Kooragang Wetland Rehabilitation Project: History of Changes to Estuarine Wetlands of the Lower Hunter River

R.J. Williams, F.A. Watford and V. Balashov

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

PWCS

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R.J. Williams[1], F.A. Watford[2] and V. Balashov[3]

[1]NSW Fisheries Office of Conservation
Cronulla Fisheries Centre
P.O. Box 21, Cronulla, NSW, 2230
Australia

[2]Present address: BAE Systems
Bruce, ACT

[3]Present address: NSW Environment Protection Authority
Sydney, NSW

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Authors: R.J. Williams, F.A. Watford, V. Balashov

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"…. land along the lower reaches of the river, with the exception of the hills on the south side of the river mouth, on which Newcastle now stands, was low, swampy and subject to flooding."

report from the voyage of HMS *Lady Nelson* to the Hunter River, 1801. (Perry 1963, p. 56)

"The islands of the lower Hunter are abounding in fish, duck, kangaroos and pigeons".

Sydney Gazette 1829 (as noted by Ruello 1976)

PREFACE

Three forms of environmental compensation are increasingly recognised as appropriate strategies by which to mitigate for loss of natural resources. These strategies are to *create* new habitat, to *restore* damaged habitat as closely as possible to its previous condition and to *rehabilitate* damaged habitat by changes perceived to increase present utility.

Commissioned in the early 1990s, the Kooragang Wetland Rehabilitation Project has so far operated in the latter ambit. It was the first large-scale estuarine rehabilitation project in NSW, and documenting its progress is an important part of compensating for loss of wetland habitat in the Hunter estuary, and of determining the project's utility as a model for activities initiated at other coastal sites.

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- Kooragang Wetland Rehabilitation Project Steering Committee, comprised of
  - Community representatives
  - City of Newcastle
  - NSW Department of Land and Water Conservation
  - Hunter Catchment Management Trust
  - NSW National Parks and Wildlife Service
  - NSW Fisheries
  - Port Stephens Shire
  - University of Newcastle
- Landcare Australia
- Mitchell Library
- NSW Public Works, Manly Hydraulics Research Laboratory
- The Wetlands Centre Australia Ltd.

NON TECHNICAL SUMMARY

Kooragang Wetland Rehabilitation Project: History of Changes to Estuarine Wetlands of the Lower Hunter River

Principal Investigator: R.J. Williams

Address: NSW Fisheries Office of Conservation
Cronulla Fisheries Centre
PO Box 21, Cronulla, NSW, 2230
Telephone (02) 9527 8411
Fax (02) 9527 8576

Goals:

To assess and enhance the fish and fisheries habitats of Kooragang Island with a view to applying the lessons learned to the rehabilitation of other degraded estuarine habitats in NSW.

Non technical summary:

The Kooragang Wetland Rehabilitation Project (KWRP) was initiated in recognition of the role played by estuarine wetlands in supporting food chains, modifying hydrologic events and maintaining water quality, and that in combination these factors contribute significantly to human welfare. One of the first studies initiated within the ambit of the project was the preparation of a simple descriptive model of the wetland habitats of Kooragang Island. The geographical extent was subsequently expanded to include estuarine wetlands on the northern shore of the lower Hunter River. Hexham Swamp has not yet been assessed.

Old maps were analysed within a geographic information system (GIS) to extract information about changes to the amount of land and water in the estuarine portion of the Hunter River over the past 200 years. Aerial photographs were analysed to determine changes in area of mangrove and saltmarsh over the past 40 years.

Examination of the historical record suggests environmental change with the lower Hunter River was encompassed within four major periods: an early development stage (1796 - 1895), mid development stage (1896 - 1950), late development stage (1951 - 1989) and rehabilitation stage (1990 - present). In the early development stage, wetlands were primarily altered by the agricultural and shipping needs of the colonists at Newcastle, whereas the mid and late development stages were characterised by surges in industrial expansion. From the 1980s there has been an increase in community interest in wetland conservation, and it is convenient to assign the commencement of the rehabilitation stage to the washout of a culvert on a tidal creek on Kooragang Island in April 1990. This incident, among other things, re-established full tidal flow onto what had once been wetland, and outlined the implied potential of simple and inexpensive rehabilitation techniques.

Analysis of historical maps shows the progressive consolidation of the complex of islands in the mouth of the Hunter River into one land mass. Most of the consolidation came about by dredging and spoil disposal. The area of land now present is approximately 20% larger than shown on the naval chart of 1801.

The number of islands in the study zone has decreased from twenty-one to six, and in turn the length of shoreline has fallen from 154 km to 121 km. Much of the existing shoreline has been modified by breakwaters, retaining walls and bank protection works.

The construction of roads, railways and agricultural structures such as levees and drains has modified the flow of water across the study site. Flow within wetlands has been modified by water crossings (e.g., bridges, culverts and fords), floodgates and levees.

Analysis of aerial photographs from each of the decades beginning in the mid 1950s and up to the mid 1990s showed a decrease in the amount of open water in the study area. Three hundred and forty four hectares (13%) of open water was lost, most of it due to reclamation.

Seagrass was not identified in the aerial photos and has not been seen along the foreshores of the lower Hunter River for at least the past three decades. It is likely to have been present at some earlier stage as it occurs in all other analogous rivers in NSW. The cause of its demise is not known.

The area of mangrove increased substantially from the mid 1950s to the mid 1990s, from 1310 ha to 1711 ha. This was in spite of the loss of over 200 ha during the development of the industrial site on Kooragang Island and the loss of another 40 ha along Throsby Creek. Some of the increase was into the main and secondary channels of the Hunter River, particularly in the Tomago/Fullerton/Stockton region, but also on Kooragang Island. Much of this expansion occurred upslope of existing mangrove stands and seemingly at the expense of saltmarsh. The reasons for the expansion are not clear, but may be related to change in soil salinity levels brought about by periods of enhanced rainfall and/or change in tidal levels in the estuary.

In contrast to the gain in mangrove, there was a long-term loss in the area of saltmarsh; of the 2133 ha present in 1954, 1,428 hectares (67%) was gone by 1994. Most of the loss was in the Tomago/Fullerton/Stockton region (871 ha), followed by Kooragang Island (508 ha). The small amount present at Throsby Creek was completely gone by the mid 1970s. The rate of loss has since stabilised on Kooragang Island and along the South Bank, but not at Tomago/Fullerton/Stockton. Drainage works, reclamation and infiltration by mangrove are assumed to be the main reasons for these losses.

The distribution of wetland vegetation in the lower Hunter River is controlled by the amount of substrate that is tidally inundated. Over past millennia the rise and fall of sea level has been the primary determinant of these conditions, modified by sediment redistribution after major floods. In the post colonial era, catchment clearing and small scale works to exclude tide and drain wetlands initially played a role in modifying the area under mangrove and saltmarsh, but large scale reclamation for industrial facilities in the middle portion of the 20th century has had a greater impact. Mangrove species move quickly onto any newly available and suitable substrate, including where tidal flushing has been re-established, and thus appear to have a competitive advantage over saltmarsh.

There have been a number of disturbances to the wetlands of the lower Hunter River over the past 200 years, but the impact on fauna is still little understood. In regard to the fish community, two types of impact are considered likely, change in the number of species and/or change in the abundance of fish present. Assessing these changes is difficult, due to a lack of historical data for the Hunter River at any time in the recent past, much less 200 years ago. A separate study would be needed to investigate this issue.

Recommendations:

A number of recommendations arise out of each of the chapters in this report and are consolidated below.

Chapter 2. History of change in wetland habitats on Kooragang Island.

1. There is still more to be learned about the nature and evolution of the wetlands of the lower Hunter River. Incentives should be offered to further study habitat changes that have occurred there.

Chapter 3. Analysis of change in landforms and drainage in the lower Hunter, 1801-1994.

2. To provide a fuller understanding of change in the estuarine portion of the Hunter River, modifications to the Hexham wetlands over the past 200 years should be assessed and integrated with the results of this study.
3. To assess the extent of change caused when overland or tidal flow is enhanced or reduced, a formal monitoring program should be initiated.
4. To confirm the loss of open water along the tidal portion of the river, Manley's (1963) investigations should be updated.

Chapter 4. Analysis of change in estuarine vegetation of the lower Hunter River, 1954-1994.

5. While aerial photographs of the lower Hunter Valley were taken prior to 1954, neither the originals nor copies were found. If available, they should be analysed to provide further assessment of historical change.
6. To complement this study, an assessment of the change in distribution of open water, mangrove and saltmarsh at Hexham Swamp should be commissioned.
7. The discrepancy between Buckney's (1985) and our assessment of the area of mangrove and saltmarsh present in the late 1970s and early 1980s, particularly as it relates to tracking short term changes in the distribution of estuarine macrophytes, should be further investigated.
8. To redress the loss of saltmarsh, potential sites for re-establishment should be identified.
9. To assist in projecting the long term recruitment of mangrove, data on sedimentation rates within the lower Hunter River should be updated.
10. To assist in projecting the long-term dynamics of wetland vegetation, investigations of changes in mean sea level on Kooragang Island and elsewhere in the lower Hunter River should be initiated.
11. To facilitate future planning of rehabilitation efforts, a fine scale elevation model of Kooragang Island and other relevant wetland sites should be constructed.

Key words: wetlands, estuarine wetlands, mangrove, saltmarsh, GIS, aerial photographs, Hunter River.

1. INTRODUCTION

1.1. Background

Wetlands are recognised as transitional habitats situated between terrestrial and open water systems. Their uses fall into four broad categories: food chain support, hydrologic functions, water quality improvement and human values (NRC 1992). Estuarine wetlands, as a subset of wetlands generally, fulfil all of the above functions. In supporting food chains, estuarine wetlands are among the most productive of natural systems, and provide habitat for a wide variety of species. Australian marine and estuarine fish are noted to be dependent on coastal wetlands (Kailola *et al.* 1993).

Some of the hydrologic values of estuarine wetlands are often overlooked but are best conceptualised in terms of loss to the community. For example, drained coastal lands do not support drought resistant forage and can produce the unwanted effects of acid sulfate soils. The general public, particularly taxpayers and the insured can also incur losses, where drainage has reduced flood retention time as downstream damage is increased. The reclamation of wetlands in urban neighbourhoods also prevents the spread and dissipation of floodwaters and enhances the impacts of recurring flood events.

Wetlands can improve water quality by trapping inert particles such as clay and other silt particles, or by trapping waste and toxic compounds. This role has been investigated in NSW to a limited degree (e.g., Soukup *et al.* 1994), but further work is needed to identify the cost effectiveness of using, and at the same time conserving, natural systems rather than investing in the conventions of pumps and pipes.

Food chain support, hydrologic and water quality functions are translatable into human values, and in many cases overt recognition of these attributes has been followed by protective management strategies, e.g., the protection of coastal wetland in NSW (Adam *et al.* 1985). The private sector also has an interest in protecting wetlands. One in three residents of NSW is estimated to go fishing once a year (Pepperell 1996), and on the expectation of a catch of fish, or at the very least of a pleasurable experience, large sums of money are spent on boats, bait and other accessories. Fishers are well aware of wetlands as nursery and foraging areas, and have become more vocal in their demands for an adequate catch. The "Habitat is where it's at" or "No habitat, no fish" campaigns and the proliferation of bumper stickers saying "I fish and I vote", give evidence of these sensitivities.

The rehabilitation of degraded wetlands is now fully in public focus as government agencies, conservation organisations and private individuals increasingly attempt to mitigate for past damage to aquatic habitat. A number of texts have appeared that reinforce the need for, and ways by which to undertake, rehabilitation activities (National Research Council 1992, Thayer 1992, Marine Board 1994). The rectification of environmental damage adds to the community's wealth of renewable resources.

1.2. Need

In line with the global rehabilitation initiative, in the early 1990s NSW Fisheries investigated the feasibility of compensating for past losses of fisheries habitat on Kooragang Island through the creation and restoration of wetlands. A report was prepared to assess the feasibility of such a proposal and to simultaneously educate the community on the value of the Hunter Estuary as a fishery resource (Shortland Wetlands Centre and TUNRA 1992). The report identified constraints and opportunities for wetland rehabilitation.

In 1992, a steering committee representing three state, one regional and one local organisation was established to consider the matter further. The committee endorsed the recommendations of the feasibility document and in November 1993 the Minister for Agriculture and Fisheries formally launched the Kooragang Wetland Rehabilitation Project (KWRP). NSW Fisheries commenced fieldwork at the project's Ash Island site in November 1993. In 1996, a management plan was produced that set two aims (Svoboda and Patterson Britton & Partners 1996):

* "...to rehabilitate, restore and create fisheries and other wildlife habitat in suitable sites of the Hunter River estuary. Opportunities for research, education, recreation and tourism will be developed as integral parts of the habitat work to enhance appreciation and appropriate use of the estuarine ecosystem."

* " to demonstrate that modern industry and environment conservation can work together to their mutual benefit."

Furthermore, the objectives of the project were placed into three categorises:

* habitat rehabilitation and creation,
* community involvement, and
* development of estuary management models.

Financial support grew from the onset and direct funding, and in kind support, have underwritten studies on birds, fish, mosquitoes and wetlands (Svoboda and Patterson Britton & Partners 1996). As these studies are completed, their results and recommendations are progressively integrated into the project to modify future research and management activities.

1.3. Goals and Objectives

The aims of NSW Fisheries were to assess and enhance the fish and fisheries habitats of Kooragang Island with a view to applying the lessons learned to the rehabilitation of other degraded estuarine habitats in NSW. To achieve these aims, four objectives were set:

* devise a simple descriptive model of the habitats of the western end of Kooragang Island (this report),
* devise a simple descriptive model of the fish and macroinvertebrate assemblages at the western end of the island (see Williams *et al.* in prep.),
* use the models to estimate the effects of different hydraulic manipulations on floral and faunal species composition and/or abundance (this report and Williams *et al.* in prep.), and
* monitor the impact of the hydraulic works over time (see Williams *et al.* in prep.).

One of the main goals of NSW Fisheries was to document the changes in fish habitats on Kooragang Island and in the surrounding wetlands of the lower Hunter River. To achieve this objective it was necessary to examine a series of historical reports, and analyse other types of spatial data, each with a varying degree of accuracy. These other data sources included naval charts, survey maps and aerial photographs. The oldest geographic data were from the naval charts, and the earliest of these was drawn by Lieutenant J. Shortland in 1797. Shortland's chart unfortunately only shows the entrance to the river. A chart of the whole of the lower river, including Kooragang Island, was produced by Ensign F. Barrallier in 1801, and has been used in the preparation of this report.

In order to quantify the changes in landform, drainage and estuarine vegetation of the study region a Geographic Information System (GIS) was used. The GIS provides a platform for entering, storing, manipulating, analysing and presenting spatial data obtained from a variety of sources (Congalton and Green 1995). Data of varying scale and resolution can be stored digitally in one co-ordinate system at the same scale and orientation so that habitat information can be easily extracted, quantified and compared through time. For example, the GIS facilitated the overlay of mangrove and saltmarsh boundaries shown on different sets of aerial photographs.

1.4. Nature of this Report

This report presents the results of habitat investigations begun by NSW Fisheries in late 1993 on the wetlands of western Kooragang Island and other parts of the lower Hunter River to achieve the first, and part of the third objectives set out above. Following on from the Introduction, Chapter 2 relates the history of social and economic change which has impacted on wetland habitats, Chapter 3 quantifies the changes in landforms, and Chapter 4 identifies changes in saltmarsh and mangrove vegetation from 1954 to 1994. Chapter 5 integrates findings of the previous chapters, identifies the implications for the wetlands of the lower Hunter River. Chapter 6 sets out a series of recommendations.

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2. HISTORY OF CHANGE IN WETLAND HABITATS ON KOORAGANG ISLAND

2.1. Introduction

The catchment of the Hunter River (Figure 2.1) is over 22,000 km^2 in area (20,200 km^2, Bell and Edwards 1980; 22,020 km^2, Hill and Harris 1991). It is the third largest coastal catchment in NSW after those of the Hawkesbury and Clarence Rivers, respectively. Kooragang Island is located near the mouth of the river and is approximately 26 km^2 in area (Figure 2.2).

The present day wetlands of the lower Hunter River, including Kooragang Island, have been influenced by at least two fundamental aspects of geology. The first was the formation of coal in Permian wetlands more than 250 million years ago and second was the rise in sea level to its present height at the end of the last post glacial transgression (Roy 1994). While the latter event created the conditions for wetlands to form in the Hunter River estuary, it was the presence of coal that attracted the attention of the white explorers in 1797, setting in train the clearing and colonising of the southern shore, and then the rest of the Hunter River valley. Had coal not been observed, the sequence of events leading to settlement of the lower Hunter valley and the progressive modification of its wetlands may have been vastly different.

Relative to the coal seams that formed over millions of years, the Hunter wetlands at the turn of the 18th century were aged in only thousands of years. Their genesis was part of a complex geomorphological process beginning during the last major glacial era. As more and more sea water became locked in the expanding ice caps, ocean levels fell across the surface of the earth and the coastline along south-eastern Australia receded to a point possibly 25 km further east than it is today. During this time the Hunter River incised its channel to a lowered base level and Kooragang Island as we know it did not exist. The ice caps started to melt 20,000 years ago, sea level rose and then stabilised 6,500 years before the present (Roy 1994). Since that time, and with the slow accretion of sediment from land as well as sea, the coast of NSW including the mouth and lower portion of the Hunter River has assumed much of its present form.

Subsequent to the discovery of coal in 1796, the clearing of land, dredging of shoals, disposal of dredge spoil and the successive expansion of industry caused extensive modifications to the foreshores and natural wetlands of the lower Hunter River. Our aim was to describe the changes to these wetland habitats.

2.2. Methods

To create a chronology of wetland change in the lower Hunter River, data were acquired from a number of sources. Old newspaper articles, pamphlets, unpublished reports and published articles were reviewed. Many of the old accounts are in the personal collection of Mrs. Vera Deacon of Beaconhill, NSW who lived much of her early life on the then Moscheto Island. Interviews were conducted with two long time Newcastle residents: Mr. J. Latham of New Lambton and Mr. F. Ripley of Raymond Terrace. In addition, the archival charts and maps listed below were inspected at the Mitchell Library, Sydney:

Naval charts of 1797 and 1801
Survey maps of 1844, 1892, 1913, 1928 and 1941
Aerial photographs from 1954, 1966, 1976, 1986 and 1994.

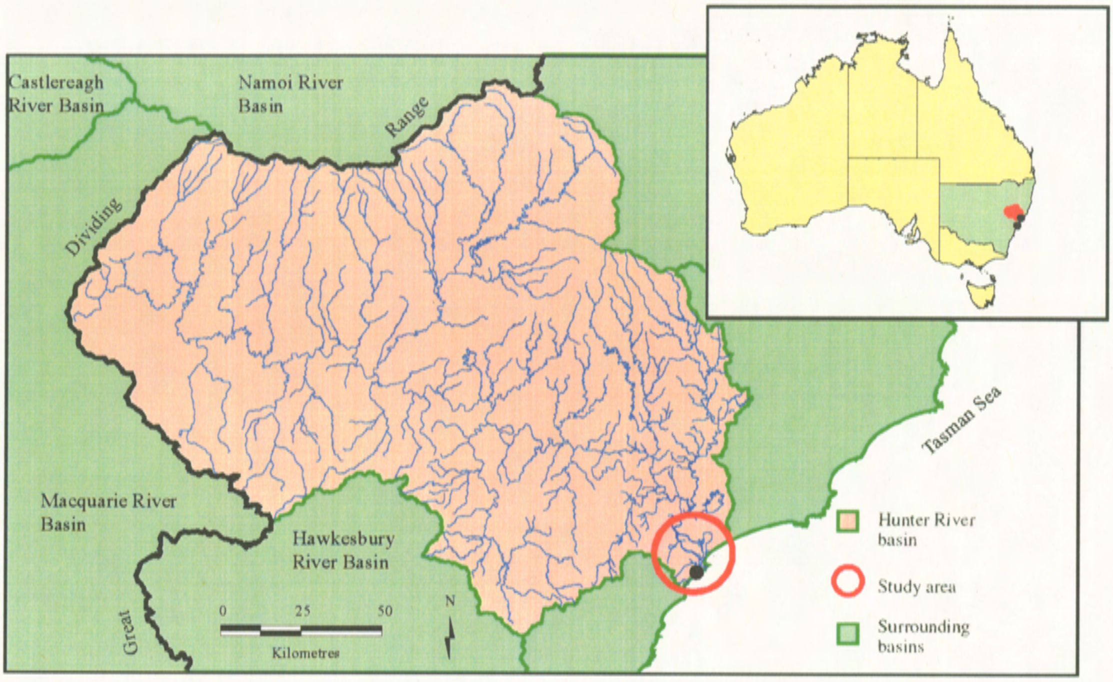

Figure 2.1. Hunter River and adjacent waterbasins. Modified from NSW Water Resources Commission (undated).

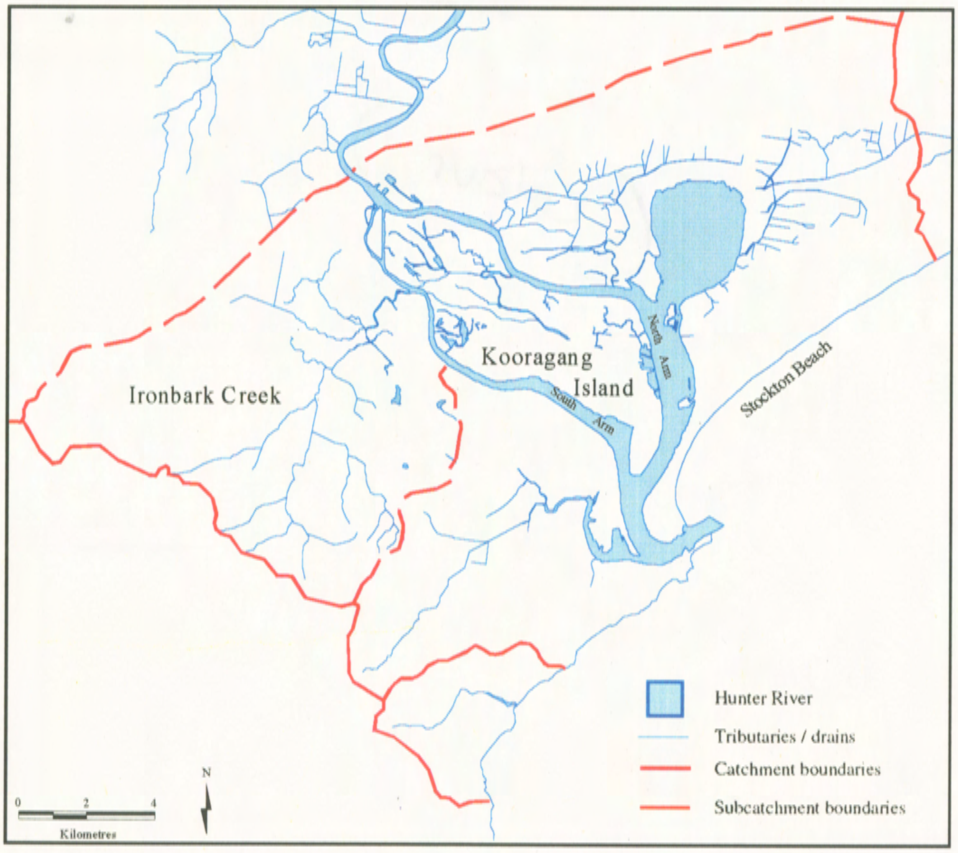

Figure 2.2. Lower Hunter River.

The naval chart of 1801 and maps of 1844, 1871, 1892, 1913, 1928 and 1941 are reproduced courtesy of the Mitchell Library (Appendix 2.1). Details of the maps, including the title and library catalogue numbers, and for the aerial photographs, including film number and photograph scale, are also provided (Appendix 2.2). As would be expected, the accuracy of the chart, maps and photographs varies depending on the date of production.

2.3. Results

The narrative that follows sets out some of the key changes to the wetlands of the Hunter River. A list of relevant dates is presented in Appendix 2.3. Reference documents are listed in the appendix rather than in the text below.

Over the past 200 years we identify four distinct stages of wetland modification based on identifiable shifts within the economic and social history of the lower Hunter River. They are:

Stage 1. 1796-1895, Early development stage
Stage 2. 1896-1950, Mid development stage
Stage 3. 1951-1989, Late development stage
Stage 4. 1990-present, Rehabilitation stage.

Justification for these stages is set out in the text below, as is a summary of events within each of the four time intervals. A qualifying statement relative to the accuracy of data obtained within each interval prefixes the text for each of the time bands.

2.3.1. Stage 1. 1796-1895, Early development stage; agriculture and shipping

Due to the paucity of data sources for the first 100 years of the colony of NSW and spatial inaccuracy of some of the maps produced at that time, observations on the change in habitat type can only be of the most general type. Place names mentioned below are shown in Figure 2.3.

Following on from the dispatch of Lt. J. Shortland by Governor Hunter to search for escaped convicts in 1797, and his report of a coal seam at Nobby's Island, a train of events led to enhanced agricultural and ultimately industrial use of the lower Hunter River. Private entrepreneurs responded to Shortland's discovery and by 1799 coal was being exported to India and other overseas locations. An assessment of the export potential, and hence royalty income, of the Newcastle area was needed and in June 1801 Governor King sent Lt. J. Grant of the ship *Lady Nelson* and Lt. Colonel W. Paterson, commandant of the NSW Corps, to survey the lower Hunter River. Ensign F. Barrallier was in Grant and Paterson's party and produced the first chart of the complex of islands now known as Kooragang Island. Paterson's recorded that a sawpit was dug and a team of timber cutters was left behind for the purpose of harvesting cedar and other timbers. A second ship on the expedition, the schooner *Francis*, soon returned to Sydney with coal and timber. Presumably, the governor's expectation of trade opportunities caused him to send the *Francis* back to with troops to garrison an outpost and instructions for Paterson to choose sites for a mine and settlement. The mines ran until the early part of 1802 when misconduct on the part of the garrison commander lead to the withdrawal of the convict miners and subsequently the military guard (Perry 1963, pp. 56 - 57).

A second penal settlement was established on south shore of the river in 1804, as a means to separate the worst of the Castle Hill and Parramatta insurgents from their fellows. Thirty-four convicts were sent to the outpost, newly named Newcastle. The instructions given to its commandants were succinct:

> "The principal object in view on the Original Establishment of a Post or Military Station at Newcastle having been to procure supplies of Coals, Timber and Lime for the service of Government." (Perry 1963, p. 58)

Salt making was another occupation of the convicts but was terminated in 1808 when lime burning began.

