Eroding landforms within the Port Davey ria estuary complex: wave wake or sea level rise?

Monitoring report for the decade 2000 – 2010

Tasmania

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Summary

The Port Davey region and its catchment area lie entirely within the Tasmanian Wilderness World Heritage Area and are in largely natural condition. Several discrete sub-estuaries contain a complex assemblage of depositional Holocene landforms that, due to their intimate genetic association with flora (and possibly fauna) of Gondwanan affinity, are probably globally unusual if not unique. Despite the depositional context a monitoring programme first established in 1992 has consistently recorded widespread erosion at a rate of a few millimetres per year. This paper reports some monitoring results and geomorphological observations collected over the past decade and makes the following recommendations with respect to management of vessel wave wake:

- maintain the existing five knot speed limit in Melaleuca Inlet and Creek;
- introduce a five knot speed limit on the Davey River upstream of Brookes Reach,
- close Manwoneer Inlet to motorised boating,

While many of the bank types present are susceptible to vessel wave wake the distribution of erosion indicates that wake is not the principle cause of the erosion recorded. It is concluded that sea level rise presents the most likely mechanism to effect the observed erosion and that in the otherwise essentially undisturbed Port Davey catchment estuarine change from a depositional to erosional regime is a clear marker of the onset of the Anthropocene epoch (in which the geological record is characterised by significant human influence). Continuation of the monitoring programme and a series of further geoscientific investigations into the geomorphic response to climate change including mapping, monitoring and process studies are also recommended.

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Introduction and previous work

The well developed trellised ria, or drowned valley estuary, of Port Davey (figure one) is the largest coastal embayment completely within the Tasmanian Wilderness World Heritage Area. Several of the rivers draining into it are navigable by boat in their lower reaches and Bramble Cove east of the Breaksea Islands has been visited by large cruise ships. Following clear demonstration that the wave wake of motorised vessels was responsible for catastrophic bank erosion on the lower Gordon River and anecdotal suggestions that Melaleuca Inlet and Creek might be similarly affected, Dixon (1992) established an erosion monitoring programme. Follow up measurements and further streambank stability assessments were conducted by Dixon (1993), Pemberton (1995) and Bradbury (1995), with a 5 knot speed limit for the upper Inlet and Melaleuca Creek being signposted under National Parks and Reserved Land Regulations in early 1995.

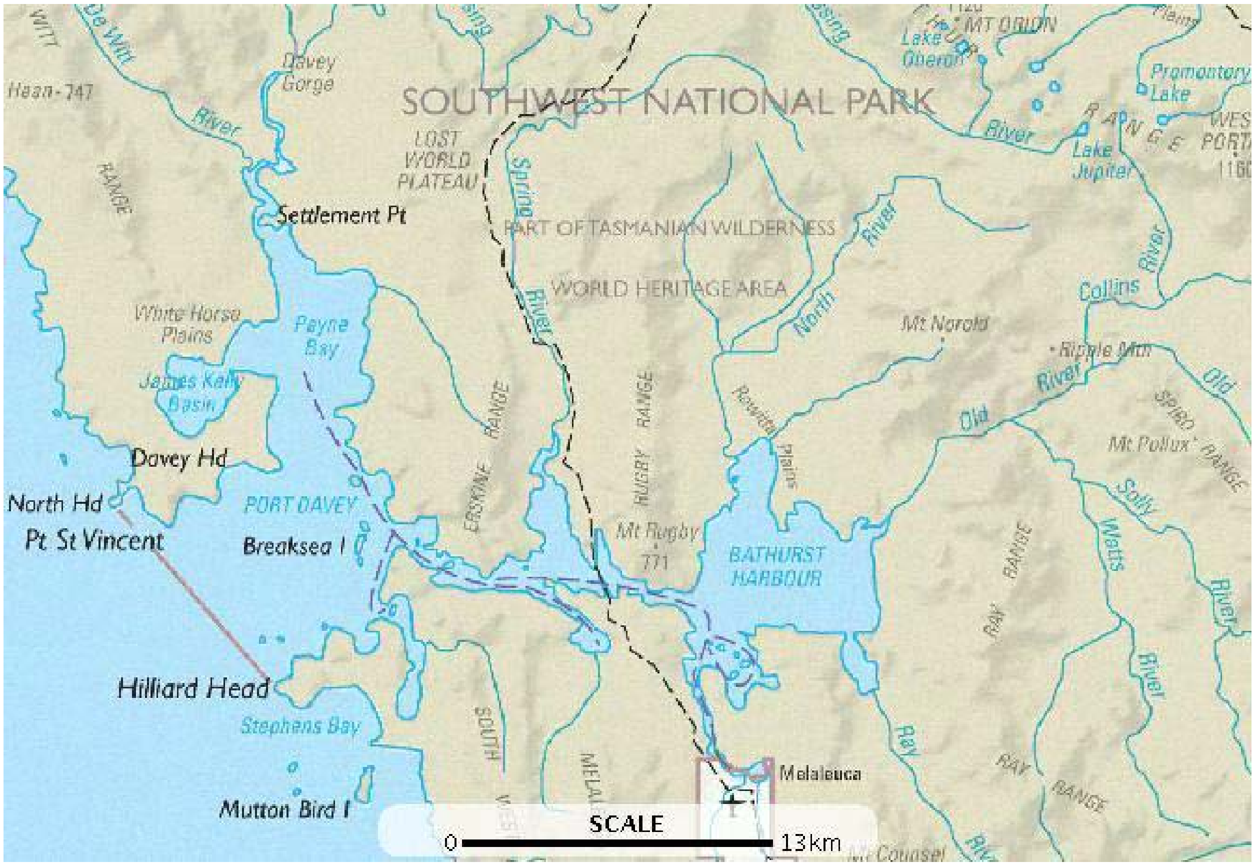

Figure 1: LIST map (2010) of the Port Davey region of south west Tasmania. In this report the term Port Davey is used not in strict nomenclatural sense but to encompass all navigable waterways upstream of a line drawn between North and Hilliard Heads.

Erosion pin measurements were again collected by Dixon (1997a) when he provided reconnaissance bank type mapping of navigable reaches of the Spring, North and Old River estuaries and established an erosion monitoring programme in each. All monitoring sites were remeasured later that year (Dixon 1997b) and the Davey River estuary was added to the monitoring programme. Additional measurements were reported by Bradbury (2000). Since then no further detailed reports have been prepared but further monitoring was undertaken in November 2001 (partial), February 2003 (partial), March 2005, July 2008 (Melaleuca Inlet and Creek only) and March 2010 (partial). Conditions allowing safe dinghy access to the Davey River from Melaleuca within working time constraints have infrequently been met, meaning those sites have been monitored less often than ideal.

This report documents monitoring results for the decade 2000 – 2010 and updates assessment of the geomorphic significance of vessel wave wake in the Port Davey region. It also attempts to place erosion measurements and other observations within geomorphological context of rising sea level.

Geomorphological outline

Estuaries are typically relatively low energy, depositional environments supplied with sediment from more energetic fluvial and marine sources. The basic sedimentological model of estuarine development and process (Dalrymple *et al.* 1994) comprises three zones distinguished on that basis; an outer zone of marine influence, a middle zone of low energy characterised by muds (often autochthonous, ie. biotically generated essentially *in situ*) and an upper fluvially dominated zone of coarser sediment. As such the rivers investigated here are regarded as estuaries within an estuary. A distinct change of scale, wave climate and fluvial influence occurs upstream from each river mouth and each river separately repeats the wave – tide – river dominated tripartite zonation of the broader estuary at a smaller scale and with more fluvial energetics.

