Inventory of Estuarine Vegetation in Botany Bay, with Special Reference to Change in the Distribution of Seagrass

F. A. Watford and R. J. Williams

NSW Fisheries Office of Conservation
NSW Fisheries Research Institute
P.O. Box 21 Cronulla, NSW, 2230
Australia

Fishcare

Project No. 97/003741

December 1998
NSW Fisheries Final Report Series No. 11
ISSN 1440-3544

Inventory of Estuarine Vegetation in Botany Bay, with Special Reference to Change in the Distribution of Seagrass

F. A. Watford and R. J. Williams

NSW Fisheries Office of Conservation
NSW Fisheries Research Institute
P.O. Box 21 Cronulla, NSW, 2230
Australia

Fishcare

Project No. 97/003741

December 1998
NSW Fisheries Final Report Series No. 11
ISSN 1440-3544

Executive Summary

Seagrasses play an important role in estuarine ecosystems by stabilising sediments and providing food and shelter to a wide variety of organisms. It is therefore important to monitor changes in the distribution of seagrass and identify the natural processes and human impacts involved so that appropriate management strategies can be adopted.

Aerial photographs taken of Botany Bay in 1995 at a scale of 1: 16 000 were analysed in a Geographic Information System (GIS) to produce maps of estuarine vegetation for the whole of the bay. Presumptive boundaries of monospecific and mixed seagrass beds as well as mangrove and saltmarsh were delineated in the laboratory and confirmed in the field. The area of each vegetation type was then calculated and compared to the results of studies previously undertaken within the bay.

The overall area of seagrass in Botany Bay is larger than that calculated by West *et al.* (1985) for 1981 and by Larkum and West (1990) for 1984-1985. It should be noted that different methodologies and classification schemes were used these two studies. As well as an increase in area, small scale changes in distribution were observed. For example, between the parallel runway and Port Botany the area of seagrass appears to have decreased substantially, whereas more seagrass is present along Lady Robinsons Beach. In contrast, along the foreshore of Silver Beach, Towra Point and part of Quibray Bay, the area of *P. australis* seagrass appears to have changed little since the investigations made in 1992 (The Ecology Laboratory 1995).

Depending on management needs, additional field investigations are necessary to describe the species composition of the mixed beds, bed densities and to determine the nature of successional sequences and their ecological significance.

Table of Contents

List of Tables

List of Figures

Introduction

The importance of seagrasses in marine and estuarine ecosystems is well recognised. As well as providing food and shelter for a wide variety of organisms including many commercial fish species (Howard *et al.* 1989, Bell and Pollard 1989), seagrasses also play an important role in stabilising sediments (Thayer 1975) and in the cycling of nutrients (Hemminga *et al.* 1991).

Globally, there are 58 recognised species of seagrass (Kuo and McComb 1989). While most countries have between two to six species, thirty species are found in Australia, one genus of which is endemic. Australia is therefore unique in having the largest and most diverse mix of seagrass species in the world (Larkum *et al.* 1989).

New South Wales has eight species of seagrass including three types of *Zostera* and three species of *Halophila* which are difficult to differentiate (Robertson 1984). There are a number of species of *Ruppia* in NSW although *Ruppia megacarpa* is considered to be dominant (Robertson 1984). Along the southeast coastline from the Tweed River at the northern border of New South Wales (NSW) to Corner Inlet in Victoria, *Zostera capricorni* Aschers. and *Posidonia australis* Hook. *f.* are the most widespread (West *et al.* 1989). The distribution of the south-east Australian seagrasses is shown in Table 1.

Table 1. Distribution of seagrass species in south-eastern Australia (Tweed River to Corner Inlet) after West *et al.* (1989).

Genus	**Species**	**Distribution in S.E. Australia**
Zostera	*capricorni* Aschers.	Whole coast
Zostera	*mulleri* Irmisch & Aschers.	Jervis Bay and southward
Heterozostera	*tasmanica* (Marten ex Aschers.) den Hartog	Port Stephens and southwards
Halophila	*decipiens* Ostenfeld	Whole coast
Halophila	*ovalis* (R.Br.) Hook. *f.*	Whole coast
Halophila	*australis* Doty & Stone	Central coast and southwards
Posidonia	*australis* Hook. *f.*	Wallis Lake and southwards
Ruppia	*megacarpa*	Whole coast

In recent years over 45 000 ha of seagrass has been lost in Australian coastal waters, assumed due primarily to a reduction of light intensity resulting from human activities (Walker and McComb 1992). It was estimated that 50% of the area of seagrass beds in NSW had been lost by the early 1980s (West 1983).

Studies in Lake Macquarie, Tuggerah Lakes and Botany Bay indicate a long term decline in the extent of seagrass. King and Hodgson (1986) calculated that 11.31 km^2 (44%) of seagrass had been lost in Lake Macquarie between 1953 and 1985. They reported similar losses in Tuggerah Lakes and suggested that a reduction in light reaching the plants through increased turbidity may have been the cause.

Seagrasses in Botany Bay

Botany Bay, which is located along the south central portion of the NSW coastline (Figure 1), is one of the few large sheltered embayments in the state and as such has a high conservation value. The Towra Point Nature Reserve, which is listed under the Ramsar Convention as a wetland of international significance, Towra Point Aquatic Reserve and Botany Bay National Park contribute to the conservation objectives for the bay (Adam 1997).

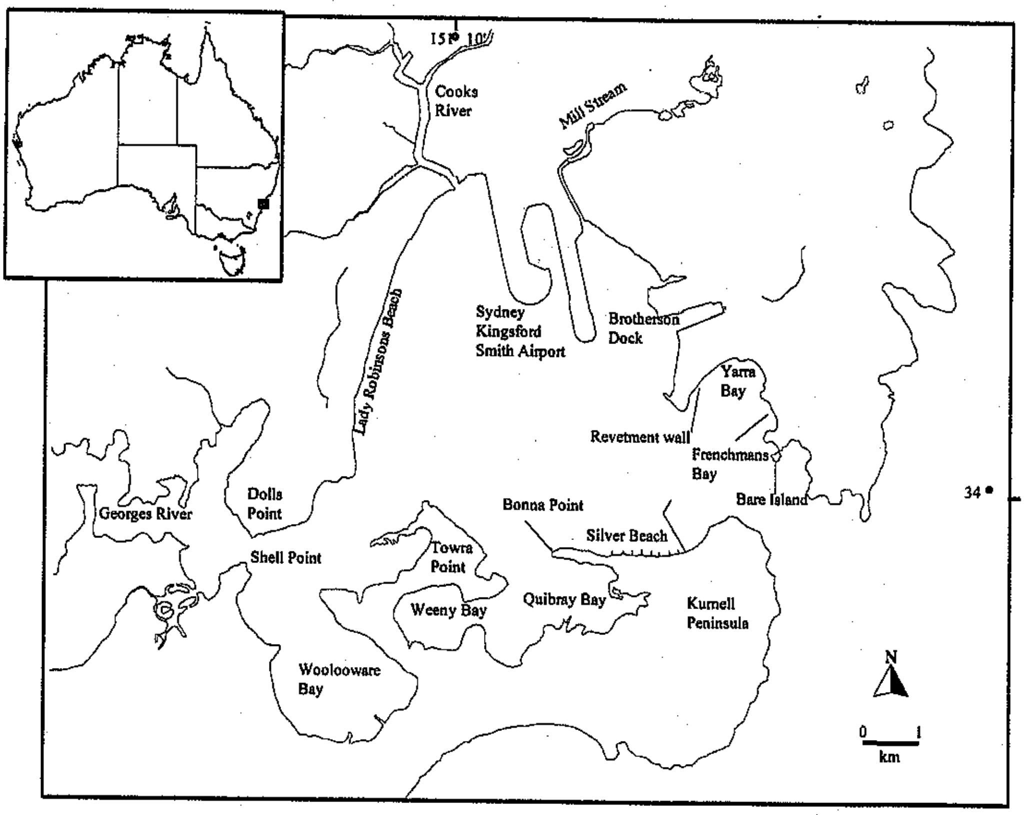

Figure 1. Botany Bay

Four species of seagrass have been identified in the bay: *Posidonia australis* along the southern shoreline, *Zostera capricorni* and *Halophila ovalis* along both the northern and southern shore and some *Halophila decipiens* in the deeper water (1-3 m) of Quibray Bay (West *et al.* 1989). *H. decipiens* has recently appeared between the two runways built into the bay at Kingsford Smith Airport (P. Gibbs, NSW Fisheries, pers. comm. 1997).

The presence of fibrous root remains of *P. australis* from sediment cores taken at a number of locations in Botany Bay (Larkum and West 1990) provide circumstantial evidence of a much wider distribution of this species in the past. This supposition is not unreasonable given the growth of *P. australis* in Jervis Bay at -10m (LAT) although the deepest *P. australis* has ever been recorded in Botany Bay is -3m (LAT) (West 1990).

An extensive chronology of events relating to changes within Botany Bay was prepared by McGuiness (1988). The first human impacts on the distribution of *P. australis*, and other species of seagrass within the bay, probably came about from the dredging of oyster shell as a source of builders' lime in the early 1800s (Larkum 1976a). Manufacturing commenced on the shores of Botany Bay in 1815 with a fulling mill that produced "coarse cloths, blankets and flannels" and two years later a paper mill was constructed (Larcombe 1963). A range of industries followed including tanneries and wool scourers (Larcombe 1963) to the point where in 1883 a Royal Commission suggested Botany as a site for noxious industries (Larkum 1976a). With no perceived need for catchment management, effluent disposal is likely to have contributed to the decline of seagrass within the bay (Larkum and West 1990).

Larkum and West (1990) used aerial photographs to track the changes in seagrass distribution within Botany Bay between 1942 and 1985. They documented the disappearance of *P. australis* on the northern shore and a long term decline of 257 ha (58%) of this species from the southern shore resulting in the fragmentation of a once continuous bed. Fluctuation in the area of *Z. capricorni* on both the northern and southern shores was also found to have occurred and many sites previously inhabited by *P. australis* had been colonised by *Z. capricorni.* These changes were attributed to a variety of causes some of which were naturally occurring such grazing by sea urchins (*Heliocideras erythrogramma* (Valenc.)), which caused a loss of 25 ha of the overall loss of *P. australis* along the southern shore between 1982 and 1984, and storm damage. The majority of the losses however were found to be due to residential and industrial development, relocation of the mouth of Cooks River in order to extend Sydney Kingsford Smith Airport, and dredging to allow the passage of large ships to and from the oil refinery at Kurnell.

Following construction of the oil refinery, it was necessary to control erosion along Silver Beach and a groyne field was built out into the existing seagrass beds. Further extension of the airport runway, and commencement of configurational dredging, to direct wave energy away from the port and onto the revetment wall, also resulted in an increase in wave energy at Towra Point and Dolls Point. Larkum and West (1990) concluded that while storm activity in the mid 1970s was responsible for further degradation and erosion of seagrass beds, the wave height in many parts of the bay was increased as a consequence of this dredging.

It is also of note that from the mid 1940s to the mid 1950s four boats dredged shell grit from the bay to be sold as an additive for chicken feed (B. Clarke, pers. comm., 1998). As with the harvesting of shells for lime, it is conceivable that the operations of these dredges had an impact on the seagrass growing in the deeper portions of the bay.

An overview of development activities carried out or planned since the mid 1990s that may have had an impact on the seagrass communities of Botany Bay is documented in Table 2. All of the major construction projects have been preceded by an Environmental Impact Statement (EIS), and in some cases the likely impact on seagrass was documented. For example, measurements of seagrass area and growth characteristics were undertaken before and during construction of the parallel runway at Sydney Kingsford Smith Airport to quantify short term impacts of dredging along the northern shore (T.E.L. 1994). However, there is a need to establish the long term impacts of the activities shown in Table 2 on seagrass and other types of estuarine vegetation through appropriate monitoring strategies, and to integrate all data gathered from particular projects.

Table 2. Activities since the mid 1990s affecting the distribution of seagrass in Botany Bay.

	Date	Development Activity	Predicted impact	Source 1	Actual Impact	Source 2
Completed	1992	Extension of the number of groynes on Silver Beach from 11 to 13	Sediment stabilisation and destruction of all *P. australis* at the groyne sites	Marine Pollution Research Pty Ltd (1992)	Not measured	NA
	November 1992 to October 1994	Construction of the parallel runway	Direct loss of 13.73 ha (42%) of northern *Z. capricorni*	T.E.L. (1994)	Assessment pending	M. Lincoln Smith, T.E.L. pers. comm. 1997
			Negligible impact on wave climate at Towra Point	Lawson and Treloar (1990)	Studies underway and to be completed in 1998. No discernible impact to date	N. Lawson, pers. comm. 1997
			Impact probable on southern shore seagrass but extent unknown.	T.E.L. (1993)	By Dec. 1993 apparent 3.2 ha increase of *P. australis* and 1.8 ha of mixed seagrass from July 1992	T.E.L. (1995)
	March 1997	Removal of 0.18 ha of seagrass from groyne site at Lady Robinsons Beach and transplant between airport runways	Removal of most of *Z. capricorni* from groyne site at Lady Robinsons Beach	Marine Pollution Research Pty Ltd (1997)	90% of seagrass removed Monitoring of transplant site ongoing.	Marine Pollution Research Pty Ltd (1997) P. Gibbs, NSWF pers. comm. 1997
	May? 1997	Construction of groynes at Lady Robinsons Beach	Impact on *Z. capricorni* at two groyne sites	Marine Pollution Research Pty Ltd (1997)	Not measured	NA
Proposed	1998 (?)	Removal of oyster racks in Quibray Bay	Regrowth of *P. australis* and *Z. capricorni*	D. Campbell, pers. comm. 1997	Pending decision which racks and how many to be removed	
	1998 (?)	Sithe Energies cogeneration plant	Minimal construction impact due to careful routing of the intake and outfall lines	T.E.L. (1997)	Pending conditions imposed by Commission of Inquiry	
	(?)	Expansion of Port Botany	Loss of most of the remaining *Z. capricorni* along the northern shore	S. Hobday, Sydney Ports, pers. comm. 1997	Mapping underway	P. Anink, Marine Pollution Research Pty Ltd pers. comm. 1998

Review of methods used to evaluate the distribution of seagrasses in Australia

The methods used to map seagrasses and changes in their spatial extent must vary according to the level of information required. Kirkman (1990) commented that techniques used to describe the presence of seagrass species over vast areas of coastline will differ from those required to map smaller areas. For the latter, a detailed description of the species mix, distribution, density and abundance is often required. It is therefore important to define the reasons why the project is being undertaken and to chose the appropriate method.