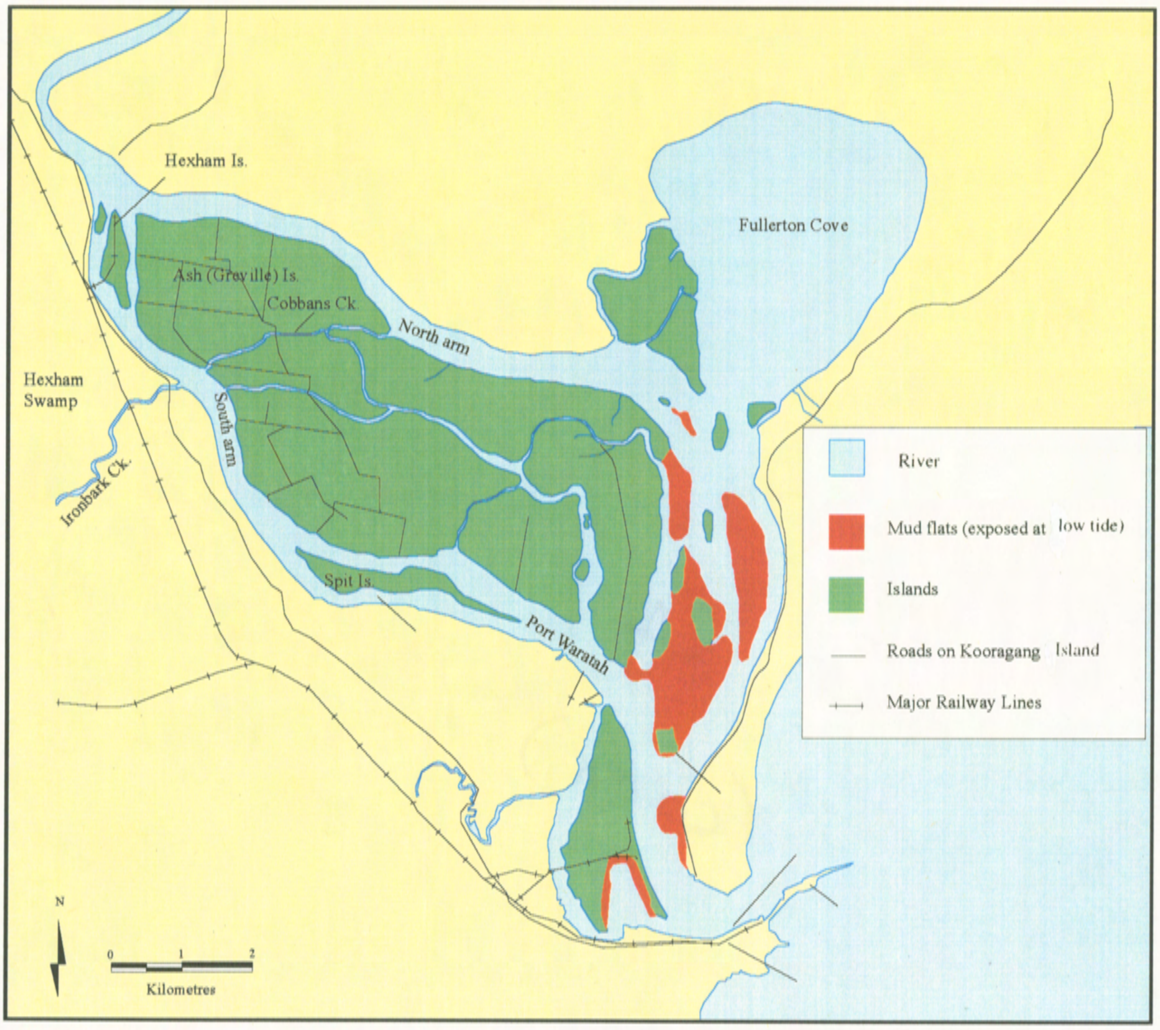

Figure 2.3. Map of the lower Hunter with early place names. Names in brackets indicate alternate names for that feature. Features are based on the 1892 map however, Walsh Island was not present in 1892 and has been added from the 1913 map.

One of the advantages of Newcastle was its remoteness and the apparent ease with which convicts could be isolated from Sydney. By 1819, however, the number of Newcastle escapees had increased markedly, particularly along the route from Windsor to the middle Hunter discovered by John Howe. This track was nominally of benefit to the free settlers who had started to arrive in the Hunter Valley in 1813. John Oxley's discovery of Port Macquarie allowed Governor Macquarie to transfer the Newcastle convicts to the new remote outpost and open the Hunter Valley for agriculture. In the three years from 1822 to 1825, approximately 15% of the valley was allocated to landholders, churches, schools and other government interests.

The *Lady Nelson* exploration of 1801 reported that all the land along the lower reaches of the river, with the exception of the hills on the south side of the river mouth was "low, swampy and subject to flooding", and there was "evidence of floods some 40 or 50 feet high" in the upper portions of the river. In spite of this, plots of land were established in high-risk areas. In March of 1819 the whole of Wallis's Plains (Maitland) was underwater with partial loss of crops (Perry 1963, p. 62). Drought conditions prevailed in the late 1820s, but as is now understood by the El Nino phenomena, these were inevitably followed by another wet period. In 1829 A.W. Scott became one of the first major agriculturalists in the district with his purchase of land on what was then known as Ash Island. Presumably, and in order to enhance production, Scott cleared any trees left standing by the timber cutters. He would also have improved access around and across Ash Island, efforts that may have included drainage of wetland and blockage of tidal flow. Drought reappeared in the 1840s along with a depression felt initially in Sydney and ultimately in the Hunter. By 1842 both banks of the Hunter River between Newcastle and Morpeth had been extensively cleared, and in 1864 there was another lengthy wet weather period. Additional drainage efforts may have coincided with these and the floods of the late 1800s, particularly the large flood of 1893. One can conclude that the earliest modifications to wetland habitat of the lower Hunter Valley were initiated by the farming community in response to needs for arable land and to control surface water.

Fuller discussion of the settlement of the district is provided by Perry (1963) who noted that the presence of the penal settlement effectively blocked colonisation of the valley until the 1820s. Prior to this time the colony of Sydney moved to the west and south, driven by the wants of the graziers for new pasture. When the Hunter was opened up to free settlers, it had the additional advantage of high quality agricultural lands and short transport times to the Sydney marketplace. Consequently, by the mid 1800s the valley was one of the most populous and attractive parts of NSW for new settlers. Additional consideration of the agricultural importance of the islands, particularly in terms of milk and butter production is provided by Turner (in prep.).

Of additional environmental significance for the wetlands was the progressive increase in shipping facilities. From simple beginnings at Kings Wharf in 1801, shipping expanded as the amount of exported coal increased, as well as for the trade requirements of the Newcastle district. From the 1830s a daily service was in place from Morpeth to Sydney via Newcastle, taking the produce of the valley to market. Following the large flood of 1857 a major dredging program was underway in the Hunter River, presumably to reopen the shipping channels. Newcastle became a hub for transportation in the mid and late 1800s, for example, produce was brought by bullock dray from southern Queensland (Hartley 1995). Inspection of the historical maps indicates a number of wetland habitats were filled to meet growing transport requirements. Land was reclaimed for the Newcastle Railway Station, and some direct loss of foreshore was due to reclamation of Bullock Island with dredge spoil.

2.3.2. Stage 2. 1896-1950, Mid development stage; establishment of industry

Within this era it is possible to document large-scale morphological change reasonably well (e.g., the shape of the island) due to the existence of three detailed topographic maps (1913, 1928, 1941). Small changes, such as the placement of structures like bridges and culverts, are not so readily tracked. Place names mentioned in this section of text appear in Figures 2.3 and 2.4.

While the first industrial facility in the lower Hunter River is commonly recognised to be the saltworks constructed on Moscheto Island in 1836, in turn joined by a small sulphuric acid plant, we consider the advent of industrial era to have began in 1896 when BHP acquired 10 ha of waterfront land at Port Waratah to be used for smelters. Modification of the eastern end of Moscheto Island was begun in 1898 with the construction of the Walsh Island training wall; reclamation continued behind this wall for the next 20 years. In the early 1900s the Newcastle Iron and Steel Works Act was passed (NSW Parliament 1912), increasing the amount of land available to BHP for heavy industry, and identifying portions of Moscheto Island for resumption by the

NSW Government. In 1912, the Minister for Public Works announced that a major centre for engineering and shipbuilding facilities would be built at Walsh Island, and construction started the next year. The flow regime in the South Channel was changed in 1930 when the Public Works Department constructed a weir between Hexham and Ash Islands. Use of the Walsh Island works was cut short due to the Great Depression; in 1933 the dockyard was closed and the reclamations begun in 1898 terminated.

The coming of the Second World War increased industrial output from the Hunter region to meet military needs, and in 1947, the Newcastle Chamber of Manufacturers proposed further industrial expansion. A Kooragang Island Development Scheme was devised that intended that the entire island be progressively reclaimed for heavy industrial use.

In addition to the changes wrought by industrial activity, modification of wetland habitats by the farmers continued during this era. Among these was the installation of drainage structures on the then Ash Island to control tidal flow. In addition, a levee bank was erected to the east of the present location of the Waterpipe Road, and another levee bank was built east of the Powerline Road. The exact date of installation of these levees is uncertain; they are not shown in the 1941 topographic map but are seen in the 1954 aerial photographs.

2.3.3. Stage 3. 1951-1989, Late development stage; expansion of industry

Geographic changes within this era are due mostly to industrial expansion and are well documented through the aerial photographic record. The written record is also strong, based on media and community interest in the 1955 flood and its aftermath, and the commission of inquiry called to deal with complaints about air pollution. Place names used in this section are shown in Figures 2.3 and 2.4.

In 1951 the NSW Public Works Department began a new program of dredging and land filling in the Hunter River. These activities were supported by the passage of the Newcastle Harbour Improvements Act, (NSW Parliament 1953) that had among its major objectives the intent to create a single landmass of the islands of the lower Hunter. In early 1954, bunds were placed in Platt's Channel after the State government gave approval to use this backwater as a site for industrial waste, and then as a site on which industry could expand. Filling of the channel commenced in 1960, ultimately connecting Spit Island to the mainland. In 1958, Walsh and Moscheto Islands were linked.

Sometime between the late 1950s and early 1960s the NSW Department of Public Works commissioned the Newcastle Harbour Siltation Investigation. It would seem that the amount of silt deposited in the harbour, from an undefined source, was high enough to warrant this investigation, including the possible installation of a "pneumatic or hydraulic barrier at the entrance to the harbour" (Manley 1963, p. ii). One useful by-product of the investigation was Manley's (1963) historical analysis of the estuary, and much of the recent chronology of wetland change (Appendix 2.3) is derived from his analysis.

In 1966 the industrial railway to the island was started, and the channels around Dempsey Island were filled. One impact of the railway was to block off Moscheto Creek; another was the uncertainty brought in relation to diversion of water flow during major floods. Changes in the elevation were brought about by construction of the water pipeline across Kooragang Island, as well as the service roads associated with electricity powerlines. Each of these height modifications would have had impact on drainage patterns. By 1968 so much filling had been undertaken that the NSW Geographical Names Board applied the name "Kooragang Island" to what had originally been a complex of islands.

Substantial modification to the flow of the river and shape of the riverbanks was engineered in the late 1960s and early 1970s. For example, Seaham Weir was built across the lower portion of the

Williams River in 1968 and in 1970 floodgates were put on Ironbark Creek, the main drainage channel for Hexham Swamp. The riverbank at Millers Forest, a section of the Hunter River upstream of the Williams River, was dredged in 1969 as part of a package of flood mitigation works.

Concerns about air pollution from industries newly arrived on the island, and about the proposed extent of the industrial reservation, were raised by the public in the early 1970s. A Commission of Inquiry into Kooragang Island was convened in 1972, the first inquiry of its type under the then recently passed State Pollution Control Commission Act. In finding that 27% of the island had been reclaimed for industrial purposes, that there was no sewerage system and that dying mangroves were evident, the Commission suggested that future engineering works be done in an ecologically sensitive way and that a fairly large part of the undisturbed area of the island should be preserved in its natural state, together with, around and adjacent to Fullerton Cove. The then NSW State Fisheries, along with other agencies, made a suggestion to the inquiry that a tidal channel be constructed to the North Arm of the Hunter River to compensate for the habitat damage caused by the construction of the industrial estate, including the railway, and the closing off of Moscheto Creek at its confluence with the South Arm. An impression of such a channel is given by Coffey (1973) in Figure 6.1.1.4 of his report. The Inquiry also referred to studies by the then Water Conservation and Irrigation Commission on the loss of alluvial soils due to erosion in the upper part of the river. Some of these silts would have been deposited downstream in the estuarine wetlands.

In 1976 the NSW Minister for Public Works and Ports considered that a need existed for active involvement of authorities other than his department in the planning for development of the island, and the Kooragang Island Advisory Committee was therefore established to initiate and respond to development ideas. The advisory committee noted that the reclamation begun in 1951 was completed in 1977 at a cost of $100 million, yet 80% of the reclaimed land was idle and would stay so until the 1980s. The committee provided its first report in 1979, addressing among other things the boundary lines dividing the island into five areas designated "A to E", and suggesting that Area C should not be included in the nature reserve being considered at that time by the NSW National Parks and Wildlife Service (NPWS).

It should be recognised that one legacy of the Kooragang Inquiry was the attempt by the then NSW Department of Planning and Environment to blend the industrial needs of the Hunter region with conservation of the environment by commissioning a number of studies of the natural attributes of the island. The NPWS subsequently gazetted the Kooragang Nature Reserve in 1983, the prime function of the reserve being to protect the habitat of migratory wading birds. A Newcastle Local Environmental Plan was released (Department of Planning and Environment 1987) creating two major zones on Kooragang Island: Zone 4(b), a General Industrial zone covering the south and west, and Zone 7(b), an Environmental Protection (Wetlands) zone for the Kooragang Nature Reserve.

The Sydney to Newcastle gas pipeline was constructed at the end of this era. At first glance its construction and operation appear to have been of minor impact, but as detailed below, its installation may have been responsible for undermining a culvert at the mouth of Cobbans Creek, and so indirectly bringing a new era of environmental change to Kooragang Island.

The agricultural impact on the wetlands of the lower Hunter River during the late development stage relates primarily to the aftermath of flood of 1955. Estimated to be a 1: 200 year event, its impact engendered the Hunter Valley Flood Mitigation Act of 1956.

The Act supported the construction of levees and floodgates at numerous locations in the valley, including the construction of the ring drain and headworks at Fullerton Cove in 1966. In 1970 headworks were installed at Ironbark Creek that reduced tidal range and water level in Hexham Swamp.

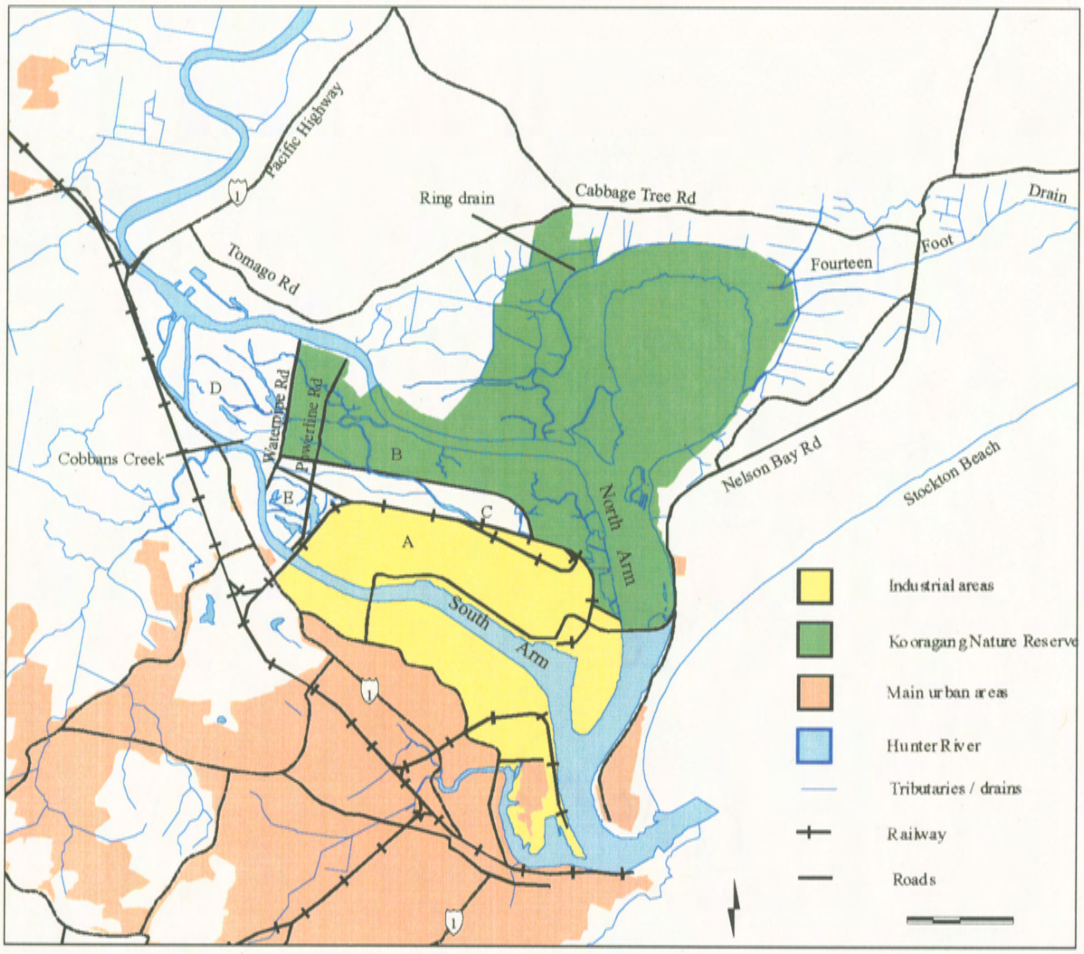

Figure 2.4. Main infrastructure of the lower Hunter River. Sub-regions A-E are those shown in Shortland Wetland Centre and The Newcastle University Research Associates (1992): A = Industrial Region, B = Kooragang Nature Reserve (south), C = Central region, D = Western Kooragang Island, E = Experimental area. NR = Kooragang Nature Reserve (north).

2.3.4. Stage 4. 1990-Present, Rehabilitation stage

This era saw the commencement of a number of habitat rehabilitation initiatives. Changes in wetland habitats are well documented due to availability of aerial photographs, and community and local government understanding of, and willingness to participate in, wetland conservation and rehabilitation issues. Relevant place names are shown in Figure 2.4.

The erosion and undermining of a culvert at the mouth of Cobbans Creek in April 1990 can be considered the start of the rehabilitation era of Kooragang Island. The loss of the culvert has never been described and we offer the following interpretation of events. In the late 1980s the Sydney-Newcastle gas pipeline was laid under the creek about 80 m from its junction with the South Channel of the Hunter River. To prevent erosion and protect the pipeline, the south bank of the creek was armoured at the crossing with rock baskets, and a small weir was put in place upstream of the pipeline. These installations focused ebb currents and/or flood runoff from the upstream wetlands onto the armoured portion of the south bank, that in turn were reflected downstream and onto the opposite bank at the road culvert, progressively undermining the structure. Once breached, erosion would have been self-catalytic: ever-greater volumes of tidal water would have flowed into the wetland on the flood tide and hastened the erosive process on the ebb tide. The wetlands, now subject to a tidal regime in which the high tide would have been higher and the low tide lower, would among other ways have responded by an expansion of the mangrove zone. The remains of the culvert were removed from the creek by the KWRP works supervisor in late 1996.

In early 1995 the KWRP Steering Committee removed culverts from other two creeks on the western end of Kooragang Island and replaced them with bridges. Details about the replacements have been provided elsewhere (Streever *et al.* 1996), but the cost was approximately $12 000 at each site. Various wetland, bird and fish studies were initiated before and after the removals. A number of publications describe the initial impact of the new bridges (Genders 1996, MacDonald 1996, Streever *et al.* 1996, Turner and Streever 1997a, b, Kingsford and Ferster Levy 1998, Williams *et al.* in prep.).

2.4. Conclusions

The first 100 years of human activity at Kooragang Island were based on the progressive clearing of land for agricultural purposes and an increase in shipping facilities. Clearing would have been accompanied by attempts to drain wetlands and improve access on and around the complex of islands present at the mouth of the Hunter River. The construction of land transportation systems would also have had an impact on wetlands, for example the reclamation to build the Newcastle Railway Station. Foreshores were modified at Bullock Island and elsewhere with spoil dredged to keep the navigation channels clear.

The next 50 years saw the emergence of the industrial future of the lower Hunter River, with the NSW Government resuming land from the Kooragang farmers and reclaiming a large area from the river channel at the eastern end of Moscheto Island (Walsh Island) as a site for engineering and shipbuilding facilities. Other impacts to wetlands occurred when levee banks near Waterpipe Road and east of the Powerline Road were installed to reduce the extent of tidal inundation.

The latter part of the 1900s saw a further increase in drainage activities (an outcome of the 1955 flood) and a massive investment in engineering infrastructure, including the installation of the water pipeline, various powerlines and associated service roads across Kooragang Island. Of major significance was the building of the railway across the South Channel and its blockage of Moscheto Creek. The Coffey Inquiry of 1973 publicly recognised that habitat damage had occurred and suggested a need for remedial action.

An era distinguished by rehabilitation of wetland habitat commenced in 1990 with the undermining of the culvert at the mouth of Cobbans Creek and continues today with the efforts of the KWRP Steering Committee. Of particular note is the Committee's replacement of culverts on two tidal creeks at the western end of Kooragang Island with bridges and the initiation of a number of studies to define wetland attributes to measure the benefits of habitat rehabilitation.

More detailed analysis of change in landform is provided in the next chapter, including changes in the size of island from 1801 to the present, and a description of changes in internal geography and wetland habitats.

2.5. Recommendation

1. There is still more to be learned about the nature and evolution of the wetlands of the lower Hunter River. Incentives should be offered to further study habitat changes that have occurred there.

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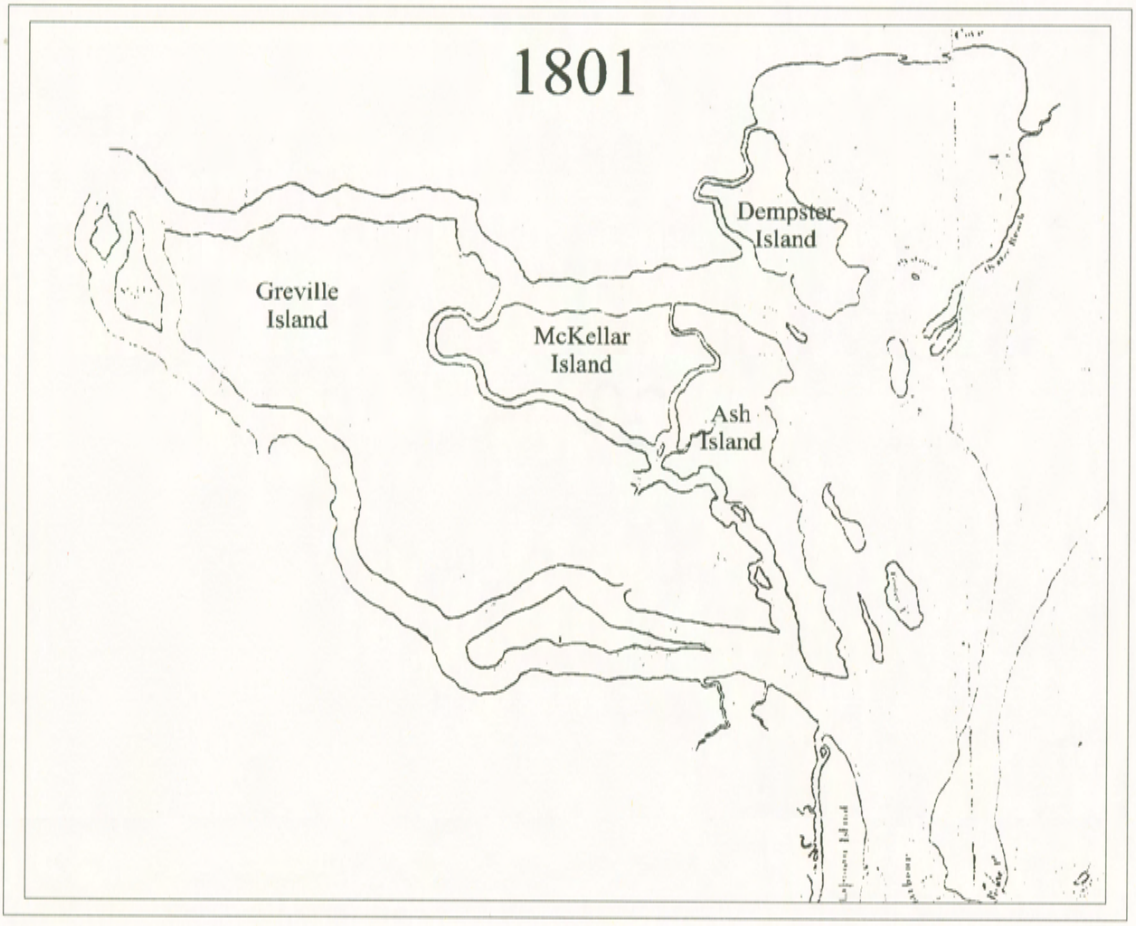
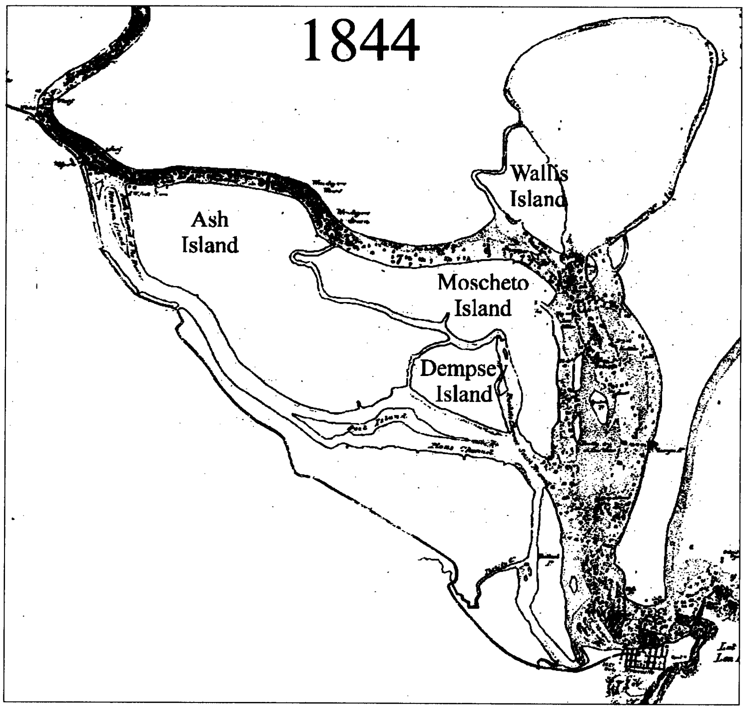
Appendix 2.1. Historical maps of the lower Hunter River

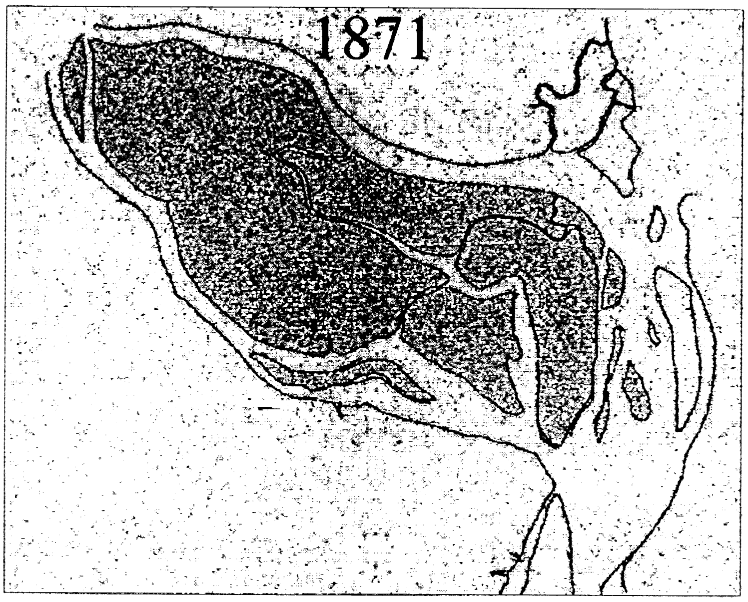


(a) Coal harbour and rivers on the coast of New South Wales. Barrallier, F. (Mitchell Library catalogue number M3 811.23/1801/1).

Appendix 2.1. Continued



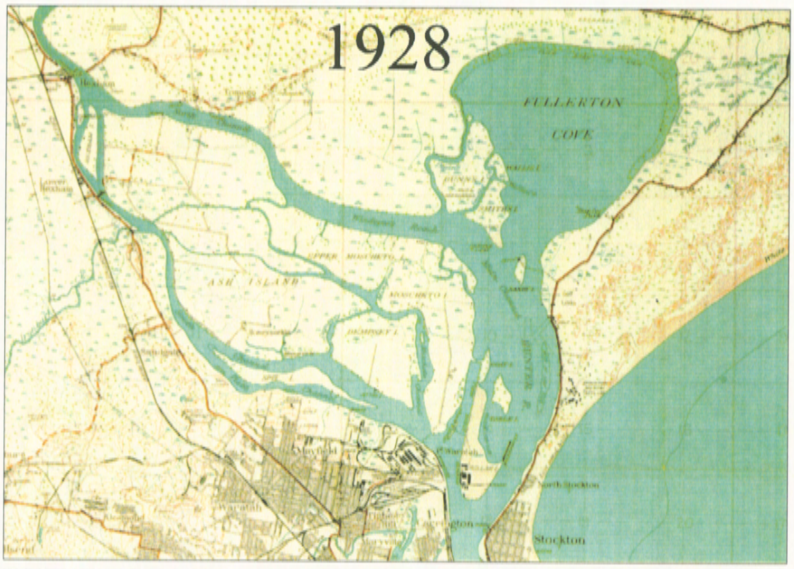
(b) Map of Country around Newcastle. Parrot, T. (Mitchell Library catalogue number M3 811.25/1862/1).



