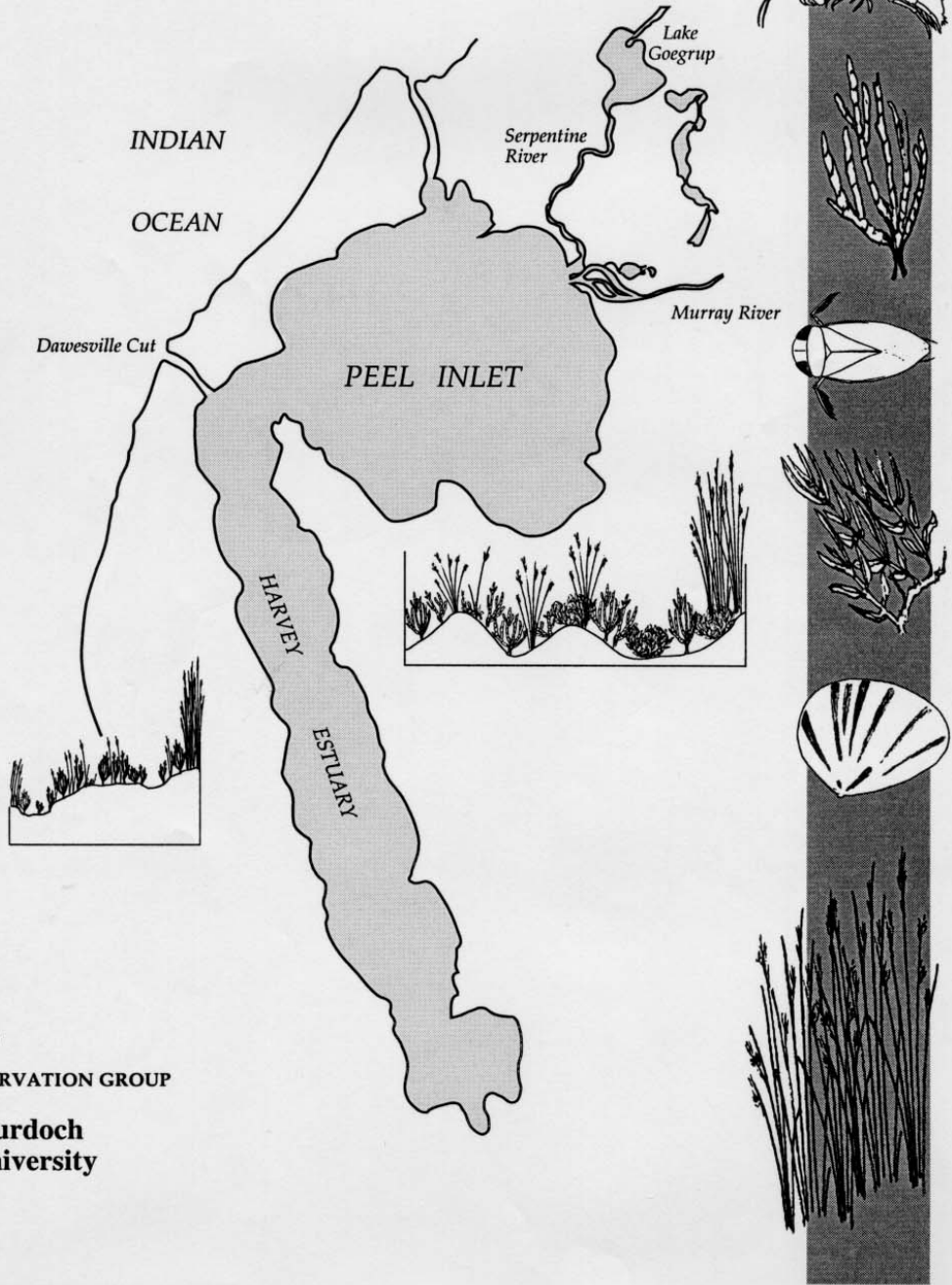


SAMPHIRE MARSHES OF THE PEEL-HARVEY ESTUARINE SYSTEM WESTERN AUSTRALIA



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SAMPHIRE MARSHES

OF THE

PEEL - HARVEY ESTUARINE

SYSTEM

WESTERN AUSTRALIA

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

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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.

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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.

