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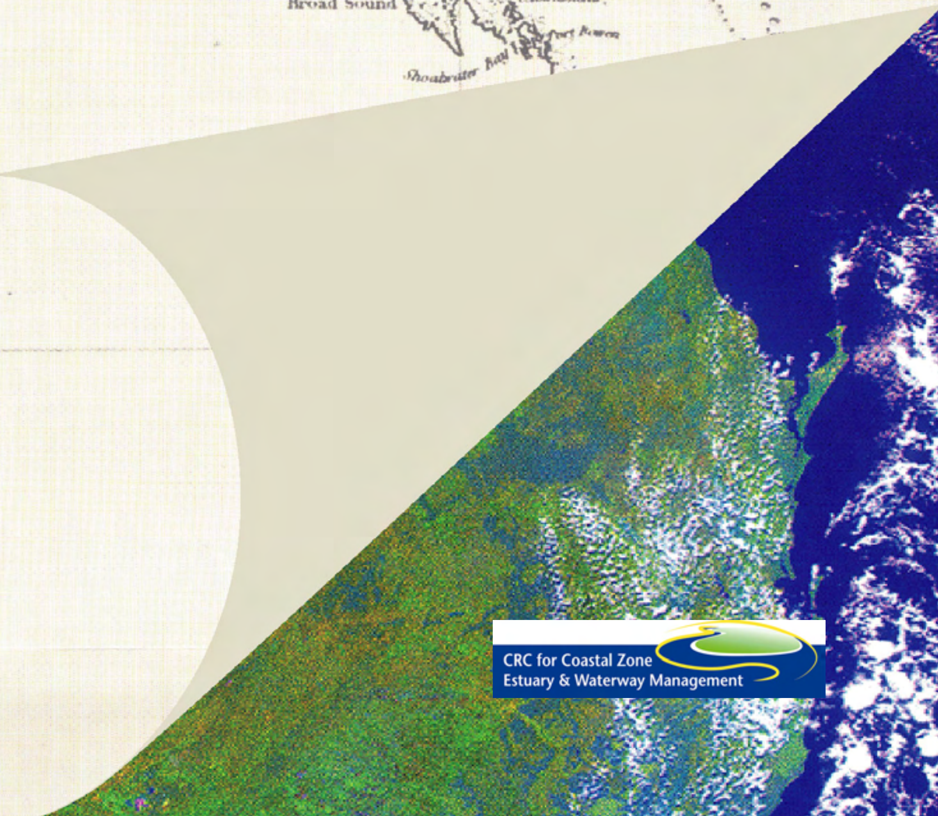

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CRC for Coastal Zone Estuary & Waterway Management

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THE UNIVERSITY OF QUEENSLAND AUSTRALIA

CRC for Coastal Zone Estuary & Waterway Management

**Report to the
CRC for Coastal Zone Estuary and Waterway Management**

July 2003

Submitted: July 2003

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Citation Reference:

Duke, N. C., Lawn, P. T., Roelfsema, C. M., Zahmel, K. N., Pedersen, D. K., Harris, C. Steggles, N. and Tack, C. (2003). Assessing Historical Change in Coastal Environments. Port Curtis, Fitzroy River Estuary and Moreton Bay Regions. Report to the CRC for Coastal Zone Estuary and Waterway Management. July 2003. Marine Botany Group, Centre for Marine Studies, University of Queensland, Brisbane.

COVER PAGE FIGURE: One of the challenges inherent in historical assessments of landscape change involves linking remote sensing technologies from different eras. Past and recent state-of-the-art spatial images are represented by the Queensland portion of the first map of Australia by Matthew Flinders (1803) overlaying a modern Landsat TM image (2000). Design: Diana Kleine and Norm Duke, Marine Botany Group.

A Report to the Coastal CRC and its Stakeholders

This report contains the findings of the historical assessments of the Port Curtis, Fitzroy River estuary and Moreton Bay regions. The information and findings were gathered over the duration of a three year program with the Historical Coastlines Project of the Coastal CRC.

The work presented applies particularly to the HC2 task and includes one aspect of the HC4 task, namely the assessment of field information on wetland vegetation structure and species composition. The Methods and Strategy used have been developed further in this assessment to identify and define the ecological indicators being used and developed in this and associated projects. The findings in this report represent the final stage of an iterative process designed to combine expert evaluation and stakeholder feedback within the Coastal CRC.

Executive Summary

During the past two centuries, human development has increased dramatically, resulting in massive alterations to coastal features to accommodate ever-growing demands of industry, trade and population. Notable significant losses have been observed for tidal wetland habitat in coastal areas. Accurate quantification and interpretation of these long-term changes are essential to provide comprehensive resource information that will enable more effective management of coastal habitats threatened by human and natural influences. The aims of the current report were to document and assess historical change of coastal features and vegetation (e.g. mangroves) in Moreton Bay, South-East Queensland, particularly over the last 50 years, and to relate these changes to human or natural drivers. This was achieved through time comparisons of digitised aerial photograph images spanning 50 years for both the region (broad-scale) and detailed case studies (localised fine-scale). The detailed case studies comprised a site under direct human influence (The Greater Brisbane River region: Luggage Point, Bulwer Island), and a site primarily under natural control, distal to direct human influence (Cobby Cobby Island in Southern Moreton Bay). Vegetation maps of the regional and case study sites were produced depicting current and historical mangrove and saltmarsh/ saltpan distribution. Port Curtis, Fitzroy and Moreton Bay represent areas of industrial, rural and urban development, respectively.

In Port Curtis, there was a regional loss of mangrove (1470 ha or 38%) and saltmarsh (1340 ha or 34.8%) between 1941 and 1999. In the human-affected case study (Calliope River and Auckland Inlet), a 339 ha (30%) loss of mangrove area and a 2 ha (0.4%) loss of saltmarsh was found over the same 58-year period. The substantial loss of mangrove was largely attributed to reclamation activities. In the naturally-affected case study (Endfield Creek, southern Curtis Island), small losses of mangrove (5 ha or 3.5%) and saltmarsh (4 ha or 12.5%) were measured between 1959 and 1999.

In the Fitzroy River, there was a gain of 300 ha (9.1%) of mangrove and loss of 1150 ha (40.9%) of saltmarsh between 1941 and 1999 for the human-affected case study (Fitzroy River Estuary), also representative of the regional view. Notably, there was a 40 ha (14.3 %) gain of mangroves in the newly-formed islands in the river mouth, and a 210 ha (11.2 %) gain of mangroves in the broad river mouth region. These gains were largely attributed to depositional gains, possibly due to changes in sediment loads and river hydrology. In the naturally-affected

case study (Balaclava Island), losses of mangrove (4 ha or 4.8%) and gains of saltmarsh (7 ha or 3.3%) were detected from 1956 to 1999. As zonal shifts were observed, these changes appear to have been related to climate change.

In Moreton Bay, there was a regional net loss of both mangrove (313 ha) and saltmarsh/ saltpan (3041 ha), during the period 1974-1997, comprising a total loss of approximately 3353 hectares of tidal wetland (19.5 %). Between 1946 and 2002, in the Greater Brisbane River subregion alone, there was a significant loss of tidal wetland, totalling 1513 hectares (46 % decline), comprised of 543 hectares of mangrove and 973 hectares of saltmarsh/ saltpan communities. This subregion has been a major focus of disturbance to wetlands in the region, with major losses resulting directly from human driven change. For instance, a large proportion of this disturbance (850 ha) was due to the development and expansion of the Brisbane Airport around 1980. However, industry and port development in this region have also contributed significantly. Similar trends of wetland change within the Luggage Point and Bulwer Island case studies were observed, where 273 hectares (54 %) and 136 hectares (61 %) of tidal wetland area were lost (respectively) principally due to human development (reclamation). The Cobby Cobby Island case study revealed significant historical shifts in vegetation. These may be indicative two relatively natural processes: (a) local sea level rise, with zonal shift as encroachment of wetland areas into terrestrial habitat with corresponding loss at the seaward edge, and (b) climate change, with mangroves being replaced by saltmarsh/ saltpan. However, it is not yet clear whether the effects observed on Cobby Cobby Island are localised or characteristic of the wider region and acting on a global scale.

One of the chief objectives of this study has been to detect and quantify both natural and human-driven change in coastal ecosystems. Clearly, by providing such information and revealing the relative effects of particular drivers, such as reclamation and climate and sea level change, in the past, the study will aid future decision-making and management of all coastal areas. Knowing the causes of change will allow environmental managers and developers to predict the likely consequences of their actions, and place them in a position where they might mitigate, accommodate, or plan around change. It is proposed with this study, also, to tease apart natural trends from human drivers of change, so there might be better-informed application of effective longer-term planning and management.

A major outcome of the project has been the development of a practical classification system for assessment of change in tidal wetlands in 12 main types. For each type of change, ground and remote sensing indicator tools, based on major diagnostic features were used to identify the most likely driving factors, where this was not otherwise known and documented. Dichotomous keys provide further useful tools for making decisions about identifying change in tidal wetlands, based on both ground observations and for use in remote sensing interpretations. These classification and indicator systems will have broad use as effective management tools in the assessment, evaluation and monitoring of coastal and estuarine habitat. Such information is essential for the practical application of adaptive management strategies to protect and preserve the quality and beauty of our coastal environments.

Acknowledgements

Information and images published in this report have been collected and derived from numerous sources, including various organisations and people.

For the Port Curtis region section of the report, we acknowledge the generous assistance provided by, and would like to thank: Rolly Rupp for his assistance in the field, Noel Bowley, Graham Kuss and Judy Logan (GPA) for their time, and for sharing their knowledge of the region's history and development, and to Noel Davison (Nixon Communication) for the aerial flight.

For the Fitzroy River region we would like to thank the following people: Bob Packett (DNRM) for organizing the logistics and boat for the Fitzroy work, and his assistance in the field, and Bob Noble (DNRM) and Phil Ford (CSIRO) for their support and assistance.

For the Moreton Bay region section of the report, we acknowledge the generous assistance provided by: Brian DeBryn and Paul Marshall (BP Bulwer Island Refinery) for Bulwer Island case study; Malcolm Dunning (DPI Queensland Fisheries Service Trends Unit) for GIS fisheries habitat maps; Rob Fearon (Coastal CRC) for valuable general advice on this report; Jon Knight (UQ) for help with Cobby Cobby Island case study; Fiona Manson (CSIRO/UQ) for information on interpreting change in mangrove habitat in Moreton Bay, 1974-1997; Stuart Phinn (UQ, BRG) for advice on remote sensing; Kath Stephens (BCC) for help with Luggage Point case study; Kate Brimblecombe for her wonderful help in collecting the historical photos; and, Department of Natural Resources and Mines Landcentre (for aerial photos).

Generally, we would like to thank Katherine Ewel (USDA Forest Service) for early ideas for the keys, Nadeine Milton and Michael Herring (EPA Rockhampton) and Dave Orgill (EPA Gladstone) for providing Arnold data and aerial photographs, to Alistair Melzer (CQU) for the loan of his aerial photographs, to Belinda Grigg (GPA) for historical information on reclamation activities in Port Curtis for use in the timeline, to Emma Gentle for assistance with assessment of the transects, to Matthew Ball to resolving computer problems, to Jon Knight for his advice and assistance with scanning aerial photos, and a big thanks to Jane Thomas for her keen eye and her expertise when it comes to overall presentation and help with the figures.

Thanks must also go to Diana Kleine for assistance in designing the front cover and help with the posters and handouts, and to the Marine Botany Group for their continuing support and feedback.

And to Alicia for helping to put the finishing touches on the report.

TABLE OF CONTENTS

1. Introduction & Review of Assessment Tools

During the past two centuries, human population and development in Australia have increased dramatically, particularly in coastal regions. Impacts have included replacement or modification of wetlands, reclamation, river 'training' and dredging, hardening of the landscape, increased pollution, altered water quality and flow, and increased erosion and sediment loading. As a consequence, the coastal environment has undergone extensive alterations, both to physical features and to intertidal habitats and vegetation.

