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Mangrove Encroachment of Salt Marsh in Western Port Bay, Victoria: The Role of Sedimentation, Subsidence, and Sea Level Rise

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ABSTRACT: Surface elevation tables, feldspar marker horizons, and ^{210}Pb analysis of core profiles were implemented at four sites in Western Port Bay, Victoria, Australia, to provide information on the role of sedimentation, subsidence or compaction, and enhanced sea-level rise in contributing to salt marsh decline. Photogrammetric surveys indicate that the rate of salt marsh decline that is attributable to mangrove encroachment is lower in Western Port Bay than in comparable sites in New South Wales. Differences in the rate of mangrove encroachment at Western Port Bay may be attributed to the inverse relationship found between the degree of mangrove encroachment and surface elevation increase. While sedimentation contributes to surface elevation changes, surface elevation is not solely explained by sedimentation; factors including auto-compaction and changes in the water table also play a significant role in Western Port Bay. Historic sedimentation rates measured using ^{210}Pb dating techniques corresponded to contemporary sedimentation rates determined from feldspar marker horizons. Core sediment profiles show no change in sedimentation rates at three sites. A fourth site (French Island) was the only site that exhibited high rates of sedimentation, which appears to be related to local land-use changes in the area. All sites maintained their elevation with respect to sea level over the study period. Historic sedimentation exceeded sea-level rise for the past 32 yr, but it is difficult to determine the extent to which belowground processes affect surface elevation, causing deviations between surface elevation and sedimentation over longer periods.

Introduction

Mangroves and salt marshes are an important component of the estuarine ecosystem of Western Port Bay, Victoria, Australia. Although the grey mangrove (*Avicennia marina* var. *australisica* (Forssk.) Vierh.) nears its southern limit of distribution, it is able to sustain a biomass of 20 kg m^{-2}, cover over 40% of the shoreline, and provide significant levels of detritus to intertidal and nearshore communities (Clough and Attiwill 1975). It is these communities that are the most productive and diverse of the coastal inlets of Victoria (Chapman 1974). The salt marsh habitat supports a greater floristic diversity than comparable salt marshes elsewhere in mainland Australia (Adam 1990) and is an important roosting habitat for migratory birds, rare species of parrots, and fish (Zann 1997).

Salt marshes are vulnerable to pressures of development and estuary modification. In southeastern Australia, mangrove encroachment of salt marshes has contributed to salt marsh decline over the last five decades (Saintilan and Williams 1999, 2000). The results from 28 photogrammetric surveys published since 1982 reveal that the loss of salt marsh is in excess of 30% in over 70% of the estuaries studied. These changes may be the result of elevated sea levels, changes to the tidal prism, or the response of these systems to changes in the quantity and nutrient level of tideborne sediments.

This research is part of a comprehensive mangrove and salt marsh monitoring program commenced by the Victorian Department of Natural Resources and Environment in its assessment of the marine resources of Western Port Bay. The purpose of the study is to provide quantitative information on the dynamics of mangrove and salt marsh vegetation and changes in rates of sedimentation and surface elevation within mangrove and salt marsh habitats. These changes were examined in the context of sea-level rise throughout southeastern Australia over the past century. The study incorporates sites of varying degrees of catchment development including sites where direct human effects upon wetlands were anticipated, and significantly less affected sites in more remote locations. The preliminary results of a 3-yr baseline study are discussed.

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Study Location

Western Port Bay (38°21′00″S, 145°13′00″E) is east of Melbourne, Australia. The climate of Western Port Bay is described as a cool temperate climate with mean daily temperatures at Stony Point ranging between 7.1°C and 24.1°C and annual rainfall averaging 763.8 mm yr^{-1}. Annual rainfall between April 2002 and April 2003, the height of a drought, totalled 598.3 mm at Cranbourne (38°06′S, 145°16′E).

The saline coastal wetlands of Western Port Bay primarily comprise of mangrove forests and salt marsh plains. *A. marina* is the only mangrove species occurring south of Merimbula, New South Wales, and is close to its southern limit in Corner Inlet (38°46′S, 146°20′E). The salt marsh plains are floristically rich, supporting approximately 30 species including a number species endemic to this region. Following a process of literature review, photogrammetric and LANDSAT survey, and community consultation estuarine wetlands at French Island, Kooweerup, Quail Island, and Rhyll were selected as the primary study sites (Fig. 1).

