Chapter 3: Wetland Habitat Mapping Protocols

3.1 Introduction

This chapter outlines the decision rule process and final recommendations for the mapping of coastal wetland habitats in this study, and which can be applied in other studies, in order to increase the opportunities for comparison between projects. The methods employed for the mapping produced in Chapter 4 are established.

3.1.1 Objectives

In recent times an increasing number of research projects have concentrated on determining the extent to which changes in wetland boundaries have taken place, many of which were listed in Table 1.1 of Chapter 1. These projects have mapped the spatial and temporal changes in coastal wetland habitats for a number of purposes (e.g. inventory or monitoring) and at a number of scales. A broad range of methods has been applied, which vary in accuracy, as detailed in this report. It is evident that a common mapping protocol ought to be established to facilitate comparisons between mapping programs. This report seeks to contribute to this goal through the review of existing methodologies, and the presentation of a series of recommendations to guide future programs.

Specifically, this report aims to assess the range of methods currently being implemented in mapping methodologies of mangrove and saltmarsh habitats, and proposes seven key recommendations for future mapping. These recommendations are made to promote cross-referencing between mapping exercises conducted by various bodies, so that final results, such as habitat boundary changes and calculations of habitat areas, can be compared, using the same set of definitions and classifications. The recommended protocols of this report refer to mangrove and saltmarsh habitats only, and exclude seagrass habitats, as seagrass habitats require a different set of methodologies for habitat boundary identification (Environment Australia, 1997).
3.1.2 Inventory versus Monitoring Mapping

The National Coastal Vegetation and Landforms Data Workshop (October 1997; Sinclair Knight Merz, 1998) aimed to construct a national classification scheme for coastal vegetation and landforms on behalf of the State of the Environment Reporting Unit, Environment Australia. The workshop drew an important distinction between mapping for inventory and monitoring purposes, with the following specifications:

- **Resource Inventories:** Resource inventories (for example square kilometres of mangroves) can be derived from map products, particularly those within a GIS format. However, the figures derived from small scale mapping may seriously misrepresent the true situation. This is caused by the generalisation required to represent areas at 1:100 000 or 1:250 000. As a result, small or linear areas of a feature will not be represented and large areas of a feature will be represented without smaller gaps or patches.

- **Resource Monitoring:** Mapping of a resource per se is not necessarily sufficient for change detection, this is especially so for smaller scale mapping (i.e. less than 1:25 000). Monitoring requires detailed baseline data to ensure that the features that display change are reliably detected and that the detectable change of these features will exceed the intrinsic error of the methods used within a given time frame.

Sinclair Knight Merz (1998), pp. 19-20

Further to this, the workshop recommended that routine mapping of coastal vegetation and landforms be carried out at 1:25 000 and the results aggregated for State and National mapping and reporting requirements and that the monitoring of representative areas occurs at scales of at least 1:10 000 (Sinclair Knight Merz, 1998, pp. 1, 17).
3.2 Previous Exercises in Mangrove and Saltmarsh Mapping

The most comprehensive map inventory for New South Wales is West et al.’s (1985) “An estuarine inventory for New South Wales, Australia”, which was undertaken by the then Division of Fisheries in the NSW Department of Agriculture. It contains maps of mangrove, saltmarsh and seagrass habitats in major New South Wales estuaries, based on aerial photographs and groundtruthing, mapped between 1981 and 1984. The areas of each major vegetation unit in each estuary and in total area for the state are documented. The scale corresponds to that proposed for inventory mapping by the National Coastal Vegetation and Landforms Data Workshop (Sinclair Knight Merz, 1998).

Other studies include site-specific larger-scale evaluations based on historical aerial photography, usually limited to a period of up to 60 years in duration due to the availability of, or limitations of, the aerial photographic record. Consequently, a collection of reports detailing spatial and temporal change in a large number of Australian wetland habitats exists (Table 1.1), though comparisons are limited by problems of scale, varying (subjective) habitat classification, lack of georectification and georeferencing in some cases, and an absence of or difficulties with data transfer methods.

This protocol has been adopted in many of the studies cited in Table 1.1, with the inventory work of West et al. (1985) being conducted at 1:25 000, and a larger scale selected for habitat change assessment (monitoring).

**Recommendation 1:** Mapping of mangroves and saltmarshes for habitat change should occur at a scale of 1:10 000 or larger. Ideally, a scale of 1:5000 or larger should be used to differentiate mangrove and saltmarsh habitats in the ecotone.
3.3 Methods

3.3.1 Data Input

3.3.1.1 Data Sources

The mapping of the spatial and temporal changes in a wetland is carried out with close reference to historical aerial photography. Archived aerial photographs exist in a number of scales, including 1:4000, 1:5000, 1:10 000, 1:15 000, 1:16 000, 1:20 000, 1:25 000, 1:40 000, 1:50 000, 1:100 000 and 1:250 000 (C. Gray, pers. comm.). This introduces the first intrinsic error, or discrepancy, for comparison between surveys. Mapping may be undertaken at a variety of scales depending on the availability of aerial photographs for desired sites and years.

Photograph quality decreases with the age of the photograph (due to deterioration and relatively poor original resolution), and this is particularly problematic when photograph scale is small. Accurate distinctions between wetland communities may not be possible on some photographs.