(c) Hunter River. Gowlland, J. (Mitchell Library catalogue number M3 811.25/1871/1).

Appendix 2.1. Continued

(c) NSW one mile to the inch series, Newcastle Zone 8, Map 96, Edition 1913.



(e) NSW one mile to the inch series, Newcastle Zone 8, map 396, Edition 1928.

Appendix 2.2. List of charts, maps, orthophotomaps and aerial photographs analysed in this study. Where appropriate, Mitchell Library reference numbers are listed.

Charts

1801. Coal harbour and rivers on the coast of the New South Wales. Barrallier, F. M3 811.23/1801/1.

Maps

1844. Plan of River Hunter. Allan, J. M3 811.25/1844/1A.

1862. Map of Country around Newcastle. Parrot, T. M3 811.25/1862/1.

1871. Hunter River. Gowlland, J. M3 811.25/1871/1.

1892. Map of Country around Newcastle, NSW. Author unknown. M3 811.25/1892/1.

1913. NSW one mile to one inch series. Newcastle Zone 8, Map 396. Edition 1913.

1928. NSW one mile to one inch series. Newcastle Zone 8, Map 396. Edition 1928.

1941. 1: 25 000 topographic maps: Raymond Terrace, Newcastle. NSW Department of Lands.

1990. 1: 25 000 topographic maps, second edition: Beresfield, Hexham, Newcastle, Wallsend. NSW Land Information Centre.

Orthophotomaps

1972. 1: 4 000 orthophotomaps: Beresfield, Fullerton Cove, Hexham, Kooragang Island, Newcastle, Wallsend, Williamtown. NSW Central Mapping Authority.

Aerial photographs

Date	Agent	Film no.	Run no.	Frames	Format	Scale
22/07/1954	LIC	252	3N	66-70	B&W	1:30 000
14/08/1966	LIC	1464	3N	88-91	B&W	1:41 000
20/08/1976	LIC	2404	10	93-95	C	1:25 000
			11	81-82	C	1:25 000
22/08/1976	LIC	2406	9	117,119,121	C	1:25 000
01/12/1976	LIC	2421	8	57	C	1:25 000
31/07/1984	BHP	830	-	8888	IR	1:16 000
19/04/1986	Coastal	3509	44	11	C	1:25 000
20/04/1986	Wetlands		45	183-189	C	1:25 000
			46B	202	C	1:25 000
			47	18-22	C	1:25 000
27/11/1993	BHP	1555	2	9423-31	C	1:10 000
			1	9433-44	C	1:10 000
			3	9446-52	C	1:25 000
30/01/1994	Hunter	4183	3	119, 121, 123	C	1:25 000
	Bushfires		4	92, 94, 96	C	1:25 000

Appendix 2.3. A list of dates relevant to the change of wetland habitats at Kooragang Island and elsewhere in the lower Hunter River. Dr. J. W. Turner, Honorary Associate of the Department of History of the University of Newcastle, confirmed many of the facts and dates.

Year	Event
	1796-1895 Early Development Stage
1796	Fishermen driven ashore find coal littering the beach near the unnoticed mouth of the Hunter River (Perry 1963).
1797	Discovery of mouth of Hunter River by Lt. J. Shortland when directed by Governor Hunter to recapture convicts escaped from the Sydney settlement (Coffey 1973). Subsequently, two commercial vessels visit the river, one of which carries coal and cedar to Sydney (Perry 1963).
1799	First coal shipment (Manley 1963).
1801	Under orders from Governor Hunter, the lower Hunter River is surveyed by Lt. Col. W. Paterson. Paterson gives the name "Ash Island" to what we now know as Moscheto Island after the trees which resembled the English ash (cedar and gum trees were also present). A sawpit is dug on the island and operates for some months. Ensign F. Barrallier produces the first map of the group of large islands in the lower Hunter River. First rock and sand wharf facilities constructed in vicinity of present day Kings Wharf (Anon. 1950, Anon. 1954, Manley 1963, Coffey 1973).
1802	Closure of first penal settlement at Newcastle (Perry 1963).
1804	Second penal settlement when convicts from the Castle Hill uprising are sent to Newcastle (Perry 1963, Hartley 1995). Sydney Gazette reports "Strata of coal is immense, quantities of fish are easy to be procured and up the river is an abundance of wildfowl." (Anon. 1804).
1808	Salt production halted and lime (burning of oysters) begun (Perry 1963).
1818	Howe's road from Windsor to Wallis Plains (Maitland) (Perry 1963).
1818	Breakwater to Nobby's Island begun (Manley 1963, Dames and Moore 1978).
1819	Traffic in people and convicts on Howe's Road (Perry 1963). Maitland flood (Perry 1963).
1822-1823	Penal settlement at Newcastle closed; new penal settlement started at Port Macquarie (Perry 1963, Hartley 1995).
1827	Newcastle resident Mr. A.W. Scott buys 1000 ha of land on Ash Island and plants an orange orchard. His oranges become famous throughout the colony (Anon. 1993).
1829	The islands of the lower Hunter are described in the Sydney Gazette as "abounding in fish, duck, kangaroos and pigeons" (Ruello 1976).
1825-1828	Drought, followed by wet period (Hartley 1995).

Appendix 2.3 continued.

1830	First small farmers (squatters) on Dempsey Island (Turner in prep.).
1831	Daily vessels track from Sydney to Newcastle to Morpeth (Manley 1963).
1836	Saltworks constructed on Moscheto Island; later a sulfuric acid plant is built and operated until 1870 (Coffey 1973).
1840	Depression and drought in NSW (Hartley 1995).
1842	Except for swampy foreshore downstream, both banks of Hunter cleared between Newcastle and Morpeth (Hartley 1995).
1845	Dairy farming commences on the islands (Anon. 1954).
1846	Nobby's Breakwater completed, but later breached by storms (Manley 1963).
18??	Commercial prawn fishing commences in the Hunter River in mid 1800s (Ruello 1969, Turner in prep.).
1854	Nobby's Breakwater repaired (Manley 1963).
1857	Major flood.
1858	King's Wharf begun; land for Newcastle railway station reclaimed (Manley 1963).
1859	Possibly stemming from the flood and/or the need to load coal, dredging is commenced in Newcastle Harbour and approach channels with the spoil being dumped east and west of Bullock Island. Dredging continued intermittently for many years (Manley 1963, Coffey 1973, Dames and Moore 1978).
1860s	Floods.
186?	Start of Walsh Island in the early 1860s from spoil dredged to make a channel to the site on which the steelworks now stands. (Dames and Moore 1978).
1862	Bullock Island reclamation further enhanced with the construction of a long training wall known as the Bullock Island Dyke along the alignment of the South Channel (Manley 1963, Coffey 1973).
1864	Flooding serious enough to wash away approaches to vehicle and railway bridge, isolating East and West Maitland (Hartley 1995).
1866	Scott's farm fails and his property is cut into farms (Anon. 1893a, Turner in prep.).
1867	Ballast jetties built at Bullock Island (Manley 1963).
1868	Wallaroo Mining and Smelting Co. opens a copper works at Port Waratah, works closed in 1893 (Turner in prep.).
1872	Dempsey Island Salt Works erected (Turner in prep.).
1878	Wharf construction along southern bank completed (Manley 1963).

Appendix 2.3 continued.

188?	Newcastle railway station built on reclaimed land.
1886	District Inspector of Schools reports a population of 220 on Moscheto Island, 62 of school age.
1890	Construction of Miller's Forest Wharf (Manley 1963).
1893	The "Great Flood" causes Moscheto Island residents to take to the roofs and leaves a dry area of about 2 ha near the school at the eastern end of the island (Anon. 1986). Moscheto Island is "suffering effects of excessive rains, and in consequence the grass is almost perished" (Anon. 1893b).

1896-1950 Mid Development Stage

1896	BHP acquires 10 ha of waterfront land at Wallaroo to smelt lead and zinc ore. Smelter did not proceed (Anon. 1935).
1898	Construction of the first section of the Walsh Island training wall; reclamation continues behind it for the next 20 years (Manley 1963, Coffey 1973). Construction started on southern guide wall; completed 1902 (Manley 1963).
1899	Bullock Island merged with mainland; small islands in the North Channel removed.
1901	Further reclamation of Bullock Island (Manley 1963).
1903	Start of series of reclamations at Throsby Creek (Manley 1963).
1907	Two fishing boat hire services with 60 boats between them are available in Newcastle but this is not adequate to meet the demand for recreational fishing (Ruello 1976).
1912	Newcastle Iron and Steel Works Act of 1912-1913 is passed to allow the construction of heavy industrial facilities (Anon. 1935). The Act provides 40 ha of Crown Land and grants a 50 year lease on a water frontage of 14 ha; the State government undertook to dredge and maintain a channel between the works and the sea; the company also purchased another 46 ha freehold (Anon. 1935).
1913	State Engineering Workshops, including dockyard, commenced at Walsh Island. NSW Minister for Works resumes 240 ha of Moscheto Island for homes for dockyard workers. No homes were ever built on Moscheto Island for this purpose; they were built at Stockton instead (Anon. 1940, Coffey 1973).
1913-1928	Levee bank constructed around Fullerton Cove; large drains including Dawson's, 14 ft., 10 ft. and numerous side drains dug, beginning of ring drain.
1915	Production of steel by BHP commences at the Port Waratah works; Walsh Island dockyard and shipbuilding flourishes from this time (Coffey 1973).

Appendix 2.3 continued.

1917-1928	Carrington Wharf (old Bullock Island) constructed; start of wall to link Goat, Walsh and Spectacle Islands, and subsequent reclamation; reclamation at Wickham and Throsby Creek (Manley 1963). Wharf construction around the east side of Bullock Island extended along the northern shore. Walsh, Goat and Spectacle Islands further consolidated by reclamation.
1930	Public Works Department constructs weir between Hexham and Ash Islands to increase flow in North Channel and lessen siltation (Manley 1963, Turner in prep., J. Latham pers. comm.).
1933	One outcome of the Great Depression is the closure of the Walsh Island dockyard and the termination of reclamation begun in 1898 (Coffey 1973).
1935	Large scale removal of shell from Fullerton Cove by the Sulphide Corporation for cement manufacture (Turner in prep.).
1938	Construction of Wallis Creek floodgates at Maitland (Manley 1963).
1939-1945	The Second World War enhances industrial output from the Hunter district. Antiaircraft batteries are placed on the eastern end of Moscheto Island (V. Deacon pers. comm.).
1941	State Dockyard established (Manley 1963).
1947	Newcastle Chamber of Manufacturers proposes the extension of port facilities and new industrial sites including "development of islands in the lower Hunter River into industrial land" (Coffey 1973).
1950	NSW Government approves BHP application to block off Platt's Channel to use firstly as a disposal site for waste and then as an expansion site for industrial facilities (Irwin 1968).

1951-1989 Late Development Stage

1951	Dredging and island reclamation/consolidation is recommenced (Dames and Moore 1978, Turner in prep.).
1953	Newcastle Harbour Improvements Act is passed. Resumption notices are issued to 17 families resident on Ash Island; NSW Public Works is given ownership of the Kooragang islands and the formal responsibility to construct a "single land mass" and co-ordinate all industrial development and servicing. Reclamation commenced almost immediately with material dredged from the harbour (Coffey 1973).
1954	Bunds placed in Platts Channel.
1955	1: 200 year flood in the Hunter valley (Coffey 1973).

Appendix 2.3 continued.

1958	Walsh and Moscheto Islands are linked by reclamation; Walsh and Dempsey Islands joined by filling in Moscheto Creek (Dames and Moore 1978). A gravel road is built along the southern shore of Ash Island to link the Ash Island Bridge to the site of the future Stockton Bridge (Turner in prep.).
1960	BHP begins to fill Platts Channel (Anon. 1960). Northumberland County Planning Scheme was introduced, under which Kooragang Island was zoned Industrial B (Heavy), meaning that industries other than those considered to be offensive or hazardous could be established on the island (Coffey 1973).
1963	A record monthly prawn catch from Stockton Bight after repeated large scale flooding of the Hunter region in April and early May (Ruello 1973).
1964	Greenleaf Fertilizers Ltd. is the first company to take up a lease on Kooragang Island (Coffey 1973).
1965	Tourle Street bridge links Kooragang Island with Mayfield (Dames and Moore 1978).
1966	Start of construction of railway which cuts Moscheto Island in half, facilitating the reclamation of the southern portion of Moscheto Island and Dempsey Island. West bank of North Channel stabilised with training and retaining walls (Moss 1983).
1967	Mouth of Mangrove Creek filled for road construction (Moss 1983).
1967	Seaham Weir constructed (Ruello 1976).
1968	Kooragang Island officially named by NSW Geographical Names Board (NSW Government Gazette 1968).
1968	Minister for Public Works approves Williamtown-Long Bight-Tomago drainage scheme including enlargement of ring drain and heightening of levee bank around Fullerton Cove (Turner in prep.).
1969	Highest recorded salinity at Raymond Terrace (18.2 ppt.) after a large high tide (Ruello 1976).
1969	Levee banks constructed along the Hunter River at Millers Forest (upstream of the junction with the Williams River) (Ruello 1976).
1970	Construction of floodgates at Ironbark Creek (Hexham Swamp) (Ruello 1976).
1971	Stockton Bridge completed (Dames and Moore 1978); high dust carryover to Stockton and elsewhere from industries sited on Kooragang in the late 1960s causes residents' complaints (Coffey 1973).
1972	Ramsar Agreement on wetlands of international significance especially in terms of waterfowl habitat (Ramsar 1996).

Appendix 2.3 continued.

1973	The "Inquiry into Pollution" is begun in June to deal with residents' complaints. This is the first inquiry conducted under the terms of the State Pollution Control Commission Act of 1970. Over 300 ha now fully reclaimed under Newcastle Harbour Improvements Act. The NPWS and (the then) State Fisheries advocate the extension of Moscheto Creek to overcome ecological problems arising from the blockage of the creek by the railway (SPCC 1973).
1972	650 acres now fully reclaimed under Newcastle Harbour Improvements Act; Minister for Works announces 600 ha (19%) of Kooragang Island to be left in its natural state Coffey 1973).
1976	Ring drain around Fullerton Cove begun (Kingsford and Ferster Levy 1998).
1976	Reed beds not yet regrown at Millers Forest after dragline construction of river levee in 1969 (Ruello 1976).
1979	The Kooragang Advisory Committee, constituted by the Minister for Works to resolve a number of alternative planning ideas, provides its first report recognising different attributes and potential of areas "A - E" (Moss 1983).
1981	Department of Planning and Environment commissions the NSW Institute of Technology to report on the natural areas of Kooragang Island (Moss 1983).
1983	Kooragang Nature Reserve is gazetted by the National Parks and Wildlife Service.
1985	Promulgation of SEPP 14 establishes protected wetlands in NSW, including Kooragang Island (Adam *et al.* 1985).

1990-Present Rehabilitation Stage

1990	The culvert at the mouth of Cobbans Creek (Creek 2) is washed out (Genders 1996).
1992	"Kooragang Island Wetland Compensation Project Feasibility Study" (Shortland Wetlands Centre and TUNRA 1992) is printed.
1993	NSW Minister for Agriculture and Fisheries launches the Kooragang Wetland Rehabilitation Project in November.
1995	Culverts that restricted tidal flow in Creeks 1 and 5 on western Kooragang Island were replaced with bridges by the KWRP in July and August. The presumed beneficial impact is to be monitored as part of the research program set up two years before.

3. ANALYSIS OF CHANGE IN LANDFORMS AND DRAINAGE IN THE LOWER HUNTER RIVER, 1801-1994

3.1. Introduction

Drainage works, levees, dredging and reclamation can modify tidal flow, as does the installation of industrial infrastructure such as pipelines, power transmission lines and their access roads. In turn, altered tidal flow can have a large impact in modifying wetland habitats. For example, small-bore road culverts installed in tidal creeks reduce the intertidal area, leading to a loss of available habitat for fish (Williams and Watford 1996). Similarly, habitat for many species of migratory wading birds can be lost when tidal flats are reclaimed (Kingsford and Ferster Levy 1998). These types of impacts are seen in the lower Hunter River, and are associated with the evolution of socio-economic patterns in agricultural, shipping and industrial pursuits (Chapter 2).

Wetland habitats are also changed by natural processes. For example, naturally occurring deposition and erosion alter the shape of river channels and islands and the extent of wetland habitats within the floodplain. Some of these processes are ongoing and gradual, but floods such as those experienced in the Hunter River in 1857, 1893 and 1955 may have had a dramatic impact on wetlands and other landforms over a short space of time.

This chapter describes the extent to which natural and artificial processes have contributed to shaping the estuarine wetlands of the Hunter River over the past 200 years. Our objectives were to assess changes in the area of land and open water, number of islands, length of shoreline and drainage patterns. These assessments were made using geographic data from charts, maps, aerial photographs and reports spanning nearly 200 years, and included one of the earliest charts of Kooragang Island, produced in 1801, and colour aerial photographs taken in 1994.

3.2. Methods

Our study area extended from the present day location of the Hexham Bridge (the location of which we estimated on the early maps) downstream to the breakwalls at the mouth of the river. The surrounding transport corridors determined the terrestrial boundary: the Pacific Highway, New England Highway and the Main Northern Railway in the west, Tomago Road in the north and Fullerton Road in the east. This area, amounting to approximately 195 km^2 (Figure 2.2) did not include Hexham Swamp.

In order to evaluate the extent of change, reproductions of charts, maps and photographs from between 1801 and 1994 were electronically scanned, geometrically corrected and analysed in a Geographic Information System (GIS). The quality of the data varied in terms of the amount of detail present and scales of the original maps, as well as the reproduction formats available. The GIS allowed us to view and analyse the data from each map or set of photographs at a common scale and orientation within an established co-ordinate system, and to display the results in various maps, tables and graphs.

The first naval charts of the lower Hunter River, drawn by Shortland in 1797 and Barrallier in 1801, and other maps printed by NSW Lands Department in 1844, 1871 and 1892 are held by the NSW State Library. Due to the historical significance and fragility of documents of this age, copies of the originals are stored on microfilm and we purchased photocopied enlargements. The chart of 1797 and map of 1871 provide only partial coverage of the study area and so were not used in the assessment. Topographic maps produced in 1913, 1928, and 1941 are also held in the archives of the State Library and photographic reproductions of the relevant sections of these maps were obtained.

Anecdotal accounts suggest the first vertical aerial photography of the lower Hunter was undertaken in 1941, but advice from the Royal Australian Air Force (RAAF) indicates the negatives have since been lost through fire. The NSW State Library, the National Library in Canberra and the RAAF were unable to locate any prints of these photographs. The next oldest aerial photographs were taken in 1954 and contact prints from this year and for one year in each subsequent decade (1966, 1976, 1986 and 1994) were obtained. Details of maps and photographs used to assess changes to landform, drainage and vegetation are contained in Appendix 2.2. In all, data from 11 years were acquired and assessed (1801, 1844, 1892, 1913, 1928, 1941, 1954, 1966, 1976, 1986 and 1994).

Secondary sources of information included topographic and orthophoto maps produced between 1971 and 1990 at scales of 1: 4 000, 1: 25 000 and 1: 100 000 (Appendix 2.2). If not held by NSW Fisheries, these maps were purchased from the Land Information Centre (LIC) to aid in interpretation of aerial photographs (see below). The orthophoto maps were also used as the source of Australian Map Grid (AMG) co-ordinates to position each map or photograph within the GIS.

The chart, maps and photographs were scanned with a colour flat bed scanner at a resolution of 300 dpi (dots per inch) to produce a raster image where the data were stored as small internally uniform cells (pixels) arranged in a grid (Eastman 1992). As the data sources were of varying scales, the size of the pixels in ground units (metres) also varied for each image. For example, a 1: 25 000 scale map when scanned at 300 dpi produces an image with a resolution of 2.1 m while a 1: 50 000 map produces a 4.2 m resolution image. Appendix 3.1 lists the photographs utilised and the resolution of the scanned images produced in each case. While the aerial photographs and more recent maps have known metric scales, the older maps and charts were made in imperial units, or had no scale indicated, and so estimations of scale were made. Although the scanner used is capable of performing at higher resolutions, 300 dpi was chosen due to considerations of disk storage space, image processing speed and data requirements. Higher resolution images have larger file sizes and consequently lower processing speeds.

While the chart from 1801 and other early maps were of a scale that enabled them to be scanned in a single image, the 1941 map and all sets of aerial photographs required a number of scans to provide full coverage. AMG co-ordinates (Zone 56) provided a way to link overlapping images to form a mosaic covering the whole study area for any one data set.

In addition, registering each image with the AMG co-ordinates enabled correction of the distortion inherent in aerial 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 its centre (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. In an estuarine environment situated in a large flood plain such as is the case in the lower Hunter, effects of terrain variation on scale are minimal although changes in the altitude of the plane during the run will alter the scale between frames. Other distortions may result from scanning contact prints, as paper products suffer from stretching and shrinkage (Burroughs 1990).

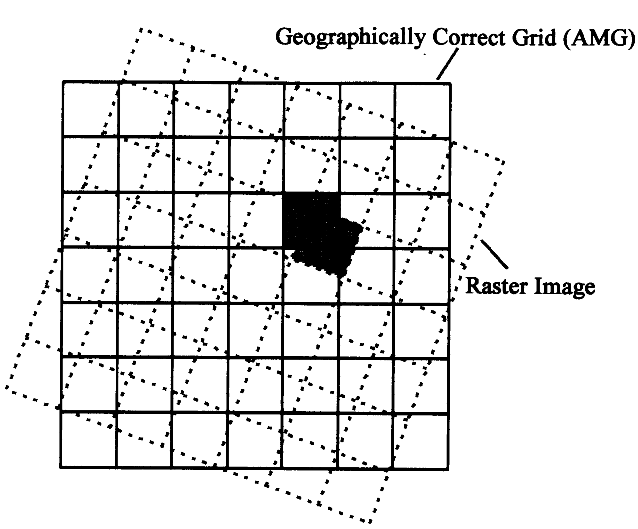


Figure 3.1. Resampling a raster image to a geographically correct grid using the Nearest Neighbour Method (modified from Curran 1988).

To geometrically correct these variations, the scanned image was rectified to position each pixel in relation to a known base grid (AMG) using the resampling process provided in IDRISI GIS software (Figure 3.1). Prominent features such as road and drainage intersections or buildings common to both an image and the relevant 1: 4 000 orthophoto map were identified as Ground Control Points (GCP). These GCPs were located as x, y co-ordinates from the row and column position in the image and their AMG co-ordinates were determined by measuring the position of the feature in relation to the 500 m grid on the map. Care was taken to ensure that all GCPs were located at approximately the same elevation and that a number of common points were used in adjacent photographs. Where possible the same GCPs were used for each set of aerial photographs. A minimum of six GCPs were used to rectify each photograph using a first order polynomial (linear) transformation and nearest neighbour interpolation. Eastman (1992) advises that although three control points may be used for a linear transformation, twice this number should be used for a reasonable fit. The effectiveness of this transformation was tested by viewing the root mean square (RMS) error and the mosaic produced by overlaying each of 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. RMS errors are listed in Appendix 3.1.

The size of the study area and restrictions of storage space led to a pixel size of 2.5 m being chosen as the resolution for resampling output for each photograph except those from 1966 where the resolution of the original image was approximately 3 m (Appendix 3.1). The 1966 photographs were therefore resampled to a 5 m resolution.

Due to the unknown scales and/or projections of the historical maps, and the distortions associated with reproductions and paper products, a similar process was undertaken to align map images within the same co-ordinate system as the aerial photographs and therefore allow the images to be overlaid and analysed. Our ability to quantify change from one map to the next was limited by the accuracy with which they were drawn and reproduced, and by the lack of features remaining constant through time that could be used as control points.

The resampled IDRISI images were imported into MAPINFO, a vector based GIS, and elements of each image were digitised into separate layers. Layers showing the shoreline boundary, islands and major infrastructure were digitised from each image and the length and area of relevant features determined. In order to assess where these changes were occurring, the shoreline and adjacent islands of the study area were divided into five sections: Western Kooragang Island, Eastern Kooragang Island, Throsby Creek (including Platts Channel), Tomago/Fullerton/Stockton and the South Bank (Figure 3.2). The section that included Throsby Creek was terminated where the main railway line crosses the creek. Hexham Swamp, including Ironbark Creek, was not evaluated in the assessment of the South Bank.

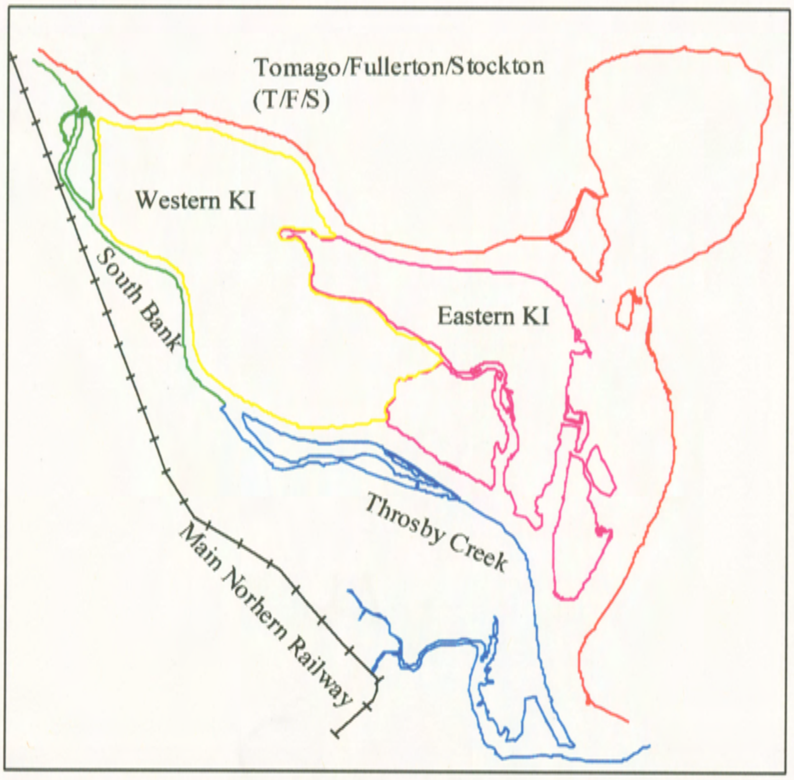


Figure 3.2. Shoreline sections used for calculations.

As would be expected, the photographs provided a much greater level of detail than the historical maps. This was particularly evident with the small creeks. The location of many of these creeks could not be tracked from one map to the next due presumably to variations in cartographic intent and/or accuracy. As much detail as possible was digitised from the photographs, but these data were also generalised for comparison with the maps. Unfortunately this precluded a finite assessment of change in width of the creeks which infiltrate the islands.

Inspection of the historical maps allowed us to draw inferences about the drainage patterns and catchment boundaries that existed prior to the settlement of Newcastle. Present day drainage patterns were established via the aerial photographs and field observations made over the latter part of 1993 and the early part of 1994. Maps were produced to illustrate the changes that occurred.

As part of the investigation of drainage patterns, pipes, roads, road culverts and levees were located. Coincident with the commencement of this study, the Australian Fisheries Research and Development Corporation funded a project to identify these and other structures influencing tidal flow throughout the estuaries of NSW (Williams and Watford 1996). Structures identified elsewhere in the lower Hunter River during the course of the FRDC project and which have an influence on tidal flow are identified in this report.