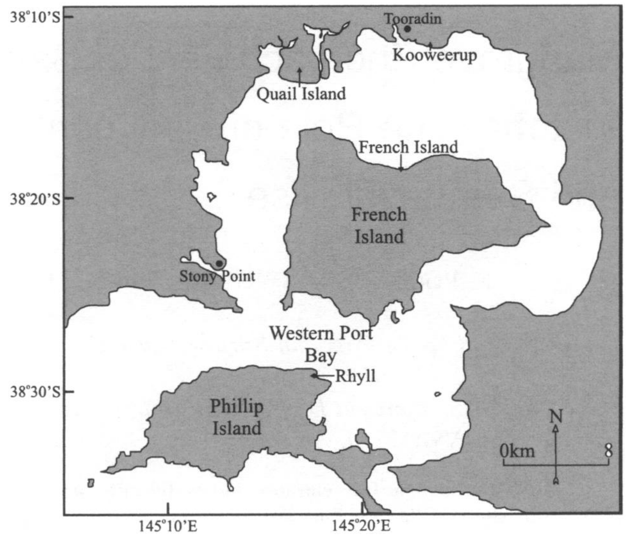

Fig. 1. Location of French Island, Kooweerup, Quail Island, and Rhyll study sites within Western Port Bay.

Materials and Methods

To analyse changes in estuarine wetland vegetation and sedimentation at Western Port Bay, photogrammetric mapping, surface elevation, and sedimentation studies were employed at each study site.

Photogrammetric Mapping

Historical aerial photographs of each study site dated 1939, 1967, 1973, and 1999, were scanned and imported into the ArcView Geographic Information System (ESRI Inc. version 3.2) as digital images. All digital images were georectified using a minimum of six ground control points. Vegetation community boundaries were delineated in accordance with the protocols of Wilton and Saintilan (2000). The area of vegetation units was determined and the changes in extent analyzed to determine whether they occurred at the seaward or landward boundary of mangrove and salt marsh.

Surface Elevation and Sediment Accretion

To analyze surface elevation, version IV of Surface Elevation Tables (SETs) were installed (Cahoon et al. 2002a). SETs enable detection of change in surface elevation of intertidal and shallow subtidal environments by taking high precision measurements of surface elevation (Boumans and Day 1993). A total of 24 SET monitoring stations were installed at Western Port Bay. At each site, 3 SETs were established in the salt marsh and 3 in the mangrove, to characterize the sedimentation and elevation properties of these vegetation units. Initial measurements were taken in October 2000 and additional measurements taken in November 2001, December 2002, and November 2003.

Sediment accretion was measured in conjunction with each SET monitoring station. At the time of SET installation, three 0.25-m^2 feldspar marker horizons were established on the marsh surface at the perimeter of each SET monitoring station. These horizons served as sedimentation markers against which sediment accretion was measured. Mini cores were taken from each feldspar horizon in November 2001, December 2002, and November 2003, and the distance from the marsh surface to the marker horizon was measured.

Analysis of variance was used to determine whether surface elevation change and vertical accretion varied consistently over the study period and between mangrove and salt marsh environments.

Continuous cores, with dimensions of approximately 10 cm diameter and 0.5–1 m length, were extracted from the muddy sediments of the salt marsh at Kooweerup, Quail Island, French Island, and Rhyll, Western Port Bay. Cores were taken to the Australian Nuclear Science and Technology Organisation, where the length and compaction of the core was recorded. The sediments were divided into 1 cm slices and a selection of slices was analyzed using standard ^{210}Pb dating techniques.

Results

Photogrammetric Mapping

Photogrammetric mapping of the estuarine wetlands at Western Port Bay indicate that despite varying degrees of development, the loss of salt

TABLE 1. Total area (hectares) and change in area (percent change over study period) of mangrove and salt marsh at study sites in Western Port Bay between 1939 and 1999.

Site	Vegetation Type	Vegetation Extent				Percent Change
		1939	1967	1973	1999	
Kooweerup	Mangrove	11.32		14.40	18.13	60.09
	Salt marsh	41.57		31.96	23.02	−44.61
Rhyll	Mangrove	40.04		57.86	62.28	55.54
	Salt marsh	174.27		153.72	139.83	−19.76
Quail Island	Mangrove			73.84	97.47	32.00
	Salt marsh			157.52	138.71	−11.94
French Island	Mangrove		185.16	178.32	189.23	2.20
	Salt marsh		518.63	510.92	490.63	−5.40

marsh due to mangrove transgression is apparent at each site (Table 1). Mangrove is primarily replacing salt marsh by extending along tidal creeks draining the salt marsh and expanding into the salt marsh interior.

Surface Elevation

Marsh surface elevation did not increase consistently at all sites in Western Port Bay (Table 2). Rhyll exhibited a net elevation gain in both the mangrove and salt marsh zones, while there was no net elevation gain in both mangrove and salt marsh zones at Kooweerup (Fig. 2). Both French Island and Quail Island exhibited an elevation increase in the salt marsh zone and an elevation decrease in the mangrove zone over the study period. Annual rates of surface elevation change did not differ significantly between mangrove and salt marsh zones at Kooweerup ($p = 0.983$), Quail Island ($p = 0.244$), and Rhyll ($p = 0.540$), but was significantly greater in the salt marsh zone at French Island ($p < 0.001$). Rates of surface elevation increase or decrease differed significantly ($p < 0.001$) over time at French Island, Kooweerup, and Rhyll, but not at Quail Island ($p = 0.131$).

