MANGROVES AS SUCCESSIONAL STAGES ON THE HAWKESBURY RIVER

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ABSTRACT

The mangrove environments of the Hawkesbury River estuary, New South Wales, are described in relation to the geomorphic units of the marine and fluvial segments of the river. A model of seral succession is presented which sees mangrove environments replaced with saltmarsh and *Casuarina* associations with continued progradation during the Holocene stillstand. Preserved mangrove peats beneath the *Juncus kraussii* plains of Mangrove Creek, a tributary of the Hawkesbury, are presented as evidence supporting this model. Recent expansion of mangroves into the saltmarsh is therefore contrary to the longer-term successional trend of the Holocene.

INTRODUCTION

Mangroves and saltmarsh form shore-parallel zonations over broad geographical regions (Chapman 1974). The same zonation is also evident in tidal flats from the mouth to the headwaters in many estuaries, with intertidal flats at the seaward end of the estuary dominated by mangroves, with an increasing representation of saltmarsh in successive flats headward through the estuary until floodplains emerge above tidal elevations and saltmarsh gives way to *Melaleuca* or Eucalypt forest.

Pidgeon (1940) was the first to suggest that this spatial zonation reflected a temporal seral progression, which saw saltmarsh replace mangroves following substrate accretion. This model was followed by Chapman (1974) though more recently has been questioned by Mitchell and Adam (1989a) who failed to find evidence of succession in stratigraphic cores from the Georges River.

The diversity of intertidal environments within the Hawkesbury River estuary make an ideal setting for the study patterns in mangrove and saltmarsh distribution. The size of the estuary and the intermediate stage of infill (Roy 1984, 1994) allow a comparison of environments extending from point bars of the fluvial, upstream segment of the estuary to the tidal delta sand flats of the Broken Bay mouth. In particular a clear succession of point bars of successively increasing elevation extend headward through the estuary. These point bars are occupied by mangroves seaward and saltmarsh/*Casuarina* headward.

METHODS

(i) The Study Site

The Hawkesbury River is a large drowned river valley immediately to the north of Sydney and receives an even distribution of rainfall throughout the year. Recent authors studying the Hawkesbury River Estuary have divided the estuary into three zones, on the basis of salinity (Jones *et al.*1986, Gray *et al.* 1990) or on the basis of substrate texture, process and morphology (Roy 1984, Nichol *et al.* 1997). Though not identical, the zones nominated by these authors generally concur, consisting of a marine,central and freshwater section (Figure 1). The intertidal environments within the marine zone consist predominantly of marine sands (Roy 1994) where salinities are consistently at seawater concentrations (Gray *et al.*1990). The central zone, a zone of mixing of fluvial and marine discharge, is variable in salinity (Gray *et al.*1990) and contains the seawardly prograding fluvial delta (Roy 1984) of terrigenous sands with muddy intertidal flats. The freshwater zone is normally fresh, though experiencing occasional saltwater intrusion (Gray *et al.* 1990) and dominated by terrigenous sands extending to the tidal limit near Richmond, 105 km from the mouth.

(ii) Vegetation survey

The mangrove environments of the Hawkesbury River have been surveyed using 23 transects through tidal flats

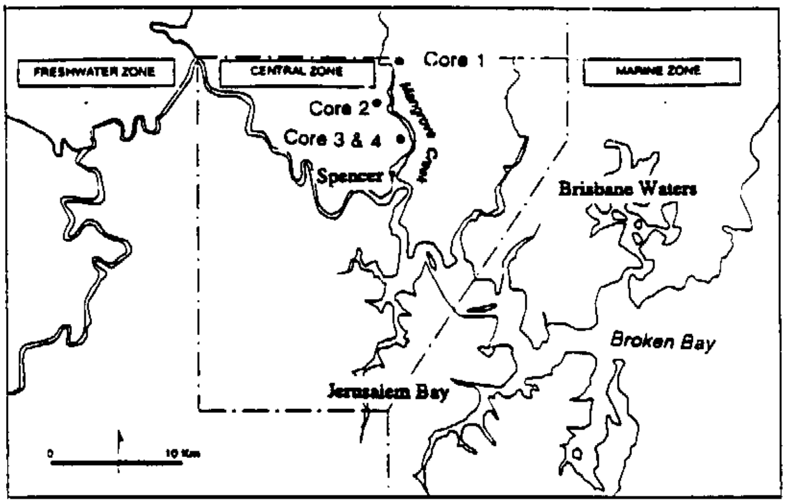

Figure 1. Location of hydrological zones and core samples on the Hawkesbury River Estuary

