Foreshore Vegetation in the Peel-Harvey Estuary: Changes since the opening of the Dawesville Channel

A REPORT PREPARED FOR THE WATER AND RIVERS COMMISSION, WESTERN AUSTRALIA.

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EXECUTIVE SUMMARY

The Dawesville channel was constructed in April 1994, as part of a management plan to control eutrophication. With increased exchange between the nutrient-rich waters of the estuary and the nutrient-poor waters of the Indian Ocean there was considerable speculation as to the effects of altered water exchange on inundation, salinity, sedimentation and erosion. The work described here examined a number of estuarine characteristics in relation to meteorological factors and geomorphology at ten foreshore sites between April 2001 and March 2002. Comparisons were made between pre and post channel estuary conditions, and vegetation zonation examined.

This study tested the following null hypotheses:

1. That the opening of the Dawesville channel has had no effect on inundation of foreshores in the Peel-Harvey system. This was not tenable; with increased tidal amplitude, flooding has extended further into marsh than before the channel. Low-lying sites were particularly affected, with most of transects inundated more than 80% of the time of the study. The extension of *Sarcocornia quinquiflora* and *Suaeda australis* into upper marsh provided evidence that inundation has increased. Inundation was exacerbated at sites containing higher proportions of fine sediments, and on shores with beach ridges that act to trap water.

2. That the opening of the Dawesville channel has had no effect on salinity in the Peel-Harvey system. Proving or disproving this hypothesis was difficult, as the range of water salinity in this study and previous post channel years were comparable to pre channel records, and because most soil salinities were low. While hypersalinity continued to prevail in summer and autumn, higher minimum salinities this year ($17^{o}/oo$) may relate to the extreme low rainfall.

   Flooding by estuary waters may elevate salinities, especially in low-lying areas, as hypersalinity continues in summer and autumn. Vegetation structure was the most convincing indicator that salinities had altered, with encroachment of *Sarcocornia quinquiflora* and *Suaeda australis* into upper marsh. Dead *Juncus kraussii* and *Melaleuca rhaphiophylla* in topographical depressions at two sites indicated soil water and soil

salinity, may make conditions unfavorable for survival, especially in low-lying, regularly-flooded areas.

3. The opening of the Dawesville channel has had no effect on sedimentation and erosion. This was not supported. Low proportions of fine sediments and dominance of medium and coarse sands at most sites, along with consistently low turbidities suggest fine sediments may be more easily flushed from the system. Rapid oscillation between erosion and deposition between sampling dates infers that foreshore sediments are unstable, though little nett loss of land suggest rapid erosion may have already occurred during the six years after channel construction, and may now be slowing toward equilibrium.

   Foreshore erosion was indicated by a cliffed shoreline, exposed *Juncus kraussii* roots and rhizomes, and the presence of *Melaleuca rhaphiophylla* and *M. cuticularis* on the immediate shore. Erosion was more extreme at sites exposed to prevailing winds and which had sediments with a high content of coarse sand. Obvious erosion occurred at one site, where the *Juncus kraussii* was eliminated during the study.

Vegetation structure at each site reflected the interaction between increased tidal amplitude, meteorological conditions and topographical differences of the shoreline. Vegetation distribution may indicate new marsh limits, but conditions may alter naturally with climatic change, storm events and continued anthropogenic disturbance.

The study offers a better understanding of estuarine conditions six years after channel construction. The study provides a platform for better understanding of vegetation dynamics, preferred plant position and tolerances of saltmarsh vegetation.

Recommendations include:

1. Continued monitoring of parameters on a site-specific basis to account for seasonal variability.
2. Replicate vegetation and soil surveys over the long term and on a seasonal basis to determine effects of the present conditions, as well as the range of conditions imposed on individual species over time.

3. Map recent aerial photography for comparison with conclusions in Kobryn *et al.*, (2000).
4. Investigate tolerance of *Juncus kraussii* to various environmental conditions, and incorporate in revegetation programmes, to maintain the ecological integrity of this species.
5. Use existing vegetation successional patterns as a guide to assist with revegetation programmes.
6. Instigate revegetation of Erskine Reserve foreshore to enhance and improve the quality of the narrow marsh zone.
7. Investigate best shore stabilisation methods, including the use of logs to reduce wave action and promote sediment accretion.

1. BACKGROUND

The Peel-Harvey Estuary (Figure 1.1) has been receiving high levels of nutrients from the surrounding 11 000 km^2 catchment, and in consequence has since the mid 1970s accumulated excessive macroalgae and blooms of the toxic blue-green algae *Nodularia spumigena* (PIMA, 1994; DAL, 1998). In response to negative impacts on both estuarine ecology and human use of the estuary, construction of the Dawesville Channel (Figure 1.2) was completed in April 1994 (PIMA, 1994; McComb and Lukatelich, 1995; DAL, 1998). Developed as part of a 3-stage management strategy to improve water quality, the primary purpose of the channel was to increase the flushing of nutrients from the estuary (Kinhill, 1988). There was a strong certainty that water quality would improve from the channel construction, it was also recognised that there may be extensive changes to the physical, chemical and biological characteristics of the estuary in the long and short term, and that impacts may be both positive and negative (DAL, 1998).

1.1 FORESHORE VEGETATION

Saltmarsh area fringing the Peel-Harvey Estuary covers approximately 13 km^2 of the estuary area (Rose and McComb, 1980; Murray *et al.*, 1995). Marsh vegetation consists of complexes recognized by Backshall and Bridgewater (1979); Bridgewater (1982); and Creswell and Bridgewater, (1994). Murray *et al.*, (1994) describes three major complexes or plant associations characteristic of the foreshore vegetation in the Peel-Harvey, comprising communities dominated by *Sarcocornia, Juncus* and *Haloscarcia* with other marsh species that share overlapping tolerances to environmental conditions.

The soil salinity gradient within the marsh creates zonation of species, including *Sarcocornia quinqueflora* in association with *Suaeda australis* in the lower marsh that become frequently inundated by tides (Backshall and Bridgewater, 1979; Cresswell and Bridgewater, 1994). The narrow bands of *Juncus kraussii*, fringing the shoreline on higher elevations, results from the limited tidal flooding beyond the small beach ridges that dominate most of the estuary shoreline (Hodgkin *et al.*, 1980; Semeniuk and Semeniuk, 1990; Murray *et al.*, 1995). *Melaleuca* spp occupy the upper marsh zone where tidal flooding and soil salinities tend to be reduced.

Marsh width varies around an estuary due to the different types of intertidal habitats that range from sandy shores to mud flats and embayments (Roman *et al.,* 2000). Often narrow marshes are associated with steeper topography and embankments where the reduction of flooding into an area may limit landward colonization of marsh species (Chapman, 1971; Roman *et al.,* 2000). Considering the shoreline topography around the Peel-Harvey Estuary, comprising beach ridge complexes and erosional shores (Semeniuk and Semeniuk, 1990), most marsh areas fringing the Peel-Harvey are narrow (Murray *et al.*, 1995). More extensive marsh development occurs in low-lying areas that become inundated for long periods on the eastern side of the Peel Inlet and Southern part of the Harvey Estuary.

Most changes in marsh structure corresponded with natural succession in response to seasonal and local hydrological variations and these were formally minor due to the relative low tidal amplitude prior to channel construction (Hillman, 1986). Oscillation between marsh gain and loss has been observed through comparison of historical aerial photographic imagery in the low-lying areas on the eastern shores of Peel Inlet and southern Harvey Estuary (Kobryn *et al.*, 2000). Rapid retreat of salt marsh in the Peel-Harvey Estuary near the Mandurah Channel associated with dredging required to maintain permanent communication with the ocean between 1977-1986 (Glasson *et al.*, 1995). Human uses, including development and recreational activities, have also contributed to losses of foreshore vegetation. Significant losses occurred along Erskine Reserve foreshore between 1976-1990 as a result from mechanical beach clearing of deposited macroalgae (Black and Hodgkin, 1984).

After construction of the Dawesville channel in April 1994, water exchange between the Indian Ocean and the Peel-Harvey was predicted to more than double in volume, and tidal range was expected to increase from 15% to between 50 and 70% of ocean tides (Ryan, 1993, Latchford, *et al.,* 2002). With altered tidal regime it was predicted that larger areas of intertidal flats would be exposed, and indicated more than 100 m may be exposed in some very low-lying areas (Murray *et al.*, 1995). Colonisation of samphires into exposed intertidal areas was expected (PIMA, 1994), however increases in flooding extent into marsh areas were predicted to be minor (Murray *et al.*, 1994).

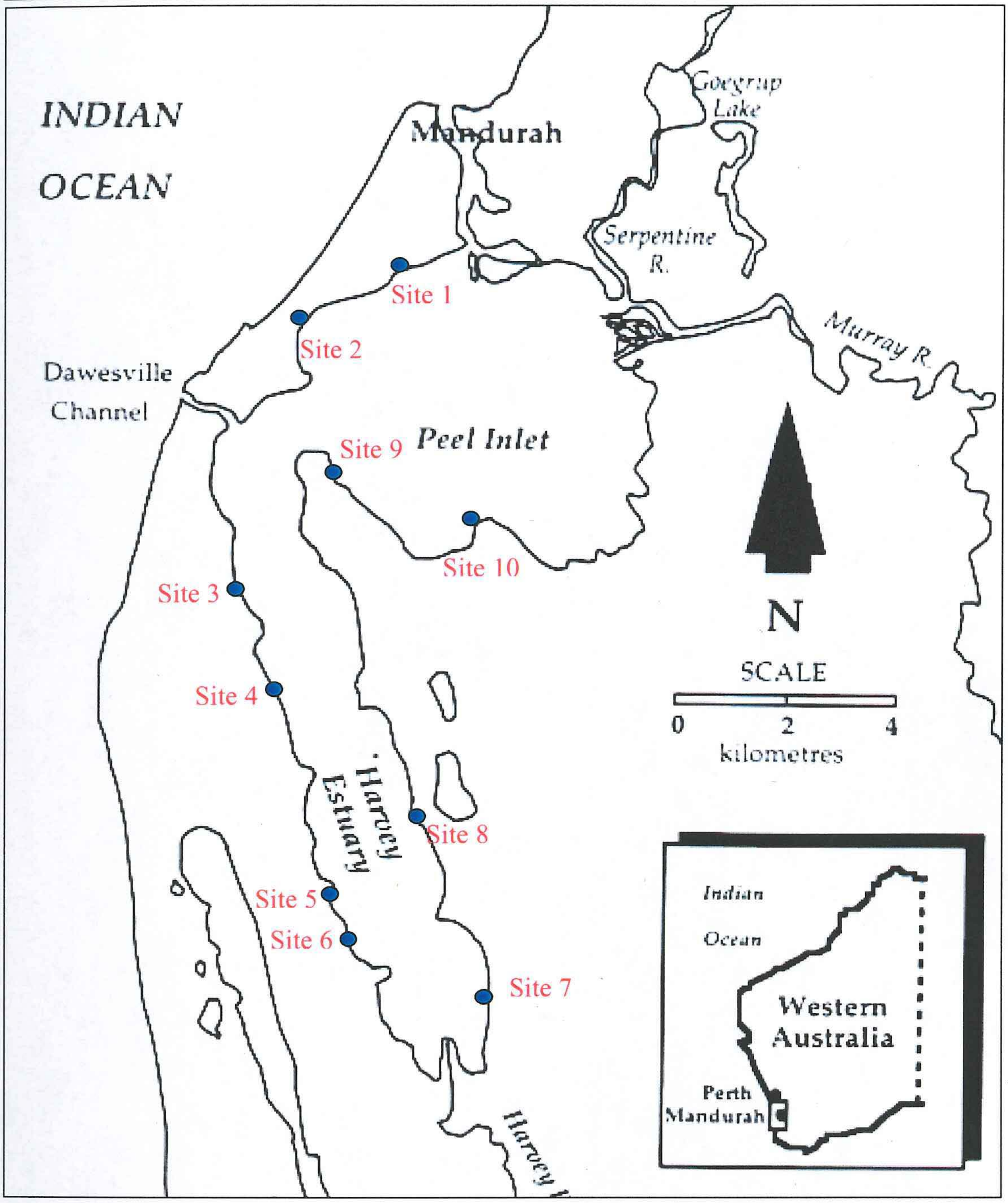

Figure 1.1: Locality map of the Peel-Harvey Estuary, Western Australia indicating project study sites 1 to 10, April 2001 to March 2002.

Figure 1.2: Aerial photograph of the Dawesville channel. Channel dimensions are 200 m wide and 4.5 m (AHD) deep at the junction of the estuary, tapering to 150 m wide and 6.5 m deep at Indian Ocean entrance (Kinhill, 1988).