Generally, the mapping of seagrass will involve the interpretation of remotely sensed data whether it be from a balloon, an aircraft or a satellite, coupled with field assessment of the study area to provide ground truth (Kelly 1980, Kirkman 1990). The current generation of satellite images have limited use for the mapping of seagrass in the estuaries of NSW as the large pixel sizes (20 - 30 m in the case of SPOT and Landsat TM, Kirkman 1990), will not discriminate the many small and narrow seagrass beds present (West *et al.* 1985). These small beds may become identifiable as the resolution of satellite imagery is enhanced.

Aerial photography, which can be conducted at a variety of scales and in a range of formats (e.g. colour, black and white and infra red), is the most common source of remotely sensed data for seagrass mapping. Runs of aerial photographs can be commissioned for a particular purpose but are also often readily available through various government agencies and commercial contractors. More recently, airborne scanners, which cover a large range of spectral bands with high spatial resolution (in the order of 1 m), have been shown to have promise for seagrass mapping projects (CSIRO 1998).

Early estimates of the area of estuarine vegetation used a planimeter (e.g., Goodrick 1970), and it is assumed this technique was applied in a number of studies which fail to set out the measurement protocol (e.g., Larkum 1976b, Larkum *et al.* 1984). From the late 1970s through to the late 1980s the "dot grid" approach was used to calculate the area of seagrass, mangrove and saltmarsh in Botany Bay and elsewhere. West *et al.* (1985) transferred the boundary of a particular bed from an aerial photograph to a 1: 25 000 base map using a Bausch and Lomb Zoom Transferscope, redrew the boundary onto grided paper then counted the number of cells that fell with in the boundary. This technique provided the first assessment of the distribution of estuarine vegetation in NSW including the overall area of seagrass within 111 estuaries.

At an early stage in the planning of this project, it was envisioned that the maps produced by West *et al.* (1985) might be readily utilised as the basis on which historical comparisons could be made. However, when a digitised version of this map (produced by the NSW National Parks and Wildlife Service in ARC/INFO format) was enlarged to approximately 1: 50 000 scale, the bed boundaries emerged as generalised polygons (Figure 2). These polygons were considered inadequate to resolve small changes in the distribution of individual species, the area of which were not provided by West *et al* (1985). However, the overall area of seagrass was determined (340 ha) and has been used for a comparison.

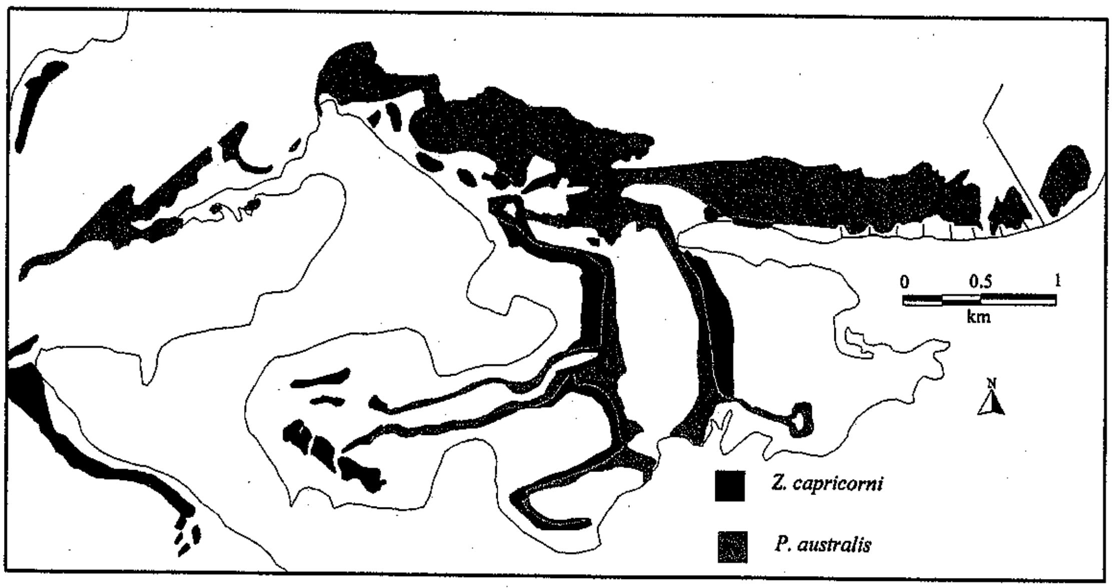

Figure 2. Extract from a digital map of data from West *et al.* (1985)

The critical issue in any mapping exercise is the establishment of boundaries in a "patchy" environment, and this is of particular significance where many small beds of seagrass (<2 m in diameter) are adjacent to one another. The analyst must make a series of subjective judgements to delimit dense and sparse vegetation types, and distinguish between the vegetated and unvegetated zones. In the early 1990s computer hardware and software developments, including the advent of GIS facilities removed the need for the labour intensive drawing and counting process and increased the accuracy of maps of estuarine vegetation that could be produced and updated (Lyon and McCarthy 1995). Two types of digital maps can be produced: vector maps where vegetation boundaries identified on the photographs and then digitised (e.g., T.E.L. 1993, 1994, 1995), and raster maps which can be created by the classification of digital images (e.g., Dasey and Potts 1997).

T.E.L. (1994) mapped the *Z. capricorni* beds along the northern shore of Botany Bay before construction of the parallel runway at Sydney Kingsford Smith Airport. In this case, 1: 6 000 colour aerial photographs taken in July 1992 were geographically corrected to remove the distortions inherent in the photographs. Boundaries of the beds were determined by differences in colour and tone on the prints and traced onto a separate clear film overlay for each frame. A semi-quantitative criterion was used to overcome the problem of subjective boundary definition by placing a transparent strip of 1 cm^2 squares each with 12 small, randomly distributed dots over the photograph. The boundary between "dense" and "patchy" seagrass was drawn where six of the twelve dots lay over unvegetated sediment. The clear film overlays were digitised for use in a GIS. T.E.L. (1994) recommended that the same methodology be applied after the runway was completed to detect any changes in the size and health of beds.

T.E.L. (1993) had previously undertaken a similar exercise to map a portion of the seagrass beds of southern Botany Bay before runway construction and repeated this mapping during construction to determine if there were any short term impacts (T.E.L. 1995). A small gain in the area of *P. australis* of 3.2 ha and an increase in the area of mixed beds of 1.8 ha was identified. This finding was of some significance as *P. australis* has classically thought not able to re-establish quickly, if at all once the bed was damaged (Larkum 1976b, Larkum *et al.* 1984).

Dasey and Potts (1997) discussed the effects of siltation and eutrophication on the seagrasses of NSW south coast estuaries, and the distribution of *Zostera* spp. within them was mapped. Colour photographs, taken in 1994 as part of a general photograph collection for the whole of the NSW coast (scale 1: 25 000), were scanned to produce digital images from which seagrass species and density were identified. Seagrass beds in portions of some estuaries remote from the entrance could not be mapped due to the turbidity of the water and only limited ground truth was undertaken. As the data were not geographically referenced, no attempt was made to quantify the areas identified. However, visual comparison with the maps produced by West *et al.* (1985) revealed a number of similarities and a range of differences: complete disappearance of some beds, reduction, migration and colonisation of others. Dasey and Potts (1997) stated that their images provide a baseline for future comparison and are suitable to be incorporated into a GIS at a later date.

When using remotely sensed data, ground truthing is essential as it is often difficult to distinguish reefs and deep holes from dense seagrass beds (Kirkman 1990, DENR 1997), or to distinguish seagrass species in adjacent or mixed beds. Kirkman (1990) describes a number of methods of ground truthing including underwater towing, bounce dives and benthic grabs, and establishing permanent transects. The advent of inexpensive yet accurate positioning devices (Global Positioning System, GPS) will further assist in ground truth operations.

Study Objectives

The management of Botany Bay continues to be a topical issue for the community, and local, state and commonwealth governments (Botany Bay Mayoral Taskforce 1998). Recently, Wetlands (Australia) dedicated an entire issue to the Botany Bay Symposium held in September 1995. Strong recommendations about management of the environment (Hatfield 1997) and planning within the catchment (Chanell 1997) were made. One of the key issues addressed was the need to preserve the ecosystems of high conservation value in an area of intensive industrial use and dense residential development (Adam 1997). Our project addressed that need through three objectives:

1) To create a digital map of the present estuarine vegetation of Botany Bay.

2) To update the history of seagrass distribution in Botany Bay by

   a) extending the work of Larkum and West (1990) with a calculation of the total amount of seagrass present in 1995, the most current year for which suitable aerial photographs were found,

   b) following the precedent of Larkum and West (1990) and examining change in area of seagrass on each of the northern and southern shores of the bay,

   c) investigating the change of seagrass along critical parts of the northern and southern shorelines.

3) To distribute this information in the context of management needs for current development proposals.

Methods

In order to achieve our objectives, we initiated a pilot study to refine the methods used to analyse change in mangrove and saltmarsh vegetation (Williams and Watford 1997, Williams *et al.* in prep.) and apply these to submerged vegetation. Details regarding acquisition and analysis of the aerial photographs, ground truth operations and map production follow.

Pilot study for seagrass mapping in Botany Bay

A pilot study (Watford *et al.* 1998) was commissioned to apply raster-based techniques similar to those used by Dasey and Potts (1997) to resolve fine scale distribution of seagrass. In a raster analysis the data are stored as small internally uniform cells (pixels) of a known size. The pixels are then assigned to the appropriate class of vegetation, coded to differentiate them from each other and a map produced from which the area for different vegetation types can be calculated. The raster analysis enabled some supervised classification to be undertaken automatically without the need to manually digitise a large number of small or fragmented beds. Figure 3 was derived from recent photographs of Port Hacking used in the pilot study. Watford *et al.* (1998) concluded that while vector data formats are useful in mapping large, semi-continuous beds, a raster approach is appropriate for irregular distributions of seagrass, particularly where some beds are of the order of 1-2 m in diameter.

Acquisition of aerial photographs and other comparative data

The NSW Fisheries collection of aerial photographs dates back to the late 1920s, but there are no current photographs of Botany Bay. As the budget for this project did not allow for the commissioning of special photographs, a search of photographs held by other agencies was undertaken. The Sydney Airport Corporation Ltd. (SAC, previously Federal Airports Corporation (FAC)) and Sydney Ports Corporation regularly commission colour aerial photographs at a scale of 1: 6 000, primarily to examine the movement of sand along the foreshores (Max Willoughby, pers. comm. 1997). As a result, these photographs do not provide full coverage of Quibray, Weeny and Woolooware Bays. The most recent of these photographs (April 1996) and other selected photographs were borrowed from Sydney Ports to assist with the analysis.

The most recent Cumberland Series (Sydney metropolitan district) of 1: 16 000 colour photographs flown by QASCO (NSW) Pty. Ltd. was also examined. These photographs were flown in April 1995 during low tide on a still day with minimal wave action and glare. After examining the available photographs, the QASCO product was considered appropriate for this project and 13 colour prints covering the whole of Botany Bay were purchased.

SAC and T.E.L. provided digital copies of the maps contained within the reports produced for the former (T.E.L. 1993, T.E.L. 1994 and T.E.L. 1995). These maps are in DXF format and were imported into our GIS for analysis of recent change along portions of the northern and southern shores of Botany Bay.

