CHAPTER 5 *Invertebrate Distribution And Samphire Marsh Ecology*

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5.1 Introduction

Invertebrates play an important role in the ecology of estuarine systems, but because of their small size and cryptic nature their importance is often neglected. Invertebrate species richness of estuarine systems is lower than that of the ocean or freshwater systems, because these species need to be able to tolerate both saline and freshwater conditions. The species richness of the saltmarshes is lower still as environmental conditions on the marsh are even more severe than that of the estuary. However, the trade-off is that the species that do occur are extremely productive, both in terms of biomass and abundance (Day, 1981).

Invertebrates play an important role in the food chains of the saltmarshes, and are important for the health and function of saltmarsh ecosystems. Within the benthic habitat, vascular plants such as samphire, are grazed by herbivorous insects including plant hoppers and grasshoppers. These are in turn fed upon by carnivorous organisms, for example, spiders. The breakdown of organic matter in the marsh is performed by microbial fungi and bacteria, which subsequently comprise a food source for the larval stages of larger invertebrates and microscopic invertebrates such as copepods. The larger invertebrates; polychaetes, molluscs and crustaceans live within or near the sediments and commonly become a food source for wading birds.

The saltmarshes that occur in selected areas of the Peel-Harvey Estuary are considered to be an important attribute of the system, and contribute to the invertebrate biomass and abundance (Plates 5.1, 5.2 and 5.3). The marine component of the fauna associated with saltmarsh sediments are generally common species of adjacent mudflats, where they form the food supply of internationally important gatherings of wading birds and waterfowl. They also play a significant role in decomposition, which in some circumstances results in a net export of carbon and nutrients into adjacent waters (Mason *et al.*, 1991).

The invertebrate species occurring on the samphire flats of the Peel-Harvey Estuary have not been well documented, and little is known about the distribution and composition of these invertebrate communities.

Boulden (1970) surveyed the shallow waters of the Peel Inlet whilst Rose (1992, 1994) investigated and compared macrobenthos and benthic zooplankton communities respectively for the Peel-Harvey and Swan Estuaries, suggesting that species abundance and diversity were lower in the Peel-Harvey. Chalmer and Scott (1984) studied fish and benthic faunal of the Leschenault and Peel-Harvey estuaries and found that both estuaries were dominated by bivalve molluscs, polychaete worms and amphipods. Wells *et al.* (1980) studied the biology of molluscs in the Peel-Harvey and recorded 34 species of molluscs, the dominant species being *Hydrococcus grandiformis* and *Arthritica semen*. A number of other studies have concentrated on the molluscs of the Peel-Harvey system (Wells and Threlfall, 1980, 1981, 1982 a, b).

Several overseas studies have dealt with invertebrate communities and distributions on saltmarshes. Mason *et al.* (1991) investigated the invertebrate assemblages of Essex saltmarshes and suggested that a holistic approach to their management is required. Ranwell (1972) suggests that the dimensions, population size and behaviour of a few species, and the degree of diversity of the remaining species seem to be the more significant biological elements of the saltmarsh ecosystems. A study by Clancy (1994) of the Sydney region found 574 species of insects, 17 species of spiders and 12 species of mites in the mangrove and saltmarsh communities.

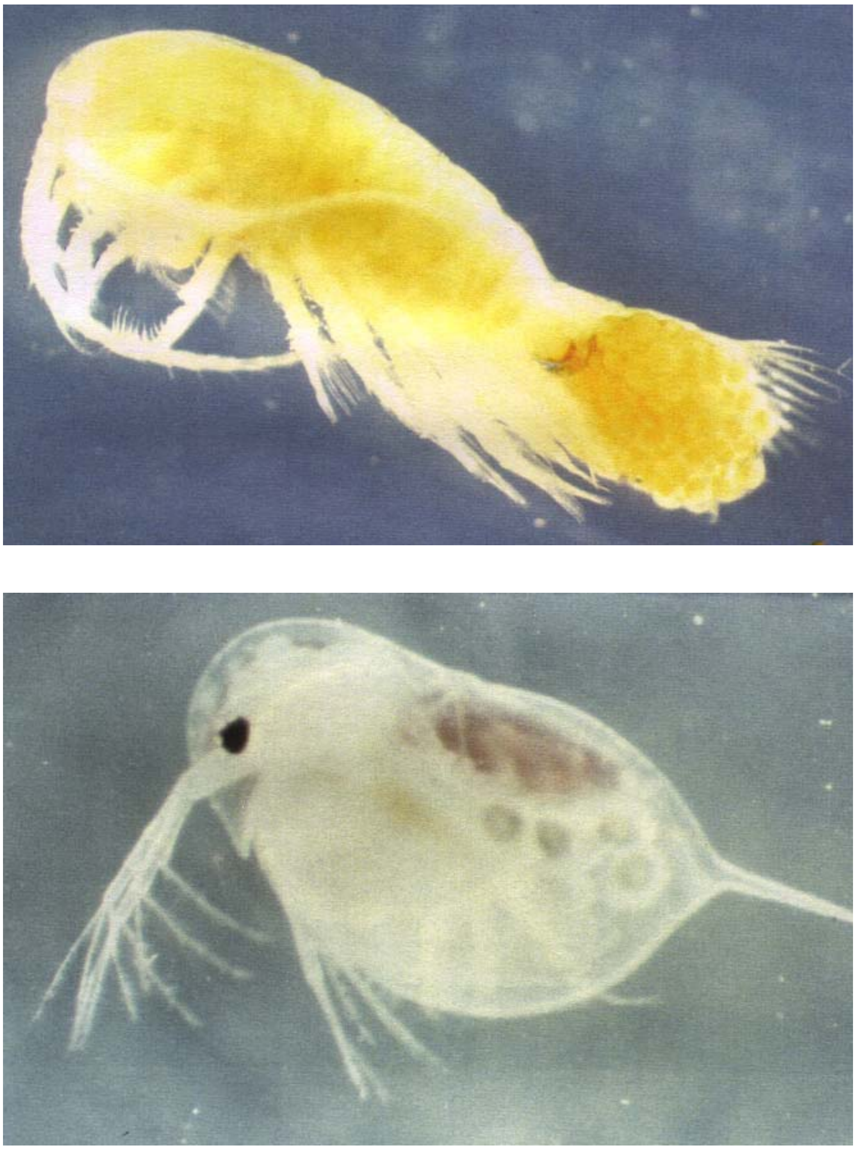


Plate 5.1 Invertebrates often found in saltmarshes of the Peel- Harvey, copepod (top), *Daphnia* (bottom).

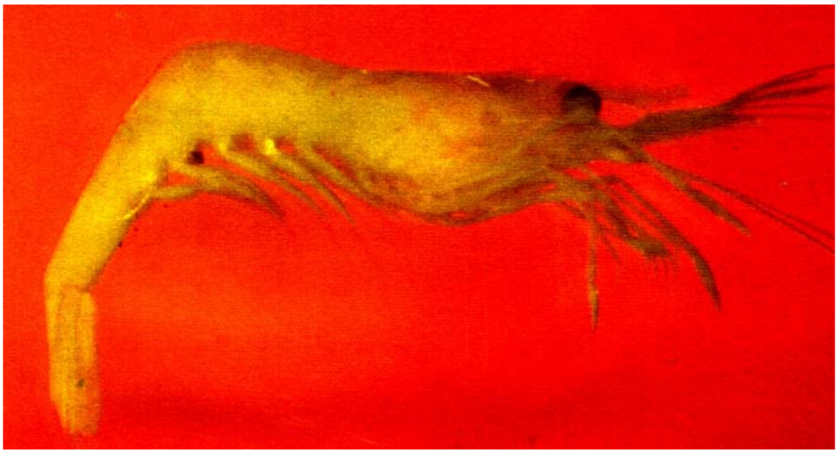


Plate 5.2 Invertebrates common in saltmarshes of the Peel- Harvey crustacean (top) and mite (bottom).

Plate 5.3 Invertebrates often found in saltmarshes of the Peel- Harvey, chironomid (top), and ostracod (bottom).

Due to the importance of the Peel-Harvey Estuary, and the limited invertebrate information available, a seasonal sampling regime was undertaken on selected areas of the samphire marshes, to find out which species occur within the different zones of the marsh.

5.2 Methods

Six transects were selected to provide representative sites for sampling invertebrates within the saltmarshes (Figure 1.1). These were: Site 2-Lake Goegrup; Site 4-Soldiers Cove; Site 6-Worallgarook Island; Site 7-Austin Bay; Site 8-West side of Harvey Estuary; and Site 10-Harvey Estuary.

The transects were separated into three defined areas (Figure 1.2). Area 1-low marsh; area 2-middle marsh; area 3-high marsh. These three areas were considered to be substantially different due to characteristics of tidal inundation, vegetation type and distance from the shoreline.

The transect areas were sampled once during the summer of 1993/94 and winter 1994 as these represented periods of differing water availability. Two types of invertebrate sampling techniques were used; core samples were taken on both sampling occasions while sampling with a sweep net was performed in winter, when more water was present.

The core samples were collected with a 10 cm diameter corer. The sediment was collected to a depth of 25-30 cm of which the top 10 cm was retained. The samples were placed in plastic bags, labelled and saturated with 70% ethanol to preserve any invertebrates which may occur within the sample. Four random replicate core samples were collected from each area within the transect.

The sweep samples were collected with a 250 μm sweep net. Two replicate sweeps, taken over a distance of 10 m, were collected at sites when sufficient water was available. Generally insufficient water was available to collect separate sweep samples at areas 2 and 3, and due to this, these areas were combined and called area 2. The samples were then placed in plastic bags, labelled and saturated with 70% ethanol.

In the laboratory samples were washed through a series of sieves, decreasing in size from 2000 µm to 250 µm. The respective fractions were then sorted and all invertebrates present were collected, counted and later identified.

5.3 Results

5.3.1 Species Abundance

The mean number of individuals occurring on each transect, of each site, was calculated from the cores collected in summer and winter, and the winter sweeps. The mean species abundance for the summer cores of the transects are displayed in Figure 5.1. In general area 1 and area 3 had a higher species abundance than area 2. High abundances were recorded at areas 1 and 3 on Site 8, while extremely low values occurred at each area on Site 7.

Species abundances recorded on the transects in winter (Figure 5.2) tended to be more consistent than in summer (Figure 5.1) over all areas. Area 3 showed lower abundances than areas 1 and 2, and could be an indication of the tidal regime. Areas 1 and 2 were generally similar in abundance, with area 3 being lower. Site 2 showed very low abundances in all areas.

In Figure 5.3 the mean species abundance for winter sweep sites indicated a substantially greater abundance at area 1 in most transects. The only exception to this was at Site 4 where abundance is half that of area 2.

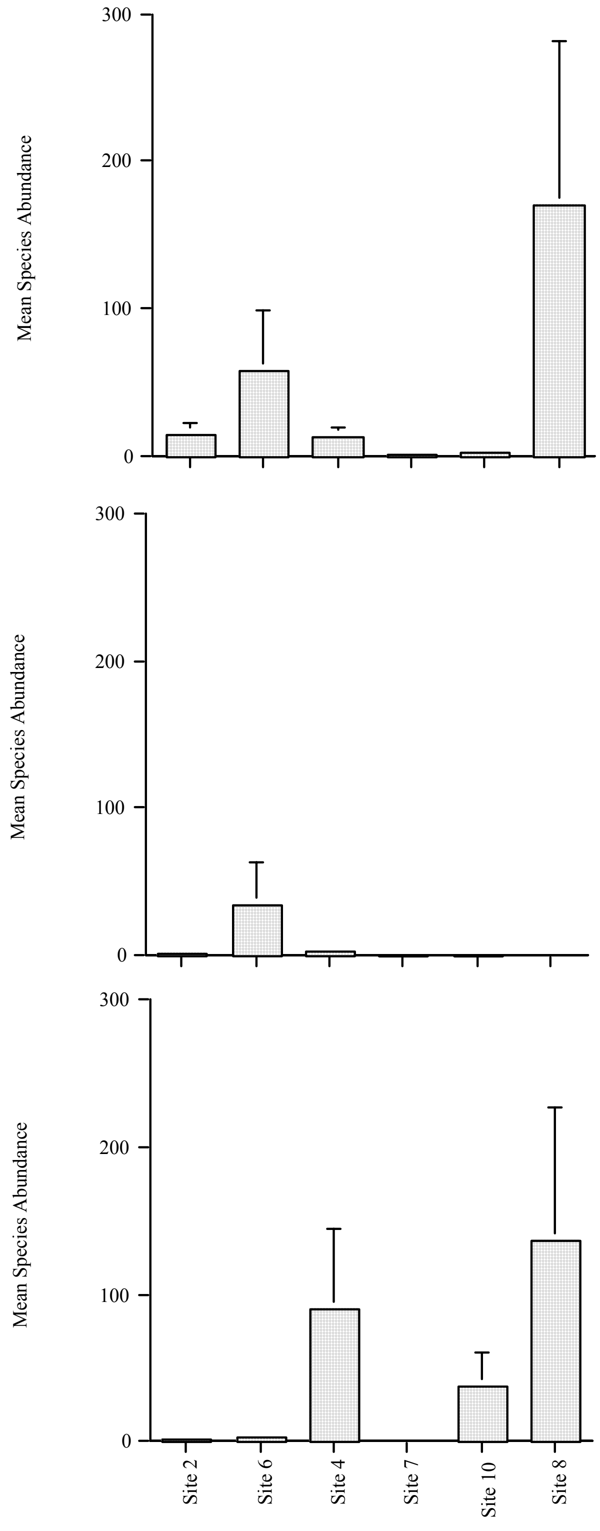


Figure 5.1. Mean species abundance for cores during summer, along a transect at selected sites, for areas 1, 2 and 3 respectively, n=4. Areas 1, 2 and 3 are the same as on Figure 1.2.

