Global Ecology and Biogeography (1999) **8**, 117–124

RESEARCH LETTER

Mangrove transgression into saltmarsh environments in south-east Australia

NEIL SAINTILAN and ROBERT J. WILLIAMS *Australian Catholic University, PO Box 968, North Sydney, NSW 2059, Australia, and Fisheries Research Institute, 202 Nicholson Pde, Cronulla, NSW 2230, Australia*
email: N.Saintilan@mackillop.acu.edu.au

ABSTRACT

The landward transgression of mangroves into saltmarsh environments in the estuaries of south-east Australia over the last five decades is established as a widespread trend through a review of a number of independent studies. This process is occurring in a range of geomorphic settings, and in some cases reversing the direction of longer-term vegetation change. Several hypotheses are advanced to explain this occurrence, including increases in rainfall, revegetation of areas cleared for agriculture, altered tidal regimes or estuary water levels, and increases in nutrient levels and sedimentation.

Key words. Succession, intertidal vegetation, sea-level, mangrove, saltmarsh, estuary, Australia.

INTRODUCTION

The coastal estuaries of south-eastern Australia originated with a postglacial marine transgression that stabilized 6500 years ago (Roy, 1984). Throughout the Holocene, infilling has occurred with the deposition of both fluvial and marine sediments, creating a range of intertidal environments from the tidal deltas and back-barrier depressions at the mouths of estuaries to bayhead deltas and fluvial point-bars in upstream reaches. All these intertidal environments are suitable for colonization by mangroves and saltmarshes, and they are important habitats for fish, crabs, prawns and migratory birds (Hutchings & Saenger, 1987).

The diversity of mangrove species declines on the Australian east coast with increasing latitude. While twenty-seven species have been identified in the Hinchinbrook Channel (Duke, 1995), the number declines to seven within Moreton Bay and five at the New South Wales-Queensland border. *Avicennia marina* (Forssk.) Veirh. is the dominant species in the estuaries of NSW, occurring in association with *Aegiceras corniculatum* (L.) Blanco, *Rhizophora stylosa* Griff., *Bruguiera gymnorhiza* L. lamk. and *Excocaria agallocha* L. in the northern estuaries, and with *A. corniculatum* alone in the estuaries of the central and southern coastline (West *et al*., 1985). Within the southern states of Victoria and South Australia, *A. marina* is the sole species of mangrove.

By comparison, saltmarsh communities are more diverse, with Adam *et al*. (1988) recording over 250 species of saltmarsh and fringe vegetation in NSW. Important species include *Sporobolus virginicus* var. *minor* F. Bailey, *Samolus repens* (J.R. & G. Forst.) Pers., *Juncus krausii* Hochst., *Sarcocornia quinqueflora* (Bunge ex Ung.-Sternb.) A.J.Scott and *Suaeda australis* (R.Br.) Moq. (Adam, 1994). Saltmarsh characteristically occurs at higher elevations than mangroves, and is, as a consequence, inundated by fewer tides (Chapman, 1974). Soil conditions of the two community types differ in response to inundation frequency, with saltmarsh soils being in general drier and subject to a greater range of salinities (Clarke & Hannon, 1967).

Owing to the fact that mangrove and saltmarsh communities are often delimited by elevation, and because mangroves have the capacity to contribute to vertical accretion, the mangrove-saltmarsh zonation has been presented by some authors as an illustration of seral succession. For example, Pidgeon (1940) and Chapman (1974) have argued that mangroves accelerate rates of accretion as adventitious roots slow tidal flows and encourage deposition. Furthermore, mangroves translate significant volumes of atmospheric carbon to their root systems (Saintilan, 1997a) thereby contributing to organic accretion, and, particularly upon senescence, contributing litter to strandline environments. It is not unreasonable to suppose that mangroves could promote the accretion of intertidal environments to supratidal elevations where saltmarsh is better suited, thereby contributing to a seral succession in the classical model of Pidgeon (1940).