Where possible, structures shown on the historical maps were located on separate data layers within the GIS to give an indication of the changes in their type and number. For some modifications of wetland habitat the dates of the installation are known (Chapter 2, Table 2.1), but for others only the time period in which the change occurred, rather than the exact date, can be identified.

3.3. Results

Long term residents of the lower Hunter region remember the major dredging and reclamation activities that took place on the southeast corner of Kooragang Island in the 1960s. These works added to the legacy of engineering activities commenced in the mid 1800s with the first dredging in the shipping channels (Manley 1963). Evidence from the photographic record and early maps indicates that works of this type have had a large impact in altering the landscape. As well, some losses and gains of river shoreline have occurred due to the natural processes of erosion and siltation.

3.3.1. Overall change in landforms

The earliest depiction of the lower Hunter is the chart drawn by Barrallier in 1801 (Appendix 2.1a). Macqueen (1993) commented on the former's effort:

> "The map is remarkably accurate in configuration and scale: comparison with modern maps demonstrates that Barrallier faithfully reproduced virtually every twist and turn, and his scale was in error by less than seven percent."

Using the GIS, Barrallier's chart was spatially corrected and used as the basis to estimate changes to landform on Kooragang Island. Reclamation and siltation resulted in an estimated 20% increase in land area from 2,170 ha in 1801 to 2,600 ha in 1994.

The change in area of open water of the study area is shown in Figure 3.3. There has been an overall decrease of water area of 37 % from an estimated 3,570 ha in 1801 to 2,240 ha in 1994 (Table 3.1). Reduction was seen primarily at four places: around the island known originally as Bullock Island and now recognised as the suburb of Carrington, within Platts Channel, on the eastern end of Moscheto Island, and in the channel between Moscheto Island and Dempsey Island. All of these locations were reclaimed as part of the ongoing urban and industrial expansion of the city of Newcastle. Accretion around the breakwaters is also shown.

As well, large portions of the North and South Channels and Fullerton Cove silted up since the earliest charts and maps were produced. The accreting material is primarily fluvial in origin (Roy 1980), at least some of it derived from clearing in the upper catchment. The narrowing of the South Channel may be related to the construction at its western end of a weir in 1930 to increase velocity in the North Channel and reduce the need for maintenance dredging in the latter (Manley 1963).

Gain in the area of open water occurred primarily from dredging at Throsby Creek, at the southern tip of Moscheto Island, at the northern edge of Spit Island and at the northern shore of the North Channel near Hexham Bridge for the slipway (Figure 3.3, Table 3.1). Water area was also increased through the creation of the drainage channels around Fullerton Cove.

The loss of open water area vastly outweighs gain with each of the processes of siltation and reclamation contributing near equivalent areas (Table 3.1). From 1801 to 1994, 1330 ha of water area was lost in the lower Hunter, 740 ha through reclamation and a further 750 ha through siltation. One hundred and ten hectares of water was gained in dredging operations, and 50 ha gained due to erosion.

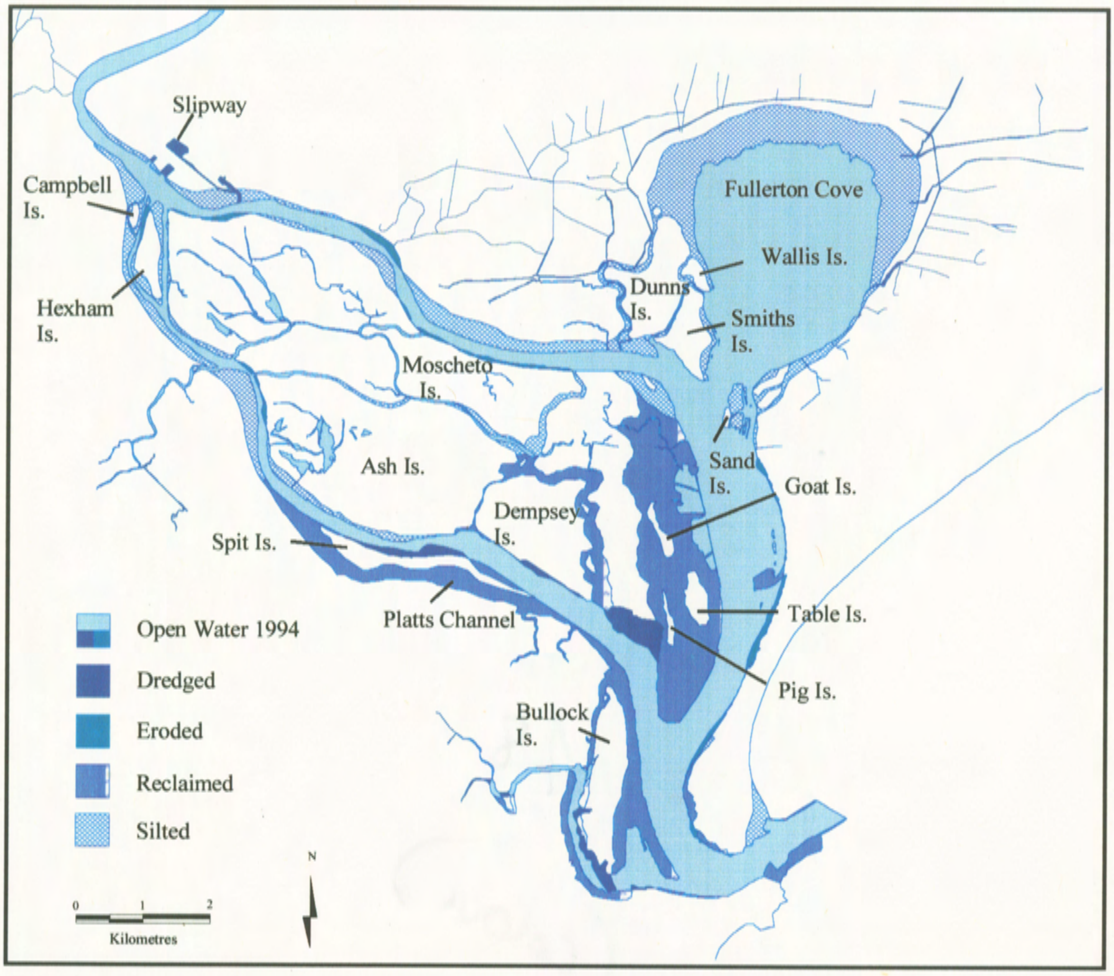


Figure 3.3. Overview of changes to the open water of the lower Hunter River, 1801-1994.

Table 3.1. Estimation of the total change in area of open water in the lower Hunter River, 1801-1994. Estimations for 1801 areas are based on manipulating Barrallier's chart to best fit the shape of the river in 1994. As a result figures are intended to give the general idea of the extent of changes and have been calculated to the nearest 10 ha only.

Total water area (ha)		Process of change	Change in water area (ha)	Change (%)
1801	1994	Total change	-1330	-37
3570	2240	Dredging	110	3
		Erosion	50	1
		Reclamation	-740	-21
		Siltation	-750	-21

3.3.2. Changes to the number of islands

Equally as important as the changes in water area are the changes in the number of islands, as these modify the amount of shoreline and hence shallow habitat for fish and birds. A count of islands present in 1801 compared with those present in 1994 shows that there has been an overall decrease from 29 to 18, with the number of major islands being reduced from 21 to six (Figure 3.4). Up until 1928 there was also a decline in the number of small islands, but it is presumed that after this time the deposit of dredge spoil increased their number from four to 12. Between 1986 and 1994, three small islands were created near Stockton Bridge.

Figure 3.5 is a flow diagram showing the evolution of the islands of the lower Hunter River. The dashed vertical lines indicate where assumptions have been about the presence of some of the major islands (marked *) when they were not drawn or labelled on the earliest maps or charts. This figure also illustrates the way in which the names of islands or island groups have changed through time.

More specifically, what we now know as Kooragang Island was, in 1801, a group of up to 10 islands of various sizes that have since been amalgamated largely due to reclamation for industrial land (Figure 3.3). However, agricultural development and the construction of levees across the channels separating the three small, unnamed islands making up Ash Island have also contributed to the formation of Kooragang Island.

In the North Arm of the river, channels around three of the four islands (Dunns Island, Wallis Island and one unnamed island) in what was originally called the Dempster Island complex have silted up to create a more uniform shoreline at the mouth of Fullerton Cove. Today, only Smith Island remains, and is separated from the north bank of the river by a narrow channel.

3.3.3. Changes to the length of shoreline

Table 3.2 and Figure 3.6 estimate changes in shoreline length in each of the five sectors identified in Figure 3.2. Overall, there was a loss of shoreline between 1801 and 1994 of about 33 km, from an estimated 154 km to 121 km. Much of the shoreline present today has been modified by retaining walls and bank protection works (see also Kingsford and Ferster Levy 1998). The South Bank and Tomago sectors were the only places where there was little change in length of shoreline.

While the section of shoreline at Tomago/Fullerton/Stockton was similar in length in 1994 to that measured in 1801, there was a noticeable reduction from 1941 to 1954 and a steady increase thereafter (Figure 3.6). The large loss was due to 6.4 km of channel between Wallis and Dunns Islands filling in, presumably naturally. The steady increase from 1954 to 1994 was due to the creation of a number of small islands in this sector (Figure 3.5) and the digging of the channel to the Carrington Shipworks.

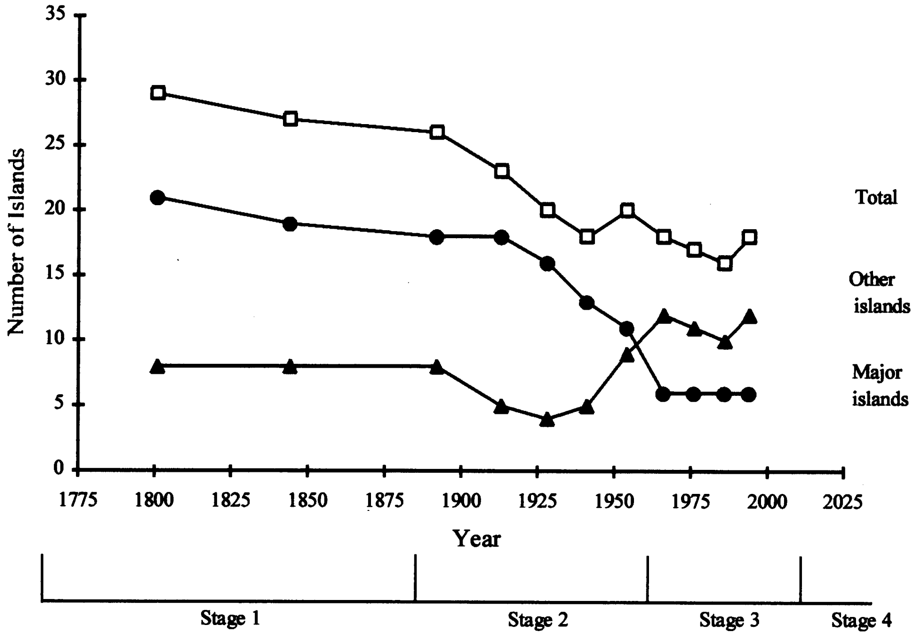


Figure 3.4. Number of islands in the lower Hunter River, 1801-1994.

Table 3.2. Summary of shoreline lengths (km) for the lower Hunter River 1801-1994

Year	South Bank	T/F/S	Throsby Creek	Eastern KI	Western KI	Total Shoreline
1801	12.0	44.6	37.2	31.9	28.1	153.8
1844	10.7	43.9	34.4	30.9	27.7	147.5
1892	10.7	42.4	34.9	31.5	27.2	146.7
1913	10.5	40.9	34.3	34.7	29.1	149.5
1928	11.3	42.1	32.5	40.8	29.4	156.0
1941	11.7	43.1	31.9	35.8	28.5	151.0
1954	12.8	36.7	26.1	36.6	26.4	138.5
1966	12.4	38.8	25.5	21.7	17.3	115.6
1976	12.5	41.6	25.5	20.0	17.4	117.0
1986	12.3	45.7	25.2	18.9	17.4	119.6
1994	12.3	46.6	25.0	19.0	17.5	120.5
Change 1801-1994	**0.3**	**2.0**	**-12.2**	**-12.9**	**-10.6**	**-33.3**

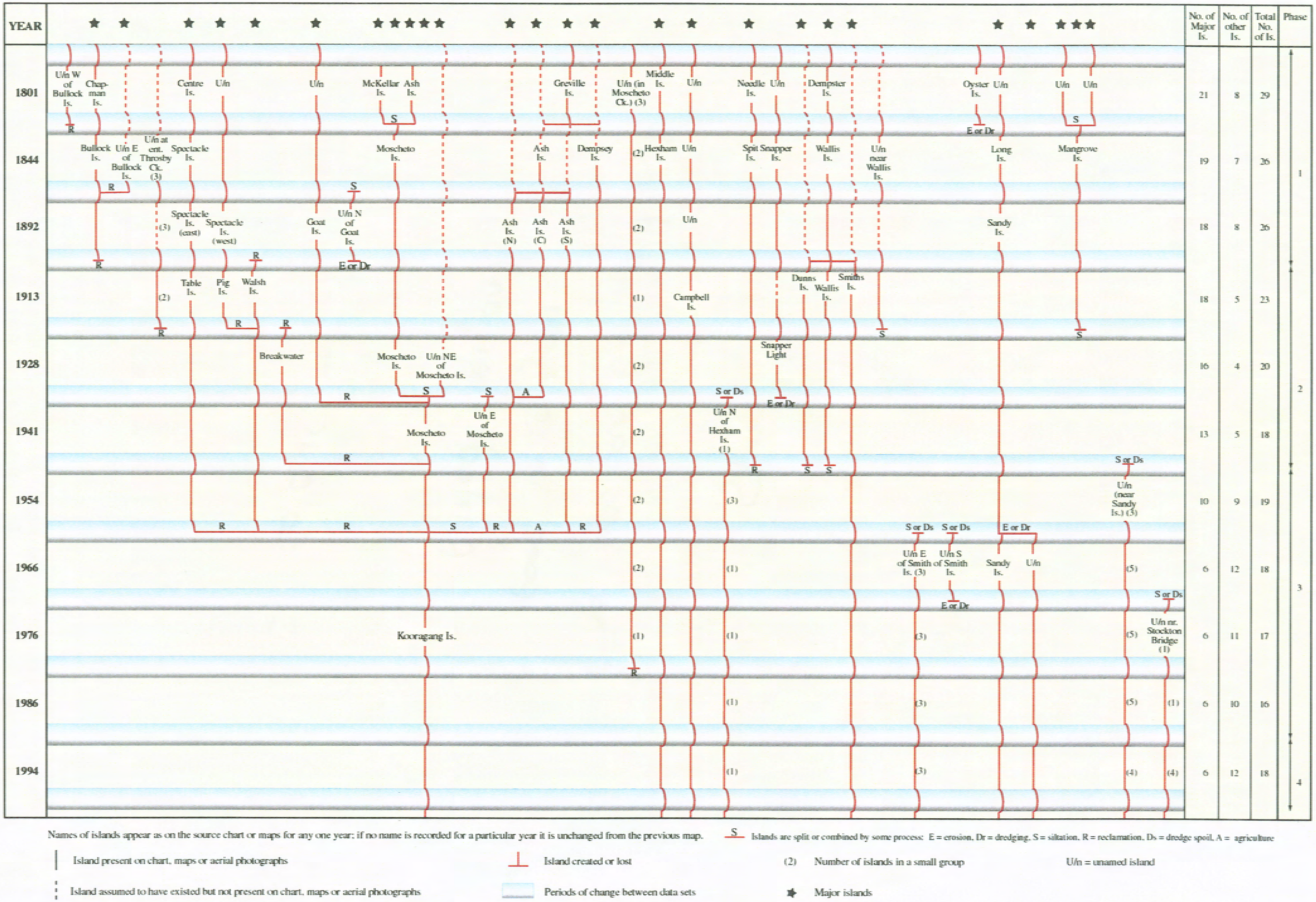


Figure 3.5. Evolution of the islands of the lower Hunter River. Phases are defined in Chapter 2.

Graphics by F.W. / J.M.

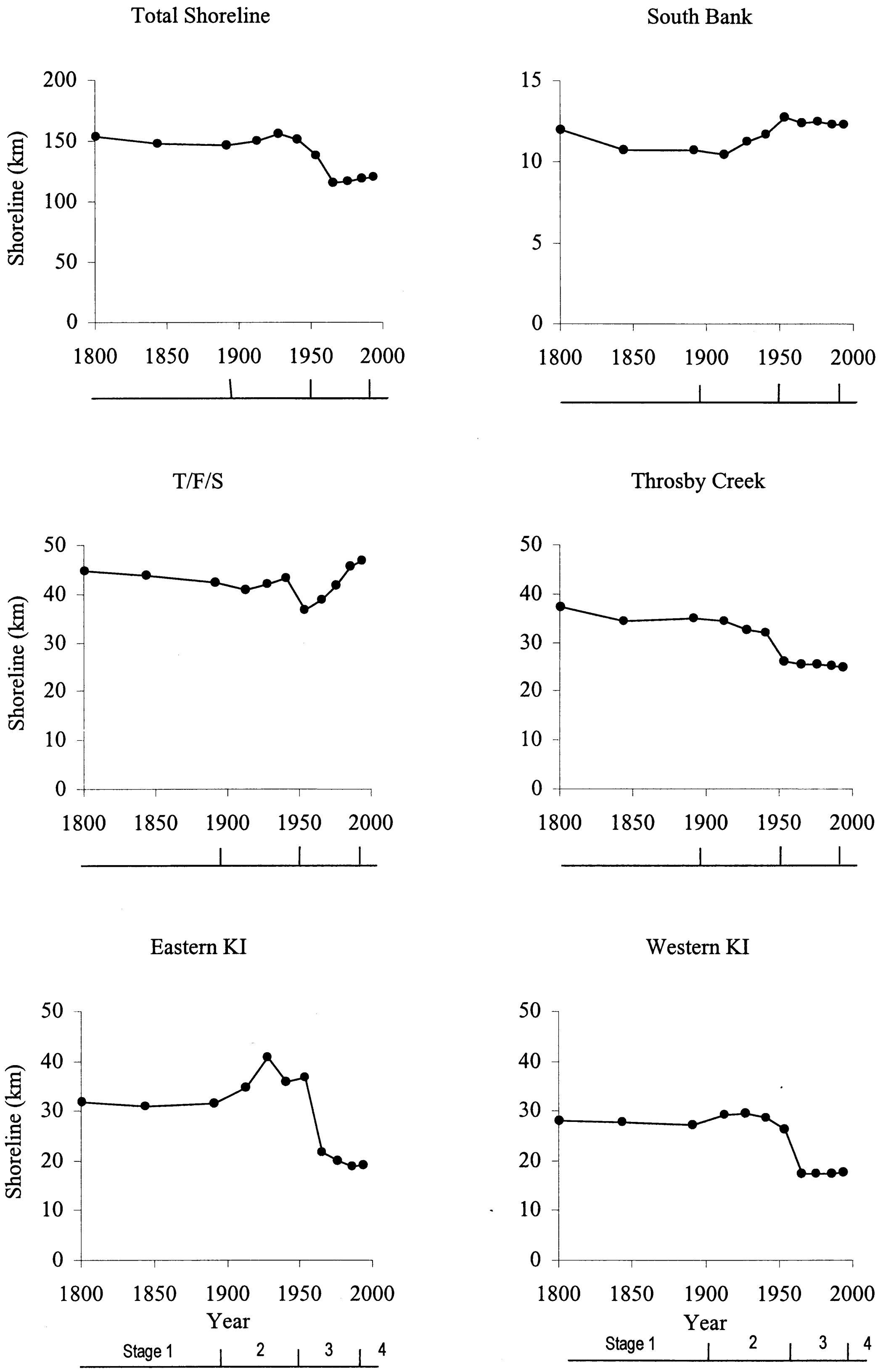


Figure 3.6. Shoreline lengths (km) for the lower Hunter River, 1801 - 1994. See Figure 3.2 for section boundaries. Calculations do not include minor creeks, drains, Ironbark Creek, Throsby Creek upstream of the railway bridge or the breakwaters at the entrance to the river due to the variation in detail present on the earlier maps.

Major changes in shoreline length occurred elsewhere. Throsby Creek (encompassing changes at Spit Island and Platts Channel) saw a loss of 12.2 km, and Eastern Kooragang Island saw a loss of 12.9 km. The loss at the latter was somewhat compensated for by the construction of the dykes (breakwaters). Western Kooragang Island saw a net loss of 10.6 km of shoreline.

Additional detail on change in the shoreline along the South Arm and close to the mouth of the river is provided in Figure 3.7. Modifications between 1844 and 1892 related to enhancement of the shipping facilities for the new settlement, including the reclamation for Nobby's Breakwater and the eastward expansion of Bullock Island. Thereafter, the changes were primarily for reclamation for industrial land, to join Bullock Island to the mainland (1892-1928) and the infilling of Platt's Channel (1928-1994).

Modification of shoreline at the eastern end of Kooragang Island was comprised mainly of reclamation that took place in three distinct stages (Figure 3.8). A large-scale operation to create Walsh Island extended from 1892 to 1928. Increases in the size of Walsh Island, as well as infilling of the channels between the other islands (Ash, Dempsey and Moscheto) occurred between 1928-1954, and again between 1954-1994. Accretion along the margins of the North Channel near the entrance to Fullerton Cove occurred between 1892-1994.

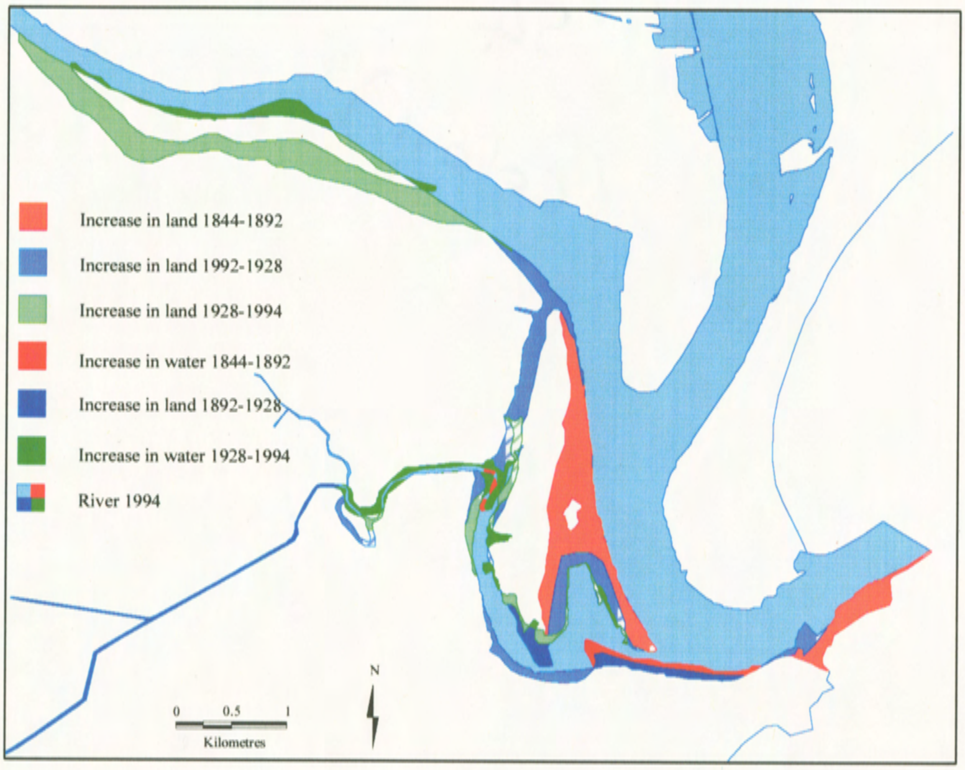


Figure 3.7. Major periods of change to the south channel, Throsby Creek and river mouth.

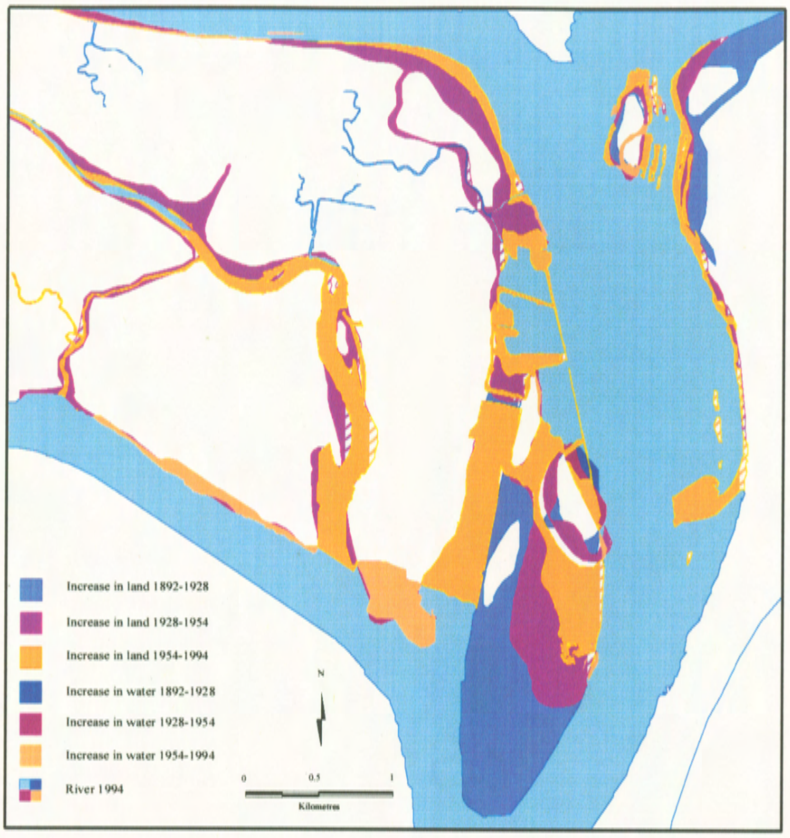


Figure 3.8. Major periods of change to eastern Kooragang Island.

3.3.4. Changes to drainage patterns: modifications to overland flow between and within sub-catchments

The construction of roads, railways and agricultural drains has had a significant impact on drainage patterns in the lower Hunter River. The map of 1844 (Appendix 2.1) shows what was presumably a wagon track from Newcastle across Throsby Creek, then across Ironbark Creek to intercept and run parallel to the South Channel to the site of the present Hexham Bridge and beyond. No other tracks appear on this map, but it is of note that in addition to Ironbark Creek, two other outflows from Hexham Swamp, both further to the north and west than Ironbark Creek, are shown. By 1892 the road network is considerably expanded, the two subsidiary outflows from Hexham Swamp are gone, and a road runs from Stockton towards Williamtown. The map of 1913 shows the Cabbage Tree Road running from the track which later became known as the Pacific Highway through Tomago to Williamtown. The Cabbage Tree Road has in many places been elevated above swampy ground. It is difficult, if not impossible, to estimate the exact nature of change in overland flow, but it seems likely these highways would have impeded overland flow during rainfall intervals. At certain other locations there may have been impact on tidal flow.

The map of 1892 also depicts the two main railway lines joined at Newcastle: the Sydney-Newcastle line and the Great Northern Railway. The former is of significance as the Newcastle Station was constructed on reclaimed land (Chapter 2). The Great Northern Railway was laid through Hexham Swamp, a feat that also would have modified water flows through the wetlands.

While there can be little doubt the early farmers constructed shallow drains to remove surface water from their holdings, the first depiction of large drains appears in the 1928 map. These are all located within the Tomago/Fullerton/Stockton section. Long Bight Swamp, east of Fullerton Cove, was intersected by three major drains (Dawson's Drain, the 14' Drain and the 10' Drain; Appendix 2.1) and a number of smaller channels. The 14' Drain is of note because it connects with Tilligerry Creek which, as a tributary of Port Stephens, would have linked flow between the latter and the Hunter River. Table 3.3 sets out the progressive evolution of the drainage lines. By the early 1970s the major ring drain and its associated floodgates were in place around Fullerton Cove.

