine Tidal Delta. This clear decrease in the number and size of patches towards the seaward zones, caused the second null hypothesis, that species of saltmarsh would be uniformly located throughout the estuary to be rejected. The absence of saltmarsh in the Riverine Channel of Middle Harbour Creek is presumably related to the small size of this zone in the incised bedrock. The equivalent zone in Lane Cove River has been extinguished by the placement of a weir and therefore contains no saltmarsh.

The count of patches showed that 70% were less than 100m^2 in area, with 38% less than 10m^2 (Table 4). In contrast, six patches greater than one hectare in size accounted for 41% of the total area; all were located on the southern shore, with four of them in the Sydney Olympic Park complex. “Sensitive” species were found in all size categories, but with a bias to the four middle size classes, particularly in the Riverine Channel (Table 4).

Distribution of saltmarsh species

Overall 29 native plant species were recorded in the 757 patches of saltmarsh of the Parramatta River-Sydney Harbour estuary. However, the number of species in each zone varied: 13 in the Riverine Channel, 11 in the Fluvial Delta, 10 in the Central Mud Basin, and six in the Marine Tidal Delta. Six were found in all geomorphic zones (Table 5). The Chenopods *Suaeda australis* (409 patches) and *Sarcocornia quinqueflora* (366 patches) occurred most commonly but were not found in the Marine Tidal Delta. Four other common species, *Tetragonia tetragonioides, Juncus kraussii, Sporobolus virginicus* and *Samolus repens* and two less common, *Baumea juncea* and *Ficinia nodosa,* were found in all zones. Occurrences for three of the latter four common species decreased downstream; the exception being *Samolus repens*, which was notably more prevalent in the Fluvial Delta. *Baumea juncea* was also more common in the Fluvial Delta and dominant at lower marsh elevations. *Tetragonia tetragonioides* grew almost exclusively in the higher marsh but was rarely extensive in any patch. The rush *Juncus kraussii* was more common in the Riverine Channel and Fluvial Delta than elsewhere and was dominant at upper marsh elevations. The most downstream geomorphic zone, the Marine Tidal Delta, had the fewest native species and was dominated by *Ficinia nodosa* and *Sporobolus virginicus.*

In the Georges River study, Pickthall *et al*. (2004) considered a number of saltmarsh species to be “sensitive” in conservation terms due to their apparent rarity and/or decline in the Sydney metropolitan region. We recorded five of these species in the Parramatta River-Sydney Harbour estuary: *Wilsonia backhousei, Lampranthus tegens*, *Halosarcia pergranulata* subsp. *pergranulata* , *Selliera radicans* and *Leptinella longipes* (Table 5).

The extensive Chenopod-dominated marshes of the Riverine Channel were the sites where patches of *Lampranthus tegens*, *Tecticornia pergranulata* subsp. *pergranulata*, and *Selliera radicans* were located exclusively. *Wilsonia backhousei* occurred more widely, but *Leptinella longipes* was only found in the Fluvial Delta. *Gahnia filum*, a species with limited distribution in the Sydney metropolitan region (P. Adam, pers. comm. 2007) was not found during this survey. The count of patches with "sensitive" species showed that 36% were less than 100m^2 in area, with 19% less than 10m^2 (Table 4).

Frequency of the sensitive species varied with patch size. Of the four species located exclusively in the Riverine Channel, *Lampranthus tegens* was found across a range of patch sizes as small as 1–10m^2, while *Halosarcia pergranulata* subsp. *pergranulata* and *Selliera radicans* were very rare and only recorded in one patch (0.1–1ha in size) (Figure 3a). Most of the *Wilsonia backhousei* (29 of 33 stands) was in the Riverine Channel but it was rare in patches less than 100m^2. There was also one stand in the Fluvial Delta (Figure 3b) and three stands in the Central Mud Basin (Figure 3c). The latter were small patches, growing high up on intertidal rock platforms, as opposed to the meadow-like stands found in the Riverine Channel and Fluvial Delta. *Leptinella longipes* was found only in the Fluvial Delta, and only in patches in the 10–1000 m^2 size categories (Figure 3b). Generally the sensitive species (except *Lampranthus*) were found in patches greater than 100 m^2; edge effects, overshading by taller species, and competition probably make smaller patches less suitable.