Historical assessment of this change and quantification of rates of change are essential steps in understanding the impact of human influence, as they can reveal the effect of certain types of activity on coastal habitats. Clearly, such information has application as a management tool, allowing environmental planners to better predict the likely consequences of an action before it is taken. This knowledge also has applications for habitat restoration, as effective restoration requires information on habitat condition before modification, in order to set realistic targets.

In addition to human-induced change, both intentional and unintentional, there may be underlying natural or ambient change. For the purposes of this report, natural change is defined as change driven by factors beyond obvious human control, such as sea level rise and climate change. Although anthropogenic influences may play some role in these processes, the contribution is largely unidentified and not easily modified. Historical assessment of this type of change, in coastal wetland areas away from direct human influence, can have important applications. Apart from aiding in interpretation of change in areas subject to human development, by providing a comparison and suggesting the relative contribution of natural versus anthropogenic drivers, it can reveal long-term localised and global trends. This information is critical for long-term management and planning.

The identification of a change as being either anthropogenically-induced or natural is important to establish, in order to determine whether the outcome can be altered. If a human-driven change occurs, possible management options include mitigation (where the driver is altered), and living with (planning around) the effects.

Rationale

In most coastal regions of Australia, mangroves dominate the tidal wetlands and provide essential habitat, shelter and protection for coastal shorelines. They protect nearshore areas where water clarity is often muddy, and sediments and substrate are typically soft. Mangroves trap fine sediments and improve water clarity by binding and holding sediments with their specialised root structures. In at least one case, a close relationship has evolved between the largely mangrove fringed shoreline of the NE Australian coastline and the coral reefs of the Great Barrier Reef (Duke & Wolanski, 2001). This relationship involves a delicate, but dynamic, balance between sediment discharge from catchment run-off (influenced partly by rainfall and, in recent times, land use practices) and the amount of riparian and estuarine fringing vegetation (determined in part also by mangrove vegetation). Where sufficient amounts of sediment were trapped and held within the estuarine mangrove forests, this had resulted in coastal waters being relatively free of suspended material and suitable for subtidal plants and photosynthesis.

However, this balance has been severely upset within the last 150 years, and there are important indications of a steady and dramatic decline in coastal ecosystems of the wider eastern Queensland region (e.g. Baker *et al*., 2003; Capelin *et al*., 1998; Larcombe *et al*., 1996; Wachenfeld *et al*., 1997; Wolanski, 1994; Wolanski & Duke, 2000; Zeller, 1998). Much of the deterioration appears related to increased levels of water turbidity, seen as muddier coastal waters and shoreline margins (Fabricius & Wolanski, 2000). Furthermore, as reported by Lough and Skirving (2001), there is a corresponding increase in severity and frequency of associated events, like coral bleaching and dieback of seagrass. In other instances (Onuf, 1994; Schoellhamer, 1996), a dieback in seagrass meadows was attributed to both low light availability within unusually turbid waters, and burial from deposition of suspended sediments from run-off. This process is accelerated by the steady decline in mangrove and salt marsh habitat resulting from human development in coastal areas. These factors are also related to large-scale and on-going clearing of catchment vegetation, especially riparian areas, freshwater wetlands and tidal mangrove wetlands. The effect has been compounded further by the development of extensive built-up (converted) areas surrounding remaining areas where run-off waters have been channelled directly into coastal waters instead of soaking into soil and being taken up by vegetation and sub-surface aquifers. Furthermore, extensive land clearing has led to higher peak run-off flow rates which equate to significantly greater erosion and removal of sediment into downstream areas, particularly the estuaries (Johnson *et al.,* 2001; Furnas and Mitchell, 2001).

Impacts and implications

Over the last 150 years, the catchment areas of most coastal river systems in the eastern Queensland region have been impacted by land use change involving the conversion of natural habitat into grazing lands, agricultural cultivation, and mining, as well as urban and industrial development areas. These often dramatic alterations in land use have resulted in the severe decline of natural vegetation, and a rapid increase in erosion of catchment sediments.

This erosion has also been increased unnecessarily by the ill-advised depletion of riparian vegetation throughout most catchment areas. For instance, many coastal rivers and streams have been reduced to hard walled, straightened drains with little to stop the export of sediments and agricultural chemicals. These drainage channels rapidly carry eroded mud to settle in estuaries, and to be carried to coastal shallows and inshore reefs. The impact of these disturbances on coastal catchments has no equal in recent geological time scales.

As might be expected, the amount of disturbance varies from system to system (Johnson *et al*., 2001). One indication of current catchment condition is provided by the amount of remaining natural vegetation. The authors reported that the percentage of remaining natural vegetation ranged from 14.9% in the Port Curtis region to greater than 90% in the Hinchinbrook region.

In the study by Neil and Yu (1996), a relationship was shown between catchment run-off and unit sediment yield (USY) in Queensland coastal catchments. When this model was applied to geological data of deteriorating late Holocene climate (over 6-7 thousand years ago) in the Brisbane River area, it showed mean flow-weighted sediment concentrations increased from about 90 mg/L to 150 mg/L (Capelin *et al*., 1998). By contrast, mean flow-weighted sediment concentrations increased to 525 mg/L as a consequence of land use intensification following European settlement over the last 200 years in the same area. For any particular level of run-off, based on the data from coastal river systems in the eastern Queensland region (Neil and Yu, 1996), the change from natural to disturbed systems involved an increase of 3.5 times the sediment load observed prior to catchment disturbance.

Benefits of mangrove tidal wetlands

The chief benefits of mangroves are based on both their primary and secondary production, as well as with standing woody biomass and structure of the forests. Briefly, these features (adapted from Tomlinson, 1986, and in no particular order) include:

- visual amenity and shoreline beautification;
- nutrient uptake, fixation, trapping and turnover;
- habitat use by fauna where mangroves are a place to live;
- meso-climate, where forests might moderate evapo-transpiration to create a specialised niche climate;
- nursery habitat, where mangroves provide physical protection from predation and food for young fauna;
- sanctuary niche, where mangroves provide protection and a food resource for mature fauna, including migratory birds and fish; food source based on photosynthesis as primary production, giving rise to forest growth; forest products, notable as timber;
- secondary production, including microbial and faunal production, as well as grazers, and via decomposition;
- fishery products, including both estuarine and coastal;
- shoreline protection, based on general mangrove tree and root structure, as well as special edge trees, which reduce erosion and provide stand protection from waves and water movement;
- carbon sequestration and sink where carbon is bound within living plant biomass; and,
- sediment trapping, based on mangroves being a depositional site for both water and airborne (aeolian) sediments, which in turn reduces turbidity of coastal waters.

Mangroves are highly valued for some benefits, such as their importance to fisheries, but most other benefits are poorly appreciated, if at all. The end result is that mangroves have been steadily removed from most populated estuaries in the region over the last 150 years. This presents a clear message that tidal wetlands are valued more for their conversion value to other land-use than for their value as natural habitat.

The continued destruction of mangrove wetlands is, however, likely to cause far greater problems than appreciated previously – with consequences extending offshore to impact on the GBR, in North Queensland. While it may have been acceptable to offset acknowledged fisheries value of mangroves against the benefits of reclamation developments, this can no longer be justified without a much wider appreciation and awareness of the longer term consequences. Recent findings reveal that perhaps a more important benefit of mangroves is their capacity to hold and bind sediment (Furukawa *et al.*, 1997; Wolanski *et al.*, 1997). Some of the sediment carried in catchment run-off is trapped and held within estuarine mangroves leaving coastal areas relatively free of turbid waters and suitable for coral reef development. Without the filtering effect of mangroves, the turbidity and nutrient levels are increased and the reef is degraded (McCook *et al.*, 2001).

Knowledge of the past is our insight of the future

If changes in the past can be identified and quantified in terms of extent and rate of change, this will help predict future trends. Reasonable predictions of future trends are possible providing that the historical information is soundly based and accurately quantified. So, just like those who depend on maps for navigation, managers of coastal habitats must also rely on accurate historical assessments to help protect and promote the survival of threatened natural coastal ecosystems. This becomes especially poignant where the health of these systems might be linked to our own health and sense of well-being.

Types of change and respective indicators – tools for assessment and monitoring

For this project, we have identified and used a number of types of wetland change to quantify changes taking place in the study areas. The studies have not been exhaustive but they have been sufficient to show some major types of changes taking place and some of the more important driving factors. The types of change and drivers were identified using tools based on ecological parameters or indicators.

The unique characteristics and responses of mangrove forests may be used as sensitive and reliable indicators of changing climatic conditions and sea level elevation. Furthermore, the relatively noisy fluctuations of these factors within decadal time scales are also expected to be integrated within the plant community response. In this way, changes and shifts in vegetation zones are expected to quantify longer term trends, shown by the changes in structure and composition of tidal wetland plant communities.

General types of wetland condition and change

There are essentially four chief categories of change:-

A. Direct – Intended - Obviously human related

B. Direct – Unintended - Obviously human related

C. Indirect – Unintended - Less obviously human related

D. Not obviously human related, if at all

Changes are grouped primarily based on the influence of human activities as either direct, where the impacts are delivered directly and the outcomes are intended or unintended (A & B), or indirect, where the impacts occur as unintended consequences of some activity (C). The final category (D) includes changes not obviously resulting from human activities, e.g. natural changes to climate. Clearly, the final category will include the broad influences resulting from atmospheric changes and global warming.

Within these four categories, 12 types of change are listed, based on the drivers of change (Table 1). Indicators for the different types of change involve quantification of wetland condition and dieback. As will be pointed out for each, however, there are significant differences which can be identified and used to categorise types of change. Quantification of these effects over longer time periods provides the essential tools for assessment of change and condition of the major ecological environments in coastal areas.

Quantification of dieback areas and mapping damage requires fine spatial resolution imagery sufficient to identify individual trees. For digital imagery, this equates to a pixel size around $1m^2$. For historical assessments, aerial photographs are usually available from the 1940's to the present day.

During the past two centuries, human progress and development have increased dramatically in coastal areas of Australia, resulting in massive alterations to landscape and coastal features.

Notable significant losses have been observed for mangrove, salt marsh and saltpan zones in many areas and, particularly, associated with city and port expansion.

Furthermore, the rate of change appears to be continuing, if not accelerating, putting greater pressure on remaining natural coastal habitat. For instance, in the Mackay region, Pioneer River mangroves have been reclaimed on average by 5 ha each year over the last 50 years and this appears to be continuing (Duke *et al*., 2001). Although tidal wetland ecosystems have acknowledged benefits, the progress of change is such that scant attention is given until remaining habitat shows signs of collapse and failure. It is then debatable whether such degraded systems can recover, given that conditions surrounding them might have been irrevocably altered. With the habitat gone, so are the benefits, along with the inevitable loss of genetic diversity and environmental sustainability. Therefore, there is considerable urgency to develop efficient and quantifiable indicators of change, and relevant management tools to identify the drivers of change.

Table 1. Four categories of tidal wetland change and 12 types of change with respective indicator tools for assessment, evaluation and monitoring of coastal and estuarine habitat. Tools include ground or field observation plus features in remote sensing imagery.