As indicated previously, historical maps indicate that prior to the settlement of Newcastle, the western portion of Kooragang Island was a comprised of three major islands (Figure 3.9). Emanating from the original punt crossing, a network of roads had by 1994 extensively altered the natural drainage patterns, with 12 small catchments now found to the north and west of the industrial railway. Furthermore, there was no through flow in Cobbans Creek (sometimes also known as Creek 2) or Creek 3 (Figure 3.10), the two channels that once separated the three islands. Drainage within the sub-catchments was further modified in 1990 when the culvert at the mouth of Cobbans Creek was washed out (Genders 1996, and see Chapter 4), and again in 1995 when the culverts at the mouths of Creeks 1 and 5 were replaced with bridges (Streever *et al.* 1996). At Creek 5 the replacement also resulted in tidal exchange between catchments, as at high tide the water overtops the boundary of subcatchment 12 and courses into sub-catchments 11 (Creek 4 Pond) and 10 (the Swan Pond), respectively).

3.3.5. Changes to drainage patterns: installation of structures modifying tidal flow

Other major changes to fish habitat have arisen from the progressive erection of structures which impede tidal flow (Figure 3.11). These structures include water crossings (bridges, culverts and fords) for agricultural, industrial and urban requirements, and floodgates and levees intended to assist agricultural production. The first water crossings on the mainland and Kooragang Island appear in the map of 1844 (Figure 3.12), but the detail on this and subsequent maps is insufficient to differentiate the type of crossing (Table 3.3). As a result, a large number of unclassifiable structures are found on the early maps.

Table 3.3 shows the distribution of structures within the five previously identified sectors (Figure 3.2). At least 111 structures were in place in 1995; most of these were at Tomago/Fullerton/ Stockton, while the fewest number of structures occurred along the South Bank. Levees were first shown on the 1928 map and their total length had increased to an estimated 20 km by 1990. Floodgates were identifiable only after 1941.

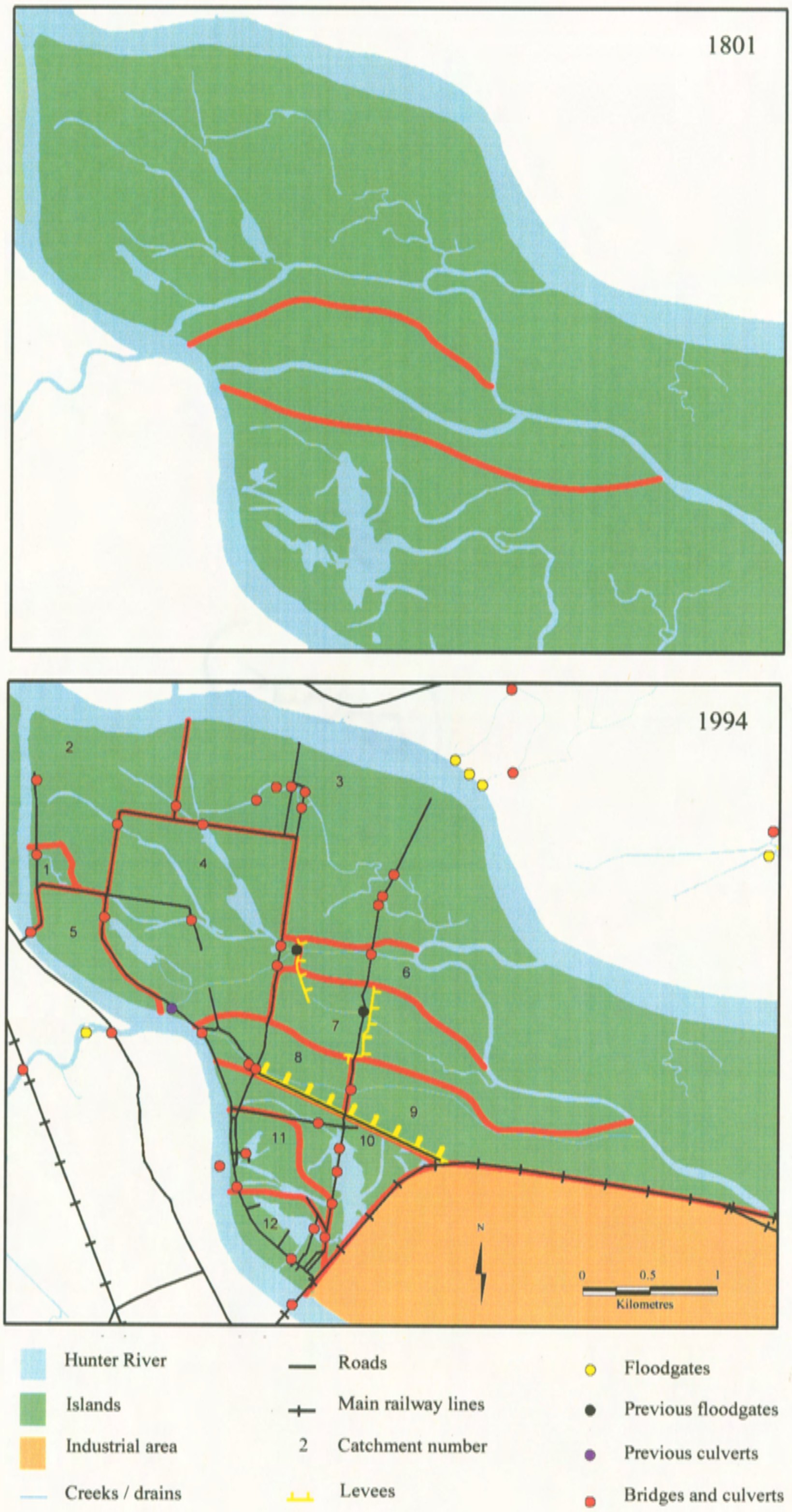


Figure 3.9. Nominal catchment boundaries on western Kooragang Island in 1801 and 1994.

Figure 3.10. Creeks affected by changes in drainage patterns on western Kooragang Island.

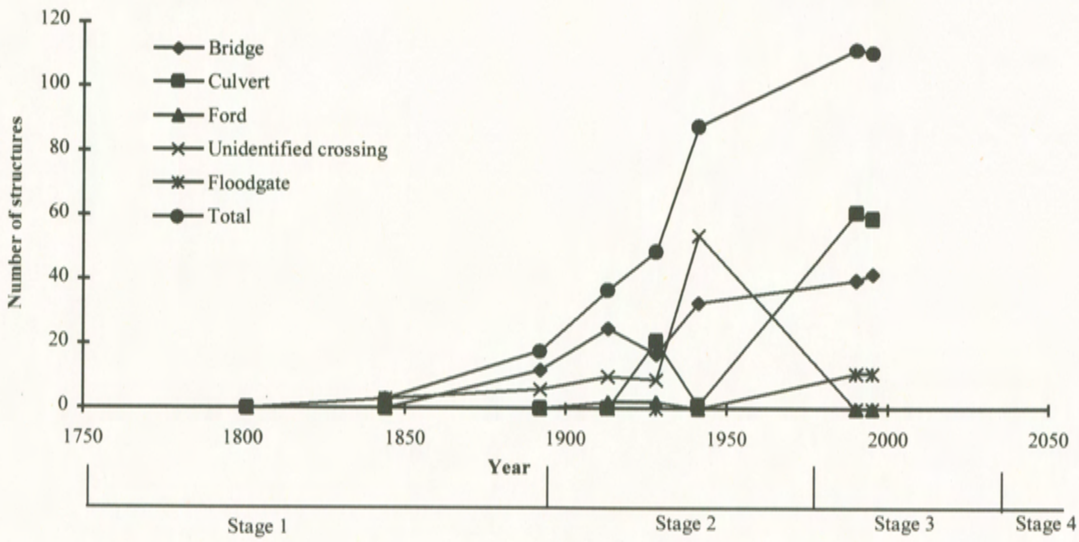


Figure 3.11. Change in the number of structures in the lower Hunter through time.

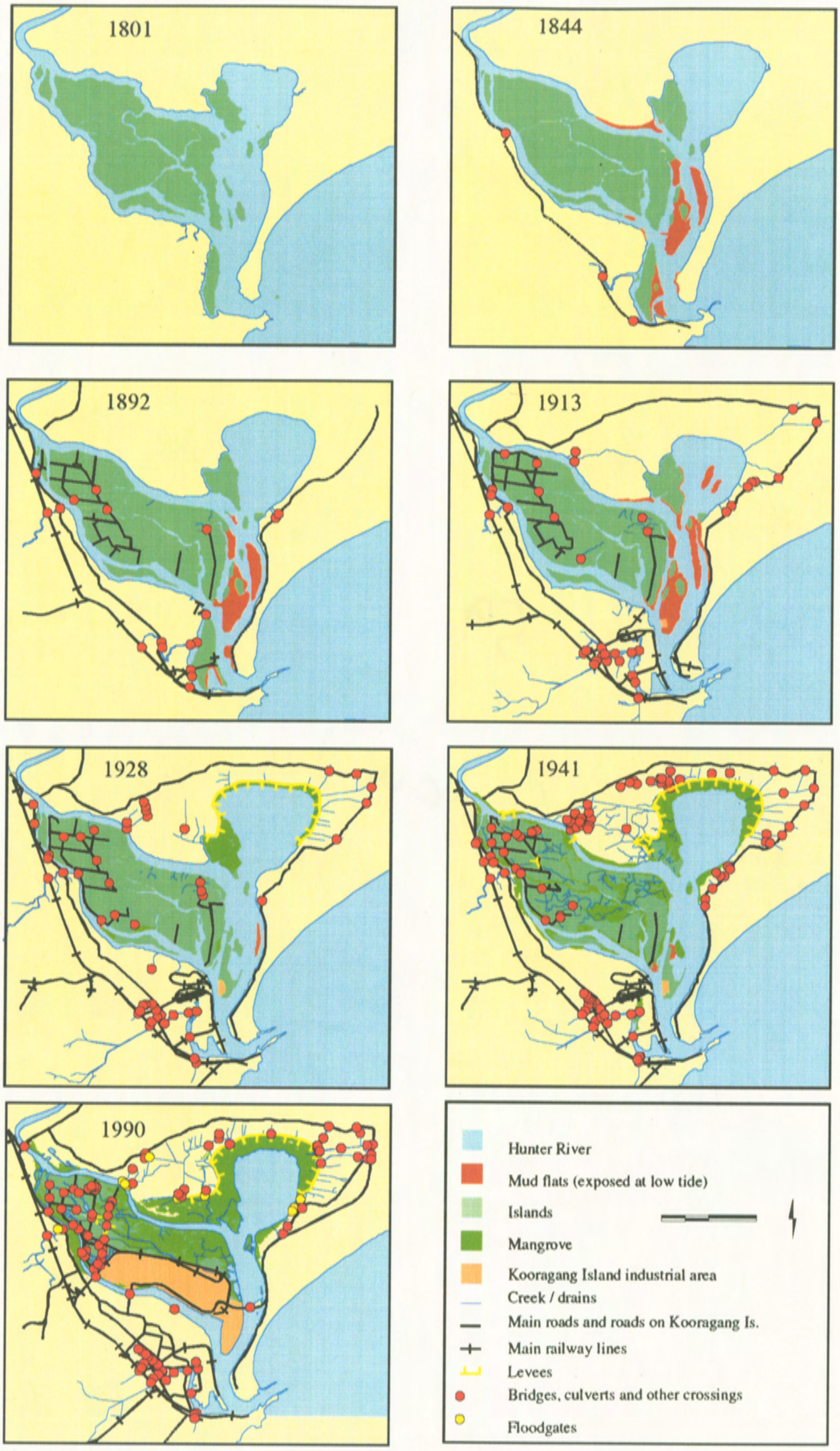


Figure 3.12. Evolution of structures in the lower Hunter River.

Table 3.3. Number of structures.

Total								
Year	Bridge	Culvert	Ford	Unidentified crossing	Floodgate	Total	Approx Length of Drains (km)	Approx Length of Levees (km)
1801	0	0	0	0	0	0	0	0
1844	0	0	0	3	0	3	0	0
1892	12	0	0	6	0	18	0	0
1913	25	0	2	10	0	37	0	0
1928	17	21	2	9	0	49	21	10
1941	33	1	0	54	0	88	57	11
1990	40	61	0	0	11	112	57	20
1995	42	59	0	0	11	111	57	20

Fullerton Stockton								
Year	Bridge	Culvert	Ford	Unidentified crossing	Floodgate	Total	Approx Length of Drains (km)	Approx Length of Levees (km)
1801	0	0	0	0	0	0	0	0
1844	0	0	0	0	0	0	0	0
1892	0	0	0	2	0	2	0	0
1913	5	0	0	5	0	10	0	0
1928	3	5	0	5	0	13	21	10
1941	40	9	0	0	0	49	40	12
1990	18	18	0	0	10	46	57	11
1995	18	18	0	0	10	46	57	11

South Bank								
Year	Bridge	Culvert	Ford	Unidentified crossing	Floodgate	Total	Approx Length of Drains (km)	Approx Length of Levees (km)
1801	0	0	0	0	0	0	0	0
1844	0	0	0	1	0	1	0	0
1892	3	0	0	0	0	3	0	0
1913	2	0	0	1	0	3	0	0
1928	1	4	0	0	0	5	0	0
1941	1	4	0	1	0	6	0	0
1990	3	0	0	0	1	4	0	0
1995	3	0	0	0	1	4	0	0

Throsby Creek (east of railway)								
Year	Bridge	Culvert	Ford	Unidentified crossing	Floodgate	Total	Approx Length of Drains (km)	Approx Length of Levees (km)
1801	0	0	0	0	0	0	0	0
1844	0	0	0	2	0	2	0	0
1892	9	0	0	0	0	9	0	0
1913	16	0	0	0	0	16	0	0
1928	11	7	0	0	0	18	0	0
1941	19	5	0	0	0	24	0	0
1990	9	15	0	0	0	24	0	0
1995	9	15	0	0	0	24	0	0

Kooragang Island (incl. bridges linked to island)								
Year	Bridge	Culvert	Ford	Unidentified crossing	Floodgate	Total	Approx Length of Drains (km)	Approx Length of Levees (km)
1801	0	0	0	0	0	0	0	0
1844	0	0	0	0	0	0	0	0
1892	0	0	0	4	0	4	0	0
1913	2	0	2	4	0	8	0	0
1928	2	5	2	4	0	13	0	0
1941	2	8	0	6	0	16	0	0
1990	10	28	0	0	0	38	0	10

3.4. Discussion

3.4.1. Overall change in land/ water area 1801-1994

The analysis of historical maps indicates there have been significant changes in the geomorphology of the lower Hunter River between 1801 and 1994. The shoreline has been extensively modified by the natural processes of erosion and accretion, but these changes have been augmented by human modifications involving large-scale reclamation. Reclamation of the complex of islands which came to be known as Kooragang Island was initiated shortly after the turn of the century with the creation of Walsh Island; and in turn the latter was joined to the eastern end of the Kooragang group. Further consolidation of the complex was achieved in the 1960s with the filling of channels between the islands. The area of the islands mapped by Barrallier in 1801 is essentially 20% smaller than at present. Other changes which have occurred over the past 200 years include the creation of small islands in the North Channel (having arisen as spoil dumps for recent dredging operations) and siltation of portions of the riverbank.

As a consequence of the change in shoreline, there have been major modifications in the aquatic habitats of the study area between 1801-1994. For example, the amount of open water area decreased from 3,570 ha to 2,240 ha (Table 3.1), while the length of shoreline decreased from 154 km to 121 km (Table 3.2). The change in shoreline was due in large part to a decrease in the number of islands from 29 to 18, with the number of large islands falling from 21 to six. The full ecological significance of the reduction of open water area is not known, but many important biological processes (e.g., photosynthesis) take place in shallow shoreline habitats. Old photographs (V. Deacon, pers. comm. 1993) show the channel around Dempsey Island to be a mixture of open shore and mangrove, and some of the lost shoreline would have been prime habitat for birds (Kingsford and Ferster Levy 1998) and fish (Gibbs *et al.* 1998). Further study of these shorelines is warranted. For example, the amount of natural shoreline should be differentiated from artificial shoreline, and the sub-elements comprising each, e.g., rock, sand and mangrove, pier, and battens should be identified. Further, the patterns of use for each habitat type should be investigated: Is the habitat nominally functional for species of aesthetic value as well as commercial importance? Does the habitat have only seasonal utility? Do some species use the habitat for only part of their life cycle?

Changes in bathymetry have also occurred, in part due to siltation but also due to major dredging of the harbour to cater for the export of coal and the import of iron ore. Upstream of the harbour the width of the river has been narrowed, initially by the eastward expansion of Walsh Island to establish the engineering works, and then by the reclamation westward from Stockton for the Stockton Bridge, at these sites significant changes in depth may occurred. Even if the bathymetry of the main channels is regularly assessed for navigation purposes, there is a need to determine depth in the backwaters. In turn, these bathymetric data need to be related to the historical investigations of Manley (1963) to track the evolution of the depth regime. Related studies might examine changes in hydrology, and disturbance to river sediments and submerged vegetation.

3.4.2. Overall change in drainage 1801-1994

Construction of a transportation network to service the Hunter Valley has played a major role in changing the wetland habitats of the lower catchment. By the early 1890s the Newcastle Railway Station (Chapter 2) and the North Coast Railway had already had some impact: the former was built on a wetland and the latter ran through Hexham Swamp. The nature of the fresh or saltwater wetland destroyed by the railway station is uncertain. Likewise, sections of the Pacific Highway running west along the South Channel and then north from the Hexham Bridge, and sections of the Tomago and Port Stephens Roads were built on reclaimed land. The railway line and roads would have modified overland flow during rainfall events.

Some of the roads in place today on Kooragang Island have evolved from the tracks shown on the map of 1844. The road network was well established on the 1892 map, interconnecting a number of properties, and was most extensive at the western end of the island, dividing what were three sub-catchments into 12 sub-catchments. The roads functioned as levee banks even if culverts were installed, and restrained overland flow (Figure 3.11).

The evolution of Cobbans Creek (catchments 4 and 6 on Figure 3.9) is a prime example of change in overland and tidal flow. Following the clearance of trees, presumably by timber gathers in the first instance, and then by the early farmers, roads would have been constructed leading to and from the original punt crossing. These roads would have interrupted runoff in normal rainfall events and may have diverted the waters of middle order floods. A.W.D. Scott, who purchased land on Kooragang Island in 1827, almost certainly would have constructed drainage works and levee banks, with the latter possibly being the predecessors of the levees which are clearly shown in the aerial photographs of 1954 (Chapter 2). There are now two levees in the catchment of Cobbans Creek, running parallel to, and to the east of, Waterpipe Road (Figure 3.9). Field inspection reveals a breach in the western levee, a breach that may have held a floodgate. Irrespective of whether a gate was there or not, the structure would have impeded tidal flow moving westward out of Moscheto Creek. Upstream of the levee, tidal range would have been substantially decreased, and downstream it would have increased. Soil salinity and wetness would have changed at both locations, leading to changes in type or extent of vegetation and ultimately the faunal communities.

As well as floodgates, other structures impeding tidal flow have been erected in the waterways of the lower Hunter Valley (Table 3.3). Each of these structures was identified in the field (Williams and Watford 1996). Unfortunately, some of these were mislabelled, and others were not shown on the maps. For example, the 1990 topographic map indicates the presence of only one floodgate (at Ironbark Creek) in the lower Hunter Valley when in fact there are at least ten others around Fullerton Cove. The "missing" floodgates are depicted as bridges or culverts, making it impossible to infer the degree of impact without field inspection. The problem of mis-identification is inherent in all historical maps, i.e., there are many instances where a road is shown intersecting a creek, but the type of crossing can not be identified. As maps are updated, it is necessary to identify structures by their primary function. In this way, the history and nature of impediments tidal flow will become more obvious.

The evolution of the catchment of Creek 1 on Kooragang Island (Figure 3.10) is also of note. Originally this creek flowed past where the schoolhouse now is and on to the South Channel of the Hunter River. Its flow was modified by a road first shown on the 1844 map. (For clarity, the lower portion of the original creek was not shown on Figure 3.10, but is included in Figure 4.7.) Changes within the catchment of Creek 1 over the ensuing years are difficult to determine because of its relatively small size and the lack of detail in some of the historical maps; but the aerial photographs of 1954 show that an entrance channel had been dug to connect its the northern extremity to the South Channel. Field inspection in late 1993 of this new channel revealed it was crossed by a road supported by a 300 mm culvert, and the tidal range upstream of the culvert was severely restricted (Williams *et al.* 1995). In July 1995 this culvert was removed and replaced by a bridge, whose span was large enough to have no impact on tidal flow (Streever 1996). In other words, within 200 years this wetland was cut off from its parent catchment, drained by a artificial channel joined to its shallow end, flushed by tides constrained by a small bore culvert, and remodified to experience full tidal flow. Substantive changes in the cover and species composition of vegetation would have followed each variation. These changes were investigated in part by MacDonald (1996).

Irrespective of the changes at Creeks 1 and 2, the largest impacts to overland and tidal flow on Kooragang Island were derived from the establishment of the industrial estate (Chapter 2), in particular due to the construction of the railway and the infilling of the channels between the islands. Because these large changes took place in the mid 1960s and can be tracked through the aerial photographic record, they are dealt with in greater detail in the next chapter.

Other than modifying the amount and distribution of wetland habitats, the implications of the suite of geomorphological changes on the fish communities of the lower Hunter River are not clear. There is no doubt that birds (Kingsford and Ferster Levy 1998) and fish (e.g., Bell and Pollard 1989, Gibbs *et al.* 1998) make extensive use of estuarine habitats. The role various types of estuarine shorelines play in determining the bird community (Kingsford and Ferster Levy 1998) is better understood than for fish. The role structures play is now coming under investigation, e.g., studies of juvenile fish reveal: a) a reduced number of species above floodgates to the east and west of Fullerton Cove compared to below the gates (Williams, unpublished data), b) an increase in number of species above culverts when replaced with bridges (Williams, unpublished data), and c) that if juvenile fish are prevented from entering the tidal creeks of the Hunter River due to floodgates, they may continue to migrate further upstream (Genders, pers. comm. 1997).

3.5. Conclusions

There has been a significant change in the landform of the estuarine portion of the lower Hunter River over the past 200 years. The amount of open water, number of islands and length of shoreline is considerably reduced relative to what it was at the arrival of the colonists in the late 1770s. Kooragang Island has seen a major change in overland flow due to modification of its sub-catchments through works initiated for transport and agricultural purposes. A large number of structures placed on the island and around Fullerton Cove have also acted to modify water flow, in particular the ebb and flood of tidal waters into the adjacent wetlands.

This attempt to create a summary of changes in wetland habitats of the lower Hunter River has met with considerable success. If it is the first attempt to deal with the historical evolution of the region's wetlands, it should not be the last; other geographical historians will add to it with the wealth of detail still hidden away.

3.6. Recommendations

1. To provide a fuller understanding of change in the estuarine portion of the Hunter River, modifications to the Hexham wetlands over the past 200 years should be assessed and integrated with the results of this study.
2. To assess the extent of change caused when overland or tidal flow is enhanced or reduced, a formal monitoring program should be initiated.
3. To confirm the loss of open water along the tidal portion of the river, Manley's (1963) investigations should be updated.

3.7. References

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Appendix 3.1 Aerial photographs used in analysis of landforms and vegetation.

Date	No. photos	Scale	Input pixel resolution (m)	Output pixel resolution (m)	RMS error (pixels)			
					Min	Max	Mean	S.E.
1954	5	1:30 000	2.5	2.5	1.1	2.2	1.6	0.2
1966	4	1:41 000	3.5	5	1.5	2.1	1.7	0.1
1976	7	1:25 000	2.1	2.5	1.4	2.2	1.9	0.1
1986	9	1:25 000	2.1	2.5	1.1	1.9	1.8	0.2
1994	6	1:25 000	2.1	2.5	1.1	2.2	1.7	0.1

4. ANALYSIS OF CHANGE IN ESTUARINE VEGETATION OF THE LOWER HUNTER RIVER, 1954-1994

4.1. Introduction

Chapter Three provides an overview of change in wetland habitats over the past 200 years for much of the estuarine portion Hunter Valley. It was prepared with old maps, the accuracy of which was limited by the technology of the day. In contrast, the availability of aerial photographs from the mid 1900s facilitates the capture of highly accurate spatial data, allowing detailed investigations of habitat and changes therein. (e.g., Lyon and McCarthy 1995).

Aerial photographs were the main source of data used in this chapter, an exercise in which the distribution and change in amount of three interrelated estuarine habitats, open water, mangrove and saltmarsh, was examined. A fourth estuarine habitat, seagrass, which is often recognised for its environmental significance (e.g., NSW Fisheries 1997), is not present in the Hunter River (Williams, unpublished data), although a small amount of *Ruppia* sp., an aquatic plant with seagrass characteristics, has been recorded (West *et al.* 1985). Anecdotal accounts (R. Hyde, pers. comm., 1999) indicate seagrass has not been present in the Hunter River for at least the past three decades. This is unusual given its presence in every other analogous river in NSW (West *et al.* 1985).

The estuarine vegetation of the Hunter River should be seen in a dynamic context. For example, an earlier exercise with historical maps (Roy 1980) documented an increase in mangrove at Fullerton Cove from 1939 to 1975, as did a study of Kooragang Island using aerial photos (Buckney 1987). Hutchings (1983) made reference to the loss of saltmarsh.

The objective of this phase of the project was to define the present boundaries of wetland vegetation in the lower Hunter River, describe their changes over the past 40 years and assess any likely reasons for changes. A geographic information system (GIS) was used.

4.2. Methods

Aerial photographs were the primary data set, but were augmented with various maps. A description of the GIS used to scan photographs, rectify images and compose mosaics is provided in Chapter Three. Data were stored as separate layers to enable the amount and direction of change in open water and wetland vegetation types to be determined through time. This analysis spans the period from 1954 (the earliest vertical aerial photographs available) to 1994 and the intervening decades (see Appendix 2.2 for details of photographs and maps). Ultimately, five aerial mosaics of the lower Hunter were produced to create map layers of wetland habitats over the last forty years: 1954, 1966, 1976, 1986 and 1994.

Water, mangrove and saltmarsh boundaries were differentiated on the scanned photographs through a combination of on screen digitising and supervised classification with the image processing software PHOTOSTYLER. Supervised classification is the process where the investigator associates a pixel value, or a range of values, measured in red, green and blue components for a true colour image, 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. Identification of vegetation boundaries was assisted by comparison with maps from Shortland Wetland Centre and the Newcastle University Research Associates (1992), Winning (1993) and Winning (1996). Verification (ground truth) of the boundaries shown on the 1994 photographs was carried out during field trips between October 1993 and March 1997. The classified images were resampled with the same ground control points used to create the photograph mosaics resulting in a raster map of the study area for each year showing the distribution of open water, mangrove and saltmarsh.

In order to add infrastructure and catchment boundaries to the GIS, a vector map for each year was created by automatically tracing the boundaries defined in each raster map with CORELTRACE and importing these files into MAPINFO, a vector based GIS. The mosaics were also imported into MAPINFO and used as the base over which the appropriate vector layer was overlain for editing and the addition of map features.
Maps of the study area showing the overall loss and gain in the distribution of open water, mangrove and saltmarsh from 1954 to 1994 were then produced in MAPINFO. Tables showing the number of hectares of each target area for each decade, and graphs giving an overview of the extent of change and the time frame within which it occurred are also presented. All calculations have been made to the nearest hectare. Analysis of change within the study area was facilitated by the delineation of the major regions identified in Chapter 3 (Figure 3.2): Tomago/Fullerton/Stockton, the South Bank and Throsby Creek. Eastern Kooragang Island and western Kooragang Island were amalgamated to form one region. Each region was further subdivided to examine change at a local level. Hexham Swamp, including Ironbark Creek, was not examined.

The surrounding transport corridors set the terrestrial boundary of each region: the Pacific Highway, New England Highway and the Main Northern Railway in the west, Tomago Road in the north and Fullerton Road in the east (e.g., Figure 4.1). To determine water area, a boundary was drawn down the centre of the adjacent channel of the river. As region boundaries were geographically referenced within the GIS, their positions remained constant for comparison between years.