Some of the less frequent native species are not obligate saltmarsh species and can also be found in a range of habitats away from coastal saltmarsh, for example *Gahnia sieberana* and *Alisma plantago-aquatica* are also found in freshwater environments, and *Atriplex australasica* is found in inland NSW as well as scattered coastal locations (P. Adam, pers. comm. 2007). *Bacopa monniera*, while not a "true" species of saltmarsh plant may be found in brackish reaches of estuaries; in Sydney it approaches its global southern limit (P. Adam, pers. comm. 2007) (Table 5).

The occurrence of other native species immediately adjacent to saltmarsh assemblages was noted (Table 6). These plants favoured an upstream distribution, with five species found in the Riverine Channel, six in the Fluvial Delta, five in the Central Mud Basin and one in the Marine Tidal Delta. *Phragmites australis* and *Cynodon dactylon* were the most common of these species.

There were 17 exotic species associated with the saltmarsh of the Parramatta River-Sydney Harbour (Table 7). The prevalence (89 locations) of *Juncus acutus* was of great concern as it was sometimes observed to occur in dense aggregations, often in the larger patches of saltmarsh.

Table 4. Size categories of all patches of saltmarsh and those in which conservation sensitive species are found.

Saltmarsh species	< 1 m^2	1–10 m^2	10–100 m^2	100 m^2–0.1 ha	0.1–1 ha	1–3 ha	Total
No. of all saltmarsh patches of the given size							
Riverine Channel	9	141	146	104	37	5	**442**
Fluvial Delta	12	68	62	45	13	1	**201**
Central Mud Basin	11	38	33	15	3	0	**100**
Marine Tidal Delta	2	7	4	1	0	0	**14**
Total	**34**	**254**	**245**	**165**	**53**	**6**	**757**
Cumulative total	**34**	**288**	**533**	**698**	**751**	**757**	
% Cumulative	**4%**	**38%**	**70%**	**92%**	**99%**	**100%**	
Total Area m^2 (%) of Total Area	**24 (0.01)**	**1255 (0.3)**	**9567 (2.6)**	**54327 (15)**	**153416 (41)**	**154036 (41)**	**372625 (100)**
Occurrences of "sensitive" species							
Riverine Channel	0	19	13	27	15	5	**79**
Fluvial Delta	0	0	3	2	1	0	**6**
Central Mud Basin	1	2	0	0	0	0	**3**
Marine Tidal Delta	0	0	0	0	0	0	**0**
Total	**1**	**21**	**16**	**29**	**16**	**5**	**88**
Cumulative total	**1**	**22**	**38**	**67**	**83**	**88**	
% Cumulative	**1%**	**25%**	**43%**	**76%**	**94%**	**100%**	