3.3.1.2 Scale Rectification

Scale rectification refers to the standardisation of scale across an aerial photograph or series of aerial photographs.

3.3.1.2.1 Variation in Scale

Scale may vary over a photograph and between photographs in a run for the following reasons:

- **Relief displacement** is the shift or displacement in the photographic position of an image caused by the relief of the object. Objects of high relief are displaced outwards while objects of low relief are displaced...
inwards. For a vertical aerial photograph relief displacement occurs radially from the principal point or geometric centre. The magnitude of the relief displacement $d_e$ for a vertical aerial photograph is given by $d_e = \frac{rh}{H}$ where $r$ is the distance on the photograph from the centre of the image of the top of the object, $h$ is the ground elevation of the object and $H$ is the flight altitude of the camera relative to the same datum as $h$ (Hanslow et al., 1997, p. 2).

- **Tilt** within so-called vertical aerial photographs occurs as a result of the pilot’s inability to keep the plane perfectly horizontal. Small tilts are present in most vertical aerial photographs and result in displacement inward on the high side of the photograph and outward on the low side. Corrections for the effects of tilt involve calculating the amount of tilt present via the use of ground control points (Hanslow et al., 1997, pp. 2-3). A tilt of 1° - 3° is not uncommon, resulting in a non-orthogonal scale across the photograph (Crowell et al., 1991).

Other distortions may be introduced through the photographic process. All camera lenses have measurable distortions that affect the representation of image points on film. Modern cameras undergo calibration, allowing correction for the effects of lens distortion.

Deformations in the film can include effects introduced during the actual photographic survey through irregularities in the temperature, humidity or spool tension or effects introduced during processing or storage of the negatives or diapositives. Film deformation can be determined and corrected by comparing the measured photographic distances between opposite fiducial marks with their corresponding values determined in camera calibration.

### 3.3.1.2.2 Correcting Scale Using GIS Programs

The lack of availability of georectifying technology led earlier studies to a range of manual approaches. Mitchell and Adam (1989b) hand-drew the distribution of mangrove and saltmarsh communities at Towra Point for the period 1942 to
Their maps were then converted to a common scale using a variable reducing/enlarging photocopier, and the areas for each habitat during each time period were calculated using a millimetre grid. West et al. (1985) traced base maps from 1:25 000 Central Mapping Authority (CMA) topographic maps upon which vegetation boundaries were drawn by visual interpretation using a Bausch and Lomb Transfer Scope.

Ideally, ground control points should be used to rectify varying photograph scale. Cassettari (1991) and Novak (1992) suggested that up to twenty ground control points be used to correct the spatial distortions inherent within aerial photography (cit. Chafer 1998a, p. 51). Williams and Watford (1997) described the use of the IDRISI GIS in the rectification of photo scale. A GIS can facilitate this process, and Williams and Watford (1997) described their use of the IDRISI system for this purpose:

To overcome distortion and produce a common scale and orientation, the images were rectified to a set of coordinates (ground control points) obtained from a base map. This was achieved within the GIS software package IDRISI by resampling each image using a first order polynomial (linear) transformation and nearest neighbour interpolation. A minimum of six ground control points were used to rectify each photo (Eastman, 1992) to Australian Map Grid coordinates from two 1:25 000 topographic maps produced by the Central Mapping Authority (now known as the Land Information Centre).

Ideally, the control points would be obtained from permanent, identifiable structures appearing in the 1941 and 1992 photographs, but the largely forested, high relief catchment did not make this possible. Furthermore, it would have been desirable to use 1:4000 orthophotomaps alone or in conjunction with the global positioning system (GPS) to establish the control points, but these maps are not available for the whole of the study area. The effectiveness of transformation was checked by calculating the root mean square error (RMS) and as well by viewing the mosaic produced by overlaying each of the resampled images. If a high RMS value was present or the photographs did not appear to fit reasonably well within the mosaic, new control points were identified and the transformation process rerun.

Williams and Watford (1997), p. 8
Meehan (1997) used the Georegistration and Image Analysis program DIMPLE to rectify photographs of Merimbula and Pambula Lakes. Six Australian Map Grid co-ordinates were read from a 1:25 000 topographic map, and this information was entered into DIMPLE as a ground control point model for the scanned image. The mean residuals for the GCP model were calculated and ground control points were checked and recalculated where necessary until the residual error was acceptably low.

The image was then re-sampled using the previously entered Ground Control Model, which removed geometric distortions from the image. The images were re-sampled at a previously calculated pixel size. This pixel size was calculated by working out the exact scale of the photograph and its relation to the scanning resolution...

Where necessary, the image was enhanced using a linear stretch. A linear stretch maps the observed range of pixels in the image to the full range of colours for display (DIMPLE Manual, 1997). This uniformly increases contrast over the entire image, which increased the detail that could be seen, and allowed for more accurate mapping...

Meehan (1997), pp. 25-27

As Meehan (1997) noted, the number of ground control points correlates positively with the accuracy of the georectified image. Areas with the highest number of GCPs had accuracy to within 5 metres. Accuracy in areas most distant from the GCPs was reduced to 30 metres.

