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Potential Climate Change impacts on the mangroves and saltmarshes of the Sydney region

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Abstract

Mangroves and saltmarshes are sentinel species in their response to climate change, being sensitive to changes in temperature, sea-level, rainfall and atmospheric CO₂. Over recent decades widespread encroachment of saltmarsh by mangrove has been observed in most estuaries, a trend consistent with higher relative sea-levels and temperatures. We used climate change projections, including the outputs of down-scaled regionally-specific climate models to project changes in mangrove and saltmarsh vegetation in the Sydney region over the coming century. Temperature changes are likely to promote an increase in the diversity of mangroves capable of colonising estuaries in the Sydney region, and a decrease in the diversity of saltmarsh, which is strongly associated with cold temperatures. The capacity of mangrove and saltmarsh to respond to sea-level rise through landward encroachment will be constrained by topography in some estuaries (Port Hacking, Hawkesbury) and development in others (Georges River, Parramatta River).

Introduction

The impacts of climate change on coastal wetlands have been investigated over the past few decades with an emphasis on mangroves, salt marshes and tidal flats. These investigations include the wetlands along the coast of Kakadu National Park (Bayliss *et al.* 1997; Finlayson *et al.* 2011) the Great Barrier Reef (Lovelock and Ellison 2007), and north-western Australia (Semeniuk 2013). The information from these cases have highlighted the vulnerability of coastal wetlands to rising sea levels and to storms and storm surges, particularly in the tropics. These and other investigations have also considered adaptation options for responding to rising sea levels, including “doing nothing” and allowing the wetlands to change. This raises the spectre of the decline or loss of those mangrove species and communities facing the ocean and inland migration of those species or communities on the landward side. Inland migration of mangroves will have impacts on the saltmarshes that often occur on the landward edge of mangroves.

In urban areas any such migration will be influenced by the presence of infrastructure, especially hard structures that restrict the movement of wetland species, or limit the flow of water and nutrients required by the wetlands. Hence, very different adaptation measures may be needed in urban areas. The impact of climate change on mangroves and salt marshes in urban areas in the Sydney Region are investigated in this paper.

Climate change scenario

The NSW Office of Environment and Heritage developed a Climate Impact Profile for the State (DECCW 2010) and incorporated an integrated assessment of the biophysical changes projected for the state as a result of climate change. It covered likely changes in climate (temperature, rainfall and evaporation) by 2050; the physical consequences of these climate changes (rise in sea level and changes in run-off, flooding behaviour and fire regimes); and subsequent impacts of projected climate change and associated changes in physical processes, including those on biological communities, individual species and ecological processes. In doing this it assessed impacts on the biophysical environment and coastal and flooding hazards and established a baseline of information, noting that further work was required on the implications of these changes.

The DECCW (2010) report outlined the general features associated with climate change projections, including uncertainties, such as the high uncertainty around projections in coastal areas caused by the coarse resolution of the models. The projections that are reported are made in the light that there are significant limitations in the projections for the relatively narrow coastal zones. The projections also do not account for natural variability and the ability to assess multi-decadal climate variability has not been assessed.

Subsequently, the NSW Office of Environment and Heritage commissioned the NSW/ACT Regional Climate Modelling project (NARCLiM), aimed at providing improved, regional-scale climate models. NARCLiM uses four different Global Climate Models to provide climate projections for the periods 1990-2009, 2020-2039 and 2060-2079. These projections are downscaled at a resolution of 10 km for SE Australia (Fita *et al.* 2012). At the time of writing, NARCLiM outputs had not been published, though temperature projections for the Sydney Region were included in this analysis.

Climate projections 2050 for the Sydney region from DECC (2010) include the following:

- The climate is virtually certain to be hotter, with a likely increase in summer rainfall and a decrease in winter rainfall, although rainfall in coastal regions is difficult to simulate.
- Sea level is virtually certain to keep rising.
- Changes in rainfall are likely to increase sediment shedding from the hinterland with potential changes to stream channels including bank erosion.
- Sea level rise is virtually certain to alter estuarine and coastal lowland ecosystems with seasonal drying likely to degrade freshwater wetlands and higher temperatures likely to cause changes in ecosystems.