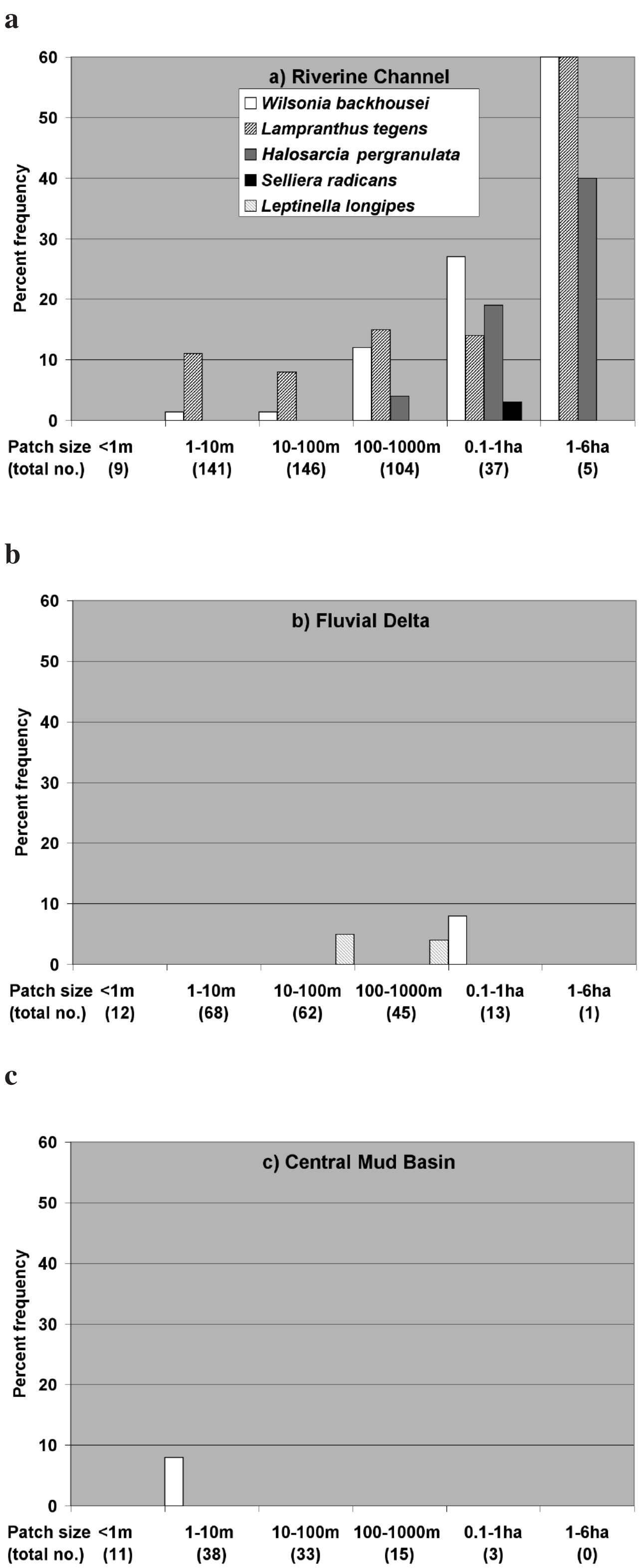

Fig. 3. Distribution of 'sensitive' saltmarsh species in Parramatta River-Sydney Harbour estuary (2005/06) in **a)** Riverine Channel (most upstream geomorphic zone), **b)** Fluvial Delta and **c)** Central Mud Basin.

The fact that it was concentrated in the Riverine Channel may indicate a physiological dependency, and this may be instructive in regard to its future management. Other exotic species appeared to favour upper estuarine locations and on the basis of these differential distributions, the third null hypothesis was rejected. The abundance of *Protasparagus aethiopicus* in the Fluvial Delta, and its distribution as the only weed species recorded from all zones, indicates the serious weed potential of this species. It has expanded considerably in abundance around the foreshores of Sydney Harbour and Pittwater in the last 30 years, in a range of sites but particularly in relatively undisturbed foreshore and bushland sites (D. Benson, pers. comm. 2010).

Discussion

Improvement in Air Photo Interpretation techniques

Over the past three decades there has been a progressive improvement in API techniques used to determine the extent of NSW estuarine vegetation. West *et al*. (1985) were limited to black and white air photos taken at a scale (1:16,000) that imposed limitations in finding small patches. West *et al*. (2004) were able to use 1:16,000 colour digital images, and undertook on-screen digitising at 1:1,500 scale, meaning that spatial resolution was of the order of 150mm (whereas for West *et al*. (1985) it was of the order of 2m). An increase in spatial resolution of airphotos enabled a 15 fold increase in number of patches in the latter study (from three to 30 patches) and a modest increase in the area of those patches (from 7.3 to 9.6 ha) (Table 8). Even with this enhancement in resolution, small patches of saltmarsh (in the order of 100m^2 or less) could not be identified.

The pedestrian survey in this study showed a 17-fold increase in number of patches (from 45 to 757), and a four-fold increase in area (9.6 ha to 37.3 ha) (Table 9). However, though the total area (37.3 ha) of saltmarsh found along the Parramatta River is substantially larger than revealed by previous studies, 99% of patches were less than one hectare in area, with 70% of the total being less than 100m^2 (Table 6). Only six patches greater than one hectare were identified. Ownership of these large patches is in the public domain (Kelleway *et al*. 2007), but management responsibility between government agencies for these, as well as the hundreds of other patches, requires further resolution.

This study also highlights discrepancies between three levels of pedestrian survey, any one of which must complement API. The lowest level of ground-truth, in which spurious patches are located and removed from a presumptive map, can only be considered appropriate if the objective of a mapping exercise is to generate a first approximation of the presence of saltmarsh, or if there is a need to clarify distributional data presented on other maps (e.g., West *et al*. 1985, West *et al*. in prep.). This approach eliminates false

Table 5. Number of occurrences of native species in saltmarsh patches in the Parramatta River-Sydney Harbour, 2005/06, by geomorphic zone. Most frequent species in each zone is in bold.
*=Species considered "Sensitive" in conservation terms.