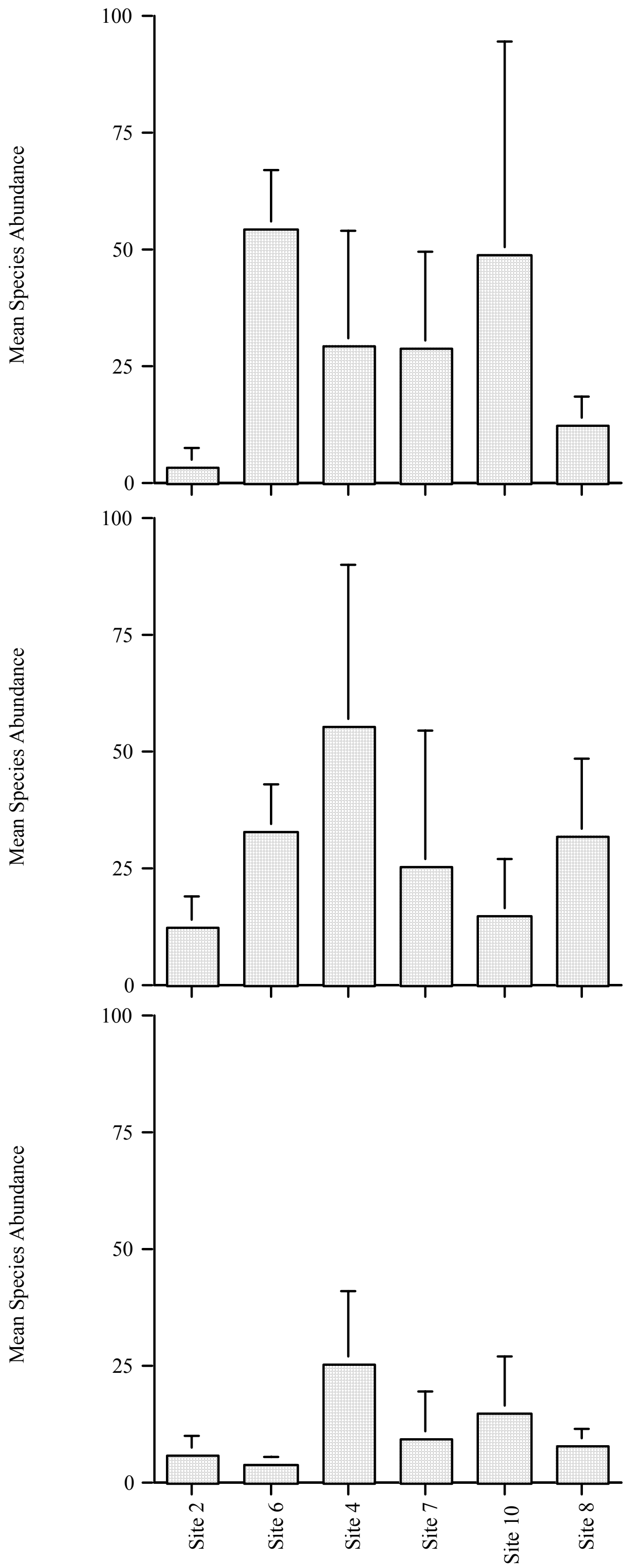


Figure 5.2. Mean species abundance for cores during winter, along a transect at selected sites, for areas 1, 2 and 3 respectively, n=4. Areas 1, 2 and 3 are the same as on Figure 1.2.

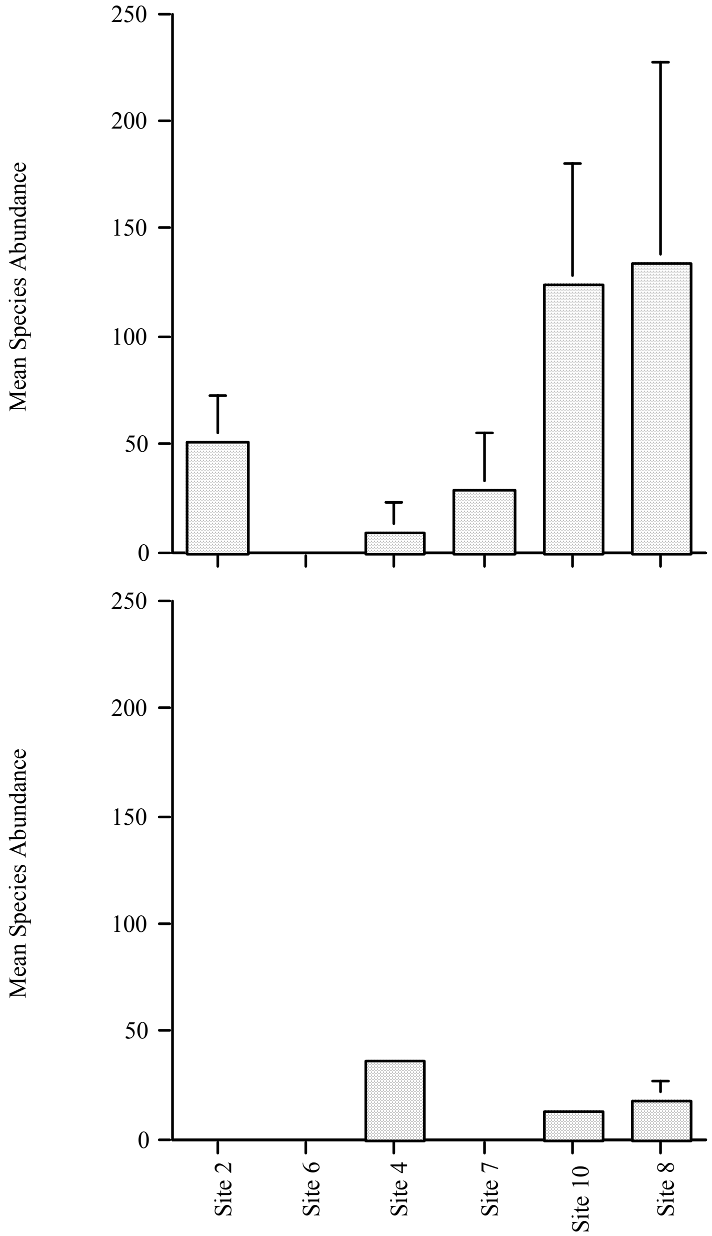


Figure 5.3. Mean species abundance for sites sampled with a sweep net in winter, along a transect at selected sites, for areas 1 and 2 respectively, n=2. Areas 1 and 2 are the same as on Figure 1.2. Note: zero abundance indicates no sample was taken.

5.3.2 Mean Species Richness

The mean number of species occurring on each transect, within each area, as collected in cores in summer and winter, and sweepnets in winter are given in Figures 5.4, 5.5 and 5.6.

The mean species richness for winter cores at each transect is illustrated in Figure 5.5. This indicates a higher richness at areas 1 and 2, although generally richness was low for all transects. A comparison between Figures 5.4 and 5.5 showed winter to have a slightly higher species richness than summer.

Figure 5.6 displays the mean species richness for winter sweep sites and indicated a substantially higher richness at area 1. Site 4 in area 2 had a higher richness than area 1, which correlates well with species abundance.

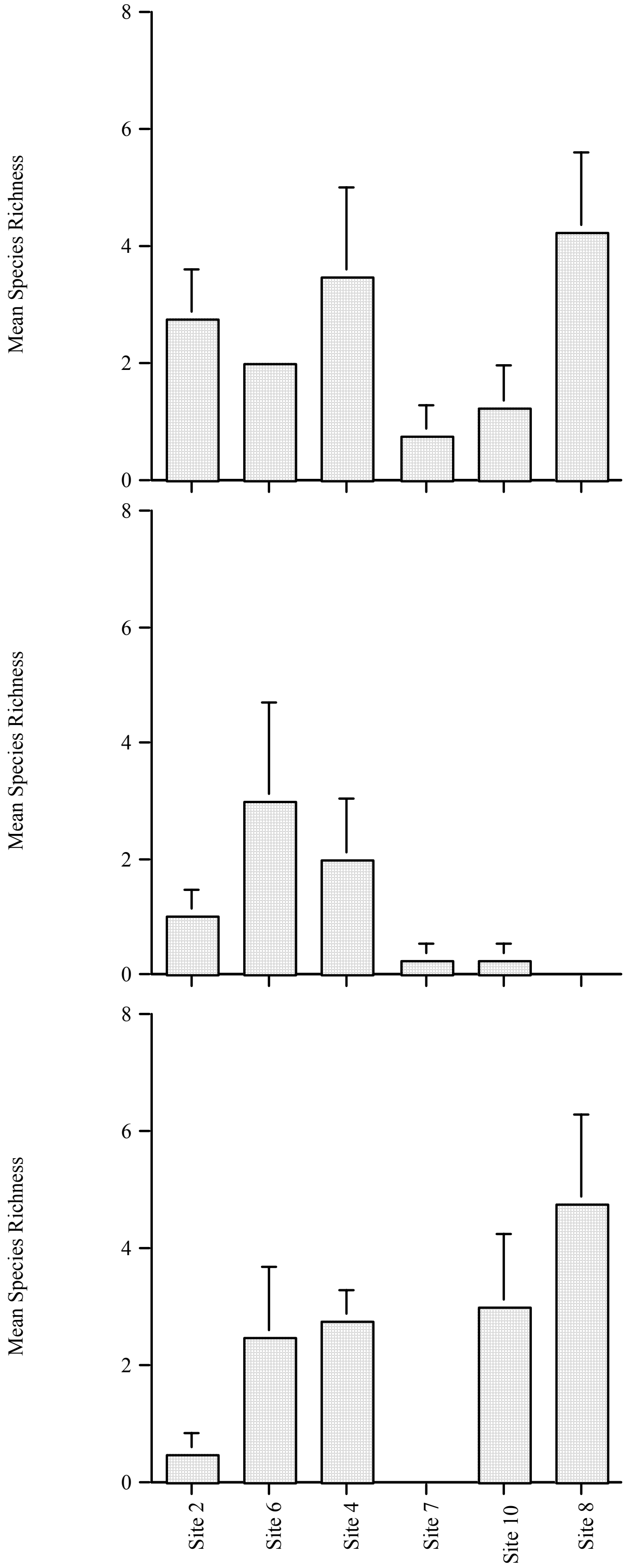


Figure 5.4. Mean species richness for cores during summer along a transect at selected sites, for areas 1, 2 and 3 respectively, n=4. Areas 1, 2 and 3 are the same as on Figure 1.2.

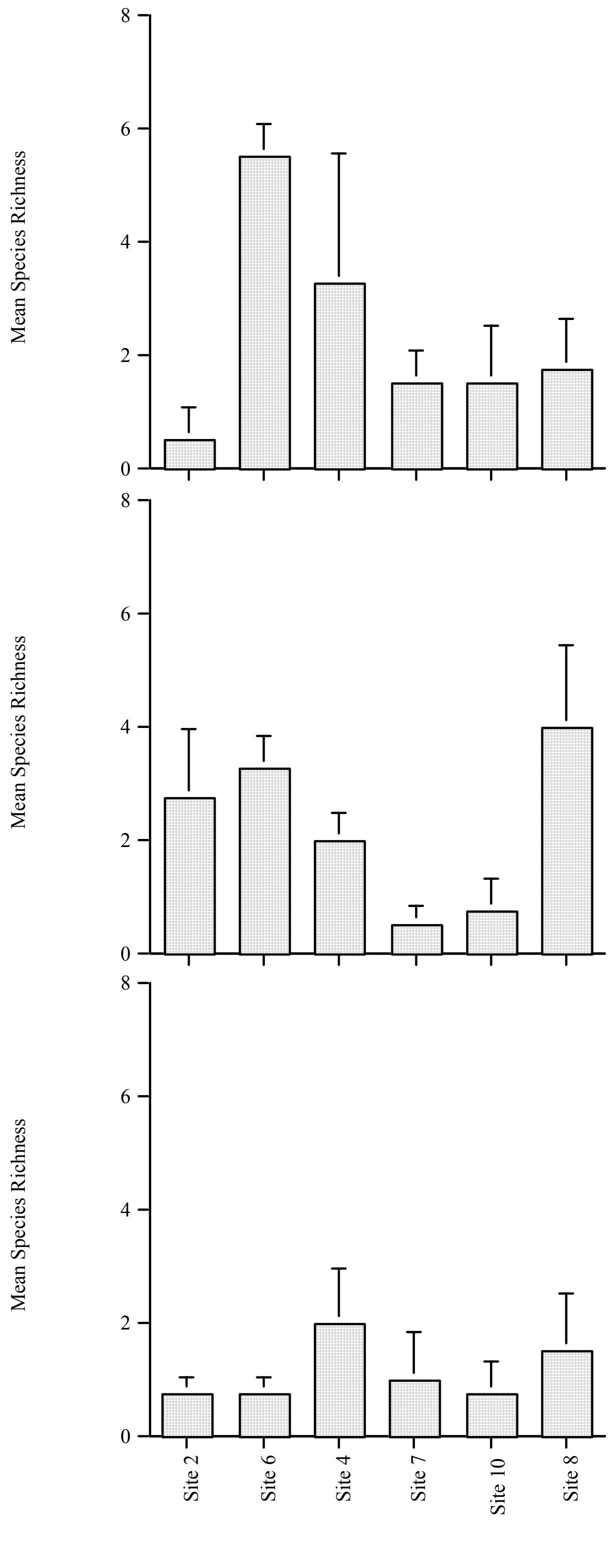


Figure 5.5. Mean species richness for cores during winter along a transect at selected sites, for areas 1, 2 and 3 respectively, n=4. Areas 1, 2 and 3 are the same as on Figure 1.2.