With these assumptions in mind, it is interesting to note the degree to which mangroves are expanding their range into saltmarsh environments in south-east Australian estuaries. In this paper, we seek to demonstrate that the combined weight of over twenty independent photogrammetric surveys conveys a regional pattern of landward mangrove incursion. A review of these papers allows for the identification of a number of potential contributing factors, each of which is discussed with reference to the broader biogeographic and geomorphic context of these observations.

OBSERVATIONS OF MANGROVE TRANSGRESSION

Analysis of historic air photographs of the past five decades by a number of investigators has demonstrated losses of saltmarsh in Queensland, New South Wales, Victoria and South Australia. The northernmost observation is that of Ebert (1995, cited in Duke, 1995), documenting the loss of saltpan in the Hinchinbrook Channel (146°10, 18°20 Fig. 1). The area of saltpan decreased by 78% in the period 1943–91. Saltpan was replaced by tall mangrove, the change being attributed to an increase in annual rainfall.

Further south, McTainsh *et al.* (1988) noted the landward incursion of mangroves at Oyster Point from 1944 to 1983, and Morton (1994) established the trend occurring over the wider Moreton Bay region (Fig. 1), noting that while mangroves in many places are recolonizing areas previously used for agriculture, at least 65 hectares of landward mangrove expansion in the 50 years following 1944 has occurred in areas not so used.

Within the northern rivers of NSW, landward incursions of mangroves have been observed in a number of locations. On the Tweed River, the most significant landward incursions of mangroves in the period 1941–94 have occurred in areas affected by agricultural practices, in the form of recolonization of previously cleared land, or the occupation of areas drained for sugar cane farming, which could have lead to local subsidence (Saintilan, 1998). Within the Brunswick and Clarence Rivers, landward mangrove incursions appear isolated to tidal channels – possibly to those affected by dredging works (Saintilan, 1997b).

A number of studies on the NSW central coast have revealed significant losses of saltmarsh to mangrove. Within the Hawkesbury River estuary, these changes have occurred in a number of geomorphic settings. Mangroves proliferating on the sand deltas in Pittwater near the mouth of the Hawkesbury have replaced 50% of the saltmarsh since 1941 (Wilton, 1997). Sites along Berowra and Marramarra Creeks within the lower estuary have lost saltmarsh to mangrove over the same period (Williams & Watford, 1997), and on the wide intertidal bars of the main fluvial delta mangroves are encroaching on saltmarsh within Mangrove Creek (Saintilan, 1997c).

Other central coast estuaries in which saltmarsh has been lost to mangrove include Port Stephens (Pipeclay Creek, B.G. Thom, personal communication), Lake Macquarie (25% of saltmarsh lost; Winning, 1990), the Hunter River from 1954 to 1994 (67% of saltmarsh lost; Buckney, 1987; Williams *et al.*, 1999), Homebush Bay within the Paramatta River (more than 80% lost, Clarke & Bensen 1988), the Lane Cove River (McLoughlin, 1987), and the Kurnell Peninsula in Botany Bay, where over 30% of the saltmarsh has been lost from the Ramsar-listed Towra Point wetland since the 1930s (Mitchell & Adam 1989b).

The barrier estuaries of the NSW south coast have been similarly affected. Mangroves have replaced saltmarsh in Currembene Creek, Jervis Bay (Fig. 2), particularly in the period 1944–84 (Clarke, 1995), although in some creeks within Jervis Bay saltmarshes have expanded their range (P.J. Clarke, personal communication). A survey of wetland distributions within the Minnamurra estuary (Chafer, 1998) revealed a 49% reduction in the saltmarsh area between 1938 and 1997, as mangroves expanded their range landward and swamp oak forests encroached seaward. Landward incursions of mangroves have been noted in Cullendulla Creek (A.D. Short, personal communication) and have been described as ‘extensive’ in Corner Inlet, Victoria for the period 1941–85 (Vanderzee, 1988). Landward incursions of mangroves have also been observed in South Australia. On the eastern shore of the Gulf St.