Family	Species	"Sensitive"	Riverine Channel	Fluvial Delta	Central Mud Basin	Marine Tidal Delta	Total
Chenopodiaceae	*Suaeda australis*		**324**	54	31	0	409
Chenopodiaceae	*Sarcocornia quinqueflora*		**266**	53	**47**	0	366
Aizoaceae	*Tetragonia tetragonioides*		**201**	84	34	4	323
Juncaceae	*Juncus kraussii*		108	**104**	**49**	3	264
Poacae	*Sporobolus virginicus*		113	87	37	**8**	245
Primulaceae	*Samolus repens*		52	**113**	29	2	196
Chenopodiaceae	*Atriplex prostrata*		111	26	24	0	161
Juncaginaceae	*Triglochin striatum*		46	29	13	0	88
Cyperaceae	*Baumea juncea*		1	36	8	1	46
Cyperaceae	*Ficinia nodosa*		9	5	14	**11**	39
Chenopodiaceae	*Atriplex australasica*		23	10	0	0	33
Convolvulaceae	*Wilsonia backhousei*	*	29	1	3	0	33
Asteraceae	*Cotula coronopifolia*		11	3	4	0	18
Cyperaceae	*Isolepis cernua*		1	0	6	0	7
Amaryllidaceae	*Crinum pedunculatum*		0	2	2	0	4
Chenopodiaceae	*Atriplex semibacatta*		2	1	0	0	3
Cyperaceae	*Isolepis inundatus*		0	2	1	0	3
Lomandraceae	*Lomandra longifolia*		2	0	1	0	3
Juncaceae	*Juncus usitatus*		2	0	1	0	3
Scrophulariaceae	*Bacopa monniera*		1	0	1	0	2
Species restricted to one geomorphic zone							
Aizoaceae	*Lampranthus tegens*	*	50	0	0	0	50
Cyperaceae	*Bolboschoenus caldwellii*		14	0	0	0	14
Chenopodiaceae	*Halosarcia pergranulata* subsp. *pergranulata*	*	13	0	0	0	13
Asteraceae	*Leptinella longipes*	*	0	5	0	0	5
Cyperaceae	*Cyperus laevigatus*		0	0	2	0	2
Alismataceae	*Alisma plantago-aquatica*		2	0	0	0	2
Cyperaceae	*Fimbristylis ferruginea*		1	0	0	0	1
Juncaceae	*Juncus bufonius*		1	0	0	0	1
Cyperaceae	*Gahnia sieberana*		0	1	0	0	1
Goodeniaceae	*Selliera radicans*	*	1	0	0	0	1
Number of saltmarsh patches			**442**	**201**	**100**	**14**	**757**
Number of species	**30**	**5**	**25**	**18**	**19**	**6**	

positive patches (e.g., bare mud, freshwater reedlands, water, grasslands and anthropogenic structures) from preliminary map products and can substantially reduce API estimates of cover, but, while relatively inexpensive in terms of person days (Table 2), this method does not join patches in aerial photographs that appear disjunct due to canopy cover, nor does it locate medium and small size patches.

A higher level of fieldwork is necessary to show where mangrove or other canopy covers saltmarsh. That API was unable to determine understorey features was evidenced by the large number of patches (64%) that were growing completely or partially under canopy predominantly of mangrove, but also of swamp-oak and eucalypt canopies (Allen & Williams in prep.). In this study these areas are considered to increase the actual area of existing saltmarsh, but they may in fact also be areas of saltmarsh that have been recently invaded by mangroves, and ultimately, through shading and competition result in the loss of the saltmarsh species at these sites. These sites may provide warnings of future saltmarsh loss and the dynamics of species there should be further studied.

An even greater intensity of fieldwork will also increase resolution of the total number of patches in the estuary as well as the distribution of small patches that contain sensitive species (Table 4). Intensive field survey resulted in the discovery of saltmarsh growing in non-typical sites such as intertidal rock platforms; on these platforms three previously unknown occurrences of the listed Vulnerable species *Wilsonia backhousei* were located. The limited distribution of plants such as *Selliera radicans* might make it a candidate for a higher conservation status than it currently holds. We therefore advocate that the objectives of a mapping exercise must be clearly stated and the fieldwork geared to meet the objective. Ideally, high order ground truth exercises would include an inventory of species in each patch.