1.2 OBJECTIVES

Few studies have been carried out on the foreshore vegetation of the Peel-Harvey Estuary before and after the opening of the Dawesville Channel in 1994 (DAL, 1998). Studies carried out during 1994 to 1995 attributed vegetation losses and gains to natural environmental variation rather than directly to the effects of the altered tidal regime (DAL, 1998). A preliminary survey of shoreline erosion in the Peel-Harvey Estuary conducted by Kobryn *et al.,* (2000), employed historical aerial photography and developed changes in the structure of shoreline vegetation with time. It was concluded that erosion and deposition rates had accelerated and that vegetation loss had occurred.

There has been considerable speculation about the possible effects on sediment transport of altered water movement following the opening of the channel. The work described in this report was carried out to test the following specific null hypotheses:
That the opening of the Dawesville channel has had no effect on:

- Inundation;
- Salinity;
- Sedimentation and erosion

This was achieved through assessment of a number of estuarine characteristics and processes (Table 2.1) in relation to meteorological conditions, and by comparing pre and post channel records. The report compiles findings described in an Honours thesis (Calvert, 2002) with additional summer data. The effects of increased tidal amplitude on foreshore vegetation dynamics since channel construction are discussed.

2. MONITORING

Monitoring of sites was conducted between April 2001 and March 2002.

2.1 SITE LOCATION

Ten sites were chosen for investigation representing a variety of geographical settings (Figure 1.1). Associated shoreline geomorphology is summarised in Table 2.1. Panoramic photographs describe sites selected (Appendix I). Detailed site description is in Calvert (2002). Methods have been summarised in Table 2.2. Full details of methods are in

Calvert, (2002). Multiple regression analysis was conducted to assess correlations between parameters (Appendix II).

Selection of study sites was based on the following criteria:

- Locations approximated sites employed in other studies (eg. Kobryn *et al.*, 2000);
- There was *Juncus kraussii* or *Melaleuca* species were present at each site;
- Sites covered a broad area of the Peel Inlet and Harvey Estuary and included a range of habitats and environmental conditions;
- Sites received minimal public access, reducing disturbance and protecting equipment;
- Accessibility by 4WD or boat;
- Personal safety.

Table 2.1: Geomorphology characteristics of the study area within the Peel-Harvey Estuary WA, 2001
Source: Semeniuk & Semeniuk (1990); Weaver (1999)

Study site	Dune association	Dominant soil type	Shore landforms	Main formative process
1	Spearwood dunes	yellow deep sand	beach ridge complex	waves & wind
2	Spearwood dunes	yellow deep sand	beach ridge complex	waves & wind
3	Spearwood dunes	yellow deep sand	beach ridge complex erosional sandy shore elongate fluvial delta	waves; wind; erosion & longshore transport by waves and currents
4	Spearwood dunes	yellow deep sand	beach ridge complex erosional sandy shore elongate fluvial delta	waves; wind; erosion & longshore transport by waves and currents
5	Spearwood dunes	yellow deep sand	beach ridge complex erosional sandy shore elongate fluvial delta	waves; wind; erosion & longshore transport by waves and currents
6	Spearwood dunes	pale deep sand	beach ridge complex elongate fluvial delta	waves & wind
7	Bassendean dunes	self-mulching cracking clay	lobate fluvial delta complex	deltaic & estuarine processes; reworking by waves & currents
8	Bassendean dunes	pale deep sand	limestone cliff pocket beach	erosion by shoreline currents & wind waves
9	Bassendean dunes	pale deep sand	limestone cliff pocket beach	erosion by shoreline currents & wind waves
10	Bassendean dunes	yellow deep sand	beach ridge complex	waves & wind

Table 2.2: Summary of methods employed at sites in the Peel-Harvey Estuary during study period April 2001 to March 2002.

Parameters Investigated	Sampling dates	Method Employed
Vegetation		
Survey	11/6/01 all sites	Vegetation structure and species along each transect was measured and recorded (Appendix III). Position of tree trunks, canopy and approximate height along with location of dead or unhealthy plants were also recorded.
Tree Canopy	11/6/01 sites: 4,5,7,8,9,10	Tree canopy photographs were taken from a known distance above corresponding pegs along selected transects. Multi-spectral image processing method was employed to analyse percentage canopy cover. The temporal extent of tree canopy cover (%) was compared.
Soils		
Grainsize	6/6/01 all sites	Soil core sections were oven dried at 90°C for 48 hrs. Samples were weighed, mechanically shaken and proportion of grainsize classes determined according to Wentworth, (1922).
Tides		
Inundation	1/4/01-31/3/02	* Hourly tidal data was provided by the Department of Transport for the period between April 2001 and March 2002. Data was employed to assess water level changes in the estuary and percentage of time over the study period in which water was above surveyed peg height was calculated along each transect.
Salinity		
Water salinity	20/3/01-27/9/01 16/3/02+17/3/02 all sites	Water was collected 15-20 m off shore. Samples were analysed using a WTW LF 330 Salinity meter and measured as mS/cm and °/oo.
Soil salinity	6/6/01 16/8/10+29/8/01 16/3/02+17/3/02	Air dried surface and sub-surface soil profile sections were mixed with deionised water 5:1 ratio by volume (water:soil). Soil core extraction was repeated at the same site locations and temporal soil salinity comparisons were made.
Erosion		
Turbidity	20/3/01-27/9/01 16/3/02+17/3/02 all sites	Turbidity (NTU) of collected water samples was analysed and spatial and temporal comparisons made.
Sedimentation processes	20/3/01-27/9/01 16/3/02-17/3/02	The extent of erosion and deposition over each peg along transects was measured (the depth of soil deposited or the height of peg exposed). Sedimentation patterns were evaluated by comparing the initial survey heights. Rates were determined by taking the average between erosion and deposition near the open water at each site.

Note: * . The location of the datum points, 55 cm below AHD in the Peel Inlet and 59 cm below AHD in the Harvey Estuary. Tidal recordings and topography (initially surveyed to a relative point) were adjusted to AHD.

3. RESULTS
3.1 CLIMATIC CONDITIONS

Rainfall over the study period was lower than the long term averages, only May, September, November and December approaching the long-term records of the Bureau of Meteorology based on 105 years of rainfall data (Table 3.1).

Table 3.1: Total monthly rainfall between April 2001 to March 2002 in comparison to long term monthly average rainfall recorded at Safety Bay Station No. 001149.

Month	Total rainfall (mm)	Monthly long term rainfall average (mm)
April	2.84	44.0
May	108.4	120.2
June	84.4	189.7
July	106.2	175.4
August	98.8	126.6
September	82.0	84.7
October	24.4	51.8
November	23.6	22.8
December	17.2	11.6
January	9.0	9.6
February	0.0	13.3
March	3.4	9.4
Total	**560.2**	**859.1**
No.of rainy days to 31/3/02	94/365 days	

Winter winds prevailed from NNW in the mornings and W-SW in the afternoons, while during summer months prevailed from the E and SW (Table 3.2). Highest wind speed (44 km/hr) occurred on 23/8/01 (NNW direction) and 22/11/01(SW direction). Monthly average wind speeds were comparable during the winter, and highest average wind speeds occurred in summer (Table 3.2).

Harvey sites and site 1 in Peel faced prevailing winds for 8-10 months (Table 3.2). Sites 9 and 10 were sheltered from most winds, but exposed to NE-NW winds during June and July. With prevailing E winds in summer, site 2 was protected from winter winds (Table 3.2).

Table 3.2: Monthly average wind speed, prevailing wind direction and sites most exposed in the Peel-Harvey Estuary over the period April 2001 to March 2002.

Month	Average wind	Prevailing wind	Exposed sites
April	12.14	NE and W	NE 2,3,4,5,9 W 7,8
May	10.18	SE and NE	SE 1,3,4,5,6 NE 2,3,4,5,9
June	8.80	W and SW	W 7,8 SW 1,7,8
July	9.90	NW and SW	NW 7,8,10 SW 1,7,8
August	12.10	N and SE	N 7,8,9,10 SE 1,3,4,5,6
September	14.20	NE and E	NE 2,3,4,5,9 E 1,2,3,4,5,6
October	19.34	S and SSW	S 1, 3,4,5,8 SW 1,7,8
November	21.72	SE and SW	SE 1,3,4,5,6 SW 1,7,8
December	22.30	E and S	E 1,2,3,4,5,6 S 1, 3,4,5,8
January	21.0	E and SW	E 1,2,3,4,5,6 SW 1,7,8
February	21.75	E and SW	E 1,2,3,4,5,6 SW 1,7,8
March	17.68	E and SW	E 1,2,3,4,5,6 SW 1,7,8

Maximum wind speed 44.00 on the 23/8/01 (NNW) and 22/11/01 (SW).

3.2 TOPOGRAPHY

Sites were less than 0.5 m above the Australian Height Datum (AHD). Highest elevations were at sites 1 and 9 and landward at sites 5 and 10. Sites 3, 6, 7 and 8 remained below AHD, while at sites 2, 4 and 10 most of the transects were below AHD (Figures 3.1-3.4). For most sites, gradients were steepest between the low tide mark (peg 1) and the shoreline (peg 2-4). Beyond the shoreline, elevations flattened beyond the beach ridges at sites along the western shores of the Harvey Estuary and at sites 1 and 9 in Peel-Inlet. Sites 3 (Figure 3.1) and 8 (Figure 3.3) had the steepest gradient from beach to shoreline, sites 7 and 10 the lowest (Figure 3.2).

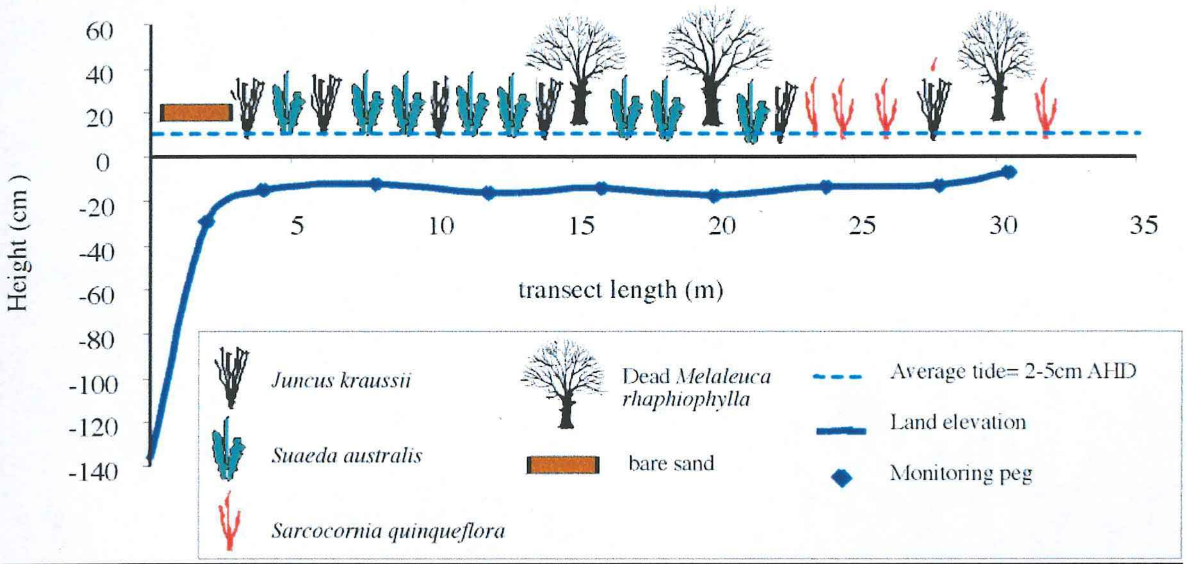

Figure 3.1: Vegetation distribution at study site 3 – Warragup Springs, Peel-Harvey Estuary WA, 2001. (Land elevation is in relation to AHD and water levels during annual average tides (see Appendix III).