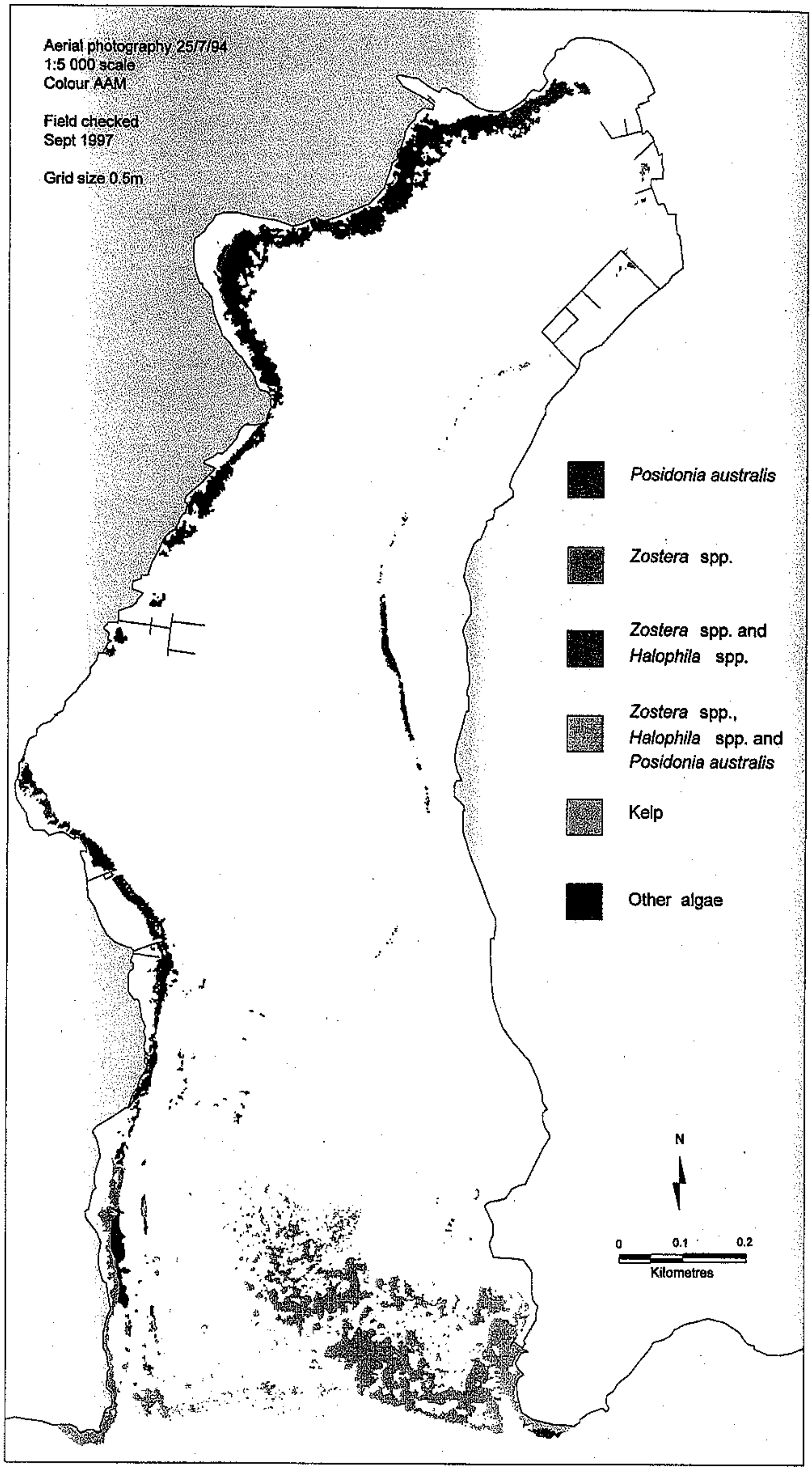

Figure 3. Pilot study results from Gunnamatta Bay (Watford *et al.* 1998)

Image processing and analysis

The first step in the analysis was to scan each photograph with a colour flat bed scanner at a resolution of 300 dpi (dots per inch) to produce a raster image. This resulted in the creation of images with a ground resolution of approximately 1.4 m.

Ground control points (GCPs) were used to fix each image in space and link overlapping images to form a mosaic covering the whole study area. The Australian Map Grid (AMG) co-ordinates of prominent features such as road and drainage intersections or buildings were readily determined from the four 1: 10 000 orthophoto maps which cover the study area produced by the NSW Surveyor Generals Department; Appendix 1). These GCPs were located as x, y co-ordinates from the row and column position in the image and their AMG co-ordinates then determined by measuring the position of the feature in relation to the 1 000 m grid on the orthophoto map. Care was taken to chose points of low elevation and at approximately the same vertical height above AHD.

In addition, the AMG co-ordinates were used to correct some of the distortion inherent in photographs due to movement and tilt of the aircraft and lens effects that increase from the centre of the photograph towards the edges. The scale of a vertical aerial photograph, determined from the altitude and the focal length of the lens, is only approximated at the centre of the photograph (directly below the lens) on flat terrain. As the distance to the lens changes vertically through differences in relief, and horizontally from changes in position within the field of view, the scale is altered. Other distortions may result from scanning contact prints, as paper products suffer from stretching and shrinkage (Burroughs 1990).

To geometrically correct these variations, each scanned image was rectified to position each pixel in relation to the base grid (AMG) using the resampling process in IDRISI GIS software (Figure 4). A minimum of six GCPs, with three or more points common to adjoining images, were used to rectify each image using a linear transformation. Eastman (1992) advises that although three control points may be used for a linear transformation, at least twice this number should be used for a reasonable fit. The effectiveness of the transformation was tested by viewing the root mean square (RMS) error and the mosaic produced by overlaying the resultant images. If a high RMS value was calculated or the photographs did not appear to fit reasonably well within the mosaic, new control points were identified and the transformation process rerun (Appendix 1).

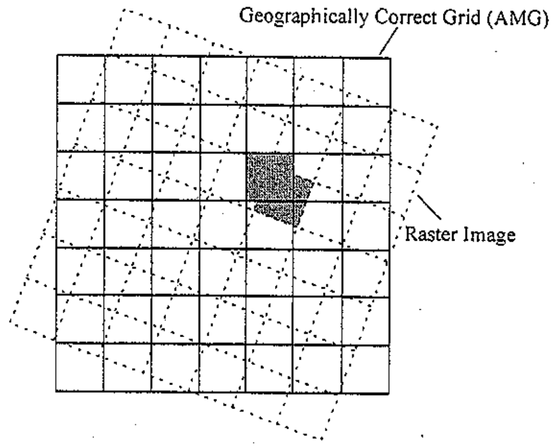

Figure 4. Resampling a raster image to a geographically correct grid using the nearest neighbour method. (Modified from Curran 1988)

Because of the relatively large size of Botany Bay (~100 km^2) and the resolution of the scanned photographs (1.4 m), a 2m pixel size was chosen as the output resolution during resampling for each photograph.

Presumptive boundaries of saltmarsh, mangrove and submerged vegetation were identified from the scans of the original photographs, before resampling, in order to retain as much information as possible. Monospecific seagrass beds and/or mixed beds were identified through a combination of on-screen digitising and supervised classification with the image processing software PHOTOSTYLER. Supervised classification is the process where a pixel value, or a range of pixel values, measured in red, green and blue components for a true colour image, is associated with a particular cover type that is known to exist in that area of the image. Pixels of these values can then be selected from the remainder of the image automatically and assigned the same cover type. The classified images were resampled with the same GCPs used to create the photomosaic, resulting in a raster map of the study area showing the distribution of seagrass, mangrove, saltmarsh and kelp.

Field work and image classification

The draft map was taken into the field to confirm the bed classification and distribution identified from the images. Field work took four days to complete, spread from mid June to mid July as the work was tidally dependant in some parts of the bay and undertaken as weather conditions permitted.

A small boat drove slowly over each bed and ran a number of transects perpendicular to the shore to assess the change in species composition with depth. A bathyscope constructed from PVC pipe with sealed perspex at one end was used to assist with field identification of seagrass and kelp (Figure 5). When clamped to the side of the boat, the bathyscope excluded the effects of waves and glare. In calm conditions, the bathyscope could be used whilst the boat was moving at a speed of 1-2 knots. We were able to discriminate between the three main types of seagrass (*P. australis*, *Z. capricorni* and *Halophila* spp.) in all parts of the bay except region 7 which was too deep.

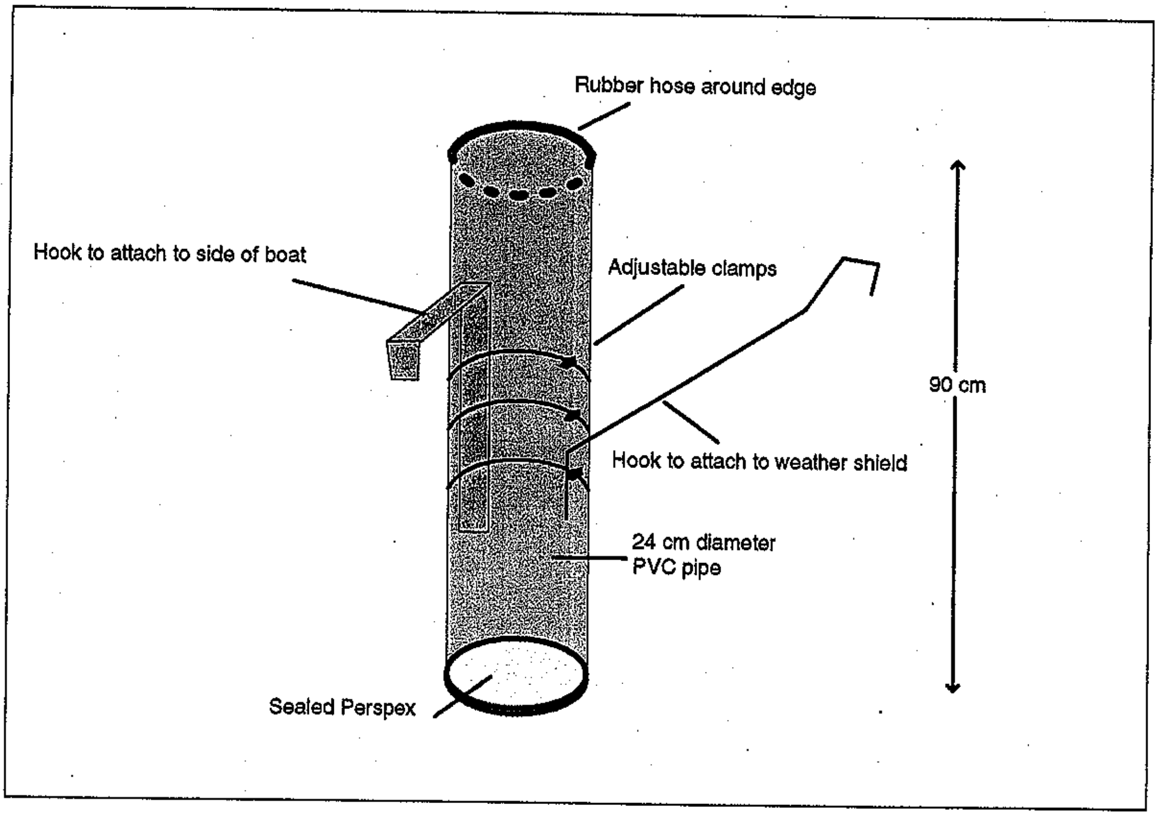

Figure 5. Bathyscope constructed to examine seagrass from a moving boat.

Following the ground truth investigations, the bed boundaries on the presumptive map were edited as necessary. Six categories of submerged vegetation and two categories of emergent vegetation were created (Table 3).

Table 3. Classification for mapping and area calculations

Vegetation Type	Class Name	Species
Submerged	*P. australis*	*P. australis*
	Mixed Posidonia	*P. australis* and/or *Z. capricorni* and/or *Halophila* spp.
	Z. capricorni	*Z. capricorni*
	Sparse Zostera	*Z. capricorni*
	Mixed Halophila	*Halophila* spp. and *Z. capricorni.*
	Kelp	*Sargassum* spp. and/or *Ecklonia* spp.
Emergent	Mangrove	Not differentiated
	Saltmarsh	Not differentiated

No attempt was made to measure the density of leaves or shoots within seagrass beds, except for a subjective assessment in the case of *Z. capricorni* where some areas were designated as **Sparse Zostera**, or to assign dominance categories to species present in the mixed beds. Because *P. australis* has a limited range along the NSW coast (West *et al.* 1985), occurring in the marine dominated estuaries from Wallis Lake to Merimbula Lake, and because its decline in Botany Bay has been noted (Larkum 1976b, Larkum and West 1990), the presence of this species has been emphasised by the creation of two classes, *P. australis* for monospecific beds and **Mixed Posidonia** for other beds where the species is present but may not be dominant. In contrast, some *P. australis* was noted in the **Mixed Halophila** beds along the eastern end of Silver beach (region 7) but the area was considered too small to warrant inclusion in this class.

Other submerged vegetation such as the algae *Caulerpa scalpelliformis*, although know to occur within the Bay (Davis *et al.* (1997), was not targeted as part of this study.

The classification scheme was applied to the raster images by recoding the pixels of each type of vegetation to the appropriate class in IDRISI. The area of each category was calculated by determining the number of $4m^2$ (2m x 2m) pixels that were assigned to each class and a map illustrating the distribution was produced.

Comparison of results with previous studies at two sites

To assist in comparisons with previous and future studies, the bay was divided into seven regions; three along the northern and western shore (regions 1, 2 and 3), and four regions along the southern shore (regions 4, 5, 6 and 7). Where possible surrounding roads were used as the outer boundary to encompass all the wetland habitats of the bay (Figure 6).

Region 5 is the most complex of all regions because of the diversity of estuarine vegetation and also because of its management arrangements. This region encompasses the Towra Point Aquatic Reserve of NSW Fisheries and the Towra Point Nature Reserve of NPWS as well as the surrounding wetlands from Shell Point to Bonna Point. The boundaries of the aquatic reserve are defined from the metes and bounds description of the Fisheries Management (Aquatic Reserves) Regulation 1995-No. 13. To add the reserve as a layer within the GIS, surveyed co-ordinates were obtained for a number of offshore boundary features including Waterways Authority channel markers, State Survey Marks and oyster lease corner posts. The upper boundary of the aquatic reserve was less easy to delimit, particularly as it is described by the mean high tide mark and a number of unsurveyed posts. As a consequence the location of this boundary has been estimated in some places. The boundary of the nature reserve was imported as a digital layer from the NSW NPWS Estate Version 4/1998. As the lower boundary of the nature reserve is also defined in places by the mean high tide mark, we did not attempt to differentiate between these two reserves but have regarded the combined area as one protected entity.