As remote sensing techniques evolve, it is likely the number of patches and total area of saltmarsh will be able to be tracked more efficiently. In future it will therefore be necessary to differentiate between increases in cover that come about from expansion of distribution, rather than by improvements in mapping methods. If this distinction is not made clear it is inevitable that erroneous conclusions might be drawn about "expansion" of saltmarsh when in fact addition resolution has been provided.

Saltmarsh distribution in Parramatta River-Sydney Harbour compared with Georges River

Both Sydney Harbour and the Georges River are drowned river valleys, and both systems include saltmarsh dominated by the subshrub *Sarcocornia quinqueflora* and grasslands of *Sporobolus virginicus*. In the former estuary *Wilsonia backhousei* was located primarily in the Riverine Channel (Table 5), a finding that parallels that of Pickthall *et al.* (2004). Similarly, *Selliera radicans* was only found in the upper estuary in both studies. The factors controlling the distribution of the rarer species may also be at play in determining the distribution of the introduced weed *Juncus acutus* as it also appears constrained to the brackish portions of both Sydney Harbour (Table 8) and the Georges River (Pickthall *et al.* 2004).

Even though adjacent, there are some notable differences between these estuaries. *Juncus kraussii* was more prevalent in the Georges River, being found at 51 of 70 sites (73%) with intertidal vegetation (Pickthall *et al.* 2004), while we found it at 264 sites out of 757 patches of saltmarsh (35%) in the Parramatta River (Table 5). Part of the explanation might be the greater resolution of our study, but *Juncus kraussii* grows at a high elevation in the tidal plain; in the Parramatta River it grew at a region most likely to have been lost to land reclamation and infilling. Alternatively the impact of freshwater floods that occur in the Georges River but not in the Parramatta River (which has a relatively small catchment), may maintain areas of brackish water suitable for this species.

The total area of saltmarsh in Parramatta River-Sydney Harbour (37 ha) is small compared to the Georges River-Botany Bay system (153 ha – Pickthall *et al.* (2004)) even though its shoreline length is distinctly shorter than that of the former. One possible reason for this is that shallow tidal flats as at Towra Point (now reserved as a Nature Reserve) are absent from the analogous part of Sydney Harbour. These distributional differences suggest that local sedimentary environments (determined by geomorphology) are important factors controlling the distribution of estuarine saltmarsh.

The geomorphic stratification of an estuary (*sensu* Roy 1984) applied in these studies can be readily applied to other NSW estuaries using aerial photographs, topographic maps and bathymetric contours, and if necessary can be confirmed with sediment sampling. Geomorphic zones so established can be used to test hypotheses about extent of cover and species composition, and to initiate distribution modelling. Zones can be used to stratify searches for selected species in unsurveyed estuaries, be applied in conservation management to control access, and be used to initiate the rehabilitation of degraded sites.

Saltmarsh in Parramatta River-Sydney Harbour

At the species level, differences in distribution within the estuary of the Parramatta River can be related to estuarine geomorphology. Marine Tidal Delta facies are comprised of calcareous sands of marine origin (Roy 1984). The Riverine Channel sediments are terrestrial alluvium derived from Hawkesbury Sandstone and Wianamatta Shale (Chapman & Murphy 1989). Fluvial Delta sediments will be similar to those of the Riverine Channel, whereas facies at the shoreline of Central Mud Basin environments will be marine sand at the downstream end and fluvial material upstream. How these different types of sediments affect the ecology of individual saltmarsh species is unknown; further distributional surveys, as well as manipulative experiments, are needed.