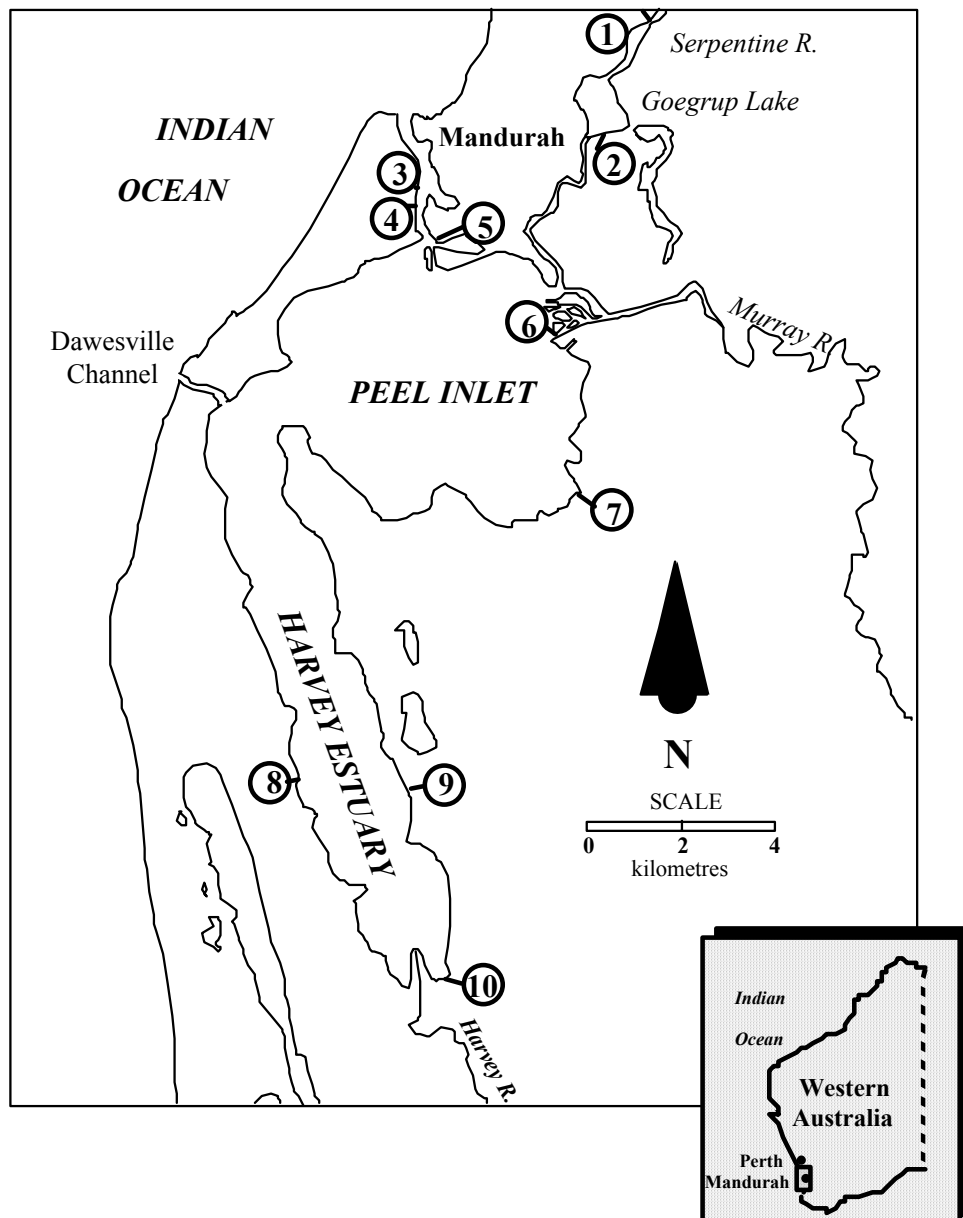


Figure 1.1. The location of study sites within the Peel Harvey estuarine system.

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 km²) 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).

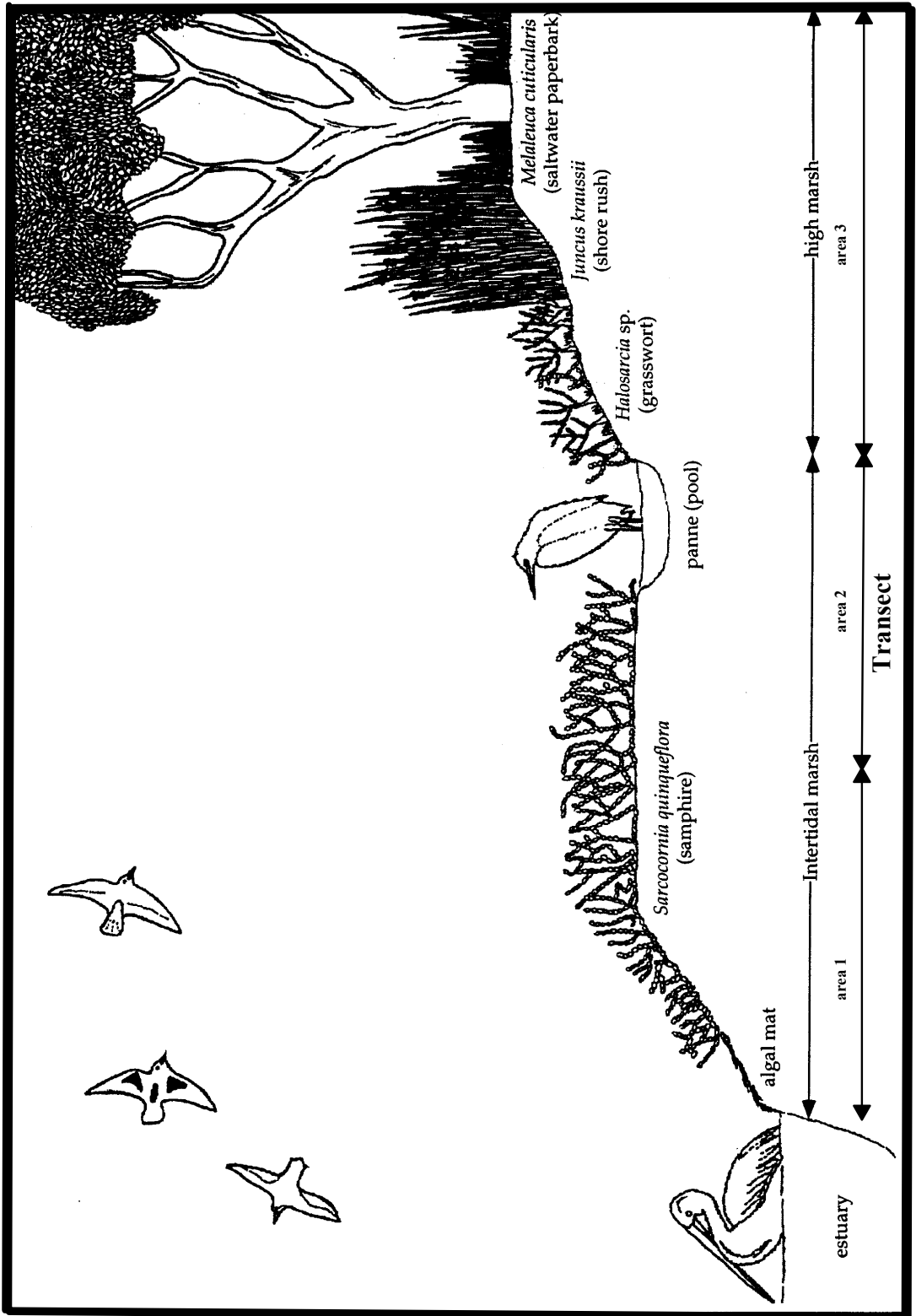


Figure 1.2. Cross section of a typical saltmarsh in the Peel-Harvey estuary.

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).