Sea levels along the coast are rising and this rate is certain to accelerate with projected rises above the 1990 mean sea level of 0.4 m by 2050 and 0.9 m by 2100. This will lead to increases in low, mid and high tide levels and likely result in larger areas of low-lying land around coastal waterways being exposed to more frequent tidal inundation. The IPCC (2007) projections suggested an increase of between 0.05 and 0.3 m by 2050, relative to 1990, based on the range of future emissions scenarios. By taking into account ice discharge from glaciers and polar ice caps a further 0.1–0.2 m would be added to the upper limit of sea level rise by 2100,

Table 3.8.1. Summary of components contributing to future projections of sea level rise in NSW (DECCW 2010).

Component	2050	2100
Sea level rise due to thermal expansion	0.3 m	0.59 m
Sea level rise due to accelerated ice melt	(included in above figure)	0.2 m
Regional sea level rise variation	0.1 m	0.14 m
Rounding	–	–0.03 m
Total	0.4 m	0.9 m

Table 3.8.2. Projected changes in climate for the Sydney region by 2050 (DECCW 2010).

Summary of temperature and rainfall changes in the Sydney/Central Coast region to 2050				
Season	Minimum temperatures	Maximum temperatures	Precipitation	Evaporation
Spring	2.0–3.0°C warmer	2.0–3.0°C warmer	10–20% increase	10–20% increase
Summer	1.5–3.0°C warmer	1.5–2.0°C warmer	20–50% increase	10–20% increase
Autumn	1.5–3.0°C warmer	1.5–3.0°C warmer	No significant change	No clear pattern
Winter	1.5–3.0°C warmer	2.0–3.0°C warmer	10–20% decrease	No clear pattern

although higher values cannot be excluded. A recent study by CSIRO and DECC (McInnes *et al.* 2007) predicted a NSW regional variation above global levels of up to 0.08 m by 2030 and 0.12 m by 2070. These projections are included in the NSW policy position for sea level rise (Table 3.8.1).

Projected changes in the climate of the Sydney region for 2050 are summarised in Table 3.8.2. These include an increase in the mean daily maximum and minimum temperatures in all seasons of 1.5–3.0°C; increased rainfall in summer with smaller increases likely in autumn and spring, with a moderate decrease in winter; evaporation likely to increase moderately in spring and summer, with no clear pattern for autumn and winter.

The consequences of these changes will include drier soil conditions in spring; a minor increase in annual average run-off, especially in summer; short-term hydrological droughts to become more severe while medium to long-term droughts likely to become less severe; increases in flood frequency, height and extent in lower portions of coastal catchments; increased sediment transport from catchments; coastal recession from sea level rises; increased salinisation in coastal freshwaters and inundation of some coastal acid sulphate soils; and more freshwater inundation on floodplains. The interactions between freshwater flooding and sea

level rise and erosion are expected to be complex and driven by local topography and vary over time and will require further investigation.

Mangroves and saltmarshes

Mangroves and saltmarshes are important components of estuarine foreshores in the Sydney Region. Detailed studies at Towra Point, Botany Bay, have demonstrated the significance of these wetlands as a habitat for a range of fish species (Mazumder *et al.* 2006a,b). The mangrove and saltmarsh of the Sydney region also provide other ecosystem services, including habitat for migratory shorebirds (Lawler 1996), the sequestration of carbon (Saintilan *et al.* 2013), and the cycling of nutrients (Clarke 1985).

The most recent estimate of the extent of mangrove and saltmarsh in the Sydney region, corrected as of 2006, is provided by the NSW Comprehensive Coastal Assessment, and incorporated into the databases maintained for the Estuaries Monitoring, Evaluation and Reporting (MER) strategy (Table 3.8.3). The Hawkesbury-Nepean system supports 58% of the total extent of mangrove and 67% of saltmarsh.

The mangrove and saltmarsh extent listed in Table 3.8.3 is a remnant of the pre-European extent. It is difficult to estimate the original area of mangrove and saltmarsh across the region, but

Table 3.8.3. Area of mangrove and saltmarsh in the estuaries of the Sydney Region. (Source: Comprehensive Coastal Assessment, data provided by P. Scanes, OEH.)