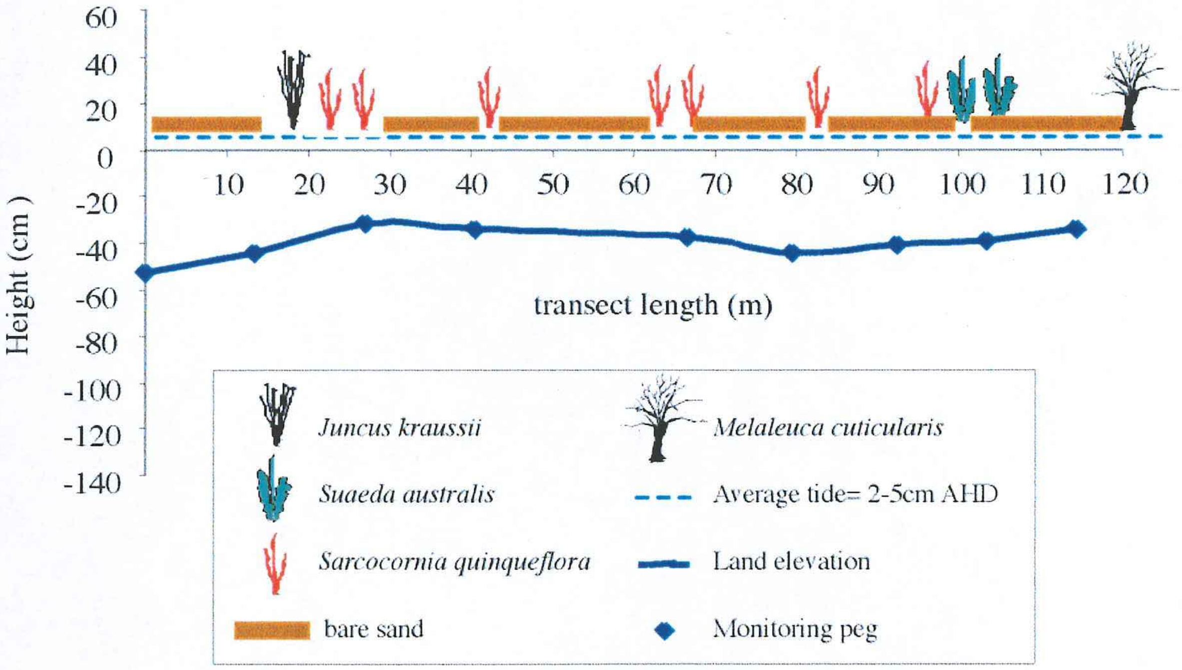

Figure 3.2: Vegetation distribution at study site 7 – South Kooljerrenup, Peel-Harvey Estuary WA, 2001 (Land elevation is in relation to AHD and water levels during annual average tides (see Appendix III).

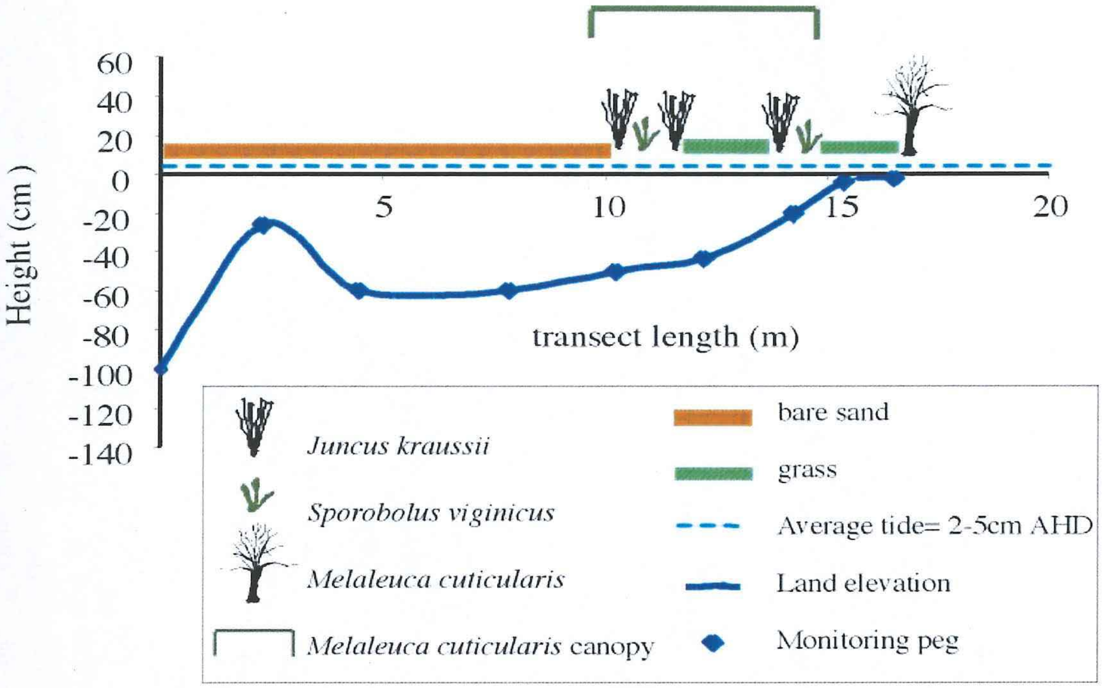

Figure 3.3: Vegetation distribution at study site 8 – Mealup Point, Peel-Harvey Estuary WA, 2001
Land elevation is in relation to AHD and average annual tides (see Appendix III).

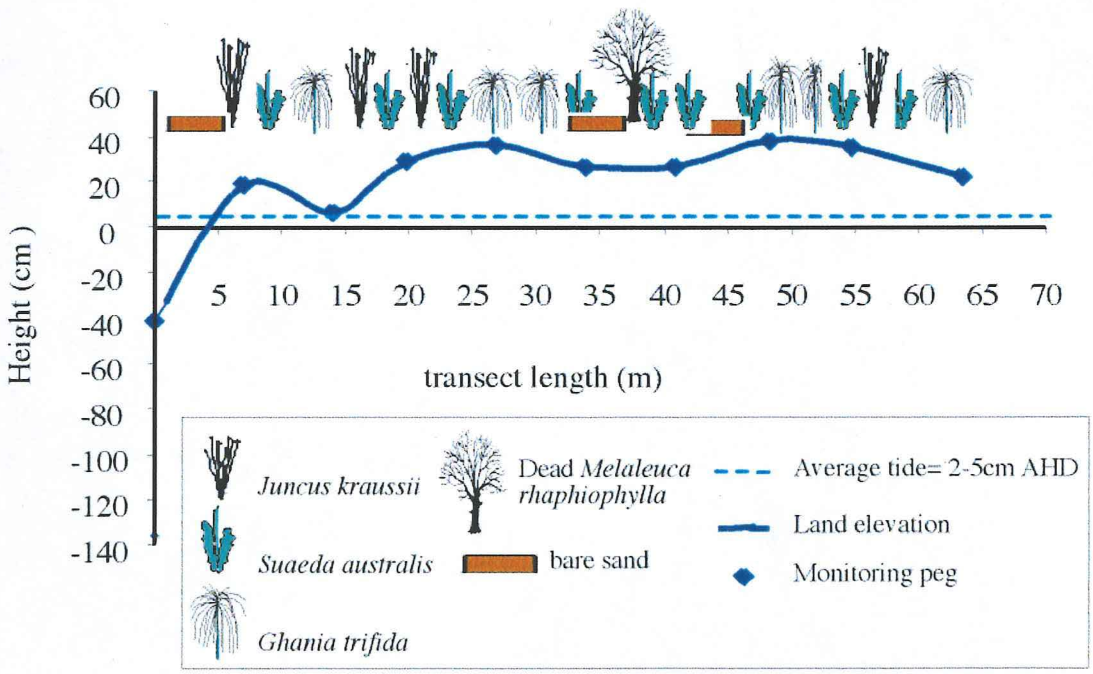

Figure 3.4: Vegetation distribution at study site 9 – Point Grey, Peel-Harvey Estuary WA, 2001
Land elevation is in relation to AHD and average annual tides (see Appendix III).

3.3 VEGETATION

Vegetation was made up of species assemblages rather than monospecific stands (Table 3.3, Appendix III). Boundaries between lower and upper marsh zones were diffuse, and most species were distributed throughout the marsh. Lower marsh assemblages comprised mainly *Sarcocornia quinqueflora* and *Suaeda australis* in association with *Juncus kraussii. Sarcocornia quinqueflora* and *Suaeda australis* also occupied topographical depressions, and extended along a number of transects such as sites 2, 3, 6 and 7. Live *Melaleuca rhaphiophylla* and/or *cuticularis* occurred in the mid and upper marsh at sites 2, 3, 4, 5, 9 and 10, on the secondary shore at site 7, and beyond the beach at site 8.

Unhealthy plants (*Juncus kraussii* and *Melaleuca* spp) were associated with waterlogged areas at sites 2 and 7, and on the immediate shoreline at sites 1, 3, 8 and 9, where roots and rhizomes were undercut or exposed (Figure 3.5, Figure 3.6). At site 8 there was frequent flooding, smothering and collapse of foreshore *Juncus kraussii* was observed, and elimination noted on the 16/8/01 (Appendix IV). During the summer monitoring period, root stubble of *Juncus kraussii* was all that remained in a swale at site 2 (Figure 3.7, Figure 3.8). Most dead trees were located along the immediate shore or in the lower marsh at sites 3, 4, 6 and 8, while were in association with a swale at site 9.

Table 3.3: Characteristics of vegetation assemblages in the lower and upper marsh areas at each study site.

Study sites	Lower marsh Assemblages (dominant)	Upper marsh Assemblages (dominant spp.)	Approximate Marsh width (m)
1	*Juncus kraussii, Casuarina obesa* (dead canopy)	*Kunzea ericiflolia,* grasses, *Melaleuca preissiania*	2-4
2	*Suaeda australis, Juncus kraussii*	*Melaleuca cuticularis, Suaeda australis, Sarcocornia quinqueflora,Juncus kraussii*	40
3	*Juncus kraussii, Atriplex* sp., *Suaeda australis*	*Melaleuca rhaphiophylla, Suaeda australis, Juncus kraussii*	30
4	*Suaeda australis, Sarcocornia quinqueflora, Juncus kraussii*	*Melaleuca rhaphiophylla, Ghania trifida*	30
5	*Suaeda australis, Juncus kraussii, Watsonia bullillfera*	*Melaleuca rhaphiophylla, Watsonia bullillfera, Juncus kraussii*	30
6	*Suaeda australis, Sarcocornia quinqueflora, Juncus kraussii*	*Suaeda australis, Sarcocornia quinqueflora, Juncus kraussii*	60
7	*Sarcocornia quinqueflora*	*Melaleuca cuticularis, Suaeda australis, Juncus kraussii*	100
8	*Juncus kraussii*	*Melaleuca cuticularis*	5
9	*Suaeda australis, Juncus kraussii, Ghania trifida*	*Suaeda australis, Ghania trifida*	40
10	*Suaeda australis, Sarcocornia quinqueflora, Juncus kraussii*	*Melaleuca cuticularis, Tetragonia* sp.	15

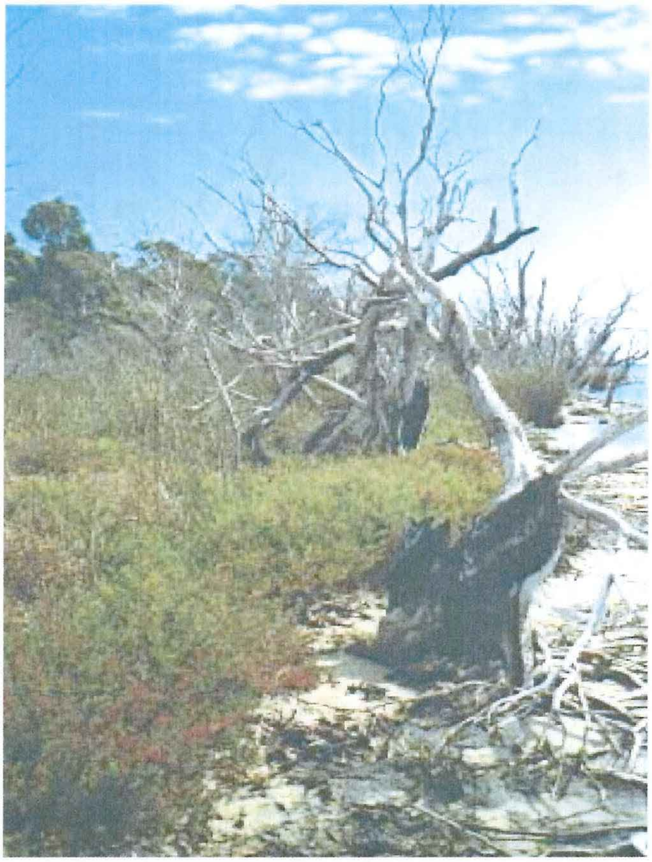

Figure 3.5: Dead tree-line on the foreshore at site 3, Warragup Springs Harvey Estuary, 2001.

Figure 3.6: Exposed roots and rhizomes of foreshore *Juncus kraussii* at site 3, Harvey Estuary, 2001.

Figure 3.7: *Juncus kraussii* in waterlogged conditions during winter sampling period at -31.8 cm AHD (peg 5) site 2, Ward Point, Peel Inlet WA, 2001.