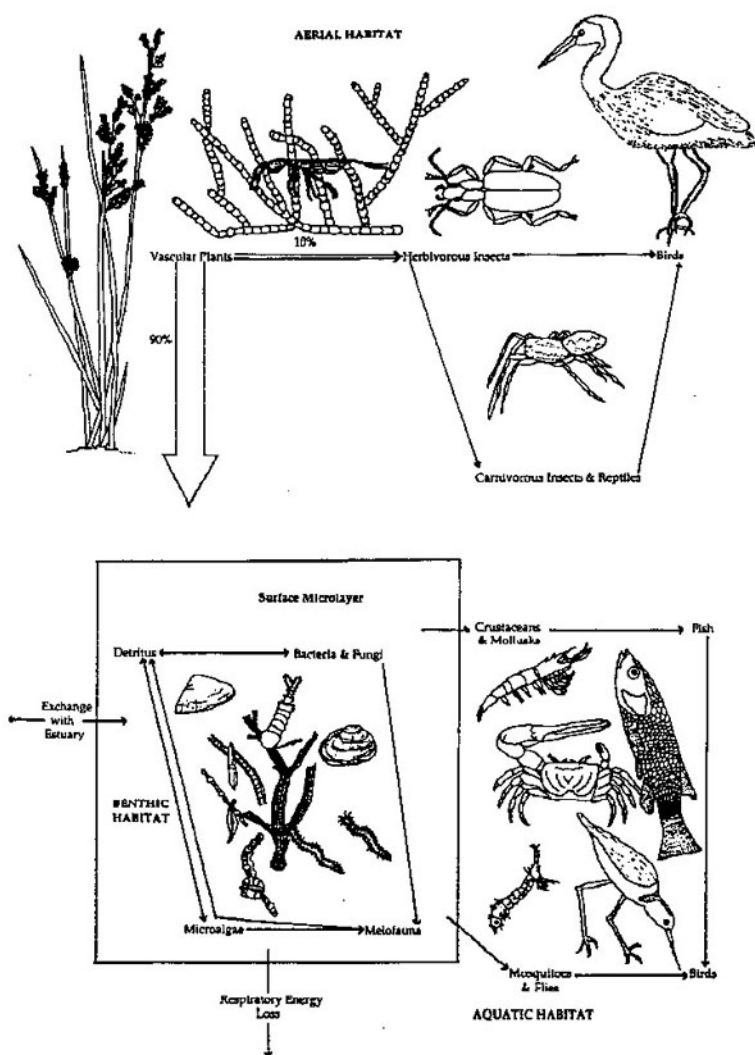


Figure 1.3. Food chain of a typical saltmarsh system.

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; Ninnox, 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 ($<3^\circ$ from vertical), then the photograph is accepted as vertical. The point where the optical axis of the camera meets the earth's 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 ($>70^\circ$) and super-wide angle ($>100^\circ$) 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.

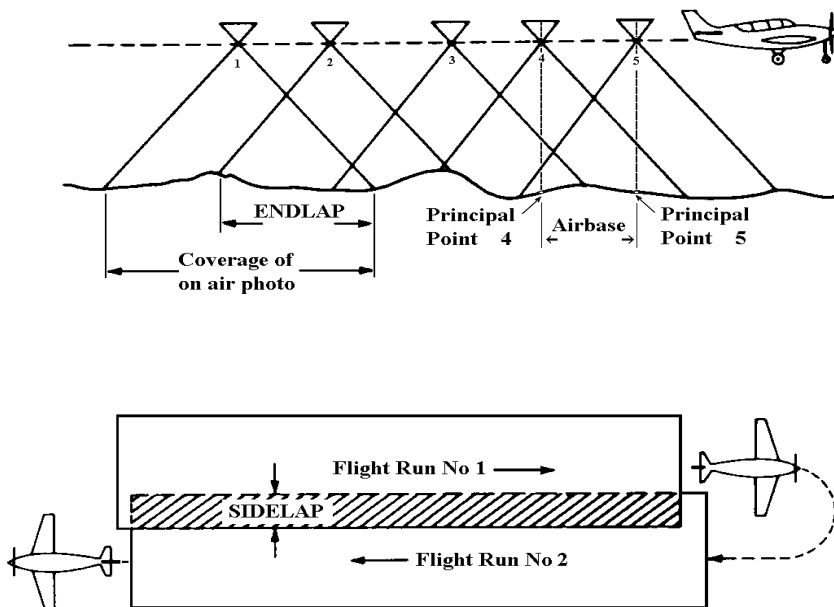


Figure 2.1. The acquisition of air photography. Aircraft fly in runs exposing film at a given intervals to photograph portions of the earth so that each successive photograph overlaps the next both along the direction of flight and between adjacent flight runs (Modified after Wolf, 1983).

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

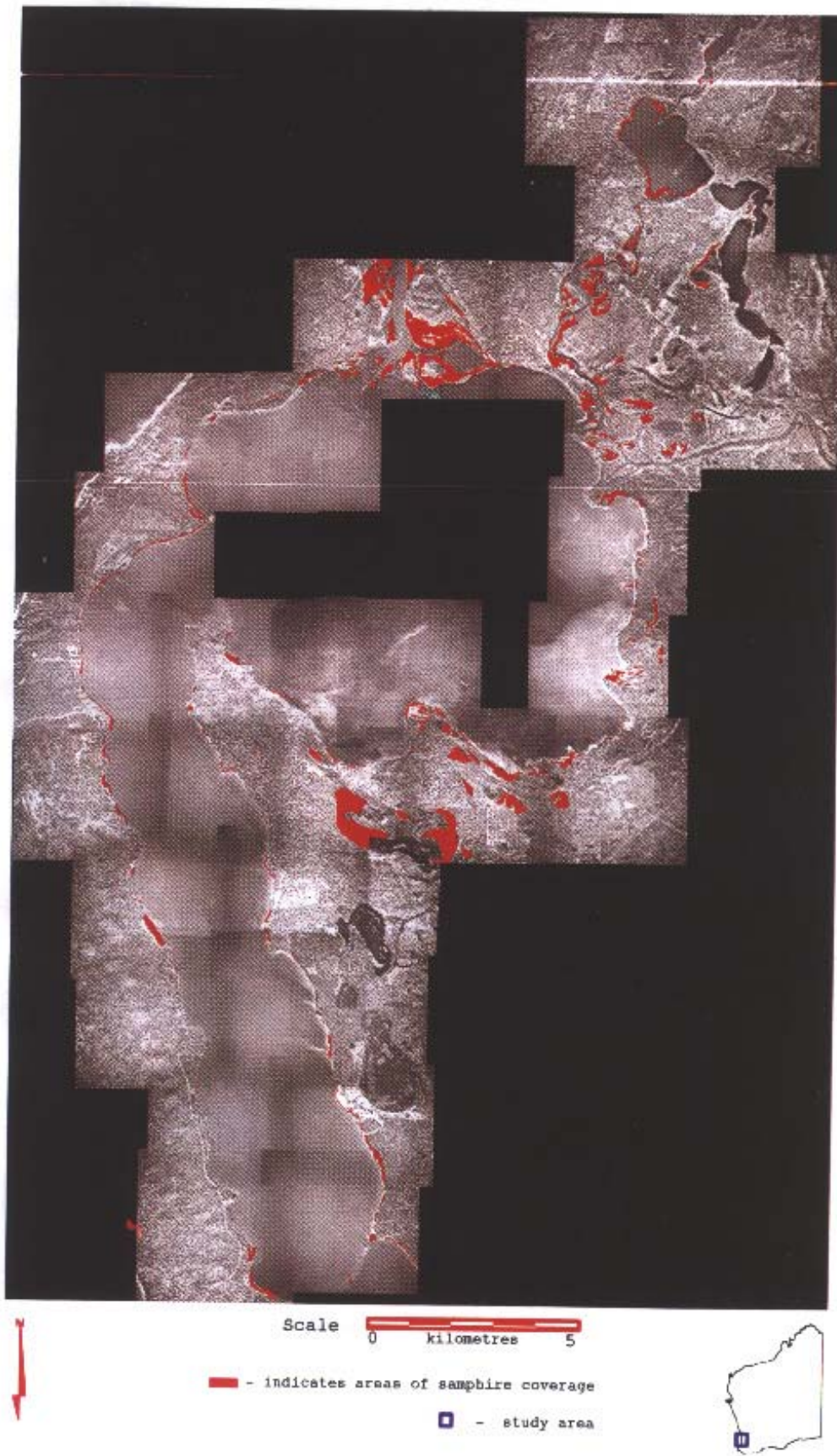


Figure 2.2 Samphire marsh distribution in 1957.