representative of each geomorphic unit (Saintilan 1986) and mapping from the 1984 Coastal Wetland Series air photographs (Saintilan 1995). Air photographs of the river from 1947 (NSW Department of Land and Water Conservation historical collection) were also used to determine patterns in vegetation dynamics.

Schematic transects have been drawn on the basis of these surveys and represent the most common geomorphic units identified on the river.

(iii) Stratigraphic analysis

Cores were dug in supratidal flats within Mangrove Creek (Figure 1), to a depth of 0.5m using a shovel and to a further 1.2m using a hand auger, to determine whether mangrove peats could be found beneath the *Juncus kraussii/Casuarina glauca* association.

RESULTS

(a) Description of intertidal environments in the marine and central zones.

Within each zone of the Hawkesbury River estuary, mangrove assemblages are closely related to habitat types, the occurrence of which may be linked to geomorphic units of common origin. This provides a framework for an understanding of patterns of mangrove distribution and vegetation dynamics.

1. The marine mouth

The Hawkesbury River flows into Broken Bay, a steep-walled embayment of Mesozoic sandstone. The bay is protected by headlands from the full impact of ocean waves, though it is dominated by diffracted and refracted ocean waves, and locally generated wind waves to the extent that quiescent tidal flats occur only in protected tributary bays and within small barrier estuaries at the mouth of the larger estuary.

(i) The Flood-tide Delta

Transgressive marine sands up to 25m thick fill the Brisbane Water valley to the north of Broken Bay, forming an extensive barrier system at Woy Woy (Thom *et al.* 1978) and intertidal flood tide deltas colonised by mangroves, saltmarsh and *Casuarina glauca* Sieber ex. Spreng.

Brisbane Water is a large barrier estuary with a restricted entrance channel (the Rip) and tidal amplitude is correspondingly small (approx. 100 cm, Manly Hydraulics Laboratory 1992). The deltas are composed of well-rounded fine to coarse-grained sand with variable amounts of shell detritus.

(ii) Fluvial Sand Deltas.

Small tributary creeks feeding tributaries into the lower Hawkesbury commonly form sandy deltas at their mouths. The quartz-rich nature of this sand reflects the sandstone composition of their catchments. Substrates are correspondingly infertile, though often tributaries to the south have nutrient additions from treated sewerage effluent and urban storm-water runoff.

Tidal amplitudes are higher than in barrier estuaries, and clear zonations exist at Jerusalem Bay (Figure 1) between a lower zone of *Avicennia marina* and stunted *Aegiceras corniculatum*, to an upper tidal bare zone and a landward zone of *Casuarina glauca* (Figure 2).