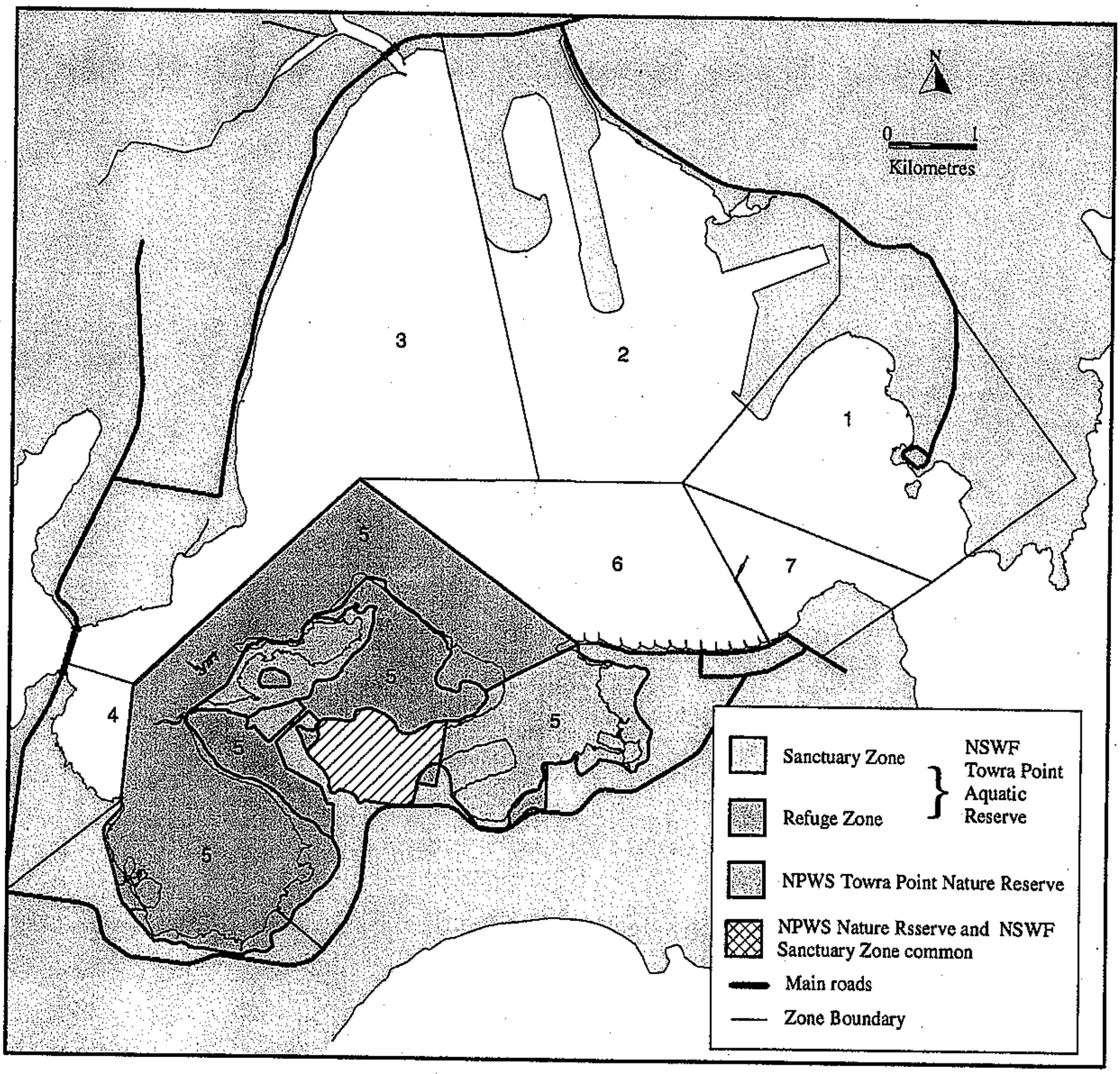

Figure 6. Botany Bay study regions.

Boundaries follow main roads where possible. Reserves protected by NSW Fisheries and NPWS are also shown within region 5. NSW Fisheries Towra Point Aquatic Reserve digitised from Fisheries Management (Aquatic Reserves) Regulation 1995-No. 13, Schedule 7; NPWS Towra Point Nature Reserve boundary from NPWS Estate GIS coverage version 4/98.

To examine recent changes along the section of the northern shore between the parallel runway and Port Botany, the studies of Kinhill (1990) and T.E.L. (1994) were consulted and compared with data from our corresponding region.

In order to assess short term change in the distribution of nearshore seagrass from Silver Beach to Towra Point, the investigations of T.E.L. (1993) and T.E.L. (1995) were examined. These two studies were based on the SAC and Sydney Ports Corporation aerial photographs, and hence excluded the eastern end of Silver Beach, part of Quibray Bay, and all of Weeny and Woolooware Bays. The maps in T.E.L. (1993) contain an AMG co-ordinate grid from which it was possible to determine the spatial limits of their study zone and to use these limits to extract data compatible to our results. That is, we removed portions of the **Mixed Posidonia** and **Sparse Zostera** beds from our map for comparison. The *Halophila* spp. identified in T.E.L. (1993) is included in our **Mixed Posidonia** class. T.E.L. (1995) remapped a portion of the beds identified in their 1993 study but as we were not able to easily determine which of these beds were common to the earlier study, we did not try to integrate this information.

Results

The distribution of seagrass, mangrove, saltmarsh and kelp in Botany Bay in 1995 is shown in Figure 7 and the total number of hectares of each of the vegetation classes is shown in Table 4. As the field work was undertaken in 1998 it was to be expected that there would be some differences between the 1995 images and what was seen in the field. Three of the most notable differences were that the 1995 photographs do not show the groyne field now in place at Dolls Point, the amount of *Z. capricorni* seen along Lady Robinsons Beach is now greatly reduced from the amount indicated in the photographs, and *Z. capricorni* and *H. ovalis* have regrown between the runways and to the east of the parallel runway (P. Gibbs, pers. comm. 1998).

The total area of seagrass present in 1995 was estimated to be 624 ha (Table 4). The largest area for any one class was 226 ha of *Z. capricorni*, but another 85 ha of **Sparse Zostera** was also identified. There were 163 ha of *P. australis,* and 111 ha

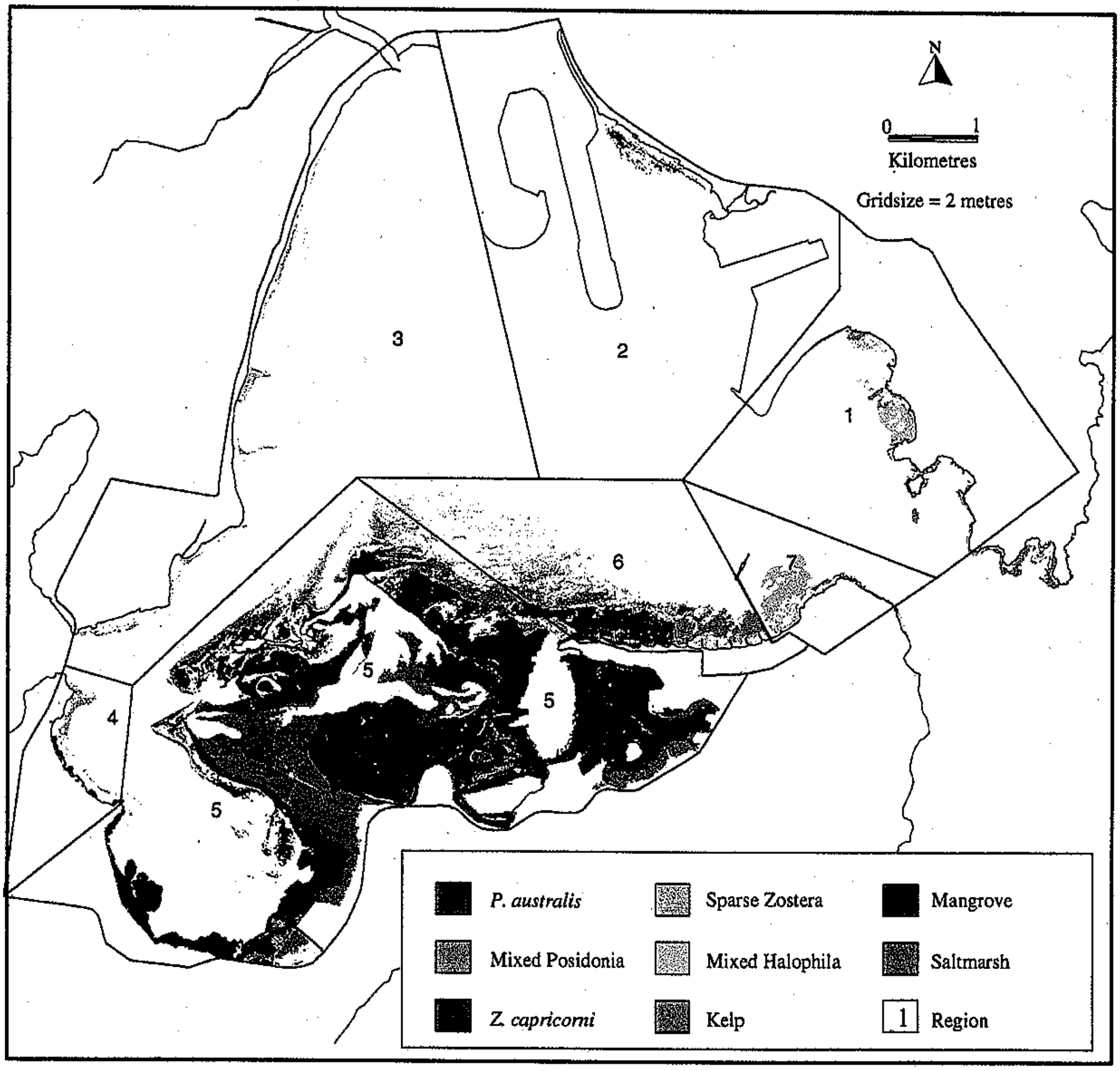

Figure 7. Distribution of seagrass, mangrove, saltmarsh and kelp in Botany Bay, 1995. **Mixed Posidonia** indicates presence of *P. australis* and/or *Z. capricorni* and/or *Halophila* spp.; **Mixed Halophila** indicates presence of *Halophila* spp. and *Z. capricorni*; kelp indicates presence of *Sargassum* spp. and/or *Ecklonia* spp.

Table 4. Area (ha) of seagrass, mangrove, saltmarsh and kelp in each region of Botany Bay, 1995. * Region boundaries are indicated on Figure 6. **Mixed Posidonia** indicates the presence of *P. australis* and/or *Z. capricorni* and/or *Halophila* spp.; **Mixed Halophila** indicates the presence of *Halophila* spp. and *Z. capricorni*; Kelp indicates presence of *Sargassum* spp. and/or *Ecklonia* spp.

Region number *	***P. australis***	**Mixed Posidonia**	***Z. capricorni***	**Sparse Zostera**	**Mixed Halophila**	**Total Seagrass**	**Kelp**	**Mangrove**	**Saltmarsh**
1	0	0	0	0	12.2	12.2	16.9	0	0
2	0	0	7.5	0	0	7.5	0.1	0	0
3	0	0	0	15.2	0	15.2	0.1	0	0
Sub total Northern shore	0	0	7.5	15.2	12.2	34.9	17.1	0	0
4	0	0	0	9.0	0	9.0	0	2.9	0
5	119.7	60.5	214.4	26.6	0	421.2	0	419.8	157.3
6	43.1	50.7	4.3	33.7	2.2	134.0	0	0	0
7	0	0	0	0	24.8	24.8	3.9	0	0
Sub total Southern shore	162.8	111.2	218.7	69.3	27.0	589.0	3.9	422.7	157.3
Total	**162.8**	**111.2**	**226.2**	**84.5**	**39.2**	**623.9**	**21.0**	**422.7**	**157.3**

of **Mixed Posidonia** which was found only on the southern side of the bay. Although some *Halophila* spp. was found within the **Mixed Posidonia** beds (regions 5 and 6), this taxon was the dominant species in the two regions closest to the mouth of the bay, regions 1 and 7, where 39 ha of **Mixed Halophila** occurred. A small, but unquantified amount of *P. australis* was contained in the **Mixed Halophila** of region 7.

Kelp, which includes *Sargassum* spp. and *Ecklonia* spp. is known to occur around the mouth of Botany Bay (Kennelly and Underwood 1992) and also along the runway walls and other seawalls (M. Lincoln Smith, pers. comm. 1998). In our presumptive classification kelp was identified as seagrass in some places but reclassified following field inspection. Twenty one hectares were identified, but this may not necessarily represent the full extent of kelp distribution within the bay. An extensive bed of kelp was once documented in the channel between Dolls Point and Towra Point (NSW State Fisheries 1973), but it was not identified in the 1995 aerial photographs due either to its demise, the depth of water in which it is found, and/or the turbidity of the water where the Georges River flows into the bay. Emergent vegetation, 432 ha of which was mangrove and 157 ha of saltmarsh, was found only on the southern shore (regions 4 and 5).

Northern shore

Thirty five hectares of seagrass was identified on the northern shore (regions 1, 2, 3) in the aerial photographs of 1995 (Table 4). These beds consist of *Z. capricorni*, **Sparse Zostera** and **Mixed Halophila**. No *P. australis*, mangrove or saltmarsh was found on the northern shore. Seventeen hectares of kelp was identified.

