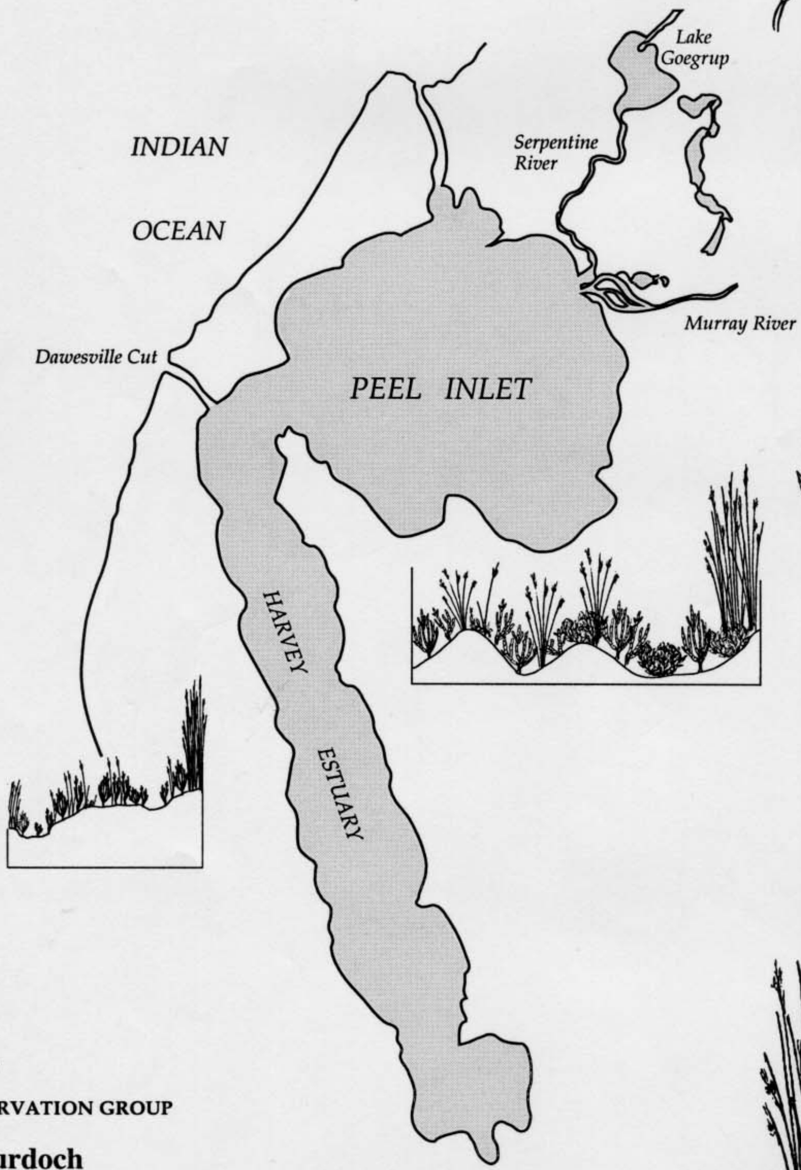
SAMPHIRE MARSHES
OF THE
PEEL-HARVEY ESTUARINE SYSTEM WESTERN AUSTRALIA



PUBLISHED BY PEEL PRESERVATION GROUP AND

Murdoch University

SAMPHIRE MARSHES

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PEEL - HARVEY ESTUARINE SYSTEM

WESTERN AUSTRALIA

Edited by Prof. A.J. McComb, Halina T. Kobryn, Jane A. Latchford

October 1995

ISBN 0-86905-470-8

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ACKNOWLEDGMENTS

The editors would like to thank the Peel Preservation Group for procuring the funding which enabled this study to occur. The groups enthusiasm about saltmarshes provided the spur to continue in difficult circumstances. This project was funded under the National Estate Grants Program, a Commonwealth-financed grants scheme administered by the Australian Heritage Commission (Federal Government) and the Heritage Council of Western Australia (State Government). This project also received funds from the Gordon Reid Foundation, City of Mandurah, ALCOA, Peel Inlet Management Authority, and Peel Development Commission. Department of Planning and Urban Development and the Department of Transport provided all the aerial photography used in the study.

A special thanks to the volunteer interpreters Richard Segal, Tim Leerey and Frederick Bouckaert without which the aerial photograph component of the study would not have been completed. Richard Segal also contributed extensively in the proof reading of the final report. Thanks also to Nicola Fletcher, Nick Long and Dieter Hodge who assisted in the initial transect establishment; Ross Warmsley, John Watts and Brad Smith for assisting in the fieldwork.

The cartography and secretarial staff within the Environmental Science were also very supportive of the study, in particular Mike Roeger. Mary Quayle provided all colour photography for this study.

Rosalind Murray and Matt Keally participated in the study as part of their Environmental Science Degree providing input into the design and implementation of their component of the study. Ron Glasson's experience and patience was tried on numerous occasions when compiling the aerial mosaics, but still he persevered with a smile. Tom Rose provided valuable support and management details, always stressing the need for the study.

Thanks to Eric Paling for advice on nutrient exchange; Jenny Davis for overseeing the invertebrate study; Alan Rossow for assistance in levelling all the vegetation transects; and the Marine and Freshwater Research Laboratory for analysing water and plant samples.

Thanks to Jason Byrne from the Peel Inlet Management Authority for helpful discussions on environmental planning matters.

Lastly thanks to David Everall for originally suggesting the study.

SUMMARY

The Peel-Harvey saltmarshes are important locally and regionally for some of the following reasons. Firstly, plant and animal material produced within the marsh is exported into the estuary. This material then supports food webs becoming food for fish and crustaceans, so forming a resource base for commercial production and recreational pleasure. Secondly, saltmarshes, like fresh water wetlands, act as 'biological filters' which remove nutrients and pollutants, preventing these compounds from reaching the estuary waters. Thirdly, the saltmarshes are important areas for the rich array of birds that inhabit the estuary at various times of year. Finally, they provide physical stability to the shores of the Peel-Harvey estuary.

Saltmarshes within the Peel-Harvey estuary are declining both in quality and quantity. The greatest areal loss has occurred outside reserve areas. Reserve areas and those of special interest are showing evidence of decline in quality of samphire cover. Decline in the quality of samphire can further accelerate loss and degradation of vegetation and animal species. The loss of samphire from the Creery wetlands presents a urgent case for management consideration due to the proximity to urban development and development pressures in general and also because this area represents one of the largest remaining contiguous areas of samphire. This should not be interpreted that other areas are less deserving of management consideration but that Creery wetland represents unique opportunities for preservation and conservation and its current land tenure requires urgent management consideration. Its conservation and preservation should be considered a high priority.

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

The complexes found in the Peel-Harvey display a clear relationship with the percentage of annual tidal inundation received. The link between tidal inundation and communities was not so clear, although some trends were apparent. Other factors indirectly affected by the tide, such as gradient, sediment deposition; soil composition and nutrient availability may have a greater contribution in determining community distribution. Other forms of inundation such as river

flooding and infrequent extremely high tides would also affect the distribution of saltmarsh plants.

It is believed that not only are there likely to be changes in the extent of vegetation complexes with changing water regimes resulting from the Dawesville Channel, there is expected to be different changes affecting most species, and thus communities, within the saltmarsh.

The study of invertebrates of the saltmarshes of the Peel-Harvey revealed a broad range of animals which were related to the location and time of sampling, especially sites 4 (Soldiers Cove), 6 (Murray River delta) and 10 (Harvey River delta) contained substantial richness and abundances.

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. It is believed that not only are there likely to be changes in the extent of vegetation complexes with changing water regimes resulting from the Dawesville Channel, there are expected to be different changes affecting most species, and thus communities, within the saltmarsh. No real impacts upon the invertebrate assemblages can be gauged from this study due to the limited timespan 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 implications of this are that tidal ranges will be more variable and more frequent which may alter saltmarsh distributions and hence alter invertebrate distributions. The effects of the tidal patterns is predicted to be greater in the Harvey Estuary 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. 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.

Saltmarshes have been identified as critical to the wellbeing of the estuarine ecosystem in a number of ways. 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.

ABSTRACT

The Peel-Harvey saltmarshes are important locally and regionally, because they support extensive food web and act as a biological filter for the receiving waters. This study was undertaken to examine the ecology and extent of saltmarshes of the Peel-Harvey. The extent and composition of the samphire saltmarshes was investigated over the period of 37 years (from 1957 to 1994), using aerial photography over the whole estuary, and detailed field surveys at ten sites. Saltmarshes within the Peel-Harvey estuary are declining both in quality and quantity. The greatest areal loss has occurred outside reserve areas. The loss of samphire from the Creery wetlands presents an urgent case for management consideration due to the proximity to urban development and development pressures in general and also because this area represents one of the largest remaining contiguous areas of samphire.

Within the saltmarshes of the Peel-Harvey there was a distinct zonation of plant complexes, and trends in the distribution of saltmarsh communities along transects, thought to be related to tidal inundation.

The complexes found in the Peel-Harvey display a clear relationship with the percentage of annual tidal inundation received. It is believed that not only are there likely to be changes in the extent of vegetation complexes with changing water regimes resulting from the Dawesville Channel, there is expected to be different changes affecting most species, and thus communities, within the saltmarsh.

The study of invertebrates of the saltmarshes of the Peel-Harvey revealed a broad range of animals. 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.

CHAPTER 1 The Significance of Saltmarshes

J.A. Latchford, A.J. McComb

Saltmarshes are complex ecosystems. Numerous studies have been undertaken on them in different parts of the world, mostly in the northern hemisphere. A few previous studies have been made of the marshes of the Peel-Harvey System (Rose & McComb, 1980; Backshall & Bridgewater, 1981; McComb & Lukatelich, 1986) but increased pressure for development, and the need for an understanding the possible effects of the then proposed Dawesville Channel highlighted the lack of information about saltmarshes in the area. This report endeavours to addresses this lack of information by presenting recent research into the extent, composition and functioning of the Peel-Harvey saltmarshes.

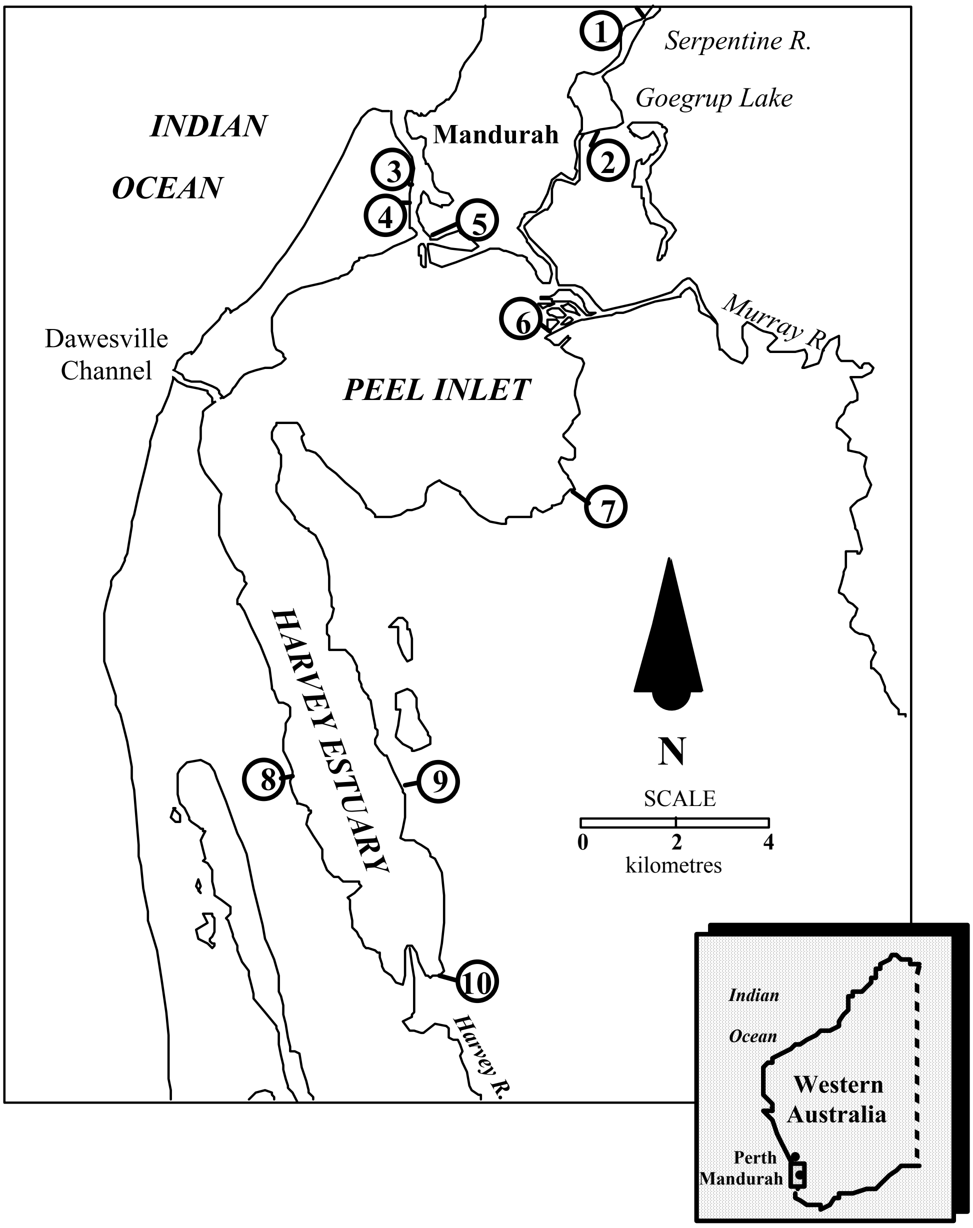

Figure 1.1. The location of study sites within the Peel Harvey estuarine system.

1.1 Peel-Harvey System

This system is 75 km south of Perth by road (between 32°21' and 33°00' south, and 115°30' and 115°30' east). It is a large (133 km^2) shallow water body which is fed in winter by three rivers, the Murray, Serpentine and Harvey (Figure 1.1). It lies on the western edge of the Swan Coastal Plain within the Darling System of Western Australia, and is separated from the sea by a line of sand dunes, the Spearwood system, which has a core of Tamala limestone.

The system has strongly seasonal river flow and, until recently, very limited water exchange with the Indian Ocean. Over geological time, natural processes would gradually complete the infill process towards a marsh system (Waterways Commission, 1992). Human impacts have accelerated this process of infilling, and fertiliser runoff has led to severe eutrophication problems; massive accumulations of macroalgae in Peel Inlet, and seasonal blooms of the blue-green 'alga' *Nodularia spumigena* in Harvey Estuary. These problems have reduced the commercial and recreational values of the system (McComb and Lukatelich, 1986). To ameliorate these problems several management recommendations have been adopted, one of which has been the construction of a new channel from the Harvey Estuary directly to the Ocean near Dawesville. The aim of the channel is to increase water exchange between ocean and estuary.

Before April 1994 astronomic tides were of small amplitude (typically about 10 cm) superimposed on longer-term changes in water level of similar magnitude. These long-term changes are due to barometric effects, coupled on occasions with river flow, with cycles of 5 to 15 days (DCE, 1980). The amplitude of the tide increased to 40 cm once the channel had been opened (Ryan, 1993).

There are saltmarshes on either side of the Mandurah channel, on the eastern side of Peel Inlet and around the southern part of Harvey Estuary. Narrow fringing marshes also border the Serpentine River (DCE, 1980).

1.2 Definition

Saltmarshes are defined as areas of land, vegetated by herbs, grasses or low shrubs, bordering saline water bodies (Chapman, 1974). They are among the most productive ecosystems in the world (Montague and Wiegert, 1991) and are distributed along coastlines in temperate climates. Different plant groups dominate different coastlines, but the ecological structure and function of saltmarshes are essentially similar in different parts of the world (Chapman, 1974; Montague & Wiegert, 1991; Adam, 1993;

Mitsch & Gosselink, 1993). Saltmarshes in Western Australia are usually found in estuaries or on sheltered coastlines, in the north west often adjacent to mangroves (Bridgewater *et al.*, 1981). They are subjected to periodic flooding as a result of fluctuations in the level of the adjacent water body (Adam, 1993).

A saltmarsh can be regarded as a highly modified terrestrial ecosystem, as the organisms which characterise saltmarshes are vascular plants of terrestrial origin. However, as the marsh occupies areas at the interface between land and sea, its environment has some features of both land and sea, and its biota has marine and terrestrial elements (Adam, 1993).

One of the dominant features influencing saltmarshes is water level fluctuation which is usually tidal in origin. Tides control soil salinity and the degree of waterlogging; they also carry sediment and nutrients in and out of the marshes. Saltmarshes are highly dynamic environments subject to erosion, accretion and progradation. Other environmental factors which characterise saltmarsh, such as nutrient availability, may modify the nature and distribution of the biota (Adam, 1993).

1.3 Physical Characteristics

Saltmarshes may occur as narrow fringes on steep shorelines, or on more shallow slopes as flat expanses up to several kilometres wide. They are found near river mouths, in bays, on protected coastal shores and around protected lagoons. Coastal saltmarshes are predominantly intertidal, that is, they are found in areas at least occasionally inundated by high tide but not flooded during low tide. In the tropics of Australia saltmarshes are partially replaced by mangrove swamps, which function in a similar manner, any saltmarsh present existing adjacent to the mangrove community (Allen & Pye, 1992; Adam, 1993) (Plate 1.1).
The sediments that build saltmarshes originate from upland runoff, marine reworking of coastal shelf sediments, and organic production within the marsh itself. The long-term stability of a saltmarsh is determined by the relative rates of two processes acting on the marsh: sediment increase or accretion, which causes the marsh to expand outward and grow upward in the intertidal zone; and by loss, or submergence, caused by rising sea level and marsh surface subsidence (Allen & Pye, 1992).

Although physical processes dominate sediment accretion, the effects of plants and animals can also be significant. Algae have an important role in the stabilisation of mudflats, which can then be colonised by flowering plants. These plants then slow water movement, allowing sediment in the water to accrete in the marsh, where it can be trapped by algal, bacterial and diatom mats (Adam, 1993).

Saltmarshes act as a buffer to the intertidal zone. Erosion of the surface of the marsh and its edges protects the shore behind it from erosion by high-energy waves. Saltmarsh creeks also allow the dissipation of tidal energy, which would otherwise erode the mudflats and the shoreline behind them (Allen & Pye, 1992).

Tides influence a wide range of physical and chemical processes. These processes in turn influence the species in the marsh and their growth. The lower and upper limits of the marsh are generally set by the tidal range. In fact, the marsh is often divided into two zones, the upper (or high) marsh and the lower (or intertidal) marsh. The upper marsh is flooded irregularly and has a minimum of ten days of continuous exposure to the air, whereas the lower marsh is flooded almost daily (Allen & Pye, 1992; Adam, 1993).

A notable feature of saltmarshes, and especially the low marsh, is the development of pans and tidal creeks. The term 'pan' is used to describe shallow depressions in the marsh which are filled periodically with water (Plate 1.2). They range from half a metre to several metres in width and a few centimetres to a half a metre deep. Because of their shallow depth and occasionally submerged vegetation, pans are used extensively by migratory wading birds searching for food. Tidal creeks, another feature of saltmarshes, serve as important conduits for material and energy transfer between the marsh and the adjacent body of water (Allen & Pye, 1992).

The development and zonation of vegetation in a saltmarsh are influenced by several chemical factors. Salinity of the overlying water and soil water is a dominant factor determining the species present and their rate of growth. Salinity is affected by the frequency of tidal inundation; rainfall; soil texture; vegetation; depth of water table; fresh water inflow; and occurrence of salt deposits (Montague & Wiegert, 1991; Adam, 1993).

As the elevation of a marsh surface increases, the number of flooding tides decreases. This may be expected to result in decreased salinity, but the salinity of the interstitial soil water does not have a constant relationship with elevation. In the lower marsh, with frequent immersion, soil salinity is relatively constant and rarely exceeds that of the flooding water. At higher elevations there is a stronger interaction between flooding and climate, leading to greater variability in soil salinity (Adam, 1993).

Soils of the saltmarsh are frequently waterlogged and anaerobic. After tidal immersion many areas of marsh drain slowly, as a result of local topography and the low hydraulic conductivity of many saltmarsh soils (Adam, 1993).

Plate 1.1 A saltmarsh within the Peel- Harvey estuary

Plate 1.2 A saltmarsh pan within the low marsh.

1.4 Productivity

Tidal marshes are amongst the most productive ecosystems in the world. Woodwell *et al*. (1973) have suggested that although saltmarshes and estuaries make up only 0.35% of the world's surface area, they are estimated to produce some 2% of net world primary production.

Saltmarshes are often cited as exporting nutrients to the estuary, but this view has been challenged and refined in recent years. It is now believed that coastal marshes display a high degree of individuality. They are still able to fix carbon at very high rates, but the fate of this carbon is not readily predicted. Systems with large river flows are likely to transport large fractions of their net primary production during spring runoff; those systems with broad tidal amplitude may export organic matter year round; or marshes experiencing rapid sea-level rise may accumulate plant matter in the sediments; and finally small, semi-enclosed marshes may use the energy of photosynthesis to produce organic matter and recycle large portions of their fixed carbon. Thus, the high productivity is either exported as detritus, accumulated as peat, or released in respiration (Zedler, 1992).

In the Peel-Harvey system during winter and spring, there is the potential for organic matter and nutrients to be washed into the estuary from the marsh. At other times, there may be an import of organic matter and nutrients from the estuarine waters. Saltmarshes also convert nutrients into forms that can be easily absorbed by estuarine plants and animals (Mitsch & Gosselink, 1993).

The availability of nutrients in the saltmarsh soil, particularly nitrogen and phosphorus, is important for the productivity of the saltmarsh ecosystem. Several studies have shown that saltmarsh vegetation can be nitrogen limited (Valiela & Teal, 1985; Barko and Smart, 1981). Phosphorus, however, accumulates in plant tissue at relatively high concentrations and apparently does not limit growth. Other nutrients which may influence the productivity of the marsh are iron, manganese and sulphur (Mitsch & Gosselink, 1993).

1.5 Ecosystem Structure

The saltmarsh has many biological components. These include vegetation, animal and microbe communities in the marsh itself, and also plankton, invertebrates, and fish in the tidal creeks, pans, and open estuarine waters (Montague & Wiegert, 1991; Mitsch & Gosselink, 1993).

The saltmarsh flora is composed of bacteria, fungi, algae, and flowering plants. In general the diversity of the flora increases with elevation above sea level, which results from differences in the soil, and competition among plant species (Adam, 1993).

Bacteria and fungi are important components of saltmarsh microflora. They are responsible for breaking down plant and animal matter and transforming it into forms of nutrients available to other organisms. Fungi are also found in the soil and on the flowering plants in the higher marsh. Almost three-quarters of the detritus produced in a saltmarsh ecosystem is broken down by bacteria and fungi (Montague & Wiegert, 1991; Adam, 1993).

Algae are found attached to flowering plants, as free-living phytoplankton, and as macroalgae. The algae are important as food sources for aquatic and terrestrial animals. Algal mats, dominated by blue-green algae, diatoms and green algae are also present (Montague & Wiegert, 1991; Adam, 1993; Mitsch & Gosselink, 1993; Paling & McComb, 1994).