3.3.1.2.3 Correcting Scale Using the AC3 Stereo Plotter

Photogrammetric analyses for the NSW Department of Land and Water Conservation are undertaken using a Wild Aviolyt AC3 stereo analytical plotter. Hanslow et al. (1997) described the process of image correction as follows:

This type of instrument produces high resolution digital topographic data from stereo pairs of aerial photograph diapositives. The AC3 measuring system is constructed strictly in accordance with the Abbe comparator principle and is
equipped with linear encoders with a resolution of 1 μm. Working in real time the AC3 automatically corrects for systematic instrument errors, film shrinkage, lens distortion, tilt, earth curvature and refraction...Up to 30 ground control points with known coordinates are then observed and the final photogrammetric model fitted using a bundle solution. The final model incorporates corrections for camera tilts and rotations. Residuals for model fit to the available ground control are automatically calculated and presented in terms of easting, northing and elevation.

Ground control is based on Integrated Survey Grid (ISG) control points provided by the NSW Land Information Centre and additional points, which are identified in the field by the photogrammetrist. These supplementary control points are derived from ground survey, GPS and Land Information Centre ISG photography. They include non-moving features observable in each data of photography such as distinctive rock outcrops, buildings and corners.

An indication of the accuracy of each photogrammetric model is provided by the ground control point residuals (the residual between the fitted model and the observed control points). In most situations the maximum errors (horizontal and vertical) are approximately +/- 0.2 m while the root mean square errors are approximately 0.1 m. Observation accuracy is not necessarily the same as the model fit to the ground control, however, and may also be influenced by image quality, glare, shadow, vegetation, etc. Both image quality and glare may vary across individual photographs locally reducing accuracy...Including allowances for the above factors the photogrammetrists estimate the observation accuracy for the model [presented in this paper] is +/- 0.5 m horizontal and +/- 0.2 mm vertical. This level of accuracy is typical of recent photography however the accuracy of pre-1960 photography is generally lower ( +/- 1 m to 1.5 m horizontal and +/- 0.5 m vertical) due to the lack of camera calibration.

Hanslow et al. (1997), pp. 3-4

Saintilan (1997b, 1998) conducted a photogrammetric survey of the mangroves and saltmarshes of the Tweed River estuary using this method, for photographs in the period 1930 to 1994. Interpretation of wetland units was based on precedents set by West et al. (1985) and AWACS (1996a).
Recommendation 2: Distortion errors inherent in aerial photographs can be corrected using georectification, and a minimum of six Ground Control Points should be used to rectify each photo image.

3.3.1.3 Community Classification

The classification of vegetation units, or communities, is perhaps the most significant source of variation in the mapping process. This is primarily due to the absence of an acknowledged classification system for coastal wetlands. The key issue centres around the definition of saltmarsh, and the differentiation of saltmarsh from mangrove on the one side and terrestrial communities on the other. Each will be discussed in turn.

3.3.1.3.1 The Mangrove-Saltmarsh Boundary

Often the boundary between mangrove and saltmarsh is relatively sharp, and can be identified as a line on an aerial photograph. This is because the upslope limit of mangroves often corresponds to a particular frequency of inundation, such as the mean high tide. Furthermore, mangrove seedling recruitment is predominantly close to the parent tree (Clarke and Myerscough, 1991), and when upslope mangrove transgression occurs, it will often occur sequentially as a front of juveniles close to the parent (Saintilan, in prep.). In other situations microcliffing occurs at the mangrove-saltmarsh boundary promoting a discontinuity in vegetation.

However, an ecotone may develop between the mangrove and saltmarsh communities, and a decision needs to be made concerning the classification of these zones. Some authors have taken the approach of defining a mixed zone for this ecotone (Meehan, 1997; Wilton, 1998).

Other authors have sought to consistently differentiate between mangrove and saltmarsh. Chafer (1998b) categorised various habitats amongst GIS polygons if the polygon contained greater than 90% of the habitat community being classified. In his CSIRO (1989) study, Clarke drew canopy gaps within
mangrove woodland if they were of greater than 4 x 4 metres. This would allow the gap to be classified as saltmarsh, and personal observations have suggested that such a gap is sufficient for the colonisation of saltmarsh, which in general does not occur beneath a closed mangrove forest.

A sparse *Avicennia marina* woodland may sustain an understorey of saltmarsh (especially *Sarcocornia quinqueflora*). Alternatively, saltmarsh plains may in time experience a proliferation of recently germinated mangrove seedlings. For the purpose of inventory monitoring it is necessary to acknowledge the presence of both saltmarsh and mangrove in these areas, which can be signified as a ‘mixed’ category.

An important consideration is the size of canopy gap necessary for the maintenance of a saltmarsh groundcover. Small gaps in *Avicennia* forest often occur without saltmarsh groundcover. However, saltmarsh may be retained under a mangrove woodland, particularly following upslope transgression of mangrove. It is thus suggested that this mixed area be defined as areas with between 10 and 20 metre canopy gaps between mangroves, an area that allows the growth of saltmarsh.

Saltmarsh plains often contain isolated individual mangroves. This should not cause the entire plain to be classified as mixed habitat. It is proposed that saltmarsh plains with mangroves spaced more than 20 metres apart be classified as saltmarsh, while the position of individuals be identified in larger scale mapping.