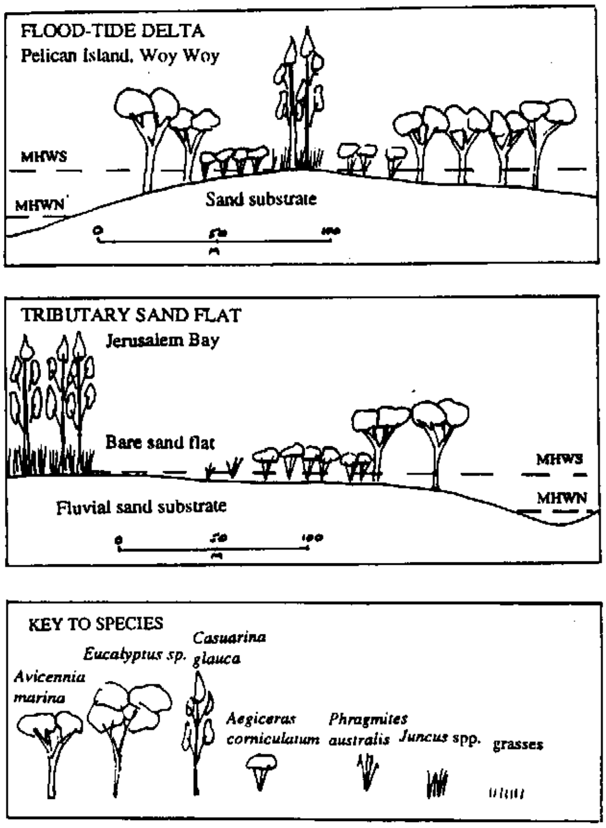

Figure 2. Schematic cross-sections of the geomorphic mangrove units of the marine zone.

2. *Central zone*

Terrigenous floodplain and levee deposits occur above high tide level in the upper central zone. They form wide intertidal point bars in the lower central zone and subaqueous point bars in the marine zone as the fluvial mud-sand unit progrades toward the mouth of the estuary. The decreasing elevation of channel-fringing flats on the lower Hawkesbury has been noted by Hickin (1970) who recognised a continuum between the floodplain terraces in the freshwater and upper central zones and the wide intertidal point bars of the lower central zone such as occur at the junction of the Hawkesbury River and Mangrove Creek.
Downstream progradation of the fluvial delta and associated estuarine and channel sedimentation in the Hawkesbury has led to the formation of four major settings for mangrove colonisation within the central zone of the estuary.

(i) Young Tidal Flats

Flats recently accreted to intertidal elevations occur at a number of locations in the central zone, including intertidal bars seaward of the extensive, older deposits at the junction with Mangrove Creek (Figure 3).

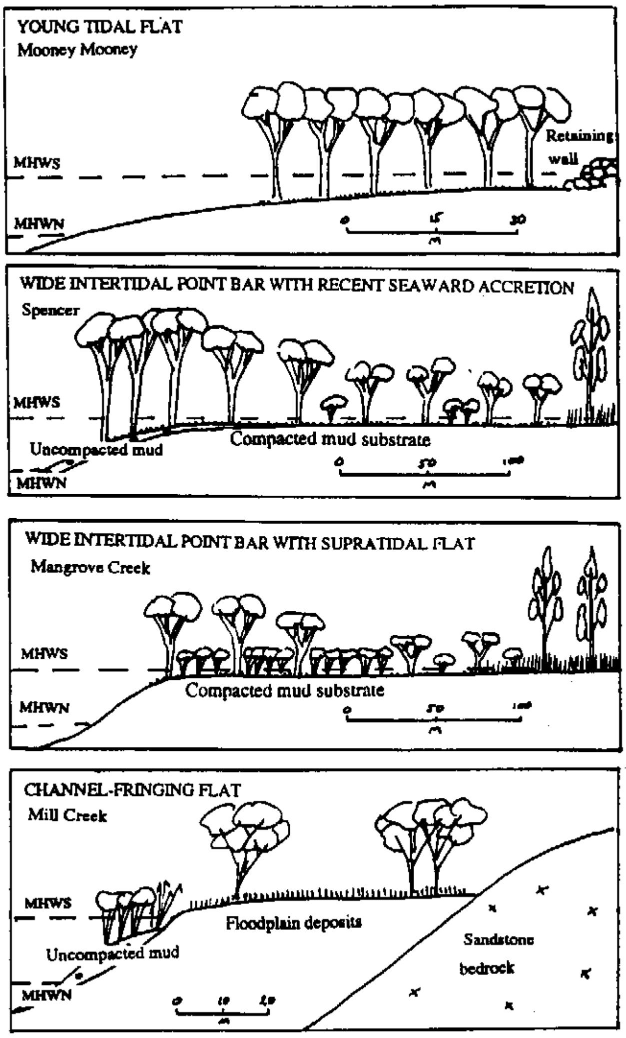

Figure 3. Schematic cross-sections of the geomorphic mangrove units of the central zone.