The flowering plants of the saltmarsh include herbs, grasses, sedges, dwarf shrubs and trees. They are dominated by halophytic flowering plants. The lower marsh is usually dominated by one species. With increasing elevation species diversity tends to increase and distinct communities of flowering plants can be recognised (Chapman, 1974; Montague & Wiegert, 1991; Adam, 1993).

In the Peel-Harvey the lower marsh is dominated by *Sarcocornia quinqueflora* (samphire) with communities of *Halosarcia* species (grasswort), herbs and grasses occurring with increased elevation inland. Further inland communities of *Juncus kraussii* (shore rush), *Melaleuca cuticularis* (saltwater paperbark) and *Casuarina obesa* (saltwater sheoak) occur (Figure 1.2).

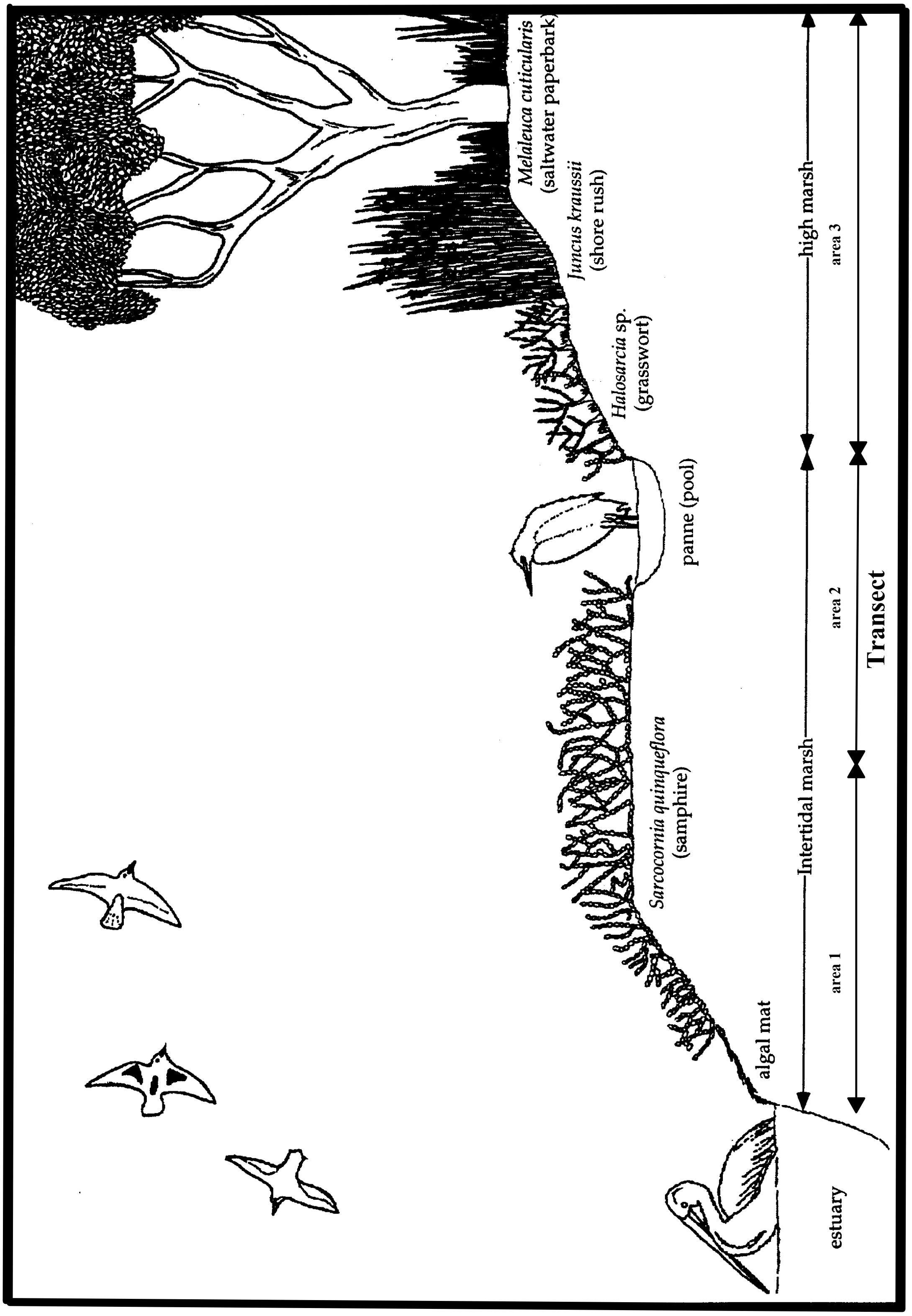

Figure 1.2. Cross section of a typical saltmarsh in the Peel-Harvey estuary.

The aerial habitat is dominated by insects such as grasshoppers, plant hoppers, wasps and beetles, and spiders that live in and on plant leaves. The stems and leaves of saltmarsh plants are also visited by snails. These animals make up the grazing portion of the saltmarsh food web (Figure 1.3). Large numbers of birds forage on the aerial invertebrate community, including egrets, little grassbirds, white-fronted chats, richard's pipits and Australian magpie-larks. The stems and leaves of saltmarsh plants are used as nesting material for resident saltmarsh birds such as the black-winged stilt, which build their nests sufficiently high to avoid all but the highest tides (Montague & Wiegert, 1991).

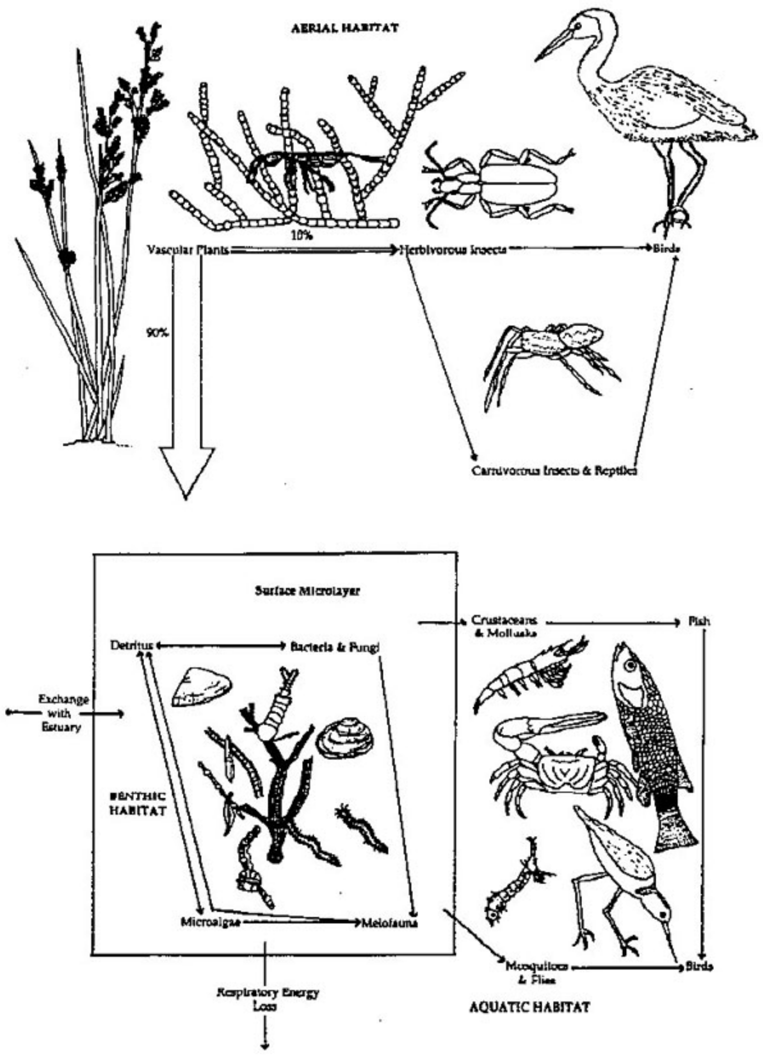

Figure 1.3. Food chain of a typical saltmarsh system.

Less than 10 percent of the plant material produced each year in a saltmarsh is removed by animal grazing. Most plant biomass dies and decays on the marsh surface, and its energy is processed by fungi and bacteria. These organisms serve as a food source for microscopic animals in the decaying vegetation and on the sediment surface of the marsh. Most of these benthic organisms are protozoa, nematodes, harpacticoid copepods, annelids, rotifers, and the larval stages of macro-invertebrates (Montague & Wiegert, 1991).

Benthic macrofauna forage on the sediment or filter floodwater. The common macro-invertebrates present in the sediment include polychaetes, gastropod molluscs and crustaceans; these in turn become food for a variety of predators such as the blue manna crab and egret (Montague & Wiegert, 1991).

Aquatic animals in saltmarshes often overlap in distribution with those in the benthic habitat of the open water (Figure 1.3). Zooplankton in saltmarsh creeks and in pans are similar in species composition and abundance to those of the open estuarine waters of the marsh. These may include copepods, ostracods and chaetognaths. These animals are important food for small fish which shelter in the saltmarsh creeks and pans. The macroinvertebrates that inhabit the saltmarsh creeks and pans include fly and mosquito larvae. These larvae in turn are food for fish, wading birds, and ducks. Adult mosquitoes feed from the nectar of plants, and in doing so help to pollinate these plants (Montague & Wiegert, 1991).

Although the main fish habitat is the creek and associated marsh edge, fish and shellfish venture from tidal creeks into the marsh when it becomes flooded. When the water recedes, small fish may remain in pans in the marsh, where they are often eaten by wading birds or eventually die of exposure (Montague & Wiegert, 1991).

The Peel-Harvey estuary is one of the largest and most important wetlands for birds in southwestern Australia. The wading birds often encountered in the saltmarshes of the Peel-Harvey estuary include the great and little egret, the white-faced heron, the yellow-billed spoonbill, the common sandpiper, and the red-necked stint. Some of the waders are listed in the Japan-Australia Migratory Birds Agreement. The marshes also support a variety of waterfowl such as the Australian shelduck, pacific black duck and musk duck (Halse *et al*, 1989; Chester & Klemm, 1990; Ninox, 1990).

Several species of reptiles occur in the Peel-Harvey saltmarshes, the most notorious being the common tiger snake which preys on frogs, fish, lizards, small mammals and birds. The native mammals most likely to be found on the saltmarshes are kangaroos and wallabies. Introduced species, such as cats and foxes can also be found hunting birds of the marshes.

1.6 Significance of saltmarshes to the Peel-Harvey system

The Peel-Harvey saltmarshes are important locally and regionally for some of the following reasons. Firstly, plant and animal material produced within the marsh is exported into the estuary. This material then supports food webs as explained above, becoming food for fish and crustaceans, so forming a resource base for commercial production and recreational pleasure. Secondly, saltmarshes, like fresh water wetlands, act as 'biological filters' which remove nutrients and pollutants, preventing these compounds from reaching the estuary waters. Thirdly, the saltmarshes are important areas for the rich array of birds that inhabit the estuary at various times of year. Finally, they provide physical stability to the shores of the Peel-Harvey estuary (Chester, 1990).

1.7 Aims

To provide more detail about these points, a study was undertaken into the ecology of saltmarshes of the Peel-Harvey. The aims of the study were:

1) To examine the extent and composition of the samphire saltmarshes and to document any changes in area and condition of the marshes with time. This was done using aerial photography over the whole estuary, and detailed field surveys at ten sites.

2) To examine the relationship between plant distribution and water level, to predict the possible effects which construction of the Dawesville Channel might have through establishing a new water regime.

3) To investigate the distribution of invertebrates in summer and winter in the saltmarsh.

4) Recommend areas of management priority and process by which they may be protected.

CHAPTER 2 Changes In The Area And Condition Of Samphire Marshes With Time

R. L. Glasson, H. T. Kobryn and R. D. Segal

2.1 Introduction

Aerial photography is especially suited to the study of vegetation, water resources and shoreline mapping (A.S.O.P, 1968). Air photographs provide a perspective of the earth's geographical features that are generally readily understood. Air photographs also provide a plan view that can be spatially compared to the knowledge an individual may have about a similar area. For those reasons aerial photographs frequently provide working documents for planners and managers. They are however, limited in spatial accuracy because the images suffer geometric distortions, particularly near photograph margins or when terrain varies in height. Also, a single aerial photograph rarely covers an entire study area. There are manual and computer assisted techniques of joining air photographs and also eliminating the geometric distortions within and between individual photographs. An assembly of aerial photographs is called a photo mosaic. Photo mosaics can be "controlled" or "uncontrolled", the former having the geometric distortions removed.

The amount of geometric distortions in an aerial photograph depends on many factors, including the physical optics of the camera and the orientation of the camera at the instant of exposure. Where the optical axis of the camera is near vertical (<3° from vertical), then the photograph is accepted as vertical. The point where the optical axis of the camera meets the earths surface is the "principal point" of the photograph. Vertical photographs are the most common type of "metric" aerial photograph, or one that is used to derive information about spatial measurements of geographical features. Geometric distortion of aerial photographs increases outwards from the principal point towards the margin. The distortions are increased if photography is acquired at low altitude, or with cameras using wide angle (>70°) and super-wide angle (>100°) lenses. Gross distortions of scale occur on individual photographs when terrain slope changes suddenly, as when a scarp, cliff or portion of a mountain is included in the photograph (Maling, 1989). Some of the distortions in vertical air photography can be avoided by using only central portions of each photograph.

Aerial photography is acquired in flight strips called "runs". Each photograph within a run overlaps the previous one by about 60% (endlap) to enable sufficient imagery to be acquired that is relatively distortion free, and to enable stereoscopic viewing of the imagery to aid in feature identification and interpretation. Each run is also overlapped to the adjacent run (sidelap), although usually by only 25-30% (Figure 2.1).

As an aid for interpretation, stereo pairs of photographs are viewed under a stereoscope. Stereo pairs share conjugate principal points, each principal point of each photograph is being visible on both photographs. The measured distance between the principal points is known as the "airbase"; which is a function of the ground speed of the aircraft and the interval between exposures. The stereoscope enables our eyes to view photographs from the same relative position as the airbase. This means that our eyes have the same optical separation as the air base, and stereoscopic depth of vision is greatly enhanced.

Interpretation of air photography is conducted in two stages. In the first stage the elements of the image are identified by attributes such as shape, size, spacing, shadow or silhouette, tone or colour , texture or association. The photographic appearance of these attributes can be affected by many factors including the amount of illumination and the reflectivity of the surface, as well as climatic factors and physical properties of the ground cover. These can quite often change the appearance of objects to resemble other features. For example shallow water stained brown with tannin, and inundating ground, can appear to be quite deep and extensive when using black and white photography.

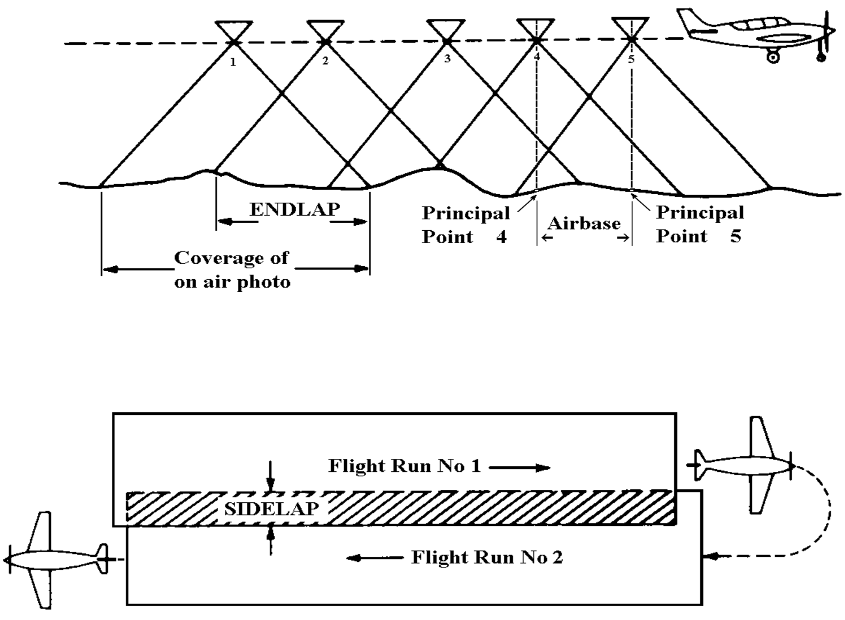

Figure 2.1. The acquisition of air photography. Aircraft fly in runs exposing film at a given intervals to photograph portions of the earth so that each successive photograph overlaps the next both along the direction of flight and between adjacent flight runs (Modified after Wolf, 1983).

The second phase consists of interpreting the factors in relation to the context for which the information is required. Interpretation may be carried out on individual photographs, in stereo pairs, on a composite photomosaic, or involving all of these procedures.

Physical assembly of a photomosaic by cutting and pasting is an exacting process in which failure can be very costly, as individual colour photographs cost about $20.00 and a mosaic may include some 50 photographs. By scanning photographs and using computer software, digital photo mosaics can be constructed and repeated without fear of costly failure. This investigation used the digital equivalent of a photo mosaic using computer software and scanned photographic imagery of the Peel-Harvey System.

A broad study into the samphire marshes of the Peel-Harvey System was initiated by the Peel Preservation Group to determine the extent and importance of these areas to the ecology of the Estuary. As part of this study a temporal perspective was required. No accurate mapping of these features existed nor had data been previously recorded about their locations or extent. To provide this historical perspective, existing archival air photography was combined with modern digital techniques to map the extent of samphire and temporal changes in the marsh.

A Peel-Harvey photo mosaic was prepared using ERDAS Imagine (*Imagine*) software on a Sun Sparc station IPX as part of the wider study of the samphire marshes. Air photographs covering the period 1957 to the present were used to determine temporal changes in samphire cover. The 1994 series of air photographs was provided by Department of Transport.

2.2 Method

The selection of images was based on approximately 10 yearly intervals, and on availability. Details of the acquired air photograph runs are presented in Appendix 1. The photographs selected had to lie within the boundaries of the Peel Harvey Estuary including Goegrup and Black Lakes. The 1957 photo set, however, did not include the Harvey River delta region at the southern end of the Harvey estuary as this was beyond the limit of existing photography. Portions of the Black Lakes region east of the Peel Inlet were excluded from the 1994 set, as this was also on the limit of the photography for that run.

A detailed technical description of the digital photo mosaic process is contained in Appendix 1. The air photographs for each date were scanned and then digitally joined, removing as much distortion as possible and orientating the photographs to conform with mapping conventions. The photographs were then interpreted to determine the extent of the samphire, which was then mapped over the digital images, enabling computer determination of the extent of samphire. As well as the completed mosaic of the entire area, smaller images were extracted for each date to enable comparison of special interest areas. The final mosaic images were compiled from some 80 sub-images, shown in Appendix 2. 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 the imagery in three dimensions. This enabled the use of terrain to assist in the identification of samphire marsh.

The subsets of special interest areas was focused on areas of conservation reserves. The geographical boundaries of each area are given in Table 2.1.

Table 2.1. Special Interest Area Boundaries (UTM Zone 50 (m)). Value of X represent eastings, whereas values of Y indicate northings.

COORDINATE/AREA	UPPER-LEFT X	UPPER-LEFT Y	LOWER-RIGHT X	LOWER-RIGHT Y
CREERY	378727	6398715	381879	6395165
LAKES	384272	6402524	388196	6395780
AUSTIN	381234	6390770	385091	6386599
ROBERTS	377316	6388819	381174	6384649
HARVEY	377121	6376654	381174	6370968
STUDY AREA	370900	6402500	388200	6370900

As field checking of classification accuracy is impossible for historical photography, only the 1994 photograph set was used to test for the accuracy of interpretation. One hundred sites were selected by the intersection of a grid overlay on the images, with areas that could reasonably be expected to contain samphire. Fifty sites of samphire cover and fifty sites of non samphire cover were used to determine by field checks for errors in the process of the interpretation.

2.3 Results

The mosaiced images for each date, including areas of samphire are shown in Figures 2.2 - 2.6. The red polygons indicate areas of samphire cover. The total area of samphire for each date and each area of interest are shown in Table 2.2. Red rectangles outlining boundaries of the special interest areas are shown in Figure 2.7. Temporal samphire changes for each special interest area are shown in Figures 2.8 - 2.12.

Table 2.2. Areas of samphire (ha) during the period 1957 - 1994 for the areas of interest, and the total over the entire Peel- Harvey study area.

AREA/DATE	1957	1965	1977	1986	1994
AUSTIN	35.286	30.308	23.395	31.851	37.758
CREERY	179.115	170.365	162.994	132.984	140.156
HARVEY	5.453*	131.099	87.652	106.995	144.783
LAKES	48.404	120.791	110.660	95.165	45.289*
ROBERTS	155.016	114.836	87.849	67.370	80.749
OTHER	252.900 •	432.771	271.783	190.327	181.405 •
TOTAL	676.174 •	1000.17	744.333	624.692	630.140 •

* - incomplete air photo coverage resulting in underestimate for area.

• - area underestimates (*) affect summed total estimates.

In attempting to describe changes that have occurred in saltmarsh coverage, two approaches can be made. One is to describe changes in a purely quantitative sense which concentrates on the magnitude of a particular change. The other is to describe the changes in qualitative terms which concentrates not only on the changes to the samphire itself but also how these changes affect the wider environment

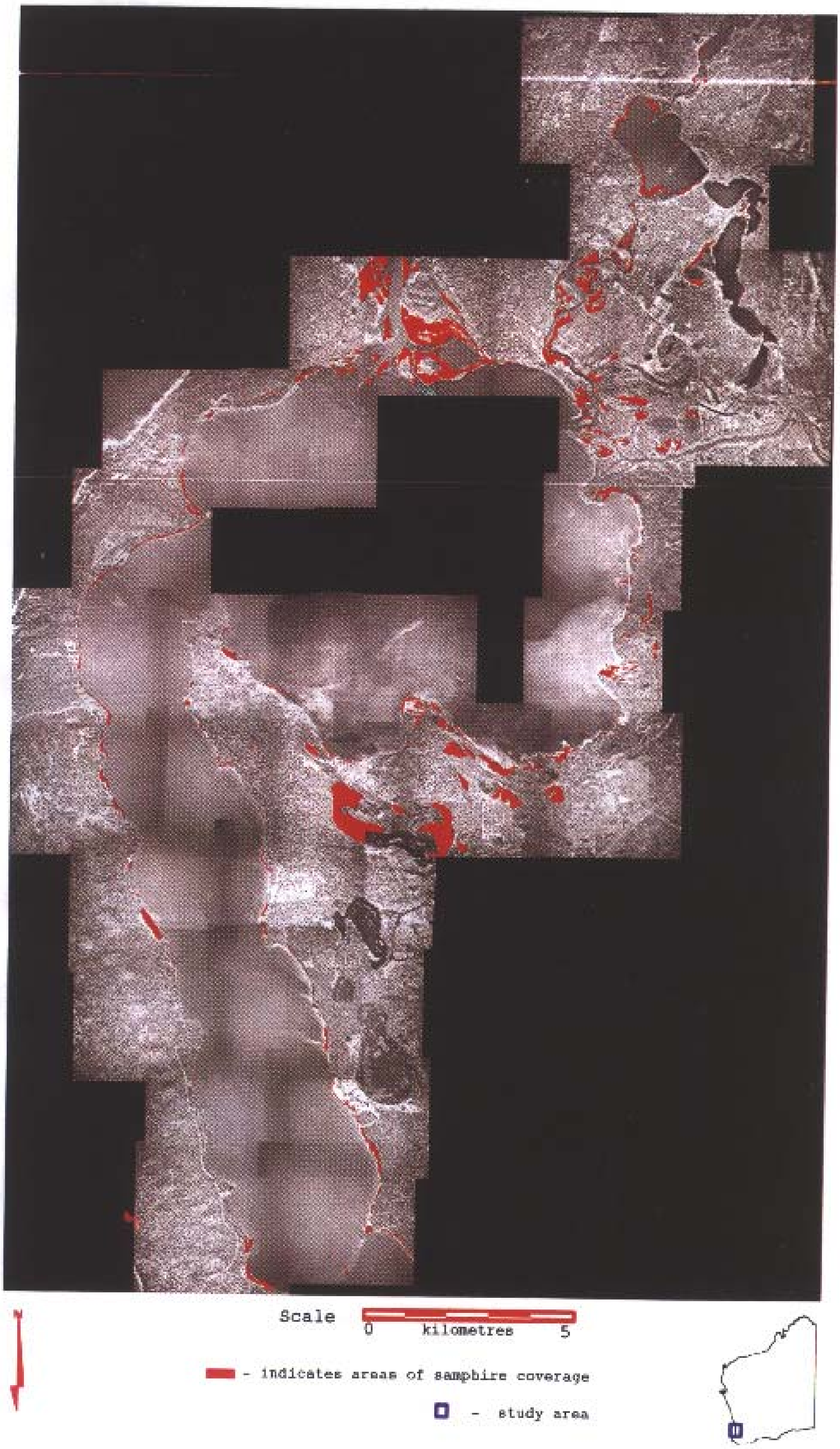

Figure 2.2 Samphire marsh distribution in 1957.