Analysis of change *within* Kooragang Island was based on Areas A-E identified by Shortland Wetland Centre and the Newcastle University Research Associates (1992), but redefined as "sub-regions" A, B, C, D and E. This was done to avoid confusion with the term "area" which denotes an amount of a habitat as measured in hectares. Subregion D (Western Kooragang Island) has been divided into four zones based mainly on the internal road structure and so avoids the large number of sub-catchments identified in Chapter 3 (Figure 3.9). This simplistic approach relates to the existing management units defined by Shortland Wetland Centre and the Newcastle University Research Associates (1992).

4.3. Results

The results are presented in three sections dealing with changes to the distribution of open water, mangroves and saltmarsh. Within each section there are two tables and four figures presenting data. An overview integrates each of the sections. Figures 4.1, 4.5, and 4.9 show the subregion boundaries referred to in the text and corresponding tables.

4.3.1. Open water

At the onset it should be noted there is a discrepancy between the amount of open water in 1994 as reported in Chapter 3 (2, 240 ha) and in this chapter (2,344 ha). The discrepancy arises in the calculation process. In Chapter 3 the area of open water was determined by adding/subtracting areas of change to or from Barrallier's chart (Appendix 2.1a), whereas in this chapter the area of the habitats of interest in each set of aerial photographs was calculated separately. The chart, while of a high order of accuracy (Macqueen 1993), cannot be rectified to the same degree as an aerial photo. In either case there was a large reduction in water area.

Between 1954 and 1994 there was a reduction in the area of open water habitat of the lower Hunter River from 2,688 ha to 2,344 ha, a loss of about 344 ha (13%; Table 4.1a). Loss of open water was seen at each of the sub-regions (Kooragang Island, Tomago/Fullerton Cove/Stockton, Throsby Creek and South Bank).

The largest loss, 153 ha, occurred in and around Kooragang Island (Table 4.1b), from 750 ha to 597 ha. That is, one fifth of the open water area found in 1954 was gone from this region by 1994. The largest change in the Kooragang region was in the Industrial Zone (A), where 114 ha of open water was lost. Another substantial amount (28 ha) was lost in the southern part of the Kooragang Nature Reserve (B), while a large percentage (33%) of open water was lost in the central portion of the island (C).

The Tomago/Fullerton/Stockton region (Table 4.1c) experienced a net loss of 114 ha (8%). Within this region 117 ha were lost from the northern section of the Nature Reserve, whereas gains nearly equalled losses at four other sites. The largest gain came about when the channel and turning basin were dug for the Carrington Shipyards (Tomago west subregion).

There was a small loss in the area of open water along the South Bank (6 ha, or 9%, Table 4.1d), but at Throsby Creek 71 ha (17%) of the open water area disappeared (Table 4.1e).

Figure 4.1 illustrates the net loss and gain of open water area. Figure 4.2 indicates the temporal framework in which these changes occurred. The large losses at the industrial zone on Kooragang Island (Figure 4.2b) and at Throsby Creek (Figure 4.2d) occurred over the relatively short span of time from 1954 to 1966. The change that took place at the Nature Reserve (north) (Figure 4.2c) was over a slightly longer time frame (1954 to 1976).

The amount of open water at the western end of Kooragang Island (Figure 4.3), the location of a number of study sites within the KWRP (e.g., MacDonald 1996, Genders 1996), showed a decrease from 99 ha to 92 ha (Table 4.2). There was a long-term increase in open water at two sites: D2 due to foreshore erosion and D4 when the culvert at the mouth of Creek 2 was washed out in 1990 (Genders 1996). Long-term decreases were seen at the three other sites, in large part due to growth of mangrove along the northern shore of the South Channel. The largest loss in open water occurred between 1966 and 1976 but an increase was seen from 1986 to 1994 (Figure 4.4).

4.3.2. Mangrove

The area of mangrove in the lower Hunter River increased from 1310 ha in 1954 to 1711 ha in 1994, i.e., by about 400 ha (Table 4.3a). Three of the four regions, Kooragang Island, Tomago/Fullerton/Stockton and the South Bank, showed increases in mangrove area of 105 ha, 311 ha and 25 ha, respectively. There was a loss of 40 ha (94 %) in Throsby Creek. The net result of changes within the four regions was an overall increase in area of mangrove of 31%.

Loss of mangrove on Kooragang Island occurred only in the Industrial Zone (A) (Table 4.3b). The amount which disappeared was large (219 ha), but it was outweighed by the gain at the Nature Reserve (B), and the other three zones in the region. There was an increase of 20% in the area of mangrove on Kooragang Island from 1954 to 1994.

The gains at Tomago/Fullerton/Stockton occurred primarily in the northern portion of the Nature Reserve (260 ha, Table 4.3c), but also at two other sites. The loss that occurred at the two remaining sub-regions was negligible.

The largest change along the South Bank was at Sandgate, which gained 15 ha of mangrove (Table 4.3d). Throsby Creek was notable for the 40 ha (94%) loss experienced there (Table 4.3e).

Table 4.1. Change in area (ha) of open water in the lower Hunter, 1954 -1994.

(a) Summary

Lower Hunter	1954	1966	1976	1986	1994	Change (ha)	Change (%)
Kooragang Island	750	644	627	585	597	-153	-20
Tomago/Fullerton/Stockton	1452	1390	1334	1349	1338	-114	-8
South Bank	66	61	58	58	60	-6	-9
Throsby Creek	420	359	347	347	349	-71	-17
Total	2688	2453	2365	2339	2344	-344	-13

(b) Kooragang Island

	Subregion*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
A	Industrial Zone	341	251	259	218	227	-114	-33
B	Nature Reserve (south)	295	280	266	269	267	-28	-9
C	Central Kooragang Island	15	14	13	11	10	-5	-33
D	Western Kooragang Island	58	58	54	54	58	0	-1
E	Experimental Zone	41	40	35	33	35	-6	-15
	Subtotal	750	644	627	585	597	-153	-20

(c) Tomago/Fullerton/Stockton

Subregion*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
Tomago west	56	56	56	66	67	10	18
Tomago east	44	43	41	37	39	-5	-12
Nature Reserve (north)	1139	1084	1034	1039	1022	-117	-10
Fullerton	8	9	9	12	12	4	43
Stockton	204	198	194	195	198	-6	-3
Subtotal	1452	1390	1334	1349	1338	-114	-8

(d) South Bank

Subregion*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
North west region	29	26	25	26	26	-3	-9
Hexham Island	19	17	15	15	15	-4	-21
Sandgate	18	18	17	17	19	1	5
Subtotal	66	61	58	58	60	-6	-9

(e) Throsby Creek

Subregion*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
Throsby Creek	420	359	347	347	349	-71	-17

* see figure 4.1 for region and subregion boundaries

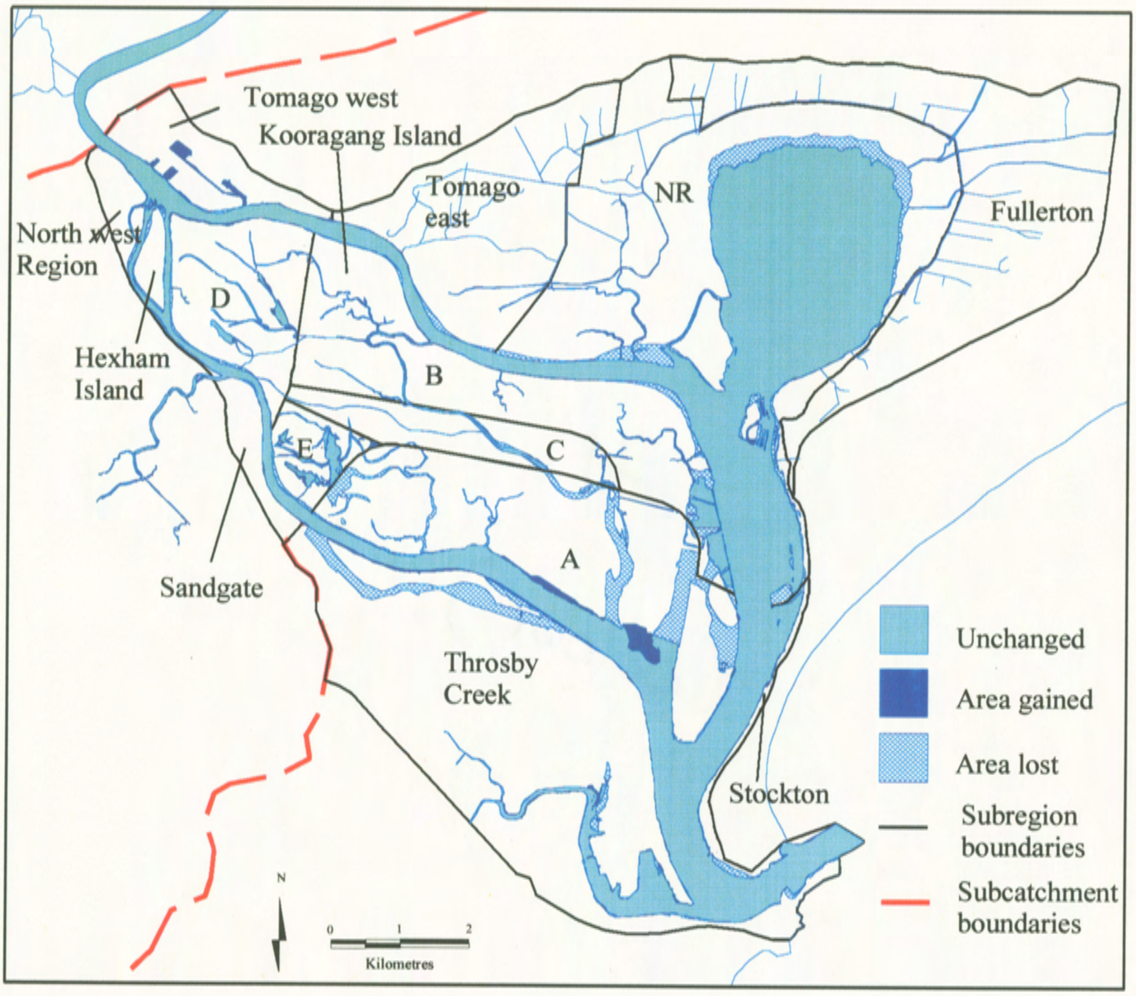
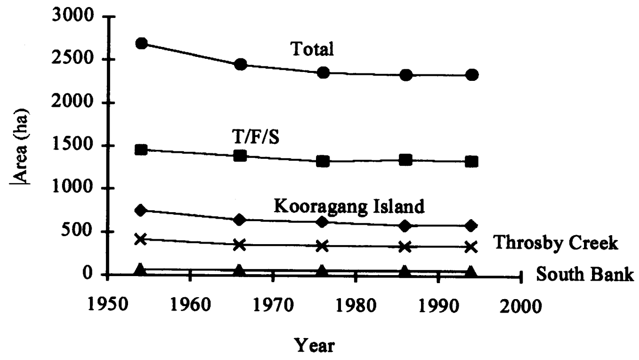
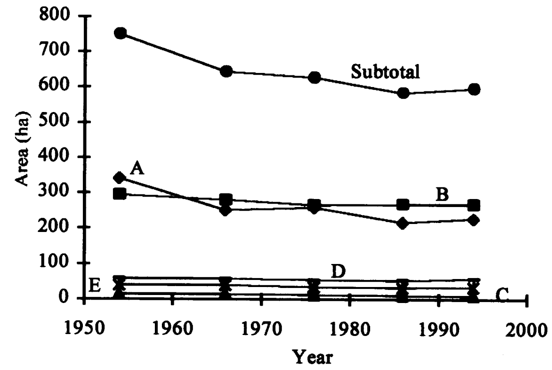


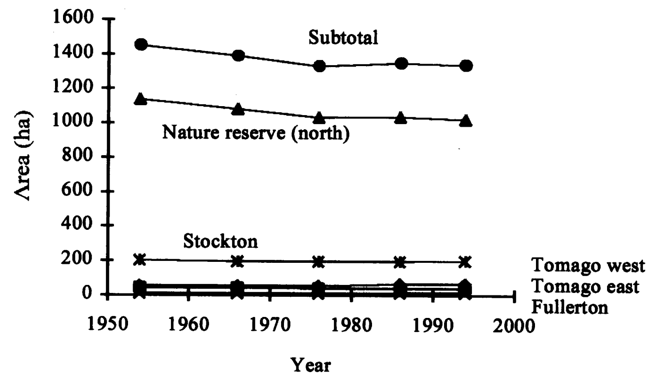
Figure 4.1. Change in open water area of the lower Hunter River, 1954-1994. Sub-regions A-E are those shown by Shortland Wetlands Centre and The Newcastle University Research Associates (1992): A = Industrial Zone, B = Kooragang Nature Reserve (south), C = Central Kooragang Island, D = Western Kooragang Island, E = Experimental Zone. NR = Kooragang Nature Reserve (north).



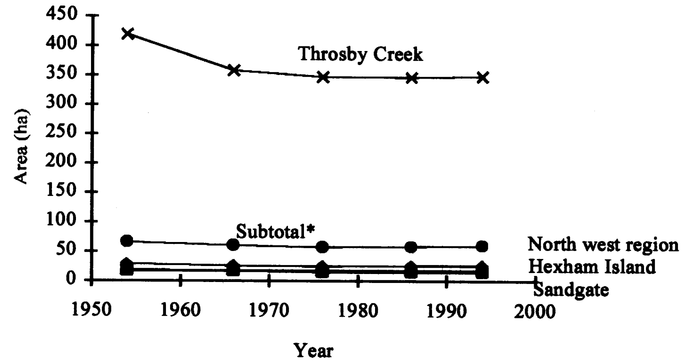
(a) Summary for the Lower Hunter



(b) Kooragang Island



(c) Tomago/Fullerton/Stockton (T/F/S)



(d) South Bank and Throsby Creek
*Subtotal is for the South Bank region only

Figure 4.2. Change in area (ha) of open water in the lower Hunter, 1954-1994.

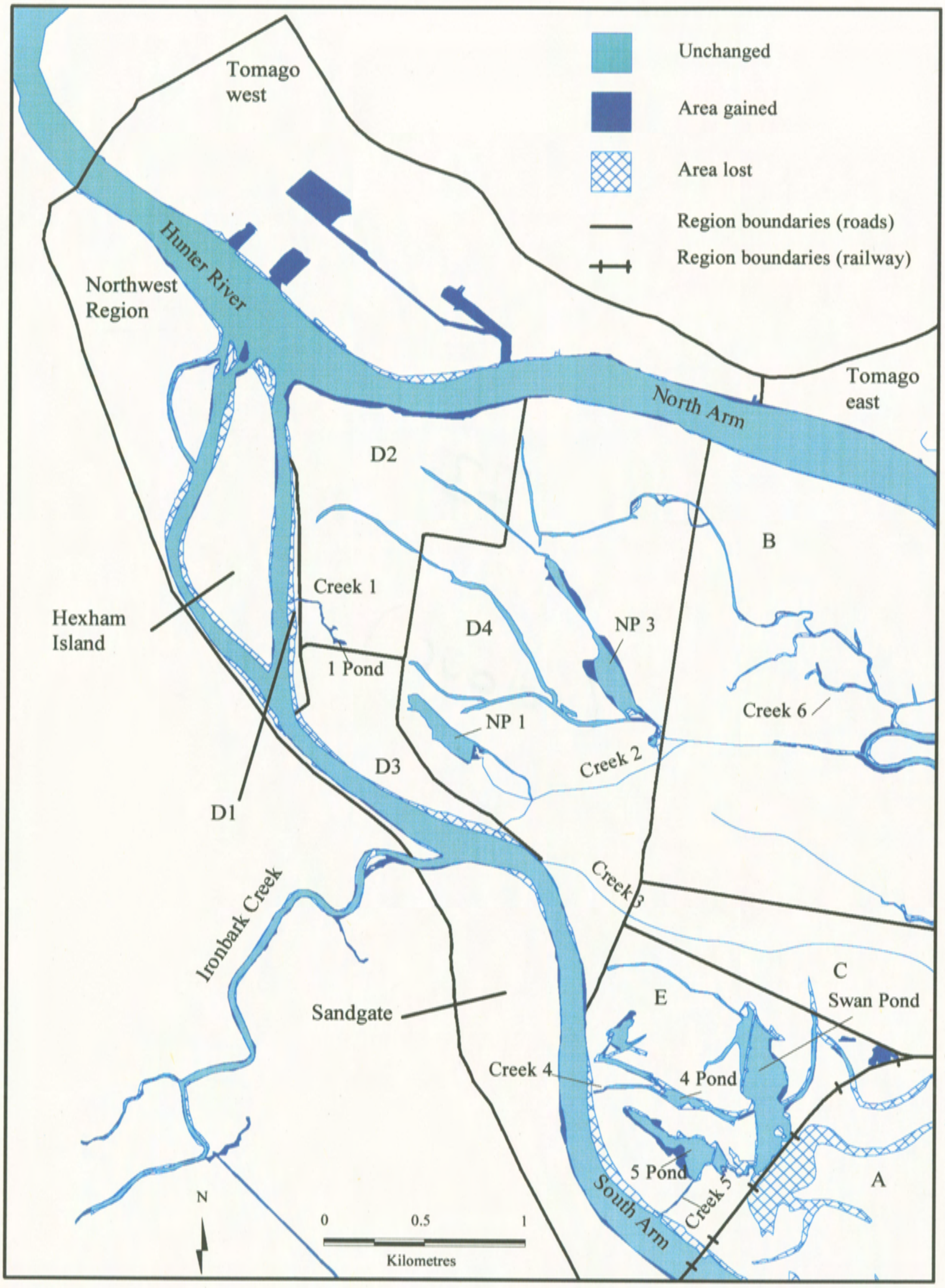


Figure 4.3. Change in the extent of open water on western Kooragang Island, 1954-1994. Sub-regions A-E are as for Figure 4.1 with western Kooragang Island (D) further subdivided.

Table 4.2. Change in area (ha) of open water for zones within western Kooragang Island, 1954 - 1994.

Zone*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
D1	7	6	5	5	5	-3	-37
D2	7	7	8	8	10	3	43
D3	13	13	10	10	10	-3	-22
D4	31	30	30	30	33	2	7
E	41	40	35	33	35	-6	-15
Total	99	98	89	87	92	-7	-7

* see figure 4.3 for zone boundaries

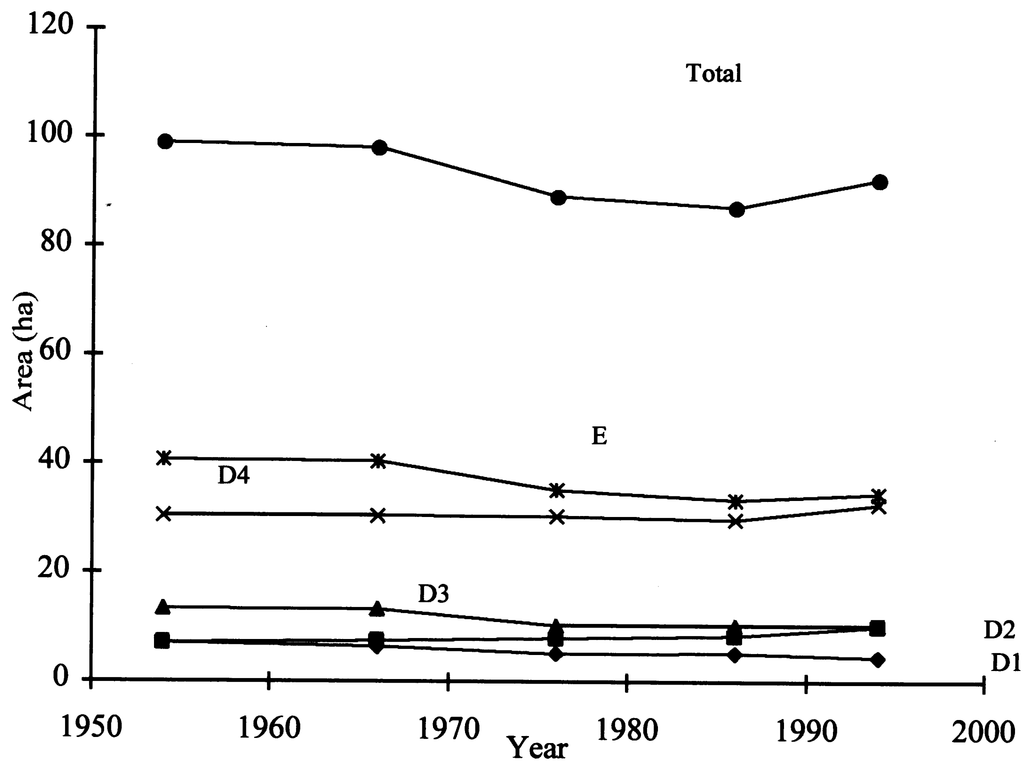


Figure 4.4. Change in area (ha) of open water for zones within western Kooragang Island, 1954 - 1994.

Table 4.3. Change in area (ha) of mangrove in the lower Hunter, 1954 - 1994.

(a) Summary

Lower Hunter	1954	1966	1976	1986	1994	Change (ha)	Change (%)
Kooragang Island	532	647	555	562	636	105	20
Tomago/Fullerton/Stockton	675	796	894	913	986	311	46
South Bank	61	72	81	82	85	25	41
Throsby Creek	43	25	4	1	3	-40	-94
Total	1310	1541	1534	1559	1711	400	31

(b) Kooragang Island

	Subregion*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
A	Industrial Zone	230	226	37	7	11	-219	-95
B	Nature Reserve (south)	201	285	363	380	434	233	116
C	Central Kooragang Island	72	100	113	132	141	69	96
D	Western Kooragang Island	24	30	36	36	41	17	69
E	Experimental Zone	5	5	6	7	10	5	102
	Subtotal	532	647	555	562	636	105	20

(c) Tomago/Fullerton/Stockton

Subregion*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
Tomago west	25	24	26	26	32	7	29
Tomago east	27	37	47	60	73	45	166
Nature Reserve (north)	619	730	817	823	878	260	42
Fullerton	1	2	2	1	0	-1	-82
Stockton	3	3	2	3	3	0	-7
Subtotal	675	796	894	913	986	311	46

(d) South Bank

Subregion*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
Northwest region	11	14	12	12	13	2	19
Hexham Island	6	6	10	11	13	8	138
Sandgate	45	53	59	59	60	15	33
Subtotal	61	72	81	82	85	25	41

(e) Throsby Creek

Subregion*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
Throsby Creek	43	25	4	1	3	-40	-94

* see figure 4.5 for region and subregion boundaries

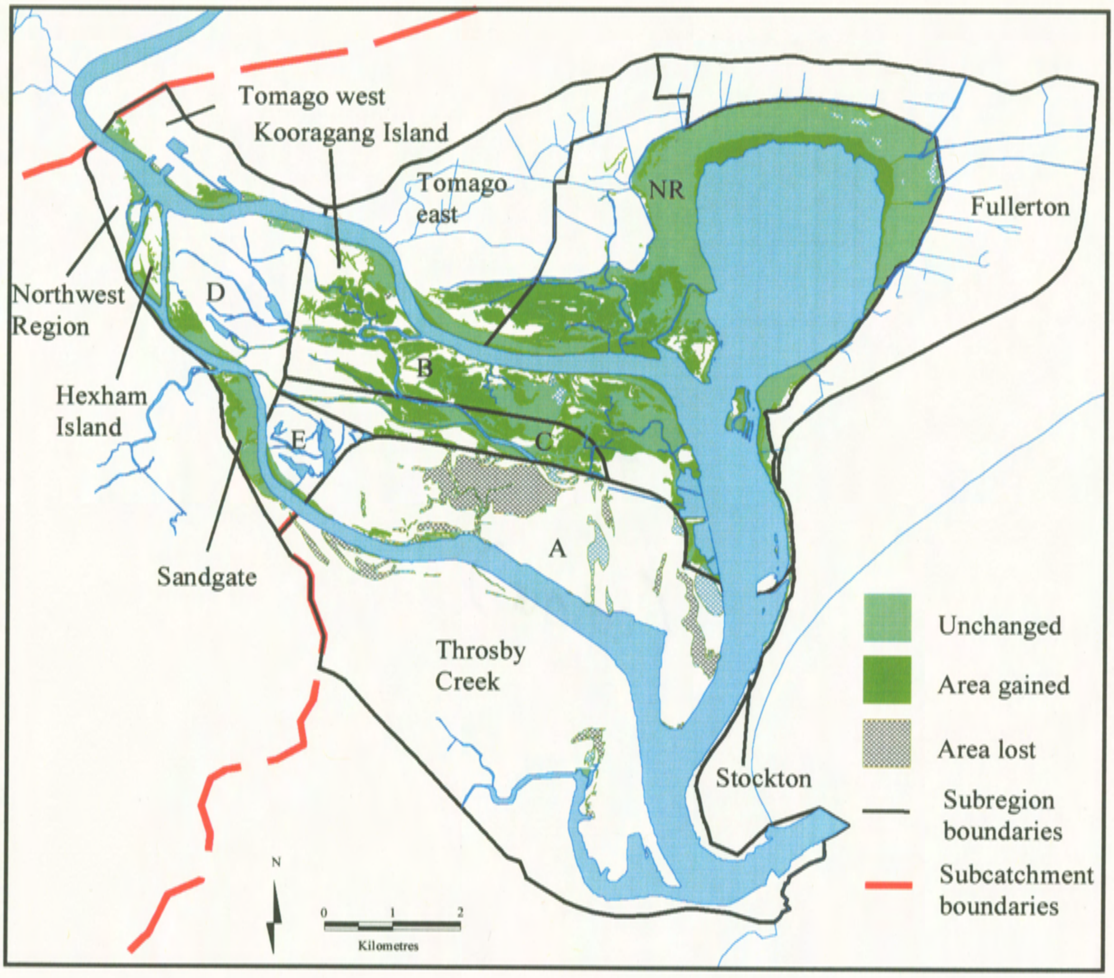
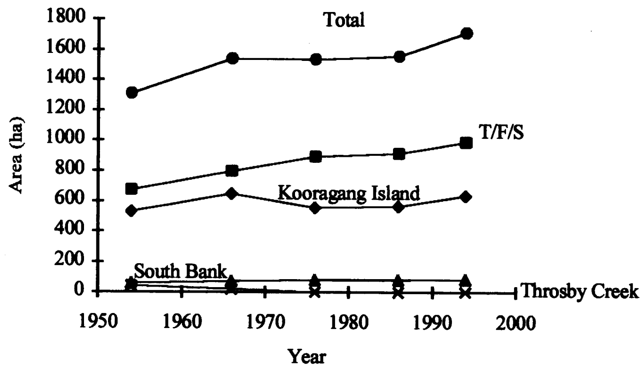
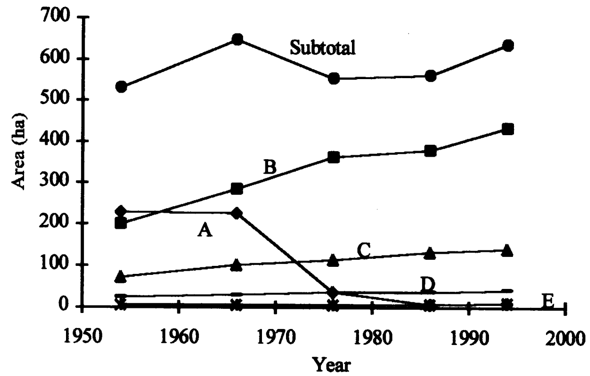


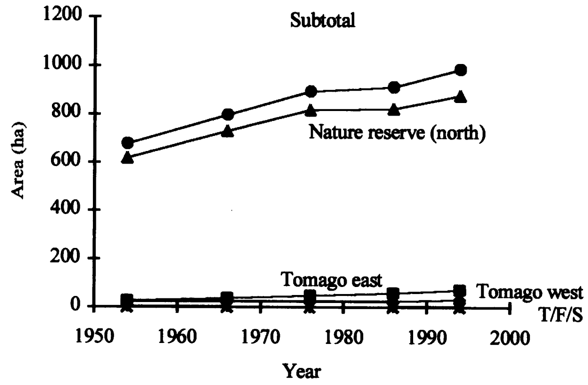
Figure 4.5. Change in the distribution of mangroves in the lower Hunter River, 1954-1994. Sub-regions A-E are those shown by Shortland Wetlands Centre and The Newcastle University Research Associates (1992): A = Industrial Zone, B = Kooragang Nature Reserve (south), C = Central Kooragang Island, D = Western Kooragang Island, E = Experimental Zone. NR = Kooragang Nature Reserve (north).