(ii) Wide Intertidal Point Bars with adjacent Channel-fringing Flats.

Wide upper-tidal point bars are common at the junction of the Hawkesbury River and Mangrove Creek and carry the largest area of mangroves.. Vertical accretion over these flats appears to be slow, the substrate is compacted and colonised by stunted individuals of *Avicennia* and *Aegiceras* with an open canopy. Upper tidal and supratidal flats occur immediately landward and upstream of the wide intertidal point bars on the Hawkesbury River and Mangrove Creek, and are colonised by *Juncus kraussii* and *Casuarina glauca* (Figure 3).

Geomorphic Unit	Substrate	Source of Groundwater	Salinity	Soil Water Content	Vegetation Assemblage
Floodplain-fringing flat	Fine sands and muds. Flood deposits	Mixture of brackish riverwater and freshwater seepage	Brackish to saline depending on degree of freshwater intrusion	Waterlogged most of the time	*Avicennia marina. Aegiceras corniculatum*
Wide intertidal-supratidal flat	Fine muds. Tidal sediments	Recharged daily to fortnightly at levels up to MHWN & MHWS respectively	Evaporation develops a gradient of saline to hypersaline landward	Waterlogged most of the time. Poorly drained	Seaward: *Avicennia marina, Aegiceras corniculatum.* Landward: *Juncus spp. C glauca.*
Young tidal flat.	Fine muds. Tidal sediments	Recharged with saline estuarine water by MHWN tides	Saline soil water	Constantly waterlogged	*Avicennia marina.*
Flood-tide delta	Marine sands and organic muds	Recharged daily to fortnightly by marine water	Saline marine water occasionally and briefly diluted by rainwater	Waterlogged during high tide, drained during ebb tide.	*Avicennia marina.* (seaward) *Aegiceras corniculatum* (landward)
Tributary sand flat	Fluvial sands, silts and organic muds	Recharged daily to fortnightly by marine water often diluted by storm discharge	Saline marine water occasionally diluted by freshwater seepage, percolation and discharge	Waterlogged during high tide, drained during ebb tide	*Avicennia marina. Aegiceras corniculatum*

Table 1. Soil properties and vegetation assemblages associated with geomorphic units on the Hawkesbury River.

More recent sediment may occur as lateral accretions adjacent to these flats. The sediment was mainly deposited in the previous four decades, judging by air photographs. These deposits are nutrient rich (Gardiner 1993) and support a tall closed forest of *Avicennia marina.* An landward extension of mangroves into bare upper-tidal and saltmarsh environments is also evident in a comparison of 1947 photographs with contemporary surveys.

(iii) Wide Intertidal Point Bars with Supratidal Flats.

Point bars elevated to supratidal levels are colonised by *Juncus* and *Casuarina* in their natural state, though vegetation within the main channel may be altered for agricultural purposes. Levee deposits may fringe these flats, and coarse brackish sands allow for the growth of tall communities of *Avicennia marina* and *Aegiceras corniculatum*, with *A. corniculatum* growing as a single-stemmed tree in some locations (Figure 3).

(iv) Floodplain-fringing Flat

Narrow strips of mangroves occur on the seaward edge of many upper-estuary point bars, which are otherwise above tidal elevations (Figure 3). Many of these mangroves environments have been