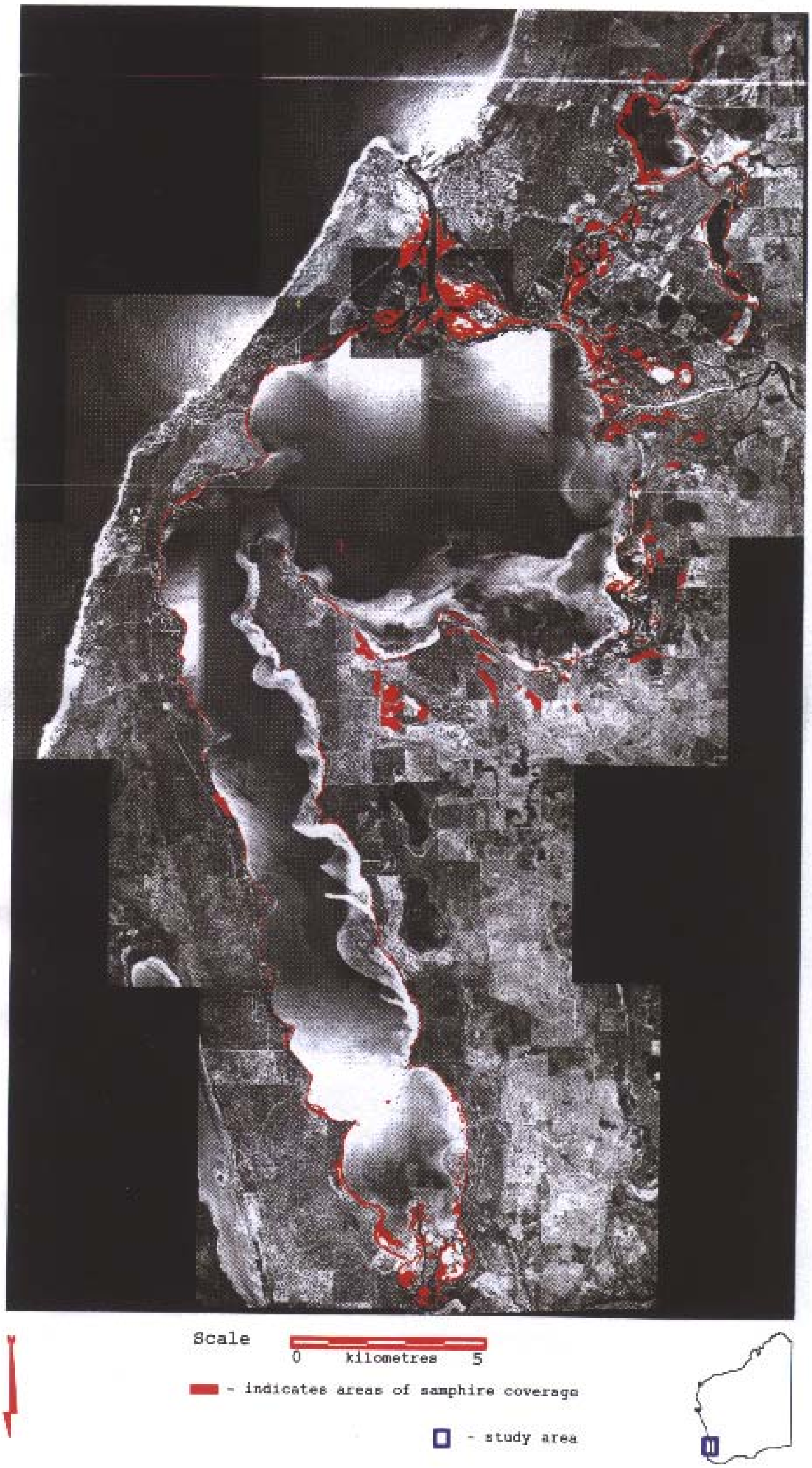

Figure 2. 3 Samphire marsh distribution in 1965.

Figure 2.4 Samphire marsh distribution in 1977.

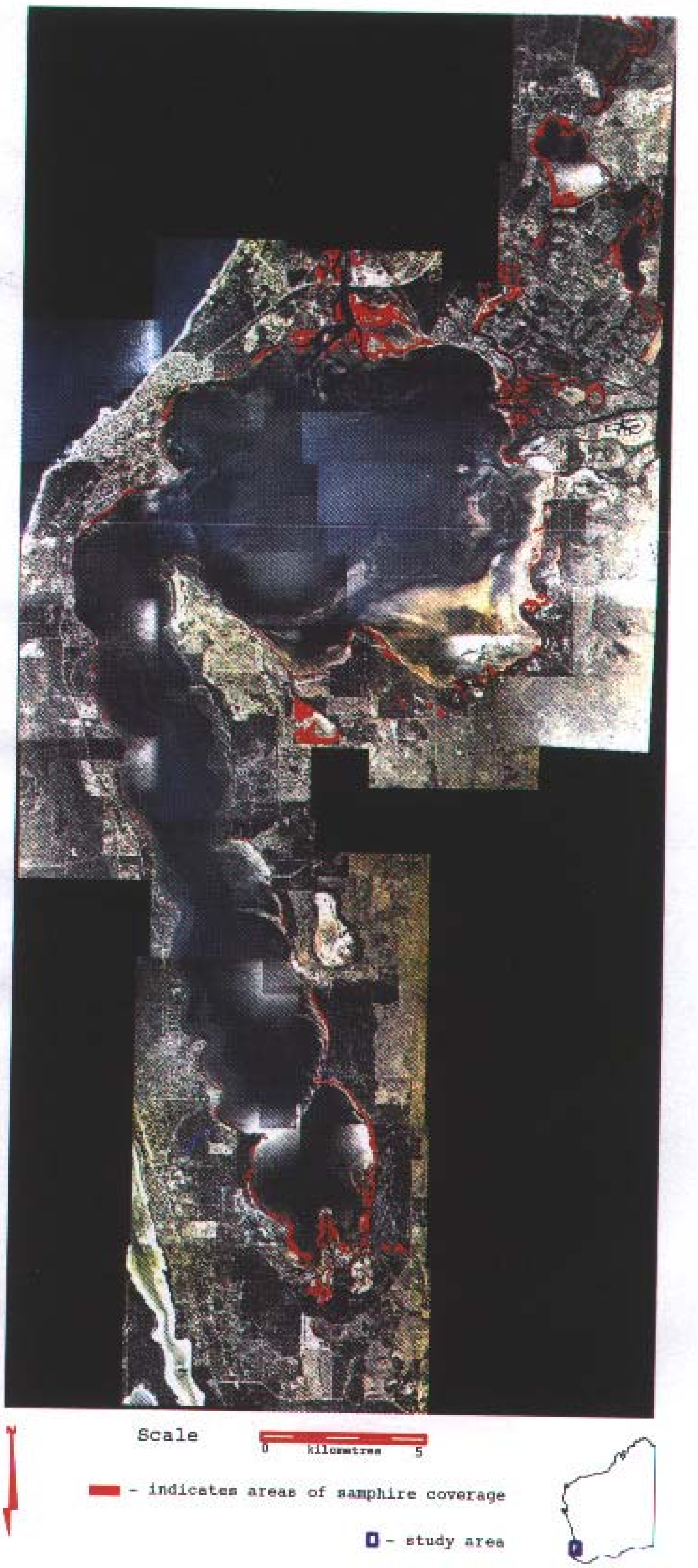

Figure 2.5 Samphire marsh distribution in 1986.

Figure 2.6 Samphire marsh distribution in 1994.

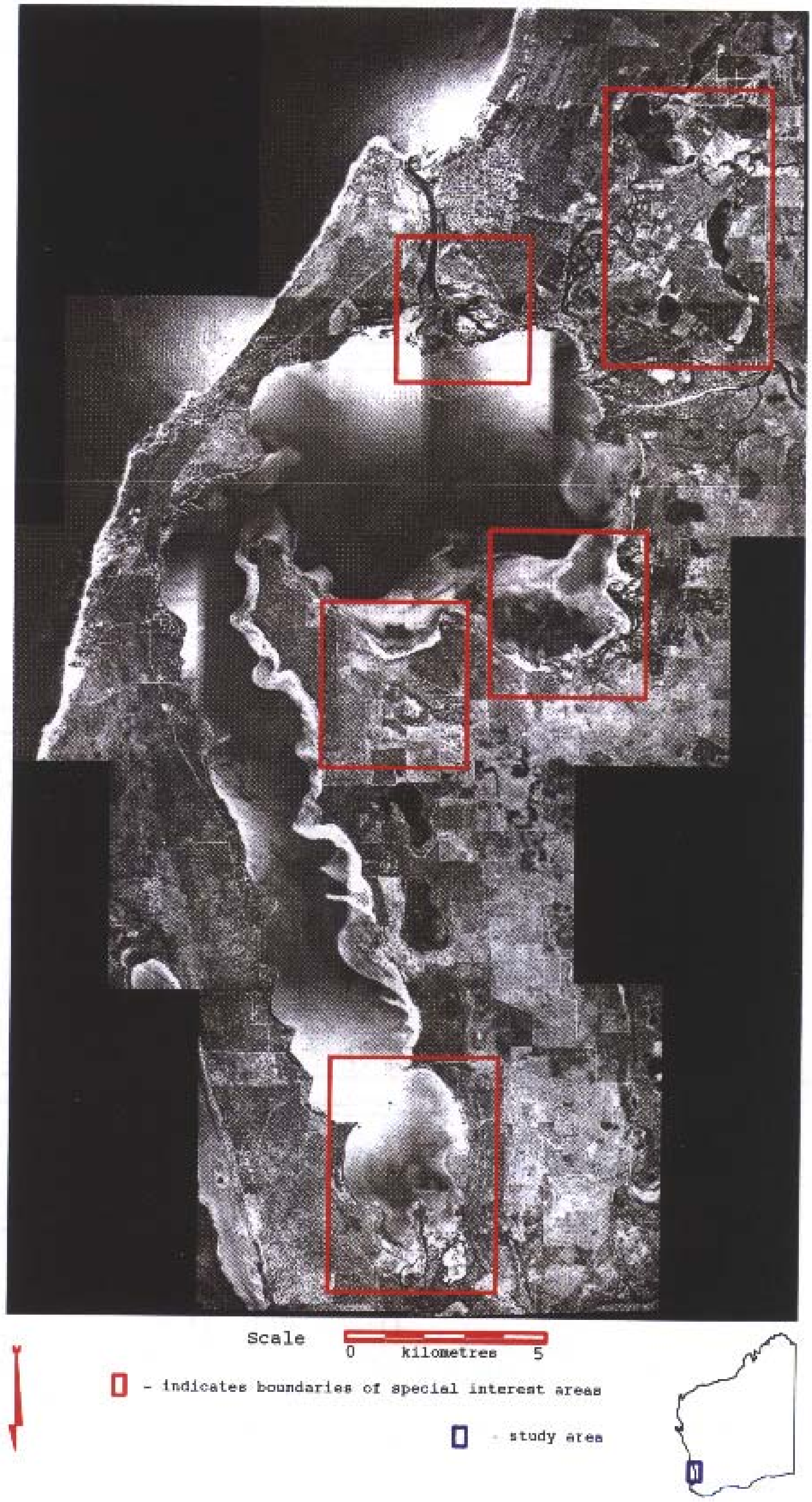

Figure 2.7 Boundaries of special interest areas.

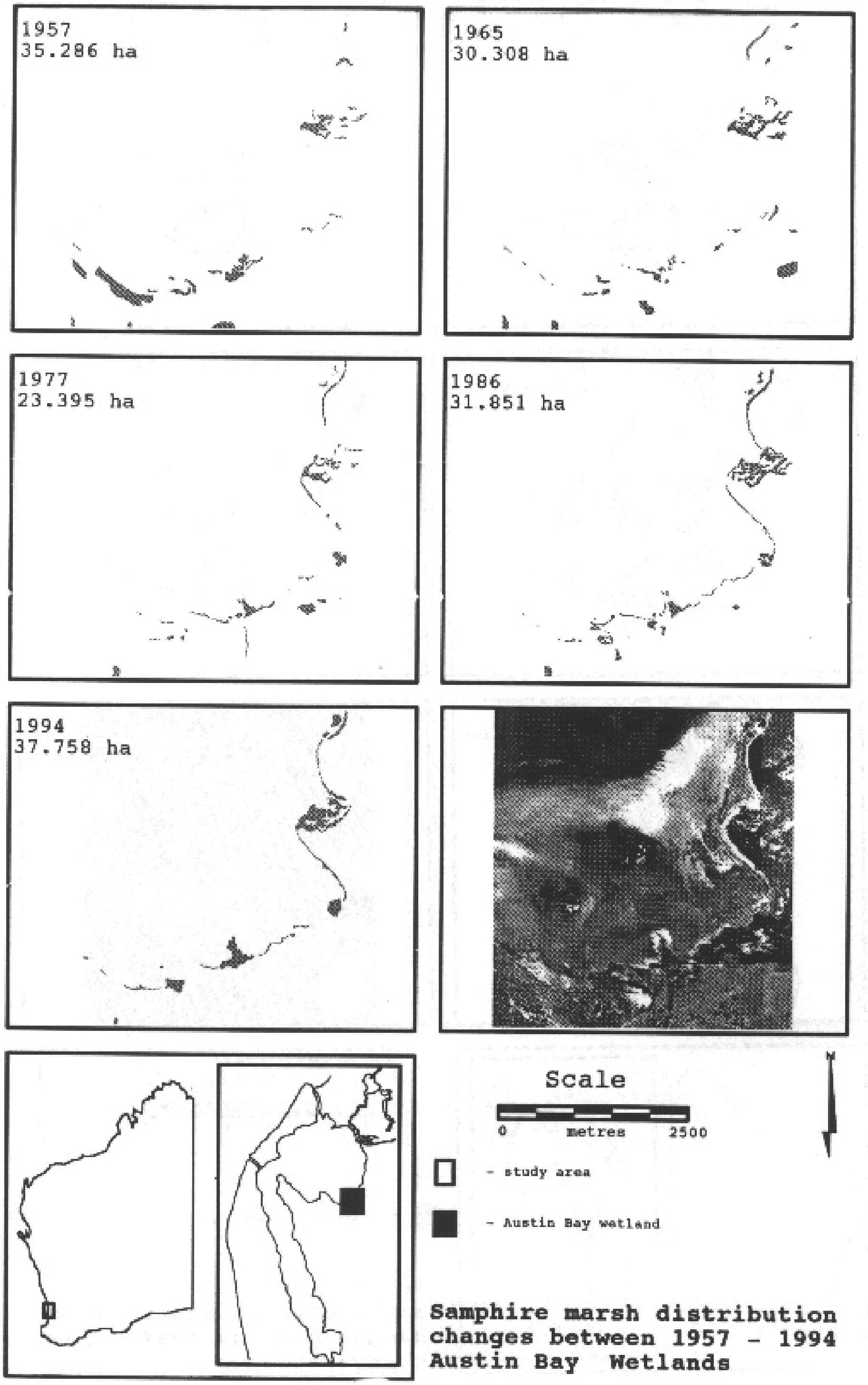

Figure 2.8 Samphire distribution in Austin Bay.

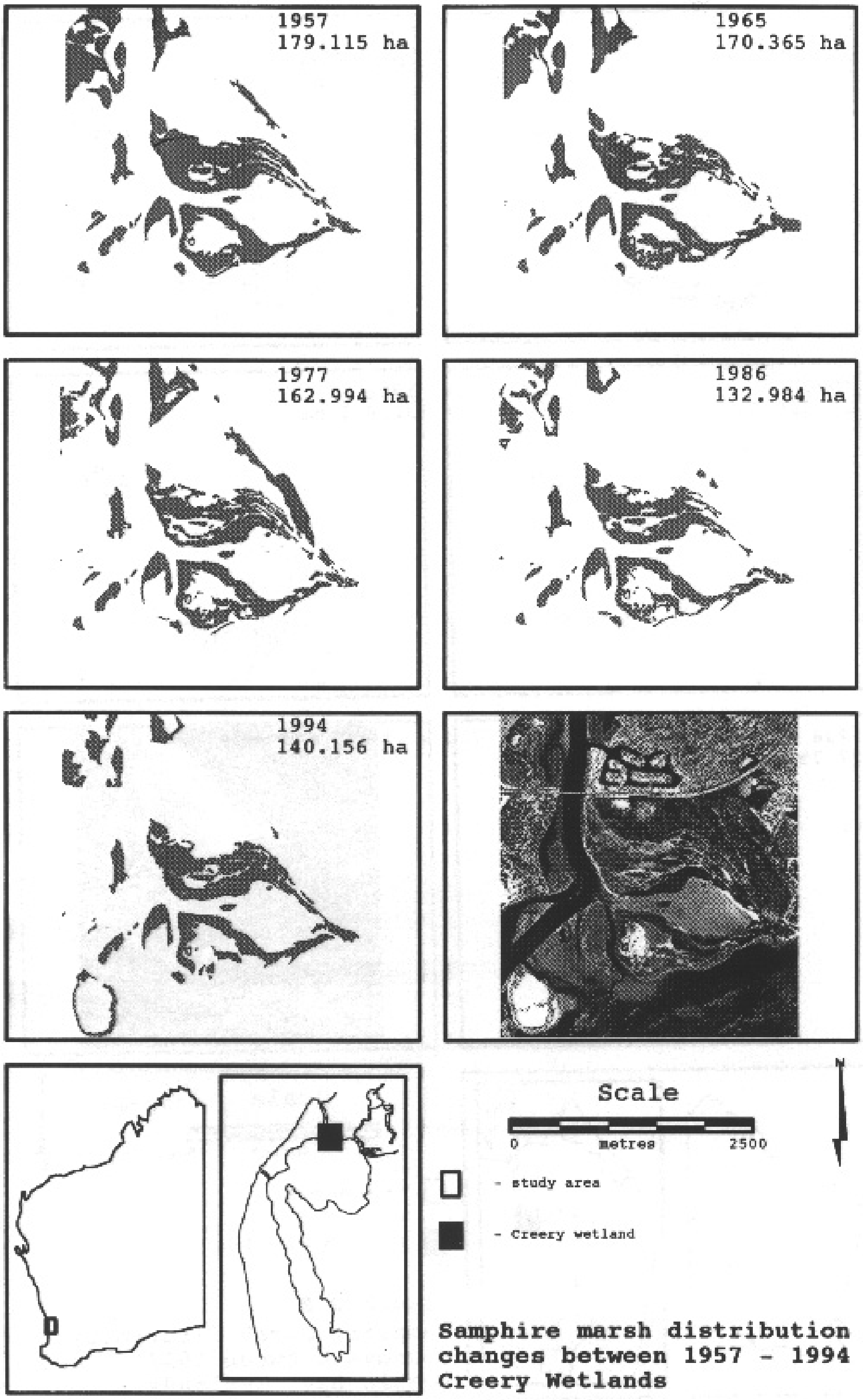

Figure 2.9 Samphire distribution in Creery Wetlands.

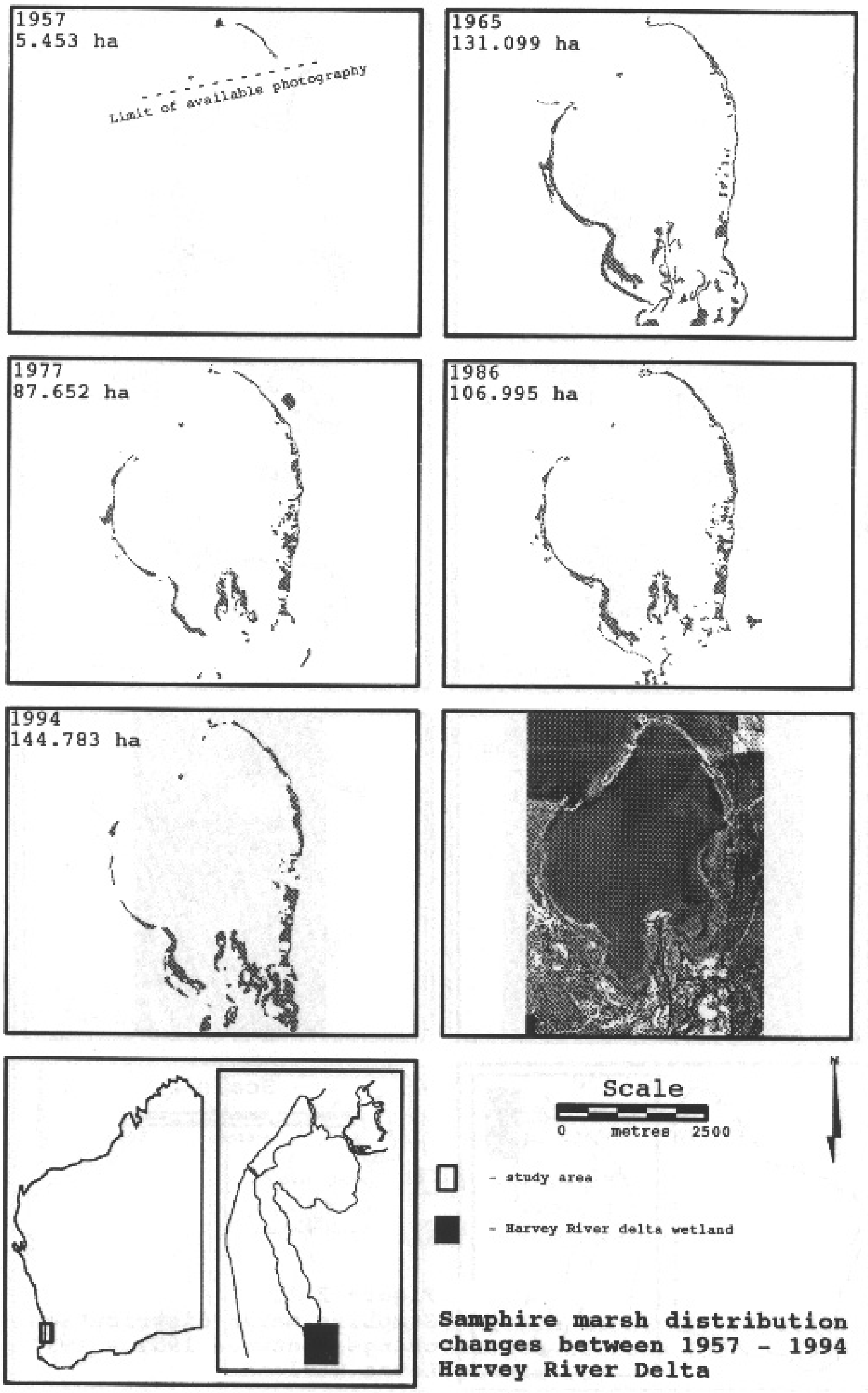

Figure 2.10 Samphire distribution in Harvey River Delta.