Table 5 and Figure 8 represent the recorded changes in seagrass distribution for the northern and western shores of Botany Bay. The data set now spans 65 years with a maximum of 10 years between measurements, and suggests the amount of seagrass now present is about the same as found by Larkum and West (1990) in 1930 and 1985 (Figure 8).

Construction of the parallel runway at Kingsford Smith airport began in 1992 and was completed in 1994. Prior to construction, Kinhill (1990) and T.E.L. (1994)

Table 5. Recorded changes in seagrass area (ha) along the northern and western shores of Botany Bay, 1930-1995. Larkum and West (1990) mapped and calculated areas of *Z. capricorni* mixed with *P. australis* and/or *Halophila* spp. and their calculations are assumed to include seagrass for each of regions 1, 2 and 3 created for this study (Figure 6). *P. australis* is no longer present on the north shore of Botany Bay and hence the area of seagrass calculated by us is comprised of *Z. capricorni,* and *Halophila* spp. (Table 4).

Year	Month	Total seagrass	Source
1930	Feb	35	Larkum and West (1990)
1942	June	93	Larkum and West (1990)
1951	May	22	Larkum and West (1990)
1961	June	49	Larkum and West (1990)
1975	April	16	Larkum and West (1990)
1976	?	87	Watkins (1976) in SPCC (1978)
1977	?	103	Larkum *et al*. (1984)
1978	?	41	Larkum *et al*. (1984)
1978	?	19	SPCC (1978)
1985	March	27	Larkum and West (1990)
1995	April	35	this study

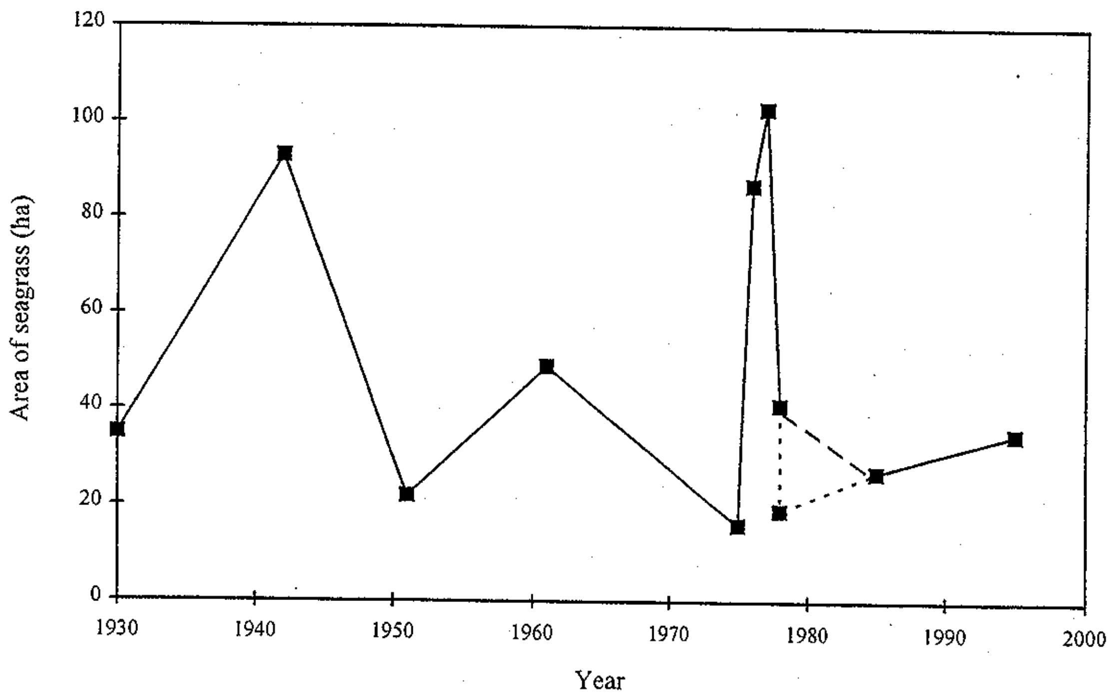

Figure 8. Potential change in area of seagrass along the northern and western shores of of Botany Bay, 1930-1995. Sources of data are shown in Table 5.

mapped the seagrass between the existing runway and Brotherson Dock and predicted the amount of seagrass that would remain after the runway was completed. The methods and date of photographs used by Kinhill (1990) are not known; T.E.L. (1994) used photographs taken in 1992 at a scale of 1: 6 000 and mapped in vector format.

The location of the seagrass measured in the two studies is equivalent to that mapped in region 2 of our study and so can be directly compared. Table 6 and Figure 9 suggest there has been a steady loss in the area of *Z. capricorni* since 1990, with only 7.5 ha now remaining. This amount is less than either Kinhill (1990) or T.E.L. (1994) predicted.

Southern shore

Seagrass is the dominate estuarine vegetation type found along southern shore with 589 ha identified (Table 4.) Mangrove (423 ha) and saltmarsh (157 ha) were only found on this side of the bay and 21 ha of kelp was also located around the rocky shore of the Kurnell peninsula.

Assessment of change for the southern shore of Botany Bay is problematic due to the mixture of species within beds.

Table 7 and Figure 10 show the recorded long term changes in seagrass distribution for the southern shoreline of Botany Bay. Five hundred and eighty nine hectares of seagrass were found compared to 516 ha determined by Larkum and West (1990) in 1984. *P. australis* (163 ha) was only found in regions 5 and 6 while a total of 288 ha of *Z. capricorni* was identified from across all the southern study regions (Table 4). Although the area of each of these two species is less than that identified in 1984 by Larkum and West (1990), the interpretation of these results is complicated by the fact that both species also occur scattered within the **Mixed Posidonia** and **Mixed Halophila** classes. While there appears to have been an overall increase in area of seagrass, if Larkum and West (1990) had measured the area of *Halophila* spp. and had included mixed beds in their classification, this difference would have been smaller.

Table 6. Area (ha) of *Z. capricorni* in study region 2, 1990-1995. Kinhill (1990) prediction is for direct loss only. Area measured by Kinhill (1990) and T.E.L. (1994) combines dense and sparse *Z. capricorni* beds.

Year	Month	Area Measured	Area predicted after construction of third runway	Source
		Total	Total	
1990	?	49.7	27.9	Kinhill (1990)
1992	July	32.48	18.75	T.E.L. (1994)
1992-1994			Construction of runway	
1995	April	7.48		This study

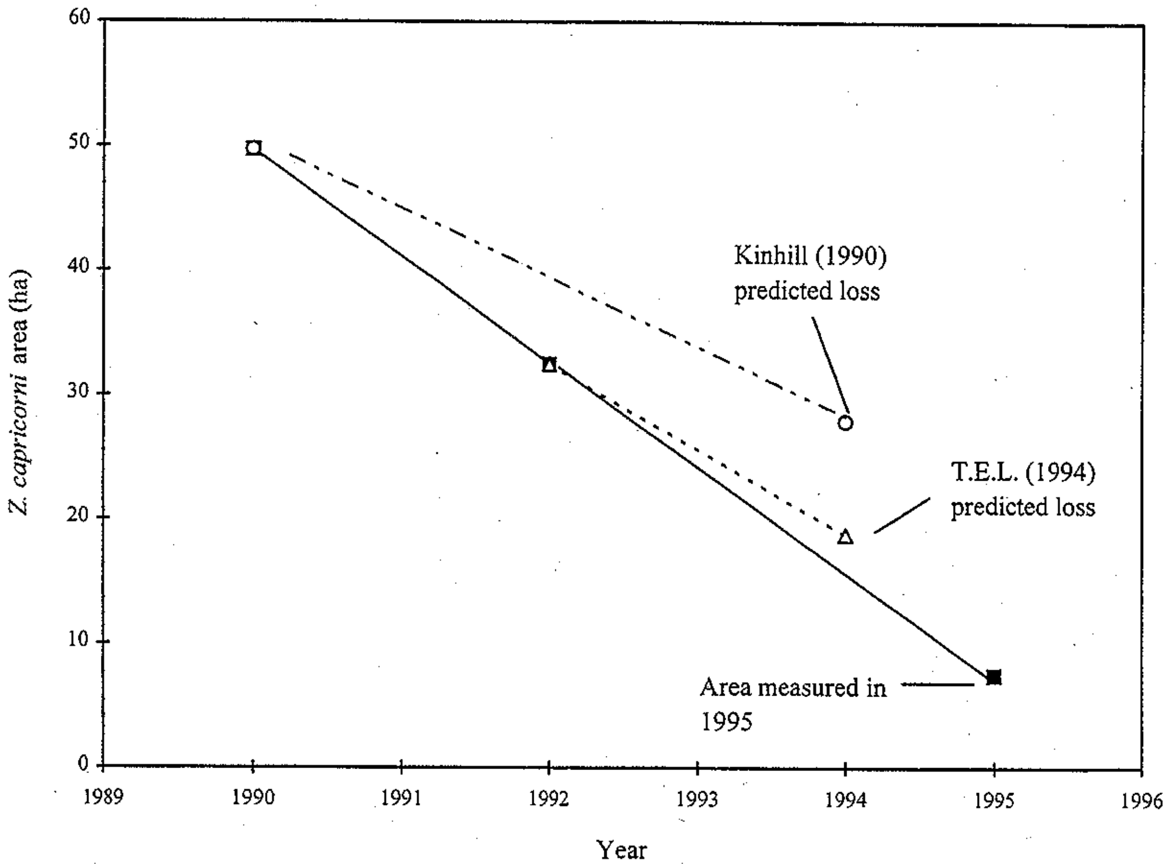

Figure 9. Predicted and measured changes to the area of *Z. capricorni* in study region 2, 1990-1995. See Figure 6 for region boundary.

Table 7. Recorded changes in seagrass area (ha) along the southern shore of Botany Bay, 1942-1995. The areas calculated by Larkum and West (1990) are assumed to include seagrass from regions 4, 5, 6 and 7 created for this study (Figure 6). Area of *Z. capricorni* for this study is derived from the summation of *Z. capricorni* and **Sparse Zostera** in Table 4. **Mixed Posidonia** indicates the presence of *P. australis* and/or *Z. capricorni* and/or *Halophila* spp.; **Mixed Halophila** indicates presence of *Halophila* spp. and *Z. capricorni*; Kelp indicates presence of *Sargassum* spp. *and/or Ecklonia* spp.

Year	Month	Total seagrass	*Z. capricorni*	*P. australis*	Mixed Posidonia	Mixed Halophila	Source
1942	July	668	223	445			Larkum and West (1990)
1951	May	567	192	375			Larkum and West (1990)
1961	May	598	236	362			Larkum and West (1990)
1970	July	740	341	399			Larkum and West (1990)
1977	April	483	159	324			Larkum and West (1990)
1979	April	394	161	233			Larkum and West (1990)
1982	July	541	328	213			Larkum and West (1990)
1984	June	516	328	188			Larkum and West (1990)
1995	April	599	311	163	111	14	this study

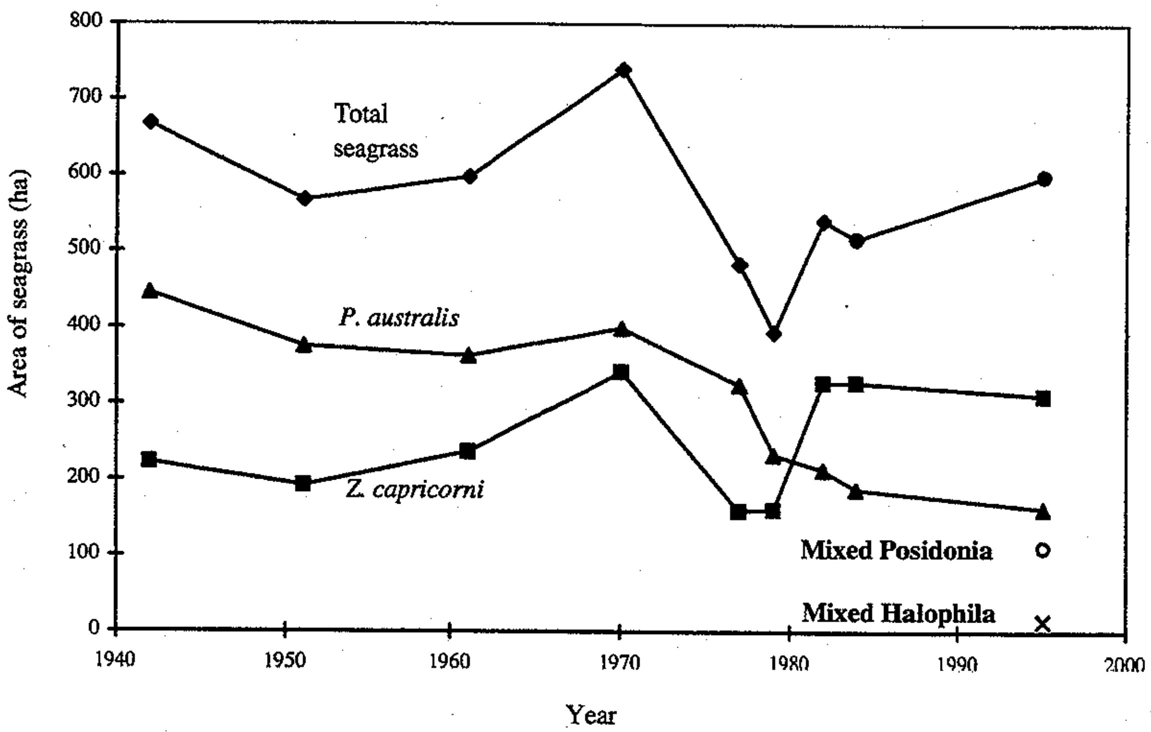

Figure 10. Potential change in area of seagrass along the southern shore of Botany Bay, 1942-1995.