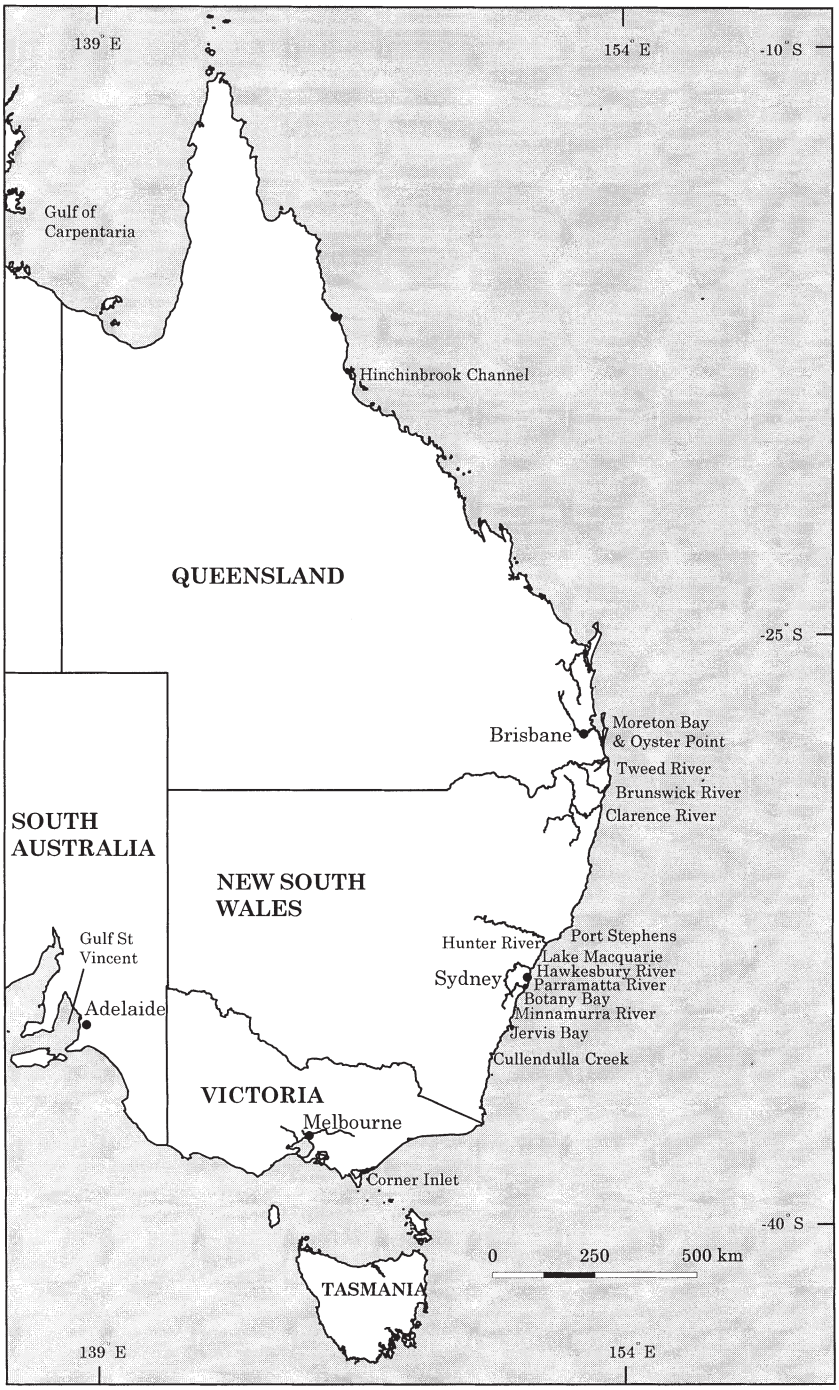

Fig. 1. Location of environments on the Australian east coast in which the landward transgression of mangroves has been observed.