Contemporary Sediment Accretion

Sediment accretion was consistently higher in the mangrove zone at all sites (Fig. 3 and Table 2). Differences between the rate of sediment accretion in the mangrove and salt marsh zones was significant ($p < 0.001$) at French Island, Kooweerup, Quail Island, and Rhyll. The rate of sediment accretion was consistent over the period of analysis at Kooweerup ($p = 0.122$) and Quail Island ($p = 0.099$); the rate of sediment accretion was significantly different over time at French Island ($p < 0.001$) and Rhyll ($p = 0.018$).

Sediment accretion over the period of analysis exceeded marsh surface elevation change at all sites and in all zones except French Island where surface elevation increase exceeded sediment accretion in the salt marsh zone. Differences in the rate of surface elevation change and the rate of sediment accretion were significant at all sites ($p < 0.001$).

TABLE 2. Mean (±SE) rates of surface elevation change (mm) and sediment accretion (mm) in the mangrove and salt marsh zones at study sites in Western Port Bay. * At Quail Island only Period 2 extends from November 2001 to January 2003 and Period 3 from January 2003 to November 2003.

Site	Zone	Measurement	Period 1	Period 2*	Period 3*
			October 2000 to November 2001	November 2001 to November 2002	November 2002 to November 2003
French Island	Mangrove	Elevation	6.69 (1.80)	−13.98 (2.06)	1.15 (1.92)
		Accretion	16.75 (2.65)	12.08 (0.99)	9.49 (2.69)
	Salt marsh	Elevation	8.79 (1.04)	5.10 (1.19)	1.73 (1.14)
		Accretion	4.39 (0.37)	4.01 (0.43)	4.37 (0.51)
Kooweerup	Mangrove	Elevation	15.65 (2.30)	−9.62 (3.21)	−6.76 (2.19)
		Accretion	11.62 (0.92)	10.41 (0.48)	7.20 (0.85)
	Salt marsh	Elevation	−0.28 (1.12)	−2.80 (1.03)	2.24 (1.42)
		Accretion	1.87 (0.36)	1.51 (0.26)	2.03 (0.32)
Quail Island	Mangrove	Elevation	−5.70 (3.38)	−4.92 (1.59)	4.77 (2.23)
		Accretion	9.48 (2.14)	6.92 (1.93)	6.77 (0.79)
	Salt marsh	Elevation	4.43 (4.68)	−1.93 (1.06)	−0.64 (1.07)
		Accretion	3.52 (0.23)	2.18 (0.50)	2.35 (0.96)
Rhyll	Mangrove	Elevation	2.78 (1.61)	−6.69 (1.98)	8.44 (3.15)
		Accretion	8.79 (1.63)	7.58 (2.65)	5.10 (0.72)
	Salt marsh	Elevation	1.02 (1.14)	−0.25 (0.95)	1.08 (0.57)
		Accretion	1.94 (0.27)	1.41 (0.41)	1.59 (0.19)