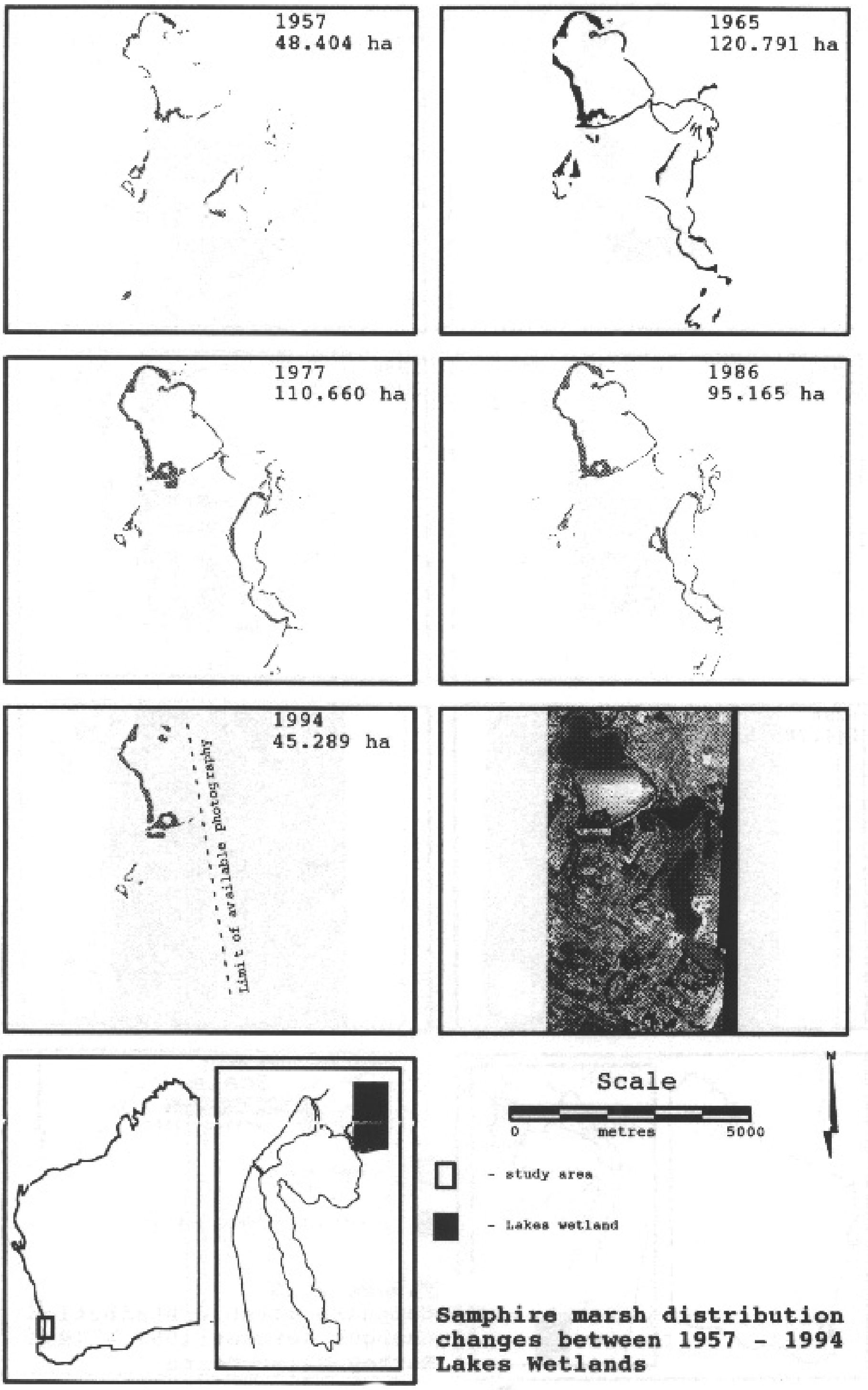

Figure 2.11 Samphire distribution in Lakes area.

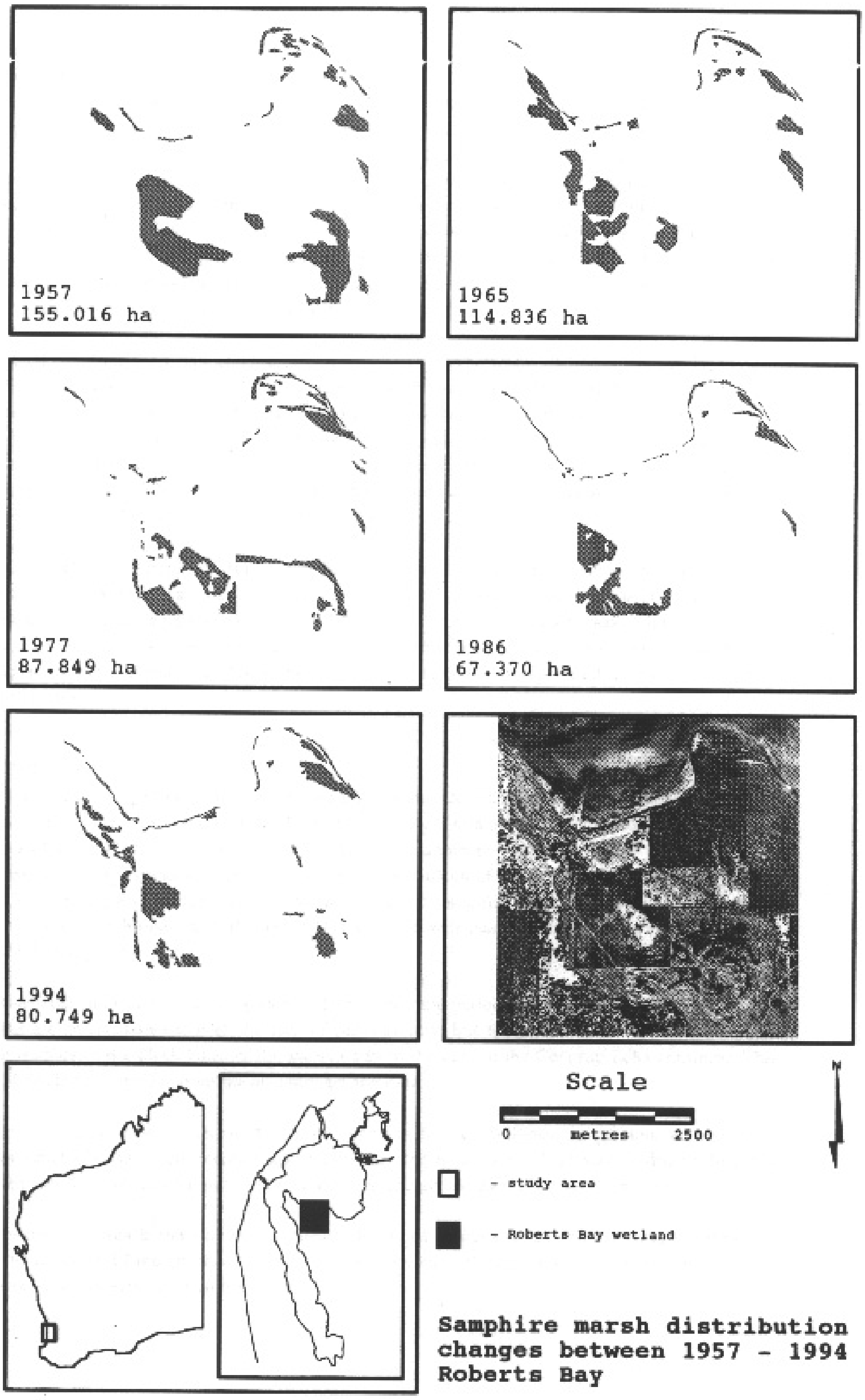

Figure 2.12 Samphire distribution in Roberts Bay.

2.3.1 Quantitative Changes

The areas of samphire are based on the number of pixel's classified as samphire in accordance with the image interpretation, in which the areas are based on pixel units of 20.25 square metres. A decline in the area of samphire marsh took place from 1965 onwards. The greatest percentage loss of saltmarsh cover between 1965 and 1994 (≈58% or 251 ha) occurred outside reserve areas. The greatest percentage loss from an area of interest was in the Lakes area (≈63% or 75 ha) and in Roberts Bay (≈48% or 75 ha). The physical distribution of samphire cover is dynamic and changes for all dates which is consistent with current understanding of the dynamic nature of marsh distribution. Total samphire loss was 36.9% (370 ha) between 1965 and 1994, the greater part of this loss occurring between 1965 and 1986 (376 ha or 37% of the cover of 1965).

The general trend for the whole study area is a significant loss between 1965 and 1986 consisting of a rapid decline between 1965 and 1977 and a slower rate of loss between 1977 and 1986. Between 1986 and 1996 the loss was arrested, and there was a insignificant increase in overall cover (0.8%). Roberts, Lakes, and Creery interest areas showed increased rates of loss between 1977 and 1986. Since 1986 four of the special interest areas have shown increases in cover from previous dates; Austin 18%; Creery 5%; Harvey 35%; and Roberts 20%. Percentage changes are based on the percentage change from the previous period for that specific area, rather than the total area of all marsh.

Some areas behaved differently from the general trends; for instance the Harvey Delta and Austin Bay showed a steady increase in area of samphire since 1977, while all other areas showed decline. The Lakes area showed a marked decline in 1986-1994 period while all other areas of interest showed increased cover. The Lakes area was the only special interest area to show consistent loss since 1965 and its rate of loss is increasing. Overall the trend is seen to be one of rapid decline from 1965 to 1986 and static to 1994.

2.3.2 Qualitative changes

In Creery wetlands the cover continuity of the samphire marsh declined since 1957. This largest single portion of samphire in the study area showed increasing damage from human contact. Increasing numbers of vehicle tracks divided largely continuous samphire marsh. The 1994 image shows a highly disturbed area broken by many tracks. The construction of Boundary Island (south of Creery wetlands) provided an area for samphire colonisation, and samphire invasion is observed in the 1994 image Increasing human disturbance of this wetland will lead to further decline in ecological quality. (See chapter 6).

The Lakes area showed an increasing rate of decline over the period of the study. The 1994 results for this area are inconclusive due to the lack of photography, but the trend of loss is clear from the middle reaches of the Black lakes chain, particularly in the area of the Goegrup Lake entrance. The cause of decline is not clear from the air photography data.

The Harvey Delta showed increased area of samphire in the south-eastern portion, with smaller separate patches of samphire increasing and consolidating their cover. This may be due to different tidal regimes and successional invasion onto the increasingly exposed soil (See chapter 6).

The Roberts Bay area is very dynamic, areas in the north eastern sector showing more continuous cover, while areas in the southern portion showed evidence of rapid and extensive change due to changing land use, especially on private land.

Austin Bay samphire showed consolidation along the shoreline, with smaller patches in the north and eastern sector growing in embayments and increased cover.

Overall the ecological quality of the samphire marsh areas is typically dynamic, individual areas showing evidence of ephemeral changes and succession.

2.3.3 Accuracy Assessment

The interpretation identification error results obtained from comparison of field sites and the interpretation are included in Table 2.3.

Table 2.3 Estimation of identification errors of samphire.

INTERPRETATION/ACTUAL	**SAMPHIRE**	**NO SAMPHIRE**
SAMPHIRE	41 (82%)	9 (18%)
NO SAMPHIRE	12 (24%)	38 (76%)

Samphire was correctly identified with an accuracy of more than 80%, with an 18% chance of overlooking its presence. Where samphire was interpreted not to be present, but was, occurred in 24% of cases. The correct identification of absence of samphire occurred in 76% of cases, and so overall it can be concluded that the interpretations were conservative in estimates and that actual presence of samphire is likely to be higher than reported here.

2.4 Discussion

Where areas of samphire have consolidated cover with time, it is assumed that the ecological niche of the samphire is assured. Conversely where large continuous areas are fragmented then continued presence of the samphire communities and its dependant species may be threatened. In all areas, the distribution of samphire is changing even though total areas may have remained similar. This is accounted for in the ephemeral nature of some of the species occupying the marsh and seasonal differences of biomass of perennial species (See chapter 3 & 6).

Differing water levels between the dates of photography influence the identification of samphire. The 1957 photography was taken at a period of high water, and this influenced the extent of cover estimation. This was particularly evident for the Lakes region. Some areas were clearly flooded in 1957 and were not classified as samphire. The same areas were exposed and identified as samphire in later photo sets. The 1965, 1977, 1986 and 1994 photography was taken during low water levels. It is probable that high water levels tend to mask areas of samphire leading to underestimates of their extent and the converse is also true. This may partially explain the increase in area seen in 1965, and also the relative increase in the rate of loss for 1986, but it is not an explanation for the overall loss trend as this was consistent, with 1965, 1977 and 1994 all being years of low water levels.

The Lakes area for 1957 showed high water levels, and the 1957 estimation is underestimating the samphire for this area. Since 1965 the total samphire for this area declined, but the subset images show that the loss was centred on the middle reach of the Black Lakes area (Figure 2.11). At this point a stream flows in from the north east, and it is possible that this stream has in the recent past either provided a increased flow of fresh water, altering the salinity regime, or is a source of excess nutrients to a competitive species, upsetting competitive relationships causing a decline in the prevalence of samphire.

The altered tidal and water level regimes of the Estuary since the permanent breaching of the Mandurah Channel (1977-1986) may be the reason for the rapid decrease in the area of samphire, and it would be expected that this loss should be arrested when vegetational succession has stabilised. This also appears to be the case for the recent small losses, in the 1986-1994 period. Further disruption to vegetation cover can be expected with the recent opening of the Dawesville channel, which should lead to further successional changes in the vegetation cover as a result of water level changes. Vegetation loss due to changing hydrology and other factors has already observed by catchment management authorities (George and Bradby, 1993).

Increased opportunities for saltmarsh invasion have occurred with the construction of Boundary Island south of the Creery wetlands. This accounts for the increase shown in the Creery area in 1986 -1994.

Another influence on the estimation of samphire is the cyclic water level changes experienced over the study period. During 1965, 1977 and 1994 the rainfall for the preceding months prior to the air photography was below average. For 1986 and 1957 the rainfall was well above average. Prior to 1977, rainfall would have had an effect on the water levels of the Estuary, as the only channel was prone to closure. This explains the low coverage seen in the Lakes area due to the elevated water levels in 1957 and the high levels in 1965 where the water level is low. This indicates that the levels of samphire recorded in 1965 and 1977 are maximised as the water levels would favour the interpretation. This implies that 1977 provides a good estimate of the total samphire both due to the favoured water levels and the infra-red photography.

Even if adjustment is made for the lack of photographic cover over the Harvey delta, and it is assumed that the area in the Harvey delta remained constant between 1965 and 1977 then there has been a steady decline in the total area of samphire since 1957. The overall loss is worrying but the parallel decline in quality of remaining areas is also of great concern. This is particularly so in the Creery wetland area which presents one of the largest contiguous areas in the whole system. Its present accessibility (and therefore threatened position) also means it's future planning demands the highest priority for management consideration (See chapter 7).

The scanning and initial photo mosaic of the orthophotographs has shown that the spatial accuracy of the orthophotographs is questionable. Enquires of DOLA reveal that a spatial accuracy of 12.5 m is obtained in the initial modelling of the orthophotographs. Measured mismatching of the edges of the orthophotographs revealed inconsistencies in both X and Y directions. This was initially thought to be the result of scanning errors introduced by the physical method used for orthophoto scanning. Consequently the images were rescanned at a higher resolution, and at the same time a comparison was made with a scan of a calibration image supplied to the scanning agency by DOLA.

The scan of the calibration image revealed a measured error of 4 mm over a diagonal distance of some 1200 mm. Measured mismatch errors between scan overlap of adjacent orthophotographs revealed distance discrepancies of up to 60 m. This discrepancy was not distributed evenly across the length of the orthophotograph but was randomly distributed along the adjoining edges. This error would result from the original orthophoto image production, and so the 12.5 m spatial accuracy for the production of orthophotographs by DOLA can be considered the goal rather than the achieved result. The displacement of the same feature can be measured where the orthophoto image files overlap. The maximum measured displacement was 60 m. The maximum measured error of 60 m is not considered to be the achieved accuracy of the overall orthophoto, as the true geographical location of displaced GCP's could only be measured in the field after considerable effort. It was assumed that a spatial accuracy of one half of this distance (by assuming each GCP is incorrect and therefore both have to be moved to merge) or 30 m should be used as the overall accuracy.

The scanned aerial photographs were resampled to conform with the orthophotos. This process achieved a better than 0.6 RMS (root mean squared) error in pixel relocation. Scanned photos therefore are considered to be within 1.2 m accuracy **of the orthophoto image.** In conclusion, a spatial accuracy of (±) 31 m can be assumed for the photomosaic image.

Different scales of photography contributed to some problems in photo interpretation. The 1965 set at a 1:40000 scale proved particularly difficult. This was also due to this set being black and white photography with relatively poor contrast. Some small areas of samphire were very difficult to resolve at that scale. Prior to 1977 black and white photography was the standard and hence was the only available option. Misinterpretation is more likely to occur with the black and white photography due to the inherent difficulty of vegetation discrimination based on colour or tone. Conversely the infra red photography of 1977 enabled a more precise estimation of vegetation cover and type. Comparison of samphire cover over the differing dates is therefore constrained by the limitations of the differing photography used in the study.

In the 1994 photography, low sun angle resulted in a large degree of shadow within areas of vegetation, which produced greatly contrasted images. This was to some degree a trade off for water penetration which was very good, and which reduced the specular reflection off water. In 1965 photography on the other hand, solar angle was high and large areas of solar reflection are apparent (Figure 2.3).

The air photographs were taken with a 25% edge overlap and a 60% forward overlap. The 25% overlap was insufficient for edge matching of raster files where the runs are not north/south or east/west. During georeferencing images are geometrically altered to conform with mapping conventions (that is north is the top of the page). The insufficient overlap results from the image being resampled at an angle after georeferencing, which produces edge triangles of null data as shown in Figure 2.13. To obtain image files without null data values requires the production of two sub-images for each air photograph. This was required because of a problem in the software, which does not allow elimination of null file values from the edge overlap reduction. The problem is being investigated by software supplier, ESRI.

Contrast matching of the final image was attempted but resulted in an as yet unidentified error with the software. This resulted in the corruption of the file statistics of the 80 images of the final mosaic. The file statistics were individually recalculated for the entire set and the final images were produced without contrast matching. Contrast matching was achieved to some degree during the cubic convolution resampling process of the smaller 8 Mb files so these images are aesthetically the best. The greatest detail resolution (about 3 m on the ground) is maintained in the ≈ 200 Mb files.

2.5 Recommendations/Conclusions

Samphire areas within the Peel-Harvey estuary are declining both in quality and quantity. The greatest areal loss has occurred outside reserve areas. Reserve areas and those of special interest are showing evidence of decline in quality of samphire cover. Decline in the quality of samphire can further accelerate loss and degradation of vegetation and animal species. The loss of samphire from the Creery wetlands presents a urgent case for management consideration due to the proximity to urban development and development pressures in general and also because this area represents one of the largest remaining contiguous areas of samphire. This should not be interpreted that other areas are less deserving of management consideration but that Creery wetland represents unique opportunities for preservation and conservation and its current land tenure requires urgent management consideration. Its conservation and preservation should be considered a high priority.

If serious spatial mapping considerations are part of the photo mosaic process then the Orthomax component of *Imagine* should be used to increase the rectification capacity of the air photograph images. This will allow a greater portion of each air photograph to be included in the final mosaic resulting in decreased file space requirements and time.

Any spatial accuracy of the final product will depend to a large degree on the spatial accuracy of the georeferenced database. Orthophotographs provide a reasonably accurate and cost effective method of providing this spatial information providing that the error associated with the **individual** orthophoto is known. That is the error inherent **within** each orthophoto and **between** orthophotographs when more than one is used. Where spatial accuracy is to be greater than that of the available orthophotographs then other methods should be investigated. This requirement may be negated by the procurement of orthophotographs at a larger scale than the final scale for study area where the study area size and file space requirements permit this and were possible procurement of orthophotographs is in the required digital format.

The contrast of any photography used is important in the aesthetic value of the final composite mosaic. This is most apparent where imagery which is used was flown for specific purposes such as high water penetration and the low incident solar angle results in hot spots or large shadow effects in areas of vegetation. Where large areas of the image are water and specular effects are apparent then this can detract greatly from the final aesthetic value of the mosaic. This may be avoided where large overlaps are available and cost is not determinant in the procurement of photography so that all photographs may be used rather than every second photograph.

Differing colour balance between individual photographs may occur if all photographs of the study area are not purchased at once. Where this is not possible and colour balance is a problem, provision of existing photography to the film developer can enable correct matching.

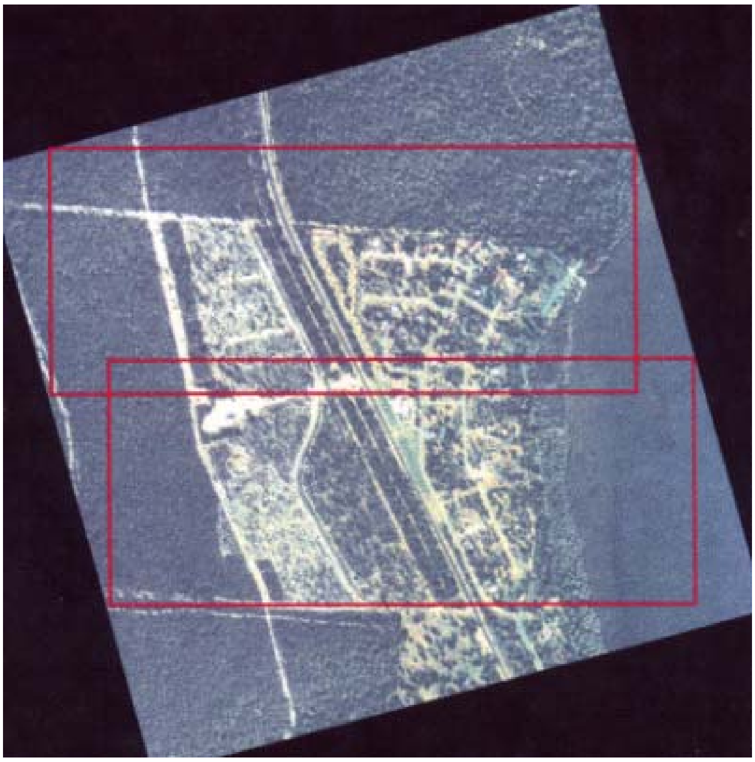

Figure 2.13. Air photograph raster image after georeferencing and resampling showing image portions of null data (in black) as a result of flight lines other than north/south or east/west. Red rectangles represent areas of subset images excluding the null file values.