Fig. 2. Juveniles of the mangrove *Avicennia marina* established in the *Sporobolus virginicus* saltmarsh, Currembene Creek, New South Wales. *Juncus krausii* and *Casuarina glauca* form the landward saltmarsh units. Photograph: N. Saintilan.

Vincent, mangroves extended their landward edge at a rate of 17 m per year in the period 1949–79 (Burton, 1982; Fotheringham, 1994).

SUGGESTED MECHANISMS FOR MANGROVE INCURSIONS

While studies of the mangrove–saltmarsh boundary have revealed a consistent trend in a range of estuaries, little unanimity exists as to the causes of the landward incursion of mangroves. Several suggestions have been made, falling into the broad categories of changing patterns of precipitation, change in or cessation of agricultural practices, altered tidal regime or sea-level, catchment modifications leading to altered sedimentation and nutrient levels, and land subsidence. Each of these mechanisms is reviewed in turn.

Precipitation

Average annual precipitation has increased in the period following 1945 along the east Australian coast (Pittock, 1988), a feature which could have diluted salts within saltmarsh soils to the extent that mangrove colonization might have been enhanced. The ephemeral nature of mangroves in the saltpan fringe has been noted by Duke *et al.* (1997). Egbert (1995, cit. Duke, 1995) suggested that the replacement of saltpan by mangrove in the Hinchinbrook channel is primarily due to increases in annual rainfall, and Duke (1995) notes in this context that Fosberg (1961) drew an association between the proportion of saltpan to mangrove and the annual precipitation. McTainsh *et al.* (1988) traced the landward expansion of mangroves along drainage lines, and suggested that higher rainfall might explain the movement of mangroves into higher intertidal environments. Extremes of salinities encountered in these less frequently inundated sites would be lessened if rainfall were more consistent between inundations.

Buckney (1987) related the expansion of mangroves in the Hunter estuary to an increase in rainfall, and noted a loss of vigour in the same mangroves during the *El Niño* drought of 1982. The observation by Chafer (1998) that oak forests in Minnamurra estuary have encroached upon saltmarsh from the landward edge would also suggest a freshening of the saltmarsh plain.

Agricultural practices

In many instances, mangroves have been observed occupying areas previously used for agriculture; this may represent a recolonization of cleared areas. Morton (1994) notes the regrowth of 65 hectares of mangroves cleared from islands in Moreton Bay following the cessation of agricultural practices, and Mitchell & Adam (1989b) suggest that much of the landward spread of mangroves at Towra Point may be regrowth following a long history of agricultural and industrial disturbance. Photographs of Currembene Creek, Jervis Bay, between 1944 and 1971, show signs of grazing, including cattle trails, and the removal of cattle from these sites might have promoted the growth of *Avicennia marina* seedlings on these flats (P.J. Clarke, personal communication).

In parts of the Sydney district, the clearance of mangroves took place from the early 1800s (Mitchell & Adam, 1989a). Initially, mangrove wood was burnt to generate alkali ash for soap. As the colony expanded, the harvesting of timber for this purpose may have moved to other regional centres, in turn contributing to additional losses. In the mid 1800s grazing areas were expanded and in the latter part of the 19th century, an oyster industry began in NSW with mangrove sticks being cut for the settlement of oyster spat. It is difficult to identify unequivocally sites that have been affected by these activities in urbanized catchments.

Altered tidal regime

Morton (1994) attributes the landward expansion of mangroves in areas unaffected by agriculture to alterations in the tidal regime of Morton Bay, due to the modification of entrance conditions, and the construction of a tidal barrage. Dredging in the northern rivers of NSW has also been noted to have altered tidal range significantly (Druery & Curedale, 1979), which may have promoted the landward colonization of mangroves in the Tweed and Brunswick Rivers (Saintilan, 1997b). Dredging of the mouths of barrier estuaries in southern NSW in the 1970s could also have influenced tidal hydrodynamics, leading to the rapid upslope colonization of mangroves. However, larger drowned river valleys, such as the Hawkesbury, are less affected by dredging, and the hypothesis cannot be applied to all situations.