Whilst the gross physiography of the estuarine basin (figure two) was inherited from earlier periods of landscape development, the complex assemblage of littoral and supratidal landforms that hold the focus of this report are unified in their development solely in response to Holocene sea level rise and still-stand. Throughout the Quaternary glacial cycles with their associated sea level fluctuations the basin would have been alternately alluvial and shallow marine. During the last interglacial (around 125 thousand years ago) global sea level is estimated to have been approximately 8.7 m higher than at present (Kopp *et al*. 2009). However mounting evidence suggests that the Tasmanian landmass is being slowly and somewhat unevenly uplifted. Raised sea cliffs at Elliot Bay suggest that in south west Tasmania the last interglacial sea level may have been up to 20 m higher than now. A lack of obvious Pleistocene estuarine landforms at or near that elevation suggests that these were stripped from the periglacial landscape and that the emergent ria infill has little preservation potential over geological time, unless transgression is maintained until the present coast is submerged below wave base.

The end of the Last Glacial epoch is indicated by a radiocarbon age of 11 760 ± 160 years obtained from basal peat exposed in the small scale Melaleuca tin workings (Thomas 1995). The present estuary is not expected to have commenced forming before the Holocene marine transgression started slowing within a few metres of present sea level around 7500 years ago. Flooding of the once terrestrial drainage system would have significantly lowered the geomorphic energy budget and initiated deposition of bedload gravel and suspended sand, mud and organic matter within the new estuary. Of the five inner estuaries investigated only the lower Davey River hosts any sand of marine origin, although the North and Old Rivers mouths may have been supplied with wave transported “Bryozoan ooze” (N. Barrett pers. com.) or sponge spicules (Reid *et. al* 2008) sourced from the shallow bed of Bathurst Harbour.

The inner estuaries have now been filled to varying extent with mud, overlain in part by a prograding alluvial sequence. Much of the estuarine system is subject to saline stratification and fresh water input from the catchment is strongly coloured. Extensive subtidal and littoral mudflats at expansion points in the fresh water channels suggest that flocculation of suspended sediment at the salt wedge boundary is a significant landforming process. Fluvial discharge and the micro-tidal prism maintain distinct and typically single thread channels as partly confined (Melaleuca, Spring, Davey, Old) or unconfined (North) systems through subtidal flats, which appear to be otherwise undergoing vertical accretion. Once a subtidal surface attains an elevation suitable for vegetative colonization it is suggested that successional development leads to accelerated subaqueous sediment generation and trapping, emergence and then lateral expansion of an upper- to supratidal surface. With maturation of the terrestrial vegetation and continued growth in landform elevation the clastic input diminishes because the frequency of overbank deposition is reduced, however accretion of organic matter continues. Coarse clastic material is generally only present near the upstream limits of navigation, which approximate the level of tidal influence. Above that point smaller and purely fluvial channels meander across drowned valley fill as they prograde their alluvium downstream.

Secondary influences on geomorphic development include:

- the fluvial hydrology of a wet temperate maritime catchment in largely natural condition, typified by blanket bogs and offering limited nutrient and sediment supply,
- local vegetation type, sediment trapping effects and organic matter production,
- local wave climate,
- underlying geology and local structural control.

Those influences are additionally overlain by the effect of significant seasonal and event driven fluctuations in fluvial base level and salt wedge penetration, resulting in shifting zones of clastic and floc sedimentation respectively. Only a cursory geomorphological description of individual rivers is provided here, for additional detail see Dixon (1997a and b) and Bradbury (2000). Despite the depositional setting and Holocene history, indicators of active or recent erosion (figure three) are almost ubiquitous and very few of the extant landforms appear subject to ongoing deposition.

Figure 2: view downstream and to west of Bathurst Channel and Narrows ria, photo: Fiona Rice.
Figure 3: exposed roots and isolated stump are evidence of recent shoreline retreat, north eastern Melaleuca Lagoon January 2000.

Methods

The rate of stream and estuarine bank erosion is determined by repeated measurement of erosion pins (Wolman 1959) installed perpendicular to the bank face, with multiple pins installed at each of 27 sites.

The pins are uniquely numbered lengths of 3/16” diameter stainless steel rod and all rust prone mild steel pins initially used have long been replaced. Change in the exposed length of pins between measurements represents the nett geomorphic change that occurred during the monitoring period. Measurements are normalised and reported as a rate in mm/year, thus allowing comparison of monitoring periods of varying length.

Following counterintuitive convention arising from the use of *erosion* pins negative values represent deposition. Monitoring sites can only be located on accessible banks or where measurement may be taken from the dinghy used, a fact that somewhat biased initial site placement toward the erosional end of the spectrum. Where possible additional pins have subsequently been installed in potentially depositional locations in attempt to offset that bias however a method of obtaining accurate measurement from subtidal pins installed in low bulk density sediment without causing extensive trampling disturbance has not yet been devised.

Pin measurement was most recently undertaken on 22 – 26 March 2010 together with a brief geomorphological assessment at each site to assist data interpretation. Conditions did not permit access to the Davey River. Eleven new pins were installed and a total of 183 measurements taken, returning 167 values for erosion rate. Rates are not returned if a pin was considered to have influenced local erosion, for example those showing coning or slotting at the base of a bent pin suggestive of disturbance by floating debris (or perhaps trampling). Such pins are straightened if necessary and reset nearby to remain in the monitoring programme but the datum from the affected monitoring period discarded. Pins may also be lost from the programme, by either erosion or failure of relocation effort. Potential for loss by erosion is assessed on site, if considered likely the average site erosion rate may be flagged as a possible underestimate. However such demonstration of the limits of the technique are uncommon and most pin losses appear temporary result of placement to minimise detection and trampling. In other words sites are unmarked and pins deliberately hidden from casual observation, therefore sometimes difficult to relocate.

Erosion pin measurements are reported for each river in text and as a spatial function for the most recent monitoring period only, providing indication of the present rate of geomorphic process. A ‘regime’ average over the life of the monitoring programme is also plotted, as are erosion time series according to bank type. Additional time series statistics are also tabulated.

Results

Melaleuca Inlet and Creek

With the smallest catchment area and greatest extent of relatively open waters the Melaleuca system appears to be the least infilled of the five inner estuaries monitored. Extensive peats demonstrate a very high ratio of autochthonous biological productivity to clastic sediment input. In general the banks of Melaleuca Inlet may be described as estuarine and those in Melaleuca Creek as alluvial. Peatland streams typically have a very low width to depth ratio and an almost square channel cross section; Melaleuca Creek is no exception. The generally subvertical banks show cantilever failure on some outside bends but otherwise mere steepness is not necessarily indicative of erosion.

Figure 4: oblique aerial photograph of marginal reed bed and incipient estuarine terrestrialisation in Melaleuca Inlet, with enigmatic peat mounds prominent in the background.
Figure 5: a variety of estuarine bank morphologies at low tide in Melaleuca Inlet, from left to right: root free, exposed roots, trampled (possible marsupial water access), reeds. Both photos July 2008.

During the period July 2008 to March 2010 the recorded rate of:

- estuarine bank erosion ranged from -2 – 13 mm/yr, with a mean of 3.8 mm/yr from 45 measurements at 6 sites. Two pins recorded no change while 1 pin showed deposition;
- alluvial bank erosion in management zone one (trafficked area downstream pontoon landing) ranged from -2 – 2 mm/yr, with a mean of 0.4 mm/yr from 12 measurements at 3 sites. Two pins recorded no change while 3 showed deposition
- alluvial bank erosion in the less frequently trafficked zone 2 (upstream pontoon landing) ranged from -3 – 5 mm/yr, with a mean of 1.8 mm/yr from 15 measurements at 3 sites. One pin recorded no change while 3 showed deposition.