Type of Change	Wetland Indicator Tool	Driver of Change	Example Reference
A. Direct – Intended & obviously human related			
1. Reclamation loss. Replacement of mangrove/ salt marsh/ saltpan habitat in coastal areas with various construction and development structures/sites – port, industry, urban.	**Ground:** Reported reclamation, constructed sea & canal walls. **Remote:** Geometric loss patterns in maps & photos.	Port, industry and urban development along coastal and estuarine margins.	Duke, 1997; Duke *et al.*, 2002; Duke *et al.*, 2003a
2. Direct damage. Dieback/damage/loss of mangrove/saltmarsh habitat caused by access, cutting, root exposure, sediment disturbance, root burial, ponded pastures & agricultural encroachment (different to 3 since change was intended).	**Ground:** Cut stumps, paths, vehicle tracks, exposed or buried roots, trampled substrate, compacted soil, structures blocking tidal exchange, dead/sick trees. **Remote:** Dieback/loss radiating from access points, & near retaining walls.	Human access, curiosity, wants, and recreation activities, plus construction of retaining walls for ponded pastures & tide blocking drains.	Duke *et al.*, 2003a
B. Direct – Unintended & obviously human related			
3. Restricted tidal exchange. Dieback/ damage of mangrove/ saltmarsh habitat associated with construction and development projects often resulting in impoundment (comparable with 2, but unintended in this case).	**Ground:** Pooled low tide water, restricted water flow, delayed tidal exchange, stagnant water, dead/damaged trees. **Remote:** Dieback/loss near reclamation & constructed levees & banks.	Constructions, like roads and sea walls, alter water flow and tidal exchange. Tree death mostly caused by excessive inundation of breathing roots.	Olsen, 1983; Gordon, 1987
4. Spill damage. Dieback/damage of mangrove/saltmarsh following incidents/ accidents involving spills of toxic chemicals in estuarine waters (compare with 7, but not associated with river flow events).	**Ground:** Reported spill incident, black tidal rings around stems, chemical (oil) in sediments, oily smell, dead/sick trees. **Remote:** Dieback/loss along tidal contours.	Spillage of toxic chemicals with local use & transport, oil spills. Tree death mostly from smothering of breathing surfaces.	Duke *et al.*, 1997; Duke, Ellison & Burns, 1998
C. Indirect – Unintended & less obviously human related			
5. Depositional gains and losses. Mangrove gains & losses at estuary mouths, & areas behind groins and training walls. Also includes dieback/damage of mangrove/ saltmarsh associated with sediment burial.	**Ground:** Colonisation downstream on banks, dieback with stream edge erosion or deposition. **Remote**: 'Island' appearances, plus edge gains & losses along water margins near mouth, and along sand/beach ridges.	Catchment vegetation clearing, soil disturbance, and construction of river/ shoreline training walls.	Duke & Wolanski, 2001; Duke *et al.*, 2003a
6. Nitrogen excess. Dieback/damage of mangrove/saltmarsh associated with excess algal growth on breathing roots (different to 8 by association with nutrients enhancing epiphyte growth *insitu*).	**Ground:-** Nutrients in water & sediment, foliage uptake of N, increased plant growth, excess macroalgae on exposed roots, pooled low tide water, dead/sick trees. **Remote**: Loss of inner stands.	Fertiliser use on crop lands in catchment areas plus sewage outflows from pipes & septic seepage.	Dennison & Abal 1999; WBM report
7. Species-specific effect. Dieback/damage of sensitive mangrove species associated with toxic chemicals brought downstream in run-off water (different to 4 by association with river flow events).	**Ground:-** Toxic chemicals (herbicide) in water & sediment, epicormic sprouting, dead/sick trees. **Remote**: Affects only select species.	Excess chemical used in catchment and coastal areas delivered in run-off. Tree death mostly from toxic effects.	Duke *et al.*, 2001, 2003b

Continued…

Type of Change	Wetland Indicator Tool	Driver of Change	Example Reference
D. Not obviously human related, if at all			
8. Wrack accumulation. Dieback/damage of mangroves associated with build-up of beach wrack (like dead algae, *Lyngbya*, seagrass) on breathing roots, and localised impoundment (compare with 6, but accumulations derived elsewhere).	**Ground:-** Wrack of dead algae (e.g., *Lyngbya*) or seagrass on roots, blocked tidal exchange, pooled water, dead/sick trees. **Remote**: Dieback/loss patches in beach & exposed stands.	Post-storm debris accumulation, and bloom debris often associated with deteriorating water quality nearby.	Duke & Pedersen, pers. obs.
9. Herbivore/insect attack. Dieback/ damage of mangroves associated with excessive herbivore/insect attacks on foliage or tree stems.	**Ground:-** Defoliated trees, insect frass on forest floor, insect presence, dead/sick trees. **Remote**: Patches of low density canopy foliage & dieback/loss.	Effects on herbivore/ insect life cycles, possibly associated with high nutrient content in foliage, and/or stressed habitat.	Robertson & Duke, 1987; Duke, 2002; Feller & McKee, 1999
10. Storm damage. Dieback/ damage of mangroves/saltmarsh associated with severe storm activity and incidents.	**Ground:-** Reported storm, damaged bark & foliage, exposed roots, broken stems, uprooted trees, sheltered survivors, dead/sick trees. **Remote**: Dieback/loss in patches or gaps.	Severe storms, cyclonic winds, strong wave activity, high stream flows, lightning.	Duke, 2001; Houston, 1999; Duke *et al*., 2002
11. Ecotone shift. Dieback/ damage of mangroves/saltmarsh associated with climate change. 'Wetland Cover Index' reflects shifts in ecotones as bands of dieback or recruitment within the tidal zone. (compare with 12).	**Ground:-** Bands of dieback within mangrove zone, along saltpans, recruitment into saltpans. **Remote**: Dieback/loss & gains along tidal contours in tidal zone.	Climate (rainfall) change affected by local and/ or global factors.	Fosberg, 1961; Duke *et al*., 2002; Duke *et al*., 2003a
12. Zonal shift. Dieback/ damage of mangroves/saltmarsh associated with sea level change. Shift in the entire tidal wetland (mangrove/saltmarsh) zone, being uni-directional beyond upper and lower elevational limits. Involves encroachment of mangrove into adjacent habitat (compare with 11).	**Ground:-** Reported sea level change, for increase case - mangrove recruitment & terrestrial dieback landward while eroded trees & losses seaward. **Remote**: Dieback/loss & gains at seaward and landward margins of tidal zone.	Sea level change affected by local and/ or global factors. May include changes in tidal amplitude.	Duke *et al*., 2002

Keys for Interpreting Change in Tidal Wetlands

The primary step in quantifying change involves identification of the different types of change observed in tidal wetland ecosystems. This is not always an easy task since some forms of change are difficult to discriminate and tell apart, while others may overlap and involve varying combinations of effects. The following keys provide comparative criteria for determining the twelve chief types of change listed in Table 1. Two keys are required since interpretations of change may be made during either: ground surveys, or assessments of aerial photographs and other remote sensing imagery. In the section following these keys, descriptions of each type provide further information and explanation of the driving factors responsible, as well as some examples of each.

Key based on ground observations

1. Loss of trees due to obvious human activities – construction, cutting, access ways.............. go to 2
1 Dead, sick trees not obviously affected by people .... go to 3

2. Cut tree stems, roads, tracks, trampling.. **(2) Direct Damage**
2. Constructed sea walls, landfill, channelled drainage.................................... **(1) Reclamation Loss**

3. Extraneous material present.. go to 4
3. No extraneous material present .... go to 6

4. Oil slick marks as rings around tree stems and above-ground roots, plus residual oil in sediment, oil sheen in footprints and on surface water .... **(4) Spill Damage**
4. Plant matter covering above-ground roots, associated with dieback...................................... go to 5

5. Wrack (e.g., seagrass, *Lyngbya*) present, associated with impoundment **(8) Wrack Accumulation**.
5. Macroalgae present on sediment and covering above-ground roots .... **(6) Nutrient Excess**

6. Abnormal appearance of trees, tree parts, and dieback .... go to 7
6. Trees with normal appearance and dieback .... go to 9

7. Epicormic sprouts, species-specific dieback (notably *Avicennia* sp.), growth deformities (e.g., with *Avicennia* pneumatophores) .... **(7) Species-specific Effect**
7. Notable damage effects in canopy foliage, branches, stems, on the ground .... go to 8

8. Defoliated canopy, leaf feeding scars, obvious frass on forest floor.. **(9) Herbivore/Insect Attack**
8. Damaged bark, broken limbs, scars & damage on 'weather' side of trees...... **(10) Storm Damage**

9. Recruitment, new stands, encroachment landward or seaward, associated with dieback .... go to 10
9. Little or no recruitment, associated construction works................ **(3) Restricted Tidal Exchange**

10. Orientated along upstream-downstream gradient, estuary tributaries and river mouths ....**(5) Depositional Gains and Losses**
10. Orientated along tidal contours, parallel to land and sea margins....................................... go to 11

11. Associated with mangrove to salt marsh-saltpan ecotone .... **(11) Ecotone Shift**
11. Associated with mangrove–seawater plus mangrove-terrestrial zone edges........ **(12) Zonal Shift**

Key based on remote sensing observations

1. Gains shown as patches of small, densely packed trees... go to 2
1. Dieback of trees or patches of trees, plus stands with low density canopies .... go to 3

2. Gains along the waters' edge, sometimes as 'islands' .... **(5) Depositional Gains & Losses**
2. Gains landward (as encroachment) and losses seaward, or vice versa .... **(12) Zonal Shift**

3. Partial canopy loss of individual trees, low canopy density ....**(9) Herbivore/Insect Attack**, or .... **(4) Spill Damage** (sublethal effect)
3. Complete canopy loss of individual trees (dieback death)... go to 4

4. Individual trees, 'freckled' effect (dead *Avicennia* sp.) .... **(7) Species-specific Effect**
4. Whole stands, or clusters of trees.. go to 5

5. Geometric boundaries, straight lines.. go to 6
5. No geometric patterns .... go to 8

6. Entire area and boundaries with geometric patterns .... **(1) Reclamation Loss**
6. Some boundaries not geometric, nearby geometric .... go to 7

7. Areas cut-off from sea/water edge .... **(3) Restricted Tidal Exchange**
7. Areas with access points, roads, paths .... **(2) Direct Damage**

8. Non-defined patches of dead trees .... go to 9
8. Dead trees along apparent contours, curvi-linear pattern.. go to 11

9. Associated with beach ridges, and in exposed stands .... **(8) Wrack Accumulation**
9. Dead trees in patches, usual interior stands .... go to 10

10. Blown over trees, directional effect .... **(10) Storm Damage**
10. Dead trees standing, no fresh broken stems, patches associated with inner areas, near saltpans... **(6) Nutrient Excess**

11. Changes associated with mangrove-saltpan ecotone .... **(11) Ecotone Shift**
11. Patches usually follow inner stand contours .... **(4) Spill Damage** (lethal effect)

Descriptions of the types of change and respective indicators for assessment and monitoring of estuarine ecosystems

The descriptions of change type are based on two criteria, ground observations, and remote sensing imagery. In the following descriptions, the chief criteria, especially those observed in the field, have been characterised in conceptual models showing a stylised cross-section of the intertidal zone (Figure 1). Vegetative cover through this zone is represented with mangrove trees from the waters edge (from left to right, starting at approximate mean sea level) to saltmarsh/saltpan in the mid section, and to mangrove at the landward margin where there is a transition into terrestrial plants. The tidal wetland zone includes both mangroves and saltmarsh/saltpan vegetation in these models.

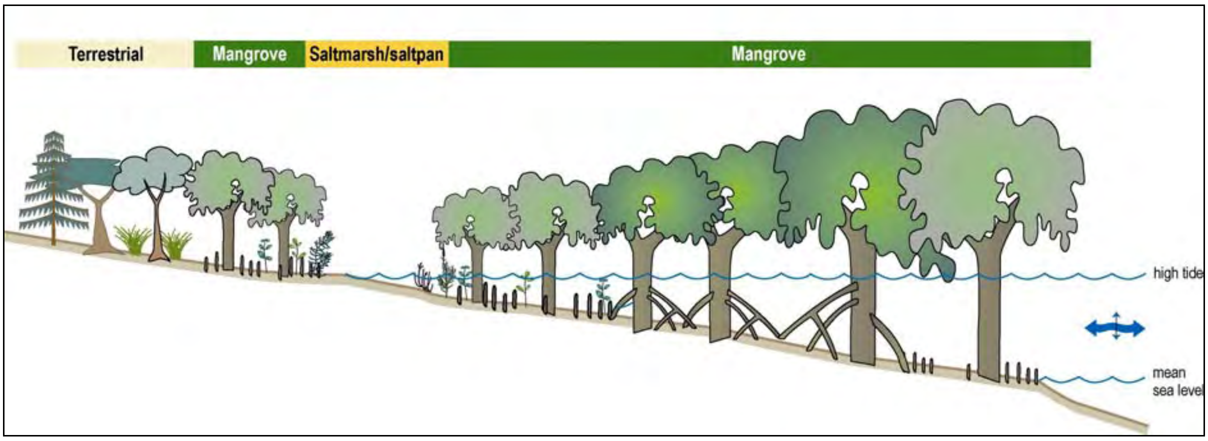


Figure 1. Idealised conceptual model of a pristine tidal wetland environment.