A small eustatic sea-level rise has been observed for the Australian east coast since the beginning of the 20th century (Gordon, 1988). This rise has averaged $0.5\,\mathrm{mm\,y^{-1}}$, and appears to follow a pattern of increasing temperature and rainfall in the latter half of the century. The low gradients of the upper intertidal zone translate small increments in sea-level into substantial alterations in the frequency of inundation over wide areas, and this may be one factor contributing to mangrove incursion upon saltmarsh.

Sedimentation and nutrients

The landward incursion of mangroves has often occurred in association with progradation at the seaward edge (Botany Bay – Mitchell & Adam, 1989b; Morton Bay – McTainsh *et al*., 1988; Hawkesbury River – Williams & Watford, 1997; Wilton, 1997; Tweed River – Saintilan 1997c). While this might be an outcome of an increased tidal amplitude, the trend is more commonly interpreted as evidence of high rates of vertical accretion. Clearing of land in the catchments of tidal rivers has increased the delivery of sediment and nutrients to these environments (McLoughlin, 1985).

While vertical accretion would lower inundation frequencies, experimental evidence suggests that fresh sediment promotes the establishment of mangrove propagules in upper intertidal environments (Clarke & Allaway, 1993). In an environment where the oxidation of sediments leads to losses of nitrogen (Boto & Wellington, 1983) and potassium (Ward & Larcombe, 1996), the introduction of a veneer of nutrient-laden sediment, coupled with elevated concentrations of nutrients in the tidal waters of developed coastal estuaries, may allow mangroves to colonize environments from which they have been previously excluded by nutrient deficient soils. Duke (1995) notes the possibility of changes in the sediment and nutrient supply of the Herbert River influencing the performance of intertidal vegetation in the Hinchinbrook Channel.

Subsidence

Subsidence of an intertidal surface influences the distribution of mangroves and saltmarsh and can be the outcome of a number of factors. Regional subsidence may play a role, due to tectonic crustal movement or underground mine collapse, a factor which has led to the dieback of mangroves in Lake Macquarie (P. Adam, personal communication). Alternatively, acid soils are present along the major portion of the eastern Australian coast and agricultural drainage practices in these areas has caused irreversible soil shrinkage leading to subsidence of estuarine floodplains (White *et al*., 1997). Furthermore, unconsolidated sediments compress under the influence of gravity, leading to the lowering of the marsh surface, unless offset by vertical accretion (Reed & Cahoon, 1993). The diversion of sediment away from intertidal marshes has led, for this reason, to the drowning of saltmarsh in the Gulf of Mexico (Guilcher, 1981).

Vanderzee (1988) draws parallels between marsh loss in the Gulf states and the drowning of low-lying coastal land in Corner Inlet, Victoria. Both environments show microcliffing at the seaward edge of the saltmarsh, a profile suggested on theoretical grounds by Orsen *et al.* (1985) to be the result of erosion following an increase in relative sea-level. Similar microcliffing at the mangrove–saltmarsh boundary has been observed in Mangrove Creek on the Hawkesbury River, and Currembene Creek in Jervis Bay.

DISCUSSION

It would be tempting to describe mangrove transgression into saltmarsh as a ubiquitous trend relating to a common causal factor, such as greenhouse-related sea-level rise. Closer examination of the observations to date suggests a more complicated picture. The trend is not ubiquitous, and mangrove-saltmarsh boundaries in many estuaries have remained stable over the time period spanned by the historic photo record. For example, within the Jervis Bay system, mangrove transgression into saltmarsh has occurred in Currembene Creek, but not in Carama Creek (CSIRO, 1994). Within Port Stephens, mangrove transgression has occurred at Pipeclay Creek, but not Tilligherry Creek (Wilton, 1997).