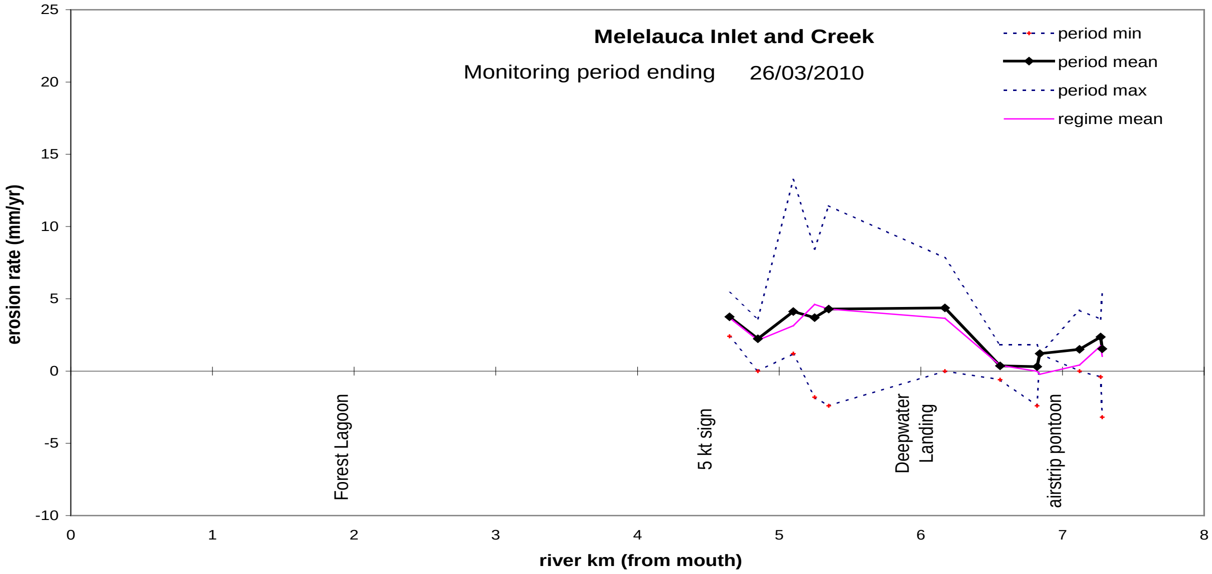

Figure 6: distribution of erosion in Melaleuca Inlet and Creek during the most recent monitoring period.

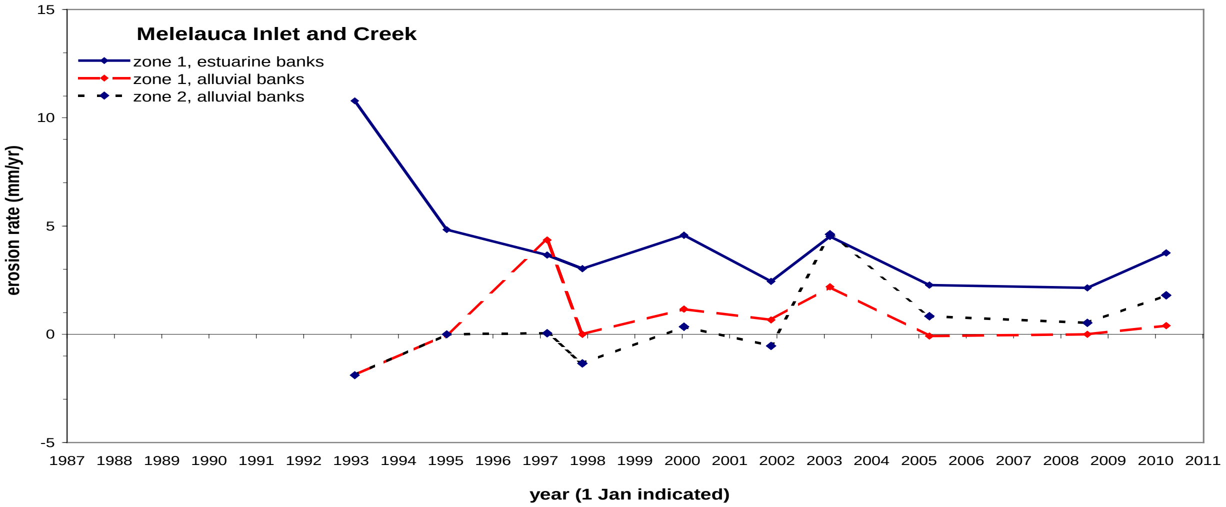

Figure 7: time series plot of erosion in Melaleuca Inlet and Creek.

Table 1: Melaleuca Inlet and Creek erosion statistics according to bank type and management zone. For this and subsequent similar tables minimum (min), maximum (max), mean and standard deviation (stdev) are reported in millimetres per year. The percentage of pins recording negative erosion (% < 0) or no change (% = 0) during each monitoring period are measures of the extent of on-going estuarine deposition and stability respectively.

	date	**count**	**min**	**max**	**mean**	**stdev**	**% < 0**	**% = 0**
estuarine	30/01/1993	10	1.9	37.8	10.8	10.8	0	0
	10/01/1995	10	0.0	9.8	4.8	3.5	0	10
	24/02/1997	17	-0.5	23.5	3.7	5.9	6	6
	22/11/1997	20	-9.4	13.5	3.0	4.7	5	25
	16/01/2000	18	-4.7	37.0	4.6	9.2	6	17
	18/11/2001	21	-0.5	8.1	2.4	2.3	10	0
	15/02/2003	26	1.6	11.3	4.5	2.6	0	0
	24/03/2005	35	0.0	5.2	2.3	1.4	0	9
	25/07/2008	34	-4.8	4.5	2.1	1.8	3	9
	26/03/2010	45	-2.4	13.3	3.8	2.8	4	4
zone 1 alluvial	30/01/1993	1	-	-	-1.9	-	100	0
(ds pontoon)	10/01/1995	1	-	-	0.0	-	0	100
	24/02/1997	4	-0.5	17.4	4.4	8.7	25	25
	22/11/1997	1	-	-	0.0	-	0	100
	16/01/2000	4	0.0	3.7	1.2	1.8	0	50
	18/11/2001	9	-2.2	3.3	0.7	1.8	22	22
	15/02/2003	17	-0.8	4.9	2.2	1.8	12	6
	24/03/2005	17	-2.8	1.9	-0.1	1.4	24	35
	25/07/2008	16	-2.4	3.0	0.0	1.5	44	6
	26/03/2010	12	-2.4	1.8	0.4	1.4	25	17
zone 2 alluvial	30/01/1993	1	-	-	-1.9	-	100	0
(us pontoon)	10/01/1995	-	-	-	-	-	-	-
	24/02/1997	5	-0.5	0.5	0.0	0.5	40	0
	22/11/1997	4	-2.7	0.0	-1.3	1.1	75	25
	16/01/2000	4	-0.9	2.8	0.3	1.7	50	25
	18/11/2001	7	-4.3	1.6	-0.5	2.1	43	0
	15/02/2003	13	-3.2	9.7	4.6	3.4	8	0
	24/03/2005	15	-1.4	5.7	0.8	1.7	13	33
	25/07/2008	12	-0.9	1.2	0.5	0.6	8	8
	26/03/2010	15	-3.2	5.4	1.8	2.3	13	7

Spring River

The Spring River maintains a distinct meandering channel through the muddy bed of the otherwise very shallow Manwoneer Inlet. Upstream, the navigable reaches lie within a 400 – 800 m wide floodplain with maximum elevation 2 – 3 m above sea level. At the limit of navigation the bedload consists of pebbles and cobbles but below the tightly meandering, fluvially dominated reaches the bank sediments are typically muddy to peaty. Alluvial sands are relatively minor, most obviously occurring as small point bar deposits or narrow, low levees. All landforms and sedimentary facies observed are consistent with the model of Holocene in-filling of a ria estuary. Despite the broadly depositional setting indicators of erosion such as scarps and exposed roots are common, although few erosional features appear active and in several instances scarps have been partly buried under more recent sediment. In estuarine reaches scarps typically have a moderate to thick coating of fibrous green algae.

Figure 8: oblique Google Earth overview of the lower Spring River and Manwoneer Inlet.
Figure 9: left bank of upper Manwoneer Inlet showing estuarine landforms, March 2010.

During the period March 2005 to March 2010 the recorded rate of:

- estuarine bank erosion ranged from -5 - 10 mm/yr, with a mean of 1.8 mm/yr from 16 measurements at 3 sites. All pins recorded some change while 3 pins showed deposition;
- alluvial bank erosion ranged from -3 - 47 mm/yr, with a mean of 3.8 mm/yr from 31 measurements at 5 sites. One pin recorded no change while 9 showed deposition.