A factor that has modified the distribution of saltmarsh through its prehistory is the level of the sea. Over the past two and a half million years (Pleistocene era) sea level has risen and fallen many times of the order of 120–130m at intervals of roughly 100,000 years. Hence the valley of the Parramatta River has been regularly flooded and emptied of seawater, and the estuary is considered a drowned river valley (Roy 1984, Roy *et al*. 2001). Twenty thousand years ago, just prior to the most recent melting of the polar ice-caps, what we view today as the estuary was a small freshwater creek at the bottom of a sandstone gorge, and the estuarine section of the river and its associated vegetation was relocated some kilometres further east. As sea level rose and then stabilised about 6,000 years ago, new foreshore features were established. Seagrass colonised sandflats that had been deposited on slopes where terrestrial plants once grew, and mangrove and saltmarsh appeared on the tidal fringes. As this cycle has been repeated many times there is an implication that at least some species of saltmarsh have robust survival features. That saltmarsh appears to have recently colonised newly available substrata in at least one new location – Wentworth Point, reinforces this survival capacity. The Point was highly modified by land reclamation between the 1930s and 1970s (Rogers *et al*. 2005), but saltmarsh has established in locations not previously recorded (S. Paul, pers. comm. 2005).

Colonial settlement along the Parramatta River from the early 1800s brought clearing in the catchment, extraction of freshwater, emplacement of tidal barriers, discharge of effluent, and most importantly, reclamation of tidal wetlands. Historical studies (McLoughlin 1987, 2000, 2002), suggest that saltmarshes were extensive in the upper Parramatta River and much of the central part of the estuary that would have once supported extensive mudflats and saltmarshes has been infilled, with seawalls currently lining much of this shoreline. Sydney Harbour, the lower portion of the estuary, has the longest history of urbanisation and the smallest amount of saltmarsh. It is within this area that the earliest infilling of tidal land began. In places such as Rushcutters Bay no saltmarsh currently exists, despite the historical implications of its name. Foreshore reserves, including Lane Cove and Garigal National Parks, now protect small areas of saltmarsh along Lane Cove River and Middle Harbour, respectively.

Many of the present day saltmarshes of the Parramatta River are highly fragmented, evidenced in part by the large number of small patches recorded throughout the estuary. Fragmentation has resulted from structures such as seawalls and levees, from reclamation of land for residential and industrial purposes, and from the expansion of mangrove stands. As a result, the habitat potential of saltmarsh for many species of fauna, including snails, crabs, fish, birds and mammals will have been reduced (Laegdsgaard 2006).

The spread of the introduced Sharp Rush *Juncus acutus* is of major concern in the Parramatta as well as Georges River estuaries. Clarke and Hannon (1967, 1969, 1970, 1971) did not note its presence in the Sydney metropolitan region, nor did Clarke and Benson (1987) find it in the Lane Cove River. Kelleway *et al*. (2007) did not find it in Lane Cove River, but located it at 89 other locations in the upper river and along the southern shore including Homebush Bay. *Juncus acutus* was recorded at the latter location some decades ago (Clarke and Benson 1988). This weed should be contained, and future management should also deal with continued disturbances caused by unauthorised access and recreational use of saltmarsh.

The policy implications arising from the NSW *Threatened Species Conservation Act* require that all patches of coastal saltmarsh be located, and that the species within each patch are properly identified. Surveys based on API with limited ground truth do not achieve these ends but are useful for the monitoring of large-scale distribution and large-scale changes in cover. Not surprisingly, intensive pedestrian survey provides a better understanding of extent of cover, species composition and condition. Once fine-scale inventories of these features are established, they need to be repeated on a short-term basis to establish small scale temporal variability. Some progress has been made in developing cost-effective methods by which to undertake temporal assessments (e.g., Sainty & Jacobs 1997, Kessler 2004, 2006).

As a final note, while the generic term "coastal saltmarsh" has some value, it should be used only in limited circumstances. Saltmarshes are complex environments that require detailed levels of understanding of their distributional and assemblage characteristics to achieve management ends.

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Table 8. Comparison of specifications of three mapping studies of the cover of saltmarsh in the estuary of the Parramatta River-Sydney Harbour.

Study	Photo run	Airphoto type	Analytical technique	Air photo resolution	Date of field validation	Ground truth technique	Patch number	Area (ha)
West *et al*. (1985)	1978	Black and white contact prints	Analog (*Camera lucida*)	2000 mm	Jan. 1981	Boat survey	3	7.3
West *et al*. (2004)	2000	Colour contact prints	Digital (GIS)	300 mm	Dec. 2002 & Jan. 2003	Boat survey	30	9.6
This study	2003	Digital images	Digital (GIS)	150 mm	Sept. 2005 to June 2006	Pedestrian survey – removal of spurious patches	148	29.8
					Sept. 2005 to June 2006	Pedestrian survey – addition of newly discovered patches	757	37.3

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