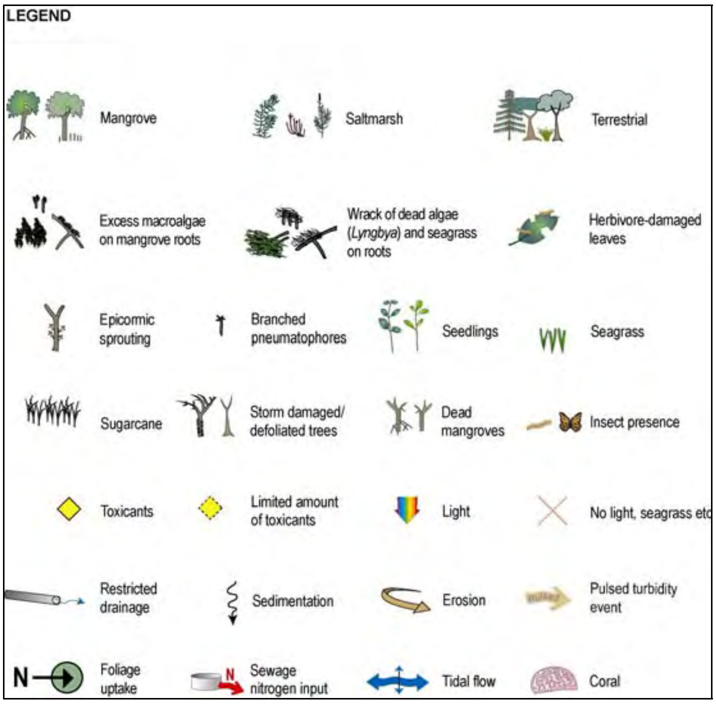


Figure 2. Legend of symbols used in the conceptual diagram models in this chapter.

1. Reclamation loss

This type of change should be quantified in detail over as long a time period as possible and, especially, over the last 150-200 years. In order to make informed decisions about changes to ecosystem function and sustainability, large-scale alterations by reclamation of wetlands need to be mapped, measured and monitored. This has been done for the Brisbane River estuary, and the changes recorded were understandably considerable, where the area of tidal wetlands was reduced by well over half to around 900 ha remaining today. It is unfortunate that this reduced area is characterised by patches of unintended dieback from a number of other pressures, discussed with subsequent indicators.

Mapping and quantifying reclamation loss over the last 60 years is important because it defines the extent of major recent change, and the current rate of change in Australia. Both measures define the status and condition of tidal wetlands today and, to some extent, the functionality of the estuarine ecosystem. The 60 year time frame is significant in that the first remotely sensed images, black and white aerial photographs, became available for sites around Australia.

An index of reclamation loss can be calculated as the percentage of habitat lost from reclamation, to the total wetland area beforehand.

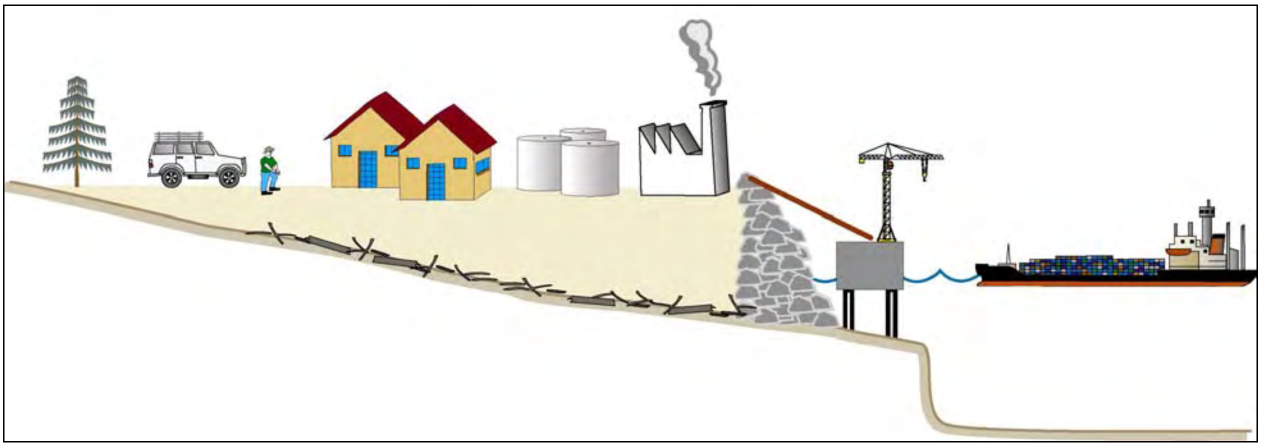


Figure 3. ***Reclamation loss*** conceptual model. Compare with the pristine tidal wetland zone profile shown in Figure 1, with legend items in Figure 2.

2. Direct damage

Damage due to cutting and direct effects is either small or difficult to quantify in Australian mangrove forests. There has been occasional localised damage caused by cutting mangrove trees for views and windways; such as for the Port Hinchinbrook site at Oyster Point, near Cardwell. In this case, 5 m tall trees were lopped to between 1-2 m, despite advice that this practice was not sustainable in the location. Perhaps the most severe and common direct effects on mangroves and salt marsh/saltpan areas are due to access, in the form of frequently-used walking tracks, roads, bikeways, paths, playing fields, fishing spots and rubbish dumps.

A recent survey was conducted by Marine Botany undergraduate students from the University of Queensland of visitation numbers to a mangrove site at Myora Springs on North Stradbroke Island. More than 160 people visited the area over a two day period, Sunday and Monday (15 & 16 September, 2002). Many people were curious to walk amongst the trees, while a bus load of school children were there as part of their school science course. Most visitors were not aware that their presence (each foot) was adding to the impact and damage to the area. Many said they thought a purpose-built mangrove walkway was a good idea and they would use it. During the survey, the tidal area adjacent to the access point was mapped and it was found that approximately 1.5 ha of mangroves were significantly damaged. Effects included: trampled breathing roots, compacted sediments, reduced seedling recruitment, reduced infauna, broken branches, high ground temperatures, greater light, damaged root mat, erosion of sediment, and exposure of underground cable roots. Although longer-term surveys should be conducted, the apparent heavy usage of this site suggests that the installation of an educational walkway may be well justified. It is expected that this would be the best management strategy for this kind of damage – although each instance of direct damage needs to be dealt with separately.

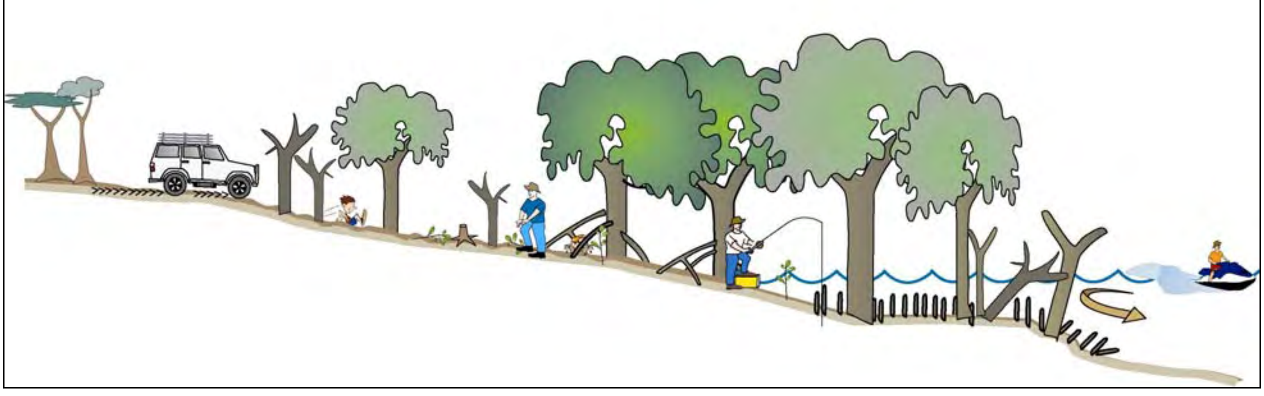


Figure 4. ***Direct damage*** conceptual model. Compare with the pristine tidal wetland zone profile shown in Figure 1, with legend items in Figure 2.

Specific remote sensing techniques are currently being explored by Steve Voke and Dan Pedersen, postgraduate students with Stuart Phinn and Norm Duke. Their findings so far are extremely favourable, suggesting hyperspectral imagery can detect subtle changes in green canopy foliage linked with apparently unhealthy mangroves surrounding dieback areas in Moreton Bay. These findings will be incorporated into the final report and publications due in June 2003.

3. Restricted tidal exchange

Mangroves and salt marsh habitat grow mostly in tidal areas subject to regular flooding and drainage. When they become flooded for long periods and their breathing root surfaces are covered then the trees will die due to lack of gaseous exchange. Changes in hydrology have been implicated in instances of dieback in Florida, USA (Turner & Lewis, 1997) and in Western Australia (Gordon, 1988).

In Florida, Turner & Lewis (1997) described examples of dieback resulting from prolonged flooding and hydrological alterations following the construction of a roadway adjacent to and across a tidal wetland margin. In a second instance, assessed over a 60 year period, there was an indirect loss of vegetation five times greater than the direct loss caused during causeway construction. This indicated that alterations to tidal wetland areas can have a five-fold detrimental effect on remaining wetland areas.

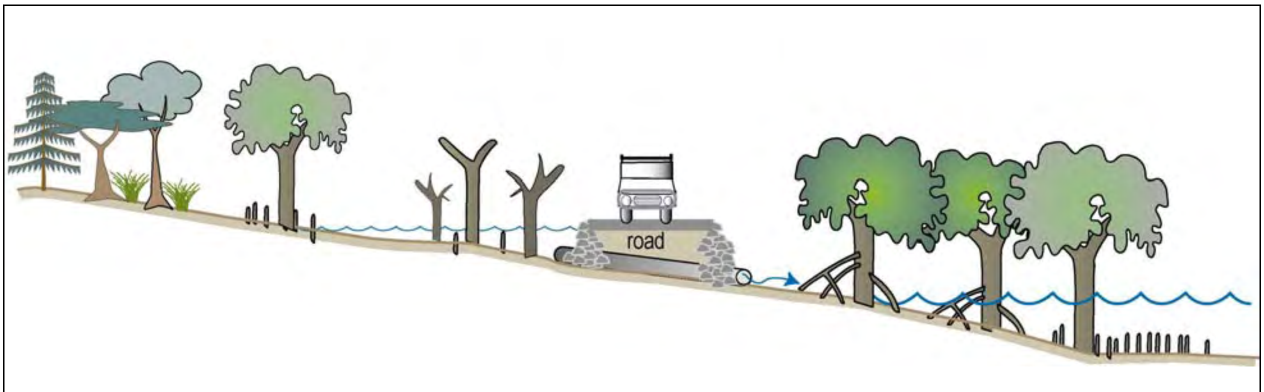


Figure 5. ***Restricted tidal exchange*** conceptual model. Compare with the pristine tidal wetland zone profile shown in Figure 1, with legend items in Figure 2.

In many cases, the effects are unequivocal but there are cases where the effects are subtle. In a site near Karratha, Gordon (1988) reported that a delay in tidal exchange was having serious detrimental effects on mangrove habitat. In this instance, an old road bridge on stumps had been replaced with a stone causeway with large pipes at the lowest point of the defined tidal channel. Unfortunately, the exchange of water through the pipes, and via seepage through the rockwall, was delayed to such an extent that water upstream of the road crossing was unable to drain during the low tide period before the tide turned. This resulted in notable dieback and deterioration in mangroves upstream of the crossing. It is of concern that this was not an isolated case, with other examples of this type of change recorded in this area (Gordon 1988).

In either case, the indicator tool for this type of change can be based on quantification of dieback from remotely sensed images linked to evidence from ground surveys or knowledge of recent constructions and earth works likely to affect hydrology and tidal exchange.