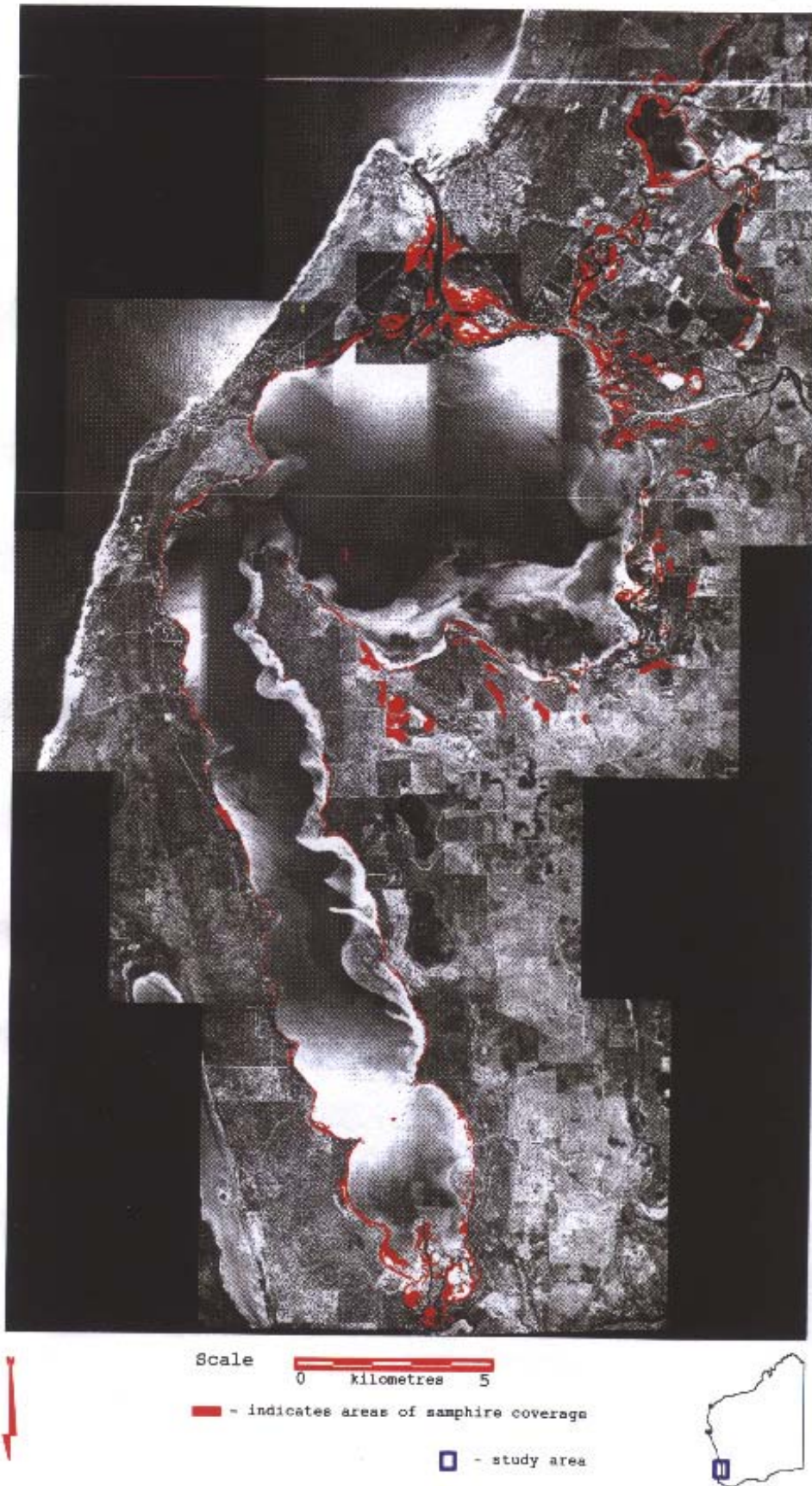


Figure 2. 3 Samphire marsh distribution in 1965.



Figure 2.4 Samphire marsh distribution in 1977.