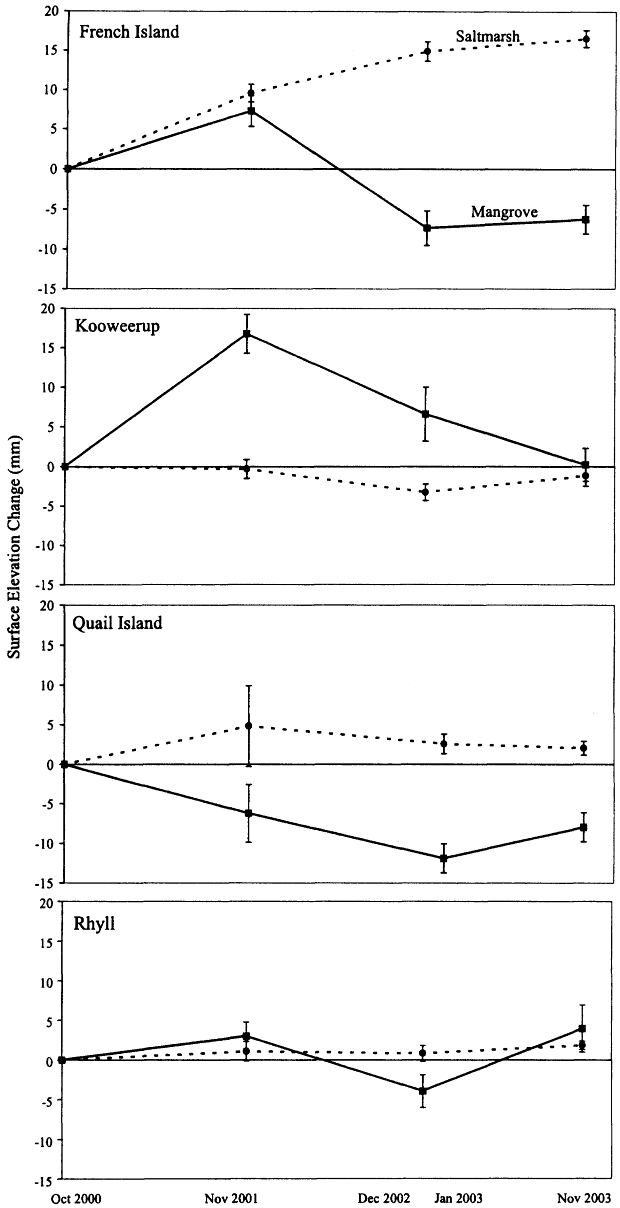

Fig. 2. Surface elevation change at study sites in Western Port Bay between October 2000 and November 2003.

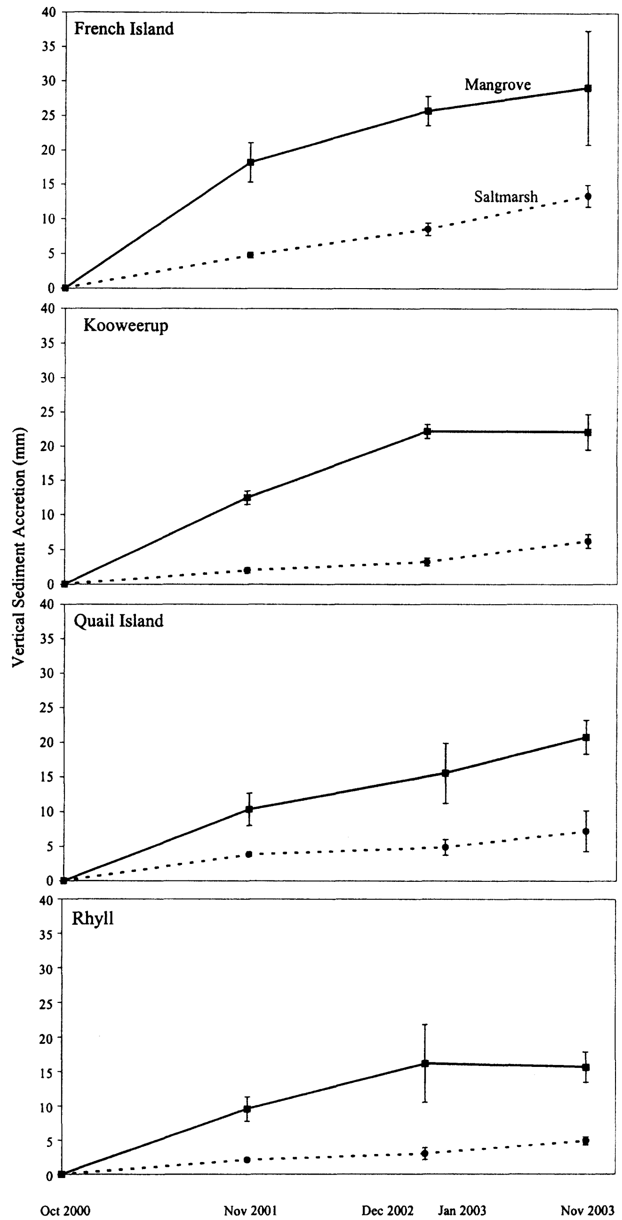

Fig. 3. Sediment accretion at study sites in Western Port Bay between October 2000 and November 2003.

Historic Sedimentation Rates

Analysis of excess ^{210}Pb activity (Fig. 4) in the cores extracted from the salt marsh at Kooweerup indicate that sediment is accreting at a mean rate of 1.63 ± 0.16 mm yr^{-1} for the past 150 yr, while at Quail Island and Rhyll sediment is accreting at 1.4 ± 0.2 and 2.5 ± 0.1 mm yr^{-1}, respectively, for the past 100 yr (Fig. 5). The best estimate of historic sedimentation corresponds closely with the contemporary sediment accretion rates estimated using feldspar marker horizons (Table 3). The upper mixing zone was excluded from estimates and may reflect the high degree of bioturbation and mixing of sediments.