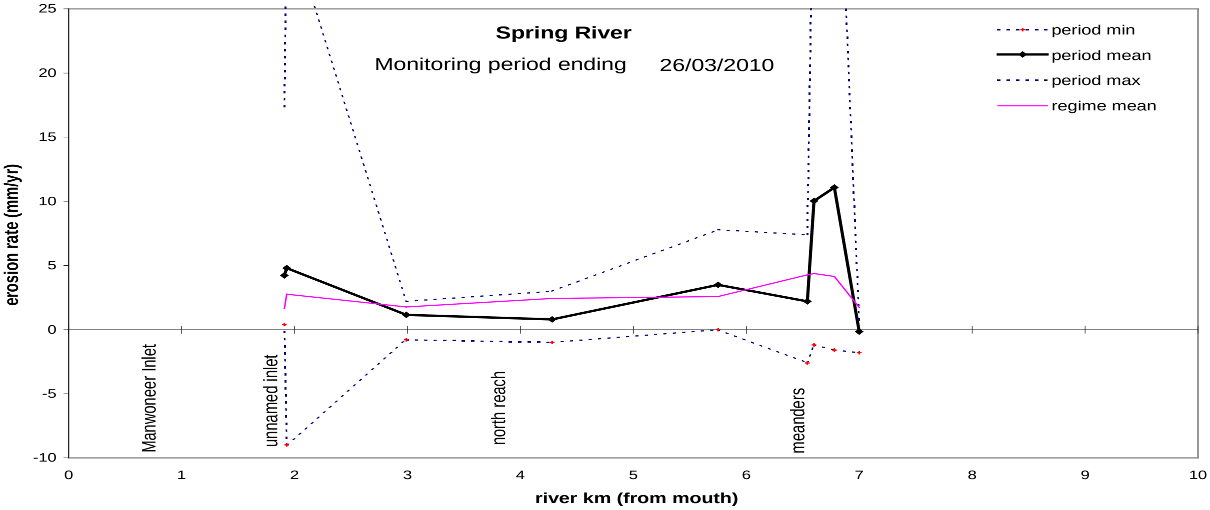

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Figure 10: distribution of erosion recorded in the lower Spring River during the most recent monitoring period.

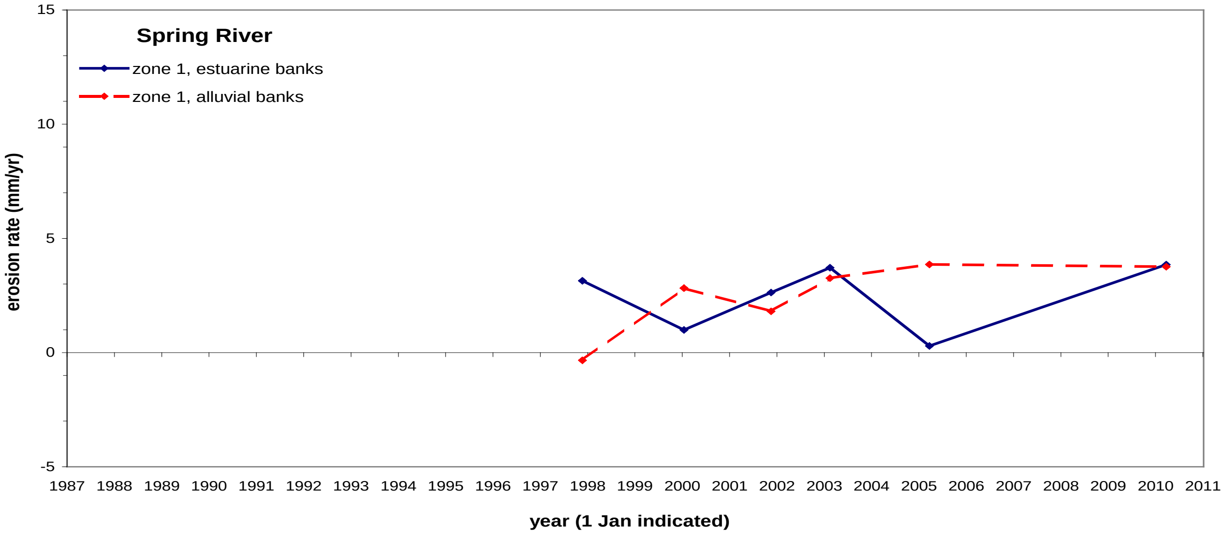

Figure 11: time series plot of erosion in the lower Spring River.

Table 2: Spring River erosion statistics according to bank type.

	date	count	min	max	mean	stdev	% < 0	% = 0
estuarine	22/11/1997	3	1.3	5.4	3.1	2.1	0	0
	16/01/2000	8	-3.7	3.7	1.0	2.2	13	13
	18/11/2001	12	-0.5	12.0	2.6	3.5	8	17
	15/02/2003	12	0.0	10.4	3.7	3.0	0	17
	24/03/2005	18	-36.2	6.7	0.3	9.3	6	11
	26/03/2010	16	-9.0	32.1	3.9	9.2	19	0
alluvial	22/11/1997	8	-4.0	2.7	-0.3	2.7	38	25
	16/01/2000	15	-0.9	9.3	2.8	3.2	20	0
	18/11/2001	19	-3.3	20.7	1.8	5.6	37	0
	15/02/2003	22	-3.2	13.5	3.3	4.3	18	5
	24/03/2005	30	-0.5	30.0	3.9	5.7	3	10
	26/03/2010	31	-2.6	46.9	3.8	10.8	29	3

North River

The North River maintains a diffuse channel through the outer lobe of an unconfined muddy sub-littoral delta on the western shore of North Inlet. The simple funnel shaped estuary narrows from approximately 80 m wide near the mouth to 10 m at the tidal limit about two km upstream. Several abandoned channels are visible from the air, some are largely filled but others remain as narrow inlets draining the low, tidally dominated fluvio-estuarine floodplain. Sediments generally consist of organic rich muds although sand content may increase upstream as the tidal limit is approached.

Sometime between 2005 and 2008 a double meander cutoff occurred at the prominent bar representing the former limit of navigation (figures 12 and 13). The downstream end of the partially abandoned channel is now marked by a silt draped cobble bar that together with low water level at the time of the most recent visit prevented access to two alluvial bank sites further upstream. The reopened channel has a shallow, silt free cobble bedload and was similarly unnavigable.

Figure 12: former configuration of the lower North River c1988 (TasVeg orthorectified aerial photograph mosaic).
Figure 13: oblique aerial view of double meander cut off at high tide 25/7/2008, north to left.

The North River represents an advanced stage of Holocene estuarine in-filling and adjustment to present sea level while limited fetch indicates that a very low energy wave climate prevails within the inner estuary. As such this is regarded the most sensitive to the wave wake of motorised traffic of the five estuaries investigated. During the period March 2005 to March 2010 the recorded rate of:

- estuarine bank erosion ranged from -4.6 - 10 mm/yr, with a mean of 1.8 mm/yr from 27 measurements at 3 sites. All pins recorded some change while 5 pins showed deposition;
- alluvial bank erosion ranged from -0.2 - 38 mm/yr, with a mean of 12.9 mm/yr from 3 measurements at 1 site.