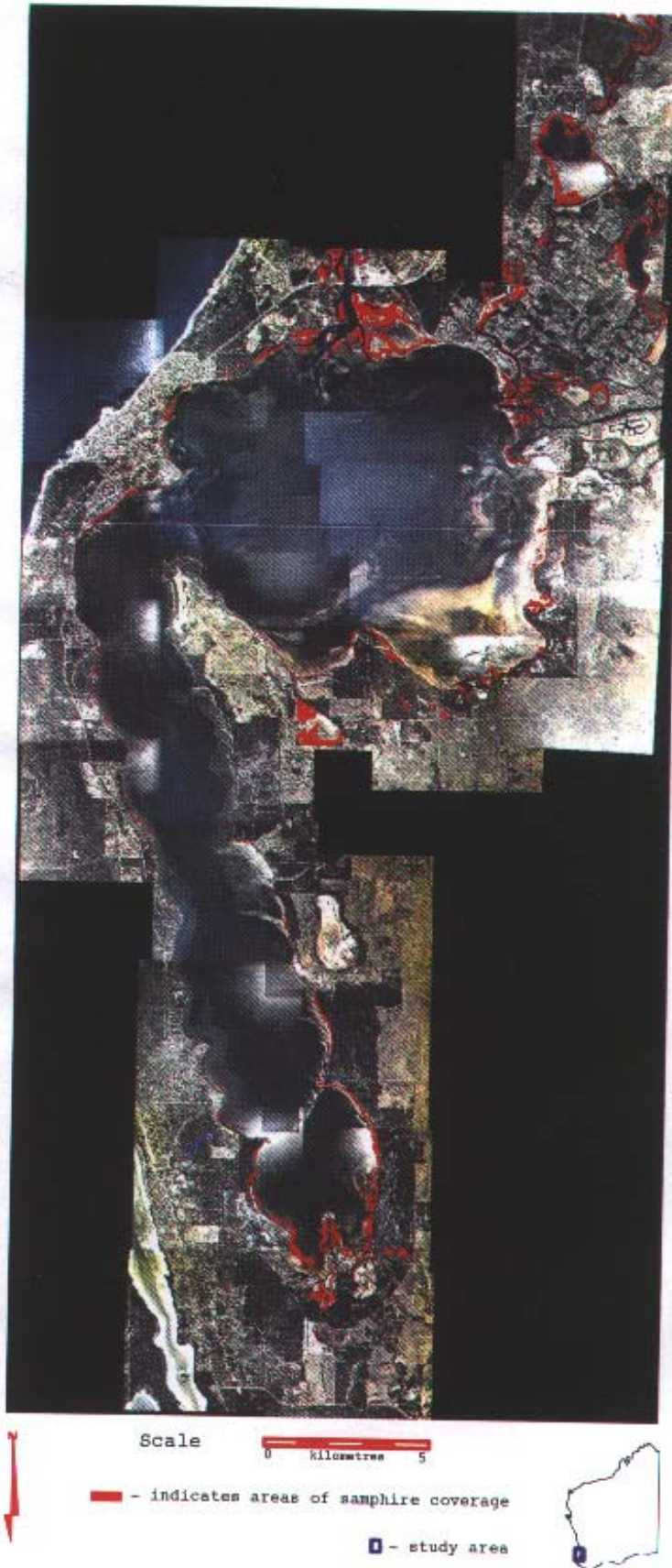


Figure 2.5 Samphire marsh distribution in 1986.



Figure 2.6 Samphire marsh distribution in 1994.

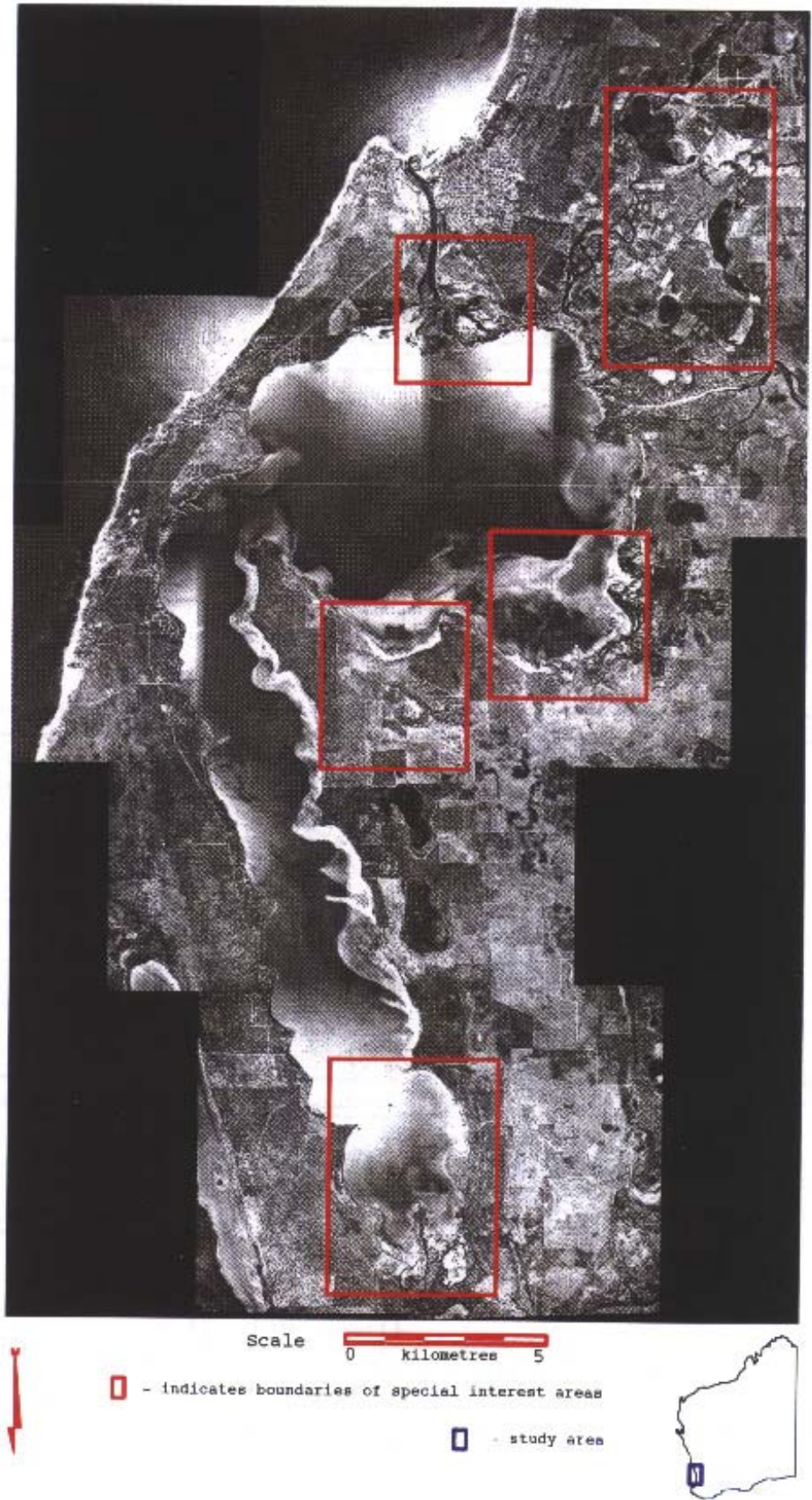


Figure 2.7 Boundaries of special interest areas.