Table 8 indicates that for the portion of the southern shore between the Kurnell wharf and Towra Point, the total area of seagrass in 1992 (327 ha) was similar to that of 1995 (324 ha). However, there was an increase in area of *Z. capricorni* of approximately 8 ha, and a decrease of *P. australis* of approximately 12 ha. There was little change in the area of *P. australis* co-existing with *Halophila* spp. when the two mixed classes are combined (60 ha vs. 61 ha).

Three of the sets of photographs analysed by Larkum and West (1990) were the same for both the northern and southern shores enabling a total seagrass area to be calculated and compared to the totals of West *et al* (1985) and this study (Table 9). The amount of seagrass Larkum and West (1990) found on the north shore for 1985 has been combined with that found on the southern shore in 1984 to give an estimate for that period.

These results indicate that the largest amount of seagrass in Botany Bay was present in 1942 where 761 ha was identified. Since then the area has fluctuated from a from low of 340 ha in 1981 to the present level of 624 ha which is similar to that found in 1961 (647 ha). It must be remembered that Larkum and West (1990) did not map *Halophila* spp. so it is conceivable that the areas for 1942, 1951, 1961 and 1984-1985 may be underestimates.

Table 8. Comparison of seagrass area (ha) from the Kurnell wharf to Towra Point on the southern shore of Botany Bay, 1992-1995. The area of seagrass from this study has been reduced to match the limits of the investigation by T.E.L. (1993). *Z. capricorni* in this table is derived from the summation of *Z. capricorni*, **Sparse Zostera** and **Mixed Zostera** for both studies. **Mixed Posidonia** is defined as *P. australis* and/or *Z. capricorni* and/or *Halophila* spp. (Table 4) for this study and in T.E.L. (1993). The area classed dominantly as *Halophila* spp. in T.E.L. (1993), is also encorporated in the **Mixed Posidonia** class of this study.

Year	Total seagrass	*Z. capricorni*	*P. australis*	Mixed Posidonia	*Halophila* spp.	Source
1992	327.1	110.3	156.4	21.4	39.0	T.E.L. (1993) corrected in T.E.L. (1995)
1995	323.6	117.8	144.0	59.6	2.2	this study

Table 9. Change in the total seagrass area (ha) of Botany Bay.
Halophila spp. is not included in the area calculations of Larkum and West (1990).

Date of aerial photographs	Date of field checking	Area (ha)	Source
1942		761	Larkum and West (1990)
1951		589	Larkum and West (1990)
1961		647	Larkum and West (1990)
1977-1979	1981	340	West *et al.* (1985)
1984-1985	1987	543	Larkum and West (1990)
1995	1998	624	this study

Discussion

It is difficult to compare the data collected in this study to that of Larkum and West (1990) or other studies where different analytical techniques were used. Aspects such as the purpose of the respective studies, methods of data acquisition (e.g. photograph specifications, time of year and quality and extent of photograph runs), variation in analytical procedure (methods to obtain positional accuracy of the photographs, differences in classification technique), and methods used to confirmation distributions (ground truth techniques) must be borne in mind.

Nevertheless, we note that the area of seagrass in Botany Bay has varied widely over the past 50 years (Table 9). When the area of *Halophila* spp. is removed from our calculations to make a direct comparison with previous studies, the amount now present (~584 ha) is intermediate to the range of areas determined in the past (340 ha to 761 ha). Furthermore, the present area of seagrass reinforces the perception of a regrowth trend since the low point of 1981 (West *et al.* 1985). Is the increase since 1981 a real one, or is it due to differences in analytical technique? If real, what features of natural variability in seagrass distribution are at play, and what features of man-induced variation can be inferred?

The use of historical aerial photographs to determine change in seagrass boundaries poses a number of problems. Old photographs, especially the early generation black and white photographs, can be difficult to analyse if taken at high altitude, when sun glare, shading or wave chop are present. Ultimately, the investigator must rely on a set of criteria developed through professional experience in defining seagrass boundaries. Even with recent colour photographs some beds are hard to delimit, for example, Larkum and West (1990) indicated *Halophila* spp. was difficult to detect due to its low canopy height and colour, and they elected to disregard it from area calculations. We found it impossible to isolate even small monospecific beds of other species from within the area dominated by *Halophila* spp. near the long wharf at Silver Beach or from within the beds adjoining the *P. australis* along Silver Beach and across to Towra Point (Figure 7). A second suite of problems arise when comparing area calculations derived by different analytical techniques. In some cases the methods used are not set out (e.g., Kinhill 1990) or the techniques used to scale and position photographs are not clear (e.g., Larkum and West 1990).

Our field work showed that *Halophila* spp. in regions 1 and 7 was always mixed with other species of seagrass. As the photographs were taken in 1995, the species composition in those beds at that time may well have been different to what was present in 1998. This situation will always arise in low-budget studies that depend on available, rather than specially commissioned photographs, and where the time lag between the date of the photographs and ground truthing may be a number of years. If this interval were to be reduced through the commissioning of specific monitoring programs, and the current generation of relatively low priced GPS equipment were employed, the accuracy of field maps would increase considerably. Allied to the issue of ground truth is the need for a set of studies to resolve the placement of boundaries around mixed beds, short term variation in species mix, density, biomass, reproductive status and bed health.

Globally, large fluctuations have been seen in the distribution of seagrass beds (e.g., Larkum and West 1983). The variation in distribution seen in Botany Bay (Larkum and West 1990) has been seen elsewhere in NSW, e.g., at Gunnamatta Bay in Port Hacking (Watford *et al.* 1998), and is expected as a consequence of natural and man-induced factors such as storms and disease, and/or dredging and pollution. So far, the maximum area of seagrass recorded for the whole of Botany Bay was 761 ha in 1942 (Tables 5 and 7, from Larkum and West 1990). Coincidentally, Australia was in the El Nino phase of ENSO at that time (Allan *et al.* 1996) and the Sydney metropolitan district in drought. Water clarity may have been at its best, allowing maximum potential for seagrass expansion.

The importance of water clarity in determining the growth and survival of seagrass beds is well recognised (CSIRO 1994, Dennison and Kirkman 1996, Koch and Beer 1996). Water clarity is in turn influenced by rainfall, wind and effluent discharge and there is a real challenge to unravel the role each of these has played in modifying the distribution of seagrass in Botany Bay. Of these three influences, and there may be others of significance, that of rainfall is in part easy to track due to the efforts of Allen *et al.* (1996) who compiled a global pattern of the El Nino phenomenon from 1891 to 1994. There is a danger, however in assuming synoptic summaries apply at a local scale. Compendia of wind and effluent effects of a similar type are not yet available.

If there were a relationship between El Nino and seagrass distribution, then an expansion of beds may have been expected in or around the other El Nino years: 1930, 1957-58, 1965-67, 1972 and 1982 (Allen *et al.* 1996). Conversely, excessive rainfall during the La Nina intervals would be expected to increase turbidity and depress seagrass growth. For the northern shore, the area of mixed seagrass calculated by Larkum and West (1990) for 1951 was one of the smallest on record and could be accounted for by the fact that in the early 1950s there were a number of construction projects underway in the northwestern corner of the bay, e.g., the Cooks River was diverted as part of the Sydney airport development (Botany Bay Mayoral Taskforce 1998). The works would have entrained sediments, reducing water clarity even further if a La Nina episode was current. Dredging for the initial expansion of the runway into the bay from 1964 to 1966 and in 1970 for its final extension (Botany Bay Mayoral Taskforce 1998) may have had a similar impact. In other words, the negative impact of any meteorological forces may have been heightened by the effects of construction.

El Nino returned in 1972 and 1982, but any extension of beds may have been offset by the severe storms of 1974 and 1975 (Larkum 1976b), and the reclamation of the Botany Beach shoreline between 1975 and 1978 (Botany Bay Mayoral Taskforce 1998). Expansion during the El Nino of the early 1990s may have been hindered by construction of the parallel runway. Unfortunately, the correspondence between the onset of El Nino (or La Nina) and seagrass area is insufficiently documented to pursue this hypothesis any further.

With the exception of the increase recorded from 1961 to 1970, the area of *P. australis* on the southern shore of Botany Bay has continually declined from 1942 through to 1985 (Larkum and West 1990). Dredging commenced in 1953 to give oil tankers access to the Kurnell oil refinery and continued until 1965 (Botany Bay Mayoral Taskforce 1998), causing shoreline erosion along Silver Beach, which would have uprooted any seagrass present, particularly during storms. Shoreline erosion was in part rectified by the construction of eight groynes in 1970 and additional groynes were successively added to the point where there are now 13 groynes in place.

In contrast, the area of *Z. capricorni* along the southern shore expanded from 1951 to 1970. Large losses of seagrass also occurred during the storms of 1974 and 1975 (Larkum 1976b), but there was another extension of *Z. capricorni* from 1979 to 1982, the latter being an El Nino year. As indicated previously, before a relationship can be established between El Nino and seagrass distribution in Botany Bay, additional sets of historical photographs need to analysed.

Other perceived changes in distribution of seagrass may be due to seasonal variation in abundance. The studies of West and Larkum (1979) on *P. australis*, and the studies of Larkum *et al.* (1984) and Otway and McBeth (1998) on *Z. capricorni* show seasonal changes in leaf and shoot characteristics for these species, with maxima occurring in late summer, followed by a winter dieback. A separate set of investigations (Worthington *et al.* 1992, T.E.L. 1993, CSIRO 1994) suggest seasonal growth patterns do not exist, or are irregular and unpredictable. Those studies observing dieback suggest it is less severe for *P. australis* (West and Larkum 1979) than for *Z. capricorni* (Larkum *et al.* 1984), in turn implying the former provides a more consistent or "harder" target in aerial photographs independent of season. Fortunately, the array of photographs used by Larkum and West (1990) and T.E.L. (1993) were taken from late summer (February) to mid winter (July) (Table 4), and hence correspond to the seasonal, or near seasonal, maxima in cover. Should dieback occur, photographs taken in late winter or spring might result in the underestimation of bed size.

Some of the uncertainties arising from the above issues can be dealt with by examination of change within the regions identified in Figure 2. Given that Larkum and West (1990) did not calculate the area of *Halophila* spp., there was more than 27 ha of seagrass along the whole of the northern and western shore in 1985 (Table 5). If the 12 ha of **Mixed Halophila** we found in region 1 is removed from our total (i.e., 35 ha in 1995), the area of seagrass is similar in the two studies, and it would be possible to conclude the relatively small difference was due to analytical technique and little change had occurred. However, when the Larkum and West (1990) map of seagrass along the northern shore in 1985 is compared with ours (Figure 7), a major shift in distribution is indicated. The loss which occurred as part of the reclamation for the parallel runway appears much greater than the gain seen subsequently to the east of this runway. Some additional gain appears to have arisen along the western shore (region 3), presumably in part due to the configurational dredging which took place in the mid 1970s as parts of the western shore are now subject to a lower wave energy regime than before (McGuiness 1988). Unfortunately, the distribution of seagrass along the western shoreline, was not discussed in Larkum and West (1990). As well, comparison of their figures with ours suggests the beds on the northern side of the entrance (region 1) extended further into the bay between 1985 and 1995.

In region 2, the sector between the first runway built in the bay and the Brotherson Dock, the recent trend is to a reduction in area of seagrass: in 1990, 50 ha were found by Kinhill (1990), 32 ha by T.E.L.(1994) in 1992, and 7 ha in 1995 from this study (Table 6). Note that the areas measured in the two former studies for region 2 are both larger than the 27 ha found by Larkum and West (1990) in 1985 for the whole of the north shore. In contrast to T.E.L. (1994), the techniques used by Kinhill (1990) are unknown and so it is difficult to infer the role methodology or seasonal variation plays in their analysis. In comparing the T.E.L. (1994) study with our own, it should be recalled the former used photographs of scale 1: 6 000 (vice 1: 16 000 in our analysis) which would have provided excellent resolution, but the flight was conducted in July (vice April for our analysis) and would have captured the winter dieback if such had occurred. In any case, the apparent reduction in area from 1990 to 1995 was of a magnitude as to generate another explanation, that the full extent of impact from construction of the parallel runway was far greater than that predicted. It should be noted that with the use of a robust experimental design T.E.L. (1994) identified a 24% decrease in mean seagrass cover and an increase in the proportion of bare sand which corresponded with commencement of major works to construct the parallel runway.

On the southern shore of Botany Bay, Larkum and West (1990) found 516 ha of seagrass present in 1984, whereas in 1995 we identified 589 ha of seagrass. If the area of **Mixed Halophila** calculated by us (27 ha) is removed from our total in order to standardise the results, there still is a substantive difference between the two studies: 516 ha in 1984 versus 562 ha in 1995, implying an increase in area of 46 ha. Larkum and West (1990) found 328 ha of *Z. capricorni* and 188 ha of *P. australis* (Table 7) in 1985, while our analysis showed a slight loss in area for each of these individual species, but a net gain when the area of **Mixed Posidonia** is included (Table 7). While inferring a net increase in area over the past decade, we are unable due to the inherent limitations of comparing results derived from two different techniques to relate this change to any one species along the southern shore.