Figure 3.8: Stubble remains of *Juncus kraussii* exposed after summer drying, at -31.8 cm AHD (peg 5) site 2, Ward Point, Peel Inlet, WA March 2002.

3.3.1 TREE CANOPY

There was an increase in percentage tree canopy at each site during the project period. Increases between dates were less than 10% (Table 3.4). Accuracy of tree canopy assessment was more than 96%.

Table 3.4: Temporal comparison of percentage tree canopy cover at selected sites in the Peel-Harvey study sites, 2001-2002.

Site	Dates	Area of tree canopy (%)
7	11/06/01	79.3
	04/07/01	82.4
8	11/06/01	39.6
	25/09/01	48.1
	16/03/02	47.0
10	11/06/01	76.7
	25/09/01	84.5
	16/03/02	82.3

3.4 SOILS

Coarse and medium sands dominated soils at each site (Figure 3.9). Proportions of grain size were also similar along transects within sites. Soil cores from the lower marsh near the shore consisted mainly of medium and coarse sands, with variable proportions of other grain sizes. Coarse sands were highest at sites 5, 6 and 8 in Harvey and at sites 1and 2 in Peel Inlet. Soils from sites 3, 4, 6, 7 and 9 contained the highest percentage of clay/silt soils in comparison to other sites. Sites 1, 5, 8 and 10 contained the smallest fractions of fine soils.

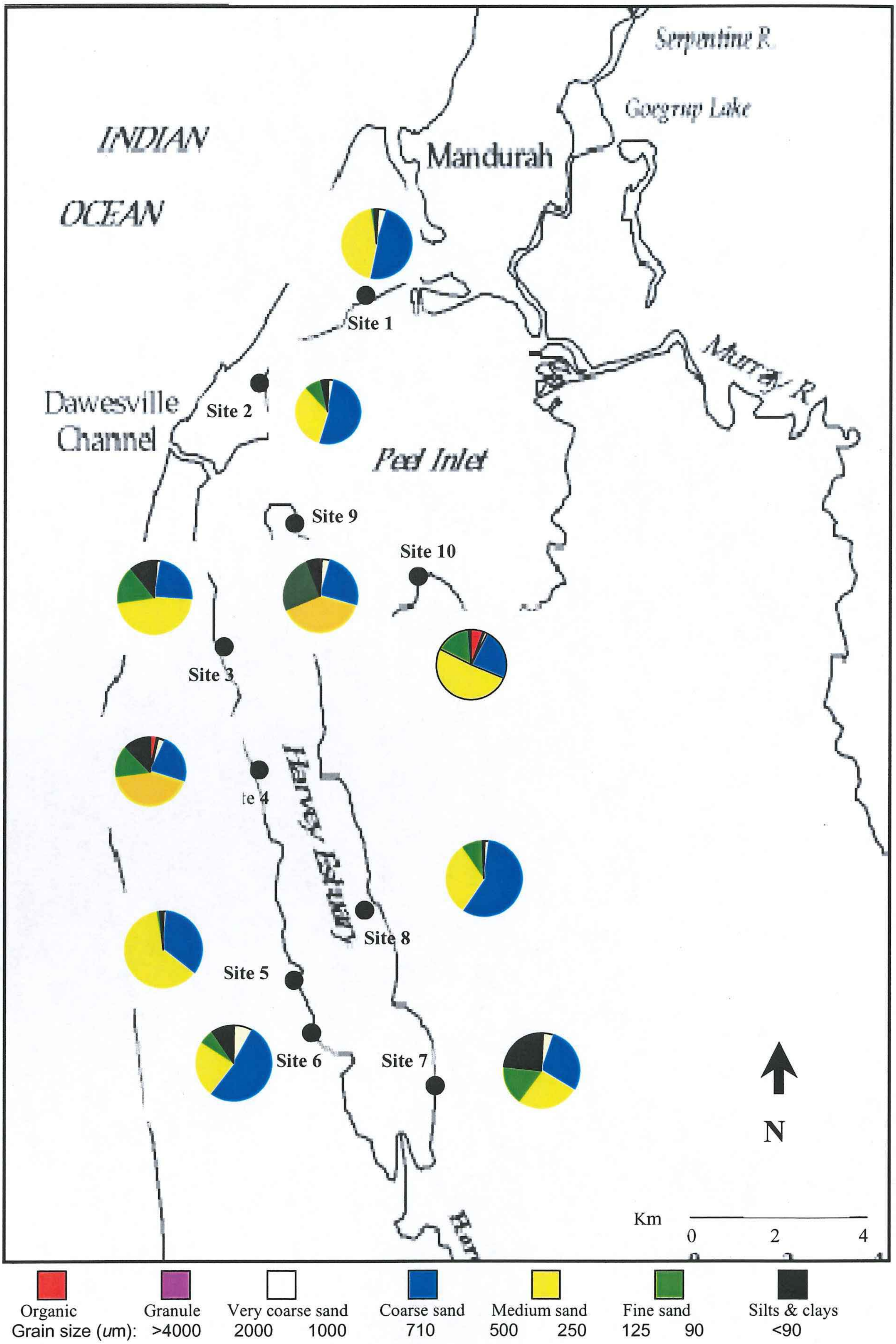

Figure 3.9: Sediment composition (by grain size) within Peel-Harvey Estuary study sites, 2001.

3.5 INUNDATION

During winter (April 2001 to September 2001), average maximum tides were higher than the summer and annual periods, while average minimum tides were lower during summer (Figure 3.10). Average maximum, mean and minimum tide heights were slightly higher in the Harvey than the Peel over the annual, winter and summer periods (Figure 3.10).

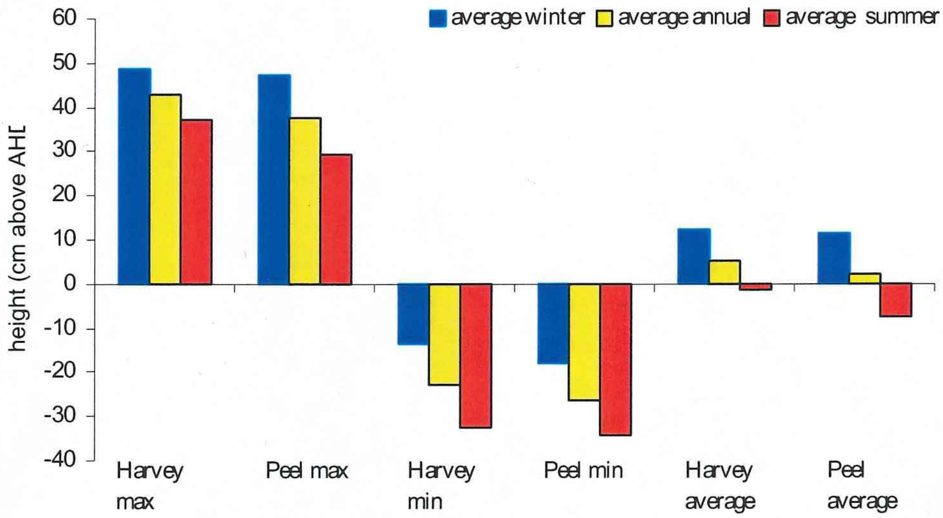

Figure 3.10: Average maximum, minimum and mean water levels (derived from maximum, minimum and mean tide heights in each tide cycle) in the Peel-Harvey Estuary over the annual period- April 2001 to March, Winter period- April to September 2001 and Summer period-October 2001 to March 2002.

Average mean tides were above the highest ground at sites 3, 6, 7 and 8 (Figures 3.1-3.3). Inundation extended to the landward pegs during average tides at sites 2, 4, 5 and 10. Average tides at sites 1 and 9 did not extend beyond the shoreline, between peg 4 and 5 at site 1 and peg 2 at site 9 (Figure 3.4).

Average minimum tides extended inland to varying degrees at sites 2, 3, 4, 6, 7, 8 and 10. Most extensive flooding occurred at sites 2, 3, 6 and 7. Even very low tides inundated entire transects at sites 3 (Figure 3.1) and 7 (Figure 3.2).

Highest recorded tide in Peel was 75 cm above AHD, which was approximately 30cm lower than the evaluated Post Dawesville Channel highest recorded tide (Figure 3.11). In Harvey, the highest tide was similar to the highest recorded post channel. Minimum levels (-43 cm below

AHD) were approximately 10 cm higher than the lowest post channel minimum tide, and comparable with the recorded minimum pre channel (Figure 3.11).

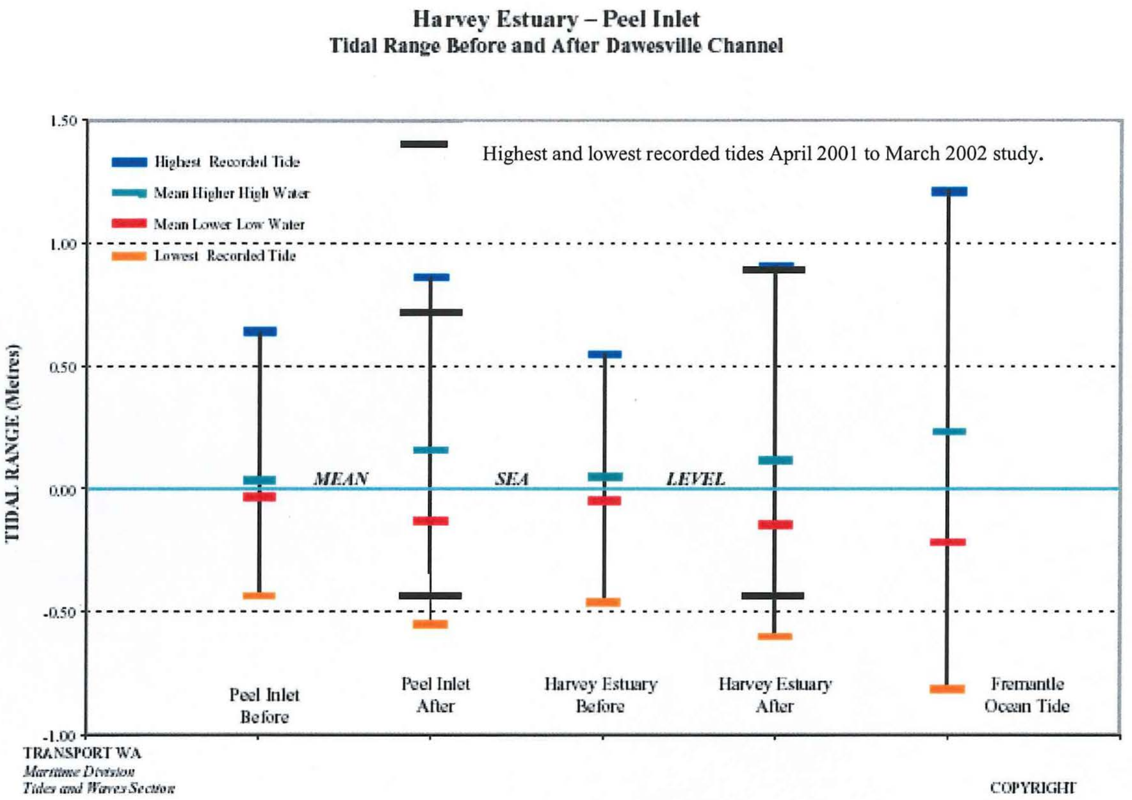

Figure 3.11: Pre-and post-channel modeled tidal data with water-levels recorded in the Peel-Harvey Estuary from April to September 2001 and from April 2001 and March 2002 (modified graph provided by the Department of Transport WA).

Transects were inundated for a longer period during winter (April to September 2001) than summer (October 2001 to March 2002) (Table 3.5 and Table 3.6). Over the annual period the low water line was submerged over 99.9% of the time at all sites (Table 3.7). Submergence inland, (to peg four) occurred more than 80% of the time along all transects apart from those at sites 1 and 9 (Table 3.7). Most of transect at sites 6, 7 and 10 were inundated more than 86% of the time (Table 3.7). The entire length of site 3 was inundated more than 80%, site 2, more than 79% of the time to 56 m into transect (peg 7) and site 10 more than 90% to 11.75 m into transect (peg 6) (Table 3.7).

Table 3.5: Percentage inundation along Peel-Harvey study transects April -September 2001 (% submergence over 180 day study period). (See appendix V for height of reference point in relation to AHD cm).