**Recommendation 3: That the following classification system be used for mangrove and saltmarsh habitat delineation:**

- **Mangrove habitat:** 0-10 m canopy gaps.
- **Mixed habitat:** 10-20 m canopy gaps.
- **Saltmarsh habitat:** >20 m canopy gaps.

Indications of these zones from an aerial perspective are given in Figure 3.1, and Figures 3.2 to 3.9 give on-the-ground perspectives of these habitats.
3.3.1.3.2 The Saltmarsh-Terrestrial Boundary

*Casuarina glauca* can periodically be inundated. Within parts of Currambene Creek, Jervis Bay, the highest astronomical tides extend through the *Casuarina* zone to the *Melaleuca* zone (Saintilan, in prep.). Chafer (1998b) noted a considerable expansion of the range of swamp oak (predominantly *Casuarina*) into saltmarsh in the Minnamurra estuary. The relative extent of *Casuarina* may be an important key to understanding mangrove-saltmarsh dynamics, and the inclusion of *Casuarina* as a distinct category in intertidal wetland mapping is encouraged.

*Recommendation 4: Casuarina glauca be mapped as a distinct vegetation unit.*

3.3.1.3.3 Interpretation of Aerial Photographs

Textural properties of communities may be difficult to distinguish on aerial photographs. Commonly cited problems are the similarity in texture of *Casuarina* and other units, including *Avicennia* and terrestrial communities of *Eucalyptus* and *Melaleuca* (Fenech, 1994), and the differentiation of saltmarsh from supratidal pasture grasses (Saintilan, 1997b).

Clarke’s CSIRO (1989) study followed an iterative process of comparisons for boundary differentiation, including:

1. *structural differences on the enlarged images,*
2. *tonal differences on the enlarged images,*
3. *colour differences on contact prints,*
4. *ground transect data,* and
5. *general ground reconnaissance.*

CSIRO (1989), p. 10

Clarity of image will depend on photo scale, and the CSIRO (1989) was able to use colour infra-red photographs taken in 1989 at 1:15 000 from which frames
were selected for rectified black and white enlargements to 1:4000 scale. The resultant maps differentiated saltmarsh communities including *Sclerostegia*, *Sarcocornia*, *Sporobolus*, *Samolus*, *Wilsonia*, *Juncus*, *Baumea*, *Gahnia*, salt pan (bare patches), *Casuarina*, and *Melaleuca*.

The use of a stereograph may make interpretation of community types easier. In particular, the Wild Aviolyt AC3 stereo plotter held in the Coastal Branch of the Department of Land and Water Conservation (Newcastle) allows high resolution 3D images of considerable magnification, which greatly facilitates interpretation.

### 3.3.1.3.4 Supervised Classification

Interpretation of community types can be enhanced in a raster file by the use of supervised classification, by which particular pixel values are associated with vegetation types, and this training set used as a basis of automatic classification by the image processing software. The system was used by AWACS (1996) for the development of Tweed River baseline distributions and Williams *et al.* (2000) in the mapping of estuarine vegetation in the Hunter River.

Supervised classifications require extensive correction by contextualisation and ground truthing, as the range of pixel values may vary more than anticipated in the initial classification process.

*Recommendation 5: While supervised classification avoids boundary definition problems associated with vector analyses, extensive ground-truthing is required to verify the accuracy of the classifications, particularly when the diversity of species is high.*

### 3.3.1.4 Community Delineation

Over the past two decades considerable advances have been made in mapping technology, particularly in the popularisation of Geographic Information Systems (GIS). The purpose of this section of the report is to describe pre-GIS
Figure 3.1: Jervis Bay (1993) showing A: saltmarsh; B: mixed mangrove and saltmarsh; C: mangrove; D: *Casuarina*.
Figure 3.2: Zone A: Saltmarsh (*Sarcocornia quinqueflora*) in the foreground, with individual mature mangrove trees in the background.

Figure 3.3: *Sarcocornia quinqueflora*. 
Figure 3.4: Zone A: Saltmarsh (*Juncus kraussii*) in the foreground.

Figure 3.5: *Juncus kraussii.*
Figure 3.6: Zone B: Mixed mangrove and saltmarsh habitat.

Figure 3.7: Zone B: Another example of mixed mangrove and saltmarsh habitat.
Figure 3.8: Zone C: Mangrove woodland (*Avicennia marina*).

Figure 3.9: Zone D: *Casuarina* woodland.
and GIS mapping procedures and to seek to determine the comparability of results.

3.3.1.4.1 Hand-drawn Boundaries

In a vector analysis, the accuracy of community delineation will depend on the scale of the photograph and the thickness of the marker used to delineate communities. Mapping using the AC3 stereo plotter begins with the identification of community boundaries on the original aerial photographs, or enlargements of the aerial photograph, initially hand-drawn as a guide with a chinograph pencil. The photogrammetrist then interprets the position of the boundary of each vegetation unit using the AC3 stereoplotter, with vector lines finer than those represented on the photograph by the pencil. In this sense the photogrammetrist extrapolates from the hand-drawn boundaries, resulting in an increase in accuracy in translating to the AC3 stereoplotter.