Estuary	Mangrove (ha)	Saltmarsh (ha)
Brisbane Waters	207.8	112.4
Hawkesbury	983.3	287.7
Pittwater	17.5	2.7
Narrabeen Lagoon	0.07	0.8
Dee Why lagoon	0	6.3
Manly Lagoon	0.02	0
Port Jackson	184.7	9.4
Cooks River	10.8	0.3
Georges River	382.4	84.0
Botany Bay	229.6	76.2
Port Hacking	29.9	12.8

significant developments up until the 1970s saw the reclamation (drainage and infilling) of large areas of mangrove and saltmarsh for commercial, residential and recreational facilities, particularly in the Georges, Cooks and Parramatta Rivers.

More recently there has been mangrove encroachment into saltmarsh with an average decline in saltmarsh across the region of 60% percent since the earliest aerial photography, primarily due to mangrove encroachment at most sites. Individual survey results are provided in Table 3.8.4. The decline of saltmarsh across NSW, as documented in Saintilan and Williams (1999), prompted the listing of Coastal Saltmarsh as an Endangered Ecological Community in three NSW Bioregions, including the Sydney Basin bioregion. Sea level rise is seen as the major driver of mangrove encroachment into saltmarsh across SE Australia (Rogers *et al.* 2006).

Potential Climate Change Impacts

Mangroves and saltmarshes are sentinels of climate change, due to their situation within narrowly defined elevations in relation to sea-level, and their sensitivity to changes in atmospheric carbon dioxide, temperature and rainfall. The following section details the basis for predictions of impacts resulting from alterations in atmospheric carbon dioxide concentrations, temperature, rainfall and sea-level in the Sydney region.

Carbon Dioxide and competition between mangroves and saltmarsh

Atmospheric CO₂ concentrations have increased from 280 ppm in pre-industrial times to 390 ppm today and could double during the 21st century (IPCC 2007). It is now recognised that increased CO₂ concentrations have direct effects on natural ecosystems, including coastal wetlands. Carbon dioxide acts as a plant fertiliser, increasing growth rates particularly in those plants that use “C-3” photosynthesis, until a point of saturation is reached at about 1000 ppm. However, a second group of plants use a “C-4” photosynthetic mechanism, which concentrates CO₂ at the point of fixation, and these plants show a lower effect of enhanced growth resulting from higher ambient CO₂.

The differential effects of increased ambient CO₂ on plant growth rate is relevant to mangroves and saltmarshes in the Sydney region because the mangroves *Avicennia marina* and *Aegiceras corniculatum* are C₃, while the dominant saltmarsh—the grass *Sporobolus virginicus*, is C₄. The increase in atmospheric CO₂ is therefore one factor favouring the growth of mangrove over saltmarsh in the Sydney region. The effect of high ambient CO₂ may be particularly advantageous in the upper intertidal environment where mangrove and saltmarsh interact, because the presence of salt and generally dryer conditions at this elevation create an environment of water stress that enhanced CO₂ partially overcomes (Ball *et al.* 1997). Plants subject to water stress (e.g. mangroves) can decrease water loss by tightly controlling stomata, given the efficiency of carbon dioxide movement between the atmosphere and the site of photosynthesis (McKee *et al.* 2012). Mangroves may be able to grow in environments from which they were previously excluded due to saline, dry conditions.

Temperature and Rainfall

Mangroves and saltmarshes in eastern Australia are limited in their distribution by temperature. Mangroves are essentially tropical genera, reaching their highest diversity in humid tropical latitudes (Duke *et al.* 1998). The diversity of mangroves consistently decreases with increasing latitude on the east Australian coast, and two species occupy the Sydney region: *Avicennia marina* and *Aegiceras corniculatum*. A recent study has noted the expansion in the range of the tropical species *Rhizophora stylosa* on the north NSW coast, with the extent of expansion (100 km) consistent with temperature increases over the past century

Table 3.8.4. Decline of saltmarsh in the Sydney Region- results of API surveys (Saintilan and Williams 2000).