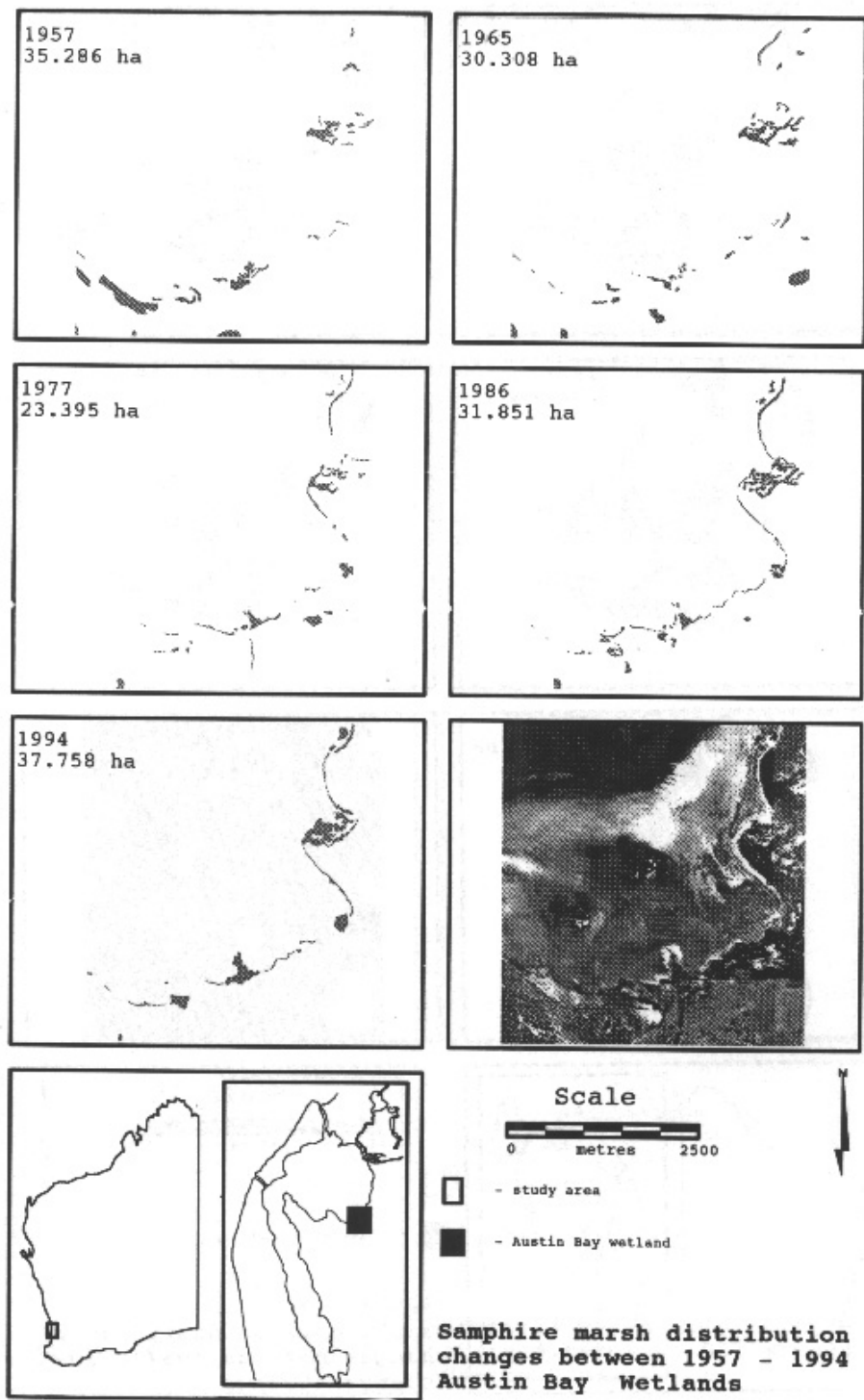


Figure 2.8 Samphire distribution in Austin Bay.

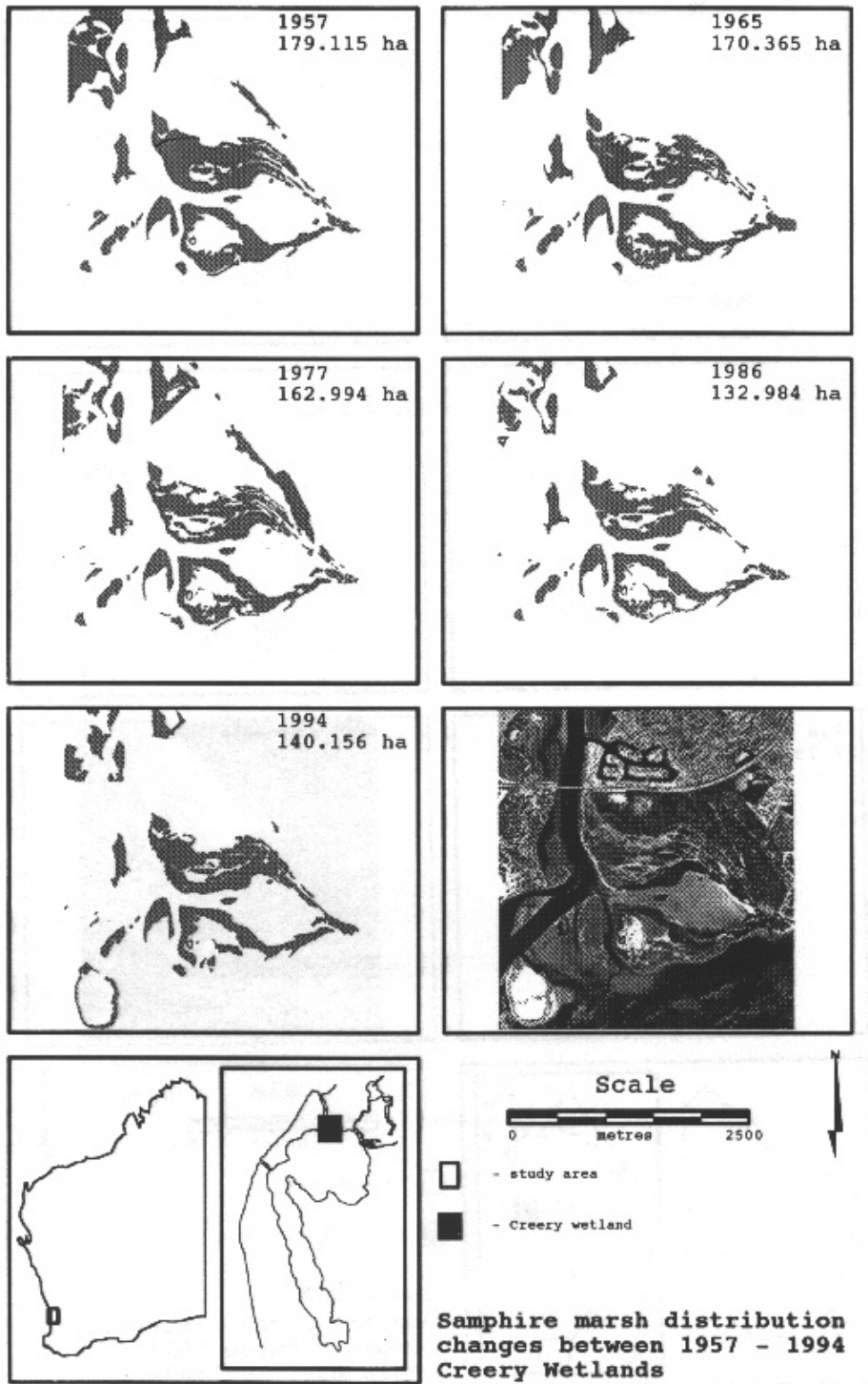


Figure 2.9 Samphire distribution in Creery Wetlands.