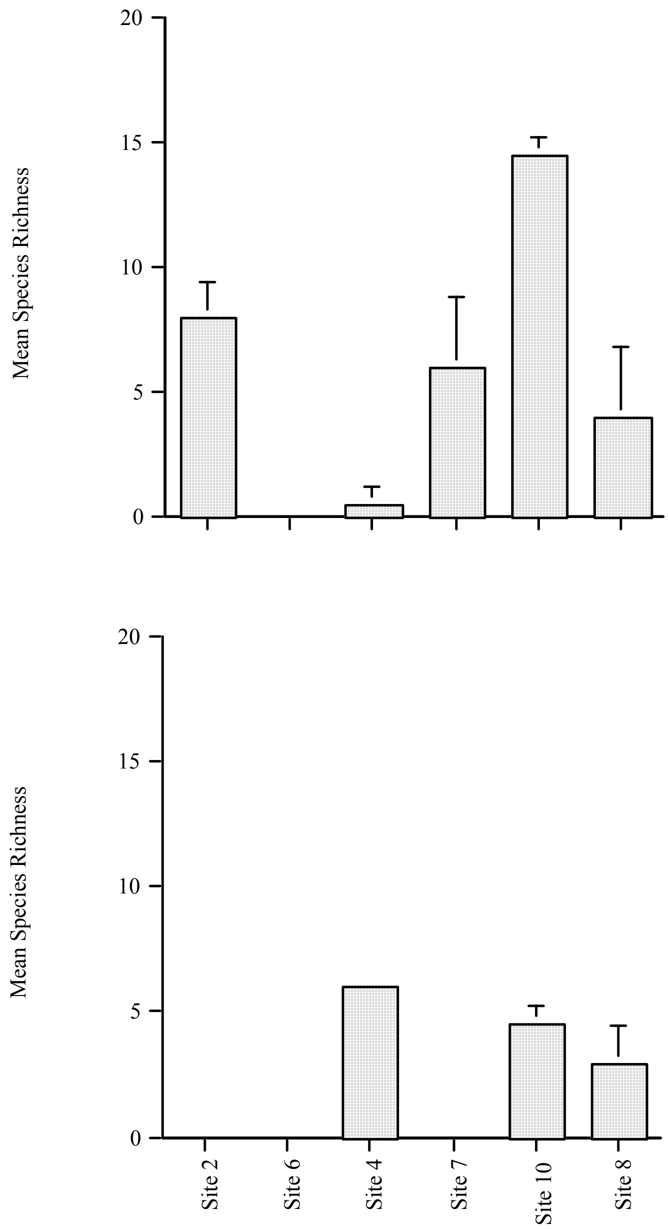
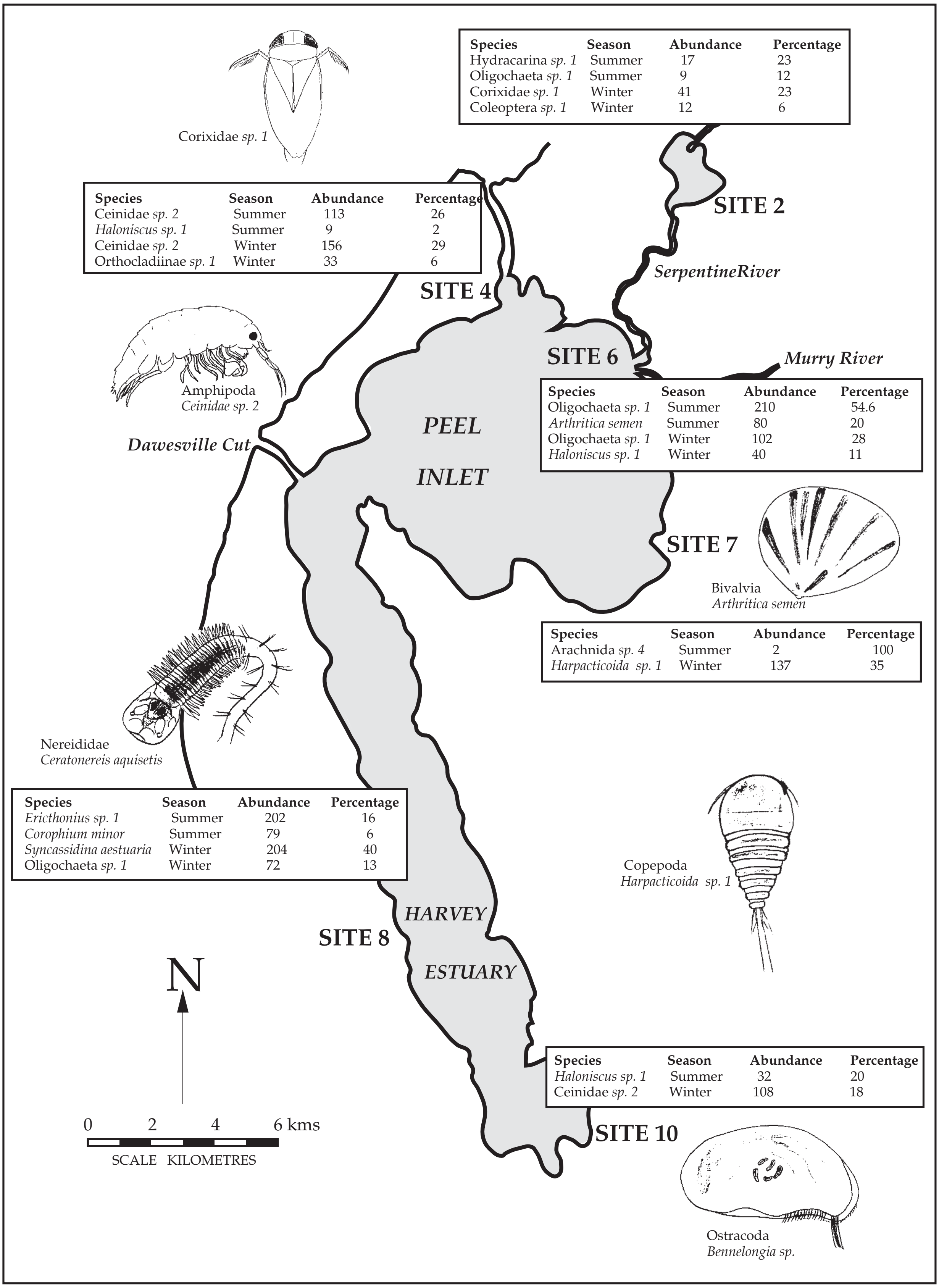


Figure 5.6. Mean species richness for sweep sites during winter along a transect at selected sites, for areas 1 and 2 respectively, n=2. Areas 1 and 2 are the same as on Figure 1.2. Note: Zero abundance indicates no sample taken.

5.3.3 Common Species

Figure 5.7 shows site locations, tables of the two most dominant species, their abundance and percentage for both summer and winter for each site, and diagrams of either the dominant or interesting species occurring at each site. The species found in the study are listed in Appendix 7. Generally, the isopods *Syncassidina aestuaria* and *Haloniscus* sp 1 were prominent, occurring within the top two ranking's at Sites 4, 6 and 10. Oligochaete sp 1 was also prominent,

dominating Sites 2 and 6 during summer and Sites 6 and 8 during winter. The mollusc *Arthritica semen* was prominent at Site 6 and was the only mollusc represented in the top ranking's. Generally dominant species represented 20-30% of the total composition, with the exception being at Site 7, where abundances were either very small or quite large.



Species	Season	Abundance	Percentage
Hydracarina *sp. 1*	Summer	17	23
Oligochaeta *sp. 1*	Summer	9	12
Corixidae *sp. 1*	Winter	41	23
Coleoptera *sp. 1*	Winter	12	6

Species	Season	Abundance	Percentage
Ceinidae *sp. 2*	Summer	113	26
Haloniscus sp. 1	Summer	9	2
Ceinidae *sp. 2*	Winter	156	29
Orthocladiinae *sp. 1*	Winter	33	6

Species	Season	Abundance	Percentage
Oligochaeta *sp. 1*	Summer	210	54.6
Arthritica semen	Summer	80	20
Oligochaeta *sp. 1*	Winter	102	28
Haloniscus sp. 1	Winter	40	11

Species	Season	Abundance	Percentage
Arachnida *sp. 4*	Summer	2	100
Harpacticoida sp. 1	Winter	137	35

Species	Season	Abundance	Percentage
Ericthonius sp. 1	Summer	202	16
Corophium minor	Summer	79	6
Syncassidina aestuaria	Winter	204	40
Oligochaeta *sp. 1*	Winter	72	13

Species	Season	Abundance	Percentage
Haloniscus sp. 1	Summer	32	20
Ceinidae *sp. 2*	Winter	108	18

Figure 5.7. Map of the Peel-Harvey Estuary showing transect locations and dominant species* occurring for both summer and winter.

*Note: Site 8 and Site 10 do not display dominant species.

5.4 Discussion

The abundance and richness of invertebrates occurring throughout the Peel-Harvey estuary was greater during the winter period, when the majority of the saltmarsh was inundated with water. This suggests that the increased availability of water was beneficial to invertebrate success and survival. The increased flushing of water through the estuarine system during the winter months generally results in the increased export and mobilisation of nutrients from the samphire marshes. These nutrients in turn help to provide an abundant source of food which will also increase species richness and abundance. Results from cores taken in winter indicate higher species richness and abundance at areas 1 and 2. This suggests that these areas are more productive and favourable for aquatic invertebrates.

During summer, the Peel-Harvey estuary dries significantly, often becoming hypersaline. Flushing in this period is decreased, water levels are low (Wells *et al.*, 1980) and an import of nutrients onto the samphire marshes often occurs (Latchford, 1994). Cores collected in summer indicate abundance and richness to be low, and this may be attributed to the estuary drying out. Higher abundances and richness occurred at areas 1 and 3, which could be due to the proximity of the marsh to water at area 1 or to a greater number of terrestrial and transitional invertebrates such as spiders, springtails and slaters (isopods) occurring at area 3. The occasional inundation of this area may provide an additional food source for invertebrates occupying these areas. Area 2 may be a more difficult environment in which to survive. It receives less water and thus the life span of aquatic invertebrates may be reduced, however, it may receive sufficient water to deter colonisation by terrestrial invertebrates.

Invertebrate abundances and richness were found to be greater at area 1 in winter. This suggests that the conditions within this area are more favourable for habitat and feeding, due to intertidal inundation. The higher abundances and richness would also be attributable to the available water, as this region is frequently inundated due to tidal influences. The lower abundance and richness of aquatic invertebrates at area 2 is due to the irregular flooding of this region. The high marsh generally has a minimum of ten days of exposure to air (Latchford, 1994). Area 2 (areas 2 and 3 combined) is found within this intertidal area (Figure 1.2).

Invertebrates occurring within the saltmarshes are a mixture of terrestrial and aquatic species, occurring within the aerial, benthic and aquatic habitats. The major species occurring in quite high numbers were Oligochaetes. Oligochaete sp 1 dominated Site 2 and Site 6. The bivalve *Arthritica semen* was prominent at Site 6 and was also found in substantial numbers at Site 7 and at Site 8. *Arthritica semen* is a filter feeder and exclusively an estuarine species (Thurlow *et al*., 1986). The location of *A. semen* at these sites may be due to the influence of rivers and drains providing nutrients for food.

The isopods *Syncassidina aestuaria* and *Haloniscus* sp 1 dominated the winter samples, with *Haloniscus* sp 1 occurring in the majority of sites. The isopods were found within samples containing a combination of plant debris and algae mats and are generally found under mats of dead, decaying plant debris (Kraeuter and Wolf, 1974). Site 10 and Site 4 also contained *Haloniscus* sp 1 as a dominant summer species. These two sites were quite moist in summer and had not dried out to the extent of Site 2 and Site 7, which may explain the invertebrates' dominance.

Site 4 and Site 8 were dominated by the amphipod species, Ceinidae sp 1 and 2, as well as *Corphium minor* and *Erichthonius* sp 1 which were present in summer and winter samples. Thurlow *et al*. (1986) suggested that *C. minor* and certain other amphipod species can tolerate a wide range of salinities. These two transect sites contained water throughout the year which suggested that the amphipod species occurring there can tolerate the varying conditions and suggests that they are a beneficial part of the food web throughout the year.

The copepod Harpacticoida sp 1 occurring at Site 4 and Site 7 in substantial numbers may be a new species. Harpacticoid copepods are strongly influenced by factors such as desiccation and oxygen availability (Dye and Furstenburg, 1981). The frequent tidal inundation of these marshes during the winter months would account for the suitable food source and oxygen availability required by the harpacticoid species, and suggests that these marshes are nutrient rich during winter. The ostracod *Bennelongia* sp 1 and the polychaete *Ceratonereis aquisetis* were not abundant species but were unique as they were only found towards the bottom of the Harvey Estuary in the sampling period. The influence of the fresh water from the Harvey river and agricultural drains as well as the sea water entering the Peel Inlet at Sticks channel may account for the dominance of these species.

Due to the limited literature available on the invertebrate assemblages of saltmarshes it is difficult to compare this work to previous studies. A comparison with Mason *et al.* (1991) who used a similar sampling technique, indicated that the sweep net samples collected were more variable in taxon richness than cores, and were a good indicator of invertebrate assemblages. Mason *et al*. (1991) indicated that cores collected low species richness but high species abundances, especially of marine species. This was true for this study, although a comparison of marine species from the invertebrate species collected has not yet been fully determined.

Mason *et al.* (1991) classified the conservation value of the saltmarshes according to community distinctiveness, species richness, species rarity and community functioning, suggesting a holistic approach to management. This approach should be considered as Sites 4, 6 and 10 contained substantial richness and abundances.

A study by Clancy (1994) on the terrestrial arthropods of mangroves and saltmarshes, found a substantial number of invertebrate species occupy the saltmarsh and mangrove areas. The sampling technique involved sweeping across the saltmarshes, collecting invertebrates which occurred on or above the marshes. Clancy’s method differed from the cores and sweeps taken by this study but an interesting comparison was the number of species of spiders found. Clancy collected 17 species of spiders compared to eight species found in this study which suggests that spiders are an important component of the terrestrial make-up of the saltmarshes.

The impact of the Dawesville channel upon the saltmarshes and invertebrate assemblages of the Peel-Harvey Estuary is difficult to predict and remains to be determined. No real impacts upon the invertebrate assemblages can be gauged from this study due to the limited time span over which sampling was undertaken and the lack of previous studies. However, some potential impacts upon the invertebrate distributions and assemblages from the Dawesville Channel are likely due to the altered tidal levels of the Estuary. The Mean Low Low Water Level to the Mean High High Water Level range has changed from 9.7 cm to 27.6 cm in the Peel Inlet and from 8.6 cm to 37.9 cm in the Harvey (Ryan, 1993). The implications of this are that tidal ranges will be more variable and more frequent (Waterways Commission, 1994) which may alter saltmarsh

distributions and hence alter invertebrate distributions. The effects of the tidal patterns are predicted to be greater in the Harvey Estuary (Waterways Commission, 1994) where higher invertebrate richness and abundance was recorded.

Other implications include greater ocean/estuarine mixing which will maintain the salinity levels in the estuary more similar to the marine environment for most of the year (Waterways Commission, 1994). This may alter the range of some invertebrate species, especially those who require a fresher aquatic environment. The greater interaction of marine species with estuarine species may also have a significant effect on the food chain, as marine species may out compete estuarine species for food or disrupt ecological niches.

The results from this study have provided useful information on the composition and abundance of invertebrates in the Peel-Harvey saltmarshes, however to obtain a good understanding of the invertebrate assemblages and distributions a longer sampling period is required. Due to the construction of the Dawesville Channel, and limited literature on invertebrate assemblages, it has been difficult to predict how the invertebrates of the Peel-Harvey Estuary will change over time. It may be that the higher tides will reduce the harshness of the low marsh increasing the productivity of this area, on the other hand it may lead to a reduction in specialised invertebrates which are adapted to the extreme conditions.

The major area of invertebrates neglected by the sampling methods of this study were terrestrial species, such as spiders and grasshoppers. The invertebrates collected in this study were generally aquatic in habitat. Terrestrial invertebrates that were collected were either in the water-column or on vegetation when sampling occurred. Studies undertaken in New South Wales indicate that spiders form an important component of the saltmarsh fauna, but little is known about the conditions they require within the marsh (Clancy, 1994).

CHAPTER 6 The ecological significance of saltmarshes to the Peel-Harvey Estuarine system

T.H. Rose, A.J. McComb

6.1. Introduction and Aims

The saltmarshes of the Peel-Harvey system are important to the environmental health of the estuary and to this region of the Swan Coastal Plain. Although there have been few scientific investigations specific to this area, a number of world-wide studies on the ecological characteristics of saltmarshes have indicated they are very important to the environmental health of estuaries and coastal ecosystems (Mann, 1982; Kennish, 1990). Unfortunately, there is a paucity of studies on Australian saltmarsh ecosystems (Fairweather, 1990). However, in a local context there is evidence that saltmarshes in the Peel-Harvey system are critical to the overall ecological health of the Estuary (Table 6.1). For example, over 83 bird species have been observed in the saltmarshes of the estuary (Ninox, 1990) (Plate 6.1) and between 18 and 25 of these species are known to be trans-equatorial migrants (Jaensch *et al.*, 1988; Wilkes, 1990). This provides the basis for listing the whole Peel-Harvey Estuarine area as a RAMSAR bird treaty area as well as for the estuary being listed in the JAMBA and CAMBA treaties.

The area is also significant for other ecological reasons which will be briefly outlined, along with the major ecological points suggested in the previous chapters, and compared with data and literature generated from saltmarsh research elsewhere in the world. In this way it is hoped that a better appreciation of the ecological significance of the saltmarshes in the Peel-Harvey Estuary will be reached.

6.2. Putting saltmarshes into context

The saltmarshes of the Peel-Harvey are in a zone representing the interface between land and estuarine habitats. Such interface areas are referred to as ecotones in ecology and they have a number of very important features. An ecotone is generally described as a transition region between two (or more) diverse communities (Odum and Odum, 1959) and it generally contains members of both communities and both the number of species and abundance of some are higher in the ecotone than on either side (Margalef, 1968). As ecotones are found between two different environments, they can also be found between two different geological areas. This can lead to a significant increase in physical

complexity or variety of habitats for the flora and fauna which can live there. In turn, habitat complexity is related to the increase and variety of plant species, from grasses and samphire to shrubs and trees, and physical terrain, from pans and flats to ridges and low relief hillocks. All of these features are provided by the saltmarsh environment and can be found in the local marshes. This physical complexity attracts the relatively high number of invertebrates and vertebrate species which can also be found in the saltmarsh. High numbers of plant and animal species combined with the variety of physical habitats creates a structurally complex ecosystem (Likens and Bormann, 1974).

Aside from structural complexity, saltmarshes are an environment with a dynamic melange of unique physical and chemical characteristics (Mann, 1982). These characteristics predispose the marsh to providing a number of important physico-chemical functions. Combined with the biota, they create a number of critical processes which heavily influence the estuarine ecosystem, for example nutrient processing and detritus and carbon fluxes (Odum, 1988). Altogether, this strongly suggests that the saltmarshes of the Peel-Harvey are extremely dynamic and complex and are probably affected by varying spatial and seasonal patterns, just as the aquatic flora and fauna of the estuary are already known to be so affected (McComb and Lukatelich, 1986; Loneragan *et al.*, 1987; Rose, 1994). Spatial and seasonal patterns exist in either plant growth or production and nutrient processing or detrital loading, all of which can affect estuarine waters, suggesting that saltmarshes provide important signals that stimulate plant and animal communities found in the whole estuarine ecosystem (Odum, 1988; Kennish, 1990).

Plate 6.1 The Peel- Harvey estuary supports a rich array of birdlife, such as Sacred Ibis (top), and Butcher Bird (bottom).

6.3 Physical Features

The results of Chapter Four indicate that most saltmarshes in the Peel-Harvey have three elevation zones. One zone is characterised by low lying flats and pans and regular tidal immersion and another zone is marginally higher in elevation and acts as a transition zone containing both low lying and higher elevation plant species which experience infrequent inundation. A third zone is typified by higher elevation with samphire, rushes and salt tolerant trees which do not experience regular tidal inundation. Such physical features provide a geological record of physical events. For example, the elevation zones indicate where storm events, tides, wave and wind action have led to deposition of sediment and created ridges, swales, flats and wash outs. The extent of these topographical features can indicate where the estuary experiences windward/leeward or tidal water movement as well as flood deposition from river discharges. They also indicate erosion and accretion areas for sediment along the estuary shore.

Many of the surveyed saltmarshes displayed elevations between 0 and 2.0 metres AHD (Table 6.1). Measuring topographical features or contours and rates of sediment deposition or loss in active areas around the estuary fringe can lead to estimates of plant species diversity and the stage of plant community succession (Kennish, 1990). In general, it has been found that accretion rates of 3 mm or less are very low while rates greater than 10 mm are high (Kennish, 1990). Contour features and rates of sedimentation provide information on the value of saltmarshes to dissipate wave energy and therefore moderate erosion processes. They also provide a record of tidal inundation and propensity of the area to be flooded which in turn indicates how salty or fresh the area will be for plants.

Previous chapters also reported that the sediment composition of the saltmarshes varied but was primarily composed of silty or muddy and detrital based sands (Table 6.1). The presence of sands provides strong evidence of the coastal origins of the sediment in the marshes while silts, muds and detritus (organic material) provide evidence of riverine and *in situ* or within system origins (Odum, 1988). These sedimentary characteristics also influence important features such as Redox profiles or vertical depth cross sections of the sediment, where oxygenated and de-oxygenated sediments lie. The depth where oxygenated or de-oxygenated sediments can be found influences chemical processes such as the pH of the soil, sulfide gas production, nutrient binding, plant root penetration and animal locations. Generally the more de-oxygenated the sediment, the more the gas production and the less the pH (more acidic) and presence of plants and

animals (Kennish, 1990). Sediment composition can also influence sub-surface hydrology, so influencing the duration of surface flooding or standing water, sediment porosity and the nature of flooding water by influencing its salinity. Furthermore, the silt and clay content in the soil affects the ability of the sediment to bind nutrients (Kinhill, 1988).

The literature suggests that the extent and proportions of flats and pans or higher relief *Halosarcia*, shrubs, rushes and trees provide a measure to estimate the age or stability of the saltmarsh (Frey and Bassan, 1985, cited in Kennish, 1990; Adam, 1993). For example, a saltmarsh such as the Creery Wetlands near the Mandurah Entrance Channel (Figure 1.1), which has roughly equal proportions of *Sarcocornia* flats and higher relief *Halosarcia* and trees, could be considered a relatively mature and stable saltmarsh. (Admittedly, the fractionation and road rutting of the low lying *Sarcocornia* flats indicates that "degradation" is destabilising this relatively mature saltmarsh.) In contrast, the wide expanses of low flats and *Sarcocornia* around the Harvey River mouth and delta suggest that these areas are young and probably the result of recent sediment deposition caused by upstream erosion.

This leads to our ***first Ecological Significance Point****. Physical features of saltmarshes leave a geological record of events, identify areas of the estuary undergoing erosion or accretion, influence chemical and nutrient dynamics, influence sub surface hydrology, influence the composition of plant and animal communities and provide a valuable service in buffering erosion and siltation events. Saltmarshes provide a physical link between land and estuary water and influence nutrient and sediment exchange between the two.*

6.4 Biological Features

6.4.1 Plant life

In previous chapters, plant zonation patterns were found to differ widely between sampling sites around the estuary and to reflect physical patterns in that area. This has been related to degree of wind and wave exposure, tidal inundation, salt exposure and topographical relief. Many factors affect the distribution of vascular plants along the estuarine saltmarsh gradient, but decades of overseas research has established that water salinity is the dominant factor (Odum, 1988). The extreme difference in salinity exposure of saltmarsh plants between the low lying flats (salty) and upland higher relief plants and trees (fresh) undoubtedly affects the different composition of plant species in these different zones.

Overall, more than 40 species of saltmarsh plants (Table 6.1) were recorded in this and other previous studies (for example Bridgewater *et al,* 1981) which indicated considerable species diversity for the total saltmarsh habitat. Most of these species also displayed seasonality, the ephemeral grasses, perennial rushes (e.g. *Bolboshoenus* spp.) and occasionally low lying *Sarcocornia* dying back considerably during winter while higher elevation perennials, such as *Halosarcia*, did not display noticeable changes in biomass (weight).

The physical features of saltmarsh plants were highlighted in Chapter Three, where in particular, above ground biomass was found to be lower than below ground biomass during certain seasons. This feature of the Peel-Harvey saltmarsh flora indicates that root systems play a crucial role in influencing the sediment. Root systems would affect sediment porosity and drainage of water, they would affect animals living in the sediment, oxygenation of the soil (Redox) and sediment nutrient dynamics. Perhaps most importantly they would help stabilise sediments and the topography of the saltmarsh. Combined with above ground plant growth, they help to act as baffles and collect suspended sediment in the water. Overseas research has indicated that root systems of saltmarsh plants anchor the sediment, stabilise substrates and mitigate against erosion (Kennish, 1990).

Previous chapters discussed the tolerance of various species of plant seeds to water saturation and duration of exposure to salty or fresh water. In turn, this suggests that the seed bank in the soils of the various zones of the marshes

would be extremely important in re-colonisation of new, denuded and degraded saltmarsh habitat. The variety of saltmarsh species found in the seed bank would be important in determining the potential for the establishment of certain plant complexes if altered tidal regimes and salt exposure caused by the Dawesville Channel eliminate current plant communities. The speed by which new saltmarsh plant communities become established because of changes caused by the Dawesville Channel is critical in terms of minimising erosion and influencing nutrient and carbon balances of nearby waters.

The results of Chapter Five indicated that saltmarshes are a haven for some animals, particularly benthic species. However, over nine taxa of spiders were collected and this indicates that the aerial portion (above ground) of saltmarsh plants is very important to this predatory taxon. Although alluded to in previous chapters but not specifically measured in this study, other animals such as snakes, lizards and terrestrial insects such as ants would be directly affected by saltmarsh plant cover. This cover provides shelter, food and substrate for prey animals. Leaves and stems serve as attachment substrate for many animals and together, aboveground and belowground habitat complexity provided by plants would help account for the relatively high densities of animals collected at some sites.

*The **second Ecological Significance Point** about saltmarshes is that their presence increases plant species diversity in the region and maintains biodiversity, provides a pool of plant species to re-colonise salt affected land, stabilises sediment minimising erosion or mobility, provides habitat diversity for animals and organic sustenance or food for bacteria and animals as either detritus or grazing material. Water exchange through tides and flooding ensures that potential food and nutrients are exchanged between the two environments, land and water.*

6.4.2 Animal Life

Primary consumers such as worms, snails and beach hoppers, play a very important role in estuaries and saltmarshes by providing food for foraging predators, consuming plant productivity, including algae, enhancing food chains and nutrient cycling (Adam, 1993). Other primary consumers are represented by more terrestrial fauna such as insects and spiders, and include some grazing reptiles, mammals and birds. Perhaps the most notorious primary consumers are the mosquitoes. However, these animal groups are very important in linking primary productivity to secondary productivity.

While there are many ways of classifying the animals of the saltmarsh, residence time may be the most appropriate for these habitats in the Peel-Harvey. This is because of the very clear seasonal differences in inundation patterns which used to exist prior to the Dawesville Channel. Winter and spring were seasons of usual inundation and where benthic and water column animals and fish could be dominant components of the marsh. In contrast, summer and autumn fauna were more typified by terrestrial fauna such as insects and birds, as most of the aquatic areas dried out during this time.

It appears that few animals are permanent residents of the marsh and this is undoubtedly due to inundation patterns. Adam (1993) has classified many animals of the marsh as permanent (such as small invertebrates found in the sediment with or without water), visitors, many of which are seasonal (such as migratory birds), daily who use the marsh only at certain tides, essential as completion of their life cycles are dependent on the marsh environment, and opportunistic. This last category may include animals which seek plant food to graze, animals to prey upon or shelter in during the day (such as macropods). The extent to which the animal communities change in relation to the Dawesville Channel is open to conjecture and will be heavily influenced by changes in plant communities and tidal immersion. One trend which has been observed is the use of the saltmarsh as a shelter or habitat by animals not normally seen regularly in that environment and this may be due to the loss of preferred habitat because of the rapid development in the region.

In the work reported in Chapter Five, more than 60 species of invertebrates (Table 6.1) were collected and this was mainly based on benthic and scoop sampling using macro sized sorting screens. It would be safe to suggest that at least another 60 species of macroinvertebrates and vertebrates could be collected throughout the year, apart from bird species. The potential for many estuarine and freshwater species to utilise this environment, including the micro- and meio- sized organisms, makes saltmarshes extremely important to conserve from a habitat and biodiversity point of view.

*The **third Ecological Significance Point** about saltmarshes is that the animals that inhabit or use them contribute to biodiversity, and enhance the food chains and carbon budget of the estuarine ecosystem. Animals acting as primary consumers contribute to the nutrient dynamics of the saltmarsh and estuary and help recycle material throughout*

the estuary. They do so by acting primarily as prey for higher order consumers and if they leave the saltmarsh after dying, thereby releasing nutrients for bacteria, fungi and plants not found in the saltmarsh.

The ***fourth Ecological Significance Point*** *about saltmarshes is that the structural complexity provided by the mixture of geological and topographical features and the biological diversity of plant and animal life makes this habitat one of the most important areas in the estuarine and coastal ecosystem. In essence the presence of saltmarshes contributes to the diversity of ecotones in the estuarine ecosystem.*

6.5 Ecological Processes

6.5.1 Productivity

Saltmarshes are one of the most productive environments in the world (Mann, 1982; Odum, 1988, Kennish, 1990). Such productivity is due to both vascular (for example *Sarcocornia* and *Juncus*) and non-vascular plant (algae) production where it has been found that with vascular plants up to 80% of above ground production and 100% of below ground production can remain within the saltmarsh (Kennish, 1990). Extensive flats of macroalgae mats found in the lower zone of the saltmarsh are also known to be very productive (McComb and Lukatelich, 1986). This results in the enrichment of the sediments with detritus and organic material and nutrients. Consequently, saltmarsh plants are rarely nutrient limited in their growth and detritus is often exported during inundation and tidal outflow to nearby waters (Kennish, 1990).

Benthic phytoplankton, macroalgae and vascular plants are affected by seasonal patterns in rainfall, inundation and the salinity of flooding waters. Reference to previous chapters also indicates that seasonal changes occur in plant biomass and fauna production. Since the saltmarsh is so productive and can export much of its productivity to nearby waters or to non-aquatic animal communities, it is very likely that the saltmarsh sends profound signals to other parts of the estuarine ecosystem. These signals may stimulate both the aquatic plant and animal communities found in the shallows and deeper basins of the estuary. Measurements of the fraction of the net primary productivity of saltmarshes to reach adjacent estuarine water range from 20 to 45% (Table 6.1) (Mitsch and Gosselink, 1986, cited in Kennish, 1990).

While the saltmarsh environment can be very harsh environment for animals, those animals which can survive inundation by brackish or salty water and desiccation during dry periods, can reach very high population densities (Day, 1981). The high population densities of some marsh fauna will influence prey communities such as birds and spiders. This may have a very significant influence on the population sizes of these predators, particularly those that depend on saltmarshes and migrate large distances to reproduce.

Such a profound export of detritus or nutrients to nearby waters may be tempered or modified by the eutrophic status of the estuary. Essentially, these signals may be overpowered by aquatic production caused by excessive phosphorus enrichment of estuarine water. It is expected that over time, the combined effects of flushing to the sea by the Dawesville Channel and catchment initiatives to reduce phosphorous export will reduce aquatic production of algae and opportunistic animals in the estuary. When this occurs the productivity signals caused by saltmarsh export of detritus and nutrients will be very important to the rest of the plant and animal communities of the whole estuary.

*The **fifth Ecological Significance Point** is that the saltmarshes of the Peel-Harvey are an extremely productive environment which must stimulate and influence production in other communities found in the shallows and deeper basins of the estuary. These productivity signals can also affect bird populations that nest or breed overseas and in the region. They can also affect commercially important fisheries. The ramifications of losing such productive environments which export a variety of organic material with a wide variety of quality may be large and should be minimised. Their loss would drastically alter the carbon budget and food chain of the estuary.*

6.5.2 Saltmarshes as nutrient sinks and sources (nutrient fluxes)

Scientific literature indicates that saltmarshes play a critical role in storing and releasing nutrients such as phosphorus, nitrogen and carbon as well as trace elements (Table 6.1) (Odum, 1988). The literature also suggests that generalisations about whether a particular saltmarsh imports or exports nutrients must be made carefully as spatial, daily and seasonal factors can affect their status. This indicates that nutrient signals which can be exported to adjacent environments will be heavily influenced by these spatial and temporal factors (Knox, 1986).

The quality of detritus, whether it can be easily assimilated by bacteria and small and large animals, or conversely will take longer to decompose and become available, depends on the proportions of lignin and fibre and various acids (Odum, 1988). In general, algae are easily assimilated while seagrasses and emergent woody vegetation take much longer to decompose and are often poor in nitrogen, or at least in nitrogen which is accessible to bacteria, fungi and animals (Kennish, 1990). Because saltmarshes have a variety of sediment types, bacteria, fungi, plants and animals, they can also act to transform nutrients, changing dissolved oxidised inorganic forms to dissolved organic reduced forms more available to consumption by microbial and animal communities found in adjacent waters. Thus saltmarshes are critical in decomposition processes (Odum, 1988).

*The **sixth Ecological Significance Point** is that saltmarshes are critical in their influence on the release or uptake of nutrients and carbon from adjacent estuarine waters. They are analogous to the human liver which acts a storage and metabolism organ for the human being, thus acting in a critical way upon the estuarine ecosystem. Saltmarshes function as either sinks or sources of nutrients depending upon the age of the marsh, salinity and sedimentary factors, upland and human nutrient inputs, tidal energy, quality and quantity of plant litter and the nature of the nutrient flux in the estuary to which the marsh is coupled.*

6.6 Conclusions

Saltmarshes have been identified as critical to the well being of the estuarine ecosystem in a number of ways (Table 6.1). Their most important attributes are that they provide a physical linkage between land and sea, they are a location for a pool of salt tolerant plants and animals thus maintaining biological and habitat diversity and they are critical to ecosystem processes such as productivity and nutrient and organic carbon fluxes. The results of such processes are that they stimulate the fish, birds, aquatic plants and other biota of the whole estuary.

The future role that saltmarshes will play in the Peel-Harvey estuarine system cannot be readily quantified. It will undoubtedly be just as, if not more influential if the eutrophic status of the estuary is reduced, longer term tidal exposure of the estuary's periphery occurs and further losses of significant portions of this habitat occur because of the impacts caused by urban development and human activity.

Table 6.1. Some major features of saltmarsh in the Peel-Harvey Estuary

Feature and or characteristic	Description
1. Location	Found around periphery of estuary and in tidal portions of tributary rivers (mid and lower estuary).
2. Topography	Varies from 0 to 2.0 AHD and displays pronounced zonation with three zones reflecting elevation differences.
3. Salinity of inundating waters	Salinity of inundating waters varies between 0 and 53 ppt (ocean is 35 ppt.)
4. Tidal range	Influenced by lunar cycle, barometric pressure, wind velocity and fetch direction.
5. Sediments	Silty-clay sands with moderate to high organic content. Redox shallow and strongly reducing with lots of dissolved sulphur, plentiful reduced iron and sulphur compounds.
6. Vascular plants	Colonise all three elevation zones, lower zone dominated by halophytic chenopods and upper zone by shrubby chenopods, rushes and trees. Zonation patterns are shown. Seed bank relatively important and asexual (rhizome) propagation important.
7. Non-vascular plants	Lower zone dominated by green macroalgae originating from both in situ growth and growth washed onto the lower areas.
8. Species diversity	Plant species relatively low but high compared to other saltmarshes, animal diversity high, both dominated by several species. Important that both are salt tolerant.
9. Animal community	Inundation phase dominated by fish and aquatic invertebrates, few snails found. Dry phase dominated by ants, lizards, snakes, birds and grazing macropods.

10. Productivity	Reported to contribute between 20 and 45% of primary productivity to estuarine ecosystem. Contributes immense material to animal productivity in terms of mosquitoes and birds.
11. Nutrient fluxes	Acts a significant source and sink of nutrients and organic material.
12. Ecotone properties	Provides a habitat where a multiplicity of biodiversity exists and where there is a variety of habitat complexity.

CHAPTER 7 Recommendations for the future management and conservation of saltmarshes in the Peel-Harvey estuarine system

T.H. Rose, A.J. McComb

7.1 Introduction

Estuarine saltmarshes can stimulate a number of senses. In a visual way, they provide a pleasing vista of procumbent to tall shrubs and trees tinged with colours ranging from red in autumn to succulent green in spring. This view is often enhanced by the sight of hundreds of wading birds feeding and dabbling along the shores and flying low over this interface between land and water. Saltmarshes also provide a contrasting sense when the rich productive smells of the marsh are detected. These smells are composed of decaying sun-baked vegetation mixing with the rotting gases of fetid muddy land. To some, the landscape features and the close proximity of open estuarine waters provides a potentially dollar-rich urban development challenge. With enough fill and re-contouring, these areas could be converted into expensive waterside homes. To all, however, the swarming mosquito hazes can drive us into our homes or cars making us wonder why nature has been so free in creating such a varied environment.

Overall, samphire marshes truly embody a large ecotone metaphor. On one side is a unique habitat providing an interface and link between land and water, and on the other side an environment fertile for human cultural conflict. Unfortunately, humans are an ecotone species and are drawn to the fringes of estuaries. To reduce conflict and successfully manage these environments requires an understanding of current land ownership, reserve status of fringing land, international treaty obligations, the planning process and the use of practical management plans and structures. It is also important to recognise the wisdom of using applied management and theoretical research plans to provide answers to management questions. They are most helpful if these plans recognise the uniqueness of most saltmarshes and give the public and estuarine manager the kind of information which allows saltmarshes to be conserved and sustained well into the future. Ultimately, any management plan must provide direction to help prevent the degradation of saltmarsh functions, such as ecologically important biodiversity, productivity and nutrient storage and release functions.

Successful management of saltmarshes also needs to recognise and plan for future pressures on these habitats. This pressure may be in the form of increased human usage from older industries such as peat mining and cattle grazing or from sunrise industries like ecotourism and permaculture. The source of such pressure can be simply attributed to the close proximity of our increasing and more concentrated human populations. In turn, increasing human proximity and pressure will require careful management of public health issues, because of the need to control mosquito borne diseases and for the potential for toxic water quality conditions to arise.

This chapter will outline issues for consideration and provide recommendations which the community, local authorities and state agencies will need to consider and hopefully implement, if the saltmarshes of the Peel-Harvey estuarine system are to be successfully conserved.

7.2 Recognising sources of degradation

There are numerous sources of saltmarsh degradation but these can be divided into two major ones - natural and human/cultural sources.

7.2.1 Natural sources

Natural activities and impacts created by weather, animals and plants can change the characteristics of saltmarshes and therefore the susceptibility of the marsh to human degradation.

The saltmarshes located on the fringes of the basins and tributary rivers of the Peel-Harvey Estuary are dynamic environments which undergo seasonal and yearly changes. Estuaries are "ephemeral" environments and can last, in a geological sense, between several and 20-40 thousand years (Barnes, 1974). The result is that each saltmarsh can reflect three basic stages or states of development and maturation, depending on processes determined by geology, the age of the estuary and human activity in its catchment. For example, saltmarshes can be accreting or growing; they can be eroding and either be becoming permanently submerged or disappearing as higher elevation terrestrial plant communities are established; or lastly, the marsh may be in relative stasis, with an equal proportion of low and higher elevation plant communities. This means that nature ultimately determines the longevity of marshes and the uniqueness of its animal and plant diversity and structure and ecological functions. Nature strongly influences the propensity for a marsh to become

degraded or be resistant to human impacts, through its overall control of tidal activity, rainfall, hydrology, river flooding and wind, storm and biological patterns.

7.2.2 Human sources

Grazing

Historically, the saltmarshes of the Peel-Harvey have been grazed by sheep and cattle. Marshes often provided the only source of late summer and autumn fodder, particularly in dry hot years and where cattle and sheep owners possessed high water titles to their land. Grazing activity was prevalent in the Creery and Harvey Estuary marshes (O.H. Tuckey, pers. comm.). The result is that many of the saltmarshes found around the fringe of the estuary have been and are still influenced by cattle and sheep grazing which affects plant and animal species diversity, the historical productivity of the marsh and its long term accretion/erosion patterns (Adam, 1993).

Hunting

Until recently, duck hunting was legal, and this strongly influenced the numbers and species diversity in saltmarshes (Adam, 1993; M. Bamford, pers. comm.). Since duck hunting ended in the late 1980s, duck numbers and diversity appear to have increased (M. Bamford, pers. comm. and T. Rose, pers. observ.). The hunting of kangaroos and other mammals has also influenced the number and diversity of natural marsh grazers, and therefore their impact on and use of the saltmarsh. Hunting can reduce the numbers of, and even eliminate common members of the fauna in saltmarshes, so affecting overall biodiversity and natural grazing patterns.

Feral animals and weeds

Human settlement has introduced feral animals such as rabbits, cats, foxes and bees into the saltmarshes of the region. European use of saltmarshes, in the main, has also introduced weeds and non-native plants. For example, *Watsonia*, bull rushes and grasses are now common components of the plant communities in most marshes. Weeds have flourished because of altered water tables due to nearby human settlement and land uses (such as irrigation and clearing). They have also flourished because of fire events which generally have not been favourable to a wide range of native plants. If fire patterns mimic more natural patterns in terms of frequency and intensity, then a wider variety of native plants

is able to compete with introduced plants and weeds (Pen, 1987). The consequences of feral invasions are that marshes become altered in structure, productivity and nutrient functions. These alterations affect other estuarine flora and fauna, including native birds and other animals.

Direct human use and access

In the past, horses and bridal trails have degraded samphire marshes. However more recently, particularly in the last fifty years, human access and use of vehicles, notably four-wheel drive vehicles and trail bikes, have degraded saltmarshes through the creation of wheel ruts, destroyed vegetation and allowed rubbish to be deposited directly in these environments. Vehicle access has allowed entry to previously isolated areas and provided opportunities for trees to be cut down or used for fuel. The creation and construction of roads and trails, both sealed and unsealed, has led to the fragmentation of once very extensive and continuous saltmarshes in the region, for example the Creery wetlands. This kind of degradation, that is slow fragmentation, has been documented in Chapter Two and affects marshes by altering hydrology, their ability to resist erosion, the processing and export of nutrients and the provision of habitat integrity which a variety of plants and animals require to persist in this habitat. The end result is a breakdown in ecological function and therefore in their importance to the Peel-Harvey estuarine ecosystem.

Human infilling

Infilling has been one of the most common ways by which saltmarshes have been lost in the Peel region. To secure land from the effects of regular and occasional flooding, humans have used the importation of sedimentary fill to raise the level of the land. Infilling immediately smothers and eliminates saltmarsh. It has been the primary method which has allowed the City of Mandurah to develop around the Mandurah Entrance Channel. Infilling is also prevalent in the lower reaches of the Serpentine River and at Yunderup Canals, on the eastern fringe of the Peel Inlet, where further stages of urban development are occurring. In addition to the immediate impacts of fill, a lot of fill contains weeds or weed seeds, and sets in train the invasion of saltmarshes with exotics with consequent long term degradation. In summary, infilling causes a loss of vegetation and can alter groundwater hydrology patterns, which may lead to de-stabilisation of marsh communities.

7.3. Considerations for management

The difficulty of managing saltmarshes in a regional or ecosystem context is that several strategic political and financial steps need to be taken at the same time in order to effectively conserve this environment. Co-ordinating synchrony can be very difficult without a unified community and political recognition of the need to conserve samphires and the will to do so. Co-ordinating cultural and political will must be combined with the co-ordination of various government bodies that can influence the conservation of these environments. The provision of financial resources is also necessary to fulfil the following recommendations.

7.3.1 Strategic Steps

The preparation of a comprehensive inventory of the location, number and extent of saltmarsh habitats would be a helpful first step. Chapter Two is very helpful in that it has identified current locations of saltmarshes as well as historical trends in saltmarsh habitat area, whether they are expanding or contracting. This inventory would need to be combined with the defunct Department of Conservation and Environment Red Book (1983) recommendations. Finally, an on-the-ground site assessment for "health" and conservation value of existing saltmarsh habitats is needed. This survey could categorise all samphire wetlands into conservation value and would complement or update the Red Book (1983). The combination of the three documents into an integrated resource document, a resource catalogue, would provide the basis for several further steps. However, to minimise controversy over boundaries which define the location and area of conservation areas, the catalogue needs high quality maps, be surveyed as accurately as possible and follow prescribed objective procedures which can be easily replicated.

Other means of conserving samphire marshes are as follows:

1. The creation of an Environmental Protection Policy (EPP) for samphire-dominated saltmarshes in the Peel Region, which could perhaps extend over the whole Swan Coastal Plain. This EPP could be a subsection of the current EPP for Wetlands of the Swan Coastal Plain. Only the Environmental Protection Authority, through the Department of Environmental Protection, can underwrite such legislation and undertake the extensive public consultation required for a regional policy. The EPP would identify areas requiring high conservation and set a target or minimum surface area for saltmarsh habitat which could not be exceeded or lost in the region. This should be based on the preceding resource inventory catalogue.

2. Integrate identified saltmarsh worthy of conservation, based on a minimum functional size into the Peel Regional Plan and Park (particularly into a regional structure plan). This should be combined with recognition for RAMSAR, CAMBA and JAMBA areas. Any areas identified for bird treaties must be clearly outlined and marked on maps, and recognised by all interests which can potentially affect their future. It would be expected that following establishment of the Peel Regional Park, the saltmarshes identified for acquisition and conservation would be included in its management boundaries.

3. The Peel Regional Strategy (formerly Peel Regional Plan) must set the framework for the establishment of an acquisition fund which would provide funds for acquiring privately-held land containing significant saltmarsh with conservation potential. This fund would need to be based on similar principles to the Perth Metropolitan Region Improvement Fund (MRIF) administered by the WA Planning Commission. This fund could also acquire land for public amenity, buffer purposes, vegetation and wildlife corridors and foreshore reserves, all of which would help reduce pressure on fringing areas of the estuary with saltmarsh.

4. Recognise and implement the recommendations in the Peel Inlet Management Authority Management Programme (Waterways Commission, 1992), which has identified a Waterways Protection Precinct. For example, the Programme recommends the retention and conservation of significant portions of the Creery Wetlands, Entrance Channel samphire areas, Austin Bay, Roberts Bay and large portions of the fringing land in the southern Harvey Estuary. Overall, this Programme recognises the need to conserve and maintain saltmarshes within the Peel Inlet Management Authority's Management Boundary and should be used as a *minimum* protection document for saltmarshes. Furthermore, the Programme is supported by several regional management plans (e.g. Western Foreshore Management Plan and Draft Eastern Foreshore Management Plan) which aim to help consolidate smaller fringing saltmarshes into more functional foreshore reserves and have identified the most appropriate vestees or managers of this land. The term *minimum* is used because many saltmarshes were assessed in the late 1980s while the Programme was being developed. The recovery and improvement in habitat value of saltmarshes previously classified as degraded may be considerable and thus make some of the Programme's recommendations outdated.

5. Incorporation of saltmarsh areas found in close proximity or adjacent to current Department of Conservation and Land Management A and B Class Reserves should be encouraged. Adequate funding for these reserves also needs to be addressed once these areas are reserved.

6. Inclusion of conservation marshes with recognised conservation values and/or significant portions of fringing saltmarsh habitat into local authority town planning schemes (TPS) would be a very strategic move. Inclusion can occur either through reservation or through adoption of landscape and special environment zones which are clearly recognised in the new TPS. These steps would be most relevant for the City of Mandurah and Shire of Murray, but have some relevance for the Shires of Jarrahdale-Serpentine and Waroona and the City of Rockingham.

The use of the Town Planning and structure planning procedures (see glossary) is critical to laying the foundations for the future conservation of the Peel-Harvey saltmarshes. Legal instruments such as by-law legislation in Town Planning Schemes can provide for penalties, and scheduling clearly defined conforming and non-conforming uses can lay the legal foundation for future use and conservation of these critical habitats. Furthermore, the ceding of land free of charge to the Crown under the Town Planning Act of 1928 is a further method of securing portions of saltmarshes. However, to use this method it must be pre-planned, broadly advertised to all development parties, and based on the provision of public or Crown access around the fringe of the estuary, as well as providing recreation and conservation uses. The concept of ceding land and foreshores for strictly conservation purposes needs to be explicitly supported by the WA Planning Commission.

7. Determine up-to-date community attitudes to saltmarshes and the potential for future ecotourism and other sustainable industries which will use saltmarshes. These studies need to be tightly linked to tourism and development plans and strategies. They would fit best as components of the Peel Regional Plan. Such studies need to be rigorously designed and defensible and would probably be best conducted by qualified university and professional firms. The results of these surveys and polls would lay the basis for educational programs and identify target groups that need to be reached. None of the above steps are

likely to succeed if society's perceptions of saltmarshes remains in continuing to perceive them as worthless habitats best filled in and developed.

7.3 2 Immediate strategic suggestions for conserving saltmarshes

While the above strategic steps should be implemented to plan for the "long term" strategic conservation of samphire of the Peel-Harvey Estuary, the studies in this report strongly suggest that several areas could be immediately gazetted for conservation purposes (see previous Point Four above). Chapter Two strongly suggests that moves should be made to reserve and immediately manage the following ecologically significant areas:

- the Goegrup Lakes system on the Serpentine River,
- all of the remaining Creery Wetlands,
- southern Peel Inlet adjacent to Austin and Robert Bays,
- the southern area of the Harvey Estuary, that is area south of Island and Herron Point across to the Harvey River, including its delta.

The last area, in addition to the Goegrup Lakes system, has already been targeted for inclusion into a park. However, the process needs to be expedited urgently. The urgency is based on the fact that development is encroaching quickly upon these areas, and there is increasing unmanaged access to and use of the areas. This is contributing to their degradation and threatening their ecological function.

7.3.3 Practical considerations - the use of plans as a basis for management

The management of reserves, particularly saltmarshes, is usually done by using formal management plans. They are most effective when a saltmarsh has been clearly gazetted for conservation or as a multiple-use park. Management plans have a greater chance of success if they are applied to functional saltmarsh units and not to those which have been fragmented and cut into halves or quarters because of arbitrary planning and decision making processes. Managing saltmarshes which have been fragmented, have altered hydrology characteristics and are becoming degraded is difficult because the resource often changes more quickly than the best adaptive management plan.

Applied management plans need to have some of the following components:

Foreshore Management plans

(Structure plans)

These can identify the most appropriate location for fences, access points, trails and roads, boardwalks, education and information boards and centres, parking facilities, toilets and maintenance and administrative structures if necessary. The inclusion of generic or specific construction standards as well as specific survey results are also helpful.

Fencing requirements

Fences help prevent urban encroachment, define the saltmarsh, keep out feral animals and can be modified when they articulate with vegetation corridors to allow wildlife to pass.

Weed control and eradication

The identification of weeds and the mapping of weed locations is essential for weed management. Outlining management options to control them is also essential. For example, fire control, manual and mechanical removal methods, herbicide and biological control are all part of such a strategy.

Feral animals

Identification of the type and the scale of feral animal problems is necessary. An adaptive trapping or control program needs to be outlined.

Fire management

This is critical from both a general safety and biodiversity point of view. The use of fire needs to be planned so that low fuel buffers are found around structures, threats of wildfire spreading to surrounding developments are minimised, and that a mosaic of fire treatments is provided. These mosaics will need to vary in fire intensity, from cool to hot, and in terms of seasonality, during spring, summer or autumn. They will also need to vary in their frequency, once every set period of years. Maintaining mosaics will help to provide a variety of habitat

conditions which allow a wide variety of plants to flourish, contribute to and help maintain the seed bank in the ground.

Inventories of land capability, plant and animal communities

These provide the basis for understanding the physical and biological resources in each specific saltmarsh and outline major management considerations.

Public Health concerns

Identification of nuisance animals and plants and their management in relation to the specific marsh is necessary. Management methods to control mosquitoes should identify appropriate biological, chemical and mechanical controls, such as runnelling or ditching (Plate 7.1).

Time scale changes

This allows the manager to understand changes which may occur over different time scales and which will affect the natural resources of the saltmarsh. For example, awareness of seasonal changes, public use periods and changes in long term tide and weather patterns. Consideration for the long term effects that the Dawesville Channel will have on marshes will also be necessary. One prediction is that there may be a slow march of fringing vegetation out into the estuary, similar to that which has occurred in Leschenault Inlet since it was opened to the ocean in 1951 (L. Pen, pers. comm.).

Public expectations of management and access

Provision for local community management committees may be both necessary and desirable. Consideration of how decisions will be made as well as how people wish to utilise the marsh is necessary, and this component needs to be carefully included in any management plan.

Inclusion of a research plan

A list of management questions, and questions about marsh biology and ecology, which can be answered by research will facilitate the development of appropriate management methods, and allow management to be responsive and adaptive to community concerns and changes in resource status, for example shrinking cover or the health of specific plant species.

Plate 7.1 Runnels, a physical mosquito control technique connect saltmarsh pans to the estuary, allowing the exchange of water. The top photograph displays the runnel, which is a spoon shaped channel, and in the bottom photograph water from the estuary is entering the pan via the runnel.

7.4 Research Plans

These plans provide for a more rigorous and methodical way of testing management tools and reviewing the biological, chemical and physical components as well as the higher order nutrient and productivity processes of the saltmarsh. The results of such research need to be disseminated at an appropriate level so that they provide the saltmarsh manager with viable and responsible alternatives to the management methods and tools used at present. Research plans can have a strong scientific component or be dominated by more applied research questions and issues.

7.4.1 Scientific plans

The preceding chapters have stimulated a number of scientific questions which could be addressed in a comprehensive manner with a properly financed research budget. These include the compilation of comprehensive species lists for plants and animals in the saltmarsh (including dry and wet phases), a measure of their density and biomass and the daily, seasonal and spatial changes which occur for both individual species and their communities. In summary, qualitative and quantitative surveys of the biota over various temporal and spatial scales are needed. Studies on establishment characteristics of native and weed plant species would be helpful. Research which measures natural and feral grazing pressure would also be very valuable.

Aside from the above biological and ecological questions, important information could be gathered from studying soil chemistry, particularly with regard to nutrient exchange and flux. Understanding how inundation by salt and fresh water and for varying periods affects chemistry is very important from an overall ecosystem perspective. Related to this direction of study are questions on plant nutrition and their uptake of nutrients.

Finally, higher order research into processes and function is critical to strategic management of saltmarshes. For example, investigating mechanisms for importing and exporting nutrients and organic matter is essential. Such research needs to also include the effect of spatial and temporal factors on these processes.

7.4.2 Applied management research

Applied research should investigate a range of tools used in the management plan. For example, investigating the effect of trail and fence locations and determining the best time to rotate these or if it is even necessary. Methodical investigation of access and the best kinds of fencing and surface treatment of trails are also examples of this kind of research. Perhaps the most important are investigations and monitoring of fire treatments and their impact on the vegetation community. This could include investigating the seed bank and determining recovery potential of various areas of the marsh. Reviewing and monitoring runnels (Plate 7.1) or ditches for mosquito control and impact on vegetation and birds would also be very important. Ultimately, research would need to look at resistance of mosquitoes to current use of larvicides as well as biological controls.

Much of applied research could be included in regular monitoring of the marsh vegetation and fauna community and the format for such monitoring to allow the manager to be adaptive and responsive to changes. Monitoring in its various forms would include overseeing the impact of ecotourism and making sure related access and use do not detrimentally impact upon the saltmarsh environment. Applied research could also examine the feasibility and success of regenerating or rehabilitating degraded marsh.

7.5 Conclusion

Degradation of saltmarshes occurs on a number of different spatial and time scales. Both natural and human assisted disturbances of the saltmarsh can vary in time from the very short to decades. Nature contributes an underlying source of "degradation" and change. This usually occurs on a relatively slow scale but storm events can occur on very short scales. Unfortunately, human activity in the saltmarsh is often chronic and occurs over a long time. Human degradation can also occur in pulses, such as during prawning and fishing seasons. In either form this degradation can occur over a significant area.

Many of the above recommendations and ideas need to be implemented by a few key organisations. Because of the value of saltmarshes to the Peel-Harvey Estuary and the fact that the Peel Inlet Management Authority is a public statutory body with a line management structure and function with extensive foreshore management plans, the majority of co-ordination could be done by this

organisation. To a lesser extent, some of the work would also need to be done by the Department of Conservation and Land Management, with its role in the management of reserves and other related categories of land. However, critical further work would need to be done by Local Authorities on their Town Planning Schemes and by the Conservation Council of Western Australia to maintain political momentum. All of these organisations could be strategically directed by an EPA Environmental Protection Policy on saltmarshes with significant assistance provided by the WA Planning Commission. The Planning Commission could produce guidelines to advise developers of the sensitivity of samphire marshes and the manner in which to develop in the vicinity of them in a sustainable way.

The conservation and preservation of saltmarshes in the Peel-Harvey region cannot be simply based on the argument that wetlands should *just be conserved*. This simplistic approach will be unsuccessful without demonstrating and proving the benefits of such a policy or proposing alternative ways of meeting community needs (Adam, 1993). Educating the community and decision makers on the very valuable role that saltmarshes perform for the environment and for the economy will be critical. Understanding the insidious role of *the tyranny of small decisions*, which defines the process coined by Adam in the mid 1980s as that of approving small incremental losses without understanding the cumulative impact this has on ecosystems and how this has eroded and degraded many saltmarshes in the region, needs to be squarely faced and understood. Reliance on mitigation procedures to sacrifice relatively functional or recovering saltmarshes for artificial or "quartered" habitats is a poor alternative. Overseas experience has shown that this rarely works unless a degraded area is returned to functionality.

The eventual fate of saltmarshes in the Peel-Harvey will be heavily influenced by the effects of the Dawesville Channel. This channel will influence the expansion or contraction of this habitat and will require managers and the public to realise that the eventual direction of change will be determined after decades of monitoring and will require flexibility in saltmarsh management.

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GLOSSARY

accretion - growth, increase by addition.

aeration - exposure to chemical or mechanical action of air.

AHD - Australian Height Datum

amphipod - order of mainly laterally compressed crustacens.

amplitude - height, extent.

anaerobic - non-aerobic, without oxygen.

annelid - segmented worms.

anthropogenic - originated by man.

arthropods - animals with jointed limbs.

articulate - jointed.

astronomic tides - tides influenced by the moon.

barometric - air-pressure, resulting from weather patterns.

benthic - living in the water or sediment at the bottom of an estuary, ocean or pool.

benthic phytoplankton - microscopic plants that live in the water on the surface of substrate.

benthic zooplankton - microscopic animals which occur in the waters on the bottom of the estuary, ocean of lake.

biodiversity - diversity in living organisms.

biological controls - plants, animals or viruses used to control pests.

biomass - amount of organic matter of a species, per unit of area or volume.

biota - living organisms.

bivalve mollusc - a class of invertebrate where the body in laterally compressed and enclosed between two oval shells.

CAD/CAM- Computer Aided Drafting/Modelling

CAMBA Treaties - Chinese Australian Migratory Bird Agreement

carbon fluxes - changes in carbon in a water body.

chaetognaths - marine arrow-worms.

chenopods - group of plants to which some saltmarsh plants belong.

conduit - pipe, channel or drain.

cubic convolution - a resampling process which uses a high order convolution process to determine image output values.

culm - stem of a plant.

DAT - Digital Audio Tape, used for storing computer data.

decumbent - lying along ground or surface of body.

detritus - any particulate accumulation of disintegrated animal, mineral or vegetable debris.

diatom mats - mats made up of microscopic algae with a cell wall composed of silica.

ditching - a form of mosquito control involving whereby water is removed from the marsh preventing the larvae developing into adults.

diurnal - of the day.

DN - Digital Number, for the 8 - bit data there will be 256 brightness levels representing reflectance of the pixel of the ground scene. It can be converted to radiance.

dpi - Dots Per Inch (resolution) used to describe resolution of an image of picture.

ecology - study of the relations of animals and plants, to their surroundings.

ecosystems - a community of organisms interacting with one another, plus the environment in which they live and with which they interact.

ecotone - zone of integration of two communities.

ecotourism - tourism based around natural resources.

ellipsoid - all plane sections through one axis are ellipses and all other plane sections are ellipses or circles.

ephemeral - short-lived, transitory.

epifaunal - animals which grow upon plants.

epiphyte - plant which grows upon another plant but is neither parasitic on it nor rooted in the ground.

ERDAS - Earth Resource Data Analysis System

ESRI - Environmental Systems Research Institute

eutrophic - waters which have very high level of nutrients.

exotics - plants and animals which orginate from countries other than Australia.

feral - plants and animals which are declared a pest.

fetch direction - direction of wind on water.

flux - inflow of tide.

gastropod mollusc - includes snails, slugs, sea hares.

Gb - Gigabyte

GCP Ground Control Point used in georeferencing aerial photographs

geomorphology - study of the physical features and processes of the earth's surface and their relation to its geological structures.

georeferencing - pixels, or elements of an image initially only have a line a column number when digital image data is acquired. The process of allocating latitude or longitude (or eastings and northings) to point in the image is often called georeferencing.

halophytic - a plant which grows in salty soils.

harpacticoid copepods - very small crustacean.

herbarium - collection of preserved plant speciments for identification and reference purposes.

hypersaline - exceeding the salinity of seawater.

IBM-PC - International Business Machines - Personal computer.

IFOV - Instantaneous field of view of the sensor.

IMG - Image file format.

interspecies - between species.

interstitial - lies within the soil.

isopods - large, diverse order of crustacean, 5-15mm long, almost always dorsoventrally flattened and adapted for crawling.

JAMBA treaties - Japanese Australian Migratory Bird Agreement

larvicides - chemicals used to kill insect larvae (juveniles).

lignin - cellulose material found in plants.

macro invertebrates - animals without back bones that are relatively large (greater than 250 µm).

macro vertebrates - animals with back bones that are large.

macroalgae - large plants eg. seaweed, kelp.

macrobenthos - larger benthic animals.

macropods - kangaroos, wallabies.

Mb - Megabyte

meio-sized - between 250 and 53 µm in size.

melange - mixture.

micro-sized - below 53 µm in size.

microbe - a micro-organism.

microflora - small plants, bacteria and fungi.

mosaic - pictures/photos joined together.

nematodes - unsegmented worms.

NIR - Near Infra Red

Null data - data of no significance.

nutrient sink - reserve of nutrients.

Oligochaeta - a class of worms that have very well-developed segmentation.

orthophoto - a photograph, which has been corrected for distortions due to camera tilt or terrain variation. Geometrically orthophoto is the same as any topographical map.

ostracoda - very small crustaceans living in bivalve shells.

periphery - outer surrounding region.

permaculture - perennial agriculture system, also an approach to designing environments which have the diversity, stability and resilience of natural ecosystems.

pH - related to hydrogen ion concentration, tests the alkalinity or acidity of water

photosynthesis - the process whereby light energy is converted into chemical energy in the presence of chlorophyll.

phytoplankton - a collective term for free-floating, or weakly swimming aquatic plants eg. certain algae or diatoms.

pixel - picture element. It is a smallest resolvable image element. It has both, the spectral and the spatial aspects.

polychaete - form of annelid, mainly marine worms, includes bristleworms, tube-worms, fan-worms.

procumbent - growing along the ground.

protozoa - animals consisting of one cell only.

quadrats - sequence of vegetation chosen at random for study of composition of vegetation in a selected area.

RAMSAR - international treaty to protect birds, their feeding and breeding grounds.

Raster Files - image files composed of discrete pixels arranged in a grid.

rhizomes - underground stem, bearing buds in axils of reduced scale-like leaves.

RMS - Root Mean Square

rotifers - very small flat, unsegmented animal.

runnelling - small, spoon shaped channels designed to flush water in to and out of the saltmarsh; preventing mosquito larvae developing through to adults.

sedimentary - attached to substrate.

seed bank - a store of plant seeds.

spatial - between areas.

spatial accuracy - degree of accuracy associated with the correct location (geographical) attributes of data. It is referring the accuracy of the position of the point in space.

spatial resolution - the level of the spatial detail depicted in the image.

spectral reflectance - measured for a specified wavelength of the incident radiant flux.

spectral resolution - range of wavebands incorporated into a particular spectral channel / band of the sensor; sometimes number of channels / bands of the sensor

specular reflection - a surface is smaller in height variations than the wavelength of the incident energy; the surface acts as a smooth reflector and most of the incident energy is reflected in a forward direction.

staff - graduated rod for measuring distances.

stratification - media separated into layers.

structure planning procedures - a broad level planning framework which establish the principles for co-ordination and promotion of regional landuse planning and development, specifically for the guidance of state and local government and private sector. For example, the SW corridor structure plan. Structure plans designate housing densities, land uses, location of public open space and reserves, transportation systems and utility and location of all services (schools hospitals etc).

TAR - Tape Archive and Read (Unix command)

taxa - a classification system for plants and animals; refers to a group.

temperate - any area of the earth between the tropics and the Artic and Antartic Circles, having a clearly defined winter and summer.

terrestrial - relating to the earth or land.

theodolite - surveying-instrument for measuring horizontal and vertical angles by means of rotating a telescope.

TIFF - Tagged Information File Format (graphics file format)

topography - landforms

transect - line of belt vegetation selected to study changes in composition of vegetation across a particular area.

vascular - plant tissue consisting mainly of xylem and phloem which forms a continuous system throughout all parts of higher plants; it functions in conduction of water, mineral salts, and synthesized food materials and for mechanical support.

WST - Western Standard Time

zooplankton - very small animals which float or drift almost passively in water.

Note

APPENDIX 1 Technical Description of Digital Air Photo Mosaic Preparation

R. L. Glasson, H.T. Kobryn

The method described below refers specifically to the 1994 air photograph series, but is equally applicable to all other series with the exception of scale details. The 1994 air photographs were acquired between 08:46h and 09:09h (WST) on 1st April from a flying height of 3810 m, using a focal length of 153.76 mm providing a scale at the principal point of 1:24778. Comparative details for the other air photography is contained in Table 1. The individual photographs were scanned by a Sharp JX320 A4 desktop flat bed scanner using Adobe Photoshop software on a Macintosh LCIII. The pixel ground resolution size for all images was measured at the principal point. The files were transferred by network to the Sun workstation in IBM-PC TIFF format. The TIFF files were imported into *Imagine* .img format using standard file import. To reduce overall file space requirements, the image files were resampled using nearest neighbour methods to a pixel resolution of 3 m.

Table 1. Air photography details.

Date	**Scale**	**Type**	**Water levels**
July 1957	1:16000	black & white	high
January 1965	1:40000	black & white	low
March 1977	1:25000	colour infra red	low
March 1986	1:20000	colour	low
April 1994	1:25000	colour	low

Orthophotographs (1:25000) were provided by the Department of Land Administration (DOLA). Georeferencing of orthophotographs was achieved by entering UTM coordinates for the edges of the images. Initial trial scans of the orthophotographs proved unsatisfactory due to errors incurred during the scanning process. The orthophoto images were rescanned until an error of < 4 mm in 1200 mm (0.3%) was achieved in the squareness of a test image provided by DOLA to the scanning agency (CAD/CAM Centre Technology Park). Poor contrast across the orthophotographs made selection of common GCP's in some areas difficult and required further adjustment of contrast to aid in identifying the selected points.

Georeferencing of air photos was achieved by matching ground control points (GCP's) on scanned orthophotographs with their equivalent on the scanned air photos. The air photograph image was then resampled using nearest neighbour methods with an output pixel size of 3 m. RMS errors for all georeferenced resampling were restricted to < 0.6 of pixel size, with the intention of maintaining a spatial error of < 1.02 m. The output pixel size of 3 m was determined to be the optimum given the overall image size and system space limitations. A pixel size of 1 m would have resulted in a composite image of ≈ 3 Gb exceeding the available system. The resultant air photograph mosaic image size at 3 m pixel resolution was ≈ 200 Mb. Each air photograph image of 20 Mb was subset to 2 x ≈ 4 Mb file sizes to provide sufficient overlap in the final mosaic while reducing the overall size of files to handle.

The final mosaic was produced using two options, firstly a feather overlap option which reduces contrast variation between sub-images of the mosaic while allowing some transparency between sub-images (Figure 1). This has the effect of blurring the overlapping components of each image and reduces the spatial accuracy of the overall image in areas of overlap. The image was given the file name 1994fs.img (Table 2) and had a file size of ≈ 200 Mb. Department of Transport requested a smaller file size for the resultant images so a smaller image was resampled using a cubic convolution method to a 15 m pixel size, this being chosen to provide a final image file size of ≈ 8 Mb. This image was given the file name 1994fsrcc.img (Table 2).

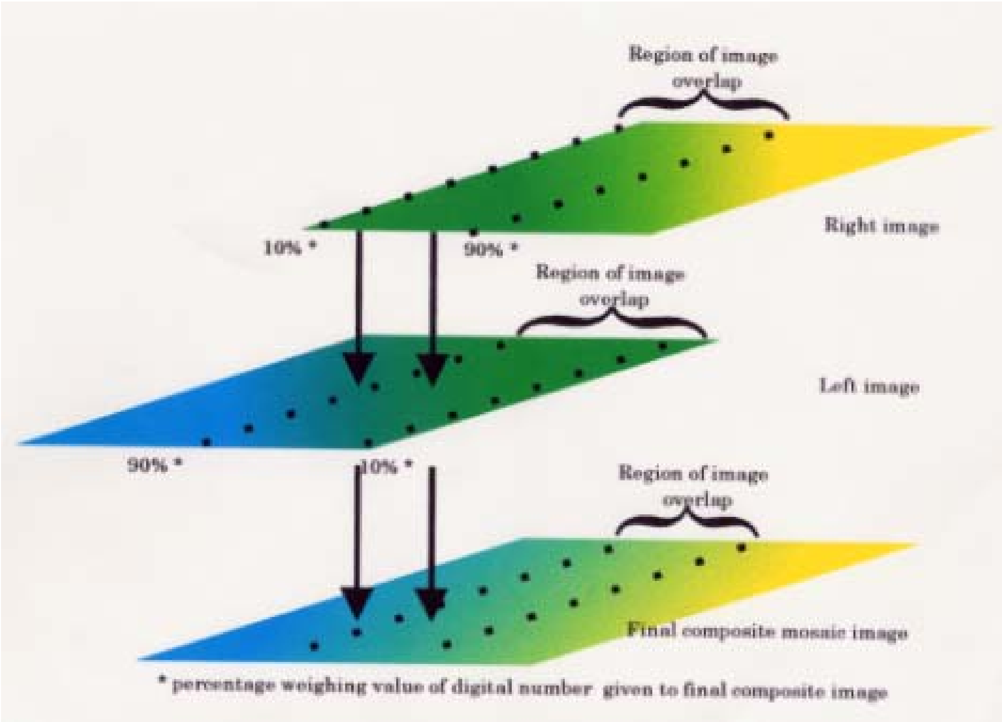


Figure 1. Linear feathering overlay reduction. The data values of final composite image in the region of overlap is determined by the distance of the pixel from the centre of the overlapping image. The further from the centre the less emphasis placed on the final pixel value.