Location	Saltmarsh Lost (%)	Period	Source
Berowra and Marramarra Creeks, Hawkesbury River	25	1941-1994	Williams and Watford 1997
Careel Bay, Pittwater	92	1938-1994	Wilton 1997
Couranga Point, Hawkesbury River	30	1954-1994	Saintilan and Hashimoto 1998
Lane Cove River	Not specified	1930-1986	McLoughlin 1987
Homebush Bay, Parramatta River	>80	1930-1986	Clarke and Benson 1988
Quibray Bay, Botany Bay	70	1950-1997	Evans 1997
Weeney Bay, Botany Bay	100	1950-1994	Fenech 1994;
Woolooware Bay, Botany Bay	63	1950-1994	Fenech 1994; Hughes 1998
Towra Point, Botany Bay	30	1942-1997	Mitchell and Adam 1989

(Wilson 2009). NARCLIM modelling has projected a 2.0°C increase in mean minimum winter temperatures in the Sydney region. A further 1.5-2°C increase in mean minimum temperature would bring the Sydney region into the thermal tolerance for several species currently limited to subtropical locations, including *Rhizophora stylosa*, *Bruguiera gymnorhiza* and *Excoecaria agallocha*. While mangroves species distributions at thermal limits are conservative for many species (Quisthoudt *et al.* 2012), improved access to southern estuaries is facilitated by the imposition of training walls and other entrance works, and the potential for deliberate or accidental transfer of propagules between estuaries.

An increase in mangrove diversity and productivity resulting from increased temperature would place further pressure on the saltmarsh EEC in the Sydney region. Saltmarshes are essentially cold temperate plants, and saltmarsh diversity increases in direct correlation with mean minimum temperature (Saintilan 2009; Figure 3.8.1). Extrapolating from this trend, saltmarsh diversity in the Sydney region would be expected to decrease from 50 species to approximately 40-45 if mean minimum temperatures rise 2.0°C (i.e. to resemble the northern NSW and SE Queensland assemblages). The following species are particularly vulnerable, not being located in latitudes characterised by these temperatures and find their northern limit in the Sydney bioregion: *Rhagodia baccata*; *Austratipa stipoides*; *Distichlis distichophylla*; *Gahnia filum*; *Lampranthus tegens*; *Wilsonia backhausii*; and *Wilsonia humilis*.

The upper intertidal environment where mangroves and saltmarshes interact is characterised by periodically high salinities in the Sydney Region (Clarke and Hannon 1969), and saltmarshes are better able to tolerate this variability (Clarke and Hannon 1970). Changes in rainfall may therefore influence the capacity of mangroves to survive in these locations, and has been postulated as one reason why mangroves have advanced and retreated in saltmarshes in SE Queensland (Eslami-Andargoli *et al.* 2009). Projected increases in rainfall of 30 percent by 2040 estimated by NARCLIM modelling might therefore favour mangrove in the upper intertidal environment.

Increased storminess is unlikely to have a major impact on mangroves and saltmarshes in the Sydney region. While storms can had dramatic impacts on coastal wetlands, particularly due to the effects of wind-throw, tree mortality and soils subsidence (Cahoon 2006), these are primarily in regions visited by tropical cyclones. The wetlands of the Sydney region occur within protected estuaries, and a recent study of the impacts of the 2007 “Pasher Bulker” storm on the estuarine wetlands of the lower Hunter River concluded that the impacts of sedimentation and accretion were short-lived (Rogers *et al.* in press).

Sea-level rise

Sea-level is an important control on the distribution of mangrove and saltmarsh, and palaeo-stratigraphic studies within the Sydney region have demonstrated that mangroves and saltmarshes are sensitive to the relationship between sea-level and the elevation of the marsh surface, which