4. Spill damage

Mangrove forests are well-known for their high vulnerability to oil spills, since floating oil settles with the tide and smothers both breathing and feeder roots plus a myriad of associated resident fauna (Jackson *et al.*, 1989; Volkman *et al.*, 1994). Oil deposited on tree roots results in the death of some trees, but it also results in depressed growth of survivors across the wider oiled area (Duke *et al.*, 1998a). A large area of *Avicennia marina* was oiled in South Australia but only a very small percentage died (Edyvane *et al.*, 1994; Wardrop *et al.*, 1998). Low levels of dieback resulting from oil pollution were also observed in mangroves dominated by *Rhizophora* in Panama (Duke *et al.*, 1997). As such, the dramatic impact of deforestation of mangroves after an oil spill (when it occurs) is indicative of a much larger impacted area.

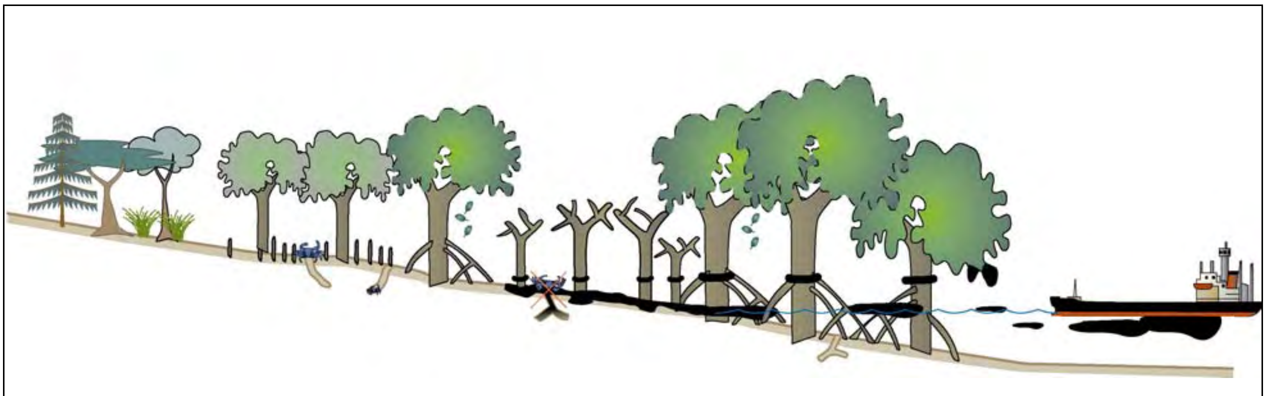


Figure 6. ***Spill damage*** conceptual model. Compare with the pristine tidal wetland zone profile shown in Figure 1, with legend items in Figure 2.

The more subtle effects of sublethal damage, manifested as loss in canopy density, also act to weaken the forest habitat, putting remaining trees at greater risk of damage from further disturbance. The longer term effect can persist for several decades (e.g., Wardrop, 1987), and result in ecosystem collapse in some cases (Duke *et al*., 1997).

This type of change is also best dealt with on an individual case level, although a specific assessment of dieback from remotely sensed images would be extremely useful since it is indicative of the larger impact. Oil-spill related dieback has been estimated to impact around one fifth of surrounding oiled areas, based on loss in canopy density (Duke *et al*., 1997). Notable additional detrimental effects on trees and fauna are expected (Duke *et al*., 2000). As noted for direct damage (2), specific hyperspectral remote sensing techniques are currently being explored by the postgraduate students with Stuart Phinn and Norm Duke. These findings can be incorporated into the final report and publications due in June 2003.

5. Depositional gains and losses

Sediment washed down from catchment areas accumulates in estuaries and along nearshore coastlines. Direct evidence of these sediments is notable today as mud along foreshore areas, as well as the often enlarged and new areas of downstream estuarine mangroves. Examples of this have been reported for Trinity Inlet, the Pioneer River, and the Fitzroy River.

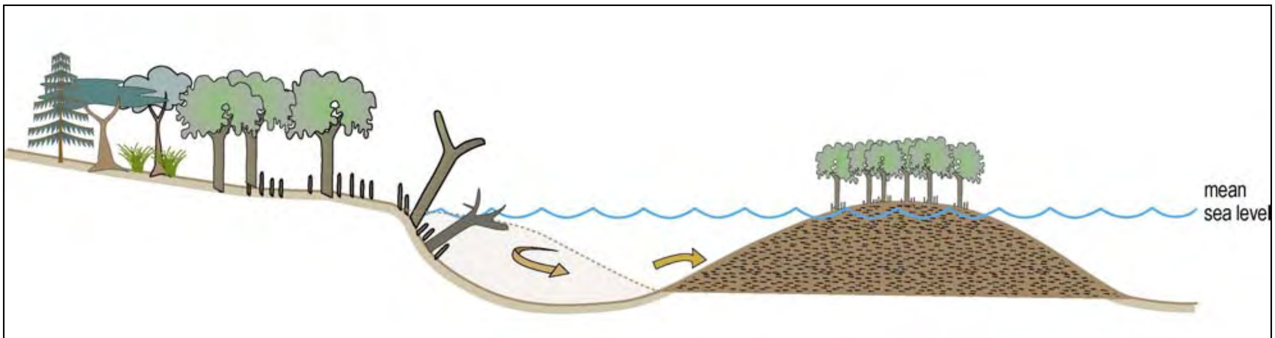


Figure 7. ***Depositional gains and losses*** conceptual model. Compare with the pristine tidal wetland zone profile shown in Figure 1, with legend items in Figure 2.

In Trinity Inlet, the coastline has become muddier over the last 100 years (Wolanski & Duke, 2000; Duke and Wolanski, 2001). Evidence for the increase in mud, and a general change from a sand/ mud dominated foreshore to the present-day mud dominated foreshore, is found in several historical records, including old marine charts, historical photographs, and anecdotal accounts from long-time residents. An assessment of this information provided evidence of mud accumulation to a level 1.5 m above that existing 100 years earlier. Furthermore, increases in mangrove vegetation of Trinity Inlet over 46 years were mostly located along the seaward margins of the original stands. Areas of new mangrove are indicative of sediment depositional banks that have risen above mean sea level. Sediments must deposit up to this level before mangroves can naturally colonise a mud bank. This observation usually only applies to areas with fine-grained sediment banks, notably mud banks, since it is the associated prevailing hydrological conditions which best suit mangrove colonisation and establishment. Another example of new mangroves colonising downstream areas within 50 years was reported for the Pioneer River estuary (Duke *et al.*, 2001; Duke and Wolanski, 2001). In this instance, once again, the greatest gains in mangrove area were at the mouth of the estuary. Limited gains were associated with smaller drainage tributaries upstream, and alongside river-training walls.

In both instances, estimates of net change in mangrove area revealed substantial net losses of mangrove area of 19.5% and 30.4%, over the last half century (Duke and Wolanski, 2001). However, comparisons based on net change can be misleading. For instance, Russell (Russell & Hales, 1994; Russell *et al.*, 1996) reports positive estimates of net change in Johnstone (14.8%) and Moresby Rivers (28.7%). Such increased areas of mangrove are not indicative of a healthy estuarine system. Instead, they are indicative of increased muddiness and sediment deposition. Therefore, it is also informative to compare areas of new mangrove, and to view these areas as advanced depositional banks made up of sediments derived from eroded catchment areas upstream, or changes resulting from alterations to estuarine hydrology, like the construction of river training walls.

Initially, the changing area of new mangrove might provide an indirect measure of fine sediment accumulation, and a possible indicator of catchment degradation or changes to estuarine flows. This parameter might integrate a complex mix of influencing factors, including both the extent of cleared land, as well as differences in land-use combined with climatic variables, particularly rainfall volume and periodicity. In any case, the combined inputs of these often nutrient-rich muds to coastal waters from run-off and dredging are considered by some to be one of the biggest threats to the coastal reefs of the Great Barrier Reef (Bell and Elmetri, 1995; Fabricius and De'ath, 2001).

The indicator tool for this type of change, the detection of mangrove gains/ losses along river edges or as 'islands' and banks in the river mouth (via remote or ground survey techniques), might be used as a longer term measure to monitor management strategies applied to reduce the amount of sediment in run-off. Of course, this must be considered with other notable influences on catchment condition, including types of land use, geomorphological condition, and variations in climate and sea level.

6. Nutrient excess

High levels of nutrients alone have not been implicated directly in mangrove dieback. Nonetheless, there is a distinct possibility that plant uptake of other toxic chemicals may be increased as a consequence of high nutrient levels enhancing growth. High nutrient levels may also alter faunal communities and this might affect the tight trophic links between mangrove trees and fauna (Robertson *et al.*, 1992). In investigations of ecosystem health, it is important to assess nutrient inputs and plant uptake. The chief sources of high nutrient loads into estuarine areas are considered to be sewage outflows, and fertiliser run-off from upstream crop lands (Baker *et al*., 2003).

High levels of the stable isotope ratio, $\partial\ ^{15}$nitrogen, are indicative of greater uptake of sewage-derived nitrogen. Atmospheric nitrogen (N) occurs in two stable isotopic forms, ^{14}N (most abundant) and ^{15}N (smaller fraction), with $\partial^{15}N$ referring to the relative proportion of ^{15}N to ^{14}N, compared to a worldwide standard (Dennison & Abal, 1999). Generally, sewage has an elevated proportion of ^{15}N, giving a higher $\partial^{15}N$ signature for both effluent and plant tissues near sewage outflows. These plants can be used as biological indicators of sewage N. Comparative data, where maximal values were recorded from mangrove trees close to sewage treatment plant outlets, are provided in Table 2.

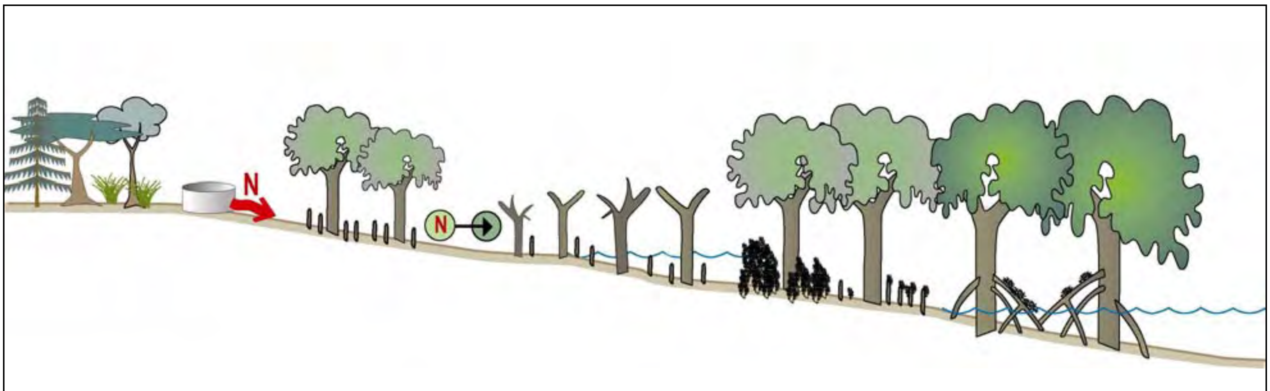


Figure 8. ***Nutrient excess*** conceptual model. Compare with the pristine tidal wetland zone profile shown in Figure 1, with legend items in Figure 2.

Table 2. ∂^{15}N of mangrove trees from selected locations, with maximal values recorded from trees close to sewage treatment plant outlets.

Location	**Species**	**∂^{15}N**	**Reference**
Moreton Bay, SE Qld	*Avicennia marina*	2.2-12.2	Dennison & Abal, 1999
Mackay region	*Avicennia marina*	2.5-16.5	Duke *et al*., 2001
Mackay region	*Rhizophora stylosa*	0.3-13.5	Duke *et al*., 2001
Hinchinbrook Channel, N Qld	*Rhizophora stylosa*	~3.20	Costanzo, unpubl. data
Florida Keys, Florida	*Rhizophora mangle*	~2.0-12.0	Fry *et al*., 2002

Instances of relatively minor dieback of *Avicennia marina* have been observed in several sites around Moreton Bay. One reason proposed for this dieback was impoundment associated with algal build-up on mangrove roots blocking outflow channels. This characteristic has direct links and comparison with ‘wrack accumulation’ (8), with the exception that this damage is known to be caused by indirect human factors, associated with ‘excess nutrients’.