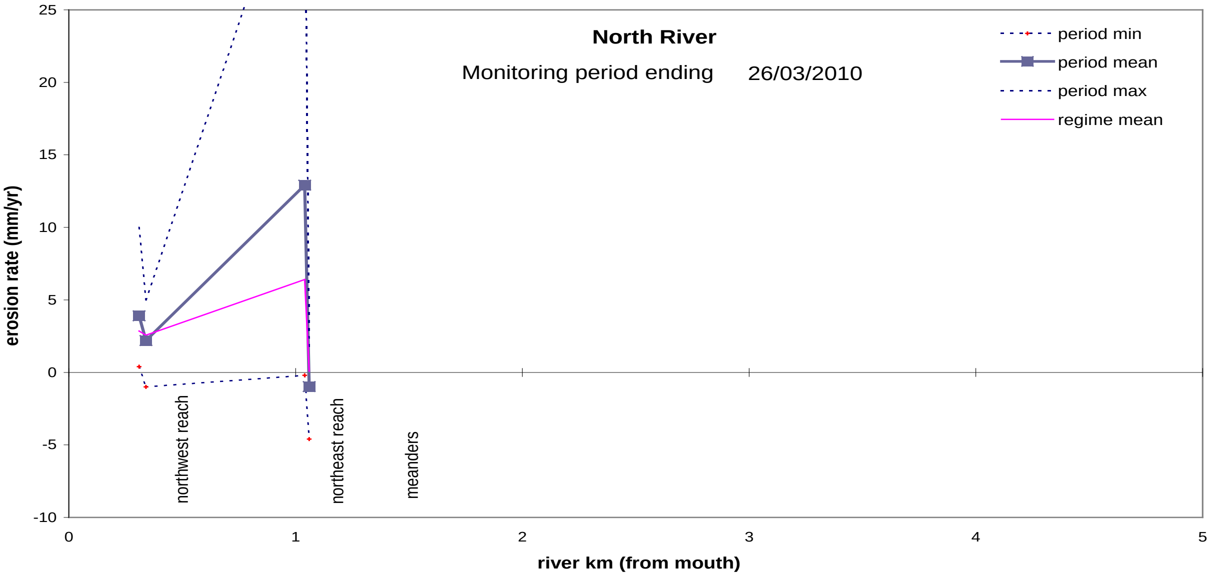

Figure 14: distribution of erosion recorded in the lower North River during the most recent monitoring period.

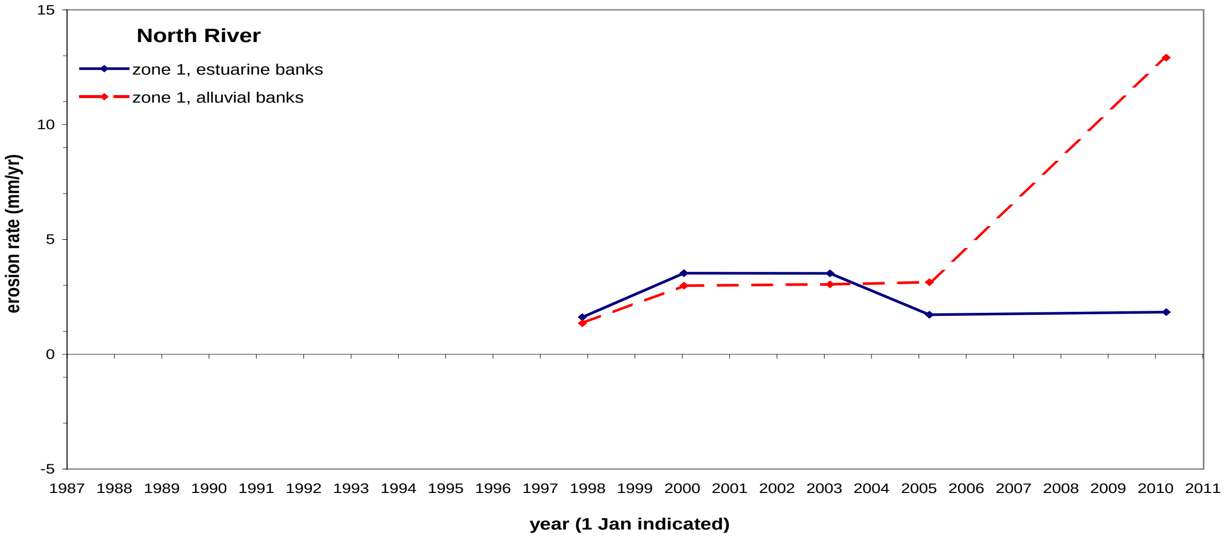

Figure 15: time series plot of erosion in the lower North River.

Table 3: North River erosion statistics according to bank type.

	date	count	min	max	mean	stdev	% < 0	% = 0
estuarine	22/11/1997	5	-2.7	4.0	1.6	2.9	20	20
	16/01/2000	7	2.3	5.1	3.5	0.8	0	0
	15/02/2003	13	0.0	8.1	3.5	2.5	0	8
	24/03/2005	27	-18.5	9.0	1.7	4.7	11	4
	26/03/2010	27	-4.6	10.0	1.8	3.4	19	0
alluvial	22/11/1997	4	0.0	2.7	1.3	1.6	0	50
	16/01/2000	7	1.4	4.6	3.0	1.3	0	0
	15/02/2003	8	0.0	7.8	3.0	2.9	0	13
	24/03/2005	15	-2.3	23.3	3.1	5.9	13	13
	26/03/2010	3	-0.2	37.6	12.9	21.4	33	0

Figure 16 a and b: a pair of slightly misaligned photomonitoring images taken in 2000 and showing stromatolitiform saltmarsh with marsupial lawn. Corresponding 2010 photos are unsuitable for reproduction, however no change could be detected at the limit of image resolution and even the apparently recently toppled block in the left foreground of the right image maintained the same approximate size and geometry in 2010.

Old River

The Old River has formed a largely subtidal muddy delta at the northeastern corner of Bathurst Harbour. Upstream from the shelter of the unnamed eastern headland the river channel narrows rapidly. It lies within a muddy, high organic matter content estuarine floodplain that remains a relatively constant 700 m wide to the islet at the limit of navigation, where it too begins to narrow rapidly. Again, all landforms and sedimentary facies observed are consistent with a model of Holocene in-filling of a ria estuary, and hence a broadly depositional geomorphic setting. However, evidence for recent, apparently natural, erosion is common, most notably in the vicinity of the islet and on the relatively exposed left bank downstream from Ngyena Creek, where root exposure and bleaching indicates retreat of several metres over a multi-decadal timescale.

During the period March 2005 to March 2010 the recorded rate of:

- estuarine bank erosion ranged from 0.4 – 4 mm/yr, with a mean of 2.3 mm/yr from 10 measurements at 1 site. All pins recorded some change while none showed deposition;
- alluvial bank erosion ranged from -2 - 14 mm/yr, with a mean of 3.9 mm/yr from 8 measurements at 2 sites. One pin recorded deposition and one no change.

One alluvial bank site was inaccessible due to the strength of the current at the time of inspection.

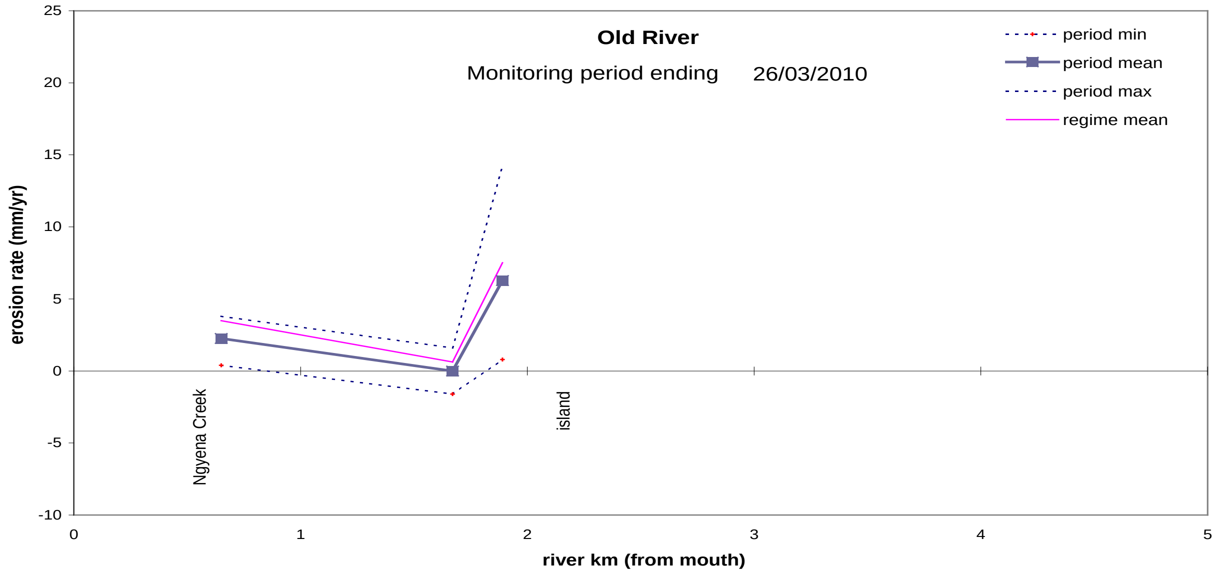

Figure 17: distribution of erosion recorded in the lower Old River during the most recent monitoring period.