Where incursions have occurred, a number of causal mechanisms can be invoked, including climatic change, altered tidal regime, sedimentation and subsidence. No single explanation suits all locations, given the diversity of geomorphic settings in which the changes are and are not occurring. Further research is clearly necessary in order to elucidate the relative importance of the contributing factors on an estuary-by-estuary basis.

Whatever the principal causes, saltmarsh appears to be a vulnerable and diminishing resource on the temperate Australian east coast. It is disturbing to note that many estuaries have lost over one quarter of their saltmarsh in the last five decades, and in some cases the figure is as high as 80%. If this trend is part of a natural oscillation of mangroves into and out of saltmarsh environments, perhaps linked to drought- and flood-dominated regimes documented for the temperate east coast (Erskine & Warner, 1988), then the issue is less of concern. However, stratigraphic examination of saltmarsh plains on the Hawkesbury River and at Curremebene Creek, Jervis Bay, has demonstrated the existence of mangrove root systems well beneath an overlying unit of saltmarsh soils, suggesting that the longer-term history of seral succession has been the replacement of mangroves by saltmarsh as vertical accretion has occurred (Saintilan, 1997).

It is unlikely that the rate of vertical accretion has recently slowed, given the degree of siltation occurring in many of these estuaries, and the concurrent expansion of mangroves at their seaward edge. That mangroves are also moving landward in many locations is more plausibly attributed to either increased nutrient levels resulting from anthropogenic inputs, or to the combined effect of increased precipitation and estuarine water levels, freshening the saltmarsh environment, renewing interstitial potassium (Keene, personal communication), and increasing the delivery of propagules to the upper intertidal zone.

Given predictions of renewed sea-level rise globally, and little prospect of a reduction in nutrient levels in south-east Australian estuaries, it would appear that coastal wetlands will continue to be dramatically impacted, with a spread in the areal extent of mangroves and a corresponding decline in the distribution of saltmarsh. In many situations, further landward progression of saltmarsh is impossible, given urban and agricultural constraints. These considerations may have important implications for the extent and biodiversity of south-east Australian wetlands.

ACKNOWLEDGMENTS

The authors would like to thank the many co-workers who drew relevant survey reports to their attention, including Ron West, Paul Adam, Norman Duke, and Karen Edyvane. Fiana Watford produced the figure.

REFERENCES

Adam, P. (1994) Saltmarsh and mangrove. *Australian vegetation* (ed. by R.H. Groves), 2nd edn, pp. 395–435. Cambridge University Press, Cambridge.

Adam, P., Wilson, N.C. & Huntley, B. (1988) The phytosociology of coastal saltmarsh vegetation in New South Wales. *Wetlands (Aust.),* **7,** 35–85.

Boto, K.G. & Wellington, J.T. (1983) Phosphorus and nitrogen nutritional status in a northern Australian mangrove forest. *Mar. Ecol. Prog. Ser.* **11,** 63–69.