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

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

3.1 Introduction

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

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

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

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

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

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

3.2 Extent of the Saltmarsh

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

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

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

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

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

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

3.3.1 Methods

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

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

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

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

3.3.2 Results and Discussion

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

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

Species Occurrence

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

Sarcocornia quinqueflora

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

Suaeda australis

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

Bolboshoenus caldwellii

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

Halosarcia ***species***

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

Frankenia pauciflora

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

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

Juncus kraussii

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

Atriplex species

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

Cotula coronopifolia

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

Zonation of Plant Communities across the Marsh

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

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

SARCOCORNIA COMPLEX *Sarcocornia quinqueflora*

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

JUNCUS COMPLEX *Juncus kraussii*

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

HALOSARCIA COMPLEX *Halosarcia halocnemoides*

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

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

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

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

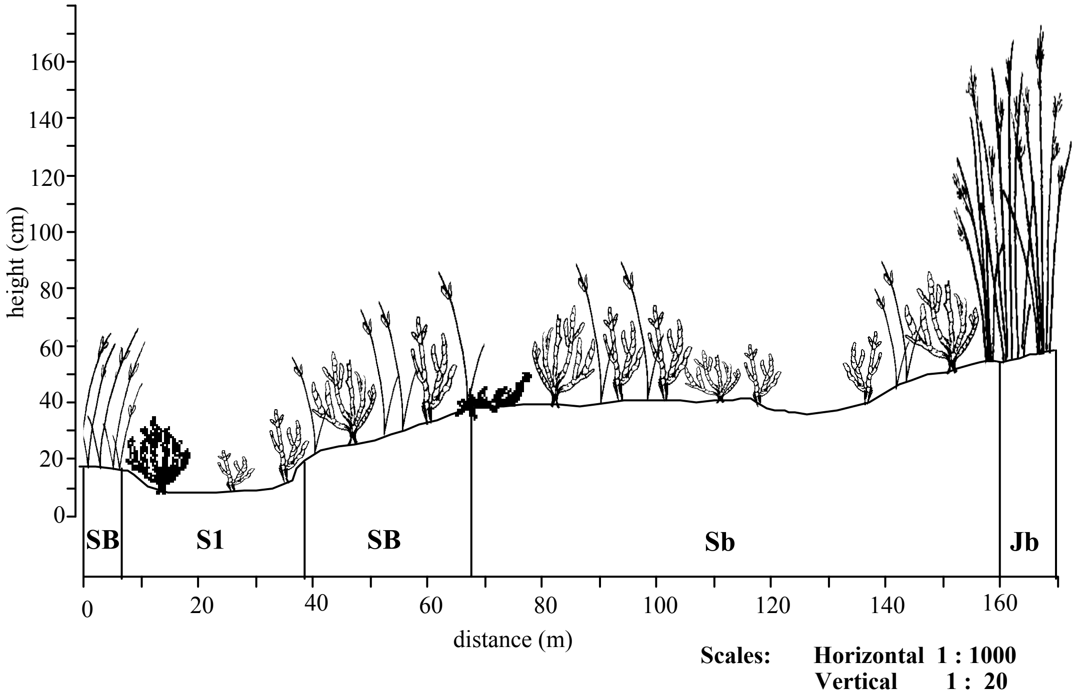

Figure 3.1. Saltmarsh communities along the South Harvey Estuary transect (Site 10) during summer (see Figure 1.1 for locality).

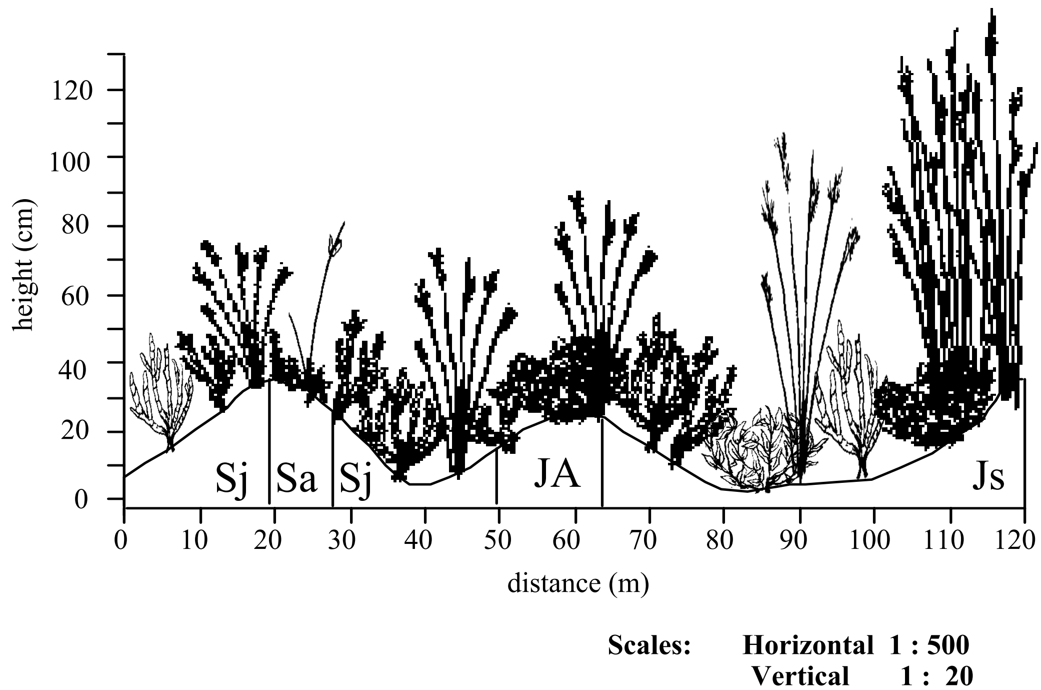

Figure 3.2. Saltmarsh communities along the Worallagarook Island transect (Site 6) during summer (see Figure 1.1 for locality).

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

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

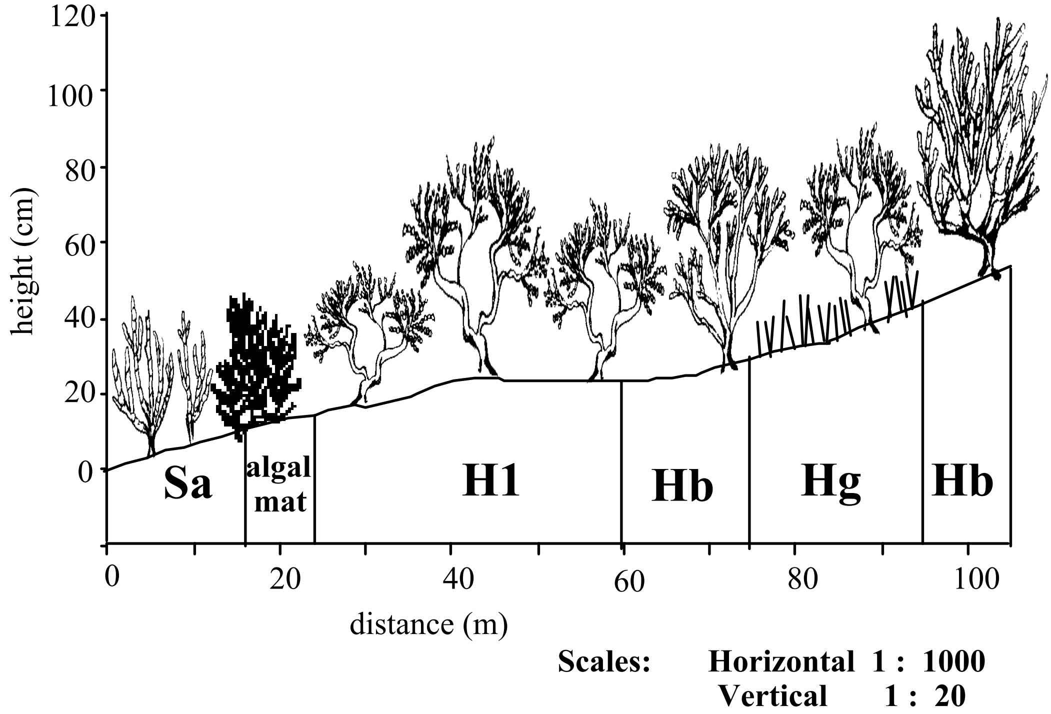

Figure 3.3. Saltmarsh communities along the East Peel Inlet transect (Site 7) during summer (see Figure 1.1 for locality).

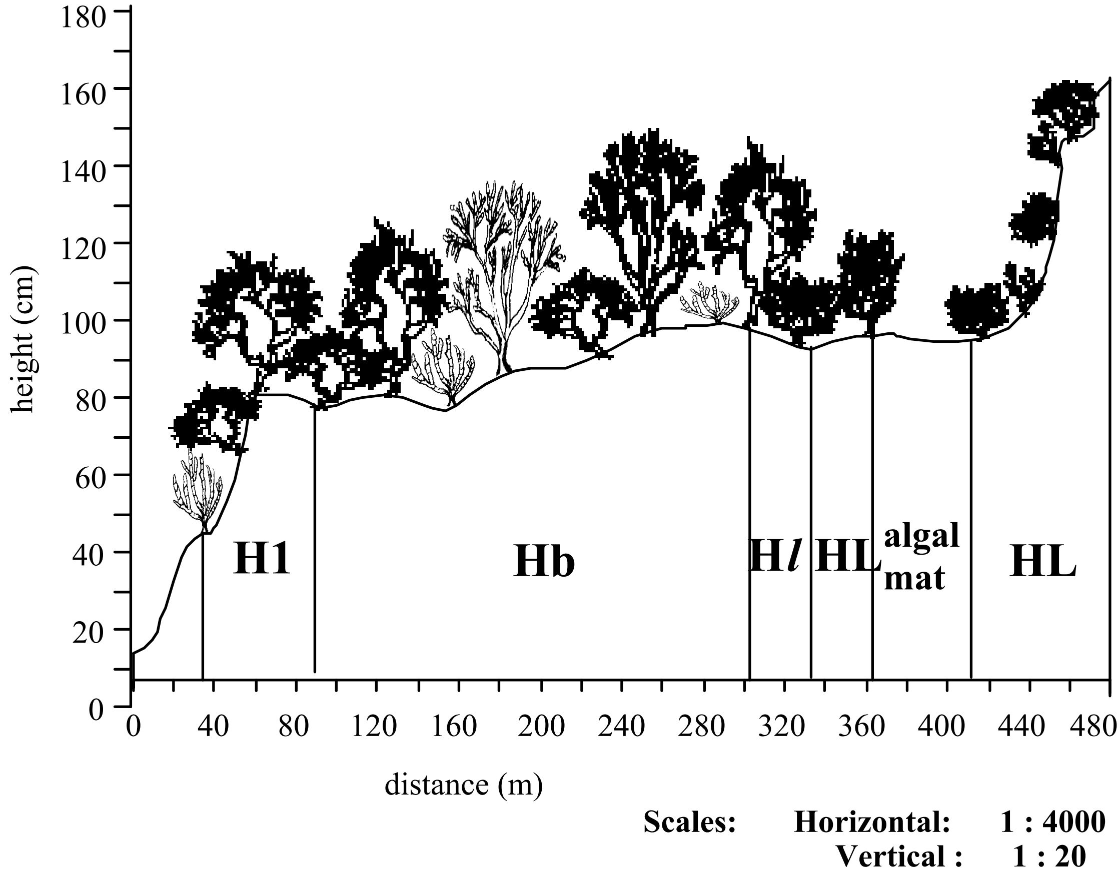

Figure 3.4. Saltmarsh communities along the Creery Wetlands transect (Site 5) during summer (see Figure 1.1 for locality).

Percentage Cover

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

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

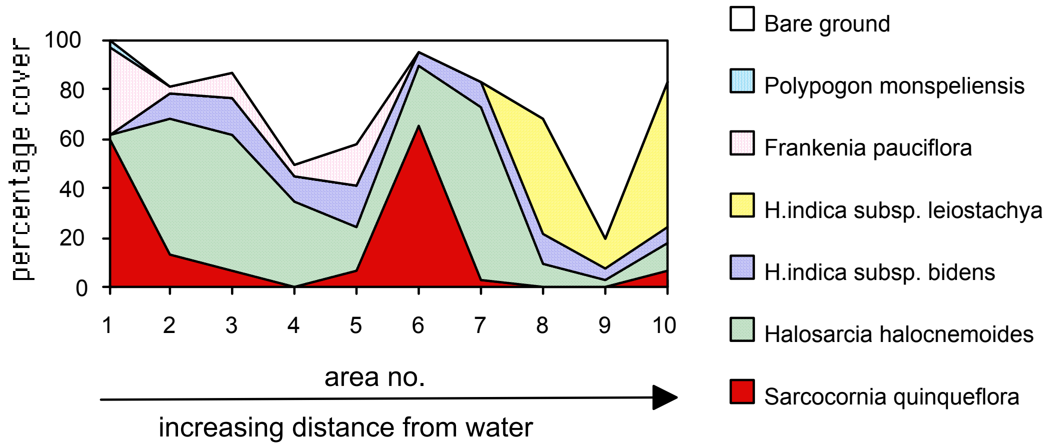

Figure 3.5. Percentage cover at Creery wetlands (Site 5, see Figure 1.1 for locality).

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

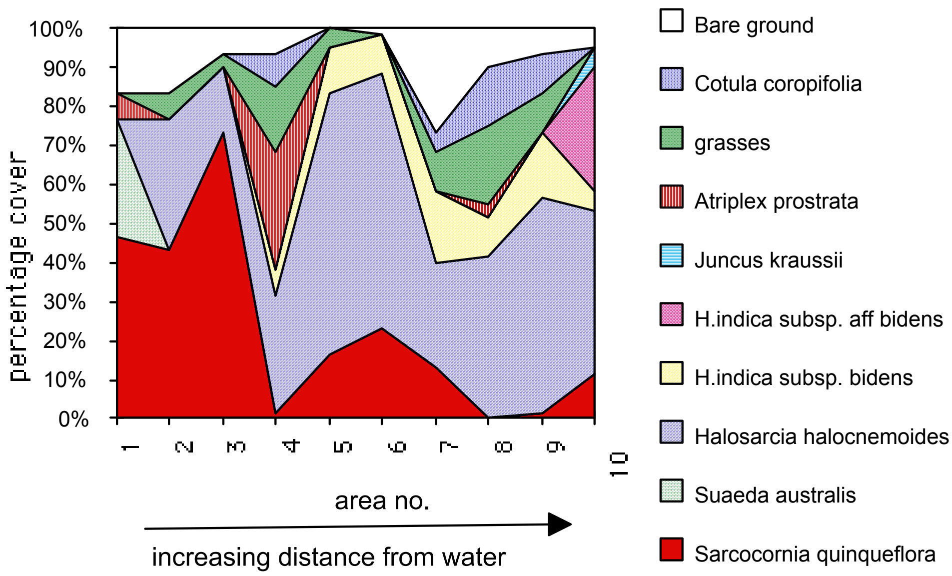

Figure 3.6. Percentage cover at the east side of Peel Inlet (Site 7, see Figure 1.1 for locality).

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

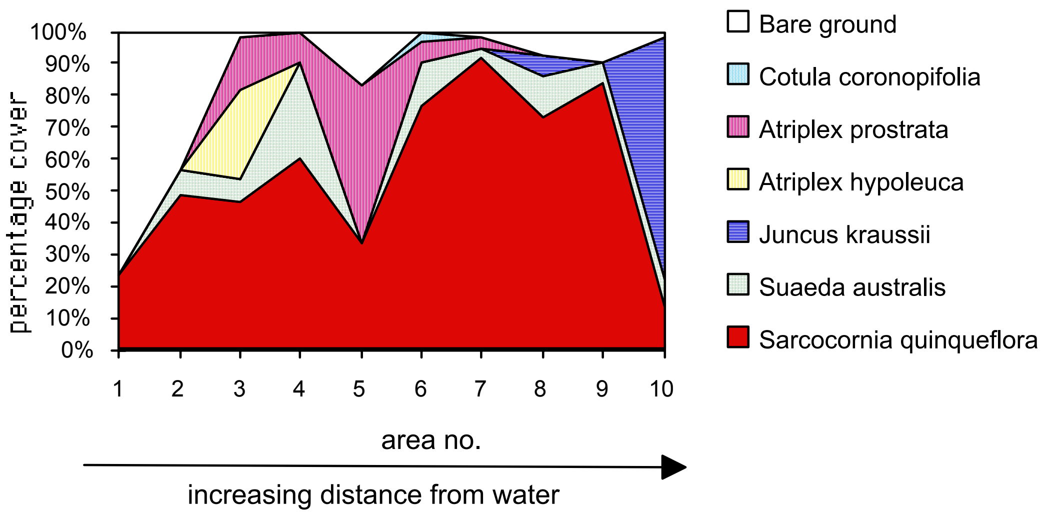

Figure 3.7. Percentage cover along a transect (Site 9) of Harvey Estuary (see Figure 1.1 for locality).

Biomass of Saltmarsh Vegetation

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

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

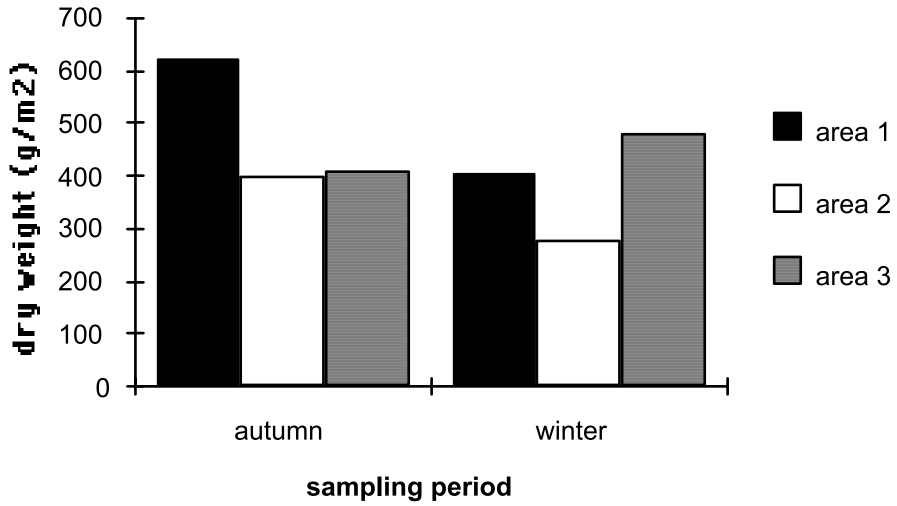

Figure 3.8. Seasonal biomass across Lake Goegrup transect (Site 2, see Figure 1.1 for locality).

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

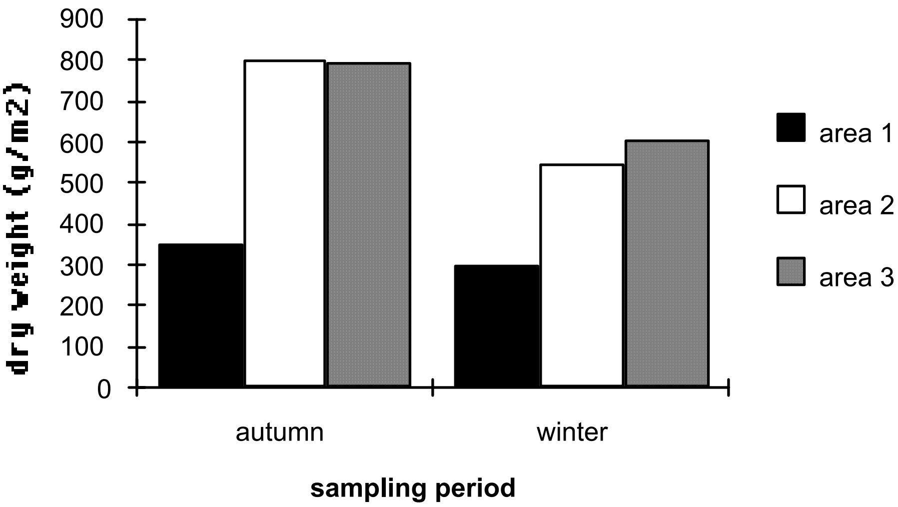

Figure 3.9. Seasonal biomass across East Peel Inlet transect (Site 7, see Figure 1.1 for locality).

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

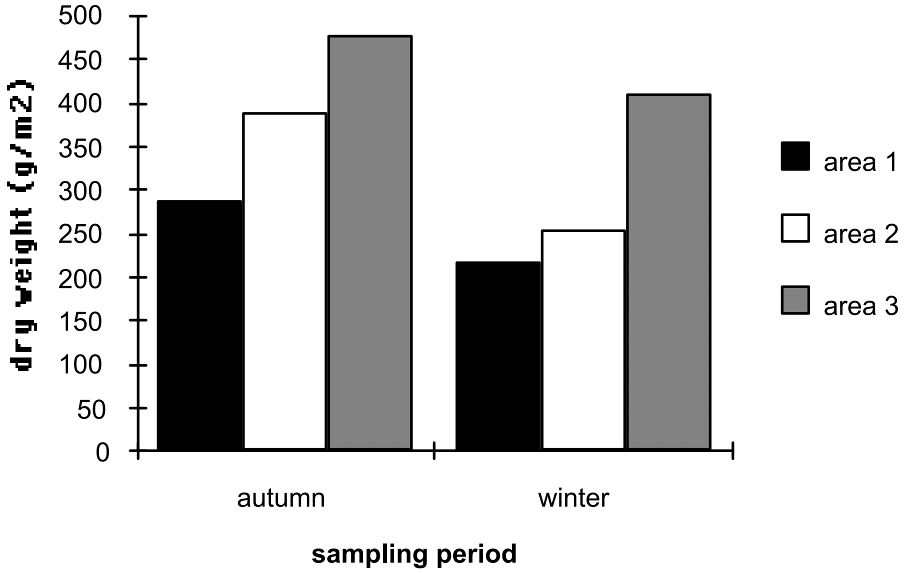

Figure 3.10. Seasonal biomass across East Harvey estuary transect (Site 9, see Figure 1.1 for locality).

