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CHANGES IN COASTAL WETLAND HABITATS IN CAREEL BAY, PITTWATER, N.S.W., FROM 1940 TO 1996.

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ABSTRACT
Between 1940 and 1996 the saltmarsh habitats of Careel Bay were significantly reduced in size, while the mangrove habitat of the bay expanded, in both a landward direction, encroaching upon the saltmarsh habitats, and a seaward direction. This is one of many examples of mangrove incursion upon saltmarsh habitats along the New South Wales coastline. Natural and anthropogenic influences upon Careel Bay were examined in an effort to determine possible causes. Patterns of change in regional sea level, sedimentation and increased freshwater delivery were found to coincide with the mangrove and saltmarsh changes, partly due to influences of the urbanisation of the catchment.

INTRODUCTION
Changes in mangrove and saltmarsh habitats during the past 50 to 60 years have been documented at a number of sites along the New South Wales coastline. In many places saltmarsh is declining at the expense of mangrove habitats. Mitchell and Adam (1989b) documented the decline of saltmarsh habitat at Towa Point in Botany Bay, Sydney, finding that between 1942 and 1986 there had been a decrease in the area of saltmarsh habitat at Towa Point in conjunction with an almost equal increase in the area of mangrove habitat. Hypotheses suggested by the authors as to the cause of these habitat changes included a rise in sea level, land clearing, urbanisation, industrialisation and increased sedimentation and nutrients levels in adjacent waterways.

McLoughlin (1987) documented mangrove habitat changes in the Lane Cove River, and Robinson et al. (1983) reported changes of both mangrove and saltmarsh habitats in Homsbush Bay. Further afield, McTainsh et al. (1986) reported an increase in the area of mangroves of Oyster Point Bay, southeast Queensland, of 119% between 1944 and 1983, with the mangrove community expanding in a landward direction. McTainsh et al. (1986) noted that maximum expansion occurred between 1964 and 1972, and attributed this to a period of high rainfall in the area in conjunction with reduced wind energy conditions and rising sea level, which possibly resulted in reduced salinity levels in the adjacent mudflats.

More recently, Saintilan and Williams (1999) established that the landward transgression of mangroves into saltmarsh habitats in estuaries in southeast Australia is widespread, suggesting a range of possible mechanisms for mangrove incursions, including periods of increased average precipitation, agricultural and other harvesting practices (such as for use as firewood), altered tidal regime, increase sedimentation and nutrient levels, and subsidence.

This paper presents a case study of mangrove and saltmarsh changes in Careel Bay, Pittwater, over the past 56 years, where substantial saltmarsh decline has occurred.

STUDY SITE DESCRIPTION
Careel Bay, located in Pittwater, a former tributary of the Hawkesbury River, is a mature, deeply incised, bedrock-confined drowned river valley (Roy, 1984), 40 km north of Sydney, on the eastern coast of Australia (Figure 1). The bay has a tidal range of 2 m, and a catchment of 10.18 km², which consists of residential, commercial and recreational development. Its mangrove flora consists primarily of Avicennia marina (Forsk.) Vierh., with small colonies of Aegiceras corniculatum (L.) Blanco, and its saltmarsh flora consists primarily of Sarcocornia quinqueflora (Bunge ex. Ung.-Sternb.) A.S. Scott, Sporobolus virginicus (L.) Kunth, and Juncus kraussii Hochst.

METHODS
Observations were made factors throughout the catchment and the region of natural and anthropogenic which might influence the extent, composition and distribution of the intertidal wetlands (see Figure 2).

The mangroves and saltmarshes of Careel Bay were mapped from aerial photographs, taken in 1940, 1946, 1955, 1961, 1965, 1972 and 1996. The photographs were scanned at 300 dots per inch (dpi) and, using Freehand software, the boundaries of mangrove and saltmarsh (as delineated by the author) were traced. Some of these maps are displayed in this paper (Figures 3 to 6).

Present-day intertidal inundation frequency in Careel Bay was measured using a modification of methods described in English et al. (1997). This involved inserting rods marked with water soluble die along transects in the intertidal plain of Careel Bay before a night Spring tide. As the tide acted as a level, the inundation frequencies deduced on the basis of the depth of Spring tide inundation. As the rods were inserted, notes were made regarding the species composition of the surrounding vegetation to provide a basis for the description of the elevation at which each species was observed.
Figure 1: Location of Careel Bay within Pittwater, New South Wales ('J' represents jetty, 'LR' represents launching ramp) (DLWC, pers. comm.).