7. Species-specific effect

Species-specific dieback is a relatively new indicator of ecosystem health for mangrove habitat although the importance of species diversity affecting distribution is well known. There are up to 38 species of mangroves from 20 plant families in Australian estuaries (Duke *et al.*, 1998b), and each species might respond differently to a potential impact agent. Mangroves use a diversity of morphological, anatomical and physiological adaptations for living in the intertidal zone, which are not common to all species. This characteristic is reflected in distinct and common distribution patterns across intertidal profiles, in upriver estuarine locations, and with latitude. Species are sorted by their different abilities with respect to key influencing factors, including: rainfall, inundation frequency, salinity and temperature. Despite these influences, or perhaps because of them, species-specific dieback is relatively uncommon in mangrove habitat not affected by human activity. The effects of climate and sea level change and the importance of these responses are discussed later for Ecotone and Zonal Shifts (11 & 12). Also, major differences in root structures for gas exchange between species do not appear to match varying levels of sediment deposition (Ellison, 1998).

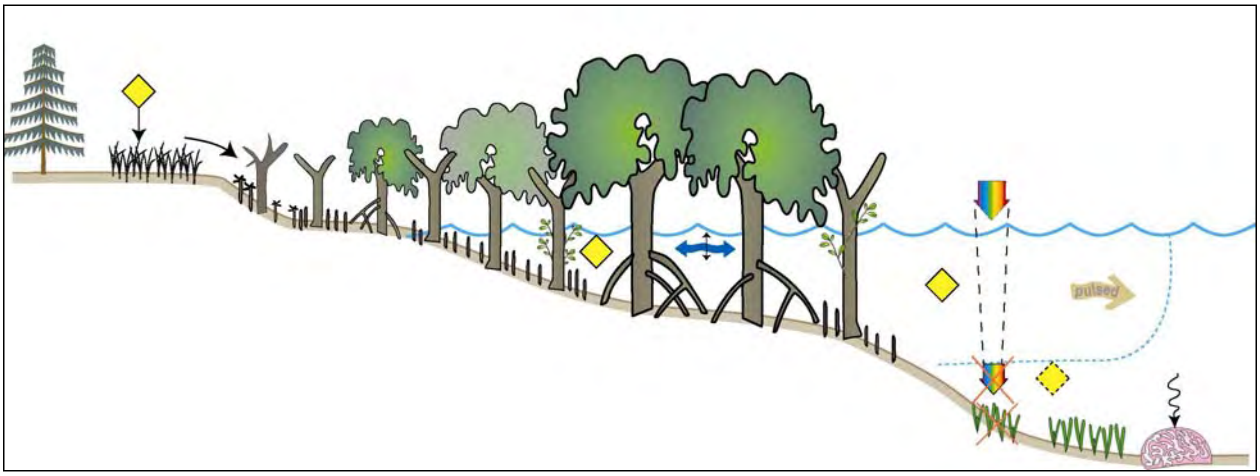


Figure 9. ***Species-specific effect*** conceptual model. Compare with the pristine tidal wetland zone profile shown in Figure 1, with legend items in Figure 2.

The recent case of mangrove dieback in the Mackay region is species-specific, directly affecting only *Avicennia marina* (Duke *et al.*, 2001). This instance of dieback was considered the worst of its kind in the world because of this specificity, coupled with the observations that this species is common, occurs widely, usually grows well in arid and wet environments, and responds better than most to physical damage. The preliminary investigation found dieback was widespread along 30 km of coastline and centred around the Pioneer River estuary where herbicides, diuron and ametryn, were detected in mangrove sediments of dieback areas. Based on such findings, it was concluded that herbicides were the most likely causative factor. Subsequent and more extensive field and laboratory investigations, currently in progress, confirm the earlier conclusion. Planthouse trials conducted by Alicia Bell during her Honours program with Norm Duke showed *Avicennia marina* was the more vulnerable of four common mangroves tested with doses of the same herbicides found in the field (Bell, 2002).

The reason for the greater susceptibility of *Avicennia marina* appears related to some well-known physiological differences of mangrove species. Physiological differences are likely to influence the amount of various chemicals (including nitrogen and salts) taken up through the roots of different species. *Avicennia marina* is known as a 'salt excretor' while other species either exclude salt or they take up smaller amounts. *Avicennia marina* also has special salt glands on its leaves to excrete salt. It is thought that *Avicennia marina* might take up toxic chemicals into its sap along with the salt, and this would explain its greater sensitivity to herbicides, and its dieback response in the Mackay region (Duke *et al.*, submitted).

Based on these current findings, *A. marina* dieback may be a useful indicator of excessive levels of toxic chemicals in water and sediments. The source of these chemicals might be deduced by association and additional forensic investigation. Irrespective of such studies, the recent challenge is to map the extent of dieback. This study is also in progress and it should be completed by the end of the year. There has been no prior suitable mapping or quantification of the damage so far. Aerial photography has only been taken since the dieback was first observed, after 1998. This dieback occurs in at least 5 major estuarine systems north and south of the Pioneer River estuary, and the extent of mangrove areas affected exceeds 31 km^2.

The challenge in the mapping concerns the discrimination of one species from 20 others where there are extensive mixed mangrove communities with sometimes only occasional *Avicennia marina*. While the other species appear healthy, if the one or two *Avicennia* trees are dead, then these areas must be recorded as heavily impacted and comparable with the more obvious occasional monotypic stands of dead *Avicennia*. This indicator of a species specific effect may be seen as analogous to the 'canary in the coal mine'. There has also been some urgency in obtaining the imagery because, once the dead *Avicennia* trees start to decompose after 5-6 years, it will be much harder to quantify the extent of impact in mixed stands.

8. Wrack accumulation

As noted for Restricted Tidal Exchange dieback, mangroves and salt marsh habitat are killed when flooded for extended periods. When they become flooded and their breathing root surfaces are covered, the trees will die due to lack of gaseous exchange. In this case, impoundment is caused by accumulation of algae, seagrass or *Lyngbya* washed into intertidal areas where it blocks tidal exchange.

A few such instances of relatively minor dieback have been observed in Moreton Bay. The most recent notable incident is the occurrence of dieback at Adams Beach on North Stradbroke Island. In this case, dieback involved *Avicennia marina* and *Bruguiera gymnorrhiza* and was caused by *Lyngbya* accumulations from beach wrack blocking a small tidal channel leading to the back-beach mangrove stand. This dieback type has direct comparison with 'Nitrogen Excess' (6), although wrack damage is not necessarily associated with human factors.

This form of dieback can be quantified from remotely sensed images with other incidents of dieback but must then be distinguished using field surveys.

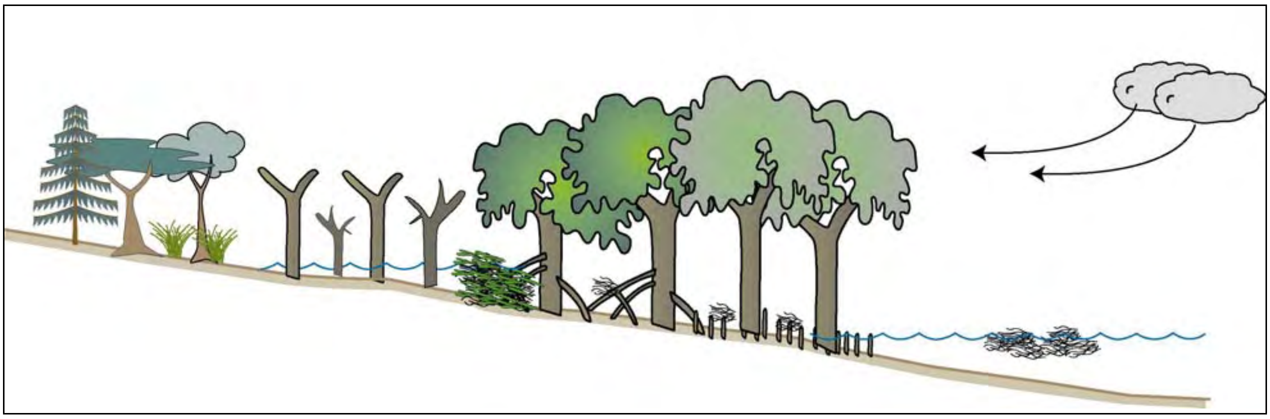


Figure 10. ***Wrack accumulation*** conceptual model. Compare with the pristine tidal wetland zone profile shown in Figure 1, with legend items in Figure 2.

9. Herbivore/Insect attack

Mangroves reportedly have few herbivores and relatively low levels of herbivory, mostly less than 10%. Overall amounts of herbivory, or leaf loss, were estimated to be around 6-12 % in various mangrove forests (Johnstone, 1981; Robertson and Duke, 1987; Lacerda *et al.*, 1986; Rau and Murphy, 1990; Farnsworth and Ellison, 1991; Saur *et al.*, 1999) and, when compared with rainforests, these levels were either comparable or much less depending on the method used to assess rates (see e.g. Lowman, 1984; Landsberg and Ohmart, 1989). Occasionally, however, mangroves are affected by instances of excessive herbivory. Examples of high levels of herbivory for various mangrove species and locations include: *Avicennia marina* in eastern Australia (West and Thorogood, 1985), in Hong Kong (Anderson and Lee, 1995), and on Aldabra Atoll, Indian Ocean (Newberry, 1980); *Avicennia alba* in Thailand (Piyakarnchana, 1981); *Excoecaria agallocha* in eastern India (Kathiresan, 1992), in northern Sumatra, Indonesia (Whitten and Damanik, 1986), and in eastern Australia (McKillup and McKillup, 1997); *Rhizophora mangle* in Ecuador (Gara *et al.*, 1990); and *Rhizophora stylosa* in north-eastern Australia (Duke, 2002).

Destructive wood boring insects have been reported from Florida (Feller and McKee, 1999). These cause limb shedding, structural damage and tree death.

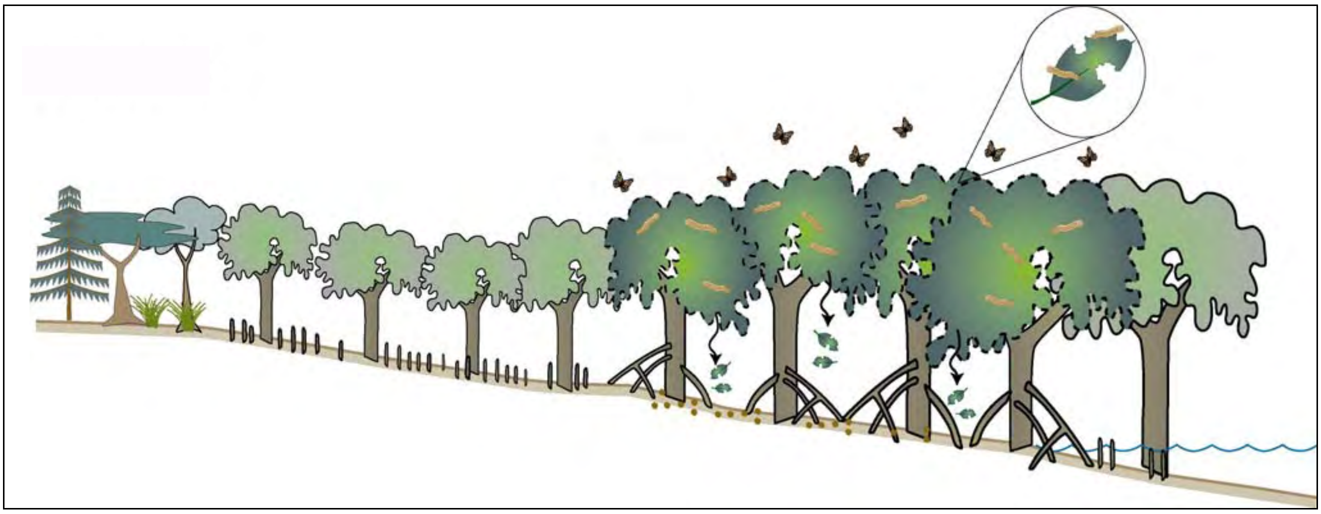


Figure 11. ***Herbivore/insect attack*** conceptual model. Compare with the pristine tidal wetland zone profile shown in Figure 1, with legend items in Figure 2.