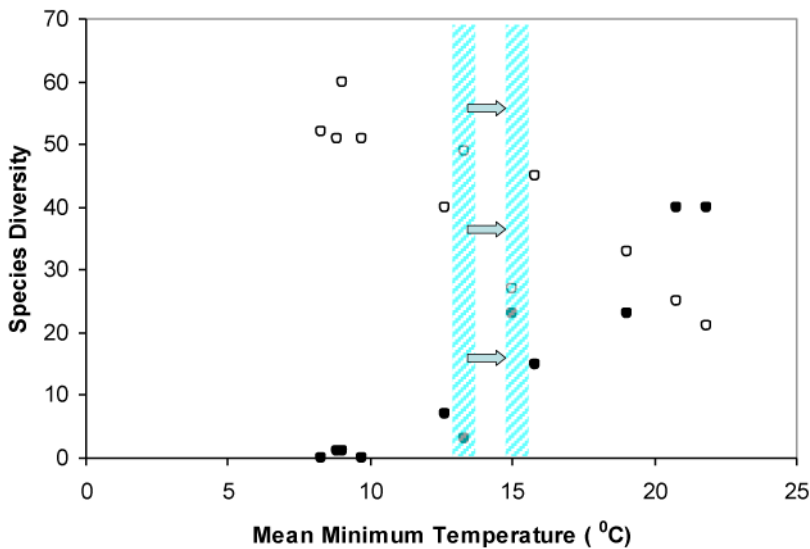


Figure 3.8.1. Changes in the diversity of saltmarsh (open circles) and mangrove (closed circles) with mean minimum temperature for bioregions on the Australian east coast. Blue lines represent the shift in mean minimum temperature from current to 2040 (an increase of 2°C, averaged for winter months across five randomly chosen sites in the Sydney region).

is driven primarily by rates of sedimentation (Saintilan and Hashimoto 1999). Tidal wetlands respond dynamically to changes in sea-level, as sea-level influences many factors contributing to the elevation of the marsh, including the rate of sedimentation, below-ground biomass production, and groundwater levels. Measurements of the relationship between sea-level and the processes driving wetland elevation have been made possible by the installation of Surface Elevation Tables (SET), a technique pioneered by the US Geological Survey but now used in 22 counties world-wide. More than 100 platforms have been installed in SE Australia since 2000, including 20 in the Hawkesbury estuary and 9 in Port Jackson (Rogers *et al.* 2006).

Results from the Sydney Basin SET's suggest that mangroves have a high adaptive capacity to respond to low-moderate rates of sea-level rise through vertical accretion, but this capacity is not shared by saltmarsh. The rate of vertical accretion in saltmarshes in the Sydney region has lagged behind the long-term sea-level trend for the region (Rogers *et al.* 2006). In a regional comparison, Rogers *et al.* (2006) demonstrated that the rate of mangrove encroachment into saltmarsh was inversely related to the extent of elevation gain in the saltmarsh relative to sea-level. The suggestion therefore is that even moderate rates of sea-level rise experienced

in the region over the past century (1.8mm y^{-1}) has been sufficient to cause changes in the relative extent of mangrove and saltmarsh. Mangrove encroachment has occurred primarily along tidal creek lines, many of which have shown signs of reactivation and expansion (Saintilan and Wilton 2001; Saintilan and Hashimoto 1999).

Opportunities and Limits to Adaptation in the Sydney Region

The extent of mangrove and saltmarsh in the Sydney region in 2100 will depend on the rate of sea-level rise, and the adaptation strategies adopted. The response of wetlands to sea-level rise has been modelled at the landscape scale using modelling tools including

SLAMM (Sea-Level Affecting Marshes Model; Clough *et al.* 2010), and the wetland response tool developed by Rogers *et al.* (2012) and recently applied to the Hunter estuary. Both are dynamic elevation models, in which the relationships between wetland elevation, accretion and sea-level rise are parameterised for particular geomorphic situations.

The models require detailed elevation models to run, and the availability of Lidar has allowed their broad application, though as yet insufficient data exist for the modelling of wetland responses to sea-level rise in the Sydney region. The site-specific commentary below is therefore of a more general nature, drawing upon observations of hinterland topography, and accretion and sedimentation data derived from the SET network.

The Hawkesbury Valley

As previously mentioned, the Hawkesbury River contains the largest extent of mangrove and saltmarsh in the Sydney region. Mangroves and saltmarshes occur in a range of geomorphic settings, from the sandy flood-tide deltas of Brisbane Waters, the tributary valleys of Berowra,