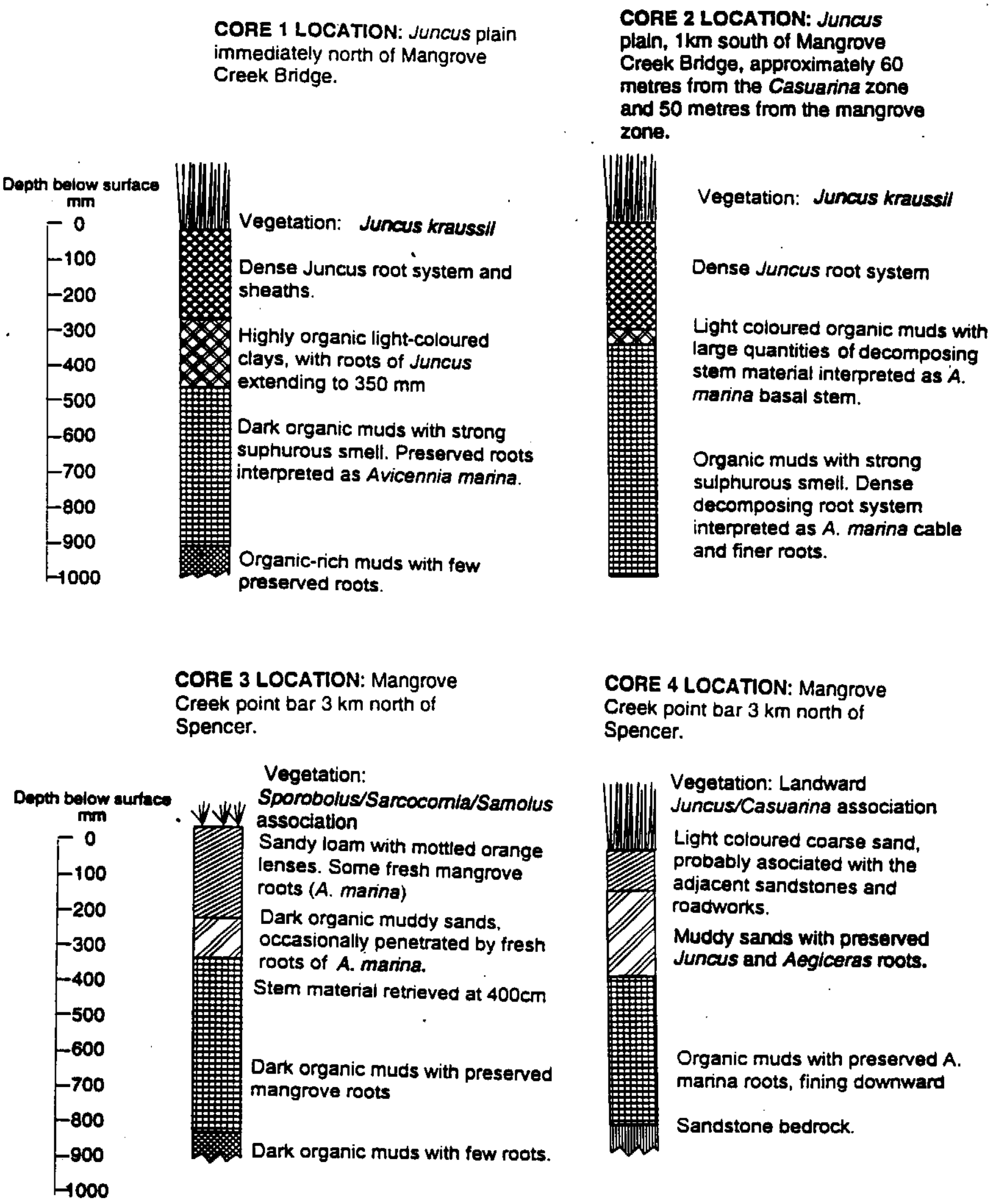

Figure 4. Graphic logs of four cores from Mangrove Creek, showing sediment characteristics preserved vegetative structures and interpretation.