Buckney, R.T. (1987) Three decades of habitat change: Kooragang Island, New South Wales. *Nature conservation, the role of remnants of native vegetation* (ed. by D.A. Saunders, G.W. Arnold, A.A. Burrbidge and A.J.M. Hopkins), pp. 227–232. Surrey, Beatty and Sons, Sydney.
Burton, T. (1982) Mangrove changes recorded north of Adelaide. *Safic,* **6,** 8–12.
Chafer, C.J. (1998) *Draft: A spatio-temporal analysis of estuarine vegetation change in the Minnamurra River* 1938–97, p. 47. Minnamurra Estuary Management Committee.
Chapman, V.J. (1974) *Salt marshes and salt deserts of the World*, 2nd edn, p. 342. Cramer, Lehre [Ger.].
Clarke, P.J. (1995) The population dynamics of the mangrove shrub *Aegiceras corniculatum* (Myrsinaceae): fecundity, dispersal, establishment and population structure. *Proc. Linn. Soc. N.S.W.* **115,** 35–44.
Clarke, P.J. & Allaway, W.G. (1993) The regeneration niche of the grey mangrove (*Avicennia marina*): effects of salinity, light and sediment factors on establishment, growth and survival in the field. *Oecologia,* **93,** 548–556.
Clarke, P.J. & Bensen, D. (1988) The natural vegetation of Homebush Bay- two hundred years of changes. *Wetlands (Aust.),* **8,** 2–15.
Clarke, L.D. & Hannon, N.J. (1967) The mangrove swamp and saltmarsh communities of the Sydney district. I. Vegetation, soils and climate. *J. Ecol.* **55,** 754–771.
CSIRO Division of Fisheries (1994) *Jervis Bay Baseline Studies. Final Report, May 1994*, p. 1282. Marmion Marine Laboratories, North Beach, Western Australia.
Druery, B.E. & Curedale, J.W. (1979) *Tweed River dynamics study. Report No. 78009,* p. 135. Public Works Department of NSW.
Duke, N.C. (1995) Mangroves in the Great Barrier Reef World Heritage Area: current status, long-term trends, management implications and research. *State of the Great Barrier Reef World Heritage Area Workshop. Proceedings of a Technical Workshop held in Townsville, Queensland, Australia 27–29 November 1995* (ed. by D. Wachenfeld, J. Oliver & K. Davis), pp. 288–299. Great Barrier Reef Marine Park Authority.
Duke, N.C., Ball, M.C. & Ellison, J.C. (1997) Factors influencing biodiversity and distributional gradients in mangroves. *Global Ecol. Biogeogr. Letts,* **7,** 27–47.
Erskine, W.D. & Warner, R.F. (1988) Geomorphic effects of alternating flood and drought dominated regimes in New South Wales coastal rivers. *Fluvial geomorphology in Australia* (ed. by R.F. Warner), pp. 223–244. Academic Press, Sydney.
Fosberg, F.R. (1961) Vegetation-free zone on dry mangrove coastline. *U.S. Geol. Soc. Prof. Pap.* **424 (D),** 216–218.
Fotheringham, C.M. (1994) *A vegetation survey of Barker Inlet, Gulf St. Vincent, South Australia*. Management Issues and Recommendations. Coastal Management Branch, Technical Report 94/1, Department of Environment and Natural Resources.
Gordon, A.D. (1988) A tentative but tantalising link between sea-level rise and coastal recession in New South Wales, Australia. *Greenhouse: planning for climatic change* (ed. by G.I. Pearman), pp. 121–134. CSIRO, Melbourne.
Guilcher, A. (1981) Shoreline changes in salt marshes and mangrove swamps (mangals) within the past century. *Coastal dynamics and scientific sites* (ed. by E.C.F. Bird and K. Koike), pp. 31–53. Department of Geography, Komazama University, Tokyo.
Hutchings, P. & Saenger, P. (1987) *Ecology of mangroves,* p. 388. University of Queensland Press, Brisbane.
McLoughlin, L. (1985) *The middle Lane Cover River: a history and a future*. CEUS Monograph no. 1. Centre for Environmental and Urban Studies, Macquarie University.
McLoughlin, L. (1987) Mangroves and grass swamps: Changes in the shoreline vegetation of the Middle Lane Cove River, 1780s to 1880s. *Wetlands (Aust.)* **7,** 13–24.
McTainsh, G., Iles, B. & Saffigna, P. (1988) Spatial and temporal patterns of mangroves at Oyster Point Bay, south east Queensland. 1944–83. *Proc. R. Soc. Qld.* **99,** 83–91.
Mitchell, M.L. & Adam, P. (1989a) The relationship between mangrove and saltmarsh communities in the Sydney Region. *Wetlands (Aust.)* **8,** 37–46.
Mitchell, M.L. & Adam, P. (1989b) The decline of saltmarsh in Botany Bay. *Wetlands (Aust.)* **8,** 55–60.
Morton, R.M. (1994) Fluctuations in wetland extent in southern Moreton Bay. *Future marine science in Moreton Bay* (ed. by J.G. Greenwood and N.J. Hall), pp. 145–150. School of Marine Science, University of Queensland.
Orsen, R., Panageotou, W. & Leatherman, S.P. (1985) Response of tidal salt marshes of the U.S. Atlantic and Gulf Coasts to rising sea levels. *J. Coastal Res.* **1,** 29–37.
Pidgeon, I.M. (1940) The ecology of the central coast of New South Wales III. Types of primary succession. *Proc. Linn. Soc. N.S.W.* **65,** 221–249.
Pittock, A.B. (1988) Actual and anticipated changes in Australia's climate. *Greenhouse: planning for climatic change* (ed. by G.I. Pearman), pp. 35–51. CSIRO, Melbourne.
Reed, D.J. & Cahoon, D.R. (1993) Marsh subsidence vs. marsh accretion: interpreting accretion deficit data in Coastal Lousisiana. *Coastal Zone 93. Proceedings, 8th Symposium on Coastal and Ocean Management, New Orleans, Louisiana*, pp. 243–257. American Society of Civil Engineers, New York.
Roy, P.S. (1984) Holocene sedimentation histories of estuaries in southeastern Australia. *W.A. Dept. Conserv. Environ. Bull.* **161,** 23–59.
Saintilan, N. (1997a) Above- and below-ground biomasses of two species of mangrove on the Hawkesbury River estuary, New South Wales. *Mar. Freshw. Res.* **48,** 147–152.
Saintilan, N. (1997b) *Tweed River estuary; photogrammetric survey of wetland distribution*. 1930–94. Report to the Department of Land and Water Conservation.
Saintilan, N. (1997c) Mangroves as successional stages in the Hawkesbury River estuary, New South Wales. *Wetlands (Aust.)* **16,** 99–107.