Figure 2: Parameters examined as possibly being responsible for the changes in mangrove and saltmarsh habitats in Careel Bay.

RESULTS

Figures 3 to 6 illustrate the changes in the mangrove and saltmarsh habitats. By 1946 the catchment of Careel Bay had experienced only a small degree of urbanisation, and the few residents were either farmers or vacationers. Mangrove was limited to the banks of Careel Creek, and formed a barrier between the sea and the inner saltmarsh (Figure 3). Between 1955 and 1961 there was a considerable increase in the areal extent of mangroves in a landward direction, encroaching upon the saltmarsh on the southern side of...
Carel Creek, with minor encroachment upon the southern part of the saltmarsh on the northern side of the creek (Figure 4).

By 1972 the Bay had been dramatically altered by development. The eastern and the northern sections of the Bay were extensively converted by landfill. The mangroves considerably increased their areal extent and degree of encroachment upon the saltmarsh. There was no saltmarsh on the northern side of the creek; the mangrove zone lining either side of the creek had widened, and in the saltmarsh on the western side of the creek the mangroves had increased so much in area that they had created two distinct patches of saltmarshes (Figure 5).

Between 1976 and 1996 the rate of change declined (Figure 6). During this time the landfill was converted to sports fields and tennis courts. The most significant changes were an expansion of the mangroves between what have become the ‘western’ and ‘eastern’ saltmarshes (as indicated in Figure 5), and more encroachment upon the northern portions of the saltmarshes. Other changes during this time included the seaward expansion of the mangroves, in conjunction with their landward encroachment.

Rates of change in the mangrove and saltmarsh habitats during the study period are illustrated in Figure 7.

Depth of inundation by a 2.0 metre tide (Fort Denison) is shown as Figure 8. The elevation range from the mangrove front to the upper tidal limit is approximately 90cm, with contemporary saltmarsh inundated to depths of 5-20cm by this tide.

Contemporary mangroves extend to locations inundated by less than 20cm of spring tide water, whereas the mangrove in the 1956 photographs appear limited to areas inundated by more than 50cm of spring tide water.

**DISCUSSION**

A number of factors were examined to determine whether they could affect the relationship between the mangrove and saltmarsh habitats of Careel Bay, including sea-level, sedimentation, succession, hydrodynamics, microtopography and land-use change.

**Sea Level Rise**

Sea-level rise has been identified by scientists around the world as potentially having a significant influence on intertidal wetland location and zonation (Orson et al., 1985; Vanderzee, 1988; Allen, 1990b; Williams, 1990; French, 1993; Reed, 1995; Stolper, 1998). Bryant (1990) reported that over the last century (1886 to 1988) sea level in Sydney (Fort Denison) had risen at an average rate of 0.54 mm/yr, though between 1946 and 1966 the rate of sea-level rise was 2.7 mm/yr. It must be noted that these figures apply only in Fort Denison, Sydney Harbour, as Pittwater does not have an historical tide gauge. Therefore, at this stage, rates of sea-level change in Pittwater are extrapolated from Fort Denison data.

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Figure 3: Careel Bay’s saltmarsh and mangrove habitats in 1946.

Figure 4: Careel Bay’s saltmarsh and mangrove habitats in 1961.
Figure 5: Careel Bay's saltmarsh and mangrove habitats in 1972.

Figure 6: Careel Bay's saltmarsh and mangrove habitats in 1996.

Figure 7: Changes in the mangrove and saltmarsh habitats from 1940 to 1996 (aerial photographs from 1940, 1965, 1974, 1986 and 1996 were analysed).

Figure 8: Comparison of rates of sea level change in Sydney (Fort Denison) during various periods of analysis (after Gordon, 1988).
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rates are higher than rates of submergence, may be an appropriate model for Careel Bay. This theory is supported by model simulations conducted by Stolper (1998), who simulated the effect of various combinations of sea-level rise, topography and sedimentation on the profile of estuarine substrates. Stolper (1998, p. 16) found that “sea-level rise reduces the relative elevation of the substrate, which leads to the landward migration of the intertidal zone. If this landward migration occurs over a substrate which becomes steeper in a landward direction then the intertidal zone will be reduced. Conversely, if the gradient decreases then the extent of the intertidal zone will be increased”.