Secondly, a maximum overlap reduction of 99.9% was applied in both X and Y axes which has the effect of butt-joining the portions of images at the centres of their overlap, thus visually eliminating the areas of overlap and maintaining the maximum spatial accuracy of the image. This image was given the file name 1994mors.img (Table 2). Again a smaller file size was requested and the cubic convolution resampled image with a 15 m pixel resolution was named 1994morsrcc.img (Table 2). The naming conventions of the image files are presented in Table 2 which gives a brief description of the file status and the process.

Table 2. File naming conventions. (*ƒ* = photograph image number; ß = composite mosaic image date)

FILE NAME	FILE TYPE	DESCRIPTION
ƒ .TIF	Tiff	Scanned single air photograph
ƒ.IMG	Img	*Imagine* image file of above scan
ƒ. R.IMG	Img	Georeferenced and resampled image file
ƒ.RS.IMG	Img	Above file subset to smaller spatial coverage
ß.RS.IMG	Img	Composite mosaic file of subset images
ß.RSRCC.IMG	Img	Composite file subset and resampled using cubic convolution
ß.LRF.IMG	Img	Composite mosaic using feathered overlay technique
ß.MORS.IMG	Img	Composite mosaic using maximum overlay reduction
ß.MORSRCC.IMG	Img	Composite mosaic using maximum overlay reduction and resampled using cubic convolution
ß.LRFRCC.IMG	Img	Composite mosaic using feathered overlay reduction and resampled using cubic convolution
ß.PS	Postscript	Composite mosaic file in postscript format
ß.TIF	Tiff	Composite mosaic file in tiff format

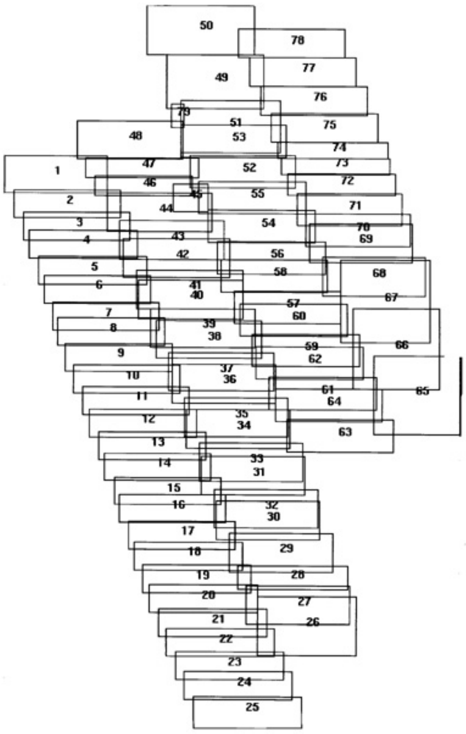
The final mosaic images were compiled from approximately 80 sub-images shown in Appendix 2. All .img files including the large and resampled mosaics and postscript and TIFF files of the mosaics, were TAR copied to DAT tape in a compressed write mode. A flow diagram of the entire process is summarised in Appendix 3. A table showing file handling procedures is contained in Appendix 4.

Air photograph interpretation was carried out for each of the dates on the air photographs using the keys contained in Appendix 5. Each photograph was interpreted independently by two interpreters using stereoscopes to allow magnification and observation of imagery in three dimensions. This enabled use

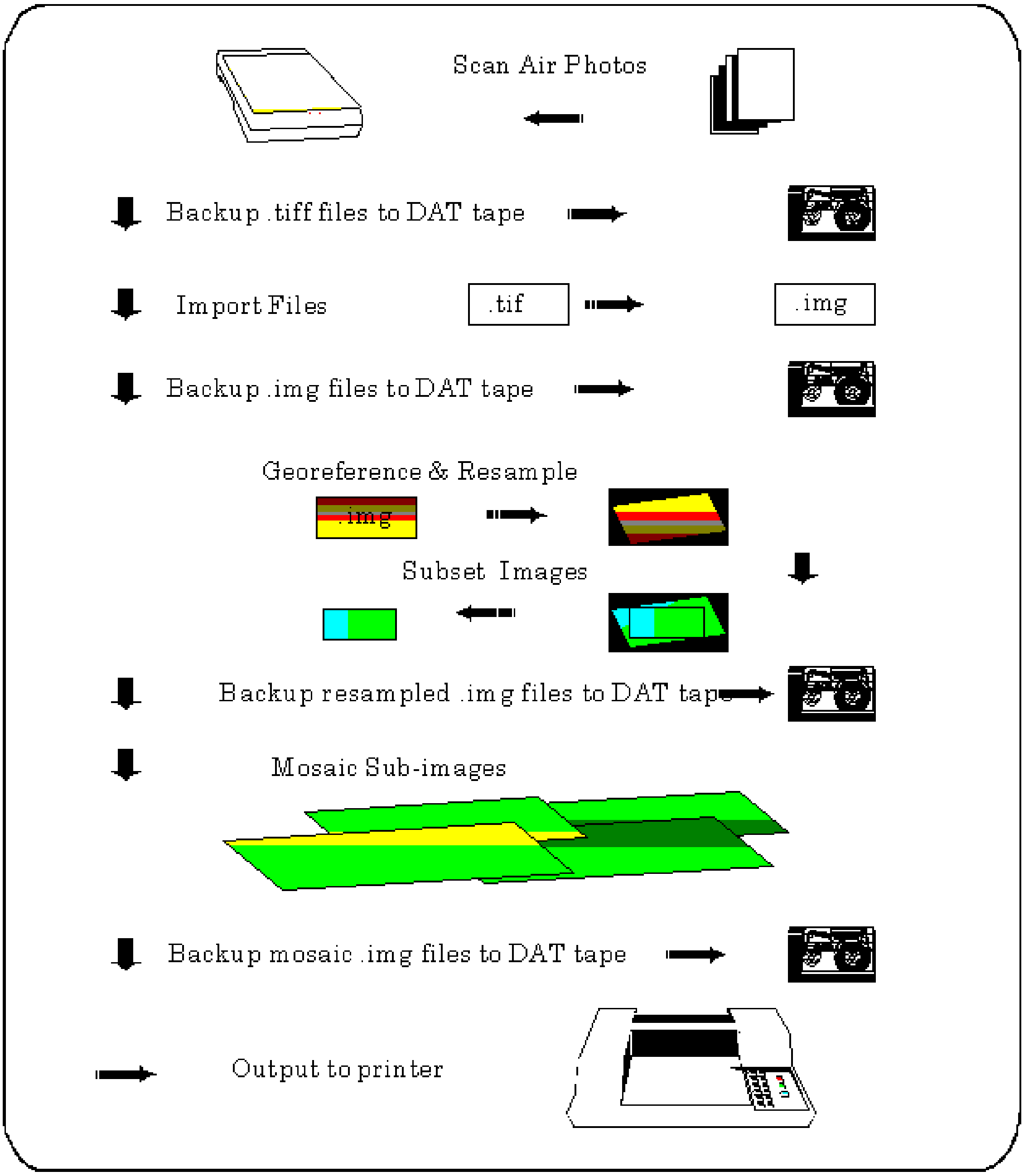
of terrain shape to assist in the identification of samphire. Both sets of interpretations of samphire cover were then transferred to a clear transparency overlay on the orthophotographs. After the samphire overlays were completed for each date they were then digitised over the digital mosaic image using on-screen digitising techniques in *Imagine* software. In all cases the union of areas determined by the two interpreters were digitised, thus only errors of commission occur in the final agreement of the two interpretations.

The digital overlays were then embedded into a image raster layer and the image classified using an unsupervised classification routine into two classes, *samphire* and *the rest*. These classes were used to determine total areas of samphire. The common pixel size for classification purposes was 4.5 m. This was dictated by software limitations. The overlay images were then used to subset a common total scene and local scenes of interest for further determination of site specific details.

APPENDIX 2 Air Photo Mosaic Preview



APPENDIX 3 Flow Diagram of Mosaic Procedure



APPENDIX 4 File Handling Table

PROCEDURE	TIME Min	FILE SIZE ≈
scan air photograph	6	20 Mb
file transfer	5	20 Mb
save	2	20 Mb
import	8	23 Mb
save	2	23 Mb
georeference	35	23 Mb
subset	8	2x 4 Mb
mosaic	120	260 Mb
subset	45	196 Mb
resample	150	15 Mb
map	30	N/A
postscript output	45	69 Mb
DAT down/upload	120	2 Gb

APPENDIX 5 Air Photograph Interpretation Key

5.1 Key for Samphire Identification Black and White Photography

Colour/Tone	mid grey
Texture	very smooth
Shape	irregular
Shadow	nil
Pattern	may have tonal contrast varied by proximity to water or water table
Orientation/Situation	parallel and adjacent to water edge, varied width with variation in slope.
Size	varied

5.2 Key for Samphire Identification Infra-Red Photography

Colour/Tone	bright orange - red
Texture	very smooth
Shape	irregular
Shadow	nil
Pattern	may have tonal contrast varied by proximity to water or water table
Orientation/Situation	parallel and adjacent to water edge, varied width with variation in slope.
Size	varied

5.3 Key for Samphire Identification Colour Photography

Colour/Tone	dark brown - mid grey
Texture	very smooth
Shape	irregular
Shadow	nil
Pattern	may have tonal contrast varied by proximity to water or water table
Orientation/Situation	parallel and adjacent to water edge, varied width with variation in slope.
Size	varied

APPENDIX 6 Species List For Peel-Harvey Saltmarshes

Magnoliopsida

Magnoliidae

Casuarinaceae

Casuarina obesa

Aizoaceae

Carpobrotus edulis

Tetragonia decumbens

Chenopodiaceae

Atriplex prostrata

Atriplex hypoleuca

Sarcocornia quinqueflora

Halosarcia sp.

Halosarcia halocnemoides

Halosarcia indica subspecies leiostachya

Halosarcia indica subsp. bidens

Suaeda australis

Frankeniaceae

Frankenia pauciflora

Primulaceae

Samolus repens

Mimosaceae

Acacia saligna

Proteaceae

Hakea prostrata

Myrtaceae

Astartea fascicularis

Melaleuca acerosa

Melaleuca cuticularis

Melaleuca rhaphiophylla

Melaleuca teretifolia

Regelia inops

Apiaceae

Ammi majus

Gentianaceae

Centaurium spicatum

Asteraceae

Cotula coropifolia

Ursinia anthemoides

Liliidae

Juncaceae

Juncus kraussii

Cyperaceae

Bolboschoenus caldwellii

Gahnia trifida

Poaceae

Aira cupaniana

Avena barbata

Briza spp.

Bromus arenarius

Bromus hordeaceus

Cynodon dactylon

Danthonia spp.

Ehrharta longiflora

Hainardia cylindrica

Hordeum leporinum

Lolium rigidum

Polypogon monospeliensis

Sporobolus virginicus

Anthericeae

Thysanotus areanrius

Iridaceae

Romulea rosea

Watsonia meriana

Cycadopsida

Zamiaceae

Macrozamia riedlei

APPENDIX 7 List of Invertebrates Occurring in the Saltmarsh Areas of the Peel-Harvey Estuary

Common name	Scientific name
Flat worms	Platyhelminthes
	Platyhelminthes sp 1
Worms	Polychaete
	Nereidae
	Ceratonereis aquisetis
	Oligochaeta
	Oligochaeta sp 1
	Oligochaeta sp 2
Molluscs	Mollusca
Clams	Class Bivalvia
	Trapeziidae
	Fluviolanatus subtorta
	Leptonidae
	Arthritica semen
Snails	Class Gastropoda
	Hydrobiidae
	Hydrobia buccinoides
	Tatea rufilabris
	Akeridae
	Akera bicincta
Arachnids	Arachnida
Water Mites	Hydracarina
	Hydracarina sp 1
	Hydracarina sp 2
	Hydracarina sp 3
Spider	Arachnida
	Arachnid sp 1
	Arachnid sp 2
	Arachnid sp 3
	Arachnid sp 4
	Arachnid sp 5
	Arachnid sp 6
	Arachnid sp 7
	Arachnid sp 8

Crustaceans	Crustacea
Isopods	Isopoda
	Sphaeromatidae
	Syncassidina aestuaria
	Haloniscus sp 1
	Haloniscus sp 2
	Haloniscus sp 3
Amphipoda	Amphipoda
	Ceinidae
	Ceinidae sp 1
	Ceinidae sp 2
	Corophiidae
	Paracorophium excavatum
	Corophiidae
	Corophium minor
	Erichthonius sp 1
	Erichthonius sp 2
Ostracoda	Ostracoda
	Cyprididae
	Mytilocypris sp 1
	Bennelongia sp 1
	Alboa wooroa
	Eucypris virens
Copepods	Copepoda
	Calanoida
	Calanoida sp 1
	Harpacticoida
	Harpacticoida sp 1
Shrimp	Palaemonidae
	Palaemonetes australis
Insects	Insecta
Springtails	Collembola
	Sminthuridae
	Sminthuridae(?) sp 1
Flies	Diptera
	Diptera sp 1
	Diptera sp 2
	Empididae

	Empididae sp 1
	Ephydridae
	Ephydra sp 1
Midges	Chironomidae
	Chironomidae sp 1
	Orthocladiinae sp 1
	Orthocladiinae sp 2
	Paratanytarsus sp 1
Sand flies	Ceratopogonidae
	Ceratopogonidae sp 1
	Ceratopogonidae sp 2
Mosquitoes	Culicidae
	Ochlerotatus
	Aedes camptorhynchus
Beetles	Hemiptera
	Corixidae
	Corixidae sp 1
	Notonectidae
	Notonectidae sp 1
	Notonectidae sp 2
	Coleoptera
	Coleoptera sp 1
	Dytiscidae
	Dytiscidae sp 1
	Dytiscidae sp 2
	Elmidae
	Elmidae sp 1
	Limnichidae
	Limnichidae sp 1
	Limnichidae sp 2
	Chrysomelidae
	Chrysomelidae sp 1
Weevil	Curculionidae
	Curculionidae sp 1