Saintilan, N. (1998) Photogrametric survey of the Tweed River wetlands. *Wetlands (Aust.)* **17,** 74–82.
Vanderzee, M.P. (1988) Changes in saltmarsh vegetation as an early indication of sea-level rise. *Greenhouse: Planning for Climatic Change* (ed. by G.I. Pearman), pp. 147–160. CSIRO, Melbourne.
Ward, I.A.K. & Larcombe, P. (1996) A geochemical comparison of modern and holocene mangrove sediments, Townsville region, North Queensland. *Wetlands (Aust.)* **15,** 10–21.
West, R.J., Thorogood, C.A., Walford, T.R. & Williams, R.J. (1985) *An estuarine inventory for New South Wales, Australia,* p. 141. Fisheries Bulletin 2, Department of Agriculture, New South Wales.
White, I., Melville, M.D., Wilson, B.P. & Sammut, J. (1997) Reducing acidic discharges from coastal wetlands in eastern Australia. *Wetlands Ecol. Mgmnt,* **5,** 55–72.
Williams, R.J. & Watford, F.A. (1997) Change in the distribution of mangrove and saltmarsh in Berowra and Marramarra Creeks. 1941–92. *Report to Hornsby Shire Council.*
Williams, R.J., Watford, F.A. & Balashov, V. (1999) *Kooragang Wetland Rehabilitation Project: Changes in wetland fish habitats of the lower Hunter River.* NSW Fisheries Office of Conservation, Fisheries Research Institute, Cronulla, NSW.
Wilton, K. (1997) Changes in mangrove and saltmarsh areas in the Sydney Region, with specific reference to Careel Bay, Pittwater. *Published, abstracts, Conference on the Ecology of Estuaries and Soft Sediment Habitats, January 1997, Deakin University.*
Winning, G. (1990) *Lake Macquarie littoral habitats study.* Report Prepared for Lake Macquarie City Council by Shortlands Wetlands Centre.