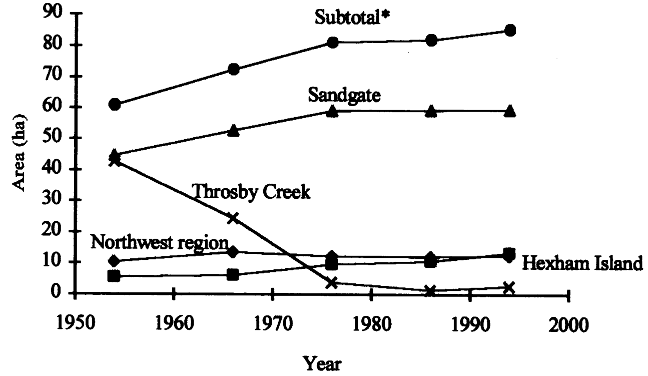
(a) Summary for the Lower Hunter



(b) Kooragang Island



(c) Tomago/Fullerton/Stockton (T/F/S)



(d) South Bank and Throsby Creek
*Subtotal is for the South Bank region only

Figure 4.6. Change in area (ha) of mangrove in the lower Hunter, 1954-1994.

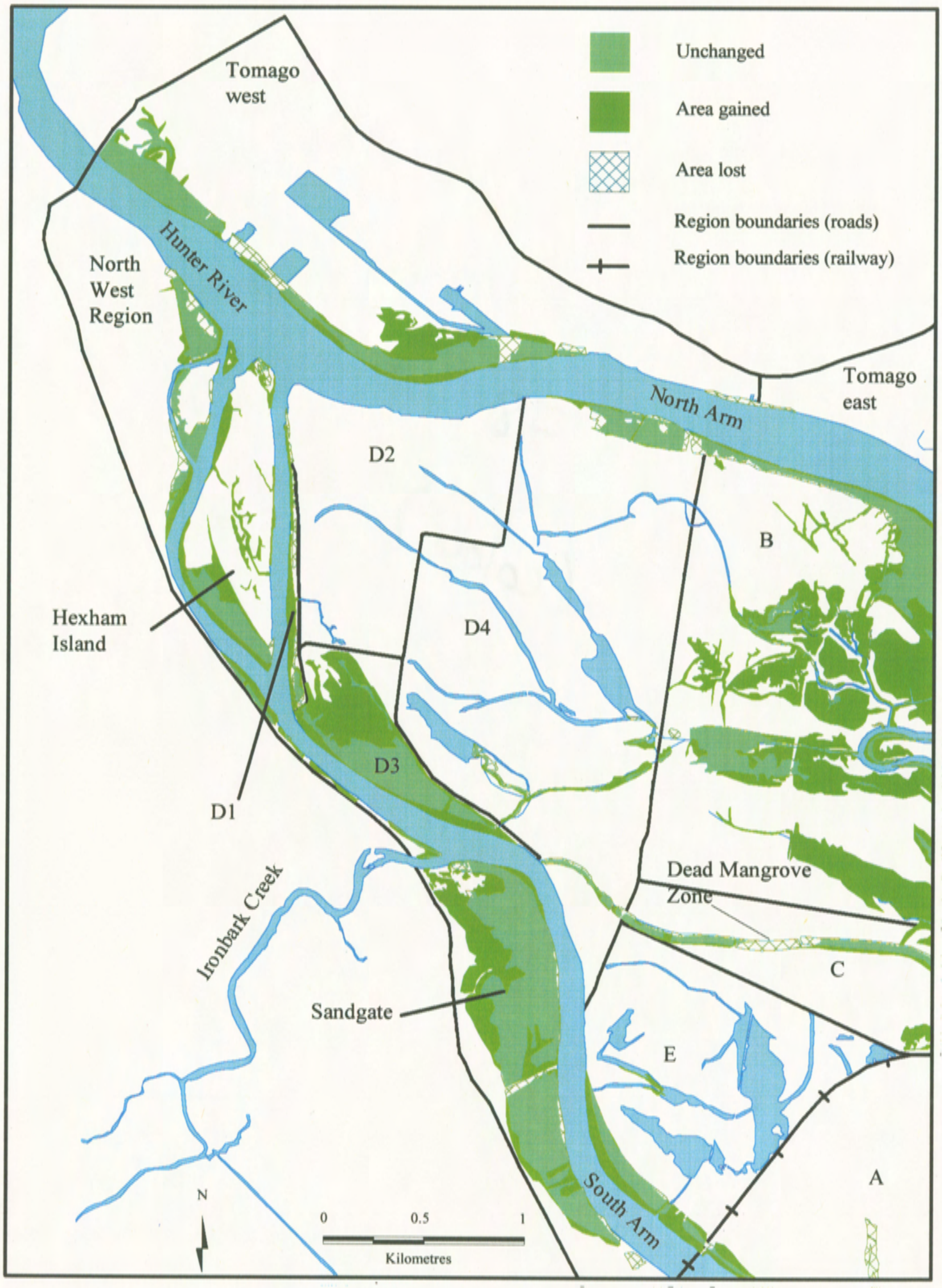


Figure 4.7. Change in the distribution of mangroves on western Kooragang Island, 1954-1994. Sub-regions A-E are as for Figure 4.5 with western Kooragang Island (D) further subdivided.

Table 4.4. Change in area (ha) of mangrove for zones within western Kooragang Island, 1954 - 1994.

Zone*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
D1	1	2	2	2	3	2	118
D2	0	0	0	0	0	0	-100
D3	13	17	24	24	28	16	127
D4	10	11	10	10	10	-1	-6
E	5	5	6	7	10	5	102
Total	29	36	42	44	51	22	74

* see figure 4.7 for zone boundaries

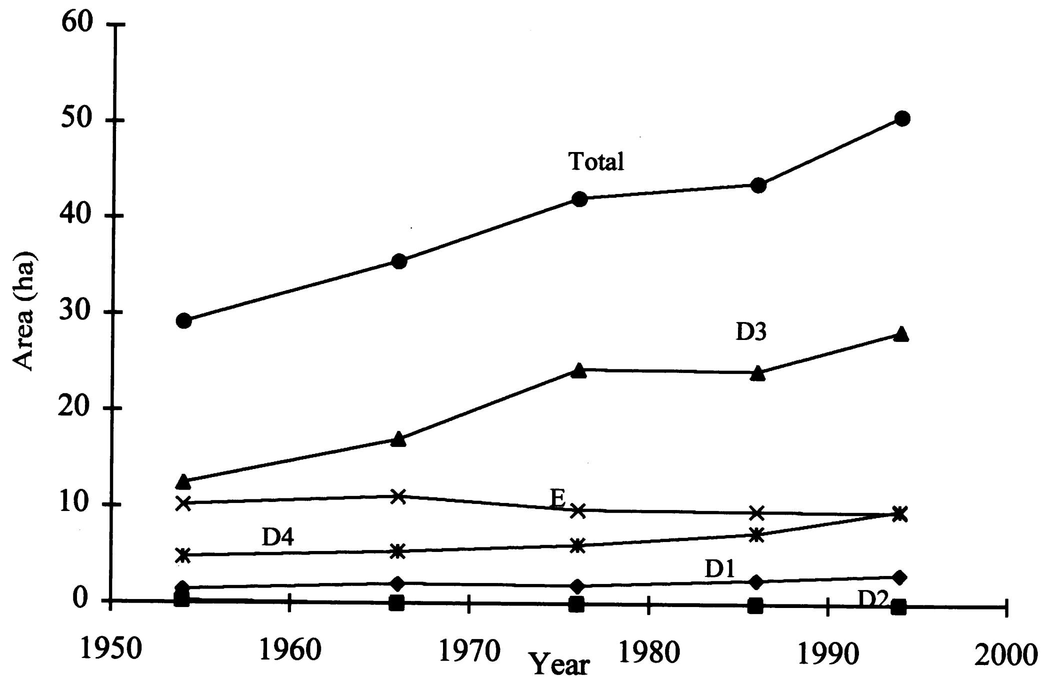


Figure 4.8. Change in area (ha) of mangrove for zones within western Kooragang Island, 1954 - 1994.

The net change in the area of mangrove is shown in Figure 4.5. The expansion into Fullerton Cove, and along both sides of the North Arm, is readily observed. Some of the loss within the Industrial Zone (A) was around the western, northern and eastern shore of Dempsey Island, a consequence of its reclamation.

Figure 4.6 indicates the temporal framework in which these changes occurred. Two periods of substantive increase were seen, the first between 1954 and 1966, and the other between 1986 and 1994 (Figure 4.6a). Both these periods of increase in mangrove are seen at Kooragang Island, where there is a decrease in the intervening years (Figure 4.6b) brought on by reclamation of land at the industrial area. The increase from 1986 to 1994 was due in large measure to advancement of mangrove in the southern part of the nature reserve. The Tomago/Fullerton/Stockton region shows continuous increase (Figure 4.6c), as does the South Bank (Figure 4.6d). The mangroves of Throsby Creek were effectively cleared by the mid 1970s (Figure 4.6d).

Figure 4.7 shows the situation on western portion of Kooragang Island, where from 1954 mangrove moved into the North and South Channels, as well as upslope (e.g., at D3 and B). A doubling in area took place at site D3 between 1954 and 1994, from 13 ha to 28 ha, and smaller increases occurred at sites D1 and E. Even though gains at the latter two sites were small in absolute amounts, they were large in relative terms. Sites D2 and D3 showed no change (Table 4.4, Figure 4.8).

4.3.3. Saltmarsh

The area of saltmarsh within the lower Hunter River decreased by 1,428 ha (67%) between 1954 and 1994 (Table 4.5a). Decrease occurred in each of the four major regions by amounts ranging from 55% to 100% of the area present in 1954. The largest loss was at Tomago/Fullerton/Stockton (871 ha, 78%), followed by Kooragang Island (508 ha, 55%; Table 4.5b, c). Eighteen ha were lost from the South Bank and all of the 31 ha of saltmarsh present in the Throsby Creek in 1954 was lost by 1976.

On Kooragang Island, loss of saltmarsh was seen at four of the five sub-regions. Virtually all saltmarsh was lost in the Industrial Zone (233 ha, Table 4.5b), coupled with other large losses (205 ha and 74 ha), in the Nature Reserve (B) and in Central Kooragang Island (C), respectively. The only site in the lower Hunter where any increase in saltmarsh occurred was at Western Kooragang Island (D), and this was of 12 ha.

The losses at Tomago/Fullerton/Stockton occurred primarily within the Nature Reserve (403 ha), but also in the Fullerton subregion (260 ha), and at Tomago east (207 ha, Table 4.5c). The largest change along the South Bank was at Sandgate (19 ha, 91%; Table 4.5d). All saltmarsh at Throsby Creek (31 ha, Table 4.5e) completely disappeared.

The losses for the lower Hunter River were widely distributed, being seen around Fullerton Cove and across the breadth of Kooragang Island (Figure 4.9). The locations where large areas remain unchanged from 1954 to 1994 are scattered around Fullerton Cove and in Kooragang Island sub-regions B, C and E.

Figure 4.10 sets out the temporal framework in which these changes occurred. Decrease took place steadily from 1954 in each of the three major regions (Figure 4.10a), but in recent years has levelled off on Kooragang Island (Figure 4.10b). It should be noted that the Industrial Zone has been essentially devoid of saltmarsh since the mid 1980s. The decrease at Tomago/ Fullerton/ Stockton was continuous from 1966 to 1994, even in the Nature Reserve (Figure 4.10c, Figure 4.10c).. The saltmarsh at Throsby was gone by 1976. Along the South Bank there was loss at Sandgate but a static situation at Hexham Island (Figure 4.10d).

Figure 4.11 shows change at the western side of Kooragang Island. There was a small net increase in saltmarsh area (4 ha), which hides the fact that losses occurring at three of the five sites were offset by the major gain (19 ha) at D4 between 1986 and 1994 (Table 4.6, Figure 4.12). Some of the increase in range of saltmarsh was upslope of its distribution in 1954. No saltmarsh was identified in area D1 in any year.

Table 4.5. Change in area (ha) of saltmarsh in the lower Hunter, 1954 -1994.

(a) Summary

Lower Hunter	1954	1966	1976	1986	1994	Change (ha)	Change (%)
Kooragang Island	930	693	553	440	422	-508	-55
Tomago/Fullerton/Stockton	1121	1064	841	619	250	-871	-78
South Bank	51	36	35	40	34	-18	-35
Throsby Creek	31	11	0	0	0	-31	-100
Total	2133	1803	1429	1099	705	-1428	-67

(b) Kooragang Island

Subregion*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
A Industrial Zone	234	139	83	1	1	-233	-100
B Nature Reserve (south)	433	333	264	249	228	-205	-47
C Central Kooragang Island	152	114	95	78	78	-74	-49
D Western Kooragang Island	41	35	38	41	53	12	28
E Experimental Zone	69	71	73	71	62	-8	-11
Subtotal	930	693	553	440	422	-508	-55

(c) Tomago/Fullerton/Stockton

Subregion*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
Tomago west	32	45	43	36	30	-2	-7
Tomago east	239	228	200	140	32	-207	-87
Nature Reserve (north)	514	455	403	333	111	-403	-78
Fullerton	337	336	195	111	77	-260	-77
Stockton	0	0	0	0	0	0	0
Subtotal	1121	1064	841	619	250	-871	-78

(d) South Bank

Subregion*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
Northwest region	6	3	8	7	6	0	-3
Hexham Island	25	21	21	28	26	1	6
Sandgate	21	12	5	5	2	-19	-91
Subtotal	51	36	35	40	34	-18	-35

(e) Throsby Creek

Subregion*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
Throsby Creek	31	11	0	0	0	-31	-100

* see figure 4.9 for region and subregion boundaries

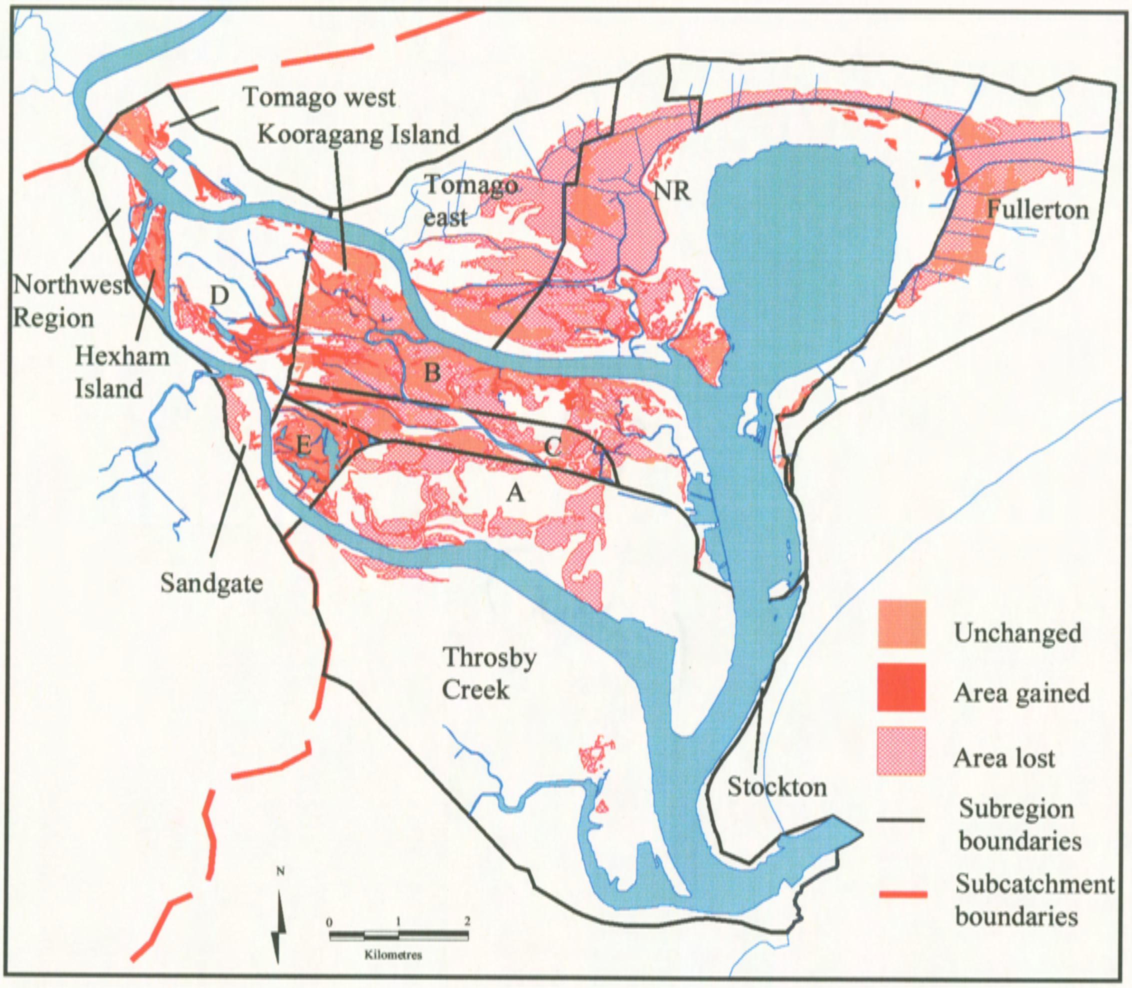
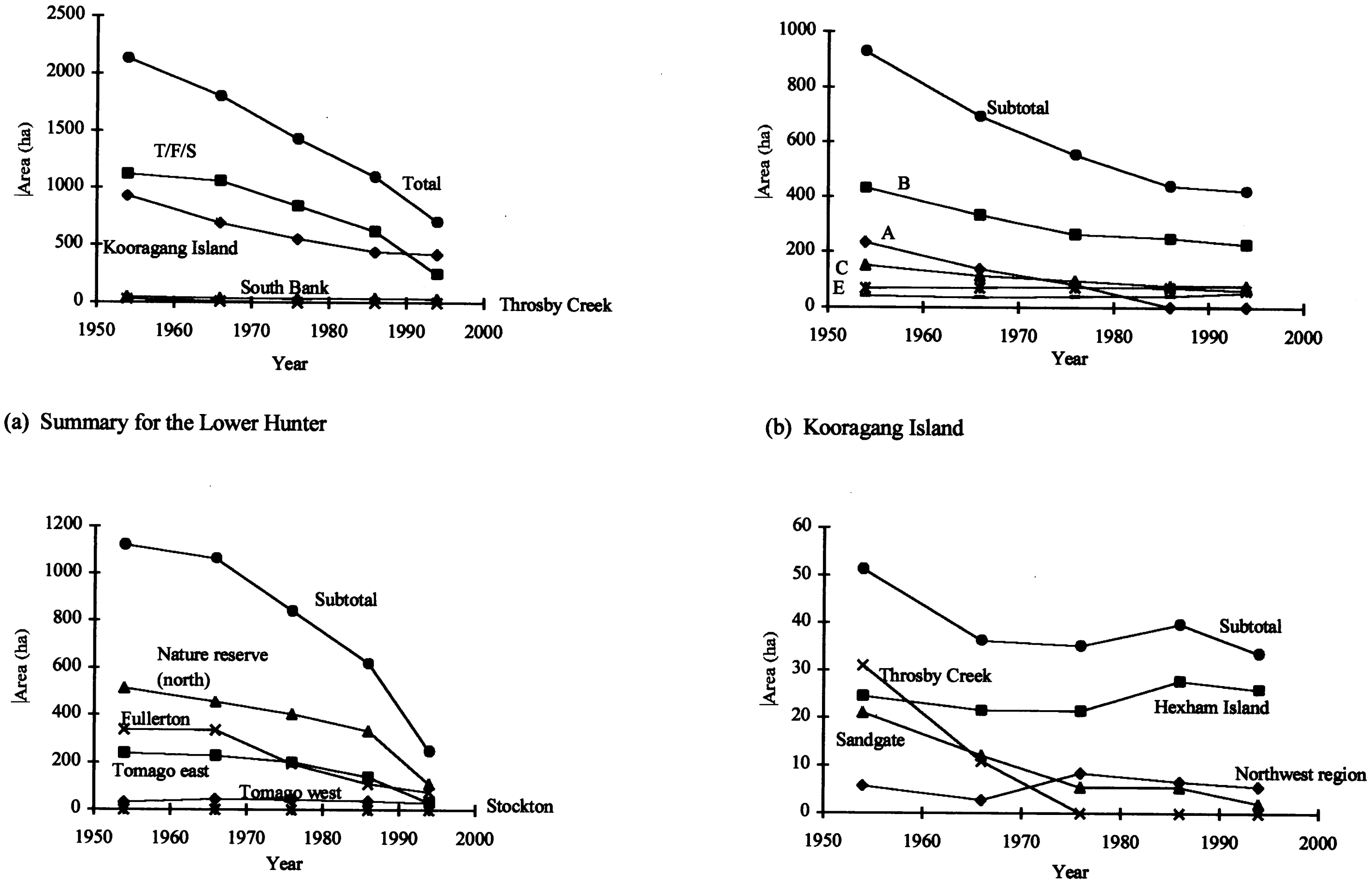


Figure 4.9. Change in the distribution of saltmarsh in the lower Hunter River, 1954-1994. Sub-regions A-E are those shown by Shortland Wetlands Centre and The Newcastle University Research Associates (1992): A = Industrial Zone, B = Kooragang Nature Reserve (south), C = Central Kooragang Island, D = Western Kooragang Island, E = Experimental Zone. NR = Kooragang Nature Reserve (north)



(a) Summary for the Lower Hunter

(b) Kooragang Island

(c) Tomago/Fullerton/Stockton (T/F/S)

(d) South Bank and Throsby Creek
*Subtotal is for the South Bank region only

Figure 4.10. Change in area (ha) of saltmarsh in the lower Hunter, 1954-1994.

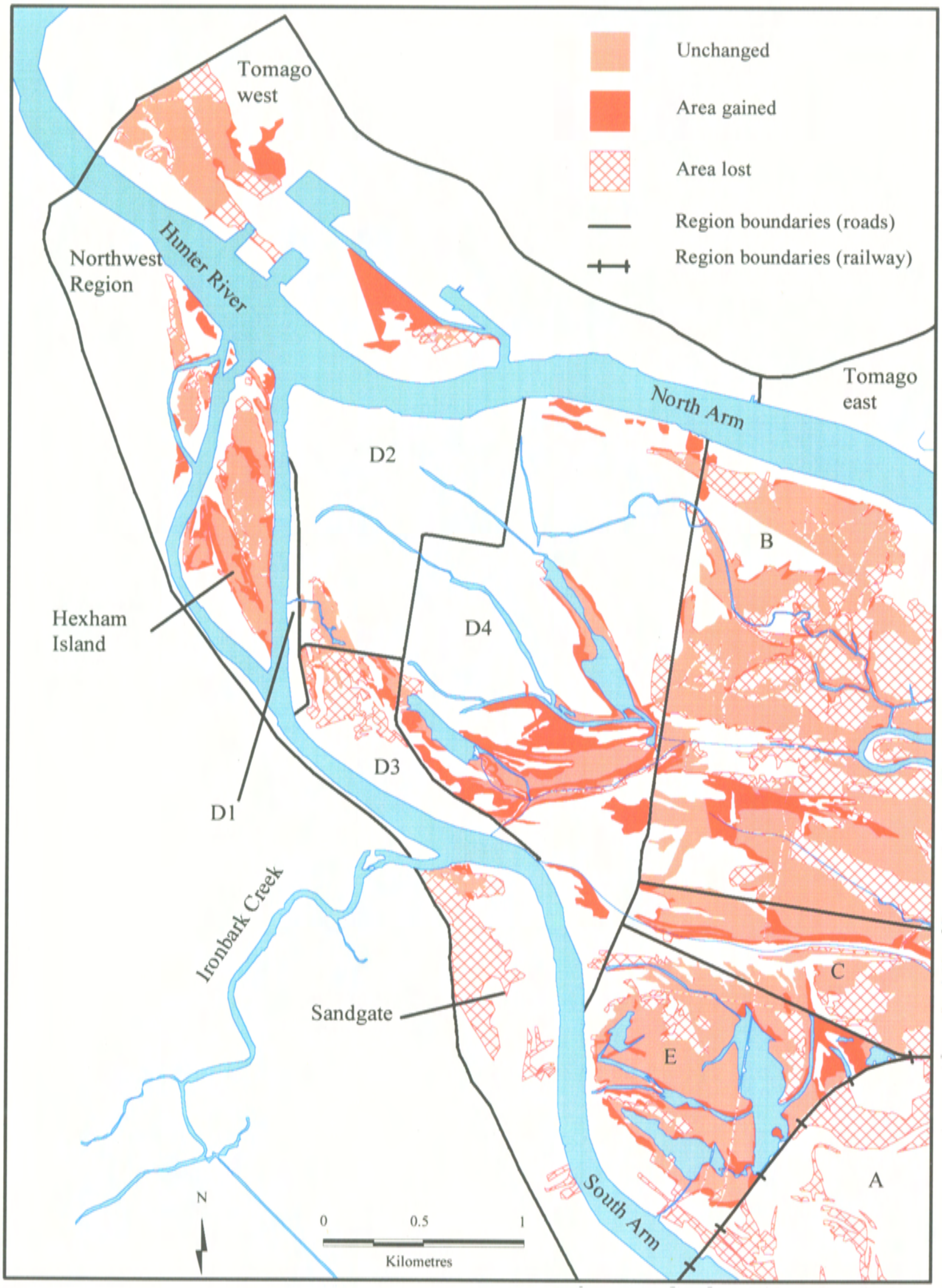


Figure 4.11. Change in the distribution of saltmarsh on western Kooragang Island, 1954-1994. Sub-regions A-E are as for Figure 4.9 with western Kooragang Island (D) further subdivided.

Table 4.6. Change in area (ha) of saltmarsh for zones within western Kooragang Island, 1954 - 1994.

Zone*	1954	1966	1976	1986	1994	Change (ha)	Change (%)
D1	0	0	0	0	0	0	0
D2	4	4	4	3	3	-1	-20
D3	11	11	8	9	4	-7	-62
D4	26	20	27	30	46	19	73
E	69	71	73	71	62	-8	-11
Total	110	106	112	113	115	4	4

* see figure 4.11 for region boundaries

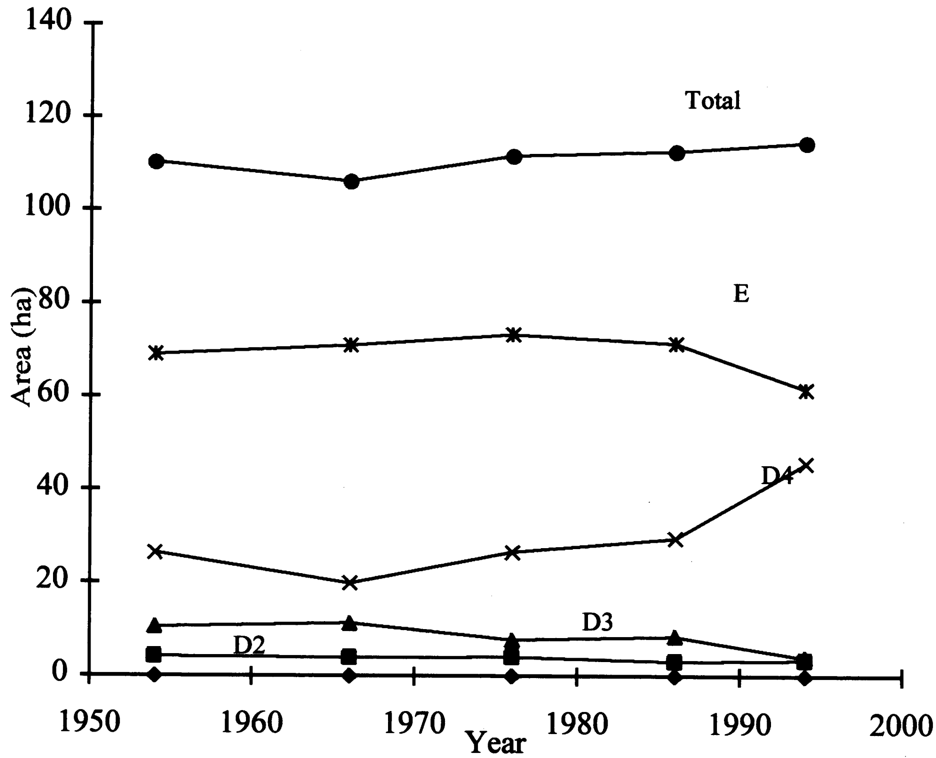


Figure 4.12. Change in area (ha) of saltmarsh for zones within western Kooragang Island, 1954 - 1994.