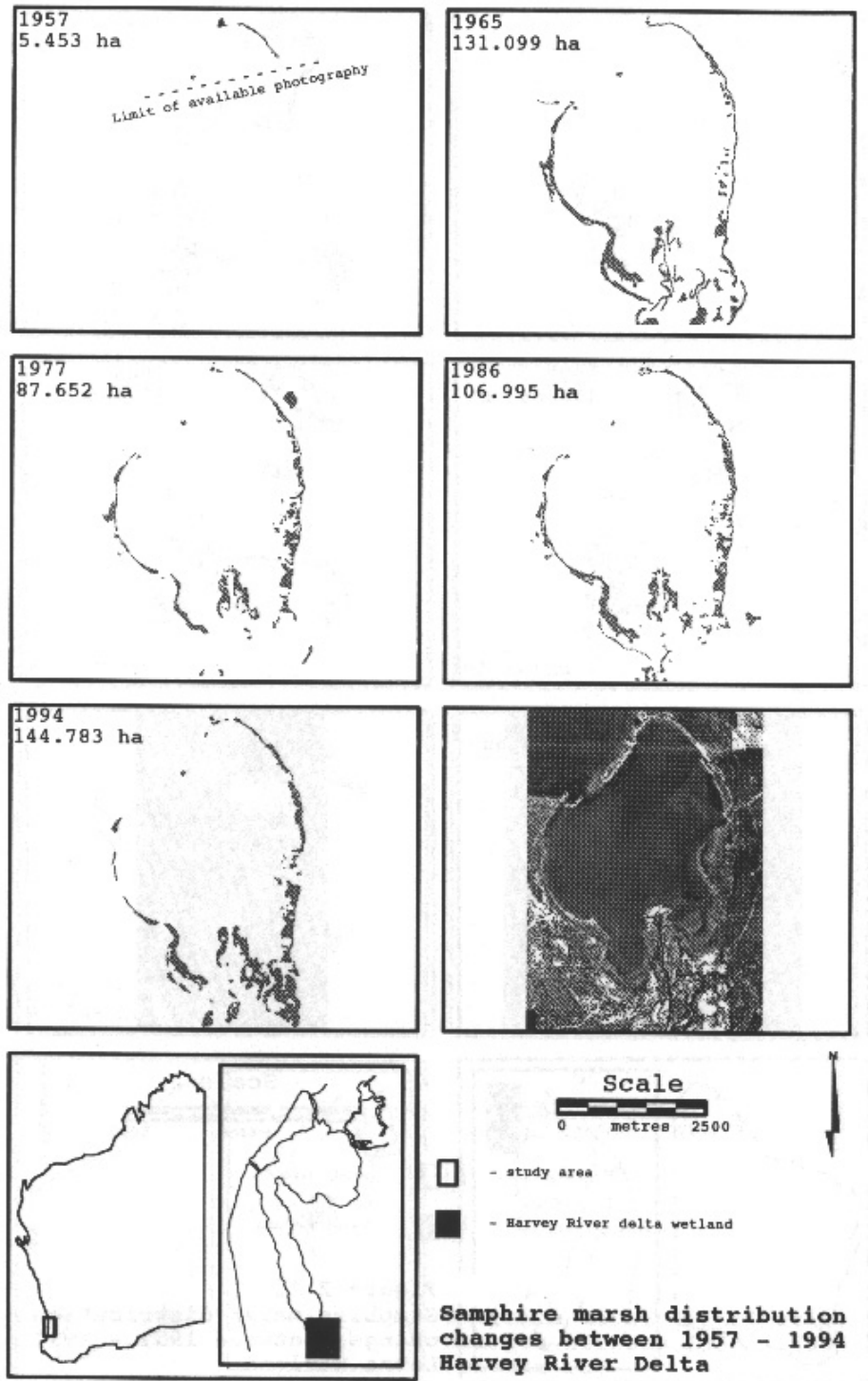


Figure 2.10 Samphire distribution in Harvey River Delta.

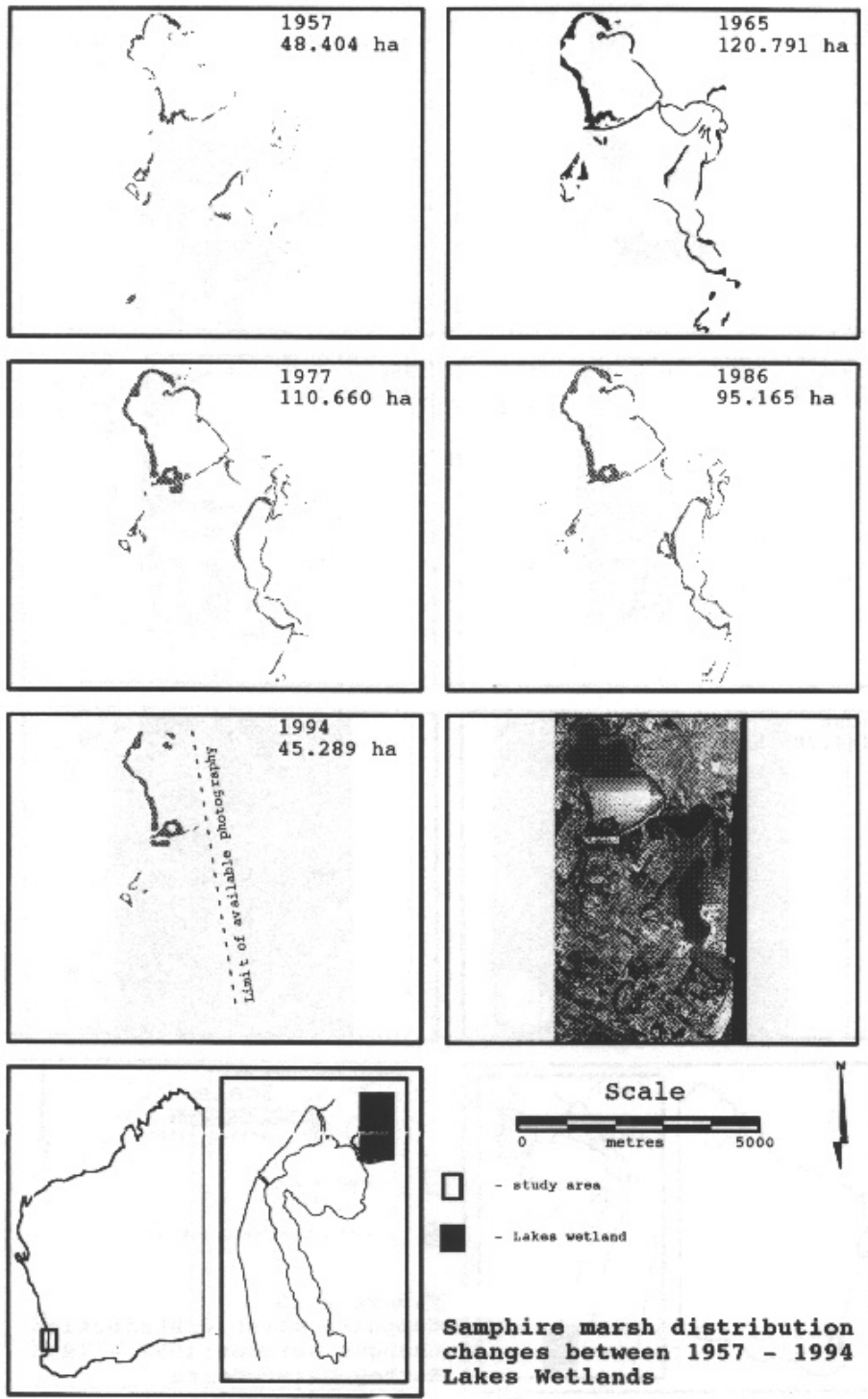


Figure 2.11 Samphire distribution in Lakes area.