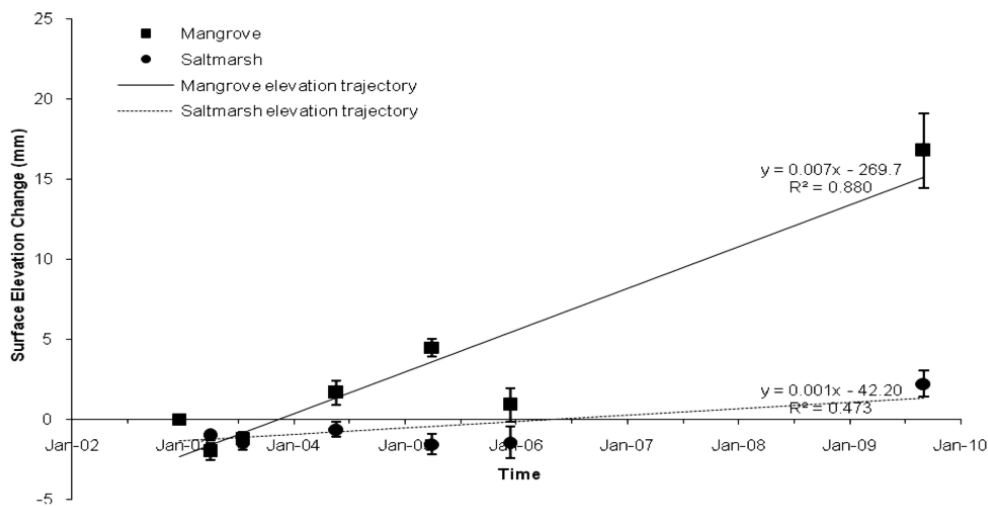


Figure 3.8.2. Surface elevation trajectories in mangrove and saltmarsh habitats at Marramarra Creek, Hawkesbury River. (Source: Rogers 2010.)

Marramarra, Cowan, and Mooney Mooney creeks, to the wide intertidal flats between Spencer and Wisemans Ferry.

The deeply incised Triassic sandstone valleys provide an important topographic constraint to upslope migration of mangrove and saltmarsh with sea-level rise. While mangrove environments show sufficient elevation gain to be sustained in-situ with current rates of sea-level rise, the saltmarsh has shown little elevation gain (Figure 3.8.2), suggesting that the trend of mangrove replacing saltmarsh identified by Williams and Watford (1997) will continue. The long-term survival of mangrove and saltmarsh within the estuary will depend on the management of floodplains, currently supratidal, or headward, of the current mangrove and saltmarsh extent.

Port Jackson/Parramatta River

The largest extent of mangrove and saltmarsh within the Port Jackson/Parramatta River estuary occurs within the boundaries of Sydney Olympic Park. Surface elevation tables were installed in the Homebush Bay site within Sydney Olympic Park in 2000. Elevation trajectories within the mangrove and mixed mangrove-saltmarsh zones are greater than current sea-level trends for the region (Figure 3.8.3). However, the saltmarsh has shown little gain in elevation in the period (less than 0.5mm yr^{-1}).

The presence of hard structures abutting the mangroves and saltmarshes of the Port Jackson/Parramatta River is the most significant topographic constraint to the migration of mangrove and saltmarsh with sea-level rise. Given the relatively small size of wetlands within the system, and their

ecological and social significance, marsh sediment nourishment may be a feasible adaptation response, particularly in sheltered situations such as the Wangal wetland and Homebush Bay, though source sediment contamination may limit this in practice.

Botany Bay Georges River

Towra Point is the only wetland in the Sydney region recognised under the Ramsar Convention as internationally

important. Towra Point is part of a continuous wetland extending across the southern shore of Botany Bay, linking Kurnell to Woolooware Bay. Saltmarsh has declined across this wetland complex due to mangrove encroachment (Table 3.8.1). The protection of brackish and freshwater wetland within Kamay Botany Bay National Park, and the extensive Coastal Swamp Oak Forest on the southern shore of Woolooware Bay will help facilitate coastal wetland migration.

Sediment yield from the Georges River catchment has been high following European colonisation, and this has contributed to the expansion of mangrove area within the estuary (Howarth 2010). However, sediment yields typically decline with urbanisation (Wolman and Schick 1967), and sediment traps are a common method for minimising pollutant loads in estuaries within the Georges River local government areas. The survival of wetlands within the Georges River will depend in part on a balanced approach to sediment delivery to the estuarine sedimentary deltas, and the paradigm of minimum sediment yield may need reconsideration over coming decades.

Port Hacking

Sedimentation patterns in the Port Hacking estuary are characterised by high marine flood-tide inputs at the mouth and the development of small alluvial fans associated with tributary creeks. Sediment yield from the main stem of the Hacking River is low, with most of the catchment protected in the reserve system. The estuary trained by incised sandstone valley walls for the entire length, and little capacity exists for either lateral expansion

of coastal wetland, or headward extension due to the presence of Audley weir and the gradient of the Hacking River beyond this point. It is therefore projected that moderate-high rates of sea-level rise would lead to a decrease in the area of coastal wetland within Port Hacking, in spite of the high proportion of wetland protected within the reserve estate within the estuary.

