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CHAPTER 4 Water Regimes And Marsh Distribution

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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.

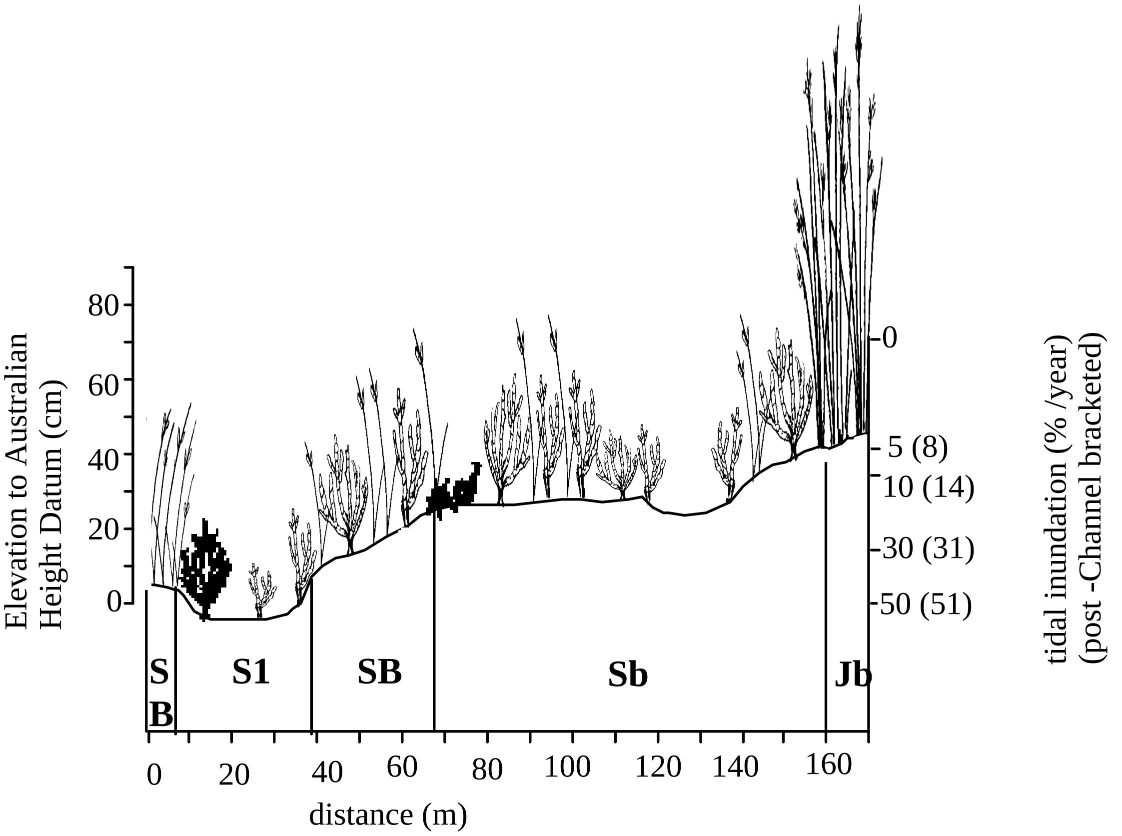
4.3. Results and Discussion

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.



Scales: **Horizontal 1 : 2000**
Vertical 1 : 20

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

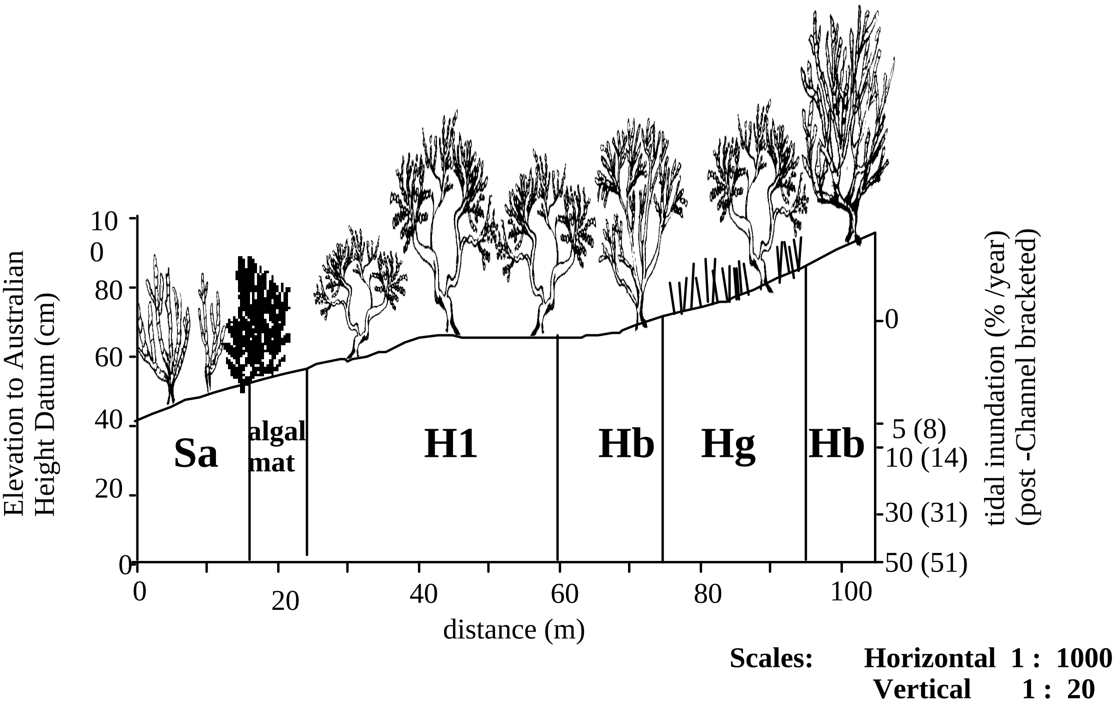
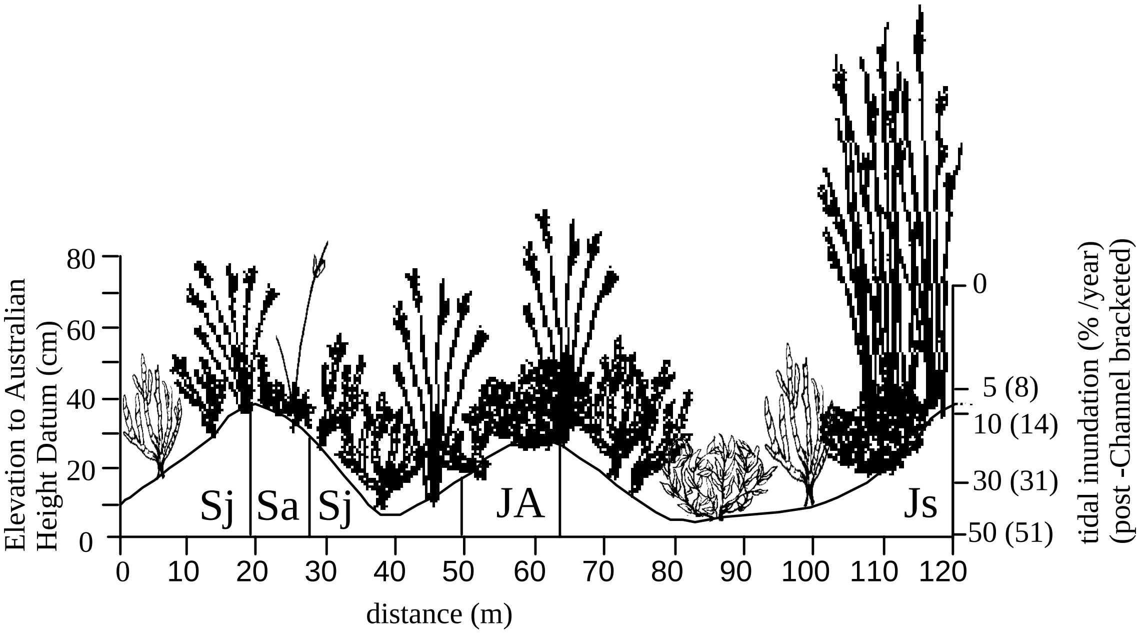


Figure 4.3. Frequency of tidal inundation and vegetation units along the East Peel Inlet transect (Site 7).

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).



Scales: Horizontal 1 : 500
Vertical 1 : 20

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.

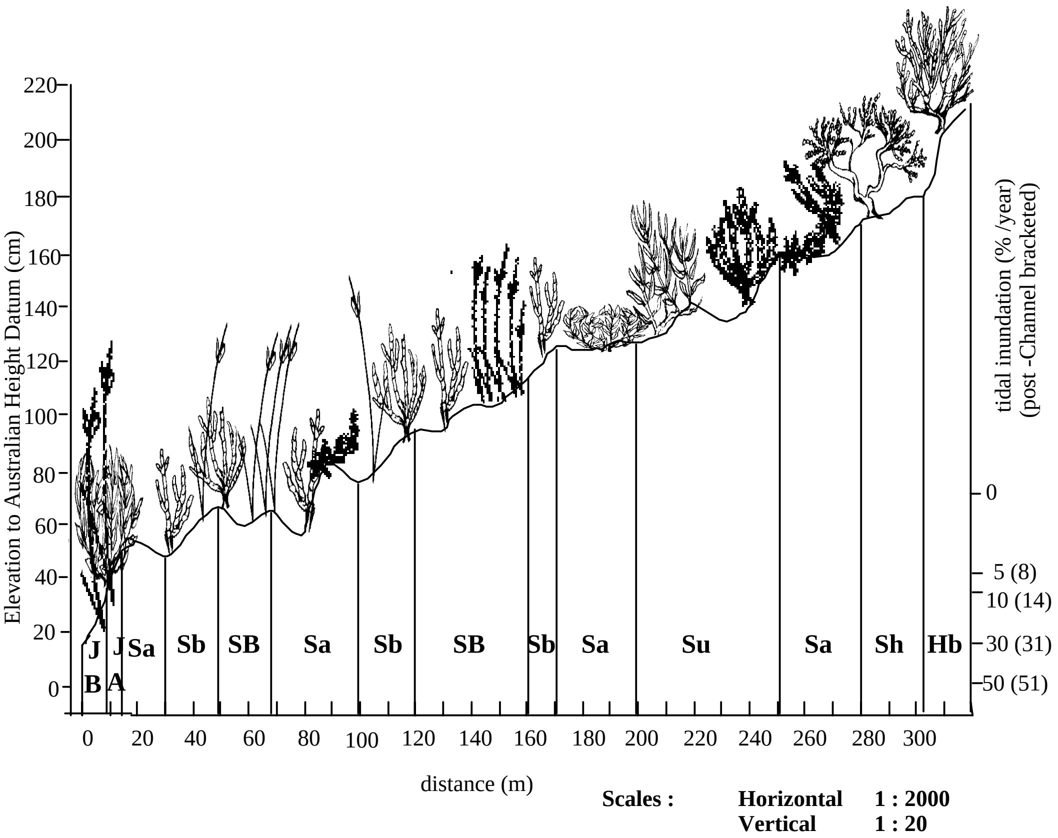


Figure 4.5. Frequency of tidal inundation and vegetation units along the Lake Goegrup transect (Site 2).

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.

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