Excess ^{210}Pb activity in the French Island salt marsh core does not reflect contemporary sediment accretion. A high sedimentation event occurred approximately 15 yr ago, accreting sediment on the marsh surface at a rate of 20 ± 8 mm yr^{-1}. Prior to this, the historic sedimentation rate is low (1.4 ± 0.2 mm yr^{-1}) compared to contemporary estimates.

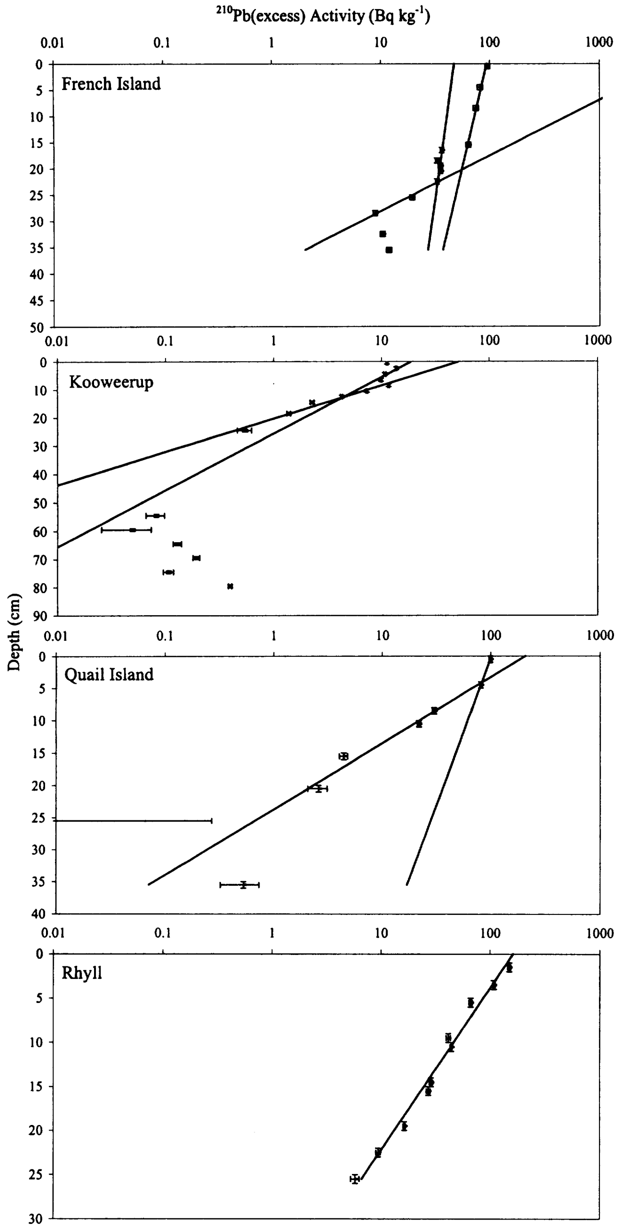

Fig. 4. Excess ^{210}Pb activity in sediments at various depths from cores extracted from the salt marsh at French Island, Kooweerup, Quail Island, and Rhyll, Western Port Bay.