Table 4: Old River erosion statistics according to bank type.

	date	count	min	max	mean	stdev	% < 0	% = 0
estuarine	22/11/1997	4	0.0	5.4	2.4	2.3	0	25
	16/01/2000	6	3.3	32.2	9.5	11.3	0	0
	15/02/2003	6	1.0	3.9	2.7	1.3	0	0
	24/03/2005	9	0.0	2.8	1.9	1.0	0	11
	26/03/2010	10	0.4	3.8	2.3	1.0	0	0
alluvial	22/11/1997	4	0.0	4.0	2.0	1.7	0	25
	16/01/2000	8	-6.5	5.1	1.1	3.5	13	13
	15/02/2003	11	-0.6	13.9	2.6	4.2	9	36
	24/03/2005	14	-0.9	30.9	5.4	9.0	7	29
	26/03/2010	8	-1.6	14.2	3.9	5.5	13	13

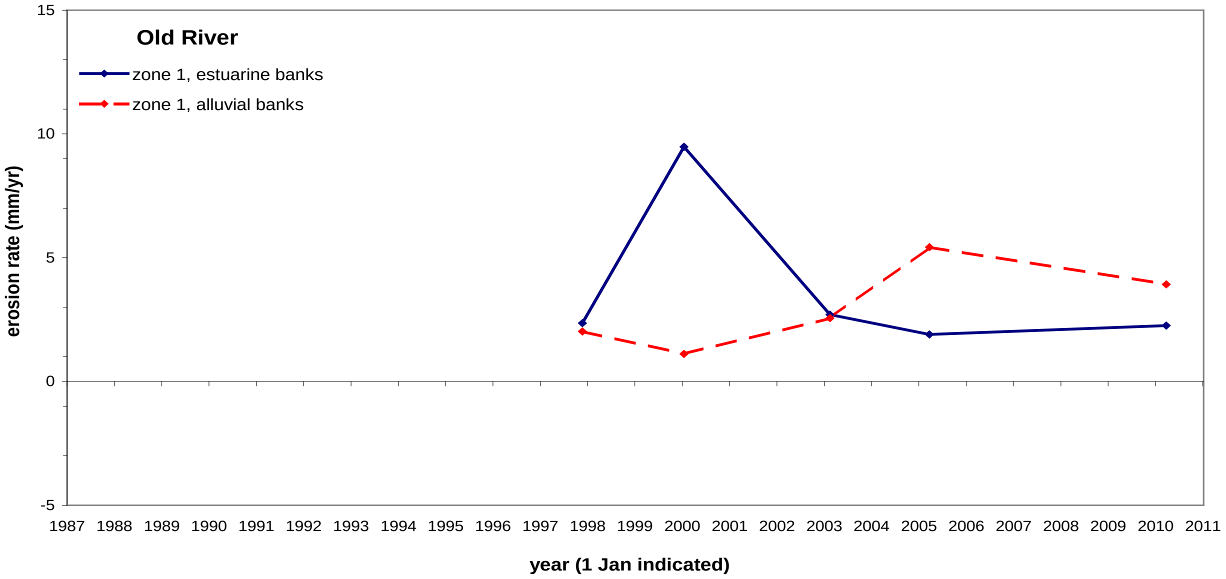

Figure 18: time series plot of erosion in the lower Old River.

Figure 19: eroding Old River saltmarsh, right bank near mouth.
Figure 20: Old River alluvial bank showing layering and cantilever failure. A buried cobble bed lies about 50 cm below water level.

Davey River

In contrast to the cross-strike Bathurst arm of the ria, the Davey arm lies along strike. The lower Davey estuary appears more deeply incised (RAN 1978) toward low Pleistocene base level and less completely filled than the other systems studied (figure 21). The shallow barway at the mouth of the Davey River and the presence of pebbly sand on the western (river) shore of Settlement Point suggest a relatively high degree of marine influence on the geomorphic processes operating in the lowermost reach. Upstream a broad central estuarine basin of irregular width extends to the northern end of Brooks Reach. This is only partly encroached upon by the distinct delta of the De Witt River and locally extensive reed beds. Most of the banks are relatively exposed to the action of locally generated waves and many face a potential fetch in excess of a kilometre.

Figure 21: oblique Google Earth (2010) image of inner Davey estuary from Piners Point to Davey Gorge.
Figure 22: Davey River estuarine bank.

Above the upstream end of Brooks Reach the estuary width becomes more consistent, progressively narrowing from 150 m to 50 m around 5 220 000 N. The slope of the tidally immersed channel margins appears to increase inversely, from gentle to sub-vertical, with a return to relatively low gradients and the first appearance of conspicuous but minor alluvial sand above Gathering Island. This channel geometry suggests a relatively high hydraulic gradient occurs immediately downstream of the islet, although the magnitude of the hypothesized slope is constrained by observational evidence that the fairweather tidal limit extends to Davey Gorge.

Again, all landforms and sedimentary facies observed are consistent with partial Holocene in-filling of a drowned valley estuary. Indicators of both erosion and deposition, generally recent rather than active, are widespread. The Davey is the largest, least accessible via Melaleuca and perhaps also the most complex of the estuaries investigated.

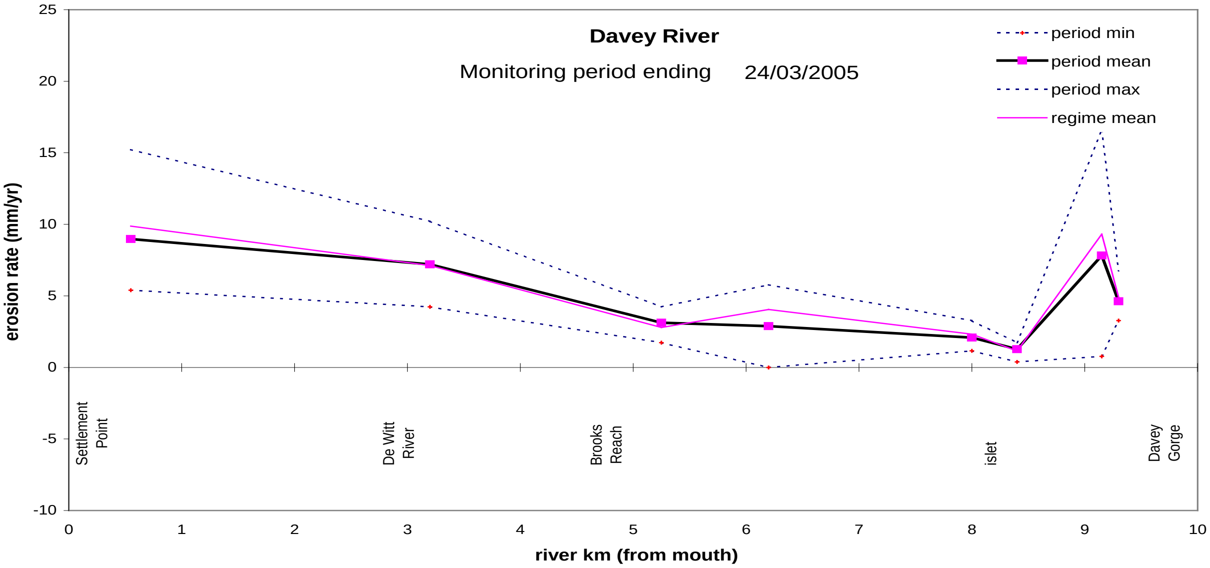

Figure 23: distribution of erosion recorded in the lower Davey River during the 2000 - 2005 monitoring period.