Tidal inundation measurements showed that mangroves in Careel Bay in August 1999 extended to approximately mean high water. Comparisons of the vertical range of mangrove transgression and sea-level rise during the past 50 years showed that mangrove transgression exceeded sea-level rise by a factor of 5. That is, as determined by mapping the habitat changes for Careel Bay for the past 5 years and comparing this with sea-level data from Fort Denison for the same period, it can be seen that while mangroves have increased their vertical range by 30-40 cm, sea-level rise has been only 5-10 cm during this time. From this it can be concluded that sea-level rise is not solely responsible for the changes exhibited in Careel Bay during the past 50 years.

These data question the hypothesis that sea-level rise is an important component of mangrove transgression.

Sedimentation and Stratigraphy

Blacker (1977) suggested that increased mangrove areas and estuarine distribution throughout the Sydney region correlated with accelerated terrestrial sediment yield resulting from urbanisation of the region, yet her model allowed only for seaward expansion of mangrove, not landward expansion at the expense of saltmarsh.

AWT EnSight (1997) argued that the current hydrodynamic and sedimentary processes in Careel Bay restrict sediment from moving out of the bay (because of the presence of the bar of sediment at its mouth), yet allow sediment to move about within the bay. AWT EnSight (1997) attribute this containment to two processes: the action of waves created by westerly winds producing active inward drift of beach sand, and the growth of seagrasses, mangroves and saltmarshes which trap sediments in the intertidal and subtidal zones, increasing the area of available substrate for mangrove colonisation.

Tidal Prism and Hydrodynamics

The Broken Bay estuary receives semidiurnal tides of up to 2.0 m (Bryant, 1980). The southern side of the Broken Bay estuary (incorporating Pittwater) is tide-dominated, whereas the northern side of the estuary is dominated by open-ocean wave activity. AWACS (1991) listed the origin of wave conditions in Pittwater as locally generated wind waves, waves generated in the ocean which penetrate through Broken Bay and refract into Pittwater, and local waves generated by boating activity.

Pittwater Council (1996, pers. comm.) is investigating the possibility that the tidal prism in Pittwater has changed, given that the legal seaward property line of waterside properties in eastern Careel Bay is being questioned by landowners following what they
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which mangrove transgression has occurred.

From observations of aerial photographs from 1946 and historical data regarding the catchment, a correlation between changes in the mangrove/saltmarsh habitats and urbanisation of the catchment appears to exist. Changes in the habitats were fastest and most significant when urbanisation was most rapid, particularly when the landfill on the eastern shores was created (Hitchcock Park). The high levels of anthropogenic stress placed upon the area may be responsible for the previous balance between the mangroves and the saltmarsh reaching a threshold, or critical zone, and being shifted toward a new balance, where mangroves became the dominant species.

Climate

Pittock (1975, 1983, 1984) noted that rainfall decreased over much of northern and eastern Australia from the period 1881-1910 to the period 1912-1945, following which rainfall increased during the period 1946-1978 by 30-40%, correlating with changes in precipitation, ENSO, the SOI and temperature.

Due to a lack of historical data, the extent of mangrove and saltmarsh in Careel Bay before the first aerial photographs were taken in the 1930s, and indeed before European settlement in the 19th century, is not known. The 1940 aerial photography documents that the bay consisted primarily of saltmarsh, with mangroves limited to the creek banks, although it is possible that mangrove trees in the bay were in fact cleared. However, no mangrove stumps were noticed in the area over

potential to be a raised high water mark. This change may have been instigated by increased sediment movement into Pittwater, into and within Careel Bay. In addition to this, the construction of the playing fields of Hitchcock Park may have altered the tidal patterns within the rest of the bay.

Land Use Changes

There are a number of key events which have contributed to the changing social and ecological character of Careel Bay, including:

- the construction of a landfill in the south-east corner of Careel Bay, adjacent to Careel Creek, in approximately 1965;
- the extension of the landfill along the eastern and northern perimeters of Careel Bay in approximately 1972;
- the conversion of the landfill to the sports fields of Hitchcock Park;
- urbanisation of the land immediately surrounding Careel Bay; and
- bushfire activity around Careel Bay and further afield throughout the Pittwater catchment.