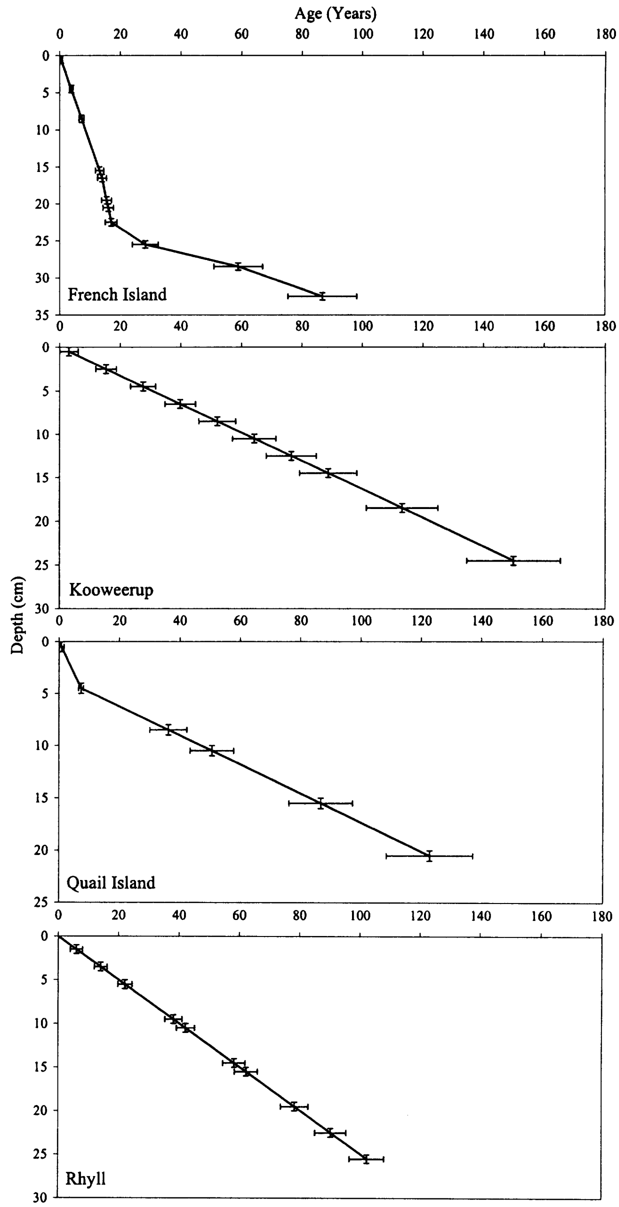

Fig. 5. Age of sediments at various depths from cores extracted from the salt marsh at French Island, Kooweerup, Quail Island, and Rhyll, Western Port Bay.

Discussion

Mangrove Encroachment in Western Port Bay

Detailed photogrammetric mapping of the *A. marina* community showed a pattern of greater change in the more developed sites. Salt marsh decline at all sites primarily occurred along tidal creeks draining the salt marsh where mangrove juveniles were observed encroaching along these creeks. Diminished horizontal movement of propagules by tides (Patterson et al. 1997) and favorable salinity, light, and sediment factors (Clarke and Allaway 1993) may enhance mangrove establishment along tidal drainage creeks.

It is evident that salt marsh decline was proportional to catchment development. The heavily affected site of Kooweerup, which is the northernmost site within Western Port Bay, exhibited the highest degree of mangrove expansion and salt marsh decline. Much of the earlier decline in salt marsh at this site can be attributed to the construction of the airport at Tooradin between 1939 and 1973, though since this time salt marsh

TABLE 3. Historic and contemporary sedimentation rates (±SE), determined from ^{210}Pb-dating of sediments and feldspar marker horizons, for study sites in Western Port Bay.

	Mean Contemporary Sedimentation		Upper Mixing Zone Sedimentation		Best Estimate of Historic Sedimentation		Other Sedimentation Events	
Site	Rate (mm yr^{-1})	Period (yr prior)	Rate (mm yr^{-1})	Period (yr prior)	Rate (mm yr^{-1})	Period (yr prior)	Rate (mm yr^{-1})	Period (yr prior)
French Island	4.26 (0.43)	0–3	12 (1) $r^2 = 0.9806$	0–13	1.4 (0.2) $r^2 = 0.9867$	16–58	20 (8) $r^2 = 0.7671$	13–16
Kooweerup	1.80 (0.31)	0–3	25.04 (42.05) $r^2 = 0.1081$	0–3	1.63 (0.16) $r^2 = 0.975$	3–52		
Quail Island	2.69 (0.56)	0–3	6.0 r^2 = na	0–4	1.4 (0.2) $r^2 = 0.975$	4–120		
Rhyll	1.65 (0.29)	0–3			2.5 (0.1) $r^2 = 0.9830$	0–100		

has continued to decline by 28% (between 1973 and 1999), while mangrove increased by 26%. The French Island site, located on the remote northern shore of the French Island National Park, exhibited the smallest degree of decline between 1973 and 1999 with salt marsh decreasing by 4% and mangrove increasing by 6%. The lower rate of mangrove encroachment on French Island may in part be attributed to a levee constructed between the mangrove and salt marsh in the 19th century as part of a salt works.

Quail Island, selected as a significantly less affected site due to the isolation of the island within a Nature Reserve, exhibited the second highest degree of decline with salt marsh decreasing by 12% and mangrove increasing by 32% between 1973 and 1999. Salt marsh decline at the Rhyll site, on the northern side of Phillip Island was in the order of 9% between 1973 and 1999, while mangrove increased by 8%.

When excluding the decrease in salt marsh that can be attributed to reclamation for the airport at Kooweerup and farmland at Rhyll, the rates of salt marsh decline in Western Port Bay are low compared to rates reported by Saintilan and Williams (1999, 2000) for estuaries in New South Wales. The median rate of decline in salt marsh due to mangrove encroachment over the same period in New South Wales estuaries was 30%.

Possible Causes of Mangrove Encroachment

There are a number of possible explanations for lower rates of mangrove encroachment in Western Port Bay than for estuaries in New South Wales. Temperature may be a factor since *A. marina* reaches its southern limit in nearby Corner Inlet, and colder air temperatures and frosts produce slower growth rates in mangroves (McMillan 1975; Saenger and Moverley 1985). The dense stands of saltbush species (*Halosarcia* and *Sclerostegia* spp.) is a characteristic of salt marshes in Western Port Bay. Saltbush may play an inhibitive role by either shading seedlings of *A. marina* or collecting sediments and building up the marsh surface to exclude mangroves. These species are absent in New South Wales except for a limited distribution of Halosarcia at Cararma Inlet and Homebush Bay. Similar competition has been reported between mangroves and *Spartina* sp. in marshes in Louisiana (McKee and Rooth 2003; Patterson et al. 1993) and *Phragmites* and *Spartina* spp. in Maryland (Rooth and Stevenson 2000).