3.3.1.4.2 On-screen Digitising

Many authors have used a flat bed scanner to digitise the photo image, and various software packages (e.g. Bolstad et al., 1990; Williams and Watford, 1997; Wilton, 1998) to digitise habitat boundaries on-screen. The preferred resolution for scanning appears to be 300 dpi (Chafer 1998b, Williams and Watford 1997). Chafer (1998a) discussed this point:

> Numerous authors (e.g. Light, 1993; Ehlers, 1991; Carstensen and Campbell, 1991; Shoshany and Degani, 1992; Wijayratne and Maclean 1992) have shown that, using a grey-scale colour pallet and a scanner resolution of 300 dpi, a more than acceptable trade-off between image resolution, landscape contrast and computer file size can be obtained...Using this criteria, ground pixel sizes ranging from 0.43 m to 1.5 m can be obtained for 1:5000 and 1:25 000 scale photos respectively.

Chafer (1998a), p. 57

In a vector analysis, on-screen digitising must be predicated by the identification
of boundaries on the original photographs and as Chafer (1998a) noted, pencil width continues to be a limitation to accuracy, even when this information was transferred to a raster file using on-screen digitising:

*Finally, once geometrically corrected, images are produced and lines need to be defined on the image prior to digitising of lines and polygons. With a sharp ‘00’ pencil, this can produce an on-the-ground thickness of 6 m on a 1:20 000 scale image, clearly indicating that the largest scale image possible should be used to acquire a final map of the coast.*

Chafer (1998a), p. 52

Other errors can be introduced and compounded in the process of preparing for and during manual on-screen digitising, including errors in data collection, age of the data, areal coverage, transcription, source map scale, source map resolution, degree of modification from the source data, computation or transformation, systematic errors caused by operator bias, instrument bias or a consistent interaction between the two, or in data reduction and transformation; and random errors including among- and within-operator variability, the digitising instruments, or operator/instrument interactions (Mead, 1982; Marble and Peuquet, 1983; Walsh *et al*., 1987; Bolstad *et al*., 1990).

**Recommendation 6:** In vector analyses, the delineation of community boundaries on photographs should proceed at least at the 1:5000 scale, and a sharp pencil used. Where photographs are digitised with a scanner, 300 dpi gives an acceptable resolution. On-screen digitising removes errors associated with hand-drawn boundaries.

### 3.3.1.5 Examples of On-screen Digitising

In order to test the method of analysing change in habitats over time, the GIS software *ArcView* (in conjunction with one of its extensions, *Image Analysis*) was employed to map wetland habitats in a section of Currambene Creek in Jervis Bay, New South Wales. Aerial photographs for 1949 (black and white) and 1993 (colour) were scanned at 300 dpi using an HP flat bed scanner. The
images were then imported into *ArcView* and georectified to the most recent topographic map of the area (in this case, 1986). Following this, six classes of habitat were identified (including both wetland species and terrestrial species) and then digitised according to Recommendation 3 in Section 3.3.1.3.1. These classes included the three primary habitats, mangrove, mixed and saltmarsh, and also any other species present on the border or within the wetland itself that were deemed to be important; in this case, *Casuarina*, *Eucalyptus* and *Melaleuca* areas were identified.

One of the problems associated with the quality of scanned on-screen images can be scale limitations, and subsequent pixel size. Generally, the older the original photograph, the poorer the image displayed on the screen. Also, the smaller the scale of the original aerial photograph, the poorer the quality.

In order to enhance on-screen digitising of habitat boundaries it is suggested that an additional magnification aid be used on the original aerial photograph to enhance clarification and delineation of habitats and their boundaries, in conjunction with the on-screen scanned photograph being digitised. Options include a binocular microscope at various magnifications, three-dimensional photogrammetric stereoplotters, or simple hand-held microscopes.

In both black and white and colour images, a pixel on the screen may show a dark section, from which the digitiser might infer a mangrove, or saltmarsh, or an algal crust in the saltmarsh zone. In other cases, small ‘trees’ may be originally interpreted as juvenile mangroves, but may actually be shrub-shaped saltmarsh species. Also, shadows can appear adjacent to vegetation, depending on the time of day at which the aerial photograph was taken, giving the impression that that particular habitat zone is larger than in actual fact. The magnification tool can enable clarification in such situations.

Once on-screen digitising has been completed, it is important to visit the site to validate the boundary locations of those areas mapped. Following this, changes can be made to the digitised image before completion.
The results of this process are displayed in Figures 3.10 and 3.11, which show the original aerial photograph side by side with the resultant digitised habitats for both 1949 and 1993. These show an increase in the area of mangroves along Currambene Creek between 1949 and 1993, at the expense of both mixed and saltmarsh habitats. Further to this, maps can be created to depict particular areas of change from one date to another, which is an example of data analysis.