Site	**Reference Points** (pegs along transect)										Transect length (m)
	1	2	3	4	5	6	7	8	9	10	
1	100	100	100	82.9	23.9	52.31	52.3	45.59	NA	NA	20.8
2	100	99.8	100	97.3	99.8	98.7	95.1	80.1	34.9	NA	74.53
3	100	99.2	91.6	88.4	93.4	91.6	94.2	90.4	89.4	81.54	30.5
4	100	94.2	98.1	96.7	96	65.8	41.4	47.6	49.9	65.8	57.24
5	100	100	97.7	98.7	56.8	43.3	86.9	12.5	91.56	NA	41.85
6	100	100	100	100	100	100	100	100	92.4	92.4	91.35
7	100	100	99.5	99.7	99.9	100	100	100	99.7	90.4	124.5
8	100	100	100	100	100	100	96.3	77.1	75.4	NA	16.54
9	100	37.2	63.9	20.2	12.5	24.6	24.6	0.1	0.1	31.4	63.5
10	100	98.9	98.7	98.8	99.6	98.8	90.9	86.9	63.9	17.3	21.47

Table 3.6: Percentage inundation along Peel-Harvey study transects October 2001 to March 2002 (% submergence over 182 day study period) (See appendix V for height of reference point in relation to AHD cm).

Site	**Peg Number**										Transect length (m)
	1	2	3	4	5	6	7	8	9	10	
1	100	100	100	33.8	0.5	0	6.6	6.6	4.3	NA	20.8
2	100	97.5	99.1	76	97.5	85.1	64	29	1.5	NA	74.53
3	100	98.4	77.8	73	82.2	77.8	83.8	75.7	73	56.6	30.5
4	100	83.8	94.4	90.7	87.7	34.6	12.7	17.7	19.1	34.6	57.24
5	100	100	93.4	96.5	25.3	14.4	67.9	0	77.8	NA	41.85
6	100	100	100	100	100	100	100	99.9	80	80	91.35
7	100	100	98.8	99.1	99.6	100	99.9	99.7	99.1	75.7	124.5
8	100	100	100	100	100	100	89.2	48.8	46.5	0.66	16.54
9	99.8	2	12.5	0.2	0	0.5	0.5	0	0	0.9	63.5
10	100	89.2	85.1	87.2	95.1	87.2	39.1	41.7	12.5	0.1	21.47

Table 3.7: Percentage inundation along Peel-Harvey study transects April 2001 to March 2002 (% submergence over 365 day study period) (See appendix V for height of reference point in relation to AHD cm).

Site	Peg Number										Transect length (m)
	1	2	3	4	5	6	7	8	9	10	
1	100	100	100	59	16.1	8.6	33.4	33.4	29.5	NA	20.8
2	100	98.6	99.5	86.5	98.6	91.8	79.3	55.4	22.6	NA	74.53
3	100	99	87.6	84.7	90.1	87.6	91.1	86.4	84.7	75.9	30.5
4	100	91.1	98	95	93.3	57.3	36.3	40.5	42.4	57.3	57.24
5	100	100	96.4	98	48.9	36.3	81.3	8.7	87.6	NA	41.85
6	100	100	100	100	100	100	100	99.9	88.8	88.8	91.35
7	100	100	99.3	99.5	99.8	100	99.9	99.8	99.5	86.4	124.5
8	100	100	100	100	100	100	94.2	68.7	67	12.7	16.54
9	99.9	24.1	40.7	13	7.8	16.1	16.1	5.6	8.6	20.3	63.5
10	100	94.1	91.8	93	97.3	93	62.8	64.6	40.7	10.9	21.47

3.6 SALINITY

Water salinity

Average salinities were comparable at all sites (Figure 3.12). Salinities for all sites did not fall below 17.5 ^{O}/oo (21.4 mS/cm) (Figure 3.12). All sites were hypersaline (higher than seawater) during summer sampling dates (20/03/01 and 16/03/02). Highest salinities (above 55^{o}/oo) were at sites 4, 5, 6, 7 and 8 in Harvey.

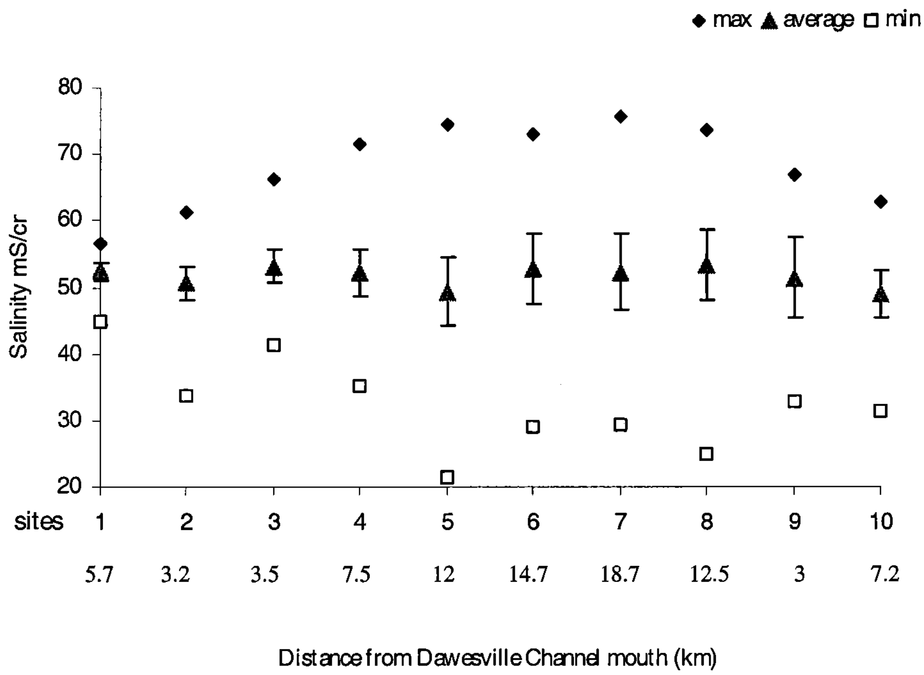

Figure 3.12: Water salinity range (maximum, average and minimum values) at each site over the study Period in the Peel-Harvey Estuary WA, April 2001 to March 2002.

The smallest salinity ranges were at Peel sites and at sites 3 and 4 in Harvey (Figure 3.12). There was a gradual decline in salinity at all sites with the onset of the wet season. A typical seasonal pattern developed where salinities declined in conjunction with increased rainfall and river flow. Salinity declined (for all sites) on the 16/08/01.

Soil Salinity

Surface and subsurface soil salinities were moderate to low in most profiles on all sampling dates (Table 3.8). Highest salinities were at sites 2, 3, 6, 7, and at site 10 where salinities equivalent to ocean values occurred on 16/3/02. Sites 1, 4, 5 and 8 had comparably low salinities (Table 3.8). There was a reduction in salinities at all sites on the second sampling period (Table 3.8).

In most cases the pattern of change along transects from inland to the open water was of increasing salinity, and higher salinities at the surface than at 50 cm depth (Table 3.8). However, higher surface salinities occurred landward at sites 2, 3 and 7 on the 6/6/01 and 3 and 7 on the 16/3/02 and 17/3/02 (Table 3.8). Salinity of soils close to the open water at sites 3 and 6 were lower than those inland on the 16/3/02 and 17/3/02 (Table 3.6).

Table 3.8: Temporal comparison of surface and sub-surface soil salinities (mS/cm) along transects at selected study sites within the Peel-Harvey Estuary, April 2001 to March 2002 (sample location = metres from the open water along site transects). Higher salinities are highlighted bold.

Site 2	sample location (m)	*9.20*	*65.25*	*74.50*
5/6/01	surface	11.30	7.70	1.30
	sub-surface	6.72	2.30	1.20
27/9/01	surface	4.85	2.09	0.26
	sub-surface	1.64	3.62	0.15
17/3/02	surface	**36.10**	12.15	0.37
	sub-surface	8.74	4.62	0.50
Site 3	sample location (m)	*4.00*	*30.50*	*40.00*
5/6/01	surface	**23.10**	**21.40**	2.88
	sub-surface	16.73	2.55	4.49
29/9/01	surface	1.07	2.45	2.86
	sub-surface	0.60	0.47	0.49
17/3/02	Surface	1.82	**29.5**	
	sub-surface	3.66	14.00	
Site 7	sample location (m)	*27.00*	*92.50*	*114.50*
6/6/01	surface	**30.50**	**20.20**	4.30
	sub-surface	3.53	2.30	13.50
29/901	surface	6.70	6.56	2.24
	sub-surface	3.42	3.20	3.52
16/3/02	surface	**24.00**		**31.50**
	sub-surface	**18.90**		**9.78**
Site 8	sample location (m)	*5.00*	*16.50*	*20.00*
6/5/01	surface	1.45	0.31	1.54
	sub-surface	1.43	0.42	0.38
16/8/01	surface	0.30	0.53	0.12
	sub-surface	1.50	0.13	0.11
16/3/02	surface	0.14	1.48	
	sub-surface	0.19	0.34	
Site 10	sample location (m)	*6.20*	*13.00*	*31.00*
6/6/01	surface	12.12	0.67	0.32
	sub-surface	3.95	1.32	0.11
16/8/01	surface	0.11	0.48	0.30
	sub-surface	3.2	0.29	0.13
16/3/02	surface	**50.8**	14.5	1.38
	sub-surface	**7.7**	7.4	0.11

3.7 EROSION

Turbidity

Turbidities were not very high at any sites. They were lowest at sites 1 and 2 for Peel, with the smallest range (Figure 3.13). Turbidities were similar for Peel sites, and between sites along the western shores of the Harvey (Figure 3.13).

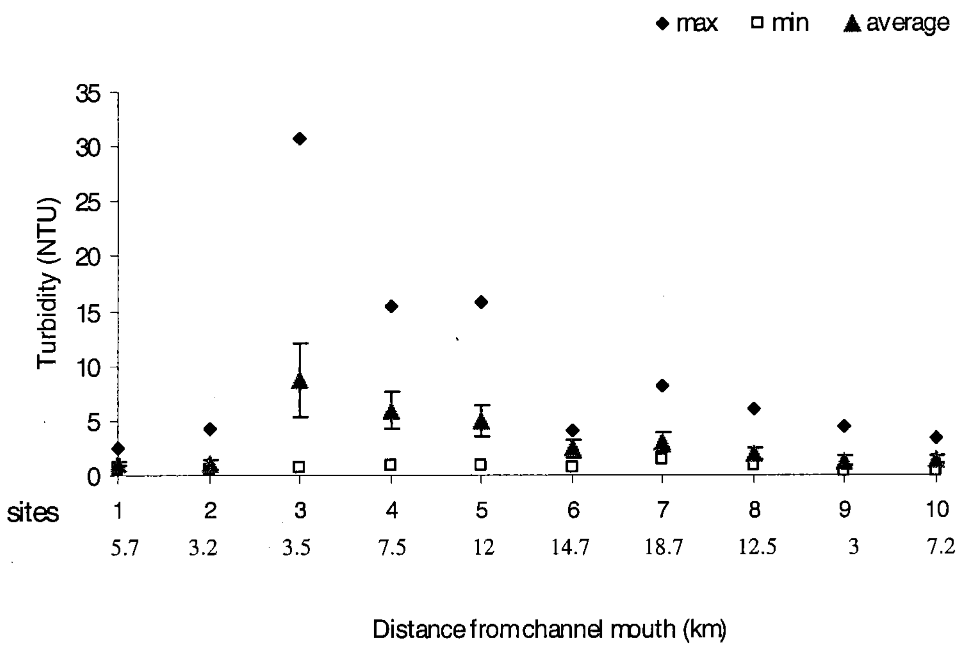

Figure 3.13: Turbidities at study sites in the Peel-Harvey Estuary over the study period, April 2001 to March 2002.

Sedimentation

Sedimentation differed at all sites (Figure 3.14 -3.19). Erosion and accretion dominated at the open water end of each transect and near the shoreline, apart from site 10, where sedimentation occurred 13 m into the transect (Figure 3.19). There was insignificant sediment movement at sites 1, 2 and 7 (Figure 3.14), sites 3, 4, 5, 8 and 10 oscillated between erosion and accretion, with site 8 having 7.5 cm gain and more than 10 cm loss (Figure 3.17). Accretion predominated at site 9 (Figure 3.18).

Erosion and deposition over the year resulted in little difference from the initial survey levels. On average, annual nett sediment loss occurred at sites 3, 4, 5, 6 and 10 (Table 3.7) Sediment gains occurred at sites 1, 2, 8 and 9 (Table 3.7).

Winter and summer nett sedimentation differed between sites. Sediment gain occurred at sites 6, 8 and 9, and erosion at sites 3, 4, 5, and 10 from April and September 2001. In contrast, accretion occurred at sites 3, and 10 and erosion at site 6 and 8, between September 2001 and March 2002. Sites 4, 5 and 6 continued to erode over summer with the highest average nett loss (-3.4 cm) at site 6.