4.3.4. Overall change

The net change of wetland habitats in the lower Hunter River between 1954 and 1994 is shown in Table 4.7 and Figure 4.13. The area of open water and saltmarsh decreased by 344 ha (13%) and 1428 ha (67%), respectively. The area of mangrove increased by 400 ha (30%), in spite of the fact that 219 ha of mangrove was lost from the Industrial Zone.

Table 4.7. Area (ha) of mangrove, saltmarsh and open water in the lower Hunter, 1954 - 1994.

	Year					Change 1954 - 1994	
Cover Type	1954	1966	1976	1986	1994	(ha)	(%)
Mangrove	1310	1541	1534	1559	1711	400	31
Saltmarsh	2133	1803	1429	1099	705	-1428	-67
Open Water	2688	2453	2365	2339	2344	-344	-13

4.4. Discussion

The area of open water and saltmarsh decreased over time, and losses were seen in almost every one of the sub-regions (Tables 4.1, 4.5). While the rate of loss of open water has slowed and stabilised, saltmarsh is still being lost (Figure 4.13).

The largest losses of open water area were at the Nature Reserve (north) (117 ha), Industrial Zone (114 ha) and Throsby Creek (71 ha, Table 4.1). The loss at the Nature Reserve (north) relates to progressive and large-scale expansion of mangrove into Fullerton Cove. In contrast, loss of open water at the Industrial Zone and Throsby Creek occurred mainly between 1954 to 1966, for industrial and housing purposes.

The rate of loss of saltmarsh is such that a simple extrapolation might suggest little, or no, saltmarsh will be left in the study zone by 2015. This assumption overlooks the fact that in two regions, Kooragang Island and South Bank, the loss rates have stabilised (Figure 4.10a). At one subregion on western Kooragang Island, D4, a 73% increase from 26 ha to 46 ha occurred (Figure 4.12). While steps are underway to rehabilitate saltmarsh at western Kooragang Island, the potential for large-scale expansion is limited by the availability of low-lying land. For example MacDonald (1996) discusses limitations on the expansion of saltmarsh within the catchment of Creek 1 (Figure 4.3) by the relatively steep gradient of the surrounding pasture, even after tidal flow within the creek was improved. As the contour intervals on standard topographic maps are not fine enough to calculate the amount of land suitable for conversion to saltmarsh, detailed surveys of the micro-topography are required.

One other point should be made about saltmarsh: nearly half the loss (608 ha) occurred within the Kooragang Nature Reserve, of this amount 403 ha disappeared from the northern portion of the reserve and 205 ha from the southern portion (Table 4.5, Figure 4.9). These losses relate partly to upslope expansion of mangrove. The implications of for avian and terrestrial fauna are unknown.

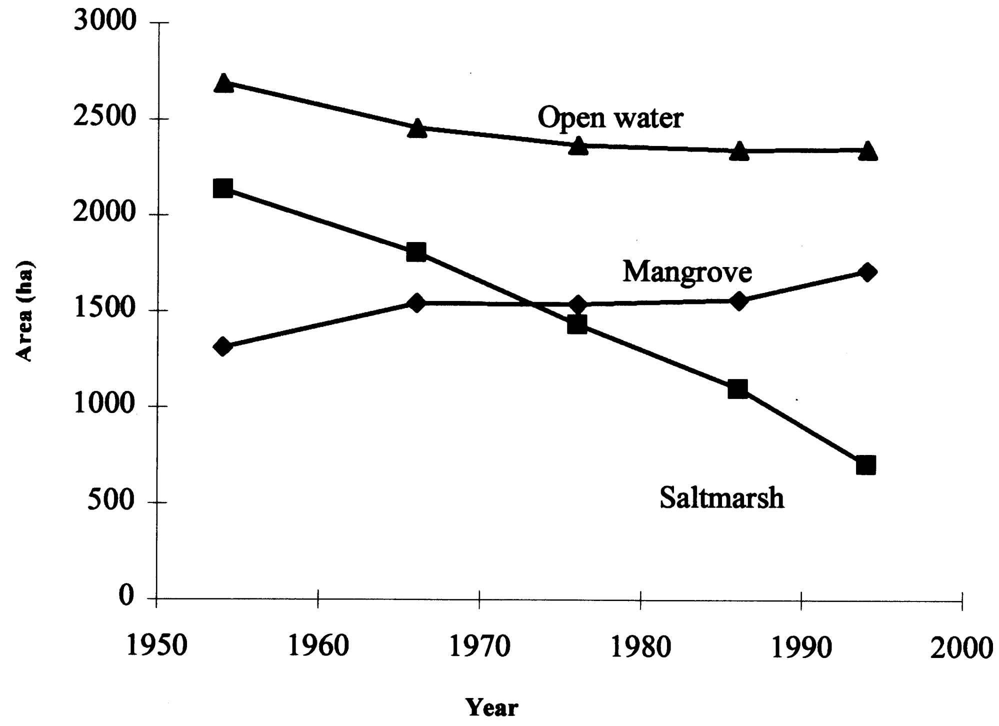


Figure 4.13. Summary of the changes in the area of open water, mangrove, saltmarsh.

As previously indicated, the area of mangrove increased by 400 ha between 1954 and 1994 (Table 4.7). Increase in mangrove has been reported over a large extent of eastern Australia, from central Queensland to South Australia (Saintilan and Williams 1999). The increase in the Hunter River was seen in most locations, the notable exceptions being the Industrial Zone and Throsby Creek where there were losses of 219 ha and 40 ha, respectively. Mangrove was cleared from the latter two sites to cater for the expanding population and industry of the city of Newcastle. Simultaneously, there was an increase of 493 ha at the Nature Reserve (260 ha in the northern portion and 233 ha in the southern portion). In the Nature Reserve (south) there was a near equivalent offset of saltmarsh for mangrove (205 ha of the former lost, 233 ha of the latter gained). Figures 4.5 and 4.9 reveal that at a broad scale, much of this change is directly attributable to the migration of mangrove upslope into the saltmarsh. However as other vegetation types such as freshwater marsh, pasture or bare ground were not mapped in this study, it is not possible to quantify the extent to which this has occurred. Further analysis of small-scale spatial and temporal change along the lines of that carried out by MacDonald (1996) is needed.

MacDonald (1996) used 1: 10 000 scale aerial photographs to map 12 different cover types over an interval of three years, from 1993 while culverts were in place at the mouths of Creeks 1 and 5 (Figure 4.3), and again in 1996 one year after the culverts had been replaced by bridges. An increase in area of mangrove and saltmarsh was reported, as was an invasion of saltmarsh by mangrove in some places. As MacDonald's (1996) study examined parts of subregions B, C and E, it is not possible to make a direct comparison between the two investigations.

While MacDonald (1996) saw no expansion of mangrove at Pond 5 (Figure 4.3), numerous mangrove seedlings were seen at this location during the sampling of the fish and crustaceans in summer of 1996/1997 and again in 1997/1998 (Williams *et al.* in prep.). The latter observations suggest the extent of limitations in spatial resolution even when relatively low level aerial photographs are analysed in a GIS. It also implies a potential for mangrove to further colonise much of the low-lying area of Kooragang Island where tidal flow is restored and suggests future study of the longer-term change in mangrove distribution is required.

The invasion of saltmarsh by mangrove on Kooragang Island was first reported by Buckney (1987). His study arose from the need to advise the New South Wales Government on the boundaries for a proposed nature reserve, an area equivalent to subregions B and C, i.e., the Nature Reserve (south) and Central Kooragang Island, respectively. Buckney tracked the extent of seven habitat types (vigorous mangroves, mangroves lacking vigour, saltmarsh, pastures, swamp, tidal flats and bare ground) from 1954 to 1982 by using clear plastic overlays to trace vegetation boundaries on aerial photographs and reducing or enlarging the results to a scale of 1: 32 000. The area of each habitat type was determined from an overlay of random dots. Some of the same photographs used by Buckney were used in our study, but the two approaches contrast due to our much larger study area, our focus on only three habitat types, and our use of GIS facilities. There is excellent correspondence between the two studies for the total amount of mangrove found in 1954 and 1966, and good correspondence between the Buckney's calculations for the 1975 mangrove area and our 1976 mangrove area (Figure 4.14). However, Buckney shows a decrease in mangrove area from 1975 to 1982. Two possible explanations are possible: one or other of the analyses is wrong, or the dynamics of mangrove change need to mapped at less than 10 year intervals.

To further examine the difference between Buckney's results and our own, we referred to data compiled by Winning (1996), who also used the aerial photos of 1954, 1966 and 1994 to draw boundaries between species of wetland vegetation. There is good correspondence between his and our boundary conditions. It would be advisable to examine the photos of 1979 and 1982 with the methodology set out in this report.

Buckney (1987) summarised some of the factors that may have been responsible for the change in habitat boundaries, and referred to the role of rainfall in reducing soil salinity and enhancing mangrove recruitment. The reduced area of mangrove he observed in 1979 and 1982 are coincident with the El Nino Southern Oscillation (ENSO) drought present along the eastern seaboard of Australia at that time. When the drought broke, it is conceivable the mangrove recovered and recruited to the degree we calculated. If there is a drought-wet cycle to mangrove growth, then attempts to describe the dynamics of mangrove recruitment at a decadal frequency may not be sufficient.

If there is a drought effect from ENSO, it was not apparent in recent analyses of the historical distribution of mangrove in Berowra Creek (Hawkesbury River). These studies showed a consistent increase in the area of mangrove in aerial photos taken in 1941, 1966, 1975, 1982, 1986, 1992 and 1994 (Williams and Watford 1997; F. Watford unpublished data; B. Coates, Dept. of Land and Water Conservation, unpublished data). However, the fastest rate of increase occurred between 1982 and 1986 (F. Watford unpublished data), the former year being the end of the El Nino drought.

Similar considerations apply to saltmarsh. Buckney (1987) saw a long-term decline in the area of saltmarsh, but the absolute amount identified by him was of the order of 100 ha less than we found (Figure 4.14). The difference may be due to the respective classification criteria. Buckney also saw an increase in saltmarsh area during the ENSO interval referred to above.

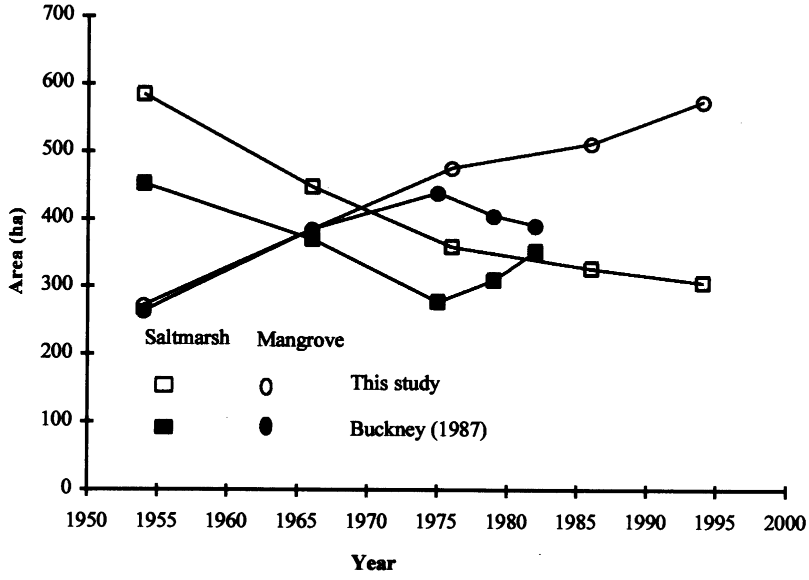


Figure 4.14. Comparison of mangrove and saltmarsh area calculated for the Nature Reserve (B) and zone (C) on Kooragang Island with those of Buckney (1987). See Figure 4.1 for zone boundaries.

In addition to the climatic effects, there are other possible reasons for the losses and gains in estuarine habitats. Downslope expansion of mangrove into Fullerton Cove was previously documented in the context of accreting substrate (Roy 1980). The new substrate became available through the deposition of sediments eroded from the upper catchment. As estuaries are sinks for sediments, this is the normal consequence of their becoming more mature.

Encroachment of mangrove upslope may relate to local changes in mean sea level brought about by land subsidence and/or changed tidal regime. Land subsidence has occurred elsewhere in the Hunter district (e.g., Lake Macquarie) and has been caused by coal mining. Subsidence may also have occurred through the extensive drainage of agricultural lands at Tomago and around Fullerton Cove. Drained soils change their chemical composition and shrink (White *et al.* 1997), an important implication in planning for rehabilitation activities as the restoration of tidal flow to such areas may result in a far greater extent of inundation than anticipated. Subsidence effects can be enhanced by changes in tidal regime; in this case an increase in tidal propagation may have occurred as a consequence of dredging Port Hunter to cater for more and larger vessels (J. Floyd, Dept. of Land and Water Conservation, pers. comm. 1995).

4.5. Conclusions

For that portion of the lower Hunter River studied, the area of open water decreased by a 344 ha (13%) between 1954 and 1994. This trend was seen at zonal and even smaller scales, and the rate of loss has levelled off in recent times. Some of this change was due to direct infilling for industrial land, and elsewhere it occurred due to sedimentary processes that culminated in mangrove colonisation.

The area of saltmarsh in the lower portion of the Hunter River decreased substantially (1428 ha, 67%) over the same time interval. While the loss rate is now stabile at Kooragang Island and South Bank, reduction at Tomago/Fullerton is still rapid. Some saltmarsh has been invaded by mangrove.

The area of mangrove in the lower portion of the Hunter River has increased by 400 ha (31%) over the past 40 years.

Some uncertainty exists about the area of mangrove and saltmarsh present in the early 1980s due to the discrepancy between our results and those of Buckney (1987). This discrepancy raises the issue of short-term response rate of estuarine vegetation to climate forcing and/or other impacts.

The reasons behind the vegetation changes seen in this study are as yet unknown, but may relate to rainfall and erosion of sediments from the upper catchment and their deposition in estuarine waters, and/or local changes in sea level brought about naturally or in relation to harbour dredging.

The loss of saltmarsh due to mangrove encroachment upslope, and the loss of open water due to mangrove expansion downslope, have not been calculated but need to be resolved.

4.6. Recommendations

1. While aerial photographs of the lower Hunter Valley were taken prior to 1954, neither the originals nor copies were found. If available, they should be analysed to provide further assessment of historical change.

2. To complement this study, an assessment of the change in distribution of open water, mangrove and saltmarsh at Hexham Swamp should be commissioned.

3. The difference between Buckney's (1987) and our assessment of the area of mangrove and saltmarsh present in the late 1970s and early 1980s, particularly as it relates to tracking short term changes in the distribution of estuarine macrophytes, should be further investigated.

4. To redress the loss of saltmarsh, potential sites for re-establishment should be identified.

5. To assist in projecting the long-term recruitment of mangrove, data on sedimentation rates within the lower Hunter River should be updated.

6. To assist in projecting the long-term dynamics of wetland vegetation, investigations into changes in the mean sea level on Kooragang Island and elsewhere in the lower Hunter should be initiated.

7. To facilitate future planning of rehabilitation efforts, a fine scale elevation model of Kooragang Island and other relevant wetland sites should be constructed.

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5. OVERVIEW

Modification of the wetland habitats of the lower Hunter River occurred within four distinct time intervals over the last 200 years:

Stage 1. 1796-1897; Early development stage, characterised by attempts to meet the agricultural and transport requirements of the early colonists,
Stage 2. 1898-1950; Mid development stage, heavy industry was established,
Stage 3. 1951-1989; Late development stage, industry was expanded,
Stage 4. 1990-present; Rehabilitation stage, attempts are being made to ameliorate for the environmental damage of the past.

The presence of coal and timber and the need to relocate convicts away from Sydney focused the colonial government's attention on the Hunter Valley. The convict settlements were short lived and on their closure the valley was opened to free settlers. Stage 1 of the modification of estuarine wetlands was denoted by the harvest of commercial timber from along the riverbanks, and the subsequent clearing of non-commercial trees from agricultural land and construction of small-scale drainage works. These activities were followed in the mid 1800s by commencement of dredging in Newcastle Harbour, particularly at the eastern end of the complex of islands destined to become Kooragang Island. Reclamation, using the hulks of old ships, ship ballast and dredge spoil, was initiated along shallow foreshores of the eastern end of the island complex and on the southern bank of the river. These reclamation activities, initiated in Stage 1, set in train a continuous reduction in the area of open water in the estuary.

Stage 2 saw industry emerge as the major force changing the estuarine habitats of the Hunter River. Additional foreshore was reclaimed, particularly that which added Bullock Island to the mainland as well as the preliminary filling for construction of Walsh Island. Analysis of historical maps indicates five large islands were consolidated with the mainland causing an estimated 11 km of shoreline to disappear. The tempo of reclamation and dredging increased or decreased depending on the state of the economy and demand on heavy industry before, during and in between the two world wars.

Expansion of the Australian economy after World War II marked the beginning of Stage 3. Large-scale reclamation of the southern shore of the Hunter River (e.g., Platts Channel) and the eastern end of Kooragang Island (Walsh Island) was undertaken. Another seven large islands and an additional 19 km of foreshore (12% of the foreshore present in 1801) disappeared. Analysis of aerial photos confirms the continuous loss of open water during this stage, as well as the increase in area of mangrove and decrease in area of saltmarsh. The 1954 flood led to the elaboration of the existing levee and drain system around Fullerton Cove and elsewhere.

Stage 4, the rehabilitation era, was inadvertently but symbolically initiated by the undermining of a road culvert on the southern shore of Kooragang Island in April 1990. Of unknown vintage, the culvert was built to facilitate access along the shoreline, a consequence of which was the restriction of tidal flow to the upstream wetlands. Tidal and/or wet weather forces undermined the structure allowing full tidal flushing in upstream locations. Analysis of aerial photographs reveals a substantial increase in area under mangrove since the structure failed. The implications of removing structures that impede tidal flow, thereby providing a low cost rehabilitation mechanism, were quickly realised, and the Steering Committee of the Kooragang Wetland Rehabilitation Project endorsed the removal of other culverts. Data recently to hand indicate enhancement of fish nursery function in creeks when tidal flushing is restored (Williams *et al.* in prep.).

In a socio-economic context, the modification of wetland habitat between 1797 and 1949 can be viewed in terms of the survival and well being of the colonists, and their move away from agricultural to an industrial base. The third stage was driven by a resurgent economy after WW II and then (late 1970s) by the demand of overseas countries for coal. The latter in turn stimulated the construction of new mines, handling, storage and export facilities. Expansion of export facilities meant dredging and the creation of vertical wharfage that replaced the foreshore shallows. The need for industrial infrastructure, including the construction of the industrial railway, meant the reclamation of additional wetland at the eastern end of Kooragang Island. Any future expansion of the coal trade may prompt the extension of the railway facilities, providing an opportunity to plan, model and implement works which recreate island habitat by reconnecting Moscheto Creek to the North Channel of the river, an idea first suggested by NSW Fisheries in 1973 (Coffey 1973). There is a further irony, as the burning of the coal exported from Australia contributes to greenhouse gasses, which is widely recognised as the mechanism for rise of sea level. In turn this will cause an as yet unquantified impact on the distribution of wetlands in the Hunter River and elsewhere in NSW. The general implications of sea-level rise for mangrove and saltmarsh communities have already been discussed (Chapter 4).

The combination of techniques developed in the mid part of this century to capture high quality aerial photos, and more recently the use of electronic technologies (GIS) to extract data from the photos, has meant an enhanced ability to track changes in distribution of estuarine habitats. However, the photos only represent a small segment of wetland history. In effect, very little is known about the distribution of mangrove and saltmarsh in the lower Hunter Valley throughout the whole of the 19th century and the first half of the 20th century. Data derived solely from aerial photos may lead to incorrect assumptions on the distribution of and changes to the wetlands of the distant past. Table 6.1 summaries this situation.

Clues to the distribution of wetland vegetation in NSW in the 1800s and early 1900s are hidden away in colonial landscape paintings (e.g., Gleeson 1971), parish maps and personal letters, diaries and recollections. An enormous effort is required to find these sources of data, but the information invaluable if we are to gain an accurate impression of the wetlands of the lower Hunter River 200 years ago, as well as the impact of white settlement. For example, it is known that one of the requirements of the Newcastle penal settlement of 1804 to 1822 was to mine coal and harvest timber for export, and to create lime for construction of buildings in Sydney (Perry 1963). The latter was achieved by collecting live oysters and burning them at Fern Bay on the eastern shores of Fullerton Cove (R. Hyde, pers. comm., 1999). The source and type of wood used in the combustion process is unknown. Reputedly, timber from the resident mangroves *Avicennia marina* and *Aegicerus corniculatum* does not provide enough heat to turn oyster shell to lime, however some mangrove timber may have been collected to ignite the reducing fires. There is at present no way of knowing the extent of the impact of the limeburners on the wetland vegetation of the Hunter River (or at any of the other locations in NSW where oysters were burnt, e.g., Limeburners Creek in the Hastings River).

In reviewing the findings of this study we create a simple descriptive model of the mangrove and saltmarsh vegetation of the Hunter River: the distribution of these vegetation types is controlled by the amount of substrate that is tidally inundated. Over past millennia the rise and fall of sea level has been the primary determinant of these conditions, modified by sediment redistribution after major floods. In the post colonial era, catchment clearing and small scale works to exclude tide and drain wetlands initially played a role in modifying the area under mangrove and saltmarsh, but large scale reclamation for industrial facilities in the middle portion of the 20th century has had a greater impact. Mangrove species move quickly onto any newly available and suitable substrate, including where tidal flushing has bee re-established, and thus appear to have a competitive advantage over saltmarsh.

Globally, the nexus between estuarine wetlands and sheltering of fish or birds is still little understood. An attempt to make a simple connection between change in habitat at Kooragang Island to change in the catch of fish recorded over the past 100 years in the Hunter River is underway (Williams, in prep.). The analysis is complicated by the lack of data in some years, and unsuitability of the effort data except for the past decade. Early indications are that the weight of catch from the Hunter River is approximately the same as it was 200 years ago, but that the catch of leatherjackets and snapper is only a fraction of what it was in the early 1950s. The data for leatherjackets reflects a finding common to other NSW estuaries and the offshore fishery for this group of fish. It is not yet possible to surmise whether progressive change in habitat or other factors such as misreporting of catch are responsible for the trends seen.

This document makes an important contribution to our understanding of the evolution of estuarine habitats in the Hunter River, and will assist in setting the rehabilitation targets of the future. While it is not possible to restore all tidal wetlands to their condition before white settlement, it is desirable to enhance the function of those still present and, as feasible, create new ones. Many changes can be achieved through simple and inexpensive solutions such as the removal of culverts.

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Table 5.1. Overview of changes in estuarine habitats of the Hunter River. The four stages of evolution are indicated, as are the dates of maps and aerial photographs used in this study.

Stage	**1**	**2**	**3**	**4**
Years	1796 1895	1896 1949	1950 1989	1990 Present
Maps	1801 1844 1892	1913 1928 1941		
Airphotos			1954 1966 1976 1986	1994
Open Water	D E	C R	E A S	E S
Mangrove	??	??	I N C R E A	S E S
Saltmarsh	??	??	D E C R E A	S E S

6. RECOMMENDATIONS AND IMPLICATIONS

6.1. Benefits

Primary beneficiaries of this research are Port Waratah Coal Services Pty. Ltd., the Hunter Catchment Management Trust and the Steering Committee of the Kooragang Wetland Rehabilitation Project. The former gains an enhanced understanding of the dynamics of estuarine wetlands and a better ability to manage those parts of its existing facility that are, or are near, tidal habitats. Any expansions or modifications of its site can be done in an environmentally sensitive manner. The Trust and the Steering Committee, in planning additional rehabilitation of the wetland landscapes of the lower Hunter River, have a better appreciation of the ways in which Kooragang wetland habitats have evolved, in particular the changes to shoreline, creation of new sub-catchments, expansion of mangrove and reduction of saltmarsh.

Secondary beneficiaries are the other residents of the lower Hunter, including the community, industry and local government, particularly in their ability to conserve and/or rehabilitate existing wetlands, or create new wetlands by modifying tidal flow. Ultimately there may be a new set of wetlands that are created by a rise in sea level.

6.2. Intellectual property

No patents emerged from this research. All results will be published by NSW Fisheries in reports, public domain scientific journals and presented at workshops and seminars.

6.3. Further development and recommendations

The study of estuaries in NSW is in its infancy and needs to be further supported in order to support the many and varied decisions needed in coastal management. This project makes a significant step by developing a methodology for the study of estuarine habitats and their sub-components. Rochford (1951) recognised a series of hydrological features that allowed him to differentiate between estuarine zones. Roy *et al.* (in prep.) recognise geomorphological features that can be used to distinguish estuarine zones and postulate certain aspects of estuarine function based on structural characteristics. The relationship between the two schemes has yet to be determined.

Arising within the various chapters of this report are a number of recommendations. They are consolidated below for convenience.

Chapter 2. History of change in wetland habitats on Kooragang Island.

1. There is still more to be learned about the nature and evolution of the wetlands of the lower Hunter River. Incentives should be offered to further study the habitat changes that have occurred there.

Chapter 3. Analysis of change in landforms and drainage in the lower Hunter, 1801-1994.

2. To provide a fuller understanding of change in the estuarine portion of the Hunter River, modifications to the Hexham wetlands over the past 200 years should be assessed and integrated with the results of this study.
3. To assess the extent of change caused when overland or tidal flow is enhanced or reduced, a formal monitoring program should be initiated.
4. To confirm the loss of open water along the Hunter River, Manley's (1963) investigations should be updated.

Chapter 4. Analysis of change in estuarine vegetation of the lower Hunter River, 1954-1994.

5. While aerial photographs of the lower Hunter Valley were taken prior to 1954, neither the originals nor copies were found. If available, they should be analysed to provide further assessment of historical change.
6. To complement this study, an assessment of the change in distribution of open water, mangrove and saltmarsh at Hexham Swamp should be commissioned.
7. The discrepancy between Buckney's (1985) and our assessment of the area of mangrove and saltmarsh present in the late 1970s and early 1980s, particularly as it relates to tracking short term changes in the distribution of estuarine macrophytes, should be further investigated.
8. To redress the loss of saltmarsh, potential sites for re-establishment should be identified.
9. To assist in projecting the long-term recruitment of mangrove, data on sedimentation rates within the lower Hunter River need to be updated.
10. To assist in projecting the long-term dynamics of wetland vegetation, investigations of changes in mean sea level on Kooragang Island and elsewhere in the lower Hunter River should be initiated.
11. To facilitate future planning of rehabilitation efforts, a fine scale elevation model of Kooragang Island and other relevant wetland sites should be constructed.

6.4. Staff

The following NSW Fisheries staff were directly employed on this project with Port Waratah Coal Service funds:

Vlad Balashov (initially)	Fisheries Technician
Fiona Watford (subsequently)	Fisheries Technician

Other NSW Fisheries staff, contributing to the project but not directly funded were:

Robert Williams	Principal Investigator
Jack Hannan (initially)	Fisheries Technician
Darryl Sullings (subsequently)	Fisheries Technician

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