Figure 3.10a: Currambene Creek, Jervis Bay, 1949.
Figure 3.10b: Digitising of selected habitats in Currambene Creek, Jervis Bay, 1949.
3.3.2 Data Analysis

3.3.2.1 Non-digital Analyses

Non-GIS surveys generally used grids to determine areas of mapped wetland units. This is true of West et al. (1985), Mitchell and Adam (1989b), Fenech (1994). The procedure was described in Fenech (1994):

*The resulting transparent maps were backed with one millimetre grid paper and then photocopied. This produced two maps of past and present wetland areas complete with a one millimetre grid. The total wetland areas were determined for 1956 and 1994. The relevant scale for each map was used to calculate the area represented by a 1 x 1 mm grid. The total number of grid cells was found for each vegetation type and multiplied by the scale factor. The total wetland area was calculated by adding the area of mangrove vegetation to the area of saltmarsh vegetation. Non-wetland vegetation was not included in these calculations.*

Fenech (1994), p. 35
3.3.2.2 Raster and Vector GIS Analyses

A GIS is a computer-based tool for integrating, storing, managing, analysing and displaying spatially referenced geographic data in a problem-solving environment, to user-defined specifications (Fisher and Lindenberg, 1989; Ehlers, 1991). The primary forms of a GIS are raster and vector models.

A raster model stores features as values within an equally spaced grid. The position of each cell within the grid stores its relative location. A value is stored in each cell indicating whether a feature is located there or not. To compare features between grids, all grids must be the same size. A separate data layer is needed to map each attribute of interest (Puotinen, 1998).

A vector model stores features as a series of points, connected into lines, and combined to form polygons. Each point has an x,y coordinate (or latitude, longitude or other coordinate system). Each data layer can be compared to another despite possible differences in sizes, with one layer able to have many attribute values linked to it (Puotinen, 1998).

Chafer (1998a) constructed a comparison of the various data structures in GISs, displayed as Table 3.1.

Table 3.1: Characteristics of raster and vector data structures used in geographic information systems (after Chafer, 1998a, p. 65, adapted from Johnston, 1992).

<table>
<thead>
<tr>
<th>Data Type</th>
<th>General</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>Raster</td>
<td>* data generalised by an array of grid cells all of equal size</td>
<td>* best for depicting areas with inexact or fuzzy boundaries * best for simple or complex overlay and modelling analyses</td>
<td>* [sometimes] requires a larger amount of disk storage space</td>
</tr>
<tr>
<td>Vector</td>
<td>* data represented by strings of exact coordinates and polygons made from curvilinear boundaries</td>
<td>* accurately represents points and linear features, and areas with exact boundaries * can be used to simulate conventional cartographic representation * excellent for network and distance relationship analyses</td>
<td>* requires large amount of memory for spatial analyses * poor modelling capability</td>
</tr>
</tbody>
</table>
The NSW Fisheries Research Institute (Williams and Watford, 1997) conducted an analysis of the changes in mangrove and saltmarsh areas in Berowra and Marramara Creeks for the period 1941 to 1992. Their methodology exemplified the raster approach followed by a vector conversion, and their description is reproduced here (the rectification procedure is described previously):

*Changes in the spatial distribution of mangrove and saltmarsh in Berowra and Marramara Creeks were evaluated using a geographic information system (GIS). Raw data were obtained from topographic maps and aerial photographs taken in 1941 and 1992. Eighteen black and white photos taken in 1941 at a scale of 1:14 500, and 12 photos taken in 1992 at a scale of 1:16 000 were analysed.*

*The photographs were scanned to create electronic images using a colour flat-bed scanner operating with a resolution of 300 dots per inch. This gave an approximate resolution (pixel size) of 1.2 m for the 1941 photos and 1.4 m for the 1992 photos. This method of capturing, storing and manipulating data through pixels is known as raster analysis. To compare the 1941 photos with the 1992 photos it was then necessary to standardise the resolution and a 5 m pixel size was chosen due to the number of photos required to cover the study area, speed of data processing and restrictions of computer storage space.*

*The vegetation boundaries were defined by firstly conducting a supervised classification with the image processing software PHOTOSTYLER, and then by refining the boundary manually (digitising). The classified images were resampled using the same method as described above to finalise the raster map of the study area for each year. We made no attempt to discriminate in the photo images or in the field between species of mangrove or saltmarsh.*

Williams and Watford (1997), pp. 7-9

Williams and Watford (1997) then took the 1992 aerial photographs into the field to reaffirm the validity of their vegetation classification. The vegetation boundaries in the maps subsequently produced were defined on each of the raster images using the software package CorelTRACE, and the resulting vector file was imported into the GIS software package MAPINFO. This software
package allowed the operators to measure the area of each vegetation type, and to determine temporal and spatial changes by overlaying maps representing separate dates.