Conclusions

In summary, increased in atmospheric carbon dioxide, temperature, and sea-level all act to promote the growth of mangrove over saltmarsh in the Sydney region. These add to other non-climatic drivers of mangrove dominance, including enhanced nutrient conditions and sediment delivery to estuaries. The gradual replacement of saltmarsh by mangrove in the Sydney region is therefore consistent with the effects of climate change and is likely to continue through the 21st century. Increased mean minimum temperature is also likely to lead to changes in the diversity of mangrove and saltmarsh in the Sydney region by 2100, with mangrove diversity increasing and saltmarsh diversity decreasing. Poleward expansion and proliferation of mangroves is a global trend (Saintilan *et al.* in press).

The shift in floristic composition of coastal wetlands within the region may have important flow-on effects to the biota occupying these wetlands. The saltmarsh grass *Sporobolus virginicus*, a C-4 plant, has been shown in studies at Towra Point to be an important source of nutrition for grazing crabs and snails (Saintilan and Mazumder 2010). These species in turn provide nutrition for fish within the estuary, including species targeted by recreational fishers. Mangroves were shown not to contribute to the nutrition of these species (Mazumder and Saintilan 2010). Also, many species of migratory shorebird occupy saltmarsh environments in the region as a roosting habitat (Spencer 2010). The encroachment of

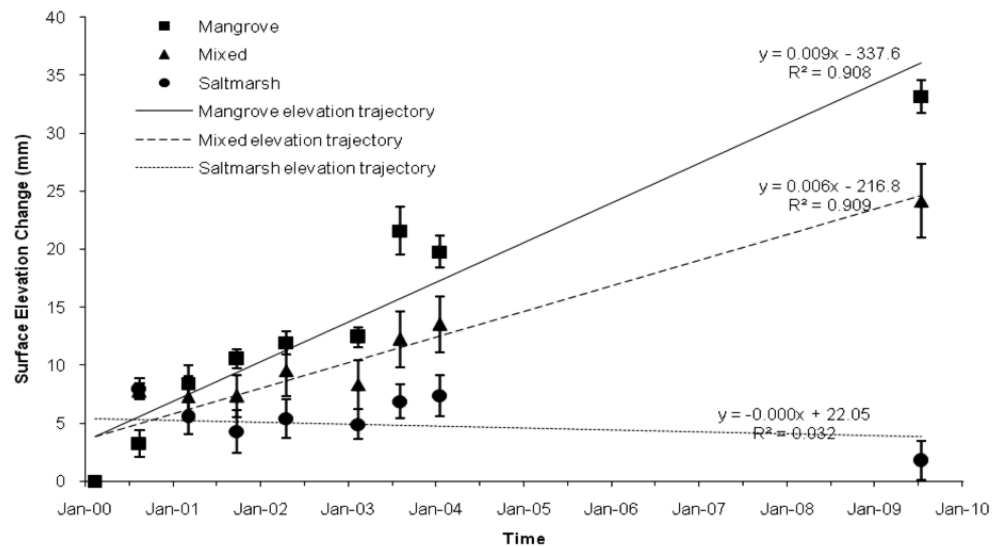


Figure 3.8.3. Surface elevation trajectories in mangrove, mixed mangrove and saltmarsh and saltmarsh habitats at Homebush Bay, Parramatta River. (Source: Rogers 2010.)

mangrove into saltmarshes decreases the utility of saltmarsh for these species (Zharikov and Milton 2009).

The major estuaries of the Sydney region vary in their adaptation potential for coastal wetlands. The deeply incised valleys characteristic of the Hawkesbury Sandstone geology, particularly within the lower Hawkesbury and Port Hacking estuaries limit lateral migration of coastal wetland communities with sea-level rise. Within the Hawkesbury, there is some capacity for headward migration on to wide floodplains currently at or above the elevation of highest astronomical tides. Management of wetlands within the highly developed catchments of the Parramatta and Georges River will depend on the management of hard structures and sediment loads.

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