Table 5: Davey River erosion statistics according to bank type.

	date	count	min	max	mean	stdev	% < 0	% = 0
estuarine	16/01/2000	17	-2.3	19.6	6.8	5.7	6	6
	24/03/2005	28	0.0	16.6	6.0	3.9	0	4
alluvial	16/01/2000	7	0.5	6.1	1.9	1.9	0	0
	24/03/2005	11	0.4	3.3	1.7	0.8	0	0

Bathurst Channel and Narrows

Out of concern for potential ship wake impacts these shores were reconnoitered for susceptible sediments in 2003. ‘Soft’ materials occupy only a few percent of the total shoreline, mostly in bay head locations. Sands and coarser clasts form pocket beaches (eg. Bramble Cove, Balmoral) with small creeks providing some sediment to Schooner Cove and elsewhere. Beaches are wave dominated landforms and not regarded as particularly susceptible to ship wake.

Estuarine muds and ‘marsupial lawn’ saltmarsh have colonized the upper levels of some of the beach sands and also the occasional shore platform. In the latter context *ad hoc* photo monitoring suggests some retreat however the erosive process appears to be tidal draw-down induced sapping rather than high tide wave action (figure 24).

Figure 24: ‘marsupial lawn’ salt marsh on the shore of Bathurst Channel south of Little Louisa Island in 2003 (left) and 2010 (right, photo Chris Sharples).

Discussion and conclusions

Estuaries and saltmarsh are commonly regarded significantly productive ecosystems. Within a context of extremely low nutrient status (Edgar *et al.* 1999), the extent of autochthonous sediment and biomorphic landform systems suggest those in the Port Davey are no exception. Much of the terrestrial organosol blankets an essentially inert quartzite substrate and is inferred to have developed primarily by vegetative fixation of atmospheric CO_2, dust and marine salts. With growth the saturated ‘peat’ pile accumulates largely vertically but in absence of any constraining barrier would also be expected to spread laterally. Since the organosols are typically both cohesive and interlaced with living roots subvertical bank faces are more characteristic of stable ecotones than indicators of erosion in this geomorphological context. A small number of repeat pin measurements suggest vertical faces colonised by silt trapping bryophytes may even be subject to minor (and perhaps temporary) horizontal accumulation.

In the case of channel-marginal estuarine saltmarsh stability may be somewhat more dynamic and possibly dependent upon the lifecycles of pioneer vegetation. The 'marsupial lawn' of the saltmarsh has been described as a globally unusual fen (Balmer pers. comm.) and the intricately embayed landforms shown in figures 16 and 26 are not known to have been reported from outside Tasmania. It is therefore inferred that these landforms have considerable bio- and geoconservation significance. It is hypothesised that the complex, two level morphologies depicted in figures 9, 16 and 19 represent randomly seeded stromatolitiforms in a progradational environment. Testing of that hypothesis would require sectioning, detailed root net mapping and dating, a straight forward exercise but beyond the current budgetary capacity of the monitoring programme.

Figure 25: distribution of salt marsh at the mouth of the Old River into Bathurst Harbour at high tide, photo Richard Koch.

Figure 26: A closer and oppositely oriented view of saltmarsh at point A

Despite mountainous headwaters and high rainfall, the catchment vegetation and widespread organosols significantly limit clastic sediment supply to the estuaries. The somewhat mineral-limited landform assemblage is inferred to have evolved by the following steps:

1. Holocene transgression and relative stillstand.
2. Initiation of clastic and bioclastic sedimentation and saline flocculation, forming current swept subtidal bars and still water shoals.
3. Colonisation and growth of aquatic vegetation and increased sediment trapping.
4. Vertical accretion (in places including storm wrack) allows replacement of aquatic flora by herbaceous littoral species, followed by development and lateral spread of a more oxygenated saltmarsh rootmat. Faunal activity may contribute to compaction and nutrient cycling.
5. Saltmarsh grades to estuarine banks with colonisation by woody vegetation. Organic matter is both generated *in situ* and delivered from the catchment during storm surges.
6. Progressive downstream progradation of an alluvial system over the estuarine flats, overbank deposition and vertical accretion of mixed clastic and organic sediment.
7. Stabilisation of floodplain elevation and return to dominantly organic accumulation.

All stages are diachronous, meaning they may be active at the same time in varied locations, with later facies overlying those produced at earlier steps in the sequence. Vegetation plays a key role in steps three, four, five and seven; therefore community structure is likely to be a significant determinant of both landforming process and the resultant morphology. The relative absence of wave damping *Triglochin* species in the Port Davey region is a possible reason for the higher proportion of saltmarsh in comparison to similarly undisturbed estuaries in western Tasmania.

Despite the strongly depositional geomorphic context and abundant observational evidence of Holocene deposition many of the banks are clearly eroding. Since commencement of monitoring in 1992 pin measurements have consistently indicated saltmarsh, estuarine and alluvial bank erosion at a rate of a few millimetres per year (table 6). These rates are lower than those recorded from the regularly trafficked lower Gordon and Arthur Rivers and comparable to or lower than those recorded on the less trafficked Wanderer River (Bradbury 2010 and unpub. data). They are comparable to or slightly higher than those of the lower Pieman River where banks are armoured by oxidised mine tailings. Measured erosion also represents a clear change from a depositional to an erosional regime.

Table 6: erosion monitoring statistics for Port Davey and western Tasmanian estuaries from commencement of the respective monitoring programmes (or in the Gordon case, since introduction of the present management regime).

	river	**count**	**min**	**max**	**mean**	**stdev**	**% < 0**	**% = 0**
estuarine banks	Davey	45	-2	20	6.3	5	2	4
	Spring	69	-36	32	2.3	7	9	10
	North	79	-19	10	2.2	4	11	4
	Old	35	0	32	3.5	5	0	6
	Melaleuca	236	-9	38	3.6	5	3	8
	Wanderer	11	-18	38	4.0	16	27	0
	Gordon	839	-97	304	6.9	24	12	33
	Pieman	47	-55	58	1.6	16	38	4
	Arthur	94	-80	66	9.8	22	15	11
alluvial banks	Davey	18	0	6	1.8	1	0	0
	Spring	125	-4	47	3.0	7	22	6
	North	37	-2	38	3.7	7	8	14
	Old	45	-7	31	3.4	6	9	24
	Melaleuca	158	-4	17	1.0	3	23	16
	Wanderer	24	-12	30	2.4	9	38	0
	Gordon	1087	-281	613	10.0	41	11	28
	Pieman	61	-11	31	3.3	8	26	23
	Arthur	83	-29	151	20.9	26	6	8

The potential erosive effects of vessel wave wake in this region were previously discussed in detail (Bradbury 2000) and the following areas are regarded most susceptible:

- Melaleuca Inlet upstream from the 5 knot speed limit sign,
- Davey River upstream from Brookes Reach,
- Old River upstream from Ngyena Creek,
- Spring River and Manwoneer Inlet,
- North river and associated deltaic shoals.

Other limited occurrence of similar sediments in bay head locations in association with smaller freshwater drainages are, by virtue of location beyond the limits of frequent navigation, not regarded particularly vulnerable to wave wake. Of those listed the Spring (upstream from Manwoneer Inlet) and North Rivers are closed to motorised boating under the World Heritage Area Management Plan (Tasmania 1999). The Old River is similarly not zoned for motorised boating however a commercial licence permitting some motorised access may remain in force. A five knot speed limit was recommended (Bradbury 2000) for the Davey River upstream from Brookes Reach.