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

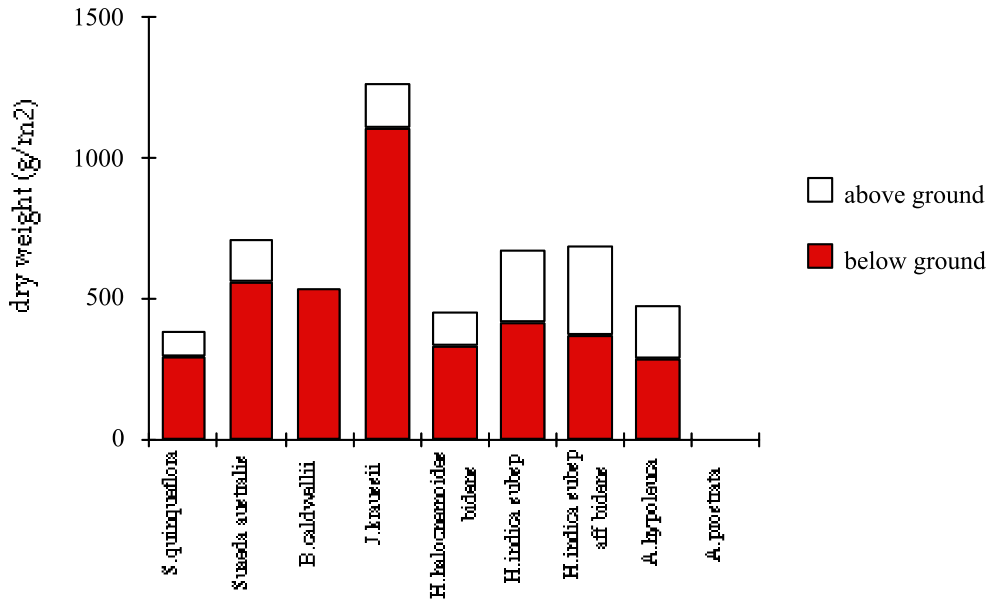

Figure 3.11. Above and below ground biomass of selected species during autumn.

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

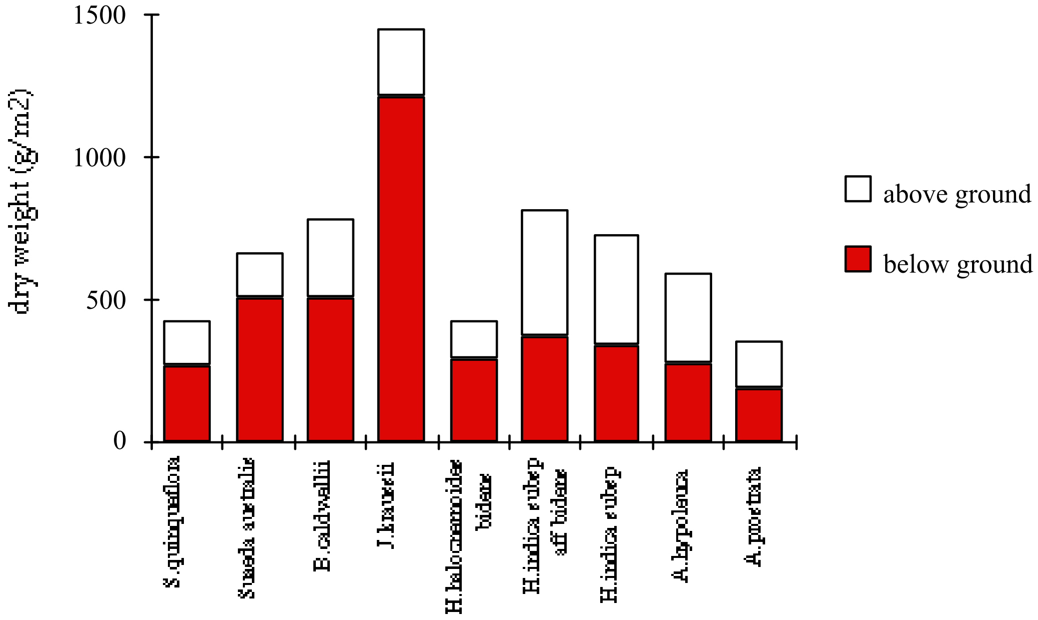

Figure 3.12. Above and below ground biomass of selected species during winter.

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

Seasonal changes in the nutrient content of saltmarsh vegetation.

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

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

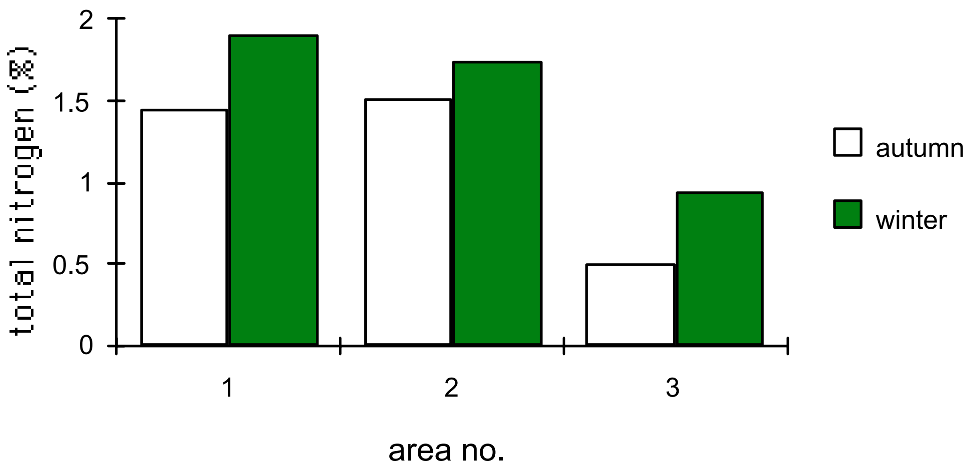

Figure 3.13. Concentration of total nitrogen (% dry weight) in autumn and winter along East Harvey Estuary transect (Site 9, see Figure 1.1 for locality).

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

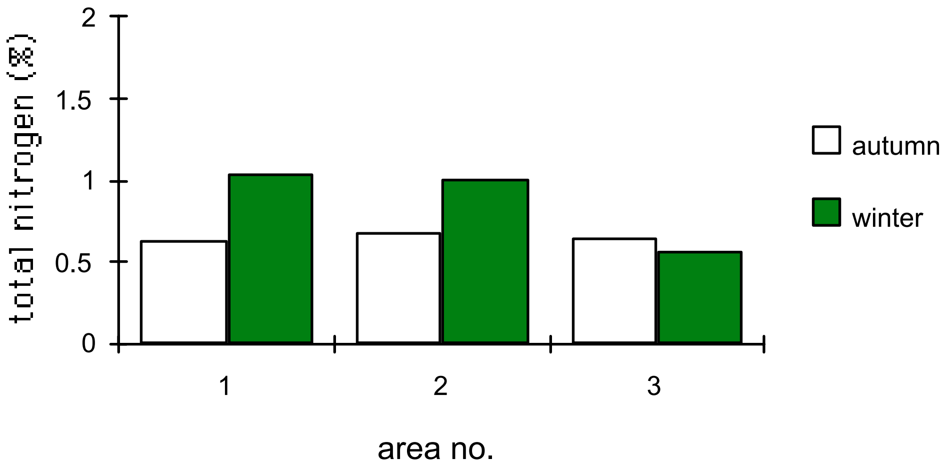

Figure 3.14. Concentration of nitrogen (% dry weight) in autumn and winter along a transect at the south Mandurah Channel transect (Site 4, see Figure 1.1 for locality).

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

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

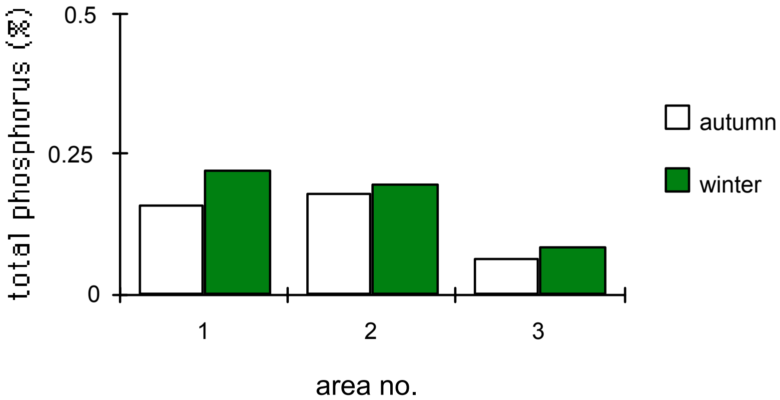

Figure 3.15. Concentration of total phosphorus in autumn and winter along East Harvey Estuary transect (Site 9, see Figure 1.1 for locality).

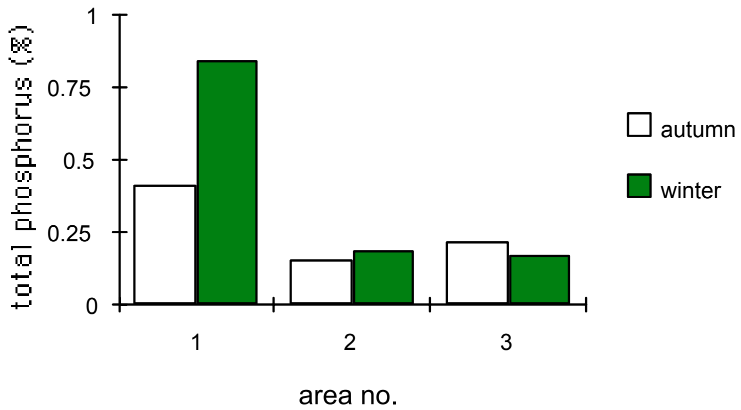

Figure 3.16. Concentration of total phosphorus in autumn and winter along South Mandurah Channel transect (Site 4, see Figure 1.1 for locality).

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

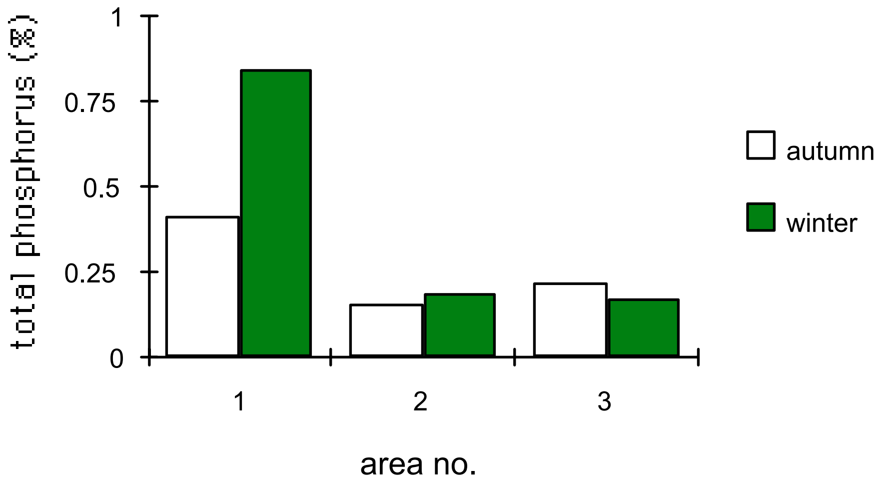

Figure 3.17. Concentration of total phosphorus in autumn and winter along Lake Goegrup transect (Site 2, see Figure 1.1 for locality).

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

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

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

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

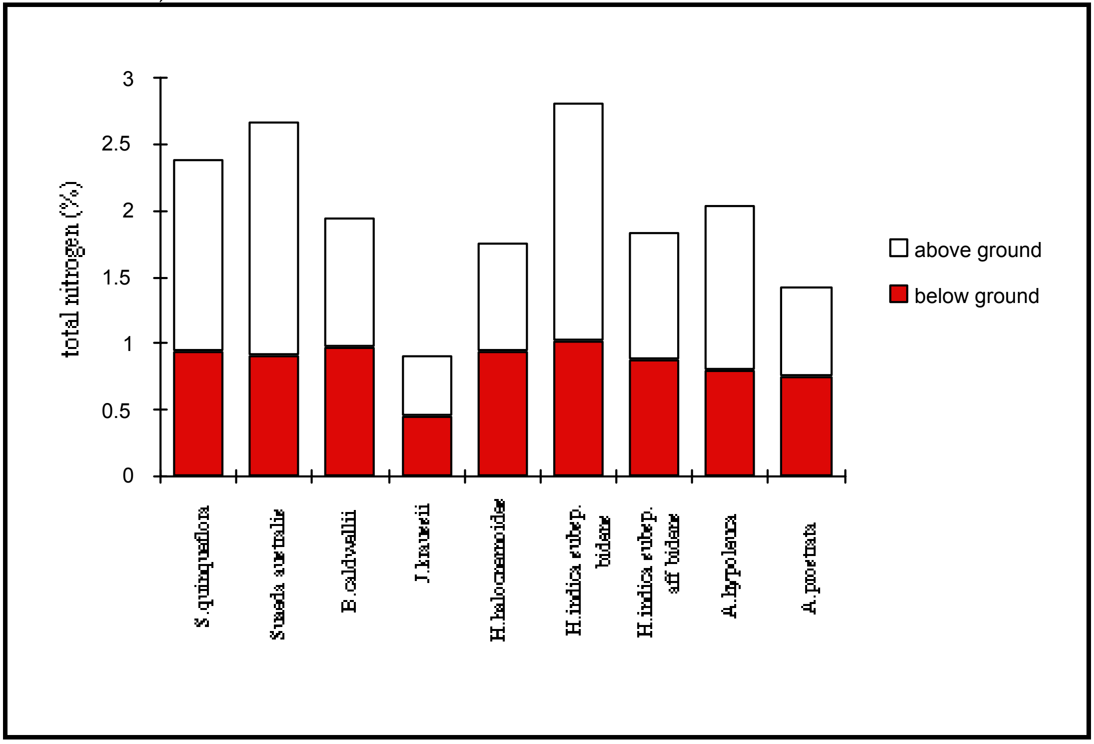

Figure 3.18. Total nitrogen concentrations (% dry weight) in the above and below ground components of saltmarsh vegetation in autumn.

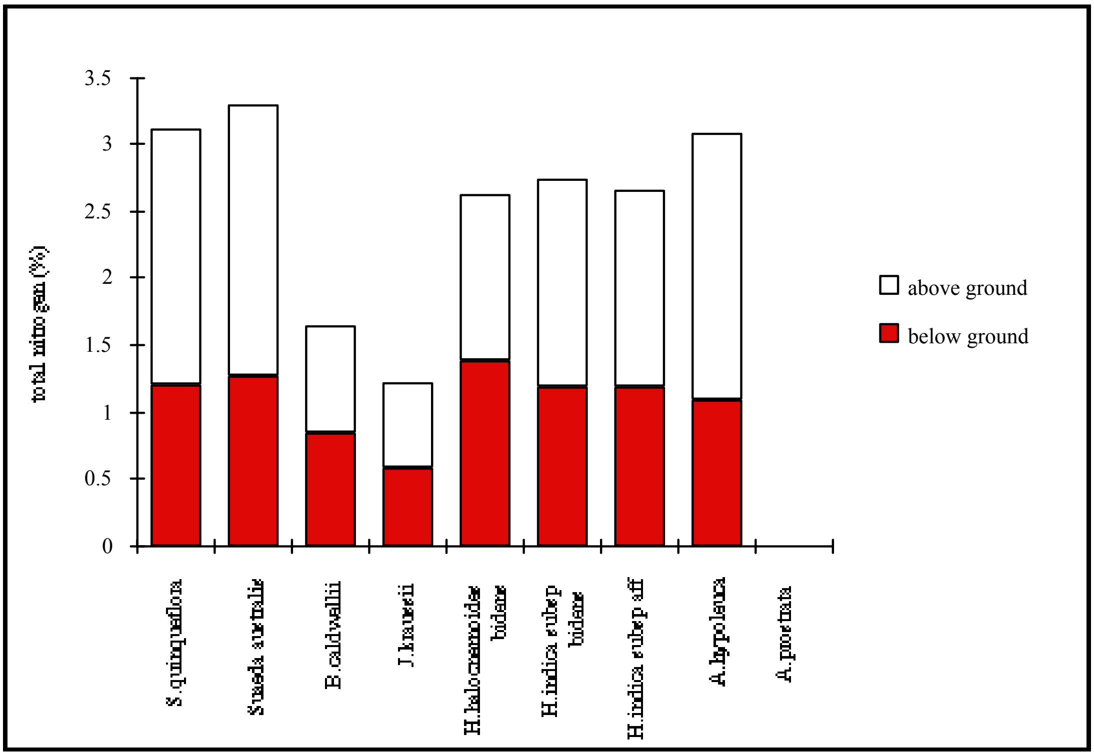

Figure 3.19. Total nitrogen concentrations (% dry weight) in the above and below ground components of saltmarsh vegetation in winter.

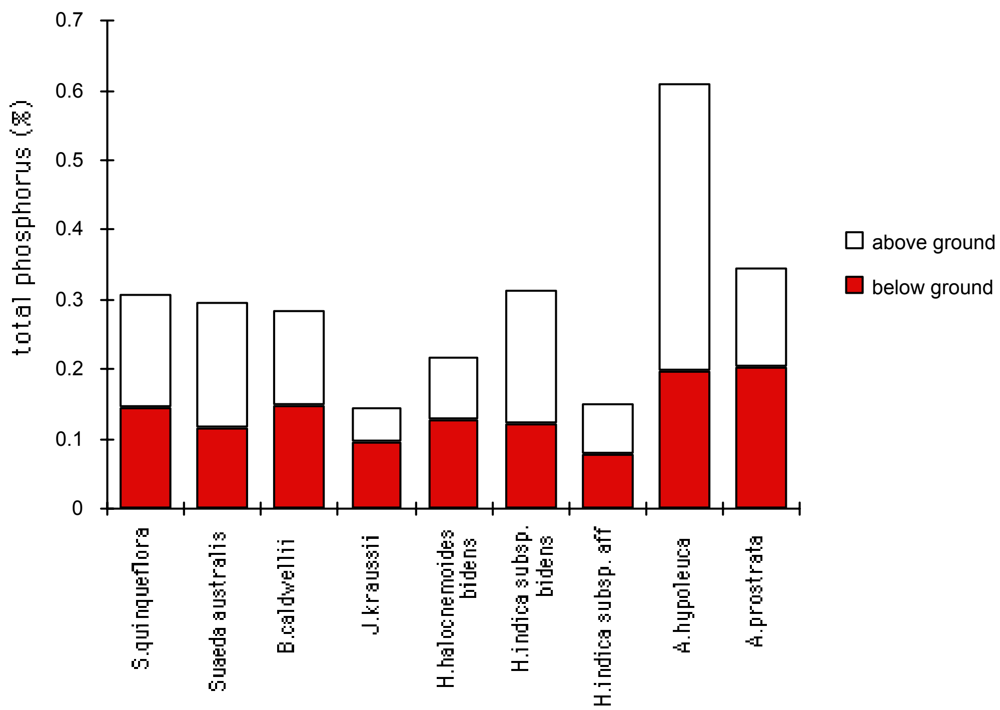

Figure 3.20. Total phosphorus concentrations (% dry weight) in the above and below ground components of saltmarsh vegetation in autumn.

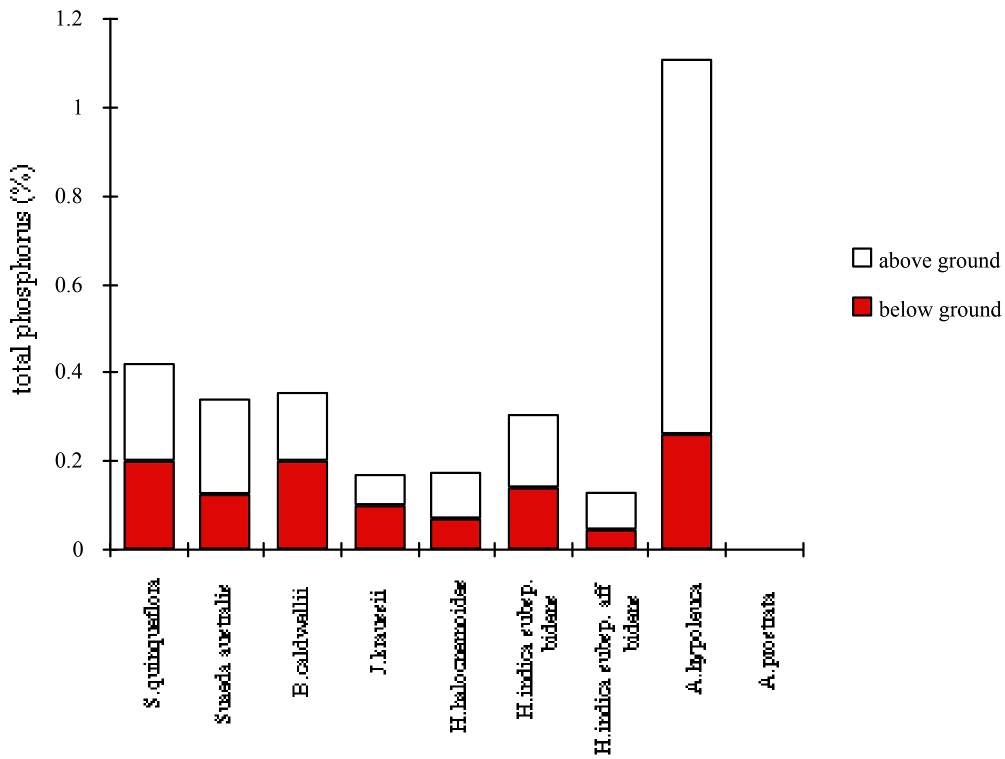

Figure 3.21. Total phosphorus concentrations (% dry weight) in the above and below ground components of saltmarsh vegetation in the winter.

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

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

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

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

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

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

3.4 Conclusions

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

CHAPTER 4 Water Regimes And Marsh Distribution

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

4.1 Introduction

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

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

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

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

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

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

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

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

4.1.1 Changes brought about by the Dawesville Channel

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

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

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

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

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

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

4.1.2 Possible effect of changing tidal regime on saltmarsh vegetation

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4.2 Method

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

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

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

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

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

4.3. Results and Discussion

4.3.1 Relation of tidal inundation to saltmarsh communities along transects

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

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

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

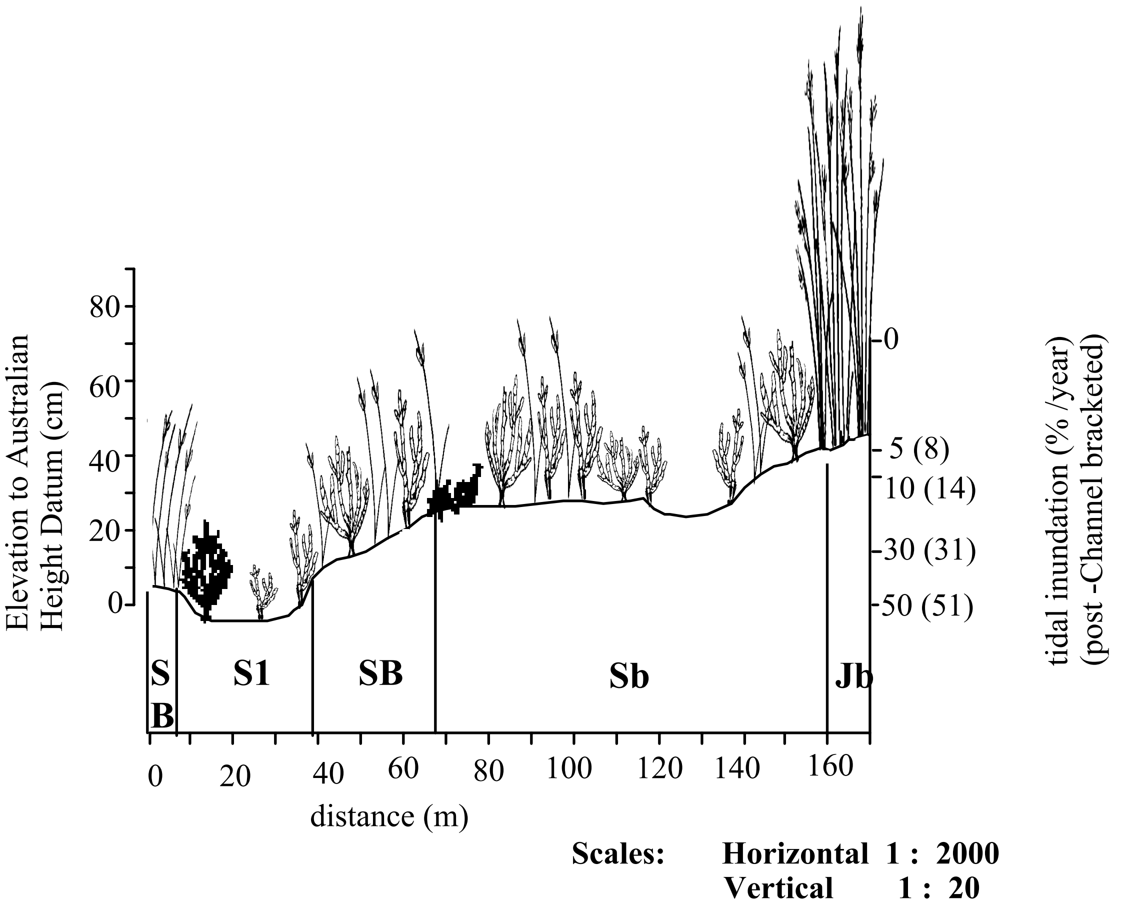

Figure 4.2. Frequency of tidal inundation and vegetation units along the South Harvey Estuary transect (Site 10).