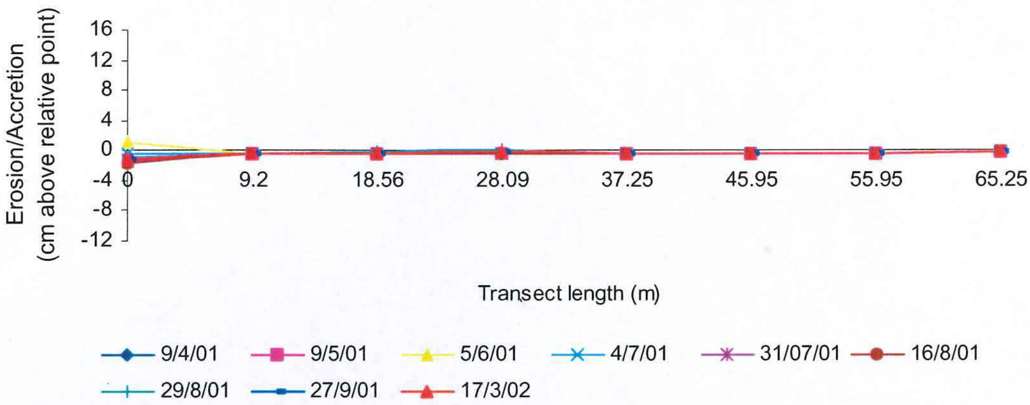

Figure 3.14: Erosion and accretion at site 2, Peel-Harvey Estuary, April 2001 to March 2002.

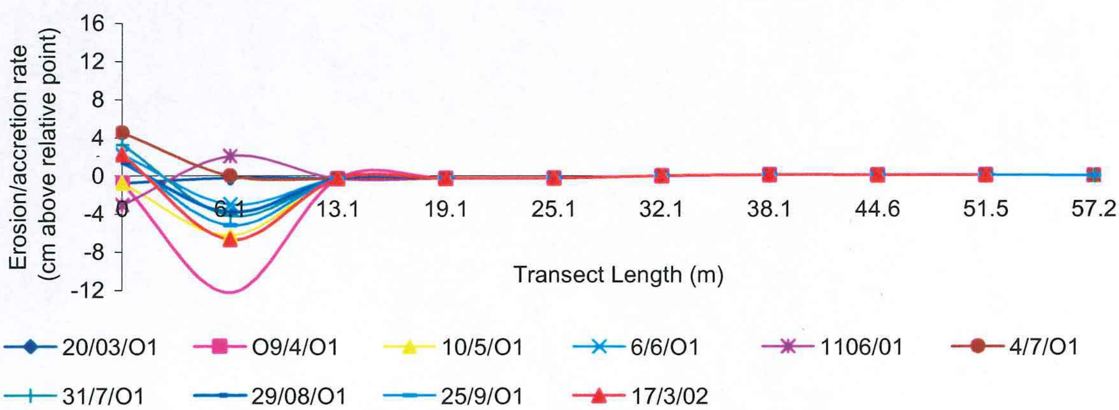

Figure 3.15: Erosion and accretion at site 4, Peel-Harvey Estuary, April 2001 to March 2002.

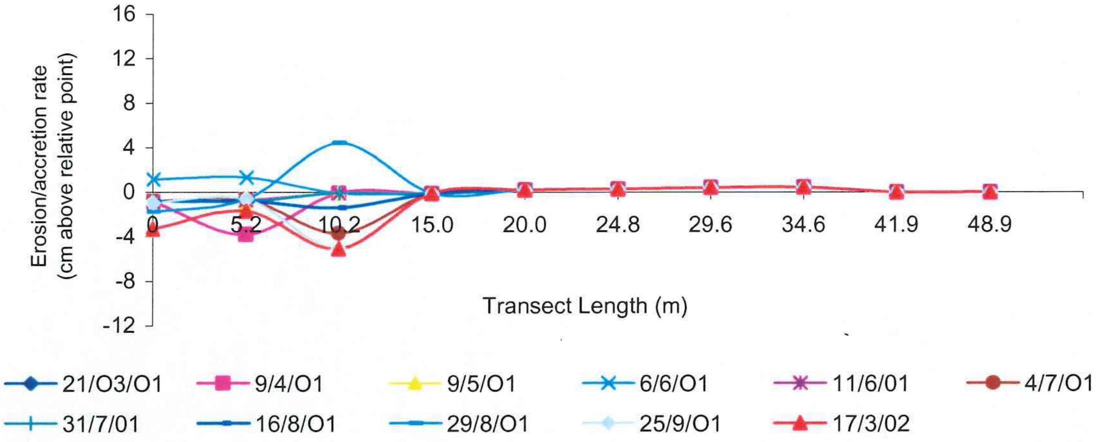

Figure 3.16: Erosion and accretion at site 5, Peel-Harvey Estuary, April 2001 to March 2002.

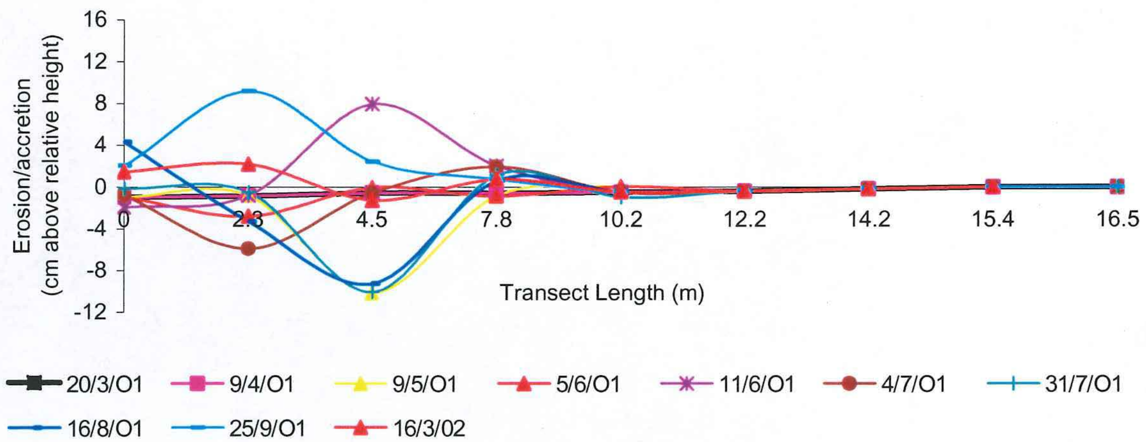

Figure 3.17: Erosion and accretion at site 8, Peel-Harvey Estuary, April 2001 to March 2002.

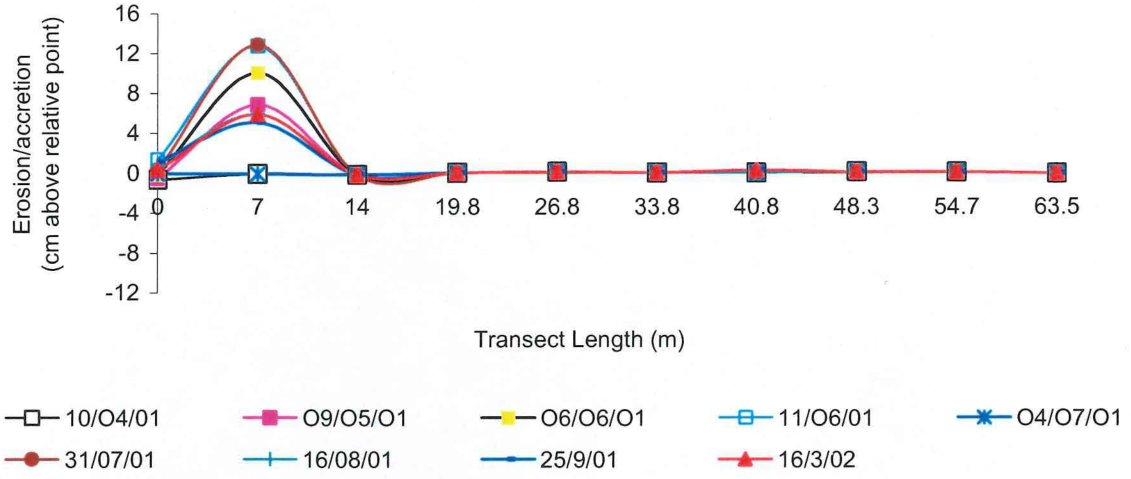

Figure 3.18: Erosion and accretion at site 9, Peel-Harvey Estuary, April 2001 to March 2002.

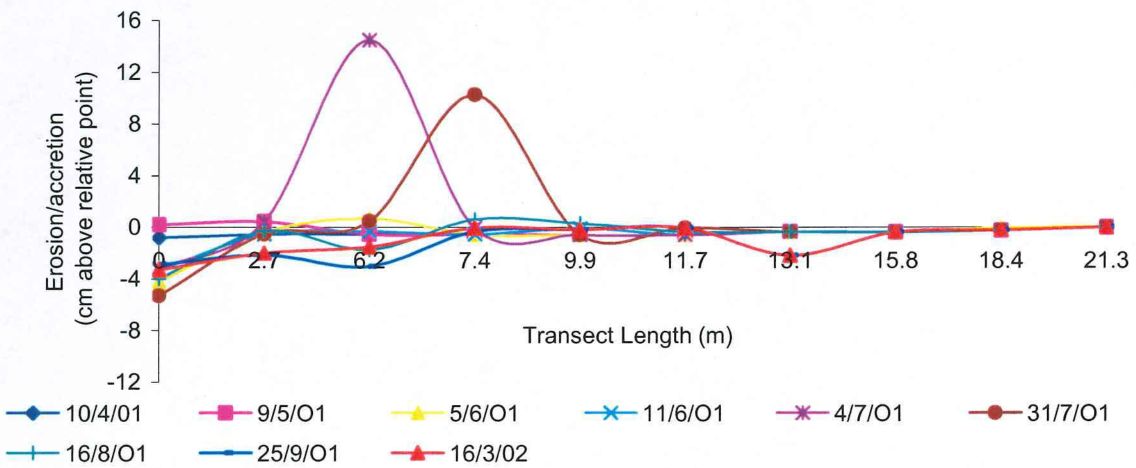

Figure 3.19: Erosion and accretion at site 10, Peel-Harvey Estuary, April 2001 to March 2002.

Table 3.7: Average nett sedimentation rates (cm) between annual, winter and summer periods at sites in the Peel-Harvey Estuary, April 2001 to March 2002 (+ indicates accretion, - indicates erosion). Sites with higher sedimentation rates are highlighted bold.

Sites	Average annual (cm)	Average winter (cm)	Average summer (cm)
1	+0.90	+ 0.90	0.00
2	+0.02	+ 0.09	0.00
3	-1.10	- 1.40	+0.26
4	**-2.52**	-1.25	-0.50
5	**-2.80**	-1.64	-1.15
6	**-2.60**	+0.83	-3.40
7	No data	+2.00	No data
8	+1.50	**+4.30**	-2.20
9	**+3.50**	+3.50	0.00
10	+2.20	-0.30	+0.22

Figure 3.20: Colonization of *Suaeda australis* in deposited beach rack at site 9, Peel Inlet, 2001.

4. DISCUSSION

This study did not support the hypotheses that the opening of the Dawesville Channel has had no effect on inundation, salinity or sedimentation and erosion in the Peel-Harvey system. Increased tidal amplitude has extended flooding, altered salinity patterns and sedimentation processes, and has induced more rapid changes than in the past. Through assessment of a number of estuarine characteristics and processes in relation to meteorological factors, and by comparing pre and post channel records, implications could be made as to the effect of altered estuarine conditions on foreshore vegetation structure since channel opening. Vegetation changes have resulted from interaction between altered tidal regime, meteorological factors and physical characteristics of the estuary shoreline.

4.1 INUNDATION

Although rainfall was well below annual averages and the actual tidal range was smaller than post channel ranges modeled by the Department of Transport, there has been a substantial increase in tidal amplitude since channel construction. Increased tidal amplitude to the extent where average tidal range (Figure 3.10), has increased to approximately three times the maximum pre channel range (20 cm) and the resulting high degree of flooding provides evidence for the rejection of the hypothesis that the Dawesville channel has had no effect on foreshore inundation.

Inundation

The frequency of inundation at 0 cm AHD was predicted by the model to increase from 50 to 51% of the time over an annual period and from 5 to 8% at elevations of approximately 25 cm (Murray *et al.,* 1995). Similar results came from modeling post channel tidal data by the Department of Transport, where elevations of 0 cm AHD were expected to be submerged for 50% of the time (Appendix VI). While predictions of inundation may differ from observations because of variations in mean sea level (MSL), inundation of marsh at 0 cm AHD over the annual period in this study was comparable with predictions. However, inundation at 25 cm AHD was more than double the predicted increase, and 80% submergence at 0 cm AHD in winter, further supports rejection of the hypothesis, suggesting inundation has increased since channel construction and low-lying sites may be most affected.

The site of lowest elevation appeared particularly affected with continuous flooding throughout the study. The low incidence of N-NW winds during the study suggest high water levels relate to site topography, and to delayed flushing because of the distance from the Dawesville and Mandurah channels, than to the effective fetch of 7.28 km in Harvey Estuary that may raise water levels in the South Kooljerrenup region. Although marsh extent fluctuated in the South Kooljerrenup and Austin Bay region because of low-lying topography before the channel opening (Glasson *et al.*, 1995), increased tidal amplitude has extended flooding and may cause changes to occur more rapidly than before.

Sediments

Higher proportions of fine sediment in soils at some sites may have prolonged inundation and contributed to unfavourable conditions for establishment and survival of *Juncus kraussii* and *Melaleuca rhaphiophylla.* Congdon (1981) observed an initial successful establishment of *Juncus* in inundated conditions approximately 20 cm deep, although seedlings died when flooding increased in winter. In contrast, inundation may be less effective in sandy soils that readily drain between tides. This concurs with Hillman, (1986) who notes that *Juncus* may tolerate greater inundation in sandy soils.

Topographic influences

Beach ridges, especially at sites on the western shore of Harvey Estuary, restrict drainage after ebb tides, and prolong inundation. Before the channel, topography at these sites was considered too steep for landward colonisation of samphires (Hillman, 1986). In the present study, samphires extended into the upper marsh, concurring with expectations in Kinhill (1988) that during high tides, there could be flooding beyond the beach ridges that may impair drainage.

Topographical depressions also trap floodwaters and prolong inundation. Dead *Melaleuca rhaphiophylla* trees in the depression in the upper marsh (site 9) indicate that high tides (despite being infrequent) have created conditions unsuitable for plant survival and establishment. *Melaleuca rhaphiophylla* is only tolerant of periodic inundation (WRC, 1997) and increased submergence in the upper marsh, as well as the encroachment of samphires, suggest that conditions for regeneration of *Melaleuca rhaphiophylla* may occur on higher ground.

Inundation effect on vegetation

Upper and lower marsh species occurred on or near the shoreline at a number of sites, where *Sarcocornia* and *Suaeda* encroached into upper marsh indicating extensive flooding, so that lower marsh areas may have become open water since the channel opened. This is despite predictions that little change would occur in the lower marsh due the flood tolerance of *Sarcocornia quinqueflora* (DAL, 1998), and the small increases in flooding expected (Murray *et al.,* 1995).

The encroachment of *Sarcocornia quinqueflora* and *Suaeda australis* into upper marsh reflects the long duration of submergence at most low-lying sites, providing further evidence of increased inundation. *Sarcocornia* will tolerate submergence up to 95% of the time (Rose and McComb, 1980), and may replace species adversely affected by increased flood duration (Chapman, 1974; Congdon, 1981).

After channel opening, samphires were expected to colonise large areas of the exposed intertidal in very low-lying regions. Considering there may be less exposure in the year of this study, with higher minimum tides than were predicted by the model (Figure 3.13), and the tendency of samphires to have extended landward resulting from submergence and inefficient sediment accretion (Nyman *et al.*, 1993) indicates colonisation may not occur, or may do so over a longer period. Studies in the Swan, Leschenault and Wilson estuaries, suggest colonisation of intertidal flats may proceed for more than 5 to 25 years with increased exposure following altered tidal regimes (PIMA, 1994).

Before the channel, Murray *et al.* (1995) found *Juncus kraussii* on the shoreline to be subject to submergence 10-50% of the year and more, while those landward were submerged 2-30% of the time. The unhealthy appearance of *Juncus kraussii* in the swale at site 2 and its disappearance over summer may be explained, given that submergence has increased to more than 80% of the time along most or all of the low-lying transects.

Increases in tree canopy cover (Table 3.4), may indicate trees will survive in the upper marsh as long as tidal amplitude does not increase further. The increase in tree canopy cover may also reflect the temporary recovery that could occur in winter with increased river flow and precipitation. Although there was little difference in general between species (Table 3.4), continuing growth may depend on plant age and the tolerance range of individual species.

4.2 SALINITY

Water salinity

General seasonal changes in salinity were similar before and after channel construction. The small salinity ranges at some sites relate to their proximity to the channel, where exchange with ocean waters maintain more constant salinities throughout the year (DAL, 1998). Higher salinity ranges in southern Harvey relate to the distance from the channel and proximity to the Harvey River. Freshwater inputs from the Harvey River, which continues to flow even in low rainfall years (Black and Hodgkin, 1984) brings about lower minimum salinities, while high evaporation rates in summer contribute to high salinities.

It had been expected that salinities would be less extreme after channel construction (DAL, 1998), but hypersaline conditions continue to prevail during the dry months of summer and autumn. This appears to support the hypothesis that channel opening may not have altered salinities. Hale and Paling (1999) recorded similar seasonal changes in salinity to those reported here during the five years immediately post channel, though minimum salinities were close to freshwater and comparable with pre channel records. Although higher minimum salinities in this study suggest salinities have altered since channel opening, they more likely reflect the extreme dry conditions and related low river-flow during 2001, and while the post channel years assessed by Hale and Paling (1999) were below average rainfall years, rainfall this year was approximately half of that in those years.

Soil Salinity

With no pre-channel soil salinity records for comparison, addressing the hypothesis that the opening of the Dawesville channel has had no effect on soil salinities was inconclusive. While most soil salinities were low, considering the hypersalinity of waters in summer and the long duration of flooding, higher soil salinities may have been expected. With increased tidal amplitude, saline waters would flood further into the marsh, altering soil water and soil salinities, with a combined effect on foreshore vegetation, especially at low elevations. Day *et al.* (2000) reported that the combined effects of saltwater intrusion, long periods of inundation and salinity caused tree death in *Taxodium* Swamps of the Mississippi Delta.

Sediments

At a two sites (3 and 7) higher recordings also corresponded with higher proportions of fine sediments which may act to enhance salinities by water and salt retention. In comparison, sandy soils with higher leaching may explain low soil salinities at most sites (Chapman, 1974).

Topographic influences

There were higher salinities at low-lying, frequently flooded sites. Higher salinities near the open water at low-lying sites were expected given that duration and frequency of flooding determines the soil salinity gradient, and that salinity tends to be highest in the lower marsh, and lower toward the upper marsh where there is less flooding (Latchford, 1997). Higher soil salinities toward the upper marsh may also reflect extended inundation caused by shoreline ridges in winter, and in summer within topographical depressions, as salinity increases when sediments dry. Highest soil salinities were expected in South Kooljerrenup (site 7) and Austin Bay (site 10) because of their low relief, tendency to flood and extreme water salinity during dry months (Murray *et al.*, 1995).

Salinity effect on vegetation

Sarcocornia quinqueflora and *Suaeda australis* encroaching into upper marsh was the most convincing indicator that soil salinities may have altered, as both species are obligate halophytes (Chapman, 1974). Establishment of *Sarcocornia* and *Suaeda* around topographical depressions and decline of vegetation within them infers soil water and soil salinity may not allow survival at low elevations. The absence of *Halosarcia* spp. and *Bolboschoenus caldwellii,* reported by Murray *et al.* (1995) as commonly associated with *Sarcocornia quinqueflora* and *Juncus kraussii,* concurs with the expectation that increased tide height may inundate and alter the dry extreme of saline areas, bringing about a decline in *Halosarcia* spp. (Murray *et al.,* 1995).

As with most marsh species, for establishment, *Juncus kraussii* requires a period of low soil salinity (less than $5^{o}/oo$) (Zedler *et al.,* 2000). If higher minimum water salinities were to continue for most of the year and fresh water input remains low, *Juncus* may not establish especially in areas of low-lying topography where submergence exceeds 80%.

The low abundance of *Juncus* at sites with higher proportions of fine sediments may indicate their intolerance to sediments prone to flooding and elevated soil salinities. In contrast, *Juncus* may survive in sandy soils (as at site 6) with a high degree of flooding and low soil salinities (Hillman, 1986).

The failure of M. *rhaphiophylla* to re-establish at one site (3) may relate to the close coincidence between a fire event and the opening of the Dawesville Channel. Juvenile M. *rhaphiophylla* may not have become fully established before increased tides made conditions unfavourable for their continued growth. Baldwin *et al.* (1996) found in pot trials that there was little effect on seedlings subjected to short term flooding and salt load, although long-term exposure greatly inhibited growth.

Given the high tolerance of *Melaleuca cuticularis* to inundation and salinity (Pen, 1992; Bell, 1999; Naidu *et al.*, 2000), this species may have been able to cope with the altered conditions better than most upper marsh species, as it survives at low-lying sites with long submergence time. Stands of M. *cuticularis* along the secondary shore at site 7 may also survive, though may be less adaptable to the changed conditions because of their immaturity. Decline in *Melaleuca rhaphiophylla* and *M. cuticularis* may still occur as changes in upper marsh have been known to continue for 25 years following hydrological alterations (Murray *et al.*, 1995).

4.3 SEDIMENTATION and EROSION

Sediments

Similar sediment characteristics to pre-channel years at a number of sites, appears to support the hypothesis that the Dawesville channel has had no effect on sedimentation and erosion, and implies that channel opening has had no effect on sedimentation. The higher proportions of fine muds and silts at sites along the western shore of Harvey Estuary concurs with findings by Hill *et al.*, (1991). Gabrielson and Lukatelich (1985) also relate high deposition rates off-shore of western Harvey sites to the reworking of sediments on the eastern side of Harvey during predominant S-SW winds, and deposition of fine sediments on the western shore as a result of an anticlockwise gyre.

A higher sand content in Peel Inlet before channel opening may also relate to proximity to the Mandurah Channel, where fine alluvial sediments may be flushed seaward (Hodgkin, 1984). The high coarse sand content at one site (8) was characteristic of sediment composition along the eastern shores of Harvey Estuary before the channel opening (Hill *et al.*, 1991). At site 7, a higher coarse sand content before channel opening may be alluvial sands that have settled quickly following discharge from Harvey River (Hodgkin *et al.*, 1980; Gabrielson and Lukatelich, 1985).

It was not possible to accurately quantify any change in sediment grain size proportions since channel construction, Fine sediments may be more easily flushed from the system and sands of marine origin may explain the high sand content, particularly at sites in proximity to the Dawesville and Mandurah channel mouths.

Low proportions of fine sediment may also reflect low river flow associated with the below average rainfall years since the Dawesville Channel opened (DAL, 1998). Day *et al.* (2000) explained the importance of delivery of fine sediments through river flow and attributes lower rates of wetland loss to high riverine inputs. Perhaps low river flows during post channel years may have contributed to low accretion rates, soil instability and vegetation change. Accretion rates may continue to be low even in years of high river flow, though with increased tidal flushing, fine sediments may continue to be flushed from the system rather than deposited in the marsh.

Turbidity of Estuary Waters

Since the construction of the channel and the absence of *Nodularia* blooms, improved water quality is reflected in decreased light attenuation in post channel years (Hale and Paling, 1999), as well as in low turbidities at all sites in this study. Although turbidities during previous post channel years were lower in spring and early summer, consistently low recordings this year may relate to reduction in fine sediments in the system because of increased flushing through the Dawesville Channel, therefore may add further support for rejection of the hypothesis that sedimentation has not altered since channel opening. Turbidities also did not reflect a trend of increasing in association with areas close to river discharge, perhaps because of low input of fine alluvial sediments because of low river flow this year. Low turbidities may also be due to improved catchment management, including farming practices and revegetation, rendering sediments less prone to erosion.

As general wind patterns remain consistent with pre-channel years, Harvey Estuary continues to be more turbid than Peel Inlet this year as reported in other pre and post channel studies. Although wind is responsible for 70-90% of the resuspension of sediments in both Peel and

Harvey, wind fetch dynamics are responsible for higher resuspension rates in the Harvey (McComb and Lukatelich, 1995).

A relationship between turbidity and sediment type was indicated where more turbid waters along the western shores than on the east of the Harvey Estuary appear related to the higher proportions of fine sediments that can be easily entrained and suspended, settling only during calm periods (Kennish, 1986), while low turbidities at most sites reflected higher proportions of coarse sands.

Sedimentation and tidal amplitude

As higher erosion rates relate to higher tidal amplitude and water movement (Congdon, 1981), it is possible that the landward shift of the high tide line and increased tidal frequency has increased entrainment and removal of foreshore sediments in the Peel-Harvey. Rose and McComb (1995) considered pre-channel sedimentation rates to be high when more than 10 mm of sediment were deposited per year, and low when there had been less than 3 mm per year. On this basis, the erosion and deposition characteristics over the study refute the hypothesis that channel opening has had no effect on sedimentation and erosion, and indicate that tidal amplitude has increased sedimentation rates since channel construction (Figures 3.14-3.19).

Dead *Melaleuca cuticularis* along the shoreline, and under cutting of *Juncus* roots and rhizomes, suggest tidal action has removed sediments from around their shallow root zone and caused trees to collapse. Erosion and deposition on the shoreline at each site indicates instability of all shorelines, and suggests there will be continued erosion and deposition, the nett outcome being determined by the balance between submergence and vertical accumulation.

Wind exposure

Regular exposure to onshore winds explains higher sedimentation rates (and turbidities) at sites along the western shores of Harvey. This concurs with findings of French *et al.* (2000) who related high erosion rates in the Blythe Estuary (England) with areas subject to high wind exposure. In the present study, although most sites oscillated between erosion and accretion between sampling dates, and nett losses were low, the extreme fluctuations at one site (8), exposure to most prevailing winds (either directly or through long shore drift) and the complete removal of shoreline *Juncus* at one location, indicates erosion has effected vegetation (Appendix II). As *Juncus kraussii* is able to withstand wave energy (Hillman, 1986) because of its dense underground biomass (Congdon and McComb, 1980), it appears this site has been severely affected by wave action. Absence of *Sarcocornia quinquiflora* also indicates a 'high-energy' shore, due to its inability to withstand direct wave movement (Hillman, 1986).

Topographic influences

Considering that shoreline shape and alignment greatly influence sedimentation (Guy and Parkin, 1994, Schwimmer, 2001), higher rates may have been exacerbated by ridge formations where sediments may be easily removed, exposing roots and rhizomes at the ridge face. Steeper gradients from the open water to the shore may also contribute to higher erosion rates.

Erosion and sediments

A high sand content correlates to areas of low water and high energy (Hill *et al.,* 1991), and it is not surprising to find a high sand content at site 8. Higher average annual nett losses at sites along the western shores of the Harvey also relate to the high sand content of foreshore soils. In contrast, lower annual nett sediment losses at a site (3) are consistent with a higher proportion of fine sediments at that site. The lack of any nett change at some sites despite high sand content, suggest erosion has slowed and there may be a move toward stability at such sites. Low erosion rates at one site (1) may relate to the removal of significant proportions of fringing vegetation during beach clearing of macroalgae between 1976-1990 (Black and Hodgkin, 1984).

Stability at one site (9) may also be promoted because of the nature of the deposited material, largely made up of *Halophila ovalis* debris and sand (personal observation, Figure 3.22). Nyman *et al.* (1993) reports that mineral content of organics deposited on shores plays a major role in sediment stabilisation, and can promote vegetation growth. Colonisation of *Suaeda australis* in the deposited material (Figure 3.20) further supports shoreline stabilisation in this area and suggests marsh gains may continue as reported in Kobryn *et al.* (2000).

While evidence from this study indicated erosion has increased at a number of sites and rejects the hypothesis that the Dawesville Channel has had no effect on erosion, there were no marked losses of land this year. Given the time frame of 6 years since channel construction and evidence of accelerated erosion in Kobryn *et al.* (2000), rapid erosion seems to have already occurred in the earlier post channel years and may be now slowing, with a move toward shoreline stability. However, below average rainfall in all post channel years and extreme dry conditions this year, it would be wise to confirm this conclusion.

5. CONCLUSION

Construction of the Dawesville Channel has affected inundation, salinity, sedimentation and erosion in the Peel-Harvey System. Vegetation structure reflected altered conditions determined by the interplay between increased tidal amplitude, meteorological factors and topographic differences along the shoreline.

The following effects of altered water movement since channel opening were identified:

Inundation

- Inundation has increased, and low-lying sites most affected, where all or most of the marsh was flooded 80% of the study time period.
- Higher proportions of fine sediments may have enhanced flooding at 2 sites.
- Inundation was exacerbated by the presence of beach ridges (particularly on the western shore of the Harvey).
- Trapped waters in topographical depressions also prolonged inundation, creating conditions unsuitable for plant survival.
- Encroachment of *Sarcocornia quinquiflora* and *Suaeda australis* into upper marsh provided evidence of increased inundation.

Salinity

Water salinity

- Water salinities generally resembled those before and after channel opening.
- Hypersalinity continues to occur in summer and autumn.
- Higher minimum salinities related to the extreme dry conditions this year.
- Salinity ranges reflected proximity of sites to channel mouths and river systems.

Soil salinity

- Salinities in most soils were low and did not reflect the hypersalinity of estuary waters in summer.
- Soil salinities were higher in areas with long duration of flooding.
- Two sites higher salinities corresponded with higher proportions of fine sediments.

- The presence of *Sarcocornia quinquiflora* and *Suaeda australis* in upper marsh indicated higher soil salinities.

Sedimentation and Erosion

Sediments

- Sediment characteristics were similar to pre channel.

Turbidity

- Turbidities were consistently low and may relate to increased flushing of fine sediments through the channel and high sand content in soils.
- Harvey Estuary continues to be more turbid than Peel Inlet.
- Higher turbidities related to a site containing higher proportions of fine sediments.

Erosion

- Erosion was indicated by dead *Melaleuca* spp. on the shoreline and undercutting of *Juncus* roots and rhizomes.
- Obvious erosion occurred at one site where foreshore *Juncus kraussii* was eliminated.
- Sites oscillated between erosion and deposition between sampling.
- Sites with higher sedimentation rates related to areas regularly exposed to prevailing winds.
- Higher erosion rates corresponded with dominance of sand in foreshore soils.

6. RECOMMENDATIONS

Research

1. Continued to monitor parameters on a site-specific basis to take account of seasonal variability.
2. Replicate vegetation and soil surveys over the long term and on seasonal basis to determine the effects of the present conditions, as well as the range of conditions exposed to individual species over time.
3. Map recent aerial photography for comparison with conclusions in Kobryn *et al.*, (2000).
4. Investigate tolerance of *Juncus kraussii* to various environmental conditions, and make it a focus within rehabilitation programmes, to maintain the ecological integrity of this species.

5. Continue to monitor conditions and changes in special interest areas (public reserves and conservation areas). Areas highlighted in this present study include, site 1 on Erskine Reserve and site 8 in the Mealup Point area where the very narrow marsh area may retreat further and affect conservation values.
6. Measure groundwater properties each site.
7. Incorporate plant trials that assimilate field conditions for different plant ages particularly for *Juncus kraussii* and *Melaleuca* spp. to better understand vegetation dynamics and improve success of rehabilitation methods.
8. To assess further the dynamics of accumulation of organic debris on the estuarine foreshores and determine the positive and detrimental effects of wrack dynamics.

Management

9. Use existing vegetation successional patterns as a guide to assist with revegetation programmes.
10. Instigate revegetation of Erskine Reserve foreshore to enhance and improve the quality of the narrow marsh zone.
11. Investigate best shore stabilisation methods, including the use of logs to reduce wave action and promote sediment accretion.

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8. APPENDICES

APPENDIX I: (see CD-ROM attached to inside back cover).

Panoramic photographs of Peel-Harvey study sites 1-10, 2001.
Adobe Photoshop - jpeg files (727 KB)
Format: HFS+ISO 9960 (Mac. And PC readable)

- P-H.site1.jpg : Study site 1- Erskine Reserve
- P-H.site2.jpg : Study site 2- Ward Point
- P-H.site3.jpg : Study site 3- Warragup Springs
- P-H.site4.jpg : Study site 4- Lot 8 Estuary Road
- P-H.site5.jpg : Lot 100 Old Coast Road
- P-H.site6.jpg : South Estuary Road
- P-H.site7.jpg : South Kooljerrenup
- P-H.site8.jpg : Mealup Point
- P-H.site9.jpg : Point Grey
- P-H.site10.jpg: Point Birch

APPENDIX II:

STATISTICAL ANAYSIS

Multiple regression analysis was employed to assess the relationships between parameters measured over the study period. Linier regression was preformed in the statistical package SPPS, using 'enter' and 'step-wise' methods for analysis (Coakes and Steed, 1996). Several multiple regression runs were undertaken with vegetation and site chosen as dependant variables. Correlations between individual independent variables and the dependant variable were also made. The level of significance used was $p \leq 0.05$.

Model summary output for each multiple regression run indicated little correlation between parameters, with R-square values ranging from 0.09 to 0.26. No significant relationship between individual parameters and the dependant variable was supported where p-values ranged from 0.10 to 0.9.

APPENDIX III

Vegetation distribution along transects in the Peel-Harvey Estuary 2001.

(Word document, CD-ROM, HFS+/ISO9960 format)

APPENDIX IV: Photographs indicating The effects of wave action on foreshore *Juncus kraussii* (on eastern Harvey shore at study site 8, Mealup Point, Peel-Harvey Estuary WA, 2001.

Format: HFS+ISO 9960 (Mac. And PC readable)
Adobe Photoshop - jpeg files (332 KB)

- Temporal.1.jpg: 28 th February 2001
- Temporal.2.jpg: 20 th March 2001
- Temporal.3.jpg: 5 th June 2001
- Temporal.4 jpg: 11 th June 2001
- Temporal.5.jpg: 30 th July 2001
- Temporal.6.jpg: 16 th August 2001
- Temporal.7.jpg: 16 th March 2002

APPENDIX V: Land elevation (cm) in relation to the AHD (in bold), at each reference point (peg) along site transects, Peel-Harvey Estuary, 2001.

Peg	1	2	3	4	5	6	7	8	9	10
Site 1										
transect (m)	0	2.8	5.6	7.8	10.68	13	15.78	18	20.8	
cm AHD	**-76.7**	**-69.7**	**-55.5**	**-3.2**	**26.4**	**34.7**	**12.7**	**12.8**	**15.5**	
Site 2										
transect (m)	0	9.2	18.56	28.09	37.25	45.95	56	65.25	74.53	
cm AHD	**-69**	**-31.8**	**-35.9**	**-18.8**	**-31.8**	**-22.6**	**-14.7**	**-1.4**	**20**	
Site 3										
transect (m)	0	2	4	8	12	16	20	24	28	30.5
cm AHD	**-136**	**-29.3**	**-14.8**	**-12.3**	**-16.2**	**-14.5**	**-17.5**	**-13.5**	**-12.6**	**-7**
Site 4										
transect (m)	0	6.14	13.14	19.14	25.14	32.14	38.14	44.64	52	57.24
c cm AHD	**-75**	**-18**	**-25**	**-22**	**-20**	**2**	**13**	**10**	**9**	**2**
Site 5										
transect (m)	0	5.15	10.15	14.95	19.95	24.75	29.6	34.6	41.85	
cm AHD	**-100**	**-96**	**-24**	**-27**	**6**	**12**	**-10.43**	**31**	**-15**	
Site 6										
transect (m)	0	11	21	31	39.5	49.15	59.85	70.55	81.35	91.35
cm AHD	**-126**	**-61.3**	**-71.8**	**-50.3**	**-59**	**-50.5**	**-56**	**-41**	**-16**	**-16**
Site 7										
transect (m)	0	13.5	27	40.5	66.5	79.5	92.5	103.5	114.5	124.5
cm AHD	**-53**	**-44**	**-31.3**	**-33.9**	**-37.1**	**-43.9**	**-40.8**	**-39**	**-33.9**	**-14**
Site 8										
transect (m)	0	2.3	4.48	7.84	10.24	12.24	14.24	15.39	16.54	
cm AHD	**-99.8**	**-85.5**	**-59.8**	**-59.8**	**-50.1**	**-43.5**	**-20.8**	**-3.7**	**-2.5**	
Site 9										
transect (m)	0	7	14	19.8	26.8	33.8	40.8	48.3	54.7	63.5
cm AHD	**-40.8**	**19.1**	**7**	**29.1**	**35.8**	**26.5**	**26.3**	**38**	**34.8**	**22.5**
Site 10										
transect (m)	0	2.7	6.2	7.4	10	11.75	13.2	16	18.62	21.47
cm AHD	**-50**	**-24.7**	**-23**	**-23.7**	**-29**	**-24**	**-6**	**-6.4**	**7**	**31**

Appendix VI: Submergence curve. Predicted percent time inundation in relation to the Australian Height Datum (AHD), in the Peel Inlet after construction of the Dawesville Channel.