As part of a Nature Conservation Branch submission to the 2005 WHA Plan 'mini review' it was further suggested that Manwoneer Inlet also be closed to motorised boating due to potential for:

- sediment resuspension and possible rapid morphological change to submerged or emergent mudbanks and shoals caused by propeller jet or wave wake without analogue in the natural hydrodynamic climate;
- dislocation of vegetation propagules from muddy shoals by breaking wake waves and disabling of an essential sediment trapping mechanism.

However it should be noted that despite the varying level of traffic in the reaches listed above the measured rates of erosion are comparable, as are rates at the few paired inside and outside bend monitoring sites. It is therefore inferred that wave wake is not the dominant erosive process.

Global sea level rose by 195 mm between 1870 and 2004 and the rate of rise is accelerating (Church and White 2006). On exposed Tasmanian coasts that rise has not yet actuated widespread change beyond the range of cyclical cut and fill (although there are some localised exceptions, both within and outside the WHA). The sheltered embayments of the Port Davey region do not however appear uncommon in their display of evidence for a recent switch from nett deposition to erosion. Sharples (pers. comm.) has suggested this re-entrant effect arises from the minor to negligible contribution of waves to landforming process and the absence of a mechanism to return any eroded sediment to the shore.

Furthermore, in the estuaries of the Port Davey region the sea level rise to date represents a significant proportion of the 'tidal' range, which is best described as microtidal with astronomical and meteorological factors being of similar effective magnitude. Recent sea level change therefore represents a significant base level change and some geomorphic response by soft, water level landforms is to be expected. Whether that response is erosional or depositional would depend upon whether or not the local sediment budget has capacity to fill the increased estuarine volume at a rate matching that of sea level rise. In the Port Davey region apparently it does not.

In these low gradient terminal streams a small rise in base level and concomitant salt wedge incursion may result in significant horizontal offset of the depositional loci for both clastic and floc sedimentation. This has potential to cause local sediment starvation and degradation of recently depositional landforms, as observed. Note however that the practical constraints of erosion pin monitoring dictate that this would be more obvious than any upstream migration of depositional loci.

More frequent inundation of low lying saltmarsh and estuarine banks would increase pore water pressure and tidal drawdown pressure gradients, potentially causing seepage erosion like that depicted in figure 24. Many of the biogeomorphic estuarine landforms of the Port Davey region are genetically closely associated with water level and vegetation stress response to increased salinity and frequency of inundation (high 'tides' and wave overtopping) is also likely to contribute to degradation of low lying landforms.

It is concluded that sea level rise presents the most plausible mechanism effecting the observed erosion. In the otherwise essentially undisturbed Port Davey region estuarine change from a depositional to erosional regime is a clear marker of the onset of the Anthropocene epoch and relatively rapid marine transgression..

Over the longer term (centuries to millennia) projected sustained sea level rise must cause a wholesale migration of both landforms and vegetation communities. Within the context of geological time the active transgression appears faster than most. The estuarine environment appears to be entering a period of rapid change and is potentially susceptible to invasion by *Spartina* and other geomorphologically significant weeds.

Recommendations

After providing the most comprehensive description of WHA open sandy coasts to date Cullen (1998) concluded with recommendations for monitoring, investigation and documentation of "unusual landforms before their further modification and potential destruction by rising sea level". Sharples has repeatedly suggested that coastal re-entrants appear more at risk than open coasts and this report observes that estuarine and salt marsh facies of the Port Davey area already show evidence of the onset of the Anthropocene epoch. More recently Sharples (in prep.) has proposed that gaining further understanding of coastal and estuarine response to climate change should be a WHA management priority. The WHA management objective to "*identify and more fully understand the World Heritage and other natural ... values of the WHA, their significance, and management requirements*" (1999 WHA plan, p 30) supports the following recommendations for further geoscientific work.

Mapping

The nature and distribution of the landforms of the Port Davey ria estuary complex have only ever been mapped to reconnaissance standard. Aerial photograph interpretation now a third of a century old was basis for the Coastal Geomorphic Map of Australia Smartline mapping, which does not provide full coverage of the inlets and estuaries and appears to have overlooked many of the smaller scale landforms typical of the region. The existing Smartline mapping should be reviewed and extended as far upstream as the limit of tidal influence. The inclusion of two additional attribute layers, rocky shore veneer and erosion status, as suggested by Sharples (pers. comm. 2010) would assist description and monitoring of geomorphic response to sea level rise respectively.

Line mapping however cannot capture the full areal complexity of the convolute shorelines of the Port Davey region. The distribution and extent of shoals, tidal and surpatidal flats etc. can only be mapped as polygons. The general nature of landforms may be inferred from aerial photographs, satellite images and digital elevation models but details like grainsize and organic matter content that are essential to distinction of the various sedimentary facies present can only be observed in the field. Given the scale of the Port Davey region field time requirements on the orders of 10 days for line mapping and 100 days for polygon mapping are estimated. For expediency line and polygon maps should be prepared simultaneously.

Sharples (in prep.) provides justification for scientific data salvage from sites where significant landform and process modification appears an inevitable outcome of rising sea level. Following that rationale it is here suggested that highest priority should be given to features displaying apparently unique attributes or those that might provide either information about past earth response to climate change or early warning of aspects of future change. Unusual landforms and other specific targets identified for priority geoscientific investigation within the Port Davey region include:

- Hannant inlet intricate marsupial lawn,
- Ray River mouth into Moulters Lagoon,
- salt marsh in the vicinity of the Old River mouth ,
- James Kelly Basin,
- Horseshoe inlet,
- a representative sample of the numerous small islets, shoals, embayments and tidal tributaries.

Process analysis

Salt marshes are known to be one of the most productive ecosystem types on Earth. The distribution, material and form of their often rapidly accumulating sedimentary deposits are strongly influenced by vegetation. The Port Davey region contains unique floral and in some cases faunal associations that require further interdisciplinary study if the risk presented by projected climate change to their World Heritage and nature conservation values is to be rationally assessed.

Catchment and marine clastic sources appear relatively minor in comparison with autochthonous generation of oozes, spiculites and other sediments rich in organic matter. A first pass quantification of sediment budgets would of necessity take a multidisciplinary approach. Some basic numerical modelling of waves and currents would also help constrain conceptual models of geomorphic process. However that would be somewhat hindered by a lack of relevant meteorological and to lesser extent bathymetric data.

Monitoring

It is recommended that the existing monitoring programme be continued with erosion pin measurements taken at five yearly intervals for the Davey, Spring, North and Old River estuaries and at a 2 – 3 yearly interval for Melaleuca Inlet and Creek (which would also allow greater opportunity for access to the Davey estuary whenever conditions were favourable).

It is also suggested that the existing monitoring programme be expanded by inclusion of photo monitoring of a representative sample of sites, as could be identified by the mapping exercise outlined above. Monitoring observations should also give focus to early detection of any incursion of geomorphically significant weed species.

Further monitoring of WHA geomorphic response to climate change is indicated where there is doubt regarding condition or trend, or there appears potential for effective active management, or where better understanding of response to climate change would assist planning, mitigation or adaptation strategies for geodiversity or its dependent World Heritage values. In that regard Sharples (in prep.) has identified the erosion and translation of salt marshes (in particular the marsupial lawn type) of sheltered and estuarine TWWHA shores as a high priority target for monitoring effort.

Why all that should be done

The WHA provides an outstandingly valuable geoscientific archive and geomorphological laboratory virtually free from direct influence of modern humans from catchment to coast. The landform and sedimentary record of Holocene transgression offer unique insight into cause and effect of geomorphic response to sea level rise that has been merely glimpsed to date. There is (for the moment at least) essentially a single variable of significance – sea level – in the experiment presently in progress. Temperature, rainfall and other parameters may become increasingly significant but to date there is no evidence that other factors have influenced the observed change from depositional to erosional regime.

The work recommended above is expected to provide information not only of benefit to management of this part of the Tasmanian Wilderness World Heritage Area but also a benchmark of natural tend, rate and magnitude of change. The latter would be potentially useful to managers of other estuarine coasts where understanding of geomorphic response to sea level rise is confounded by more diverse and pervasive anthropogenic influence.

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