Variation in the rate of encroachment between sites in Western Port Bay may be related to trends in marsh surface elevation. Changes in salt marsh relative elevation may play a significant role by increasing tidal inundation and creating environments suitable for mangrove establishment and habitation. A strong relationship exists between the rate of mangrove increase and the rate of salt marsh surface elevation change ($r^2 = 0.817$). Sites with large salt marsh surface elevation increases exhibit low rates of mangrove increase, while sites with salt marsh elevation deficits exhibit high rates of mangrove increase.

Factors Influencing Surface Elevation

Rates of sediment accretion commonly have been used as an estimate for marsh elevation. While it may be suitable to assume that accretion is the primary process controlling marsh elevation at some sites, this is not always appropriate. Recent literature featuring SETs document subsurface processes of autocompaction and subsidence of marsh sediments (Cahoon et al. 1995; Cahoon and Lynch 1997; Cahoon et al. 2000), decomposition of organic matter, root growth and increases in productivity (Cahoon et al. 1999), water storage in sediments (Cahoon et al. 1995; Cahoon and Lynch 1997; Cahoon et al. 1999), changes in the water table (Rogers et al. in press), and tidal flooding (Paquette et al. 2004) that may cause marsh elevation to differ significantly from accretion.

Rates of surface elevation change did not differ significantly from rates of sediment accretion in the salt marsh zone at French Island ($p = 0.316$), Quail

Island (p = 0.541), and Rhyll (p = 0.106). Marsh elevation in the salt marsh zone at these sites can be primarily explained by sediment buildup on the marsh surface. Since surface elevation does not differ from sediment accretion at these sites, the vulnerability of these salt marshes may be expressed as a deficit between sediment accretion and sea-level rise.

Since mangroves generally establish at lower tidal elevations and have higher inundation frequencies than salt marsh at Western Port Bay, sediment accretion was consistently higher in the mangrove zone than the salt marsh at all sites. Surface elevation change in the mangrove zone did not consistently exceed surface elevation change in the salt marsh. Sediment accretion significantly exceeded surface elevation change in the mangrove zone at all sites and the salt marsh zone at Kooweerup, indicating that marsh elevations at these sites is not solely explained by sediment accretion alone and that processes of autocompaction or subsurface subsidence are evident. A marked drop in surface elevation became evident from November 2001 to December 2002 at all sites except the salt marsh zone at French Island. This trend was particularly noticeable in all mangrove sites. A subsequent increase in surface elevation was evident at all sites with the exception of the Kooweerup salt marsh, which may have been affected by earth moving works in the vicinity.

The drop in marsh surface elevation corresponds to the period of the El Niño drought of 2002 to 2003 in southeastern Australia and was also observed at Homebush Bay, New South Wales (Rogers et al. in press) and Jervis Bay, Minnamurra River, Hawkesbury River, and Hunter River (Rogers et al. 2002). Current SET research highlights the role of belowground processes of water accumulation in maintaining marsh surface elevation. Correlations have been found between marsh surface elevation change and mean water table depth (Cahoon et al. 2002b) and marsh surface elevation change and total monthly rainfall (Rogers et al. in press). This study and SET research in southeastern Australia suggests that rainfall and subsequent groundwater recharge plays a significant role in determining interannual variability in surface elevation with respect to sea level.

Comparison of Contemporary and Historic Rates of Sedimentation

Several authors have commented on an elevated rate of sedimentation in Western Port Bay since the 1970s (Wilk et al. 1979; Hancock et al. 2001). The dieback of extensive seagrass beds on the eastern side of the bay has been attributed to this sediment. With the exception of the French Island site, there is no evidence in the salt marsh cores of any change in sedimentation rate over the past 60–100 yr. Unlike cores retrieved from the open bay by Hanckock et al. (2000), the cores presented in this paper show a consistent decline in excess ^{210}Pb after a shallow mixing zone. The cores imply that salt marshes are potentially a useful source of sediment chronology, given low biological activity and consequently low rates of bioturbation. Due to the high tidal elevation of salt marshes in Western Port Bay, sedimentation primarily occurs during spring tide events only, and may miss short-term pulses of sediment during neap tide phases.