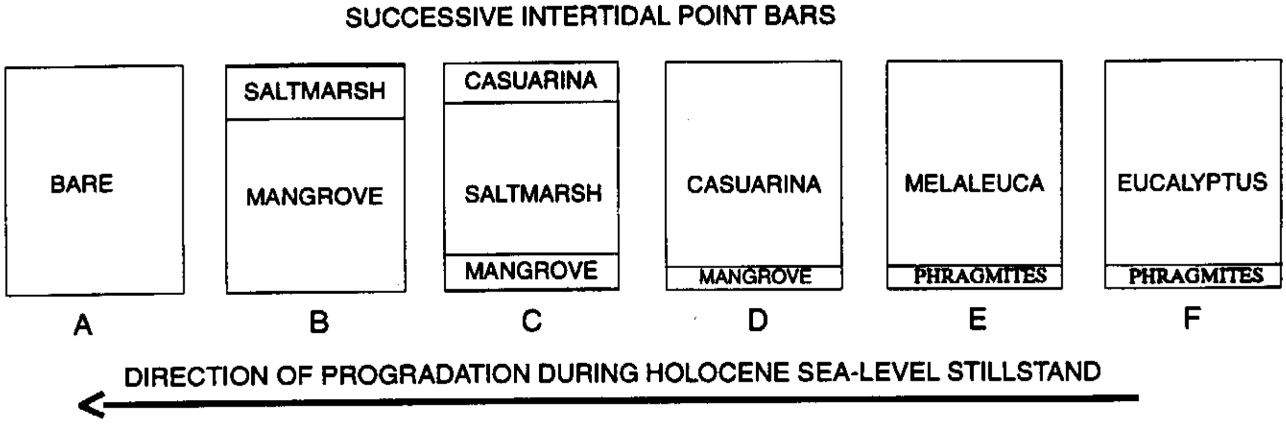

Figure 5. A model for the succession of vegetation communities on accreting flats during estuarine progradation. The sequence A-C is observable on successive flats of the Hawkesbury main channel, and tributaries of the Hawkesbury including Mooney Mooney Creek (A-D), Mangrove Creek (B-D) and Mill Creek (C-F).

established since air photo reconnaisance began in 1948. These flats support high biomass communities of *Avicennia marina* and *Aegiceras corniculatum*, with *Phragmites australis* often occurring on the seaward edge.

(b) Stratigraphic cores and their interpretation.

Four cores were retrieved from three successive point bars on Mangrove Creek, the location of which are shown in Figure 1, and represented schematically in Figure 4.

DISCUSSION AND CONCLUSIONS

Modern depositional terraces on the Hawkesbury River decrease in elevation toward the mouth of the estuary. The elevation of the terrace strongly influences the character of the vegetation. Terraces well above tidal inundation support terrestrial grasses, *Melaleuca* and Eucalypt forest. Terraces inundated during highest spring tides support *Casuarina-Juncus* associations and may have channel-fringing mangrove environments at their periphery. Terraces at intertidal elevations support mangroves, while point-bars currently accreting below mid-tidal levels are unvegetated. This entire sequence can be identified on successive point bars on both the Hawkesbury and its tributaries, (Figure 5) suggesting that the association between vegetation and terrace development may be characteristic of drowned river valley estuaries in general as they infill with sediment.

Coring on the saltmarsh plains of Mangrove Creek has suggested the prior occupation of these locations by mangroves. Mangrove peats showing preserved root and stem material of *Avicennia marina* have been found at depths of between 350 and 900mm below present saltmarsh environments within Mangrove Creek (Figure 4). Succession has clearly occurred in the classical sense, with mangroves being replaced by saltmarsh following accretion of the flat to upper-tidal elevations, an accretion brought about primarily by the deposition of plant material in situ. Furthermore, the occurrence of mangrove peats below the *Juncus* saltmarsh is widespread on Mangrove Creek, indicating that the succession from mangrove to saltmarsh is the common sequence of succession in intertidal environments throughout this tribitary. If this is so, the Hawkesbury has evolved in a way consistent with Northern Australian tidal estuaries where mangrove peats are also consistently found beneath saltmarsh units (see, for instance, Semenuik 1982 on King Sound, Thom et al. 1982 on the Ord, and Woodroffe et al.

1985, 1989 on the South Alligator)

Mitchell and Adam (1989a) were unable to find mangrove peats beneath saltmarsh on the Georges River, and suggested a model which sees saltmarsh species as primary colonisers, followed by an invasion by mangroves. This model accords with observations of initial colonisation of bare intertidal flats by saltmarsh on the northern foreshore of Botany Bay, and the spreading of mangroves into the saltmarsh zone at Towra point, Botany Bay (Mitchell and Adam 1989b) at Lime Kiln Bay and Mill Creek in the Georges River and Cabbage Tree Basin in Port Hacking.