Further to this, Hennessy et al. (1999) reported an increase in rainfall in NSW of 15-18% for the period 1910-1995, which correlated strongly with interannual variations in temperature, total rainfall, heavy rainfall and the number of rain days, finding ENSO variability partly responsible along with enhanced monsoon activity in the 1970s.

McTainsh et al. (1986) attributed the landward expansion of mangroves in south east Queensland to a period of high rainfall, in conjunction with factors such as urbanisation and sea level change. McTainsh et al. (1986) stated that the increased rainfall delivery to the area had the effect of increasing freshwater delivery to the normally hypersaline mudflats, lowering the salinity levels and allowing the establishment and growth of Avicennia marina seedlings. In addition to this, the landward expansion of mangroves was noted to be initiated in runoff discharge points, supporting the hypothesis that increased freshwater delivery from the catchment was instrumental in the mangrove expansion.

Such research supports the observation that increases in rainfall in eastern Australia during the past century may have been an important factor in the expansion of mangroves in Careel Bay, due to a possible freshening of the saltmarsh and mudflats, and to the increased delivery of freshwater from the catchment via stormwater discharge points. Furthermore, the panning of large areas of the catchment would have the effect of decreasing evapotranspiration and increasing the proportion of precipitation reaching the bay as runoff.

ACKNOWLEDGMENTS

I would like to thank my Ph.D. Supervisor, Dr. Neil Smitiland, for his helpful comments and revisions of this work; Professor Paul Adam, for his encouragement and revisions; and my Masters Supervisor, Dr. Peter Mitchell, for his help during the writing of my Master of Science research thesis. I would also like to acknowledge the support of the Australian Research Council (ARC) and the Department of Employment, Education, Training and Youth Affairs (DEETYA).
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DEFINING WETLANDS AND IMPLEMENTATION OF A WETLANDS LOCAL ENVIRONMENTAL PLAN IN WYONG, NSW

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INTRODUCTION

As part of a review of its then draft Local Environment Plan (LEP) for wetland management, in 1994 Wyong Council commissioned the preparation of a definition of wetlands which Council officers could consistently apply in identifying wetlands of conservation value. The definition was accompanied by mapping protocols that enabled officers of Wyong Council to map wetlands within its precincts for inclusion in the LEP. This definition has been systematically applied to justify the plotting of zone boundaries of wetland areas in Wyong local government area (LGA). An amendment to the LEP incorporating the wetland boundaries (amendment no. 98) was gazetted on 10 December 1999. The definitional approach adopted is presented in detail, along with observations outlining Wyong Council’s experience in applying the wetlands definition and developing its wetland protection policies.

REVIEW OF APPROACHES TO WETLAND DEFINITION

Numerous attempts have been made, both in Australia and overseas, to define the term ‘wetland’. No generally agreed definition has yet been reached internationally, within Australia or even at State level. While most definitions agree on those general attributes that are common to most wetland types, there is no total agreement on how those attributes should be defined, or whether various marginal ecosystems should be considered to be wetlands. Several detailed reviews of wetland definition are available (e.g. Misch & Gosselink, 1986; Winning, 1988; Pressey & Adam, 1995). This paper does not seek to duplicate such comprehensive reviews, but rather to provide an overview of the different approaches taken to wetland definition, specifically as they relate to the present study.

Conceptually, wetlands are generally considered to be ecosystems transitional between terrestrial ecosystems and truly aquatic and marine ecosystems (although some definitions include many aquatic and marine ecosystems - e.g. the Ramsar definition). The difficulty in definition arises when an attempt is made to differentiate between terrestrial ecosystems and wetlands, and between wetlands and aquatic & marine ecosystems (Winning, 1988).

Many ‘definitions’ of wetlands are little more than general descriptions of what a wetland is. Even definitions that are intended to have some form of legal function are little more than descriptive statements, or lack definitional rigour.

The Convention on Wetlands of International Significance (Ramsar Convention) provides an example of a descriptive approach to defining wetlands:

Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres. (UNESCO, 1971)