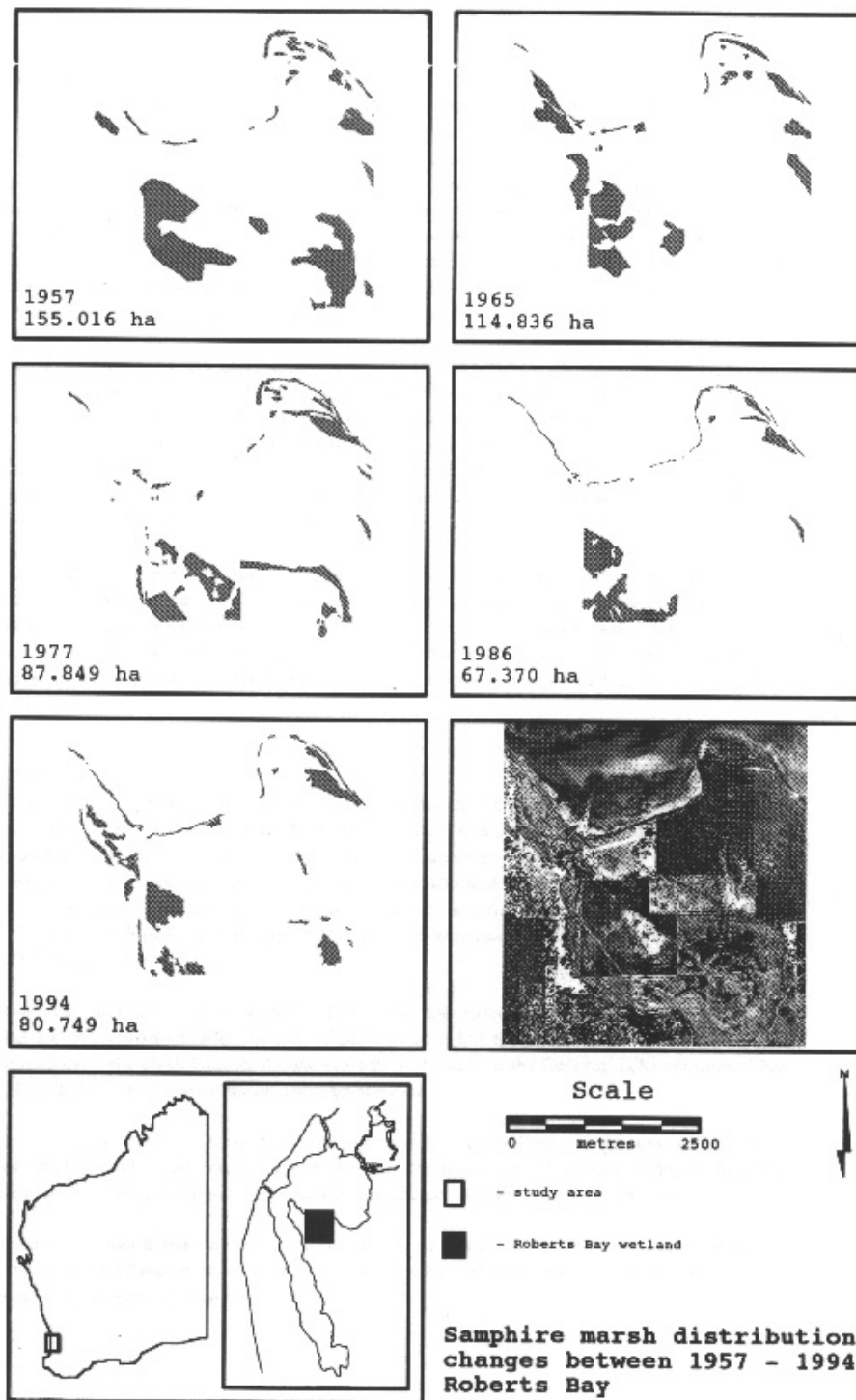


Figure 2.12 Samphire distribution in Roberts Bay.

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 ($\approx 58\%$ or 251 ha) occurred outside reserve areas. The greatest percentage loss from an area of interest was in the Lakes area ($\approx 63\%$ or 75 ha) and in Roberts Bay ($\approx 48\%$ 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 (\pm) 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 \approx 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.

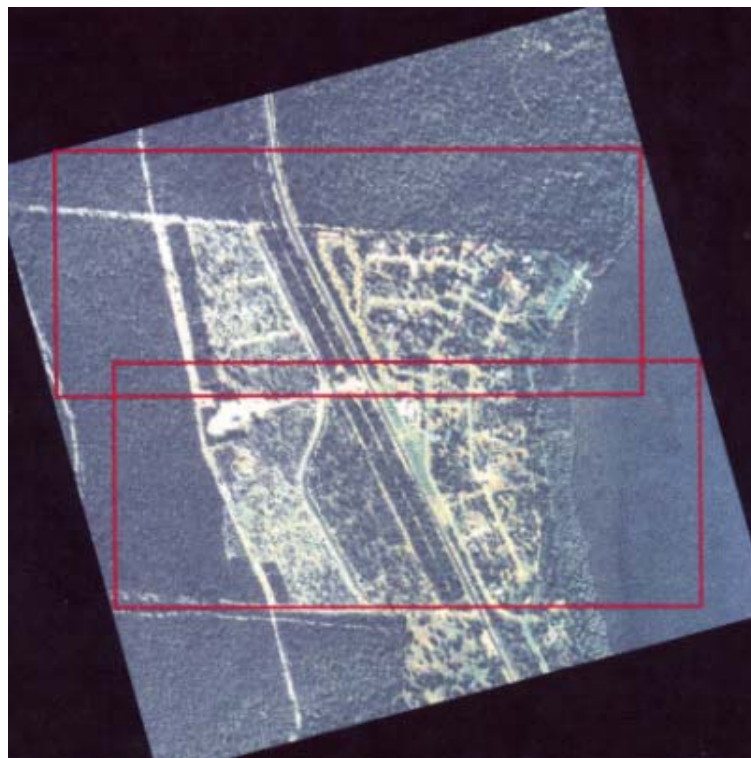


Figure 2.13. Air photograph raster image after georeferencing and resampling showing image portions of null data (in black) as a result of flight lines other than north/south or east/west. Red rectangles represent areas of subset images excluding the null file values.