This category of change is best dealt with on an individual case level because much insect damage is not lethal even when herbivory levels are severe. As an indicator tool for this type of change, the remote sensing techniques being explored by Steve Voke and Dan Pedersen offer future improvement on the identification of such sublethal impacted areas. Their findings, so far, are favourable, suggesting that hyperspectral imagery might detect subtle changes in green canopy foliage due to alterations in photosynthetic pigment concentrations that enable discrimination between healthy and sick trees, and normal and low density canopies.

In any case, while it remains essential to combine field and remote sensing studies, final indicator discrimination must rely on field observations of insect presence, frass, and leaf loss.

10. Storm damage

Severe storms, strong winds, large waves and their consequences all cause damage and dieback of mangrove habitat (Duke, 2001). Examples of storm damage include: violent wind storms (Craighead, 1964; Putz *et al*., 1984; Smith *et al*., 1994), frost damage (Lugo and Patterson-Zucca, 1977), hail damage (Houston, 1999; Steggles, 2002); lightning strikes (Paijmans and Rollet, 1977), and seasonal flooding or drought. The scale of damage caused by storm disturbances varies considerably, from the vast areas destroyed by Hurricane Andrew in Florida (Smith *et al*., 1994) to single tree incidents. Watson (1928) reported dieback of *Avicennia marina* in the Brisbane River following a major flooding event caused by siltation and smothering of breathing roots. However, the most common storm dieback of mangroves are small gaps comprising around 10-20 trees and reputedly caused by lightning.

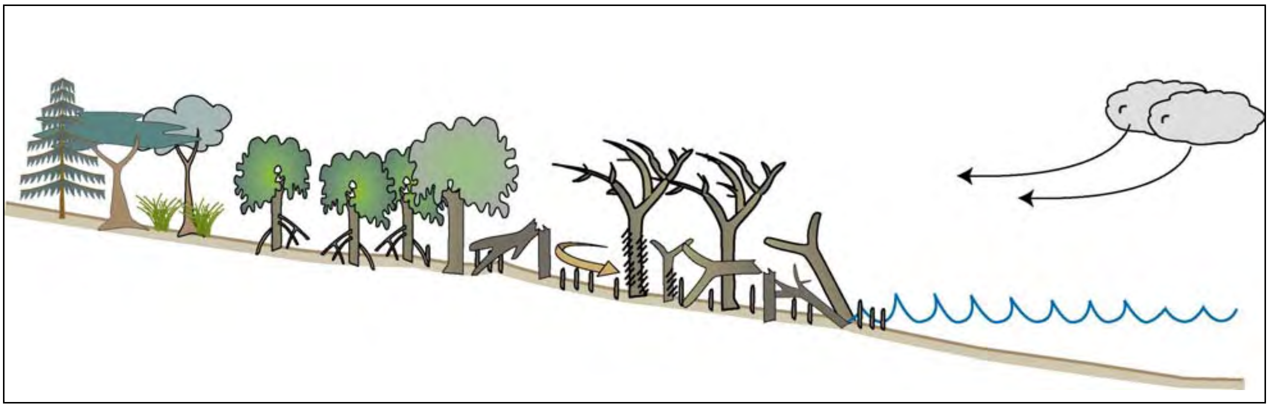


Figure 12. ***Storm damage*** conceptual model. Compare with the pristine tidal wetland zone profile shown in Figure 1, with legend items in Figure 2.

There are two incidents of hail damage reported, one in Port Curtis area, and the other in southern Moreton Bay. In each case, mangrove dieback was severe, where stems and bark were lacerated on one side of trees, and leaves were stripped. Dieback and damage occurred over more than 50 ha in each case. There has been limited recovery, but mostly restricted to regrowth of *Avicennia marina*. By contrast, other species (e.g. *Rhizophora stylosa*, *Ceriops sp*. and others) died at the time and there has been little or no recruitment.

Quantification of storm incidents involves mapping of dieback areas using fine resolution imagery sufficient to identify individual trees. For digital imagery, this equates to a pixel size of around $1m^2$.

11. Ecotone shift

Shifts in vegetation zones are expected to follow longer term trends, as shown by the periodic changes in structure and composition of tidal wetland plant communities. Changes in climate affect the relative cover of mangrove and saltmarsh vegetation, and the extent of saltpan. These upper intertidal zones vary in relative dominance in different climates, and their characteristic patterns in different areas can be quantified to monitor shifts in intertidal ecotones.

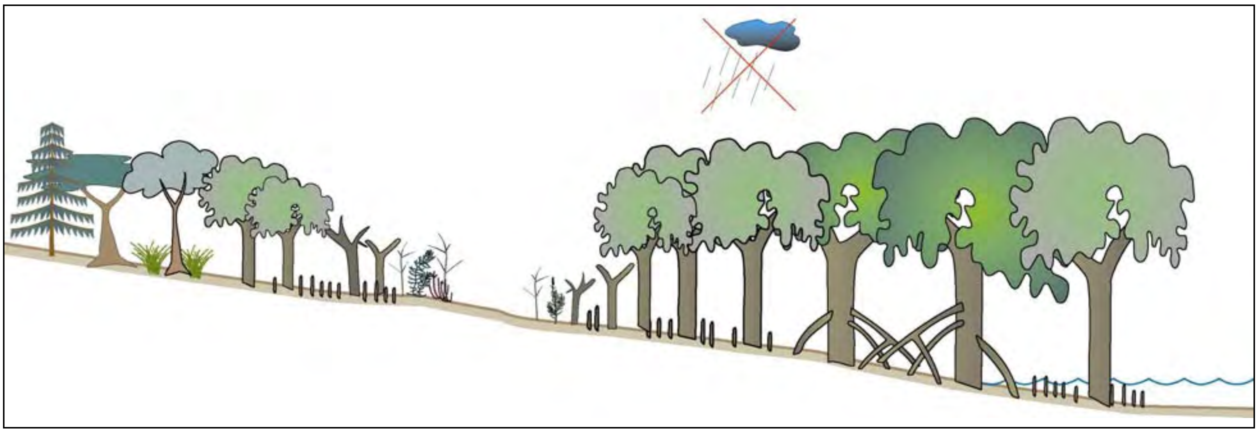


Figure 13. ***Ecotone shift*** conceptual model. Compare with the pristine tidal wetland zone profile shown in Figure 1, with legend items in Figure 2.

Fosberg (1961) noted there was an apparent relationship between the extent of vegetation-free zones (saltpans) and climate, for estuaries along the north-eastern coast of Australia. This relationship can be confirmed by comparing mean annual rainfall with an index of wetland cover. The 'Wetland Cover Index' used here is a percent ratio of the area of mangrove to the total area of the upper intertidal zone (i.e., the total area of mangrove, salt marsh and saltpan) for any given location. The reason these habitats can be grouped in this way is because they share the same ecological niche. And, as Fosberg pointed out, each is capable of occupying the entire zone under certain conditions depending on the climate, notably rainfall.

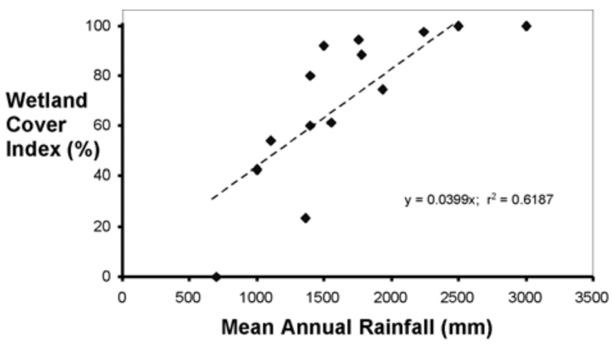


Figure 14. The relationship between mean annual rainfall and Wetland Cover Index for 14 sites in northern Queensland (Danaher 1995; Ebert 1995; Russel *et al*. 1996). The linear regression shown is highly significant ($P < 0.001$). The Wetland Cover Index is calculated for each site as the mangrove area divided by the sum of areas for saltpan, salt marsh and mangrove, and multiplied by 100.

A plot of mean annual rainfall and the Wetland Cover Index is shown in Figure 1 for marine wetland sites in northern Queensland. A linear regression quantifies the positive trend where sites with rainfall <1400 mm have less mangrove coverage and more saltpan and salt marsh, while wetter sites with >2200 mm are totally occupied by mangroves with no saltpan or salt marsh. Conversely, sites with rainfalls <1000 mm have quite small areas of mangrove. This relationship is based on sites within the tropics where temperature conditions are relatively warm most of the year. It is expected that the relationship will be more complex in temperate areas where there are less mangrove species, if any. A different index is needed for these areas.

For tropical areas, however, this relationship clearly identifies an important ecological parameter which might also be a useful indicator of subtle changes in climate over time. For instance, in the Hinchinbrook area, Ebert (1995) identified a 78% loss of salt marsh area between 1943 and 1991. This loss was almost entirely due to a corresponding increase in mangrove area without appreciable change in seaward or landward margins. It therefore appears that mangroves in the upper intertidal area increased from 94.5% to 98.8%. Based on the relationship shown in Figure 1, this is indicative of ~5% increase in annual rainfall over approximately 50 years, to a current rainfall around 2200 mm. It is reasonable to infer that there may have been a trend towards wetter conditions in this region. Actual rainfall data for the area (taken from Cardwell, adjacent to Hinchinbrook) appears to support this inference, with a period of drier years preceding the 1940's and a period of wetter years preceding the 1990's (Figure 2). If the data are grouped over 50-year periods, the average annual rainfall from 1890-1939 was 2025 mm, compared with 2180 mm from 1940-1989. This represents a 7.7% increase, very similar to the ~5% increase predicted.

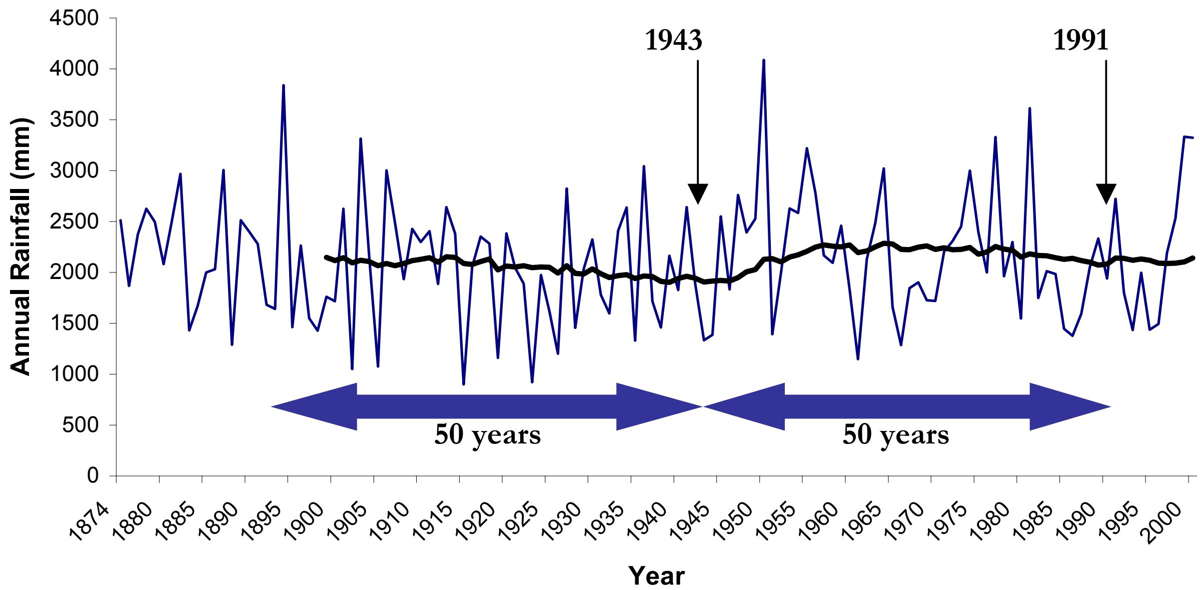


Figure 15 Annual rainfall for Cardwell, 1874-2000. Black trendline represents the moving average over a 25-year time period. (Source: Bureau of Meteorology Australia)

It is not known how long it might take for intertidal plants to respond to changes in rainfall patterns but it is expected that seasonal-annual fluctuations will be integrated within progressive longer term trends by the plants.