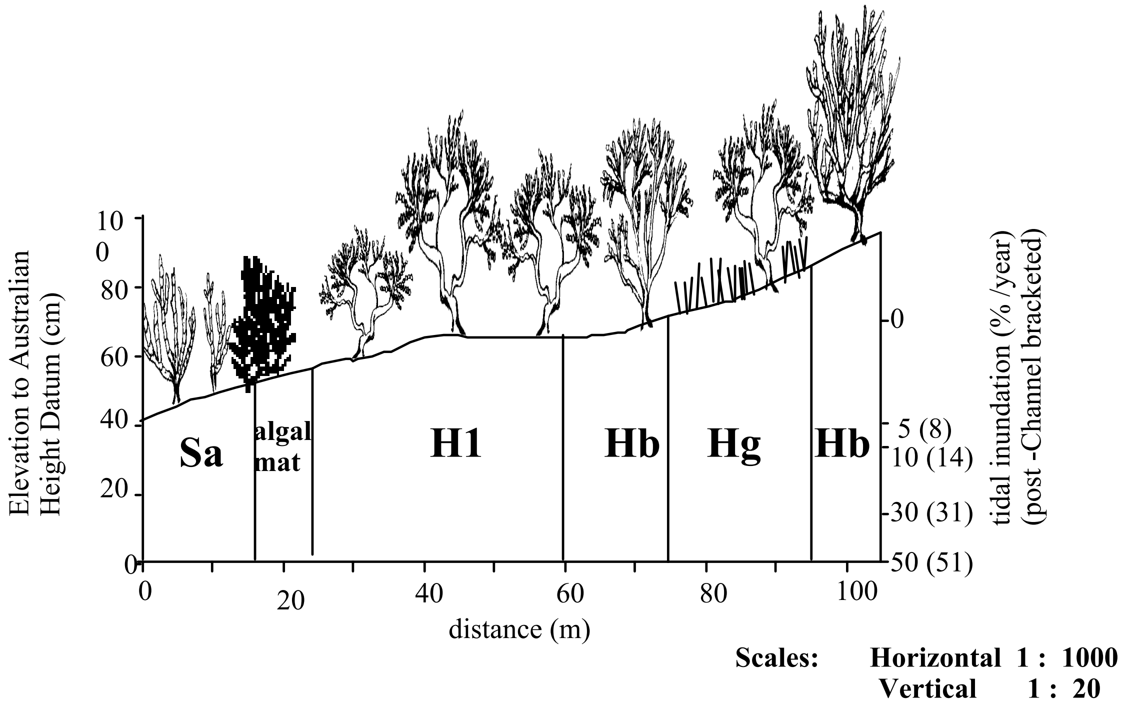

Figure 4.3. Frequency of tidal inundation and vegetation units along the East Peel Inlet transect (Site 7).

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

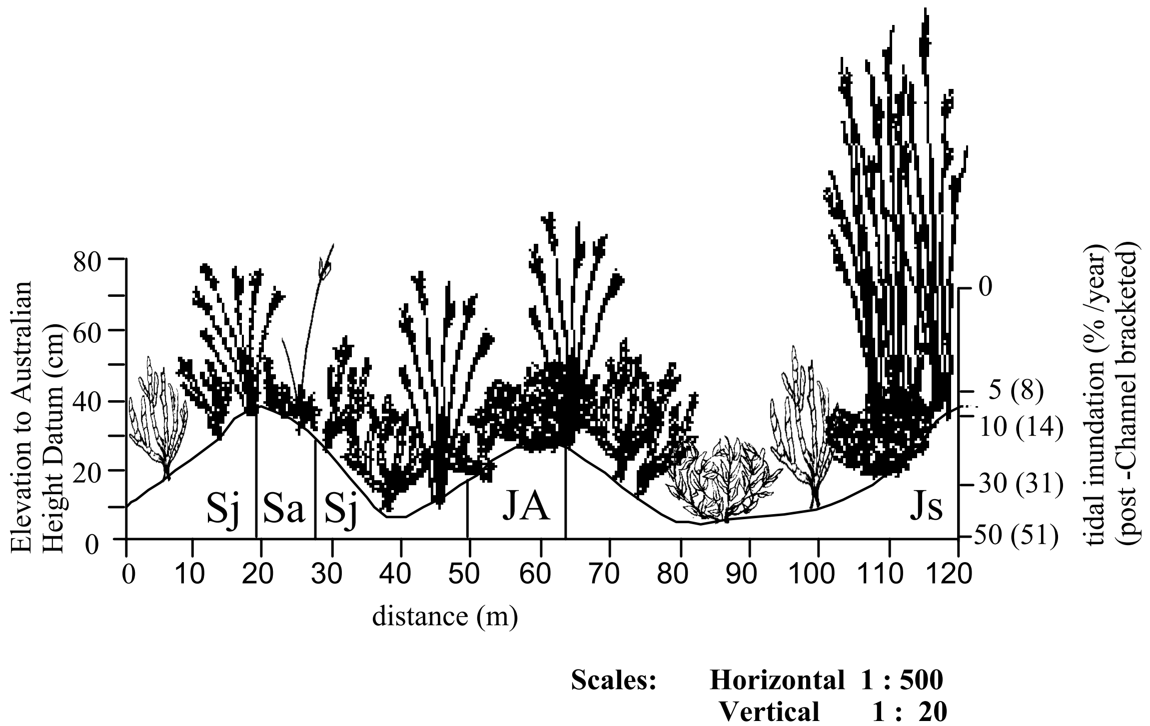

Figure 4.4. Frequency of tidal inundation and vegetation units along the Worallagarook Island transect (Site 6).

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

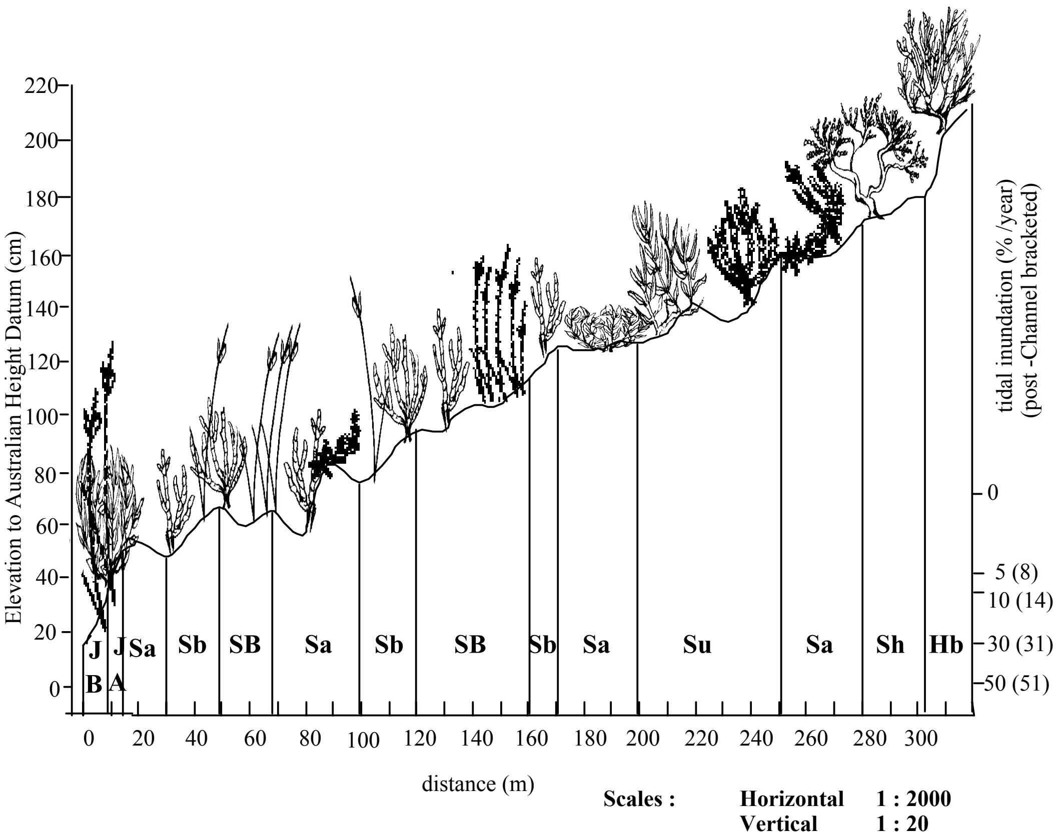

Figure 4.5. Frequency of tidal inundation and vegetation units along the Lake Goegrup transect (Site 2).

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

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

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

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

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

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

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

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

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

4.3.3 Changes to complexes with the Dawesville Channel

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

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

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

4.3.4 Changes to individual species with the Dawesville Channel

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

Sarcocornia quinqueflora

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

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

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

Suaeda australis

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

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

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

Bolboschoenus caldwellii

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

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

***Halosarcia* species**

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

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

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

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

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

Frankenia pauciflora

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

Juncus kraussii

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

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

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

***Atriplex* species**

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

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

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

4.4 Conclusions

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

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

CHAPTER 5 *Invertebrate Distribution And Samphire Marsh Ecology*

M. Keally, J.A. Latchford and J.A. Davis

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.

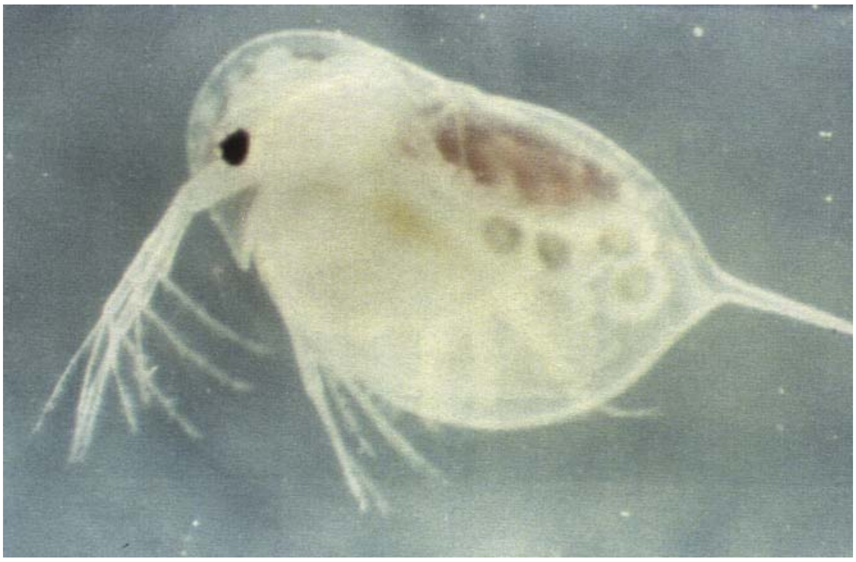

Plate 5.1 Invertebrates often found in saltmarshes of the Peel- Harvey, copepod (top), *Daphnia* (bottom).

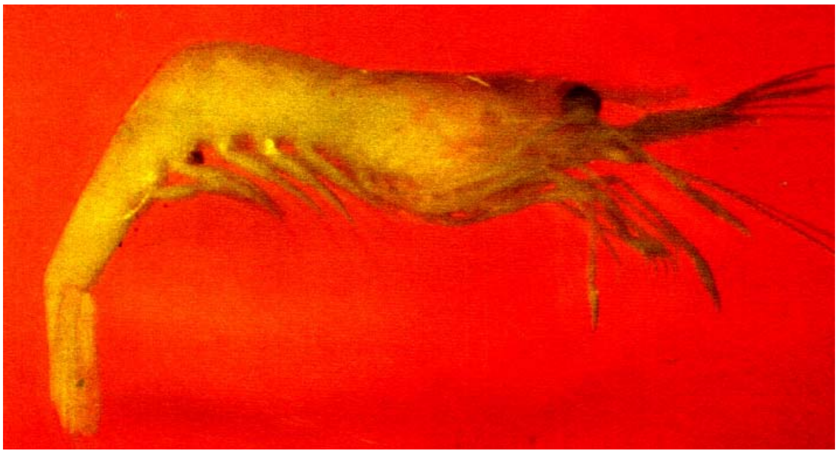

Plate 5.2 Invertebrates common in saltmarshes of the Peel- Harvey crustacean (top) and mite (bottom).

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.

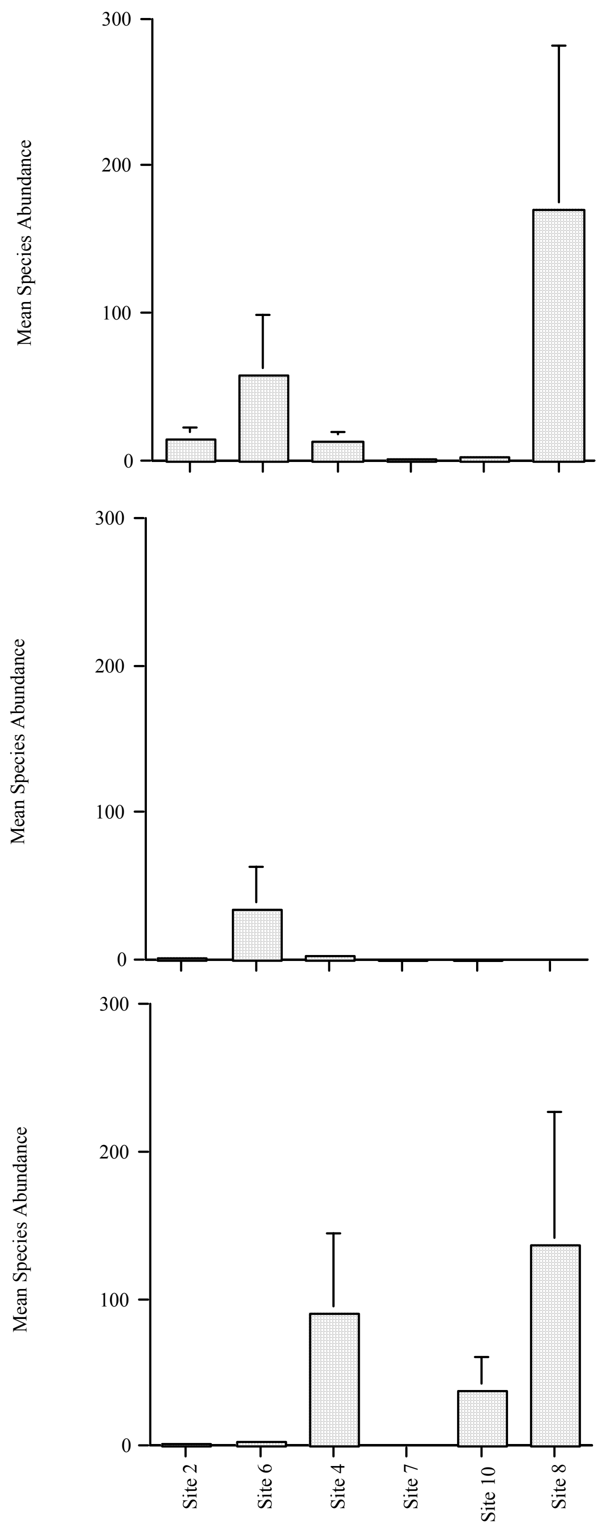

Figure 5.1. Mean species abundance for cores during summer, along a transect at selected sites, for areas 1, 2 and 3 respectively, n=4. Areas 1, 2 and 3 are the same as on Figure 1.2.

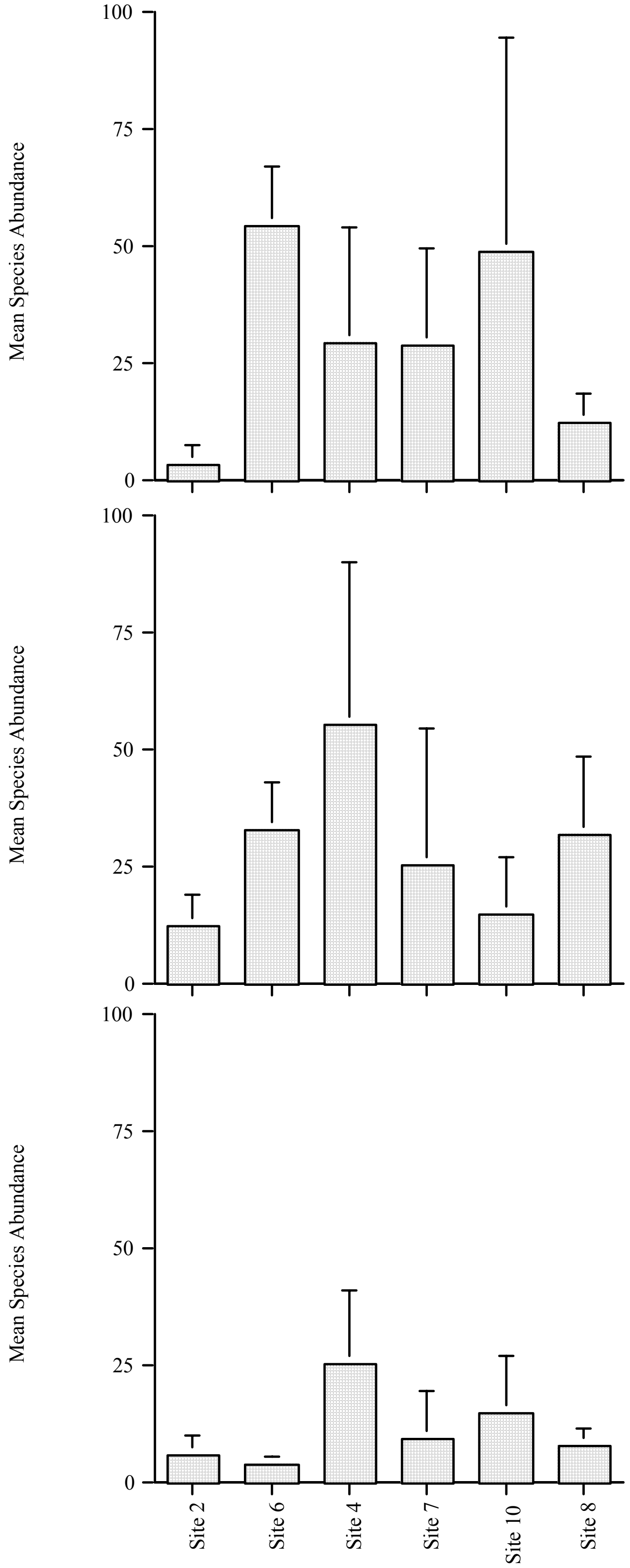

Figure 5.2. Mean species abundance for cores during winter, along a transect at selected sites, for areas 1, 2 and 3 respectively, n=4. Areas 1, 2 and 3 are the same as on Figure 1.2.

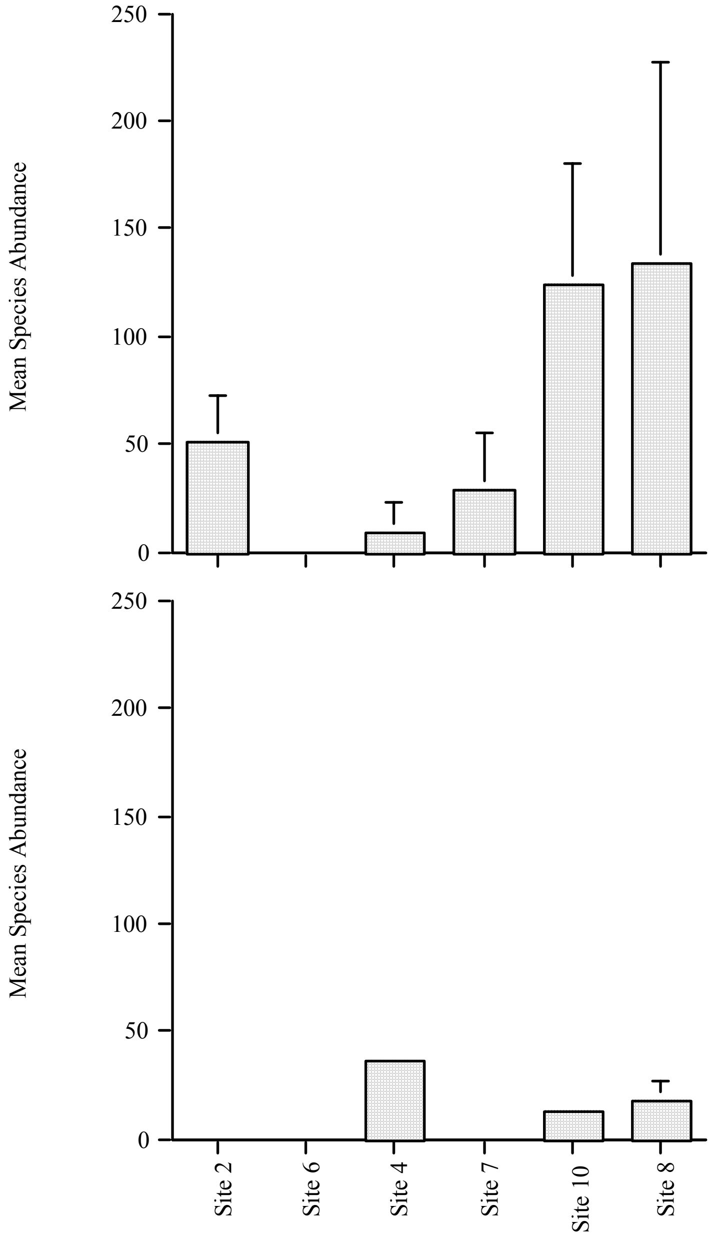

Figure 5.3. Mean species abundance for sites sampled with a sweep net in winter, along a transect at selected sites, for areas 1 and 2 respectively, n=2. Areas 1 and 2 are the same as on Figure 1.2. Note: zero abundance indicates no sample was taken.