Along the foreshore of Silver Beach and to the west of Towra Point there was a small change in total area from the early to mid 1990s. T.E.L. (1993 and 1995) identified 327 ha in 1992 and this study identified 321 ha in 1995. This difference is so small as to be explainable on the basis of the difference in analytical techniques.

The outlook for *P. australis* in Botany Bay is uncertain. In 1942 it made up the largest monospecific beds in the bay (Larkum and West 1990), but a large amount has been lost over the past 50-70 years. Larkum (1976b) inferred that a very much wider distribution existed in the past, and aside from Silver Beach and Towra Point, recorded small patches in three locations: Frenchmans Bay, Sandringham Point and the west side of Woolooware Bay. Larkum and West (1990) noted its demise from Frenchmans Bay, and as we found no sign of it at any of the three sites it is opportune to consider rehabilitation options for *P. australis*, particularly the feasibility of transplants for it and/or *Z. capricorni*. *P. australis* was successfully transplanted in Quibray Bay in the 1970s (Larkum 1976b) but the long term fate of the experiment was unrecorded. Subsequent attempts to transplant it off Towra Point in the late 1980s failed, due in large measure to storms and/or or an increase in wave energy due to configurational dredging (West *et al.* 1990). By way of contrast, *Z. capricorni* was transplanted from Dolls Point to sites between the airport runways and east of the parallel runway in 1997 and monitoring of success is underway at present (Table 2). The source material was taken from sites at Dolls Point where groynes were to be constructed to mitigate sand erosion. After 12 months, this species has established well on the eastern side of the parallel runway but has not expanded between the runways or has been lost presumably due to wave energy and/or high levels of turbidity (P. Gibbs, NSW Fisheries unpublished data, 1998). Should an inexpensive way be found to reduce wave energy between the runways, the long term success of the *Z. capricorni* transplants might be assured, and it is conceivable that similar attempts could be made to transplant *P. australis* at that site. Seagrass successfully grown between the runways might compensate for the loss of *Z. capricorni* beds from the northwest part of the bay as a result of the parallel runway construction. These particular beds were sampled for fish in the late 1980s and early 1990s and provided some of the most abundant and species rich fish habitat in NSW (McNeill *et al.* 1992).

Aside from the long term fate of seagrass in Botany Bay, another issue of significance is the role of region 5 in long term habitat conservation. The bulk of the seagrass in Botany Bay (421 ha of a total of 624 ha) is found in this region (Table 10). Nearly 60% of the seagrass in region 5 is *Z. capricorni*, whereas nearly 30% is *P. australis* and both species appear from the aerial photographs to be in what we consider to be monospecific beds. The amount and status of *P. australis* in the mixed beds is uncertain. As *P. australis* has not returned to the northern shore, the role of region 5 in its conservation should be emphasised. The upper boundary of the Aquatic Reserve is the mean high tide mark, and nominally a substantial degree of protection is afforded all seagrass therein. While NSW Fisheries has provision within the Fisheries Management Act to control dredging, reclamation and other activities prejudicial to the survival of seagrass in Crown waters generally, implying a degree of protection for seagrass in Botany Bay, the existing management framework is fixed by the fact that ownership of the bay is vested in the NSW Government Marine Ministerial Holding Corporation. Future management of seagrass within the bay will need to bear these aspects in mind.

As well as seagrass, most of the mangrove trees and all saltmarsh in Botany Bay occurs in region 5. While NSW Fisheries has provision within the Fisheries Management Act to control dredging, reclamation and other activities prejudicial to the survival of mangrove in NSW, these controls may not apply in Botany Bay for the reason listed above, and do not apply anywhere in the state to mangrove above mean high water mark. The portion of the 3 ha of mangrove in region 4 above mean high tide was not calculated, but 354 ha of mangrove in region 5 are protected within the

Table 10. Area (ha) of protected and unprotected seagrass, mangrove, saltmarsh and kelp in Botany Bay, 1995.
The protected habitat is that enclosed by the combined boundaries of the NSWF Towra Point Aquatic Reserve and NPWS Towra Point Nature Reserve (Figure 6). **Mixed Posidonia** indicates the presence of *P. australis* and/or *Z. capricorni* and/or *Halophila* spp.; **Mixed Halophila** indicates the presence of *Halophila* spp. and *Z. capricorni*; Kelp indicates presence of *Sargassum* spp. and/or *Ecklonia* spp.

Status	***P. australis***	**Mixed Posidonia**	***Z. capricorni***	**Sparse Zostera**	**Mixed Halophila**	**Total Seagrass**	**Kelp**	**Mangrove**	**Saltmarsh**
Region 5									
Protected	119.7	60.5	214.4	26.5	0	421.1	0	353.5	84.8
Unprotected	0	0	0	0	0	0	0	66.4	72.6
Other regions	43.1	50.7	11.8	58.0	39.2	202.8	33.0	2.9	0.0
Total	**162.8**	**111.2**	**226.2**	**84.5**	**39.2**	**623.9**	**33.0**	**422.8**	**157.4**

two reserves (Table 10), and another 66 ha are estimated to be unprotected, located on private land on the Towra Point peninsula or above the mean high tide mark at those parts of the aquatic reserve not adjoining the nature reserve (Figure 2). The 66 ha of unprotected mangrove is only an estimate because the high tide mark would need to be determined by surveying. It should be noted that the area of mangrove at a number of locations in NSW is increasing (Saintilan and Williams, in press), and that along the eastern and southeastern foreshore of Quibray Bay there has been a long term increase in mangrove area (Evans and Williams, submitted). In this study, 423 ha of mangrove were found whereas West *et al.* (1985) identified approximately 400 ha in 1981. At issue is whether mangrove not in the reserves needs protection.

Less protected than mangrove are the saltmarsh communities, which grow further upslope and well beyond the mean high tide mark. West *et al.* (1985) identified 160 ha saltmarsh compared to the 157 ha found in this study. Saltmarsh exists nowhere else in the bay other than region 5, where 85 ha is within one or the other of the reserves (Table 10). Unfortunately, another 73 ha is unprotected. Saltmarsh at some locations in NSW has been invaded by mangrove (Saintilan and Williams, in press), but the reasons for this are uncertain and may relate to local effects such as subsidence or increase in water level (e.g. harbour dredging at Newcastle, Williams *et al.* in prep.) or more broad scale impacts such as extended wet weather intervals (Buckney 1985). Global rise of sea level may come to play a part in influencing the distribution of this group of estuarine plants.

Soon it will be necessary to make judgements about the type of estuarine vegetation to be conserved in Botany Bay, particularly because of the long term future of *P. australis* and because the outlook for saltmarsh is bleak. There was at one stage at least one major tourist proposal before Sutherland Council which would effect the saltmarsh, mangrove and seagrass of Quibray Bay, and ultimately there may arise a proposal to extend the port facilities along the northern shore.

Conclusions

A GIS dataset of seagrass area in 1995 for the whole of Botany Bay is available and with qualifications can be used to extend the data of Larkum and West

(1990). While the purpose of both studies was similar, the methods by which the data were derived differ in the quality of aerial photographs and imaging technology available, and the classification and field sampling methods used.

There have been large fluctuations in the area of seagrass in Botany Bay over the past 65 years from a combination of natural and man-induced causes. It appears that there is now more seagrass in the bay than there was 10 years ago. The amount of *P. australis* has contracted considerably over the latter part of this century, but might now be in a state of arrested decline. Similarly, there have been large scale fluctuations in the distribution of *Z. capricorni*.

There has been an overall increase in the area of seagrass along the northern and western shoreline, but more notably, the distribution of seagrass in this part of the bay has changed. While there has been an increase along the western shore, there has been a reduction in the area of seagrass between the old runway and Port Botany which may be attributable, at least in part, to the construction of the parallel runway.

There may have been a gain in area of the total amount of seagrass along the southern shore. This result is equivocal and may relate to different analytical procedures. It appears that the seagrass area along Silver Beach and Towra Point has changed little over the recent past, but given changes in the distribution of wave energy and the potential for developments on this side of the bay there is a need to monitor changes in area, as well as other growth characteristics that will require a special set of monitoring protocols. It was not possible to assess short term changes elsewhere on the southern side of the bay, e.g. Quibray, Weeney and Woolooware Bays.

Resolution of some of the uncertainties identified in this study awaits GIS analysis of one or more sets of the older photographs. While aerial photographs provide opportunities for assessment of broad scale variations in distribution, specially commissioned field studies may be needed to assist where monitoring and/or decision making are needed for site specific decisions (e.g., T.E.L. 1993, 1994, 1995, 1997).

P. australis has not returned to the northern shore and is probably unlikely to unless assisted via a transplant program. The space between the runways, or to the east of the parallel runway, offers a measure of protection to this species, but assessment of the existing wave energy regime and ways to reduce it are needed.

Region 5 plays a special role in the conservation of seagrass, mangrove and saltmarsh in Botany Bay. The aquatic and nature reserves provide a good measure of protection for seagrass and mangrove, but the long term fate of saltmarsh is uncertain.

Recommendations

1) Due to the large variability in the historical distribution of seagrass in Botany Bay there is a need for a formal and ongoing assessment of the changes to seagrass and other estuarine vegetation. These assessments need to discriminate between natural and human causes and would be greatly assisted by:

a. adoption of a standard set of regional boundaries and calculation of the change within each. Some regions of the bay might require more regular and/or intensive monitoring than others,

b. development of a ground truthing protocol to check the boundaries and composition of both monospecific and mixed beds. This may be achieved through the use of GPS to visit random sites to confirm the successful application of classification criteria,

c. rationalisation of aerial photographic needs and costs,

d. recognition of the forthcoming shift to a new coordinate system for Australia.

2) In order to remove some of the uncertainties arising from the use of different methods (i.e., Larkum and West 1990 and this study) to examine change over large portions of Botany Bay, selected historical photographs should be re-mapped using a consistent technique and classification system.

3) There is a need to resolve small changes in the area of seagrass beds over short time intervals, particularly for the area between the parallel runway and the

Brotherson Dock, and particularly in terms of changes in species composition within beds. These assessments are best done with site intensive investigations (e.g. dive transects and/or quadrats), in conjunction with aerial photographs.

4) The long term management of *P. australis*, particularly as its distribution is still limited to the southern shore, needs to be addressed by the management agencies responsible for Botany Bay. Opportunities for transplanting this species should be canvassed and cost estimates prepared.

5) The long term management of mangrove and saltmarsh, particularly the latter, needs to be addressed by the management agencies responsible for Botany Bay.

Acknowledgements

The assistance of a number of individuals at the Fisheries Research Institute is appreciated: Darryl Sullings was the captain of our boat, Laurie Derwent forecast the future of GPS and Richard Gardiner and Alex Simpson crafted the bathyscope. Mizanur Rahman of the then Federal Airports Commission gave permission for data provided in the T.E.L. reports to be used; Peter Brown of the Waterways Authority provided coordinates of channel markers to assist with plotting reserve boundaries; Max Willoughby and Percy Bow of Sydney Ports Corporation lent a series of aerial photographs of the bay. Max Willoughby also provided valuable editorial comments as did Marcus Lincoln Smith of The Ecology Laboratory Pty Ltd.\

Cover illustration: aerial photograph of Towra Point from QASCO (N.S.W) Pty Limited Cumberland 1995 series.

References

Adam, P. (1997) Introduction to the Botany Bay Symposium. *Wetlands (Australia)* 16 (1), pp 1-3.

Allan, R., Lindesay, J. and Parker, D. (1996) *EL Nino, Southern Oscillation & Climate Variability*. CSIRO Publishing, Collingwood, Victoria. 405 pp.

Bell, J.D. and Pollard, D.A. (1989) Ecology of fish assemblages and fisheries associated with seagrass. In *Seagrasses: A treatise on the biology of seagrasses with special reference to the Australian region.* A.W.D. Larkum, A.J. McComb, and S.A. Shepherd (eds), pp 565-597. Elsevier, North Holland.

Botany Bay Mayoral Taskforce (1998) *State of Botany Bay*. unpublished report printed by Sutherland Shire Council. 20 pp.

Buckney, R. T. (1985). Three decades of habitat change: Kooragang Island, New South Wales. Chapter 19 in *Nature Conservation, the Role of Remnants of Native Vegetation.* D. A. Saunders, G. W. Arnold, A. A. Burrbidge and A. J. M. Hopkins (eds). Surrey, Beatty and Sons, Sydney. pp. 227-232.

Burroughs, P.A. (1990) *Principles of Geographic Information Systems for Land Resources Assessment*. Monographs on Soil and Resources survey No. 12, Oxford University Press, New York, 194 pp.

Chanell, M. (1997) Planning for the catchment of Botany Bay. *Wetlands (Australia)* 16 (1), pp 37-47.

CSIRO (1994) Jervis Bay Baseline Studies: Final Report, Vol 1. CSIRO Division of Fisheries. North Beach WA, pp. 103-186

CSIRO (1998) Monitoring of large-area water quality with remote sensing tools. Research Projects Sheet 1 January 1998, CSIRO Land and Water, Canberra.

Curran, P.J. (1988) *Principles of Remote Sensing*. Longman Scientific and Technical, London, 282 pp.

Dasey, M. and Potts, J. (1997) *Monitoring the effect of siltation and eutrophication on seagrass health in New South Wales far south coast lakes and estuaries*. Environmental Protection Authority NSW technical report, 63 pp.

Davis, A.R., Roberts, D.E. and Cummins, S.P. (1997) Rapid invasion of a sponge-dominated deep-reef by *Caulerpa scapelliformis* (Chlorophyta) in Botany Bay, New South Wales. *Australian Journal of Ecology* (22), pp 146-150.