The ^{210}Pb chronology for French Island suggests an increase in sedimentation rate beginning in approximately 1985. There is also a relatively deep surface mixing zone in this core. While corresponding to the suggested increased sedimentation within the bay, the result more likely reflects local changes in land use following the closure of market gardens on the northern shore of the island and inclusion of this area in the French Island National Park or the infilling of ponds used in salt manufacture in the 1880s.

Current rates of sedimentation measured by feldspar marker horizons correspond broadly with rates of sedimentation measured by the ^{210}Pb profiles. Since sedimentation rates measured by excess ^{210}Pb account for soil compaction, discrepancies between sedimentation measured by feldspar marker horizons and ^{210}Pb concentrations may be related to compaction of sediments over time and errors inherent in each measurement technique. These rates are high compared with salt marshes of similar geomorphology and catchment development in New South Wales (Rogers et al. 2002). Perhaps lower rates of encroachment is in part related to overall higher rates of sedimentation in the salt marsh at Western Port Bay.

Sedimentation, Surface Elevation, and Sea Level

Hancock et al. (2000) applied a 2-layer mixing model to interpret ^{210}Pb profiles from sediments in Western Port Bay by assuming that mixing was absent below the upper mixing zone and that excess ^{210}Pb in the lower layer decays according to its half-life. By applying these assumptions to the core at Kooweerup it is evident that sedimentation for the past 150 yr (1.63 mm yr^{-1}) closely correlates with contemporary sediment accretion. Assuming there has been no subsidence of sediments below the core extracted from Kooweerup and based on a long-term (32 yr) sea-level rise estimate from nearby Williamstown, sedimentation in the salt marsh at Kooweerup has exceeded sea-level rise, implying a buildup of the marsh surface relative to mean sea level. The same is true for the Rhyll and Quail

Island sites, where according to the 2-layer mixing model, sedimentation exceeds sea-level rise for the past 125 yr.

In the mangrove zone at French Island the rate of sediment accretion exceeded the rate of surface elevation change with the mangrove marsh elevation decreasing by 6.27 mm over the study period. Shallow compaction, being the deficit between sediment accretion and surface elevation change, was in the order of 11.53 mm yr^{-1}. The accumulative effects of high marsh compaction rates, low sedimentation rates, marsh surface elevation change, and an average sea-level rise of 0.26 mm yr^{-1} at nearby Williamstown (Mitchell et al. 2000) suggest that the mangrove forest at French Island is not sustainable under current sedimentation regimes, climate conditions, and long-term sea-level rise trends (32 yr of data at Williamstown).

Statistical analysis of surface elevation change in the mangrove zone at French Island indicates that rates of surface elevation change varied significantly over time ($p < 0.001$) and do not represent consistent trends, primarily due to the relationship between marsh surface elevation and the El Niño related drought. Sea level at nearby Stony Point has decreased by 21.8 mm yr^{-1} over the study period. When comparing short-term surface elevation change with long-term sea-level rise, there is a deficit between the rate of marsh surface elevation increase (22.0 mm yr^{-1}) and sea-level rise (+0.26 mm yr^{-1}) in the order of 22.26 mm yr^{-1}. When comparing the short-term rates of surface elevation change (22.0 mm yr^{-1}) with short-term changes in mean sea level over the study period (221.8 mm yr^{-1}), there is a marsh elevation increase relative to mean sea level in the order of 19.8 mm yr^{-1}. Since a consistent trend of marsh elevation change is not evident at French Island and is not sustainable when compared to long-term sea-level rise data, we suggest that it is more appropriate to compare short-term rates of surface elevation change with short-term changes in means sea level. The same is true for Kooweerup where the rate of surface elevation change relative to mean sea level over the study period was 21.6 mm yr^{-1} in the mangrove zone and 21.5 mm yr^{-1} in the salt marsh zone.

The salt marsh zone at French Island was the only site that exhibited a consistent trend of marsh surface elevation increase over the study period, increasing at a mean rate of 5.21 mm yr^{-1}. While there was no net surface elevation decrease in correlation with the recent drought, the rate of surface elevation increase was significantly less ($p < 0.001$) increasing at a rate of 8.79 mm yr^{-1} during October 2000 to November 2001 and 1.73 mm yr^{-1} during December 2002 to November 2003. This may be partly related to the accumulation of water in abandoned salt evaporation ponds at the site. Comparisons of mean rates of salt marsh surface elevation increase with long-term sea-level trends indicates that under current sedimentation and hydrological conditions, the marsh elevation has increased relative to mean sea level in the order of 4.95 mm yr^{-1}. It is difficult to determine the extent to which surface elevation may correspond to sedimentation history over the longer period when belowground processes are not measured. Analysis of foraminiferan assemblages within the profile would go some way to resolving this issue, in that the elevation with respect to sea level could be estimated through the core (Edwards and Horton 2000; Horton et al. 2003).

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