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.

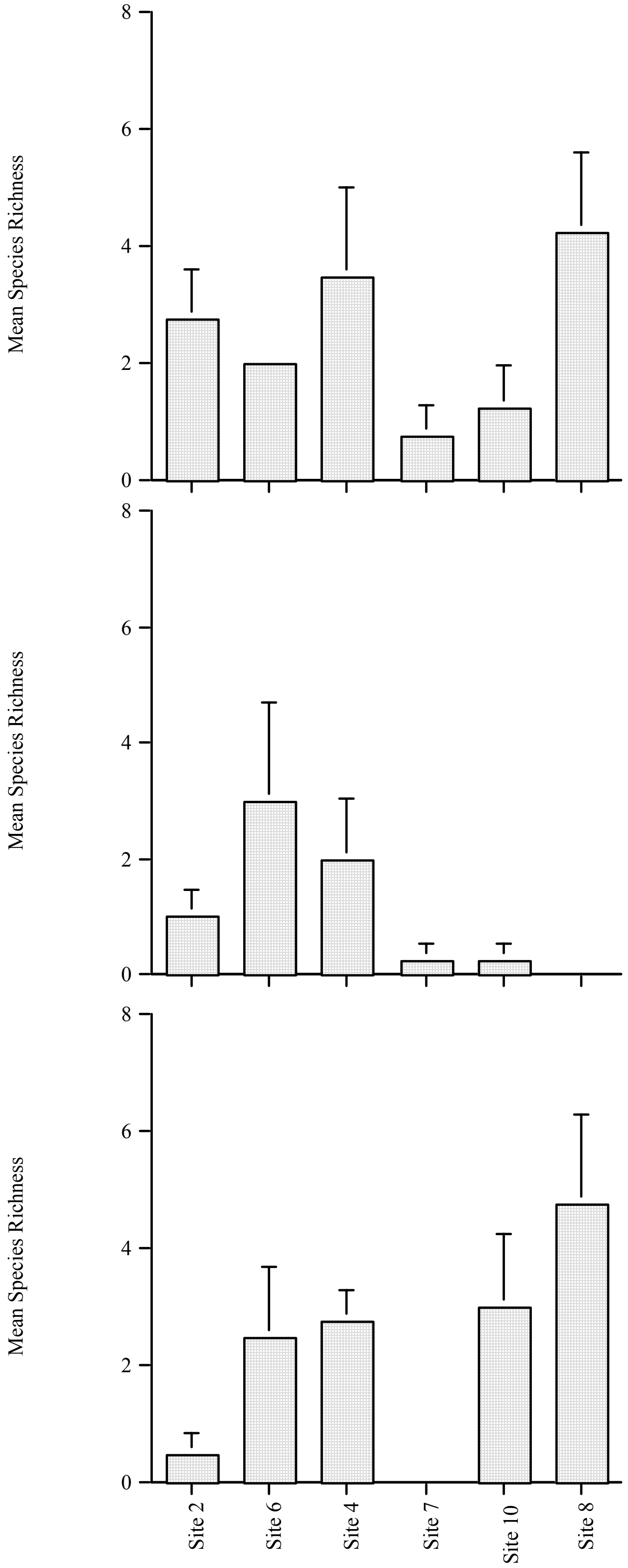

Figure 5.4. Mean species richness for cores during summer along a transect at selected sites, for areas 1, 2 and 3 respectively, n=4. Areas 1, 2 and 3 are the same as on Figure 1.2.

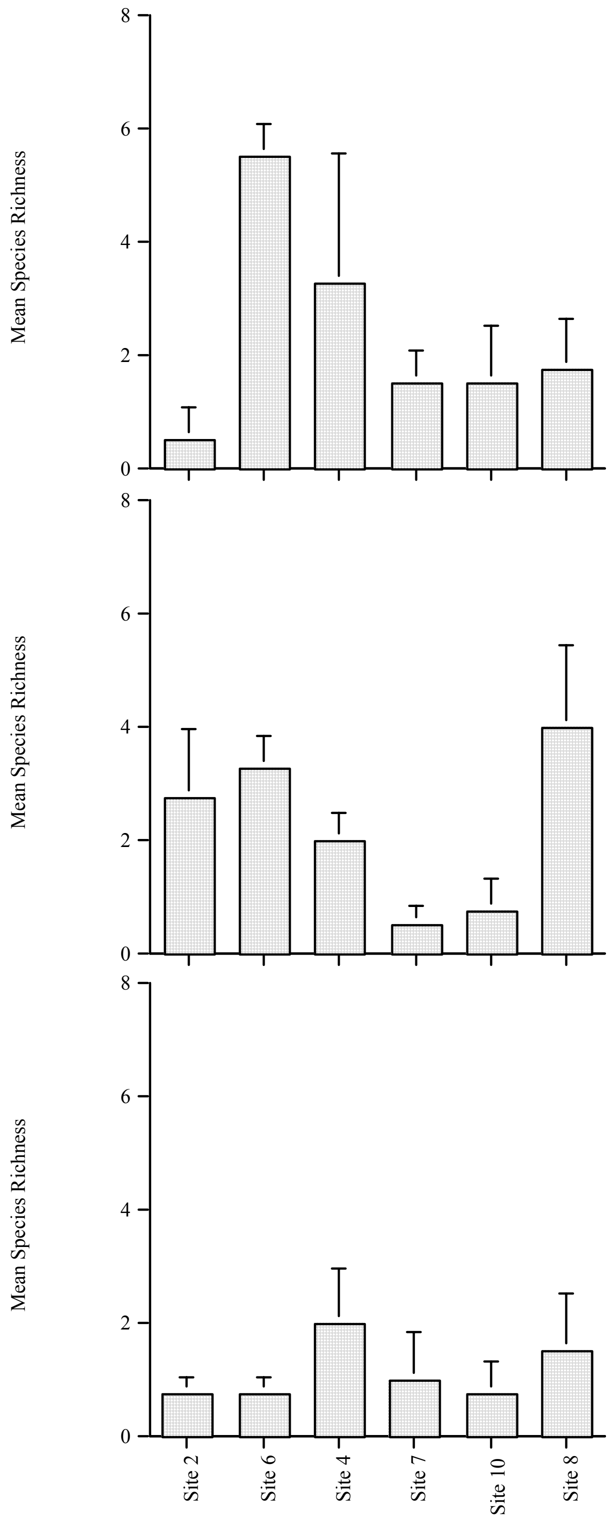

Figure 5.5. Mean species richness for cores during winter along a transect at selected sites, for areas 1, 2 and 3 respectively, n=4. Areas 1, 2 and 3 are the same as on Figure 1.2.

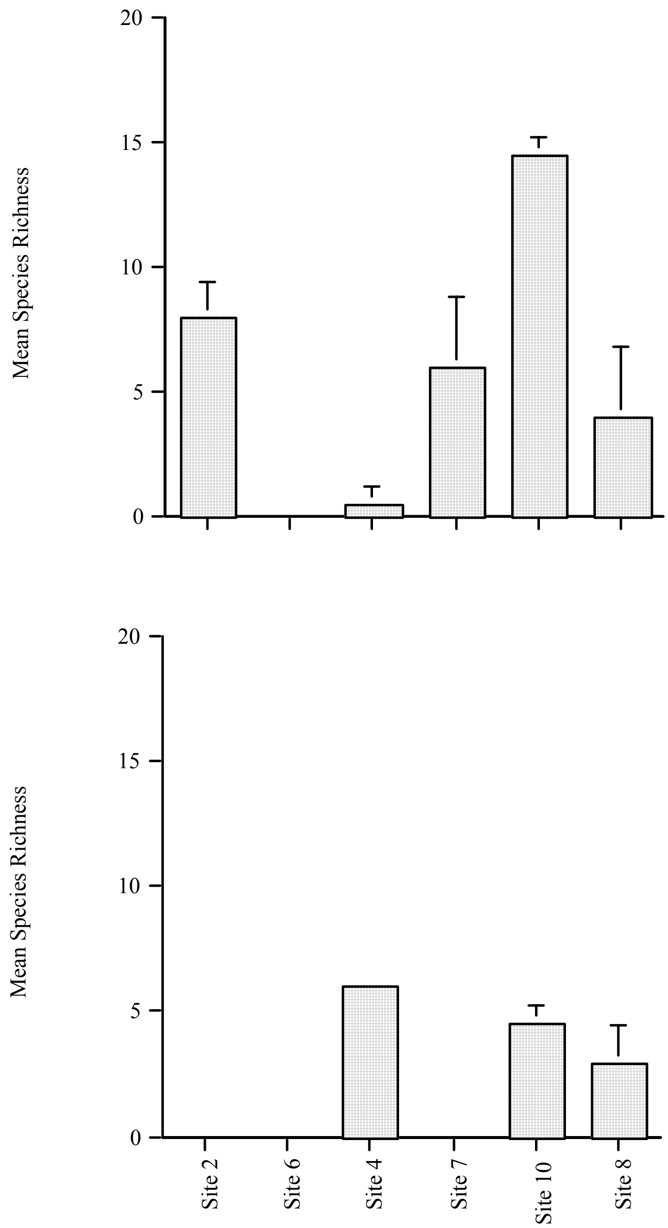

Figure 5.6. Mean species richness for sweep sites during winter along a transect at selected sites, for areas 1 and 2 respectively, n=2. Areas 1 and 2 are the same as on Figure 1.2. Note: Zero abundance indicates no sample taken.

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.

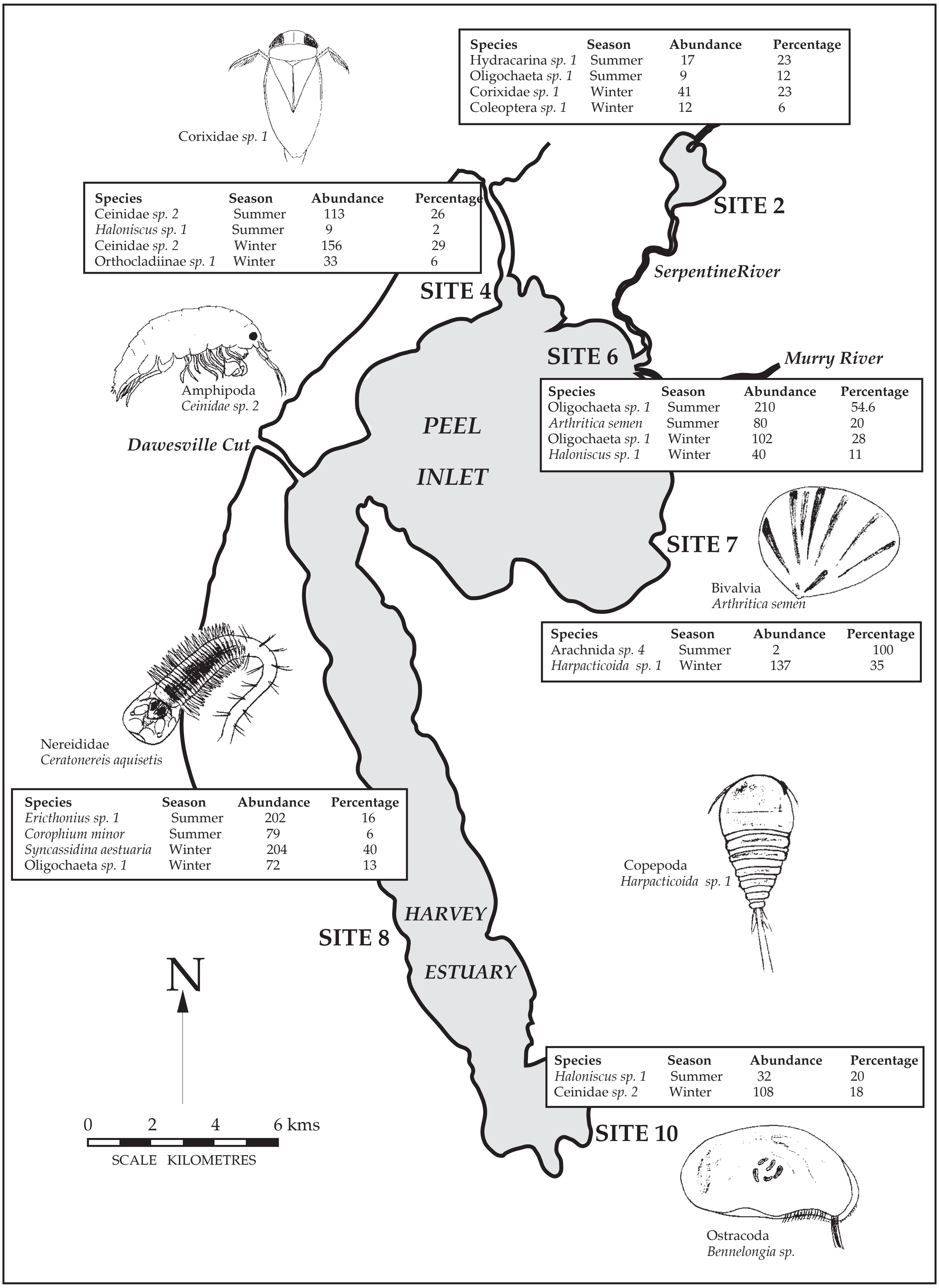

Figure 5.7. Map of the Peel-Harvey Estuary showing transect locations and dominant species* occurring for both summer and winter.

*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.

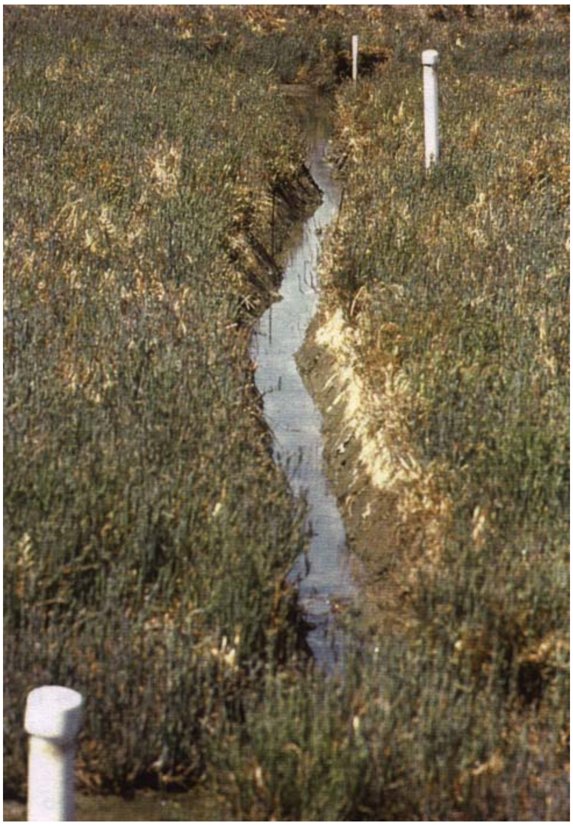

Plate 7.1 Runnels, a physical mosquito control technique connect saltmarsh pans to the estuary, allowing the exchange of water. The top photograph displays the runnel, which is a spoon shaped channel, and in the bottom photograph water from the estuary is entering the pan via the runnel.

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).

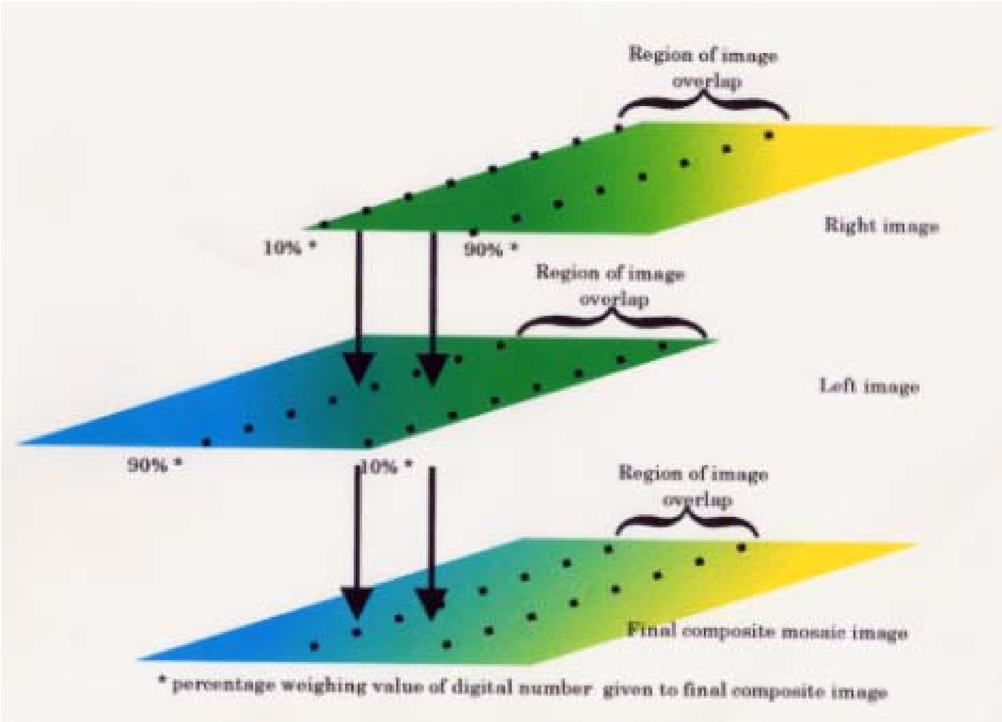


Figure 1. Linear feathering overlay reduction. The data values of final composite image in the region of overlap is determined by the distance of the pixel from the centre of the overlapping image. The further from the centre the less emphasis placed on the final pixel value.

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)

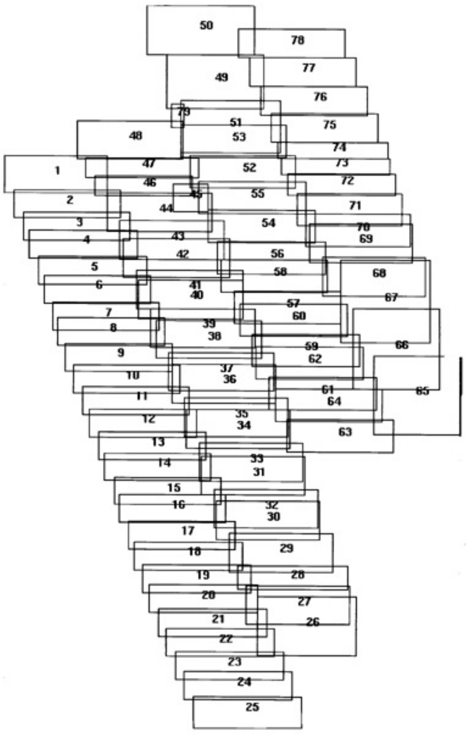
FILE NAME	FILE TYPE	DESCRIPTION
ƒ .TIF	Tiff	Scanned single air photograph
ƒ.IMG	Img	*Imagine* image file of above scan
ƒ. R.IMG	Img	Georeferenced and resampled image file
ƒ.RS.IMG	Img	Above file subset to smaller spatial coverage
ß.RS.IMG	Img	Composite mosaic file of subset images
ß.RSRCC.IMG	Img	Composite 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.

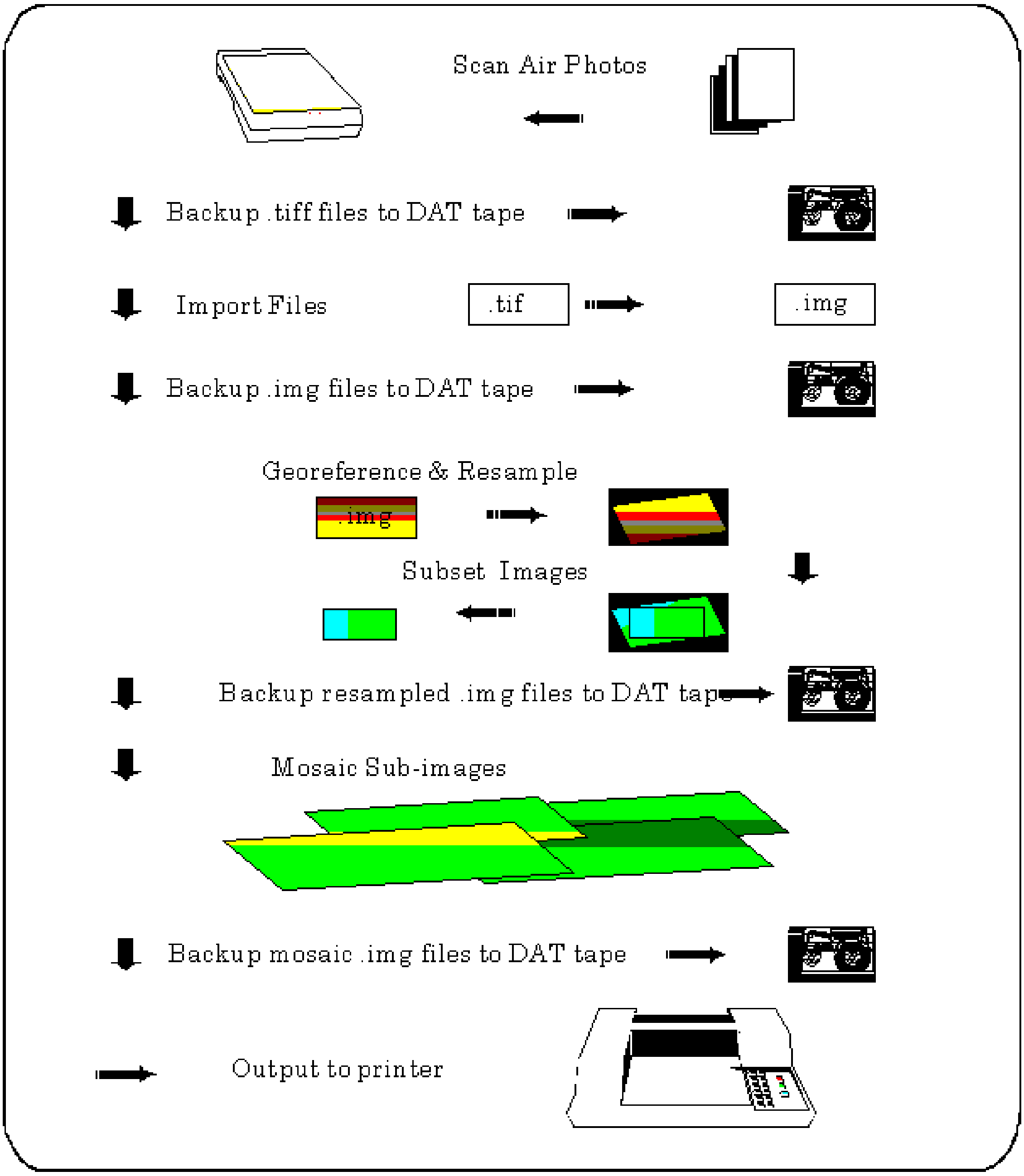
Air photograph interpretation was carried out for each of the dates on the air photographs using the keys contained in Appendix 5. Each photograph was interpreted independently by two interpreters using stereoscopes to allow magnification and observation of imagery in three dimensions. This enabled use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