Dennison, W.C. and Kirkman, H. (1996) Seagrass Survival Model. *Seagrass Biology: Proceedings of an International Workshop Rottnest Island, Western Australia, 25-29 January 1996*. pp 341-344.

DENR (1997) *Near shore seagrass change between 1949 and 1996 mapped using digital aerial orthophotography, metropolitan Adelaide area Largs Bay-Aldinga, South Australia.* Report prepared for Environment Protection Authority Department of Environment and Natural Resources, South Australia and SA Water by Image Data Services, Resource Information Group Department of Environment and Natural Resources, South Australia. 29pp. and appendices.

Eastman, J.R. (1992) *IDRISI Users Guide*. Clark University Graduate School of Geography, Worcester, USA. 178 pp.

Evans, M.J. and Williams, R.J. (submitted) Change in wetland vegetation along the Kurnell Peninsula. *Wetlands (Australia).*

Goodrick, G.N. (1970) *A survey of wetlands of coastal New South Wales*. CSIRO Division of Wildlife Research Technical Memorandum No. 5. 36 pp.

Hatfield, E. (1997) Management of the Botany Bay environment. *Wetlands (Australia)* 16 (1), pp 33-37.

Hemminga, M.A., Harrison, P.G. and Vanlent, F. (1991) The nutrient loses and gains in seagrass meadows. *Marine Ecology* (71), 85-96.

Howard, R.K., Edgar, G.J. and Hutchings, P.A. (1989) Faunal assemblages of seagrass beds. In *Seagrasses: A treatise on the biology of seagrasses with special reference to the Australian region.* A.W.D. Larkum, A.J. McComb, and S.A. Shepherd (eds), Elsevier, North Holland, pp 536-558.

Kelly, M.G. (1980) Remote sensing of seagrass beds. In *Handbook of Seagrass Biology: An Ecosystem Perspective*, R.C. Phillips and C.P. McRoy.(eds),. Garland STMP Press, New York, pp 69-85

Kennelly, S.J. and Underwood, A.J. (1992) Fluctuations in the distributions and abundances of species in sublittoral kelp forests in New South Wales. *Australian Journal of Ecology*. 17: 367-382.

King, R.J. and Hodgson, B.R. (1986) Aquatic angiosperms in coastal saline lagoons of New South Wales. IV. Long-term changes. *Proc. Linn. Soc. N.S.W.* 109, pp 51-60.

Kinhill Engineers Pty. Ltd. (1990) *Draft working paper (marine ecology vol 2.).* Report prepared for the Federal Airports Corporation, Sydney, 85 pp.

Kirkman, H. (1990) Seagrass distribution and mapping. In *Seagrass research methods: Monographs on oceanographic methodology 9,* R.C. Phillips and C.P. McRoy (eds), UNESCO Paris, pp 19-25.

Koch, E.W. and Beer, S. (1996) Tides, light and the distribution of *Zostera Marina* in Long Island Sound, USA. *Aquatic Botany* 53 : 97-107.

Kuo, J. and McComb, A.J. (1989) Seagrass taxonomy, structure and development. In *Seagrasses: A treatise on the biology of seagrasses with special reference to the Australian region.* A.W.D. Larkum, A.J. McComb, and S.A. Shepherd (eds), Elsevier, North Holland, pp 6-67

Larcombe, F.A. (1970) *The History of Botany Bay.* The Council of the Municipality of Botany, Sydney, 237 pp.

Larkum, A.W.D. (1976a) Botany Bay: national asset or national disaster? Operculum June 1976, pp 67-75.

Larkum, A.W.D. (1976b) Ecology of Botany Bay. I. Growth of *Posidonia australis* (Brown) Hook f. in Botany Bay and other bays of the Sydney Basin. *Aust. J. Mar. Freshwater Res.* 27: 117-127.

Larkum, A.W.D. and West R.J. (1983) Stability, depletion and restoration of seagrass beds. *Proc. Linn. Soc. NSW*, 106 : 201-212.

Larkum, A.W.D. Collett, L.C. and Williams R.J. (1984) The standing stock, growth and shoot production of Zostera capricorni Aschers. in Botany Bay, New South Wales, Australia. *Aquatic Botany*, 19: 307-327.

Larkum, A.W.D. McComb, A.J. and Shepherd, S.A. (eds) (1989) *Seagrasses: A treatise on the biology of seagrasses with special reference to the Australian region.* Elsevier, North Holland, pp. 1-5

Larkum, A.W.D. and West R.J. (1990) Long-term changes of seagrass meadows in Botany Bay, Australia. *Aquatic Botany*, 37: 55-70.

Lawson and Treloar Pty. Ltd. (1990) In Kinhill Engineers Pty. Ltd. (1990) *Proposed parallel runway, Sydney (Kingsford Smith) Airport*. Draft environmental impact statement.

Lyon, G. and McCarthy, J (1995) Introduction to Wetland and Environmental Applications of GIS. In *Wetland and Environmental applications of GIS*, John G. Lyon and Jack McCarthy (eds), CRC Press, USA.

McGuinnes, K.A. (1988) The Ecology of Botany Bay and Effects of Man's Activities: A Critical Synthesis. The Institute of Marine Ecology, University of Sydney, Sydney.

Marine Pollution Research Pty Ltd. (1992) *Statement of environmental effects: construction of two additional groynes at Silver Beach, Kurnell.* 16 pp.

Marine Pollution Research Pty Ltd. (1997*) Survey of seagrass cover at Ramsgate transplant site following removal.* Report prepared for P Ward Civil.

McNeill, S.E., Worthington, D.G., Ferrell, D.J. and Bell, J.D. (1992) Consistently outstanding recruitment of five species of fish to a seagrass bed in Botany Bay, NSW. *Australian Journal of Ecology* (17) pp 359-365.

New South Wales National Parks and Wildlife Service (1998) Service Estate version 4/98-digital data.

New South Wales State Fisheries (1973) Botany Bay preliminary biological investigation and proposed long term study plan in relation to Maritime Services Board proposals. Unpublished report, 79 pp.

New South Wales Fisheries (1995) Fisheries Management (Aquatic Reserves) Regulation 1995 - No. 13, Schedule 7.

Otway, N.M. and McBeth, W.G. (1998) The physical effects of hauling on seagrass beds. NSW Fisheries Final Report Series No. 10. Final report to FRDC, project No. 95/149.

Robertson, E.L. (1984) Seagrasses. Chapter 6 in *The marine benthic flora of South Australia. Part 1.* Womersley, H.B.S. ed. Government Printer Adelaide.

Saintilan N. and Williams, R.J. (in press) Mangrove transgression into saltmarsh environments in New South Wales, Australia. *Journal Biography, Global Ecology and Biogeography Letters and Biodiversity Letters.*

State Pollution Control Commission (SPCC) (1978) Environmental Control Study of Botany Bay: Seagrasses of Botany Bay, BBS3. 55 pp.

Thayer, G.W., Wolfe, D.A. and Williams, R.B. (1975) The impact of man on seagrass systems. American Scientist (63) pp 288-296.

The Ecology Laboratory Pty. Ltd. (1993) *A quantitative study of the impact of a parallel runway at Mascot on seagrasses in Botany Bay: Towra Point Posidonia*. Final report to Federal Airports Corporation.

The Ecology Laboratory Pty. Ltd. (1994) *A quantitative study of the impact of a parallel runway at Mascot on seagrasses in Botany Bay: northern Zostera.* Final report to Federal Airports Corporation.

The Ecology Laboratory Pty. Ltd. (1995) *A quantitative study of the impact of a parallel runway at Mascot on seagrasses in Botany Bay: comparison of Posidonia at Towra Point before and during construction.* Final report to Federal Airports Corporation.

The Ecology Laboratory Pty. Ltd. (1997) *Kurnell Cogeneration Plant proposal, additional studies on aquatic ecology.* Report to AGC Woodward Clyde. 14 pp plus plates and figures.

Walker, D.I. and McComb A.J. (1992) Seagrass degradation in Australian coastal waters. *Marine Pollution Bulletin,* 25 (5-8) : 191-195.

Watkins, R. (1976) Report on work done at Botany Bay since October, 1975. Unpublished report of the Maritime Services Board of New South Wales, referenced in SPCC 1978.

Watford, F.A. Williams, R.J. and Sullings, D.J. (1998) *Assessment of methods to evaluate the distribution of seagrass: Gunnamatta Bay pilot study.* NSW Fisheries report.

West, R.J. (1983) The seagrasses of New South Wales estuaries and embayments. *Wetlands (Australia)* 3, pp 34-44.

West, R.J. and Larkum, A.W.D. (1979) Leaf productivity of the seagrass *Posidonia australis,* in eastern Australian waters. *Aquatic Botany* 7, pp 57-65.

West, R.J., Thorogood, C.A. Walford, T.R. and Williams, R.J. (1985) An estuarine inventory for New South Wales, Australia. N.S.W. Department of Agriculture, Fisheries Bulletin No. 2, 140 pp.

West, R.J., Larkum, A.W.D. and King, R.J. (1989) Regional studies - Seagrasses of south eastern Australia. In *Seagrasses: A treatise on the biology of seagrasses with special reference to the Australian region.* A.W.D. Larkum, A.J. McComb, and S.A. Shepherd (eds), Elsevier, North Holland, pp 230-225.

West, R.J., Jacobs, N.E. and Roberts, D.E. (1990) Experimental transplanting of seagrass in Botany Bay, Australia. Marine Pollution Bulletin 21:197-203.

Williams, R.J. and Watford, F.A. (1997) Change in distribution of mangrove and saltmarsh in Berowra and Marramarra Creeks, 1941-1992. Unpublished report of NSW Fisheries Research Institute to the Berowra Creek Estuarine Management Committee. 21 pp.

Williams, R.J., Watford, F.A. and Balashov, V. (in prep.) Kooragang Wetland Rehabilitation Project: Changes in Wetland Fish Habitats of the Lower Hunter River. Unpublished report of NSW Fisheries Research Institute to the Steering Committee of the Kooragang Wetlands Rehabilitation Project.

Worthington, D. G., Ferrell, D.J., McNeill, S.E. and Bell, J.D. (1992) Effects of the shoot density of seagrass on fish and decapods: are correlation evident over larger spatial scales? *Marine Biology* 112 : 139-146.

Appendix 1 Map and photograph details

1:10 000 CMA orthophoto maps

Date	Map name	Map Number
1984	Kogarah	U0937
1984	Kurnell	U1830
1984	Maroubra	U1837
1984	Cronulla	U0930

Aerial Photographs

Date	Agent	Map / area	Film N°.	Run N°.	Frames
24/4/95	Qascophoto	Cumberland 1995	QAS.29773c	39E	8006, 8008
				40E	7993, 7995, 7997, 7999
				41E	7935, 7937, 7938,7940, 7941
				42	7928, 7926

Format	Scale	Pixel size (m) (scanned at 300 dpi)	Resample resolution (m)	RMS error in pixels (min - max)
Colour	1:16 000	1.4	2	2.55 - 5.37

Other titles in this series:

ISSN 1440-3544

No. 1 Andrew, N.L., Graham, K.J., Hodgson, K.E. and Gordon, G.N.G., 1998. Changes after 20 years in relative abundance and size composition of commercial fishes caught during fishery independent surveys on SEF trawl grounds. Final Report to Fisheries Research and Development Corporation. Project no. 96/139.

No. 2 Virgona, J.L., Deguara, K.L., Sullings, D.J., Halliday, I. and Kelly, K., 1998. Assessment of the stocks of sea mullet in New South Wales and Queensland waters. Final Report to Fisheries Research and Development Corporation. Project no. 94/024.

No. 3 Stewart, J., Ferrell, D.J. and Andrew, N.L., 1998. Ageing Yellowtail (*Trachurus novaezelandiae*) and Blue Mackerel (*Scomber australasicus*) in New South Wales. Final Report to Fisheries Research and Development Corporation. Project no. 95/151.

No.4 Pethebridge, R., Lugg, A. and Harris, J., 1998. Obstructions to fish passage in New South Wales South Coast streams. Final report to Cooperative Research Centre for Freshwater Ecology.

No. 5 Kennelly, S.J. and Broadhurst, M. K., 1998. Development of by-catch reducing prawn-trawls and fishing practices in NSW's prawn-trawl fisheries (and incorporating an assessment of the effect of increasing mesh size in fish trawl gear). Final Report to Fisheries Research and Development Corporation. Project no. 93/180.

No. 6 Allan, G.L., and Rowland, S.J., 1998. Fish meal replacement in aquaculture feeds for silver perch. Final Report to Fisheries Research and Development Corporation. Project no. 93/120-03.

No. 7 Allan, G.L., 1998. Fish meal replacement in aquaculture feeds: subprogram administration. Final Report to Fisheries Research and Development Corporation. Project no. 93/120.

No. 8 Heasman, M.P., O'Connor, W.A., O'Connor, S.J., 1998. Fisheries enhancement and farming of scallops in NSW using hatchery produced seedstock. Final Report to Fisheries Research and Development Corporation. Project no. 94/083.

No. 9 Nell, J.A., McMahon, G.A., and Hand, R.E., 1998. Tetraploidy induction in Sydney rock oysters. Final report to Cooperative Research Centre for Aquaculture. Project no. D.4.2.

No. 10 Nell, J.A. and Maguire, G.B., 1998. Commercialisation of triploid Sydncy rock and Pacific oysters. Part 1: Sydney rock oysters. Final Report to Fisheries Research and Development Corporation. Project no. 93/151.