Whether the mangrove/saltmarsh zonation represents a successional sequence may depend on the sites' geomorphological history. The succession sequence proposed in this paper relates to a prograding fluvial delta gradually accreting clastic and organic sediment. Tidal deltaic environments within the mouths of estuaries are more stable, and present-day patterns in elevation and vegetation were probably established upon the initial formation of these environments, and would therefore not yield evidence of succession. Similarly, pre-Holocene substrates inundated at the end of the post-glacial marine transgression, in environments of very low sedimentation rates would show mangrove saltmarsh zonation without succession from one to the other. The observations of Mitchell and Adam (1989b) may well correspond to these situations.

The absence of mangrove peats in the subsurface should be treated cautiously in the context of succession models. A situation could be envisaged in which mangroves occur throughout a river system or embayment and following vertical accretion are replaced by saltmarsh. These saltmarsh environments are incised by tidal streams, more energetic due to higher elevations, and these creeks may meander across floodplains, replacing vertically accreted facies with lateral deposits, thereby masking the evidence of the succession which initiated present-day vegetation patterns. While mangrove peats beneath saltmarsh provide strong evidence of succession, the absence of such peats does not refute the succession hypothesis as the explanation of the origins of the present-day patterns in vegetation.

The spreading of mangrove vegetation into the saltmarsh (Mitchell and Adam 1989b) is an important observation and is consistent with the current author's observations of Mangrove Creek, where the expansion of the area of mangroves landward is obvious from a comparison with 1948 air photographs and the age-structure of landward mangrove communities. This landward transgression of mangroves appears to be occurring in a number of locations in South-east Australia, including Moreton Bay (Adam pers.com.), Kooragang Island. (Williams pers.com.) and the Tweed River estuary. At least four hypotheses could be offered as an explanation of this resurgence:

- hypothesis 1: that higher rainfall in the second half of the century has decreased the salinity of the saltmarsh zone making it more suitable for mangroves.
- hypothesis 2: that higher nutrient levels within estuaries have allowed the colonisation of mangroves on flats which were previously nutrient depleted.
- hypothesis 3: higher temperatures have increased the competitive ability of mangroves (which are essentially tropical) in saltmarsh environments.
- hypothesis 4: that the landward expansion of mangroves is evidence of sea-level change, either from land subsidence or absolute sea-level rise.

Hypothesis 1 would see the relative extent of saltmarsh and mangrove as being cyclic or recurrent, with the mangroves advancing during wetter flood-dominated regimes and declining during the drought dominated regimes described by Erskine and Warner (1988). Information on the extent of mangroves at the turn of the century would help resolve this issue, though the continued expansion of mangroves during the recent drought would argue against this suggestion. Hypothesis 2 seems unlikely in the light of recent seedling experimentation by Clarke (1993) and Saintilan (1995) which demonstrated that *Avicennia marina* seedling mortality in the upper intertidal zone is no lower than in fertilised quadrats.

Hypothesis 4 includes two possiblities. The first is that land has subsided relative to sea-level, which can occur with acidification of the soil and the loss of soil structure (Coates, pers. com.) or a decrease in sedimentation rates following dam construction (Roy pers.com.). Secondly, mangroves may follow renewed sea-level transgression, and it is interesting that the documented rate of sea-level change in southern Australia, at a rate of 1.8 mm y-1 (Bryant 1988), translates into a total rise of 100 mm since the 1920s (Gordon 1988). Short-term fluctuations are of the same order as this trend, and dredging would have a similar effect, so care must be taken when applying these figures to vegetational change. However, the point needs to be made that a 100 mm rise in sea-level is meaningful in the context of the mangrove/saltmarsh zonation where elevation gradients are gentle, and sea-level transgression has already been invoked as a causal mechanism in landward movement of saltmarsh species in Victoria (Vanderzee 1988).

The significant point which emerges from the mangrove creek observations is that the current pattern of landward migration in both *Avicennia marina* and *Aegiceras corniculatum* is against the longer-term trend of the Holocene stillstand which sees mangrove vegetation replaced by saltmarsh.

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