### 3.3.2.3 Cumulative Errors

Errors are introduced into the analysis at both the georectification and the image analysis phase. These errors are additive, and Meehan (1997) sought to determine the cumulative error associated with this analysis of the Merimbula and Pambula images:

*There was a 5 m error associated with reading coordinates from a 1:25 000 topographic map, a 3 m error associated with applying GCP points to unrectified images, a 3-30 m error with the coordinates of points on a rectified image (depending on their proximity to the GCP points), and an 8-10 m error associated with mapping features on that image. However, because individual errors can work for and against each other, it is difficult to calculate the final accuracy of the results. Considering that the features were mapped to determine spatial extent and size of that extent, the digitising error is the most important. The theoretical accuracy is then 64-100 m$^2$ ($8^2 - 10^2$). In the light of this, figures representing the area extent of the features have an error of 100m$^2$. Meehan (1997), p. 32*

### 3.3.3 Comparison of Techniques

In 1997 both NSW Fisheries (NSWF) (Williams and Watford, 1997) and the Department of Land and Water Conservation (DLWC) (Christine Gray, pers. comm. 1999) mapped changes in mangrove and saltmarsh distributions in Berowra and Marramarra Creeks, 1941 to 1994. The NSW Department of Land and Water Conservation used the AC3 stereo plotter in georectification and as a guide to vegetation interpretation for the years 1966, 1975, 1982 and 1994, with digital vector maps being loaded into a CADD system running on MICROSTATION software. NSW Fisheries scanned photographs into the IDRISI GIS and after raster-based classification used the MAPINFO system to
produce vector files of mangrove and saltmarsh distributions for the years 1941, 1986 and 1994.

Although the two distinct surveys calculated mangrove and saltmarsh distributions during different years, when amalgamated they produced a positive relationship between time and mangrove area in Berowra and Marramarra Creeks, as displayed in Table 3.2 and Figure 3.12.

Table 3.2: Change in area (ha) of mangroves in Berowra and Marramarra Creeks, 1941-1994 (C. Gray and R. Williams, pers. comm., 1999).

<table>
<thead>
<tr>
<th>Year</th>
<th>Area of Mangroves (ha)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1941</td>
<td>149.09</td>
<td>NSWF</td>
</tr>
<tr>
<td>1966</td>
<td>154.50</td>
<td>DLWC</td>
</tr>
<tr>
<td>1975</td>
<td>166.78</td>
<td>DLWC</td>
</tr>
<tr>
<td>1982</td>
<td>173.90</td>
<td>DLWC</td>
</tr>
<tr>
<td>1986</td>
<td>187.41</td>
<td>NSWF</td>
</tr>
<tr>
<td>1992</td>
<td>194.35</td>
<td>NSWF</td>
</tr>
<tr>
<td>1994</td>
<td>195.40</td>
<td>DLWC</td>
</tr>
</tbody>
</table>

Figure 3.12: Change in area (ha) of mangroves in Berowra and Marramarra Creeks, 1941-1994 (R. Williams, pers. comm., 1999).

The conclusion can be made that differences in accuracy in georectification between the two approaches are negligible in the final outcome, and that a
common process of wetland definition was employed. It would be preferable, though, to standardise photograph runs in a comparison of methods to more accurately gauge their compatibility.

This is not always the case. Since so many individual research projects have undertaken own mapping exercises, the lack of strict protocols for such mapping presents a problem in uncritically comparing surveys. For example, mapping undertaken by West et al. (1985) produced very different values to mapping undertaken by Heap et al. (2001) on behalf of the Australian Geological Survey Organisation. The former study assessed simple mangrove and saltmarsh habitats based on observations largely made in the field, whilst the latter mapped vegetation units based on geomorphic facies. This method has been inaccurate in many cases since, for instance, it allows mapping of intertidal areas and mangrove habitats as separate units, when they are not necessarily so.

The level of accuracy will be determined by the unique objectives of the mapping exercise. The comparison of results of independent surveys would be facilitated by adhesion to the following recommendations.

### 3.4 Recommendations

**Recommendation 1**: Mapping of mangroves and saltmarshes for habitat change should occur at a scale of 1:10 000 or larger. Ideally, a scale of 1:5000 or larger should be used to differentiate mangrove and saltmarsh habitats in the ecotone.

**Recommendation 2**: Distortion errors inherent in aerial photographs can be corrected using georectification, and a minimum of six Ground Control Points should be used to rectify each photo image.

**Recommendation 3**: That the following classification system be used for mangrove and saltmarsh habitat delineation:

- **Mangrove habitat**: 0-10 m canopy gaps.
- **Mixed habitat**: 10-20 m canopy gaps.
Saltmarsh habitat: >20 m canopy gaps.

**Recommendation 4:** *Casuarina glauca* be mapped as a distinct vegetation unit.

**Recommendation 5:** While supervised classification avoids boundary definition problems associated with vector analyses, extensive ground-truthing is required to verify the accuracy of the classifications, particularly when the diversity of species is high.

**Recommendation 6:** In vector analyses, the delineation of community boundaries on photographs should proceed at least at the 1:5000 scale, and a sharp pencil used. Where photographs are digitised with a scanner, 300 dpi gives an acceptable resolution. On-screen digitising removes errors associated with hand-drawn boundaries.

### 3.5 Discussion

There can be a myriad of problems involved in the actual mapping of habitats delineated by polygons. These are a mixture of user-error and inherent computer issues to be acknowledged as contributing to cumulative error.

Firstly one must recognise that the mapped end product will never be a true reflection of the real-life situation on the ground. This error will be minimised by groundtruthing the map to the actual site, but some errors, as discussed by other authors, can be either unavoidable or minimisable (e.g. Bolstad et al., 1990). Green and Hartley (2000) determined that three considerations are important in analysing changing habitats: the choice of an appropriate practical method, the choice of measurement for quantifying change, and estimating the magnitude of error and uncertainty in the results.

One of the key problems in habitat mapping is the inherent need, in user-defined classification schemes, to draw a straight line between habitat types. This is a
problem because many habitats grade gradually from one to another, and so it is impossible to draw a ‘hard’ boundary. For this reason, the ‘mixed habitat’ classification was devised for this study, in an attempt to acknowledge the existence of an ecotone between mangrove and saltmarsh habitats.

Many studies have attempted to identify the various types of mapping error. One such study, by Aspinall and Pearson (1995) identified three components of uncertainty (potential error) in thematic maps: class identity, class heterogeneity within a polygon, and class boundary location. Thapa and Bossler (1992) identified up to 14 separate processes that may contribute to positional and categorical errors in the final copy of a map, which were grouped under three broader headings: inaccuracies during the georeferencing and rectification procedure, inaccuracies in the transcription and digitising phase, the subjectivity involved in photointerpretation.

Problems can occur during georectification of the aerial photograph to a topographic map when an inadequate number of ground control points are located on the aerial photograph (most software programs require at least four ground control points, but the more points there are, theoretically the more accurate the georectified photograph is), and when such points are inaccurately located on the photograph.

During the georectification process, a root mean squares (RMS) value is determined. The lower this number, the more accurate the rectified image. A value less than 5 units is generally accepted as being a suitable RMS value. This value is an indication of the ‘goodness of fit’ of the rectified image to the topographic map. This is the equivalent of a two-dimensional standard deviation and is expressed mathematically by the equation:

\[\text{RMS} = \left( \sum (x^2 + y^2) / n \right)^{\frac{1}{2}}\]

Where \( \text{RMS} \) = Root Mean Square deviation error,
\( x \) = difference along the \( x \)-axis,
\( y \) = difference along the \( y \)-axis, and
\( n \) = number of ground control points (Erdas, 1990; Caspary and Scheuring, 1992)
User-derived errors and inconsistencies can also contribute to mapping error. Studies by Green and Hartley (2000), Bolstad et al. (1990), Giovachino (1993) contributed to a list of common causes of digitising errors: unsteadiness of hand, parallax between the cross-hairs and map, the thickness of the line as depicted on the base map, generalisation of curved lines into a series of short straight line segments, the digitiser puck recording off-centre, warping/shrinkage of base maps, distortion of base maps through photocopying, season has a major effect upon the appearance of vegetation, lighting conditions, effects of the atmosphere, e.g. clouds, the stage of the tide, scale, resolution and contrast of photographs, processing, lineage, positional accuracy, attribute accuracy, logical consistency, completeness, and temporal accuracy.

Further to this, Thapa and Bossler (1992, p. 836) classified the three main types of mapping error:

1. **Gross errors and blunders:** caused by carelessness or inattention of the observer in using equipment, reading scales or dials or in recording the observations. They could also be introduced by misidentification of a control point in an aerial photograph. Gross errors may also be caused by failure of equipment...

2. **Systematic errors:** occur in accordance with some deterministic system which, if known, may be represented by some functional relationship...In surveying, geodesy, and photogrammetry systematic errors occur because of environmental effects, instrumental imperfections, and human limitations. Some of the environmental effects are humidity, temperature, and pressure changes. These factors affect distance measurements, angle measurements, and GPS satellite observations, among others. Instrumental effects include lack of proper calibration and adjustment of the instrument as well as imperfections in the construction of the instrument...[these errors] must be detected and observations must be corrected for systematic errors or they must be modelled by some mathematical model.

3. **Random errors:** the remaining variations in observations. [They] occur due to the imperfections of the instrument and observers. An observer cannot
observe a quantity perfectly. The observed quantity will be either too small or too large every time it is observed. If sufficient observations are taken, random errors possess the following characteristics:
- positive and negative errors occur with the same frequency,
- small errors occur more often than large errors, and
- large errors rarely occur.

Thapa and Bossler (1992), p. 836

One of the key contributors to mapping accuracy is the scale at which mapping took place. The smaller the scale (i.e. 1:50 000 compared to 1:4000), the greater the risk of mapping error, since habitat boundaries are much harder to determine at such small scales.

Winning et al. (2000) attempted to examine the issue of wetland boundary vagueness, with critical reference to New South Wales’ State Environmental Planning Policy 14 – Coastal Wetlands (SEPP 14). The study noted that the wetlands were mapped using a combination of visual interpretation of aerial photographs (at a scale of 1:25 000), using botanical indicators to determine boundary locations. The SEPP 14 was accompanied by a series of 1:25 000 maps delineating the boundaries. A primary criticism by the authors of the map collection was that for this scale of map the actual boundary line of the wetland is 10 to 20 metres wide, promoting inaccurate transcription from the map to the actual site. Winning et al. (2000) provide an example of the vagueness of wetland boundary determination, pointing out that wetland boundaries are inherently imprecise from site to site. An assessment of the error margin in the mapping undertaken for Chapter 4 is made in Section 4.3.1.

The lack of industry-wide mapping protocols can result in sometimes vastly differing habitat areas between discrete mapping projects. For this reason it would be prudent for the scientific community to adopt a definitive mapping protocol, such as the recommendations provided in this chapter.