The Wetland Cover Index is, therefore, a useful indicator which, when applied in an historical assessment of intertidal vegetation cover, provides a convenient retrospective measure of past climatic condition, and any longer term trends.

12. Zonal shift

Plants dependant on the intertidal zone might also be expected to shift with changing sea level. Mangroves are normally constrained by tidal range and sea level. In recent geological time, sea level has fluctuated widely, with changes of tens of meters occurring over the last 10,000 years and much more during the last 100,000 years. Since mangrove genera evolved at least 50 mya and their habitat preference appears to have remained largely unchanged (Plaziat *et al.*, 2001), then existing mangrove stands confirm the ability of these plant communities to successfully adapt to the continual fluctuations of this dynamic niche. For instance, when sea level increases, mangroves must encroach with recruitment into low-lying terrestrial habitat while there will be a corresponding dieback and retreat of established plants at the seaward margin.

The kinds of changes observed are shown in two examples of slope in Figure 3. For Profile 1, with an even slope, notice the shift upward (or inland) of the mangrove/saltmarsh zone with an equal loss at the seaward margin. By contrast, there is a very different outcome for Profile 2, with its varying, more realistic slope. The shift inland occurs at both seaward and landward margins, but the upward extent of each is very different. There is also an increase in the mangrove/saltmarsh zone, where there was only a small loss at the withdrawing seaward margin compared with the extensive encroachment into low lying terrestrial habitat.

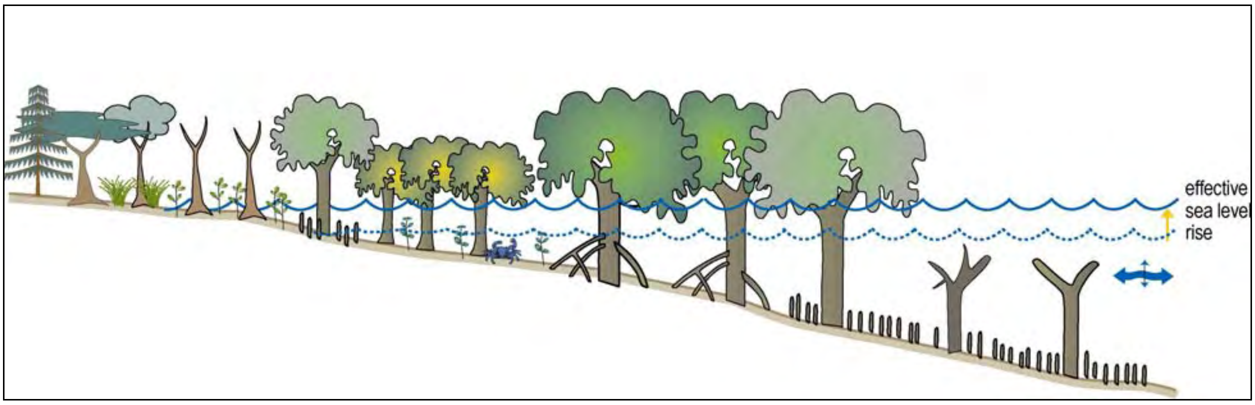


Figure 16. ***Zonal shift*** conceptual model. Compare with the pristine tidal wetland zone profile shown in Figure 1, with legend items in Figure 2.

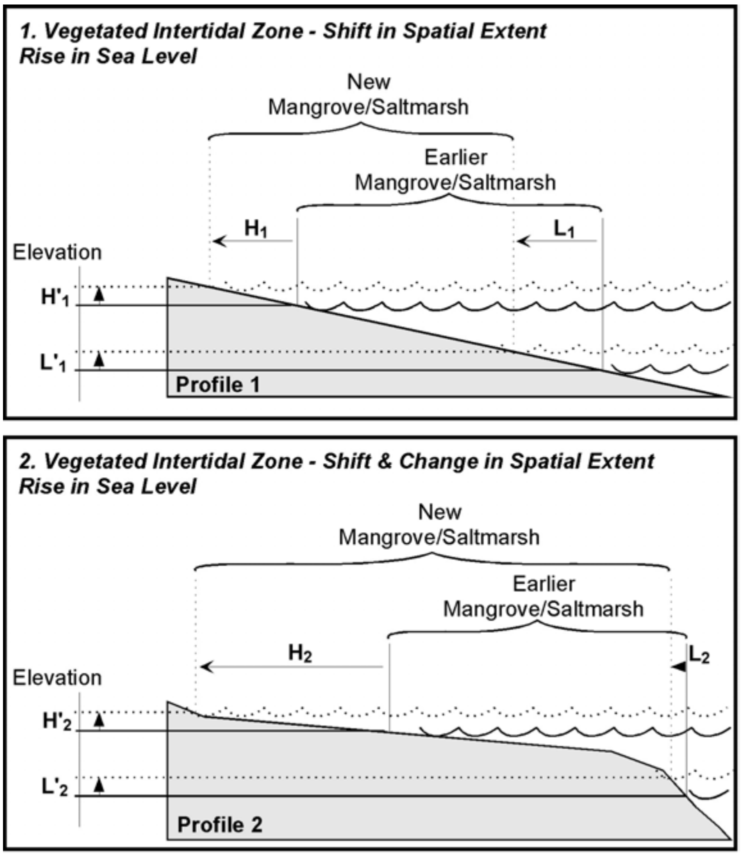


Figure 17. Profile cross-sections showing the types of spatial changes expected with an equivalent rise in sea level, and notable differences between two different slopes.

An example of this latter kind of zonal shift is thought to be that occurring in southern Moreton Bay, on Cobby Cobby Island. A preliminary assessment of vegetation change on the island (Figure 4) showed ~53 years of change in intertidal vegetation, with a net increase in mangrove area, at the expense of terrestrial and salt marsh areas. This occurs despite there being a net loss in the size of the island (defined by the extent of mangroves). There appeared to be a net shift inland of the mangrove/ saltmarsh zone, although the landward margin has shifted proportionally further inland.

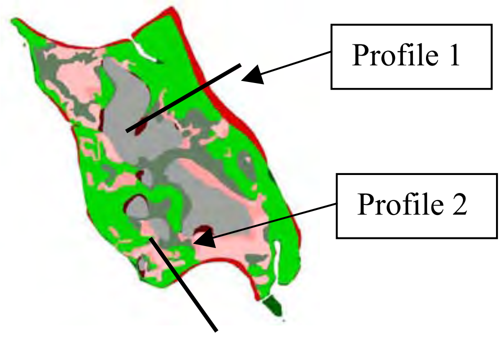


Figure 18. Cobby Cobby Island, southern Moreton Bay showing changes in vegetation from 1944 to 1997. Coloured areas: red = lost mangrove; green = mangrove unchanged; olive green = mangrove encroachment; darker pink = salt marsh encroachment; grey = terrestrial; and pink = salt marsh. Profiles referred to in the text.

Based on these findings, Zonal Shift was considered an important and quantifiable indicator of sea level change affecting marine wetlands. Further enhancement of the method might usefully involve linking elevation data with spatial interpretations of ecotones. Based on such information, it may be possible to reconstruct topography and profiles from historical imagery of intertidal zones. This has not yet been undertaken for Cobby Cobby Island but it has been assessed for both FE and PC study sites. These observations have been investigated further in this project.

2. Project Overview

The current report aims to document and assess historical change of coastal features and vegetation (e.g. mangroves) in the Port Curtis, Fitzroy River and Moreton Bay regions in Queensland. Port Curtis and Fitzroy River represent areas of industrial and rural development, respectively, whilst the Moreton Bay region represents a region of rapid urbanisation and industrialisation, with a busy international port in the city of Brisbane. The study focuses on the changes during the last century in particular, and attempts to relate these to human activities, land use, physical factors (e.g. climate) and population data. Ultimately, the study will provide comprehensive and accurate resource information that will enable more effective management of coastal habitats threatened by human and natural influences.

Within the study, both regional assessments of Port Curtis, Fitzroy River and Moreton Bay and detailed case studies of change in specific locations within each region were performed. The regional assessment included timelines depicting human activities, and broad analyses of coastal environmental change using sources such as old charts and historical photographs. The detailed case studies employed aerial photography to investigate fine-scale change in wetland vegetation over the last 50 years, comparing sites under direct human influence with those under primarily natural control, away from human development (islands). In the Port Curtis region, Calliope and Auckland Creeks in Gladstone (human influence) and Endfield Creek on Curtis Island (natural influence) were examined while, in the Fitzroy region, the Fitzroy River (human influence) and Balaclava Island (natural influence) were used. In the Moreton Bay region, the Brisbane River and Cobby Cobby Island case studies were used to depict human and natural drivers of change, respectively.

2.1 Overview of Methodology

2.1.1 Regional Assessment

The regional assessments encompass the greater Port Curtis, Fitzroy River and Moreton Bay regions, including their major water courses, embayments, wetlands and catchment areas. The assessments include two major components: the construction of historical timelines, and broad analyses of change in coastline and coastal vegetation.

Historical timelines – The historical timelines document human activities and developments that have affected the coastline and wetlands over the last 150 years, as well as including major natural events, such as floods. Headings include: general events, navigation/ construction/ dredging, land tenure and land use, reclamation/ restoration and political/ legislative/ administrative factors. The information has been compiled from diverse sources, such as books, historical accounts, articles and anecdotal information. The timelines will contribute to the interpretation of coastal change, by outlining anthropogenic factors (and natural catastrophes) driving this change.

Broad analyses of change in coastline and coastal features – This involves collection of historical photographs, old charts and maps, and broad vegetation change analysis using digitised imagery. Historical photographs, capturing snapshots of coastline at earlier points in time, are compared with modern-day equivalents, photographed at the same location to give a visual representation of change. Old charts and maps reveal coastal features and appearance of the region prior to and at time points during anthropogenic modification. Digitised imagery and vegetation maps or data are used to make broad-scale comparisons of historical change in wetland area (e.g. mangroves). Modern-day calculations of area are derived from digitised Landsat TM images (for example, from the Department of Primary Industries in Queensland). Historical calculations of area are available for the Port Curtis region, based on a study by Arnold (1995).

2.1.2 Detailed Assessments – Case Studies

2.1.2.1 River Case Studies – Area of Human Influence

The river case studies focus on a dominant river estuary of the region, subjected to different aspects of human development and influence. The rivers chosen for each region were:

- **Port Curtis**: Calliope River and Auckland Inlet – with industrial influences
- **Fitzroy**: Fitzroy River – with rural influences
- **Moreton Bay:** Brisbane River – with capitol city influences

These rivers were chosen as they were the major river systems in the three focus regions, for the Historical Coastlines report. Each region has been notably and characteristically influenced by human population increases and port development over the last 150 years. It is these differences which make the comparison of these three regions so useful and informative, assessing historical change, and in developing tools for the interpretation of change, and the drivers of change, in tidal wetland habitat.

Aerial photography, obtained from various sources. United Photo and Graphic Services and the Department of Natural Resources and Mines, was used to calculate the change in area of major intertidal vegetation types (mangrove, saltpan) along the Calliope and Auckland estuaries and Fitzroy River between 1941 and 1999, and along the Brisbane River between 1946 and 2002. This was achieved by scanning and creating a mosaic out of individual photographs, georeferencing the mosaic using Landsat TM satellite imagery and digitising the mosaic using ArcView to create area polygons. These were compared between years to calculate overall change.

Field verification was conducted at all three locations to affirm vegetation classifications, to ground truth mapped outlines and to aid in georeferencing by obtaining accurate GPS coordinates on distinguishable points (e.g. isolated trees).

2.1.2.2 Island Case Studies- Area of Natural Influence

The ‘island’ case studies focus on island sites, away from direct human contact, in order to investigate natural change driven by local and global influences, such as sea level rise and climate change. Islands are ideal for this type of study, as directional bias of prevailing climatic and hydrological conditions are minimