CHAPTER 3 Extent And Composition Of The Samphire Marshes of the Peel-Harvey System

R. Murray, H. T. Kobryn, J.A. Latchford and A.J. McComb

3.1 Introduction

In a report published in 1985, Hodgkin *et al.* pointed out that the saltmarsh vegetation of the Peel Harvey estuary constitute an important component of the fringing vegetation. They estimated the total area of marsh to be about 13 km^2. This estimate incorporated some open water as well as *Sarcocornia spp* and *Juncus kraussii* communities. Hodgkin *et al.* (1985) highlighted the importance of saltmarshes in stabilising the shoreline, and called for further studies to:

> "*obtain a better understanding of the significance of the marshes to the general ecology of the area, including their role in shoreline stabilisation, nutrient dynamics, and bird life.* "
> Hodgkin *et al.* (1985), p35

The present work addresses some of these deficiencies in our knowledge.

It was clear that much of the study would of necessity have to rest on a firm understanding of the extent and composition of the marsh, and the required mapping of the marsh was accomplished by interpretation of aerial photographs combined with field visits. The photointerpretation approach used was described in Chapter 2. That chapter described the distribution of samphire flats in the study area using April 1994 colour aerial photography, which was flown at low tide three days before the opening of Dawesville Channel.

In this study both the historic and current distributions of saltmarsh were mapped. A common approach was followed in interpreting all available aerial photographs, which included black and white, normal colour and false colour infrared photography.

As explained in detail in Chapter 2, attempts to map all saltmarshes using the photointerpretation technique proved difficult and prone to misinterpretation, especially with black and white photographs. A decision was therefore taken to map the extent of saltmarsh dominated by samphire, and exclude areas with less than 30% cover and areas dominated by terrestrial shrubs and trees.

3.2 Extent of the Saltmarsh

Based on aerial photo interpretation, it was concluded that in April 1994 there were 630.140 ha of samphire marshes in the Peel Harvey area (Figure 2.6). Five smaller areas were selected to compare their relative importance in size and condition. Table 2.1 and Figure 2.7 show the boundaries of those study areas. The samphire cover in the areas was as follows:

Austin Bay area	37.758 ha
Creery wetlands	140.156 ha
Harvey Delta	144.783 ha
Goegrup Lake area	45.289 ha
Roberts Bay	80.749 ha
other	188.405 ha
total	**630.140 ha**

To validate the photointerpretation, 100 locations were visited to check the mapping accuracy against the ground truth (chapter 2). Samphire was correctly identified and mapped in 82% of cases.

Although Harvey Delta had the largest area of samphire, the cover was very fragmented because of the geomorphology of the area. Creery Wetlands formed the largest continuous cover of samphire in the Peel Harvey region, although this was showing fragmentation due to human disturbances such as vehicle tracks.

The total area of samphire marsh, 630.140 ha for 1994 was only half of the area estimated made by Hodgkin *et al.* (1985). However their estimate included *Juncus kraussii*, and other saltmarsh vegetation. It is also not clear from that reference on what basis their estimates were based. Our estimates from the historical data (chapter 2) show approximately 9 km^2 at the time of the estimate reported by Hodgkin *et al.* (1985). The difference of 5 km^2 between the two estimates is attributed to different definitions of what has been mapped as samphire/saltmarsh.

3.3 Composition of the Samphire Saltmarshes of the Peel-Harvey System

3.3.1 Methods

Ten sites around the estuary were selected (Figure 1.1) to encompass the range of variation in saltmarsh. Preference was given to sites with least obvious disturbance, and least likely to have been vandalised. A permanent transect was established at each site perpendicular to the water's edge across the full width of the marsh, and marked with surveyor's pegs. The height of the marsh was surveyed and profiles drawn.

Records were taken of the name and dominance of each species encountered on each transect (Site map, Figure 1.1). Specimens were prepared of all species recorded, checked against the Western Australian Herbarium specimens and lodged in an herbarium at Murdoch University.

To check the health of the saltmarsh and understand the tolerances and growth rates of the plants, several investigations were undertaken to document the environmental tolerances and growth rates of key species. The first was to examine the percentage cover of saltmarsh species in 30, randomly-distributed quadrats in autumn and winter. Secondly, plant biomass was determined at six of the ten sites. For this purpose each transect was divided into three areas based on perceived similarity of vegetation in each section. Area 1 was closest to the water's edge and area 3 the furthest (Figure 1.2).

The above ground biomass of saltmarsh species in nine randomly distributed quadrats was determined by harvesting all the above ground plant material and obtaining the dry weight. Samples were harvested in autumn and winter. The total nitrogen and total phosphorus content of the biomass samples was also measured. In addition the above and below-ground biomass of the major species in these transects were determined and total nitrogen and total phosphorus concentration measured.

3.3.2 Results and Discussion

Saltmarshes usually exhibit a high abundance of a few species, and the vegetation is typified by well-defined “zones” (Bridgewater *et al.*, 1981). The ten study sites (Figure 1.1) differed in species composition and structure, the saltmarshes occurring as steep narrow fringes or long, flat expanses. The width, number and importance of such zones often varied, depending on the local environment, tidal currents and sedimentation patterns.

The findings from this section of the study are divided into the species found on the transects; the distribution of these species on the marsh; their percentage cover in autumn and winter; the biomass of the vegetation in autumn and winter; and seasonal differences in nutrient concentration.

Species Occurrence

The most common plant species occurring along the transects, and the communities in which they were found, are described below.

Sarcocornia quinqueflora

This is a small green shrub, which turns from green to red during autumn. The decumbent stems and branches are succulent, and reach 50 cm in height (Pen, 1983; Marchant *et al.*, 1987). This complex was widely distributed in the saltmarsh. It occurred as a band along the shoreline, where it formed the primary community, which was often fringed with this zone and *Juncus kraussii* or *Suaeda australis* (Plate 3.1).

Suaeda australis

This branching understorey shrub was up to 30 cm tall, with slender fleshy leaves which are light green, turning red or purple in autumn (Plate 3.1). It was found with *S. quinqueflora,* and often had obvious accumulations of organic debris.

Bolboshoenus caldwellii

This ephemeral introduced species bears long, grass-like leaves from rhizomes in the winter/spring period, when salinities are low; it senesces over summer and autumn as salinities increase (Marchant *et al.*, 1987; Pen, 1983). In this study, small stands were found interspersed with shoots of *S. quinqueflora*, forming a closed sedgeland.

Halosarcia *species*

Several species from the genus *Halosarcia* were found in the marshes. The procumbent stems of these perennial species are hard and woody, but branches contain fleshy segments with succulent branchlets are which appear articulate (Plate 3.1). They form an open heath in the high marsh, which reaches high salinities during summer, with lower salinities, close to that of freshwater, during winter (Pen, 1983; Marchant *et al.*, 1987). *Halosarcia indica* subspecies *bidens* is a large, green shrub, up to 60 cm tall (Marchant *et al.*, 1987). An apparently different growth form *Halosarcia indica* subspecies aff. *bidens* was found to conform to the species description, except that the branchlets were more succulent and appeared elongated, reaching about 20 cm tall. This was less common than *Halosarcia indica* subspecies *bidens* and was found at higher elevations, generally fringing saltmarsh concavities. *Halosarcia indica* subspecies *leiostachya,* which possesses cylindrical to ellipsoid spikes was also found (Marchant *et al.*, 1987). However, it was only found on the Creery Wetland transect at Site 5 and did not appear to have been mentioned in other studies of Western Australian saltmarshes. *Halosarcia halocnemoides* is a smaller, bushy shrub some 30 cm tall. It has reddish-green stem segments with many slender branchlets which lose their succulent tissue on maturity, and become woody (Pen, 1983; Marchant *et al.*, 1987). This species tended to occur in the drier, most saline regions of the saltmarsh, and was present on most transects.

Frankenia pauciflora

This is a small, prostrate to ascending shrub with small, linear leaves with downturned margins and small pink or white flowers (Bridgewater, *et al*. 1981). It was found on the drier banks in the marsh, and formed a heath with *S. quinqueflora* and *Suaeda australis*, or with *Halosarcia* species. These communities were restricted in distribution.

Plate 3.1 Saltmarsh plants of the Peel- Harvey system. *Sarcocornia quinqueflora,* (top left), *Suaeda australis* (top right), *Halosarcia halocnemoides* (bottom).

Juncus kraussii

This tall rush- the 'shore rush', has cylindrical, pointed, firm culms with spongy pith. The loose, clusters were often found as dense bands of closed rushes, although it was also found growing more sparsely in localised stands in the *S. quinqueflora* complex. It grew up to 1.5 m high and occurred on the drier, elevated parts of the marsh or in brackish areas where the salinities were lower (Bridgewater *et al.*, 1981; Pen, 1983). It was usually flooded by the highest tides and at some sites reached to the waters edge at low tide.

Atriplex species

These are decumbent herbs or shrubs with minute, bladder-shaped hairs which give the plants their characteristic grey colour (Morley & Toelken, 1987). *Atriplex hypoleuca* is a sprawling decumbent shrub which was found to grow up to 2 m in diameter (Marchant *et al.*, 1987). It was usually found associated with *J. kraussii* close to the water's edge. *Atriplex prostrata* is an introduced annual herb and was found to spread up to 60 cm long. The stems are slender and angular, with arrow shaped leaves (Marchant *et al.*, 1987; Morley & Toelken, 1987). This was usually found on drier, elevated banks.

Cotula coronopifolia

This small, fleshy, annual daisy germinates and grows in winter and flowers in September (Stoner, 1976). The toothed leaves loosely sheath the stem, and the solitary flower heads are yellow (Marchant *et al.*, 1987). It was found in the higher damp areas of the marsh and, according to Bridgewater (*et al*. 1981) is influenced by fresh water.

Zonation of Plant Communities across the Marsh

The vegetation units used to describe the plant communities of the Peel-Harvey saltmarsh, on the basis of species occurrence and dominance along transects, are listed in Table 3.1. There were three complexes, subdivided into twenty communities (Pen, 1983). Each community was usually dominated by a major species of the complex.

Table 3.1. Vegetation units of saltmarsh fringing the Peel-Harvey estuarine system. The first letter of the code defines the complex, and the second letter, the second most dominant species or, if capitalised, the second dominant species.

SARCOCORNIA COMPLEX *Sarcocornia quinqueflora*

CODE	COMMUNITY	OTHER SPECIES	STRUCTURE
S1	*Sarcocornia* typical community of *S.quinqueflora*		saltmarsh complex
Su	*S. quinqueflora* & *Suaeda australis*	*Atriplex prostrata*	saltmarsh complex
Sb	*S. quinqueflora* & *Bolboschoenus caldwellii*	*Su. australis* *Atriplex hypoleuca* *A. prostrata* *Polypogon monspeliensis* *Cotula coronopifolia*	saltmarsh complex
SB	*B. caldwellii* predominant	*S.quinqueflora*	closed sedgeland
Sa	*S. quinqueflora* & *Atriplex hypoleuca* or *A. prostrata*	*Su. australis* *B. caldwellii* *P. monspeliensis*	saltmarsh complex
SA	*A. hypoleuca* or *A. prostrata* predominant		saltmarsh complex
Sh	*S. quinqueflora* & *Halosarcia halocnemoides* or *H. indica* subspecies *bidens*	*Su. australis* *B. caldwellii* *P. monspeliensis* *C. coronopifolia* *Cynodon dactylon*	saltmarsh complex
Sf	*S.quinqueflora* & *Frankenia pauciflora*	*Halosarcia halocnemoides* *Su australis*	low closed heath
Sg	*S.quinqueflora* & *Polypogon monspeliensis*	*C. coronopifolia*	saltmarsh complex

JUNCUS COMPLEX *Juncus kraussii*

CODE	COMMUNITY	OTHER SPECIES	STRUCTURE
J1	*Juncus* typical community of *J. kraussii*		closed sedgeland
Js	*J. kraussii* & *Sarcocornia quinqueflora*	*Suaeda australis*	closed sedgeland
Jb	*J. kraussii, S. quinqueflora* & *Bolboschoenus caldwellii*	*Atriplex prostrata*	closed sedgeland
JB	*B. caldwellii* predominant with *J. kraussii*		closed sedgeland
JA	*A. hypoleuca* predominant with *J. kraussii*		low closed sedgeland
Jg	*J. kraussii* & grasses *Lolium rigidum &* *Polypogon monspeliensis*	*Bolboschoenus caldwellii* *A. hypoleuca* *Cotula coronopifolia* *Cynodon dactylon*	low closed sedgeland

HALOSARCIA COMPLEX *Halosarcia halocnemoides*

CODE	COMMUNITY	OTHER SPECIES	STRUCTURE
H1	*Halosarcia* typical community of *H. halocnemoides*	*Sarcocornia quinqueflora*	low open heath
Hb	*H. halocnemoides* & *H. indica* subsp. *bidens*	*S. quinqueflora*	low open heath
H*l*	*H. halocnemoides* & *H. indica* subsp. *leiostachya*		low open heath
HL	*H. indica* subsp. *leiostachya* predominant	*S. quinqueflora*	low open heath
Hg	*L. rigidum* predominant	*H. halocnemoides* & *H. indica* subsp. *bidens*	low open heath & grassland

Several patterns of zonation were recognised in the ten transects (Figures 3.1 to 3.4). There were two major sequences in which the complexes were arranged. These were, in order from the water's edge: bare ground, *Sarcocornia*, *Juncus* (Figure 3.1) and bare ground, *Sarcocornia*, *Halosarcia.* (Figure 3.3). The main factor contributing to the first sequence was thought to be decreasing salinity, and the main factor contributing to the second sequence was thought to be increasing elevation with a high salinity in summer. Although these general trends were observed at the sites, the sequence was not precisely followed at all. While a definite pattern of zonation with sharp changes between complexes occurred at all sites, the saltmarsh vegetation tended to be a mosaic of the communities represented in Table 3.1.

The *Sarcocornia* complex was found at the lower elevations, the *Juncus* complex at the higher, as was the *Halosarcia* complex. Monospecific stands of *Sarcocornia quinqueflora* (S1) were usually found at the lowest points on the transect (Figure 3.1), with *S. quinqueflora-Suaeda australis* (Su) or *S. quinqueflora-Bolboschoenus caldwellii* (Sb) communities found at slightly higher elevations (Figure 3.1). Communities of

Sarcocornia quinqueflora-Atriplex species (Sa) and *S. quinqueflora-Juncus kraussii* (Sj) had a more scattered distribution on the high elevations and, for the latter, fringing brackish waters and the *Juncus* complex (Figure 3.2). *Sarcocornia quinqueflora-Halosarcia* (Sh) communities and *S. quinqueflora-Frankenia pauciflora* (Sf) were found in isolated areas, usually on high banks on the high elevation sites.

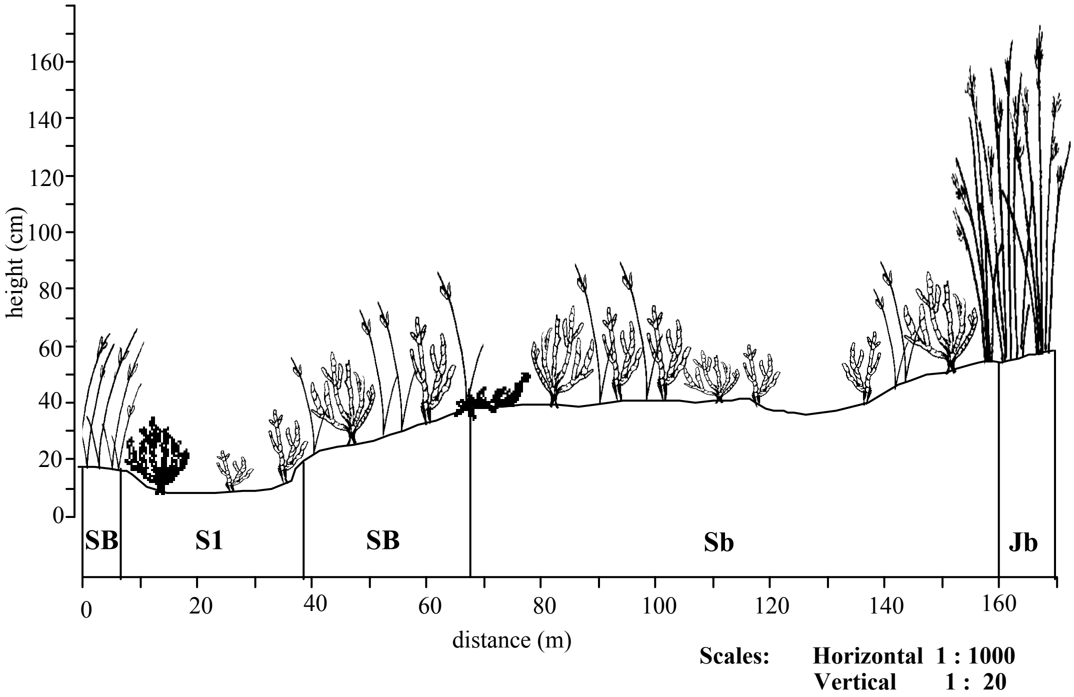

Figure 3.1. Saltmarsh communities along the South Harvey Estuary transect (Site 10) during summer (see Figure 1.1 for locality).

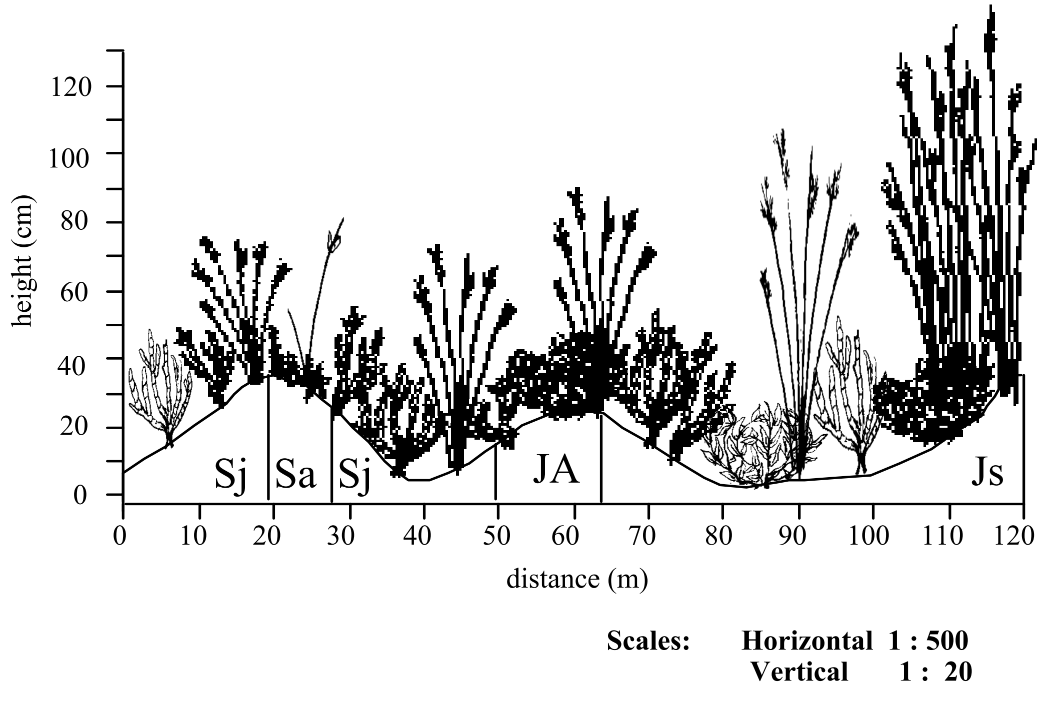

Figure 3.2. Saltmarsh communities along the Worallagarook Island transect (Site 6) during summer (see Figure 1.1 for locality).

Communities dominated by *J. kraussii-S. quinqueflora* (Js) and *J. kraussii-B. caldwellii* (JB) were found largely on the slightly elevated bank of the Serpentine River and, as well as the *Juncus kraussii* pure community (J1), towards the landward end of some sites at slightly higher elevations (Figures 1 and 2). The *J. kraussii-Atriplex hypoleuca* dominated (JA) community was usually found on elevated banks occupied by this complex (Figure 3.2).

The *Halosarcia halocnemoides* (H1) community was usually found at the lowest elevation of the *Halosarcia* complex, fringing this community on the side closest to the water (Figure 3.3). The *H. halocnemoides- H. indica* subsp. *bidens* (Hb) community is found over the higher areas as is the rarer *H. halocnemoides* grass dominant (Hg) community. The *H. halocnemoides-H. indica* subspecies *leiostachya* (H*l*) and *H. indica* subspecies *leiostachya* dominant (HL) communities were found at Site 5 (Figure 3.4) on the relatively flat concavity surrounding a salt pan, with the *H. indica* subspecies *leiostachya* community found on the fringe closest to the Mandurah Channel.

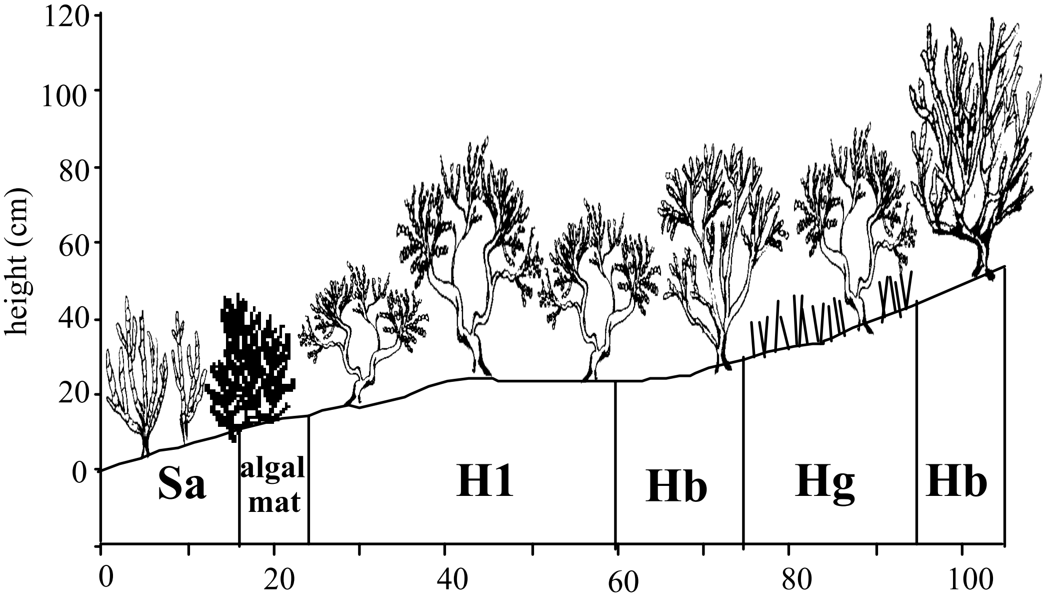

Figure 3.3. Saltmarsh communities along the East Peel Inlet transect (Site 7) during summer (see Figure 1.1 for locality).

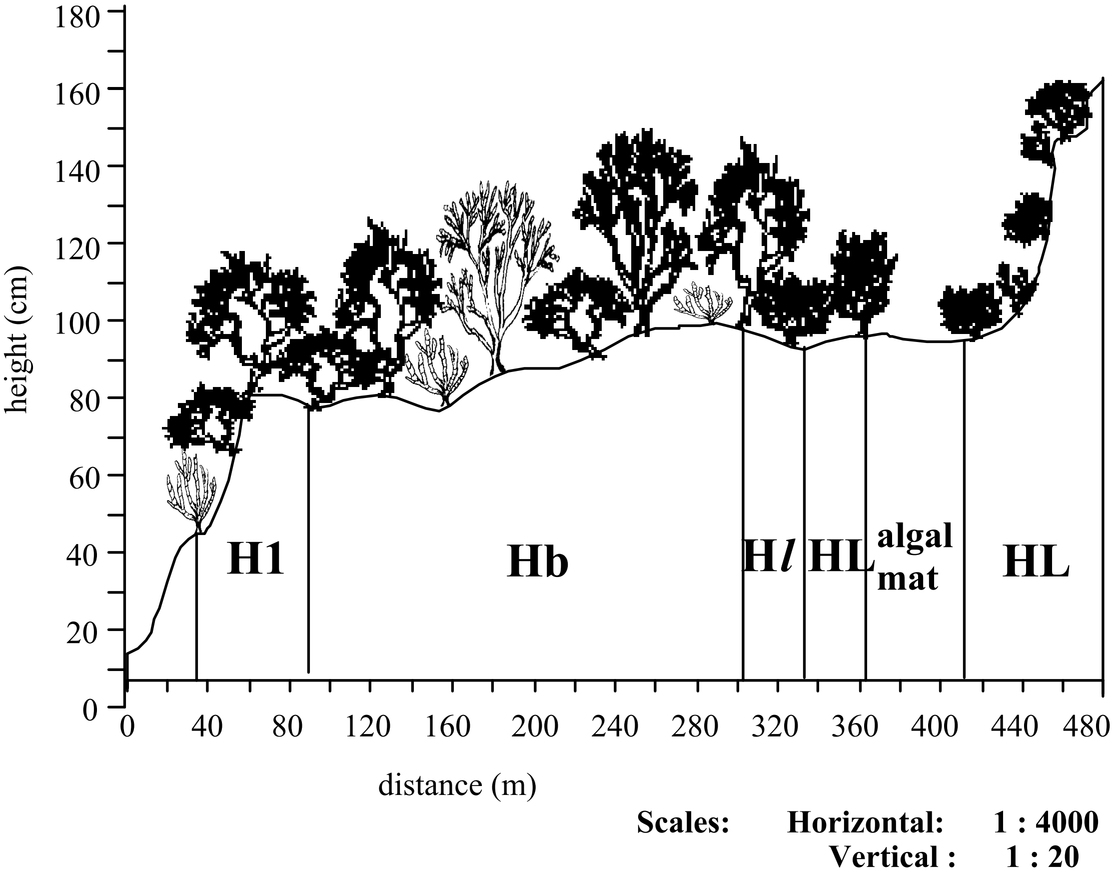

Figure 3.4. Saltmarsh communities along the Creery Wetlands transect (Site 5) during summer (see Figure 1.1 for locality).

Percentage Cover

The percentage cover results measured during autumn are shown in Figures 3.5-3.7, these figures display the mix of species within communities described above. There was little difference in percentage cover between autumn and winter, the grasses and amount of bare ground displaying most difference, although the increase or decrease differed between sites. Examples of the different percentage cover patterns found at the sites is presented below.

The *Sarcocornia quinqueflora* occurred sparsely along transect 5 across the Creery wetlands (Figure 3.5), and only formed a large percentage of cover where there was little bare ground, such as in the first area of the marsh, by the water's edge (Figure 3.5). *Halosarcia* species dominated most of the marsh, which had a large proportion of bare ground. In particular, *Halosarcia halocnemoides* dominated most of the marsh from the second area close to the water and *Halosarcia leiostachya* was found at the driest, most saline area of the marsh. This species was not found at any other site.

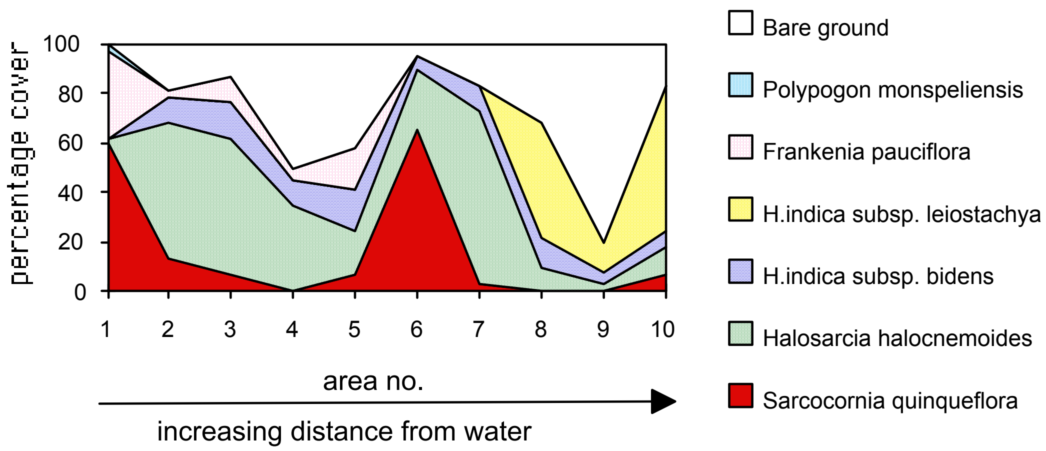

Figure 3.5. Percentage cover at Creery wetlands (Site 5, see Figure 1.1 for locality).

The areas of marsh closest to the water's edge at Site 7, east of Peel Inlet contained a higher percentage cover of *S. quinqueflora* as well as *Suaeda australis* and *Atriplex prostrata* than did other sites (Figure 3.6). *Halosarcia* species dominate the higher marsh, away from the water, in particular, *Halosarcia halocnemoides*. The grasses and daisy *Cotula coronopifolia* were also more abundant in these areas, with the rush *Juncus kraussii* being found on the landward edge of the marsh. This site on the east of Peel Inlet, displayed different communities on both the higher and lower elevation marshes.

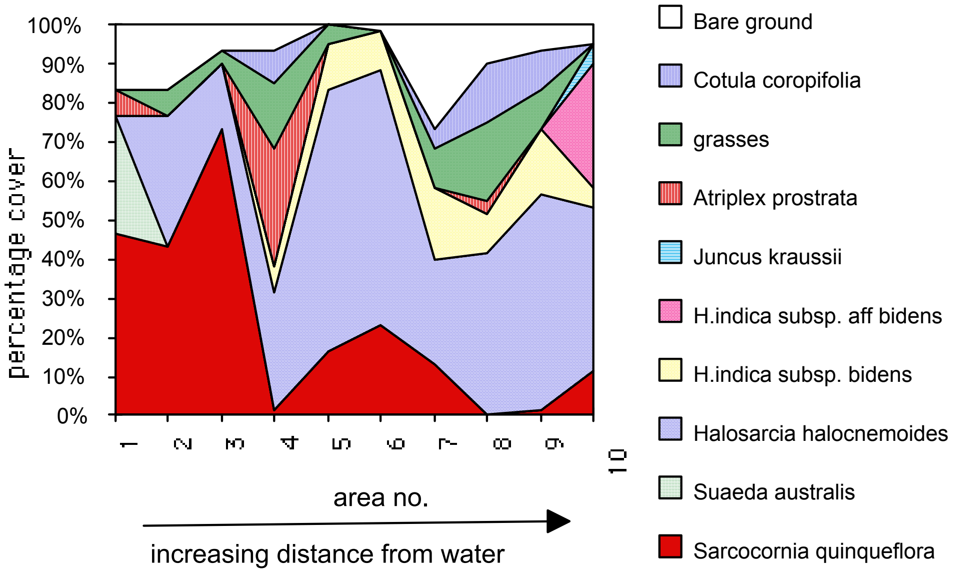

Figure 3.6. Percentage cover at the east side of Peel Inlet (Site 7, see Figure 1.1 for locality).

An example of the lower marsh in the region was found east of Harvey Estuary (Figure 3.7). This had mostly bare ground in the area edge, consisting mainly of a pioneer zone of *S. quinqueflora*. Most of the marsh was dominated by *S. quinqueflora*, with some *Atriplex species* and *Suaeda australis*, and the landward edge was dominated by the rush *Juncus kraussii*.

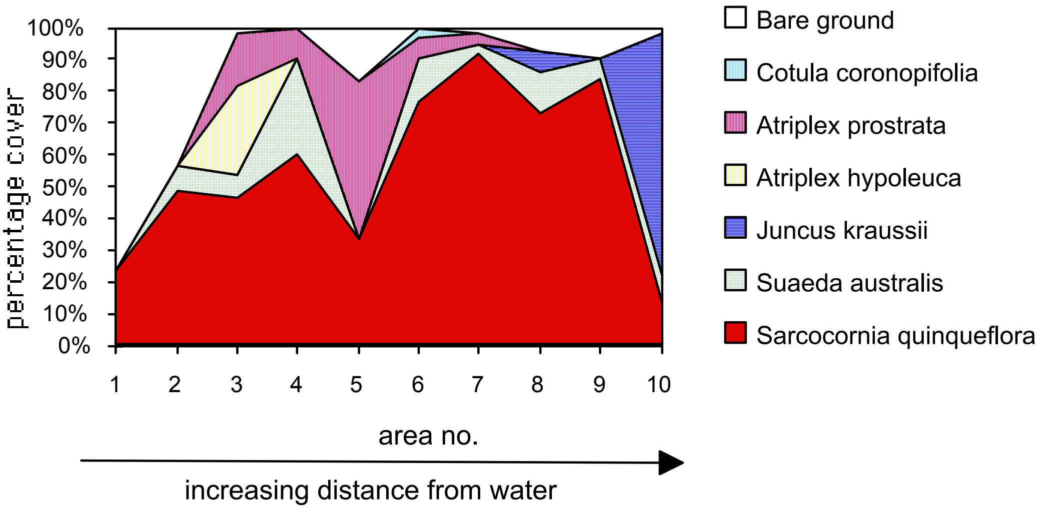

Figure 3.7. Percentage cover along a transect (Site 9) of Harvey Estuary (see Figure 1.1 for locality).

Biomass of Saltmarsh Vegetation

There was considerable variation in plant biomass between sites and areas of saltmarsh in the Peel-Harvey system. However, three main patterns could be distinguished.

The first was found at Site 2, Lake Goegrup. There was a striking decrease in biomass in area 1 and a moderate decrease in area 2, over the winter period, but no substantial change at area 3 (Figure 3.8). This decrease in areas occurred because the two dominant species in area 1, *Bolboschoenus caldwellii* and *Atriplex hypoleuca*, and a codominant species of area 2; *B. caldwellii* are ephemeral, and die back substantially during winter, while the dominant species in area 3 are perennial.

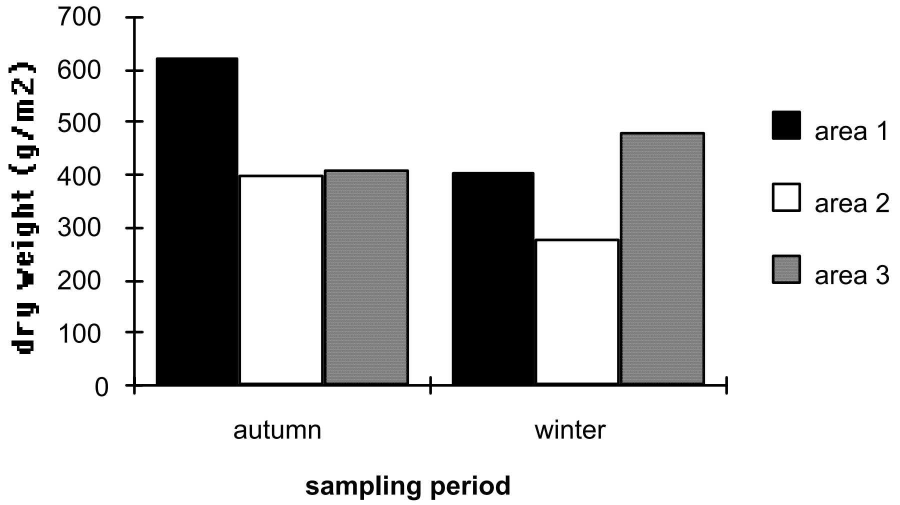

Figure 3.8. Seasonal biomass across Lake Goegrup transect (Site 2, see Figure 1.1 for locality).

In contrast, there was little seasonal change in the higher elevation marshes such as Site 7, east of the Peel Inlet (Figure 3.9). This was because the dominant species, *Halosarcia halocnemoides* and *Sarcocornia quinqueflora,* were perennial and because the high elevation ensured little wave damage to plants. The high statistical variance in areas 1 and 2 during autumn suggest a greater difference in the biomass in these areas in this season.

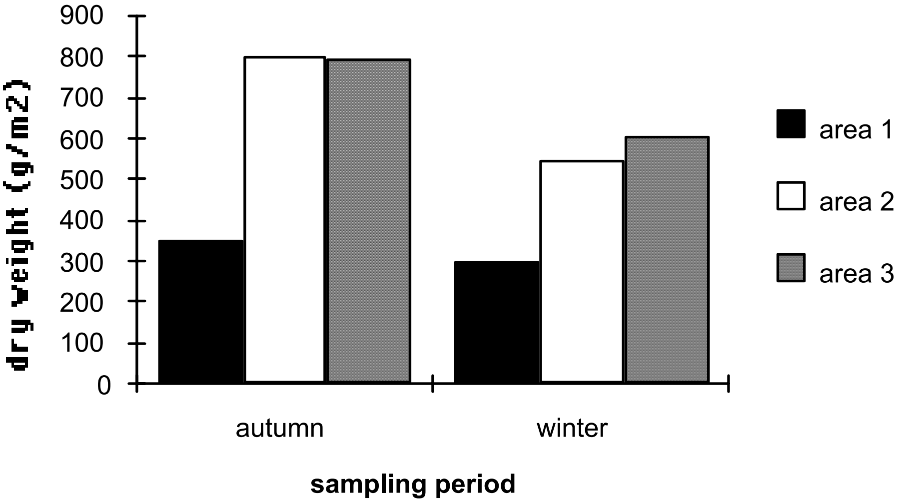

Figure 3.9. Seasonal biomass across East Peel Inlet transect (Site 7, see Figure 1.1 for locality).

The third pattern was that of a general decrease in biomass of area 2, but with little seasonal change at areas 1 and 3. This occurred because of the larger component of the annual, *Atriplex prostrata,* in area 2; this species dies back in the winter, while the other zones were dominated by the perennial species S. *quinqueflora* and *J. kraussii* (Figure 3.10).

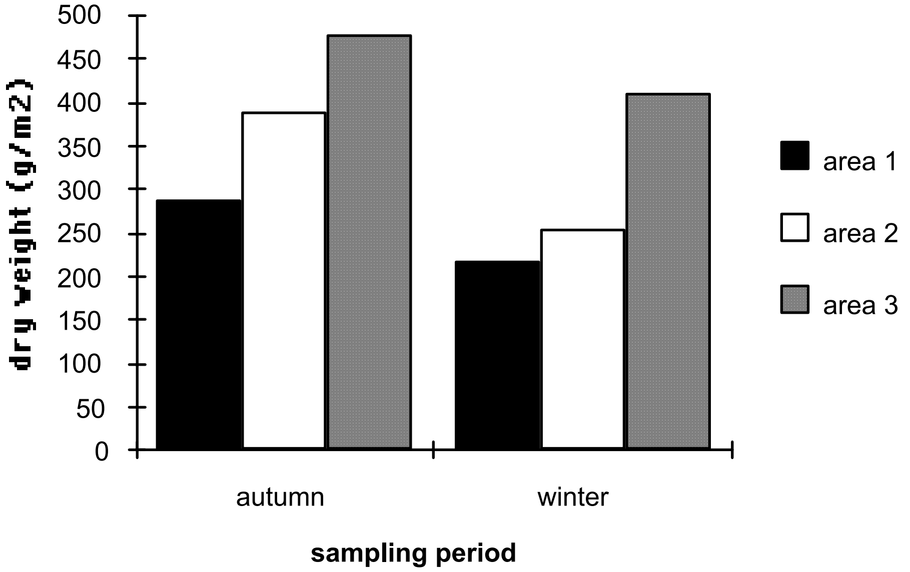

Figure 3.10. Seasonal biomass across East Harvey estuary transect (Site 9, see Figure 1.1 for locality).

Below ground biomass during autumn was substantially higher than that of above-ground material (Figure 3.11).

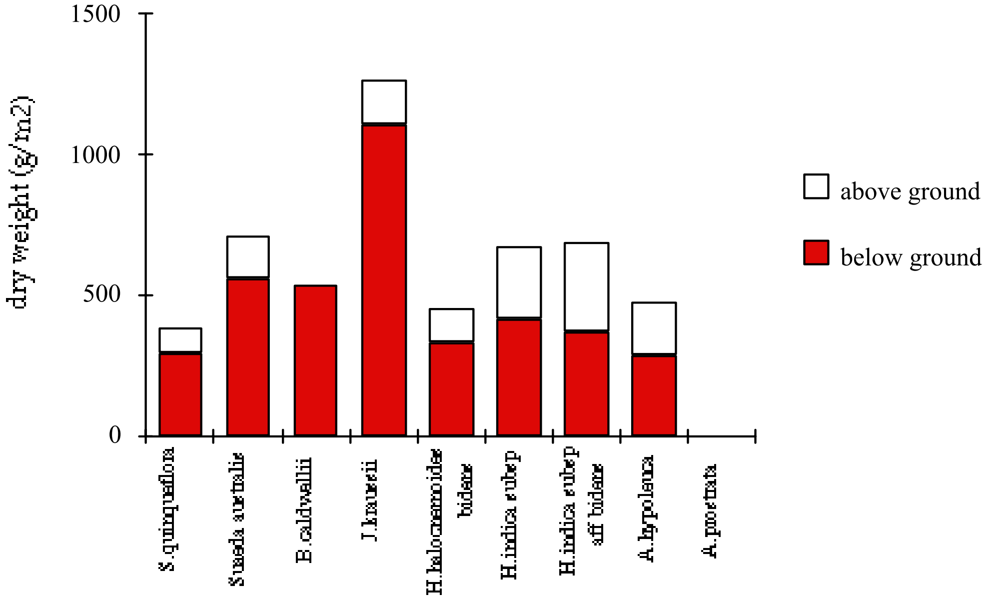

Figure 3.11. Above and below ground biomass of selected species during autumn.

The weights and the ratios of above : below ground material differed considerably with time. This variation was even greater in winter, (Figure 3.12) when the above ground components were larger, so that *Atriplex hypoleuca* and both growth forms of *Halosarcia indica* subspecies *bidens* had slightly larger above ground material compared with below-ground material.

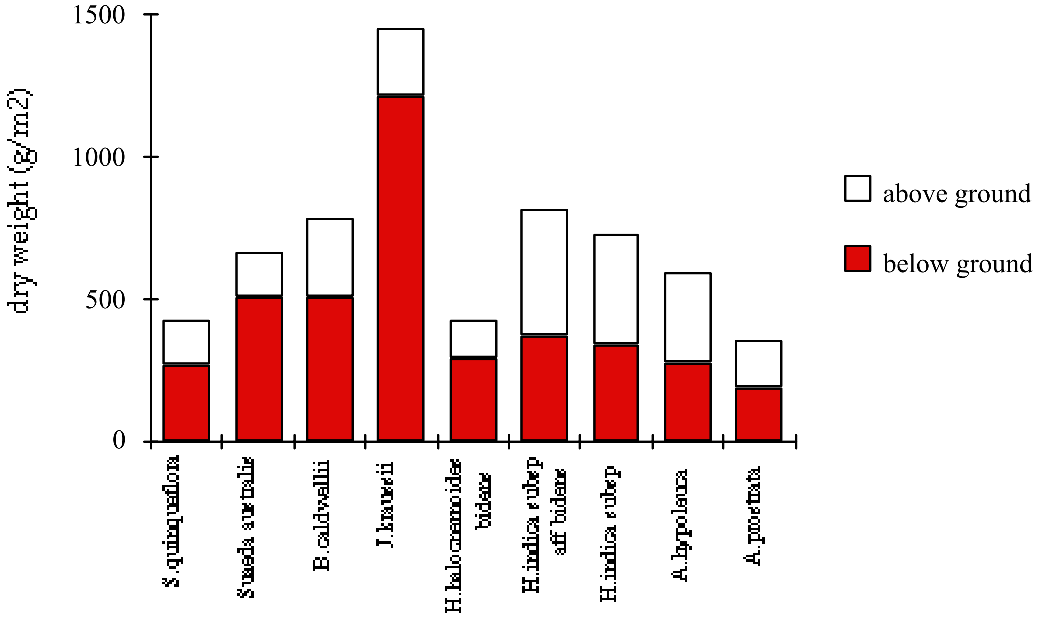

Figure 3.12. Above and below ground biomass of selected species during winter.

The occurrence of higher weight in the below ground component agreed with studies performed in Australia and Europe (Knox, 1986a).

Seasonal changes in the nutrient content of saltmarsh vegetation.

The seasonal variation in nutrient content was examined for above-ground biomass at the six transects (Figure 1.1) and above- and below-ground component of selected species at all ten transects.

There was a higher nitrogen concentration in the above-ground material in winter (Figure 3.13). This is supported by the literature which states that most nitrogen leaching from saltmarsh plants takes place in autumn, and most absorption of nitrogen occurs in early summer before maximum biomass is achieved (Knox, 1986a).

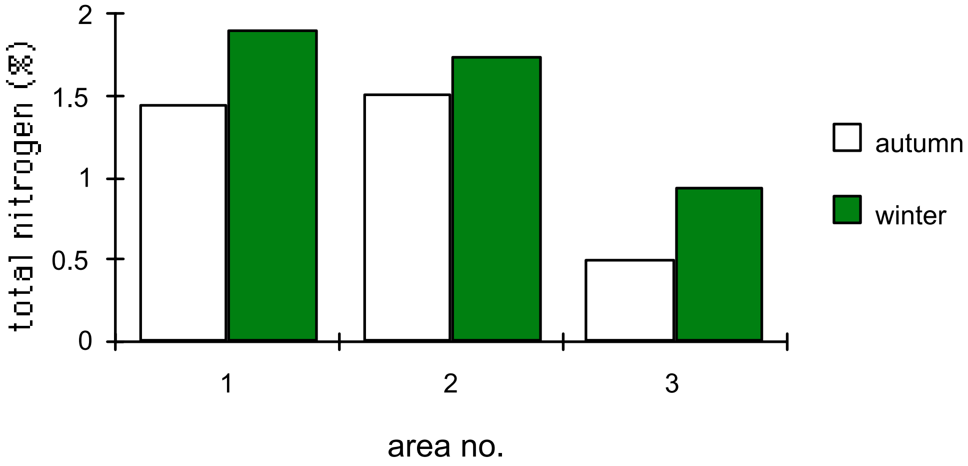

Figure 3.13. Concentration of total nitrogen (% dry weight) in autumn and winter along East Harvey Estuary transect (Site 9, see Figure 1.1 for locality).

In area 3 at a number of sites, the total nitrogen concentration in vegetation was approximately the same in both seasons (Figure 3.14). This could be related to the very dry winter prior to the winter sample, and the high elevation of area 3. Both factors would ensure less inundation by nutrient rich waters, which could limit the amounts of nutrients available for plant uptake for absorption by the plants. It could also account for the relatively lower nitrogen content of plants in area 3 of most sites, compared to other areas, of most sites during both seasons, and the greater decrease in winter.

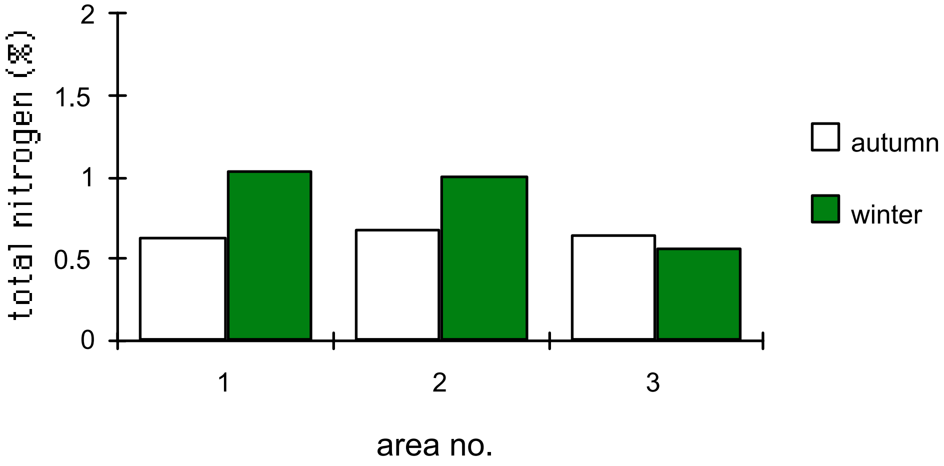

Figure 3.14. Concentration of nitrogen (% dry weight) in autumn and winter along a transect at the south Mandurah Channel transect (Site 4, see Figure 1.1 for locality).

The similarity in nitrogen content of plants at different sites, could suggest that the marsh plants concerned have similar phenology, or that physical factors acting upon them are similar at the various sites around the system. There were slightly smaller concentrations at two sites, (Figure 3.14), and these may result from their close proximity to the mouth of a river. At such sites the salinities of open water and sediment salinities would be relatively low, which may affect nitrogen transformations.

There was also a higher concentration of total phosphorus in the above ground component at most sites in winter, (Figure 3.15 & 3.16) similar results have been reported for *J. kraussii* in the Blackwood Estuary (Congdon & McComb, 1980).

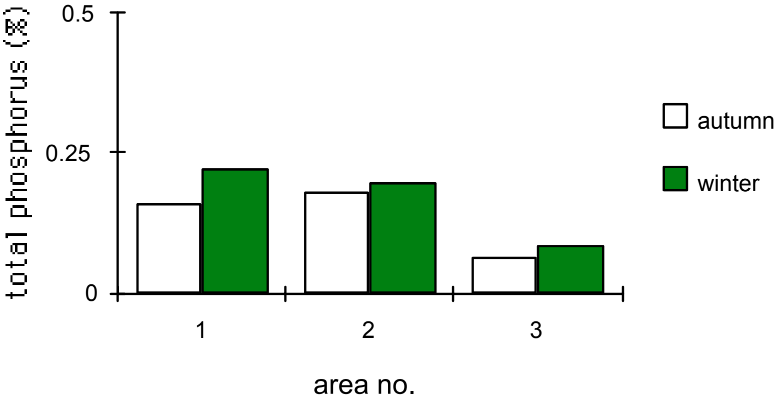

Figure 3.15. Concentration of total phosphorus in autumn and winter along East Harvey Estuary transect (Site 9, see Figure 1.1 for locality).

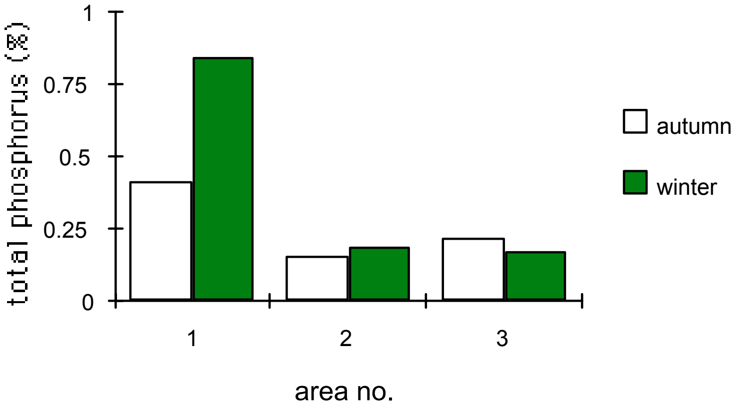

Figure 3.16. Concentration of total phosphorus in autumn and winter along South Mandurah Channel transect (Site 4, see Figure 1.1 for locality).

The concentration of phosphorus in area 1 at the Lake Goegrup transect (Figure 3.17), differs from an expectation based on the findings of Congdon and McComb (1980) who found the nitrogen to phosphorus ratios to be higher in *J. kraussii* plants fringing the water than in those at the landward edge. This can be explained by the dominant species of area 1, which consisted almost entirely of large bushes of *Atriplex hypoleuca*, with some *Bolboschoenus caldwellii*. These two species, especially *A. hypoleuca*, had very high concentrations of phosphorus and this plant showed a marked increase in phosphorus concentration in winter.

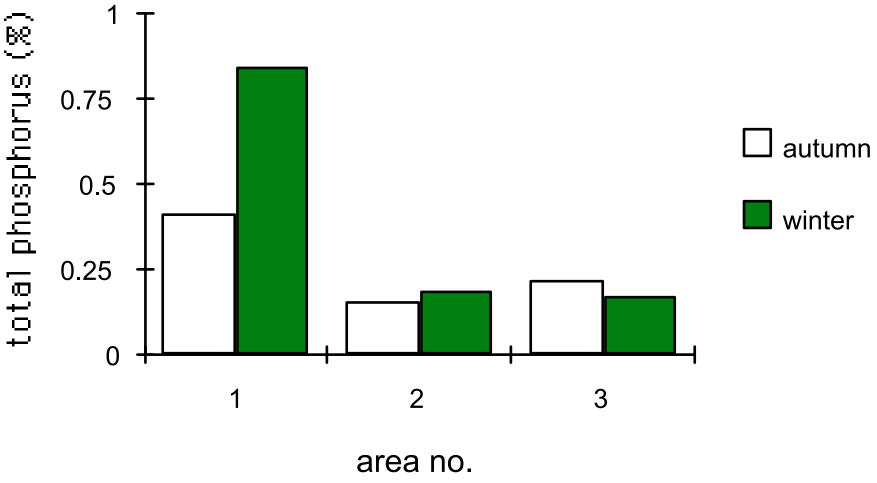

Figure 3.17. Concentration of total phosphorus in autumn and winter along Lake Goegrup transect (Site 2, see Figure 1.1 for locality).

Apart from these exceptions, there was a general similarity in the concentration of phosphorus at the different sites. The phosphorus content at area 3 at most sites appeared to be less than that of the other two areas in both seasons, as is illustrated in Figure 3.15. This is consistent with Congdon and McComb (1980) who found the nitrogen to phosphorus ratios to be higher in those plants fringing the water than those at the landward edge of the marsh.

The high nitrogen to phosphorus ratio found in all the species concurred with other saltmarsh species data (Congdon & McComb, 1980; Rose & McComb, 1980).

The higher concentration of nitrogen and phosphorus contained in whole plants, and in the above-ground components, of most species during winter (Figures 3.19 and 3.21), was the same as that found in the communities sampled in the three areas of the transects and is similar to that cited in the literature for saltmarsh plants (Congdon & McComb, 1980). This could be because most nutrients are obtained from the estuarine waters and during the winter the marshes are frequently inundated with nutrient rich waters. This similarity may result from the ready availability of nutrients in estuarine water in winter.

There was less variation in the nitrogen and phosphorus concentrations of the below ground component of whole plants, presumably because this component was not subject to the same environmental extremes as above-ground material, and tended to senesce less between major growth periods; in contrast, there was apparently an increase in the concentrations of below-ground nutrients taken from all areas (Figures 3.18 to 3.21).

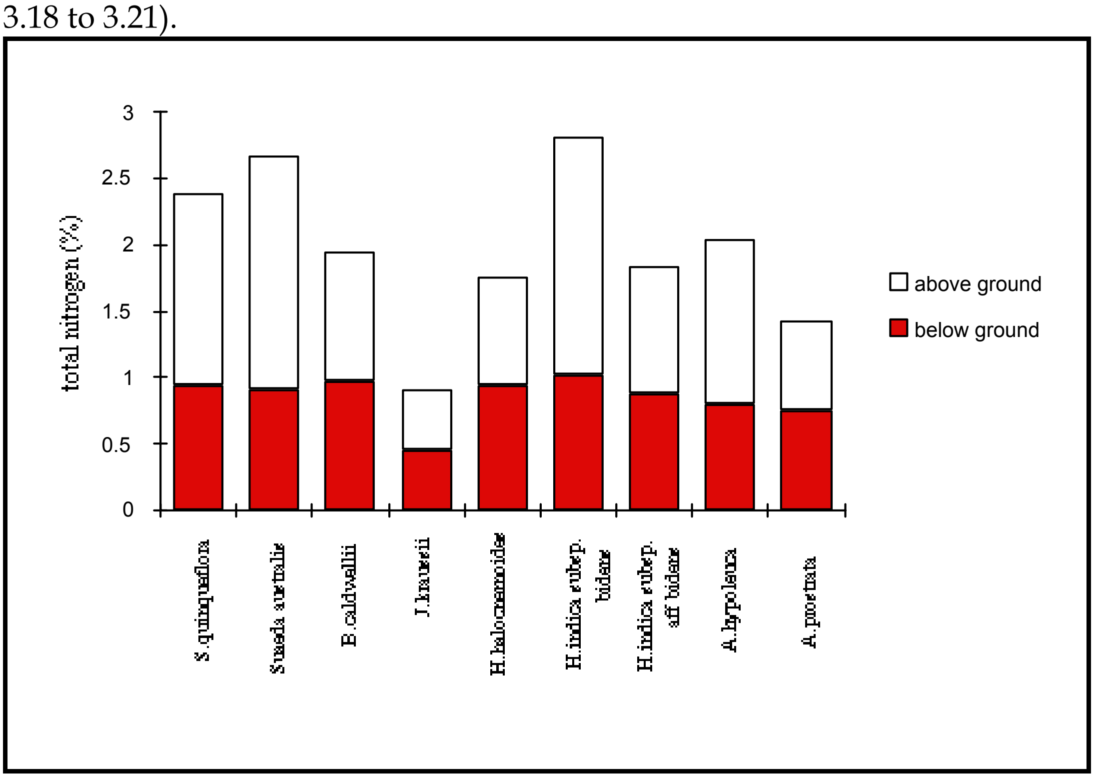

Figure 3.18. Total nitrogen concentrations (% dry weight) in the above and below ground components of saltmarsh vegetation in autumn.

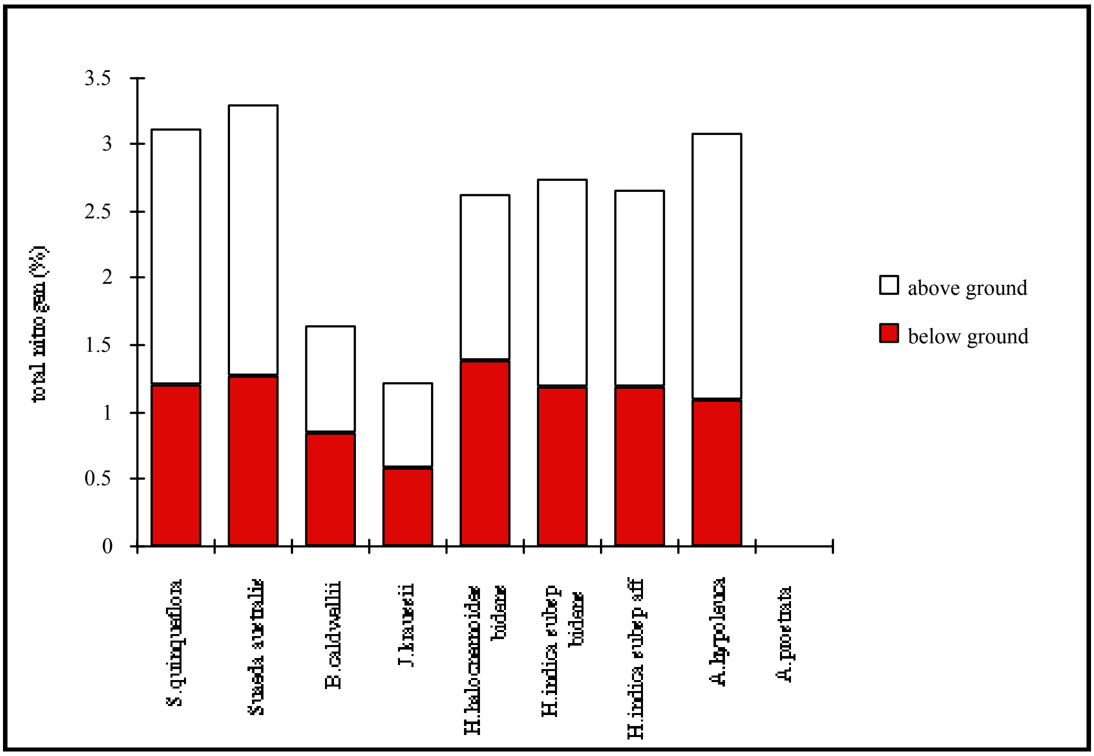

Figure 3.19. Total nitrogen concentrations (% dry weight) in the above and below ground components of saltmarsh vegetation in winter.

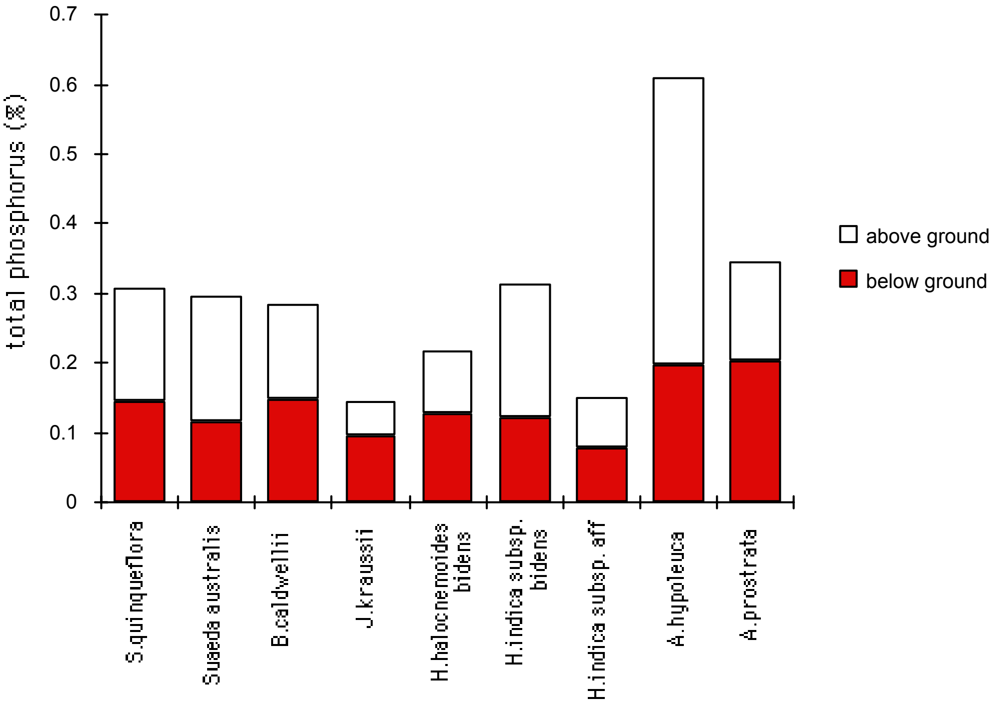

Figure 3.20. Total phosphorus concentrations (% dry weight) in the above and below ground components of saltmarsh vegetation in autumn.

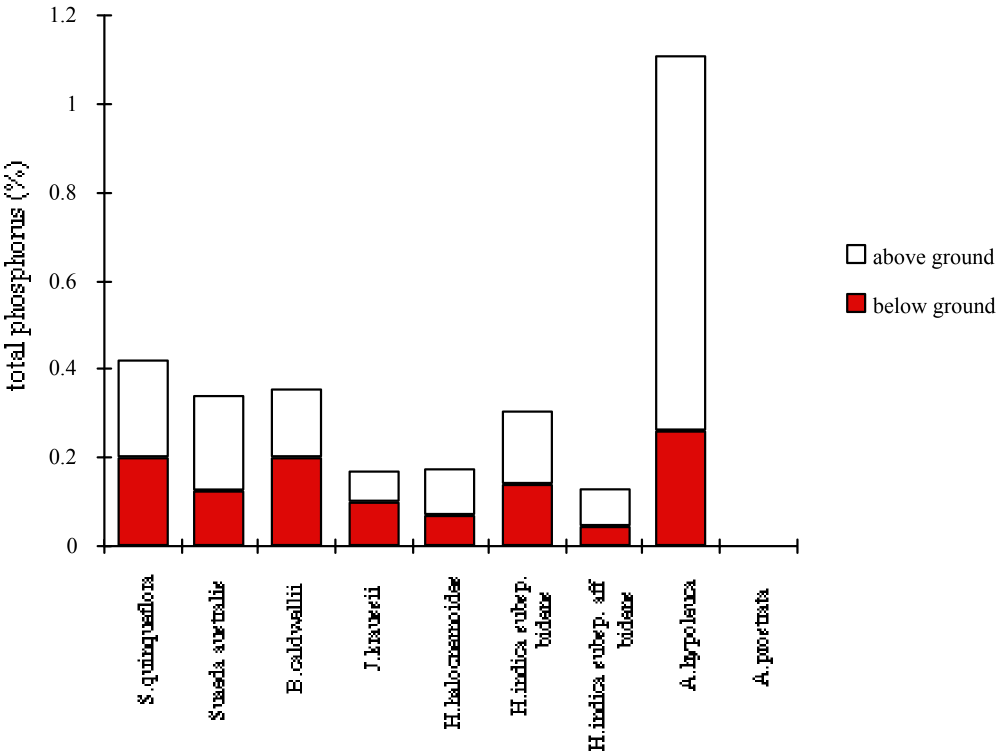

Figure 3.21. Total phosphorus concentrations (% dry weight) in the above and below ground components of saltmarsh vegetation in the winter.

In most of the species sampled there was a high concentration of total nitrogen and total phosphorus in the above-ground component. This was accounted for by the fact that much of the store of nitrogen in plants is in the protein photosynthetic apparatus which would be more evident in the above ground component. There was a smaller difference in total phosphorus, which usually more equally distributed within plants.

Nitrogen and phosphorus in the below ground material was only slightly higher in autumn than in winter in *H. halocnemoides* and *A. prostrata*. The small exceptions in below-ground nitrogen in winter included *B. caldwellii, J. kraussii* and, marginally, *H. halocnemoides.* The species with slightly more phosphorus in the below ground component were *B. caldwellii*, *J. kraussii* in both seasons and, marginally, *H. halocnemoides* in autumn. *B. caldwellii* and *J. kraussii* use salt evasion strategies such as ephemeralism and shedding of salty culms, and *Halosarcia* species use succulence, all of which are not as energy expensive as the method used by *Atriplex* species (Waisel, 1972).

The variation between seasons may have occurred because the plants with a higher content of dead material or old growth such as *J. kraussii* and *H. halocnemoides* contained fewer nutrients in above-ground material in autumn. This would be more pronounced in autumn when much of the nutrients would be transported to the roots. It would also be more pronounced in phosphorus for species such as *J. kraussii* which tended to retain its phosphorus more tenaciously (Congdon & McComb, 1980). The greater below ground nitrogen content in winter and phosphorus content in both seasons in *B. caldwellii* could be explained by its ephemeral nature. In the winter sample, the shoots were just beginning to sprout and most nutrients would still be retained in the roots, and during the autumn the nutrients were just being leached or transported to the roots as the above ground component senesced. The higher phosphorus retention is likely to be a result of a tendency to retain phosphorus similar to *J. kraussii*. The annual *A. prostrata* would likewise senesce first in the above ground component in the autumn.

The mean total nitrogen and phosphorus concentrations in the autumn above ground biomass of *S. quinqueflora* was similar to that found in *S. blackiana* by (Congdon & McComb, 1980; Rose & McComb 1980).

The small differences in nutrient concentrations between species, in some areas, may suggest similarities in phenology and physiology, however some trends were clear. The highest concentration of total phosphorus was found in plants such as *A. hypoleuca*, with the most energy-expensive salt exclusion strategy, and the lowest percentages were for *J. kraussii, H. halocnemoides* and *H. indica* subspecies aff. *bidens,* all of which have less energy-expensive methods of salt reduction. However the high concentrations of phosphorus may also occur because most phosphorus is obtained from the estuarine waters and that those closer to the water's edge would be most frequently inundated with phosphorus-rich waters.

Similar observations with nitrogen were documented during the autumn, especially in winter. *S. quinqueflora, Suaeda australis* and *A. hypoleuca* containing highest, and *J. kraussii* the lowest, concentration of total nitrogen.

3.4 Conclusions

It can be concluded that there was a distinct zonation of plant complexes, and there were trends in the distribution of saltmarsh communities along transects, thought to be related to tidal inundation. There was substantial variation within the results, some of which could be attributed to changing environmental factors and inter-species and inter-site differences. Several trends were evident. The biomass was found to be less in winter, while the nutrient concentration was greater and temporal variation was found to be higher in above- ground components of plants. Some differences in species composition and biomass were found to that of previous studies of saltmarshes. This may be due to the different locations, sampling methods, or changed environmental conditions between studies.

CHAPTER 4 Water Regimes And Marsh Distribution

R. Murray, J.A. Latchford and A.J. McComb

4.1 Introduction

Tide has long been recognised as the most influential factor determining plant zonation and the development of saltmarsh communities, and it is the tide that largely determines the structure and function of saltmarshes (Clarke & Hannon, 1969).

The zonation of species with increasing distance from the water's edge and increasing elevation is initially determined by the frequency of tidal flooding and the tolerance of various species to this (Huiskes, 1990). Tidal range usually sets the upper and lower limits of the marsh. The lower limits are set by depth and duration of flooding, and the consequent mechanical effect of the waves, sediment availability and rate of erosion. The upper limits are influenced mainly by soil water salinity and nutrient availability, both of which are linked to tidal flooding frequency (Mitsch & Gosselink, 1993), tidal water being the main source of soil salt and the major mechanism for nutrient transport (Clarke & Hannon, 1971).

Zonation is further modified by the relationships between and among the saltmarsh species, which are also tidally influenced. The long life span, common occurrence of method of vegetative production (Barnes, 1974) and often large physical size of saltmarsh vegetation, act as strong forces inhibiting colonisation. Slight changes along an environmental gradient can produce intense competition, making factors which are usually of secondary importance, significant, producing characteristically sharp changes in zonation (Clarke & Hannon, 1971).

As the tide is so influential, very small differences in micro-topography often correspond with distinct changes in plant zonation (Clarke & Hannon, 1969). Any change in tidal movement, as could occur from a rise in sea level with the onset of the “Greenhouse Effect” or with the construction of a new channel in a barrier estuary, may be expected to influence, directly or indirectly, the vegetation zonation in a saltmarsh (Huiskes, 1990).

Ocean tides in southern Australia are relatively small, ranging from 0.2 to 0.9 m (Hodgkin *et al.*, 1985), and in the Peel-Harvey Estuarine System the tidal range has been further restricted because of the shallow, narrow entrance channel. The Mandurah Channel has virtually eliminated the diurnal or semi diurnal components of the ocean tide, and dampening the long term components by 35% (McComb & Lukatelich, 1986; PIMA, 1994). Thus, the water level has responded to slower changes in seawater level.

These include those brought about by meteorological conditions such as barometric pressure, wind strength and direction, seasonal river flows and long term fluctuations in mean sea level (Marine and Harbours, undated).

Although longer period changes are of small range, they are significant in a shallow estuarine system, like the Peel-Harvey, which as noted above has an average depth of 1 m, and extensive shallows exposed at extremely low water (Hodgkin *et al.*, 1985). The shallowness of the water at the margins reduces the wave energy generated in the deeper basins (Backshall, 1977). Therefore, the astronomic tidal amplitude in the Peel-Harvey system was usually less than 10 cm, with a maximum daily range of 20 cm, whereas the variation in water level caused by meteorological factors has a range of up to 50 cm over a 5 to 15 day period (Lukatelich & McComb, 1986). There is also a seasonal change in the water level of ocean and estuary, with the summer level in the estuary being 20 to 30 cm lower than the winter (Hodgkin *et al.*, 1985).

This situation, to which the saltmarsh vegetation has adapted in the Peel-Harvey area is thought to have existed for the past 6500-7000 years (McComb & Lukatelich, 1986). Most saltmarsh is thought to have originated about 3000 years ago when the rate of sea level rise slowed sufficiently to favour marsh development (Knox, 1986a). Throughout this period there will have been successional changes in the vegetation, and some of the saltmarsh vegetation is very young; for example the thin fringe near Heron Point on the eastern shore of Harvey Estuary (Figure 1.1) is thought to be only 30 years old (Backshall & Bridgewater, 1981). However, during this time there has been little change in tidal regime (Clarke & Hannon, 1969).

4.1.1 Changes brought about by the Dawesville Channel

The tidal regime changed on the 5th April 1994, with the opening of another channel connecting the estuarine system to the sea. The Dawesville Channel, with a depth of 4.5 m below Australian Height Datum (AHD, approximately mean sea level), 200 m wide at the bottom and with side slopes of 1:5, was expected to have a volume of exchange that would more than double the previous flow through the Mandurah Channel (Ryan, 1993). An aerial photograph of the Channel at high tide is shown in Figure 4.1, three months after its opening.

The Dawesville Channel was constructed to increase tidal flushing of the system, and so reduce symptoms of eutrophication: large populations of nuisance green algae which build up in spring and summer each year in the Peel Inlet. In Harvey estuary the main symptom of eutrophication is the occurrence of large summer blooms of the blue-green alga *Nodularia spumigena*. These organisms result in nauseous odours, hinder contact recreation, foul beaches and create de-oxygenated conditions that can lead to fish kills. This eutrophication situation has been brought about by the large anthropogenic nutrient loading received from the catchment, mainly via the rivers in winter. It is anticipated that the increased flushing will increase phosphorus loss from the water column and sediments and improve water clarity. The increased salinity during the spring and early summer will also inhibit the growth of *Nodularia* (Hodgkin *et al.*, 1985).

Water levels in the system were modelled by the Department of Transport for situations both before and after the Dawesville Channel opening. The model was calibrated using data for ocean, Peel Inlet and Harvey Estuary tides, river inflow and rainfall data for the period between January 1989 and December 1991. The exact effect and extent of the increase in water exchange could not be predicted because the model assumed that all water flushed out of the estuary is replaced entirely by seawater and all incoming seawater is completely mixed with estuary water. In reality, mixing depends on wind stress and differences between sea and estuarine water density. Also, the effect of stratification, and plants and sediments in nutrient recycling has not been considered in detail (Hodgkin *et al.*, 1985). The results depicted changes in water levels expected to result from flows through the Dawesville Channel. Significant changes were expected in the daily, semi-annual and annual tidal ranges and water levels (Ryan, 1993).

Construction of the Channel was expected to result in a substantial increase in the range of the astronomic tides, with a maximum of 0.35 m. The increase in daily range should increase the height a little above that to which the water level would, normally rise, and lower the level to which it would normally fall, by approximately 2 m. The periods of inundation or exposure of shallow flat were predicted to be much shorter, hours instead of days, briefly exposing larger areas of shallows. In the flattest areas it was thought that the water would retreat more than 100 m further out than without the Channel. It was predicted that at the upper extreme there would be a small increase in the extent to which low lying areas would be flooded by daily tides, especially on the eastern shore of the Peel Inlet and the southern end of the Harvey Estuary. Elsewhere, it was thought that the steepness of the banks should prevent extensive flooding (Hodgkin *et al.*, 1985).

Figure 4.1. Dawesville Channel in July 1994. This photograph was taken at high tide. Clearly visible is the salt water intrusion from the channel.

The Dawesville Channel was expected to have no significant effect on changes in water level attributable to the long term meteorological and seasonal "tides", although it was thought that the response to storm surge peaks would be accelerated and flood levels would recede more rapidly (Hodgkin *et al.*, 1985). These changes in tidal regime, have caused concerns because of possible changes in the frequency and duration of the exposure of low-lying areas and the inundation of fringing vegetation (Ryan, 1993).

4.1.2 Possible effect of changing tidal regime on saltmarsh vegetation

Estuarine ecosystems may change relatively quickly if a factor such as hydrologic regime is altered. It has been said (Dijkema *et al.*, 1990) that the periodic character of the ebb and flood movements is responsible for zonation patterns in saltmarsh vegetation and that a change in inundation regime can affect primary production, competitive ability and reproduction in saltmarsh plants (Dijkema *et al.*, 1990).

Stresses are placed upon plants growing in a tidal saltmarsh. Alterations may be brought about in a number of factors which may affect the distribution or growth of marsh plants. These include changes in mean water depth, rate of seasonal water level change and salinity (Kozlowski, 1984). Plants invade lower areas if water levels fall, and fringing vegetation recedes if water levels rise. Habitat modification also provides more opportunities for weed invasion as native species lose competitive ability (McComb & Lake, 1990).

Species competition, growth and survival respond to differences in frequency and duration of flooding in the growing season. Increases in flooding frequency can induce leaf senescence and injury (Kozlowski, 1984), although they often favour annual plants which can quickly colonise bare soil left by the degradation of other species (Dijkema *et al.*, 1990).

Seed dispersal is a major factor in determining the existence of a plant in a specific location. Saltmarsh seeds often are often dispersed by the tide, either alongside the parent plants or sometimes over long distances. Although many saltmarsh species can reproduce vegetatively, seeding is ultimately very important in marsh succession (Kozlowski, 1984).

Tidal flooding influences germination and seedling establishment, and so contributes to species change (Clarke & Hannon, 1969). Seedling establishment may be stimulated or arrested by flooding. Usually species in the high saline regions of the marsh germinate with the onset of winter rains and high tides and subsequent decrease in salinity, while species in the lower marsh germinate later in the season when there are longer periods of marsh exposure (Kozlowski, 1984).

Most saltmarsh seeds need several days isolated from the tide to allow sufficient time under suitable conditions of light, reduced salinity, or lack of wave scouring for germination, seedling anchorage and establishment (Waisel, 1972; Stoner, 1976). A reduction in length of exposure or increase in frequency reduces the survival rate on the lower elevation sites. High salt concentrations often inhibit germination of soaked seeds, which are often more sensitive to salt than adults. Germination of some seeds requires light for up to 12 hours, which is reduced when the seeds are flooded (Waisel, 1972). An increase in mean tide level and inundation would also increase the scouring of uprooted seedlings (Stoner, 1976).

Localised water level rises around the world have been shown to significantly change the occurrence and nature of saltmarsh vegetation. Also, an increase in the number of tidal inundations and an increase in wave energy associated with a global sea level rise is perceived to be a worldwide threat to saltmarsh vegetation (Dijkema *et al.*, 1990).

A European study found that germination decreased in relation to duration of flooding for the two saltmarsh species studied. The time of flooding in relation to growth stage was significant in determining the degree to which the species was negatively affected (Huiskes, 1990).

Increasing water levels have had different effects on different types of saltmarsh vegetation in the Netherlands. Low marsh was found to withstand a change in water level of 30-40 cm, while the middle marsh changed when water level rose 3-5 cm, and an increase in flood level of only 1-3 cm was enough to change the high marsh, even though this was estimated to flood only one additional time each year (Dijkema *et al.*, 1990).

Fifteen years after the onset of higher water levels in these marshes, fluctuations in monthly frequency of inundation in a European marsh negatively affected most saltmarsh species in the middle marsh, mainly as a result of increased frequency of inundation in summer. In the high marsh the reaction was mixed, some very high positive correlations with more frequent inundation in the *Juncus* species. It was thought these were able to quickly re-establish during regeneration in the damaged saltmarsh (Dijkema *et al.*, 1990).

Huiskes (1990) theorised that a rise in sea level of more than 10-15 cm would cause middle and high marsh to be succeeded by low marsh with similar vegetation throughout. In several areas of saltmarsh, natural increases in sea level caused annual species to extend their range at the expense of other lower and middle marsh species. It was observed that a change in water regime reducing the height of tidal inundation resulted in vegetation changes within the same year. When the level of tidal inundation increased, there was a delay of one or more years before the vegetation changed (Dijkema *et al.*, 1990).

The vulnerability to changes of a particular marsh depends on the rate of accretion in the vegetated and pioneer zones (Dijkema *et al.*, 1990). Changes in substrate accretion and erosion change the surface level in marshes, and so the frequency and duration of inundation, influencing succession of plant communities (Kozlowski, 1984). It is concluded that where marsh deterioration is to be alleviated, management techniques such as erosion prevention will be required, especially in the pioneer zone (Dijkema *et al.*, 1990).

4.1.3 Predicted effects of the Dawesville Channel on saltmarshes of the Peel-Harvey System

In the Peel-Harvey estuarine system, the fringing marsh vegetation occupies the upper tidal zone from about mean water level to just above extreme high water mark. The system has only three areas of extensive fringing vegetation. Only a narrow fringe of wetland exists elsewhere, making the little that is left especially important (Hodgkin *et al.,* 1985).

The change in the Peel-Harvey system, from the pre-Channel pattern of long periods of alternate inundation and exposure to more regular and shorter periods of inundation and exposure, is likely to change a number of factors. These include the duration of high salinity and, to a lesser extent, intensity and range of salinity in each zone (Hodgkin *et al.*, 1985; PIMA, 1994), which all have the potential to influence the pattern of saltmarsh zonation (Clarke & Hannon, 1969).

The increased inundation and tidal extent range, as well as the fall in salinity range, predicted to occur with the opening of the Channel should decrease soil salinity, which is likely to allow invasion by less salt tolerant species. There is also the likelihood of increased macro-algae and the possibility that increased macro-algal accumulations may be washed up on the shore and smother vegetation (Hodgkin *et al.,* 1985).

The likely decrease in phytoplankton will change the balance among the primary producers in the system, possibly increasing the relative importance of macrophytes, including saltmarsh species (Hodgkin *et al.*, 1985).

4.1.4 Possible effect of changing vegetation and tidal range on saltmarsh ecology

Any reduction in the extent, species diversity or degraded state of saltmarsh vegetation may affect the feeding, breeding and loafing patterns of birds, as can alteration in sediments and vegetation. Some birds have been seen to avoid narrow fringes of saltmarsh vegetation, possibly as a result of increased predation and disturbance of vulnerable species by human use of the water body (Goss-Custard *et al.*, 1990). The type and abundance of plants also affects the composition and density of invertebrates through their utilisation of the marsh as a stabilising platform, food source or form of protection from predation (Kraeuter & Wolf, 1974). Waterbirds feeding on invertebrates, may be affected by these faunal changes, as well as changes to the flora.

The changing tidal regime of the Peel-Harvey system is predicted to have a number of direct effects on faunal communities, which in turn may impact the saltmarsh. Migratory waders feed mainly on intertidal areas at low tide. Larger daily tides may disrupt feeding patterns, especially during pre-migratory fat deposition in late summer/early autumn. Resident wader species may also be affected by limiting or interrupting feeding opportunities, or accessibility to preferred prey species, such as benthic invertebrates. The greater tidal range would also decrease the area available for roosting, such as sandy cays and spits, used by wading and fish-eating birds such as pelicans, cormorants and terns. The Channel, and the higher tides it will produce, should permit easier boat access to previously undisturbed areas (Hodgkin *et al.*, 1985). The increasing marine influence on the estuary will probably see further reductions in estuarine fish and invasion by marine species. The blue manna crab fishery may change (Hodgkin *et al.*, 1985), and possibly affect the saltmarsh and associated mudflats through its influence on sediment rotation and predation (Kraeuter & Wolf, 1974).

The change in faunal communities could impact on the vegetation through changed nutrient cycles. Changes to invertebrate and microbial populations could affect sediment mixing and nutrient transfer between the sediments, vegetation and open water (Goss-Custard *et al.*, 1990).

4.2 Method

At each site, the absolute elevation was determined at points along a transect line. Elevations were related to the Australian Height Datum (AHD) by traversing to the waters edge, using a theodolite and staff, and recording the absolute elevation, time and date. The height (Peel-Harvey Datum) of the adjoining water body at that particular time was obtained from the Department of Transport from readings taken from the middle of the Peel Inlet or Harvey Estuary. This was then converted to AHD (+ 0.31 m) and added to the height difference between the absolute elevation between a transect point and the water level. The accuracy of the use of water level to determine transect height was assessed by traversing to a Department of Transport Bench Mark of known height in AHD and comparing the result with that obtained for the water level at the same site. It was assumed that the water level of the Serpentine River adjacent to sites 1 and 2 would be 20 cm below that of the Peel Inlet because of dampening affects of the narrow river channel.

The annual percentage of tidal inundation of the saltmarsh fringing the Mandurah Channel was approximately 10 cm higher for any height above 0 AHD, so that there was greater inundation despite the high elevation of the transects.

Species occurrence and qualitative dominance data were compiled for plants distributed along the ten transects during April 1994 (Latchford & Fletcher, unpublished data) and a classification system developed using vegetation units, based on a system used by Pen (1983). The highest level of the system was the “complex”, a group of communities linked by floristic and structural attributes, and depicted by the first letter of the code. The base level was the “community”. The community was usually dominated by the major species in the complex: *Sarcocornia quinqueflora*, *Halosarcia halocnemoides* or *Juncus kraussii*. The second letter of the code represented the second most dominant species, or, if capitalised, the dominant species. The complexes were listed in Chapter 3.

Data on the proportion of the year in which particular elevations would be inundated by the tide was provided by the Department of Transport. The proportions in the Mandurah Channel were raised 10 cm, based on a comparison of percentage inundation comparisons between Mandurah and the Peel Inlet- Harvey Estuary (Rose & McComb, 1980). The communities at these points were then examined to determine if the communities could be related to level of tidal inundation.

This pre-Dawesville Channel inundation data was then compared with the modelled results for time of inundation, predicted to ensue after the construction of the Dawesville Channel (Ryan, 1993). The different percentages for this post-Channel period were placed in brackets next to the original percentage distribution under which the vegetation developed. The difference between the number and duration of inundation occurrences before and after the opening of the Dawesville Channel had been investigated (Ryan, 1993) and described for the height 40 cm AHD which occurred on most of the saltmarshes examined.

4.3. Results and Discussion

4.3.1 Relation of tidal inundation to saltmarsh communities along transects

The use of water levels from the middle of the Peel Inlet to estimate elevation produced a result 4 cm higher than that found by traversing from a bench mark of known elevation. This was considered to be sufficiently accurate, the difference being attributed to dampening of the tidal range at the shoreline. The fact that the measurements were taken during the ebb tide could also have had some effect, because of the slight delay between the measurement on the shore, and the gauged water level in the middle of the Inlet.

Most saltmarsh occurred between the elevations that were inundated by the tide 0 to 30% of the year. Some marsh, mainly of the *Halosarcia* complex, was found at a higher elevation, only irregularly inundated during the year.

The results of this study suggest that dominance of the *Sarcocornia* complex is related to tidal inundation. This complex dominated the marshes of lower elevation where at least a small proportion of marshes were tidal inundation on a yearly basis, as is illustrated in Site 10 (Figure 4.2) and at the lowest heights nearest to the water, on higher elevation marshes, as at Site 7 (Figures 4.3, 4.4), where the marsh was tidally inundated from 5% to 30%, and for less than 5% of the year.

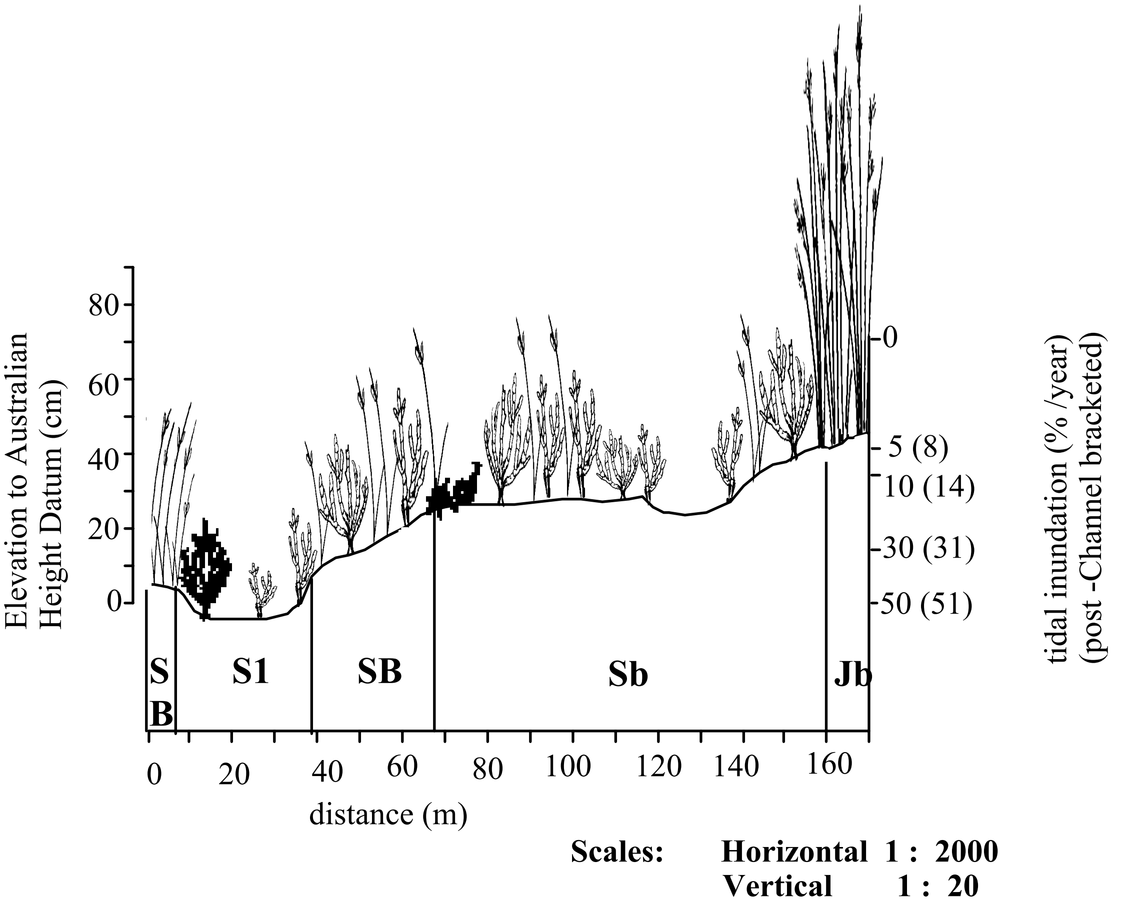

Figure 4.2. Frequency of tidal inundation and vegetation units along the South Harvey Estuary transect (Site 10).

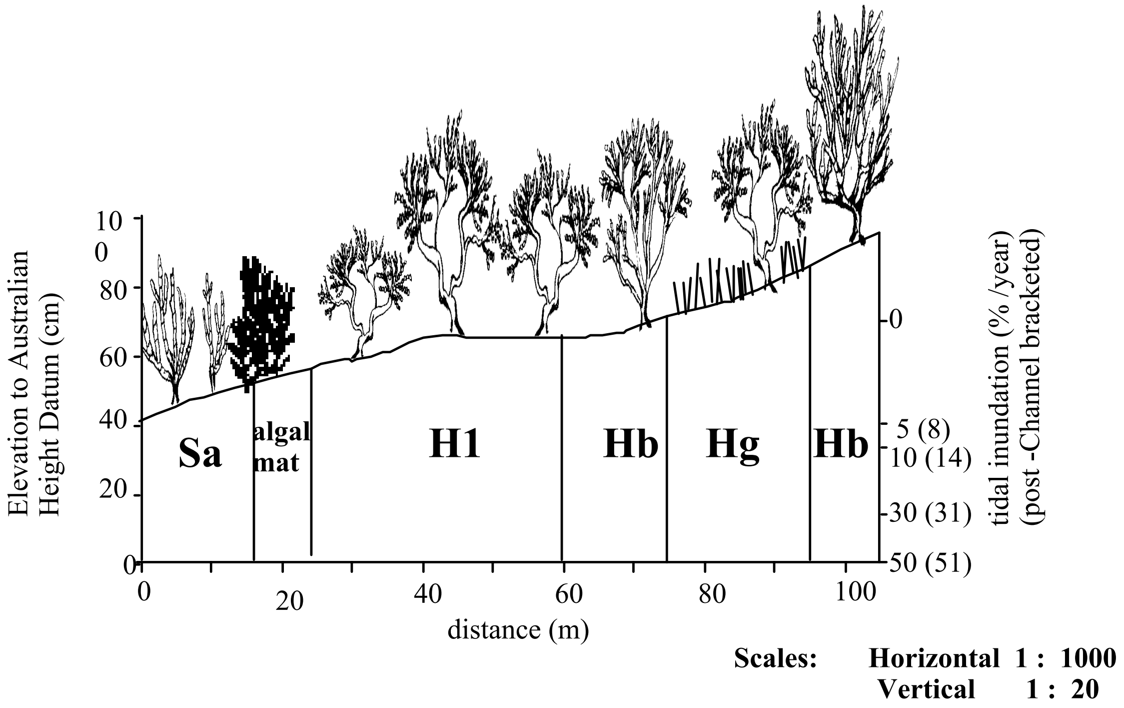

Figure 4.3. Frequency of tidal inundation and vegetation units along the East Peel Inlet transect (Site 7).

Within the *Sarcocornia* complex the communities were not obviously arranged in relation to predicted tidal inundation, although there were some general trends. A monospecific stand of *S. quinqueflora*, or sometimes *S. quinqueflora-Suaeda australis* community usually occurred at the water's edge at the level receiving most frequent tidal inundation, as is at Site 10 (Figure 4.2). Along river deltas, *S. quinqueflora-J. krausii* community is close to the water, in areas inundated for 5-30% of the year, as is seen at Site 6 (Figure 4.4). *Sarcocornia quinqueflora-Bolboschoenus caldwellii* communities also tended to be confined to levels inundated at least 10% of the year, as at Site 10 (Figure 4.2).

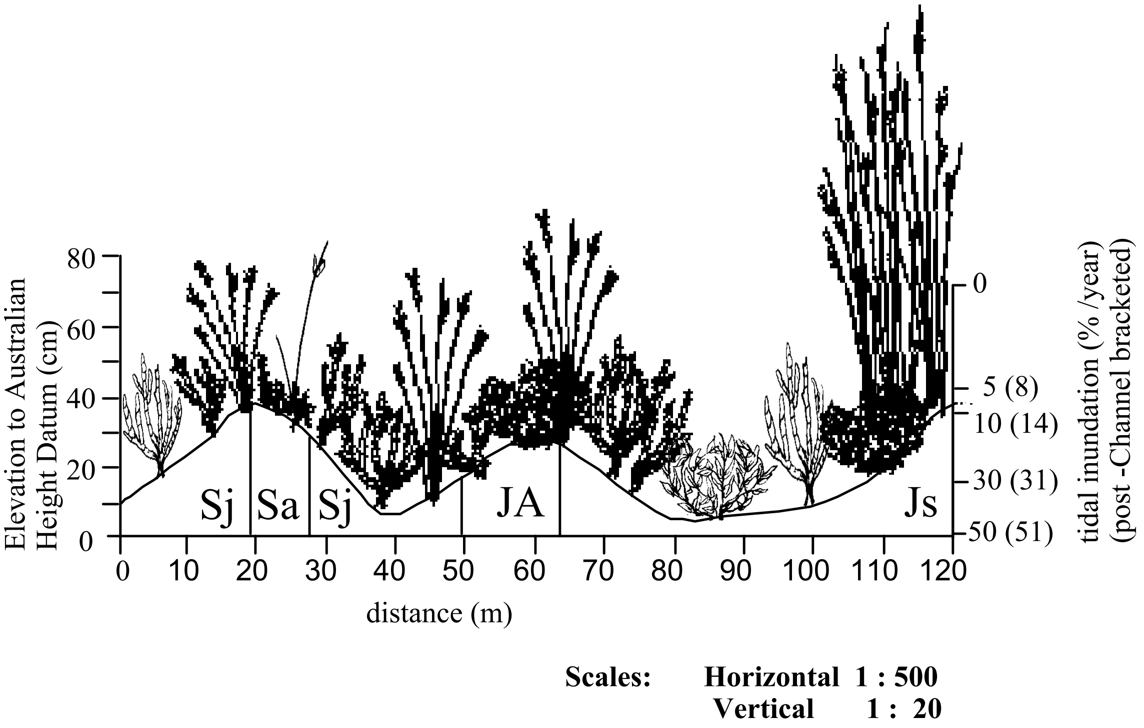

Figure 4.4. Frequency of tidal inundation and vegetation units along the Worallagarook Island transect (Site 6).

In most cases where the inundation occurs about once or twice a year by extremely large tides (above the 0% inundation height) *S. quinqueflora*-grass species, and *S. quinqueflora-Atriplex* communities extended, as at Site 7 (Figure 4.3). However, this trend was not evident at Site 2 at Goegrup Lake (Figure 4.5), where the communities of the *Sarcocornia* complex, including *B. caldwellii*, *Atriplex* species, and *Suaeda australis*, were usually found in much lower marsh. This suggests that this area of saltmarsh is inundated by means other than tidal inundation. The most likely means would be the non tidal flooding from the Serpentine River.

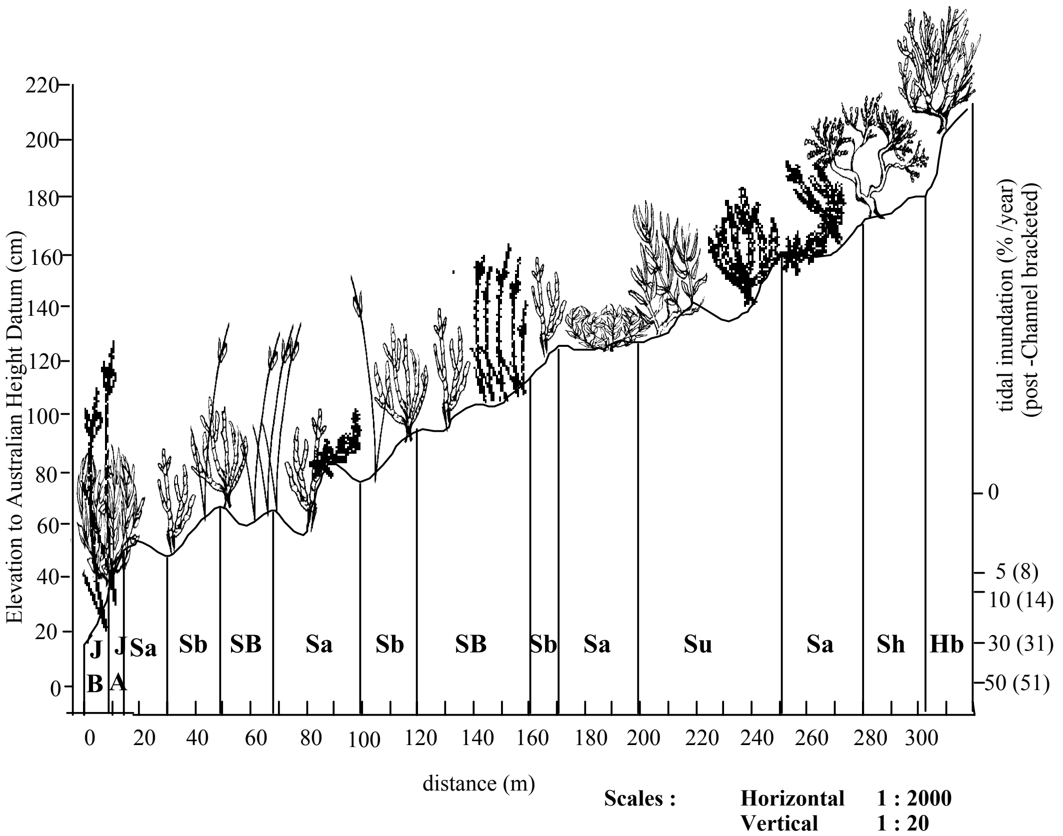

Figure 4.5. Frequency of tidal inundation and vegetation units along the Lake Goegrup transect (Site 2).

The occurrence of the *Juncus* complex and the dominance of *Juncus kraussii* in the *Sarcocornia* complex is also related to tidal inundation. It usually occurs in areas tidally inundated for more than 50% to 10% of the year, close to the water's edge along the rivers of the system, as illustrated in Site 2 (Figure 4.5). The *Juncus* complex was commonly found fringing the landward side of the marsh in areas that receive from approximately 2 to 30% of yearly tidal inundation, as found at Site 10 (Figure 4.2). This could be partially attributed to the affect of salinity in the tidal waters. In the riverine waters salinity would be lower, and might thus allow *Juncus* to occur all over the marsh, as in Site 6 (Figure 4.5) rather than largely restricted to the landward edge, as occurred in the marshes adjoining the Harvey Estuary such as Site 10 (Figure 4.2). This effect could also explain the restricted occurrence of the *Juncus* complex in areas that were not regularly inundated by the tide. Usually *J. kraussii* occurred only as isolated stands in other communities on the high elevation marsh, such as at Site 7 (Figure 4.3).

The vegetated dune that occurred parallel to the shoreline along some areas of saltmarsh, such as at Site 6 (Figure 4.5) was not thought to restrict the tidal inundation to a great extent, as they seldom extended all the way along the shore, and the tide entered through the gaps in the dune system. The dunes could still affect the vegetation, but through reduction in tidal energy and changes in nutrient deposition, rather than as a result of percentage distribution of tidal levels, examined in this section.

The occurrence of the *Halosarcia* complex appeared to be related to tidal inundation. On the more elevated marshes, the area receiving less than 5% inundation was usually dominated by the *Halosarcia* complex, for example see Figure 4.3 on transect 7. Much of the *Halosarcia* dominated marsh was above the elevation mark of zero percent inundation (Figure 4.3) and was thus inundated at low frequency or regularity. The dominance of *Halosarcia* species in the *Sarcocornia* complex usually exhibited trends which could be related to tidal inundation. When the *Sarcocornia* complex occurred in areas that were not regularly inundated by the tide, *Halosarcia* species were of secondary dominance, for example on Site 3. However, this trend was not evident at Site 2 (Figure 4.5) at Goegrup Lake until 70 cm above this percentage inundation, which could be attributed to non tidal flooding by the Serpentine River.

The results suggest that the distribution of saltmarsh vegetation is related to tidal inundation. The complexes appeared to display a clear relationship with the percentage of tidal inundation received yearly. However, the relationship between this and community distribution was not as distinct. It may be that other factors indirectly affected by the tide, such as gradient, sediment deposition, soil composition and nutrient availability, discussed previously, have a greater contribution in determining the community distribution.

4.3.2 Changes in water level along transects resulting from modified water regimes with the Dawesville Channel

The percentage distributions of tidal inundation were predicted to change slightly with the Dawesville Channel. It was found that the elevations receiving 50% and 30% per annum, would receive 51% and 31% (Figures 4.2, 4.3, 4.4, 4.5). The percentage of tidal inundation per annum also increased from 10% to 14% and 5% to 8% (Ryan, 1993).

At the point where the marsh experiences tidal inundation for 5% of the year (or for 10% for the transects in the saltmarsh fringing the Mandurah Channel) the advent of the Dawesville Channel would change the frequency of one hour submergence periods. Before the Channel, one hour inundation periods occurred three times a year in the marshes of the Peel Inlet and two times a year in the marshes of the Harvey Estuary. With the Channel, the frequency increased to 21 and 22 times a year, respectively. The pre-Dawesville Channel 10 hour submergence period, which occurred on an average of 2.5 times a year in the Peel Inlet and once a year in the Harvey Estuary, increased in frequency to four times a year in both water bodies.

The results showed that the most the percentage of tidal inundation per annum would increase with the Dawesville Channel is from 10% to 14% (Ryan, 1993). It is unlikely that this small increase in inundation will have a great effect on the lower marsh, the majority of which is inundated regularly throughout the year (more than 0% of the year). The few lower marsh communities that are tidally inundated for slightly more than 0% of the year may extend to higher elevations with the projected increases in the inundation levels. If the 0% inundation level increases proportionately, approximately 3-4%, there might be an increase in the lower marsh species on the flatter marshes where this change would affect a wider area.

It is likely to be the higher marsh above the level of 0% yearly inundation that will be most affected by the Dawesville Channel. This portion of the marsh is inundated by irregular extremely high tides, resulting from meteorological conditions, that can remain for approximately 24 hours. With the ensuing higher water levels, there are likely to be a greater number of these events that reach the very high marsh, although the levels are likely to recede more quickly (Ryan, 1993).

4.3.3 Changes to complexes with the Dawesville Channel

It is thought that the Dawesville Channel will produce the same trends as found in the European studies of rises in water levels; the *Halosarcia* complex dominating high marsh will recede, and the *Sarcocornia* complex will extend further landward. The increased water levels might aid seed dispersion, further distributing species with wide dispersal ranges, thus possibly extending the range of *Juncus*, as found in the European study quoted by Dijkema *et al*. (1990).

The increase in percentage inundation may decrease the range of the *Sarcocornia* complex in the low marsh in areas such as Site 10, where the vegetation appears limited to the locations inundated for less than half the year. It is also likely to have a greater effect on the pioneer vegetation, as theorised by Huiskes (1990), halting the colonisation of the mud flat area and increasing senescence of some existing pioneer plants.

The decrease in length of periods of exposure will also affect the low marsh. This is likely to affect the various plants differently according to their method of seed dispersion, germination and resilience to salinity and tidal energy.

4.3.4 Changes to individual species with the Dawesville Channel

Changes to water regimes are likely to have differential effects on different saltmarsh species. The anticipated effects on the major genera or species found along the transects are discussed below.

Sarcocornia quinqueflora

The *Sarcocornia* complex was widely distributed around the saltmarsh and often occurred as a band along the shoreline. Seeds of *Sarcocornia* species are usually released in April with onset of winter rains and high tides, and seedlings are usually observed in August (Stoner, 1976). This species is very resilient and the mature plant would probably not be adversely affected by the increase in tidal energy. However, the seedlings cannot tolerate prolonged inundation (Kozlowski, 1984) and may be uprooted by higher tides and increased tidal energy.

At least three days free of tidal submersion are required to allow anchorage of germinated seedlings and their establishment (Waisel, 1972). With the advent of the Dawesville Channel, this is likely not to occur at the lower elevations where the species is most dominant. Thus, *S. quinqueflora* may be limited to vegetative reproduction, which may not sustain the species in the long term. *Sarcocornia* species also germinate better under conditions of low salinity (Stoner, 1976). As germination occurs around August when the Dawesville Channel would cause an increase in seasonal salinity, the rate of germination may decrease.

An increase in flooding frequency in the Netherlands produced an increase in the cover of two annual *Salicornia* species (Dijkema *et al.*, 1990), which occupy the same niche as *Sarcocornia* species. Therefore it is possible that this complex will extend with the changes in water regime. This would concur with that found by Huiskes (1990) that the low marsh is least affected and often extends, after an increase in tidal inundation.

Suaeda australis

Suaeda australis was found with *S. quinqueflora* and in association with organic debris. There is likely to be increased organic debris on the marsh initially following the opening of the Dawesville Channel, as the increased salinity decreases the populations of the blue green alga *Nodularia* and the resultant increased light intensity promotes increased populations of green macroalgae, which accumulate on the shore (McComb & Lukatelich, 1986). This would likely increase populations of *Suaeda*, as other low marsh plants, such as *Sarcocornia*, which appear to have lower survival rates after being smothered by these debris, and appear not to colonise them as efficiently.

However, in the longer term, as the increased flushing of the estuarine system decreases the nutrient store in the sediments, the macroalgae, and thus the organic debris, are likely to diminish to below present levels (McComb & Lake, 1990). This would increase competition by other species and decrease the occurrence of *Suaeda* *australis*, especially in areas of marsh dominated by the *Halosarcia* complex where areas of organic debris is often the only place where the species occurs.

Suaeda australis has been found to release its seeds in June (Stoner, 1976). Salinity, which is likely to increase in June with advent of the Dawesville Channel, slows down germination, extending the process over a long period of time in halophytes such as *Suaeda* species and thus increasing the possibility of submergence killing the germinating plants. *Suaeda* species disperse seeds alongside the parent plants (Kozlowski, 1984) and are likely to have similar problems to *S. quinqueflora* with seedling germination and attachment. Therefore, they may be limited to vegetative reproduction, which may result in the lack of colonisation of any new organic debris accumulations on the marsh.

Bolboschoenus caldwellii

This ephemeral species grows from rhizomes in the winter/spring period. Small stands grow through *S. quinqueflora* in areas where salinities are low and senesce as salinities increase during summer and autumn. *Bolboschoenus caldwellii* flowers in August to November (Marchant *et al.*, 1987; Pen, 1983) and is likely to seed during the high tides and low salinities of winter.

Germination of *B. caldwellii* may be inhibited by higher winter salinities brought about by the Dawesville Channel, and vegetative reproduction may dominate. If the plants themselves do not senesce because of the higher winter salinities, the much reduced salinities in summer and autumn and the increased frequency and depth of inundation might result in less senescence in the lower areas of the marsh, or for a much reduced period. Thus, there is likely to be either a marked decrease or increased domination of *B. caldwellii* in the *S. quinqueflora-B. caldwellii* community and in the *Sarcocornia* complex as a whole.

Halosarcia species

These species occur on elevated areas which form extremely saline dry pans in summer, with low salinities, close to that of freshwater during winter (Marchant *et al.*, 1987; Pen, 1983). The extent of this complex is likely to change with the effect of the Dawesville Channel, the increased submergence reducing the high salinities and temperatures prevalent in most areas of *Halosarcia* complex. Conditions would probably remain sufficiently severe to prevent most other species invading, but there could be a change towards a greater number of *H. indica* subspecies *bidens* which appears less able to survive as well as *H. halocnemoides* or *H. indica* subspecies *leiostachya* in the most harsh conditions. The *Sarcocornia* complex at the water's edge would be likely to increase into the present *Halosarcia* complex. There may also be invasion on the landward side of the marsh where conditions would not be so harsh on the boarders of saltmarsh concavities.

Halosarcia species require high temperatures for germination, and temperatures might decrease with increased inundation. Thus, they would be more reliant on vegetative reproduction, which may decrease under increased tidal scouring at the edge of the complex. Other species fringing the *Halosarcia* complex at the waters edge, such as *S. quinqueflora,* with greater tolerance to increased inundations and quicker growth are also likely to gradually extend into the *Halosarcia* complex. This change is likely to be evident in 1-3 years (Dijkema *et al.*, 1990) after the opening of the Channel. This scenario would be similar to the conversion of high and middle marsh into low marsh, as stated by Dijkema *et al*. (1990) and Huiskes (1990), although it would be unlikely to occur to the same extent on most of the marshes studied.

The increased salinity in winter is unlikely to affect most of the complex, for although *Halosarcia* germinates in winter (Kozlowski, 1984), the genera have a high salt resistance at germination and are unlikely to be affected.

Presently *Halosarcia* species germinate under intensely saline conditions which preclude the germination of seeds of other species. Thus, they may not compete effectively with other plants able to germinate under the lower salinity regime. The decreased salinity in the tidal water in autumn with the Dawesville Channel, might affect the marsh. However, as was found in a European marsh (Dijkema *et al*., 1990) the most negative response to an increase in tidal height, is likely to be the increased frequency in summer inundations. This is likely to occur over the lower *Halosarcia* marsh, decreasing the high salinities. If the change is substantial, other plants would invade because of the greater dispersion of seeds over the area and the reduction of the salinities which previously inhibited competitors.

If the rise in water level and inundation frequency produce only a small change in the high summer salinity, so that other less salt tolerant species would still be precluded, the growth of *Halosarcia* species might be promoted. The *Halosarcia* bushes found in the Peel-Harvey are often half the size of that quoted by Marchant *et al*. (1987) and evident in other less saline marshes in the Eastern States (J.A. Latchford, pers. obs.). This is attributed to stunted growth caused by the high salinities particular to Peel-Harvey marshes. Thus, a reduction in salinity small enough not to induce competition, could reduce this stunting and allow the growth of larger, more dense bushes.

Frankenia pauciflora

This was found to have a restricted distribution on the drier banks. Pen (1983) claimed that *F. pauciflora* does not grow on disturbed sites because of an inability to regenerate under conditions of severe disturbance. The changing tidal regime, which would inundate the high banks more frequently, could result in damage or death of the species, which would be unlikely to recover or regenerate under the new conditions.

Juncus kraussii

Juncus kraussii is found in the drier, elevated parts of saltmarshes or in brackish areas where the salinities are lower (Pen, 1983; Bridgewater *et al*., 1981), such as the marshes of the Serpentine River (Figure 4.5). It was usually flooded at high water and at some sites reached to the water's edge at low water.

Light is required for germination which, under appropriate conditions takes 12 hours. The fresh seeds are highly salt tolerant but tolerance decreases with age (Waisel, 1972). The plants themselves possess little salt tolerance (Kozlowski, 1984).

The higher winter salinities caused by the Channel are not likely to reduce the seeding or growth. Increased erosion, or increased water level may reduce the extent of *J. kraussii* at the waters edge. Where it occurs on the landward edge of the marsh it is likely to increase in area, as found in a European high marsh where increased tide height had a strongly positive effect on two *Juncus* species. *Juncus* species have the ability to quickly re-establish after damage through vegetative regeneration, and could extend into the damaged lower areas of the marsh (Dijkema *et al*., 1990).

Atriplex species

The perennial *Atriplex hypoleuca* was usually associated with *J. kraussii* close to the water's edge, while the annual *Atriplex prostrata* was on elevated mounds on the higher marsh. Germination in *Atriplex* seeds is reduced by saline conditions, and the seeds are very sensitive to aeration, so rarely germinate when inundated (Waisel, 1972). If the increase in tide range was such that the rises where they grow were inundated during germination the species would decrease in extent, especially the annual, which can only reproduce by seed. Seed dispersal would be increased by the increase in flooding frequency, but few seeds would remain viable. Thus, the trend of increased annuals in European marshes under conditions of increased tide height and flooding frequency (Dijkema *et al*., 1990), would probably not occur in the annual *Atriplex prostrata*.

Annual grasses and daisy: *Cynodon dactylon*, *Polypogon monspeliensis* and *Cotula coronopifolia*

The trend of increased annuals in European marshes under conditions of increased tide height and flooding frequency (Dijkema *et al.*, 1990), is likely to be displayed by the above three species, which germinate and grow in winter (Stoner, 1976), probably through better seed dispersal and increased availability of bare soil caused by senescence of perennials in response to the new tidal regimes.

4.4 Conclusions

The results are consistent with data in the literature, that the distribution of saltmarsh vegetation is related to tidal inundation. The complexes found in the Peel-Harvey display a clear relationship with the percentage of annual tidal inundation received. The relationship between this and communities was not so clear, although some trends were apparent. Other factors indirectly affected by the tide, such as gradient, sediment deposition, soil composition and nutrient availability, may have a greater contribution in determining community distribution. Other forms of inundation such as river flooding and infrequent extremely high tides would also affect the distribution of saltmarsh plants.

Not only are there likely to be changes in the extent of vegetation complexes with changing water regimes, there is expected to be different changes affecting most species, and thus communities, within the saltmarsh. Thus, it is hypothesised that the opening of the Dawesville Channel will alter community distribution in the saltmarshes of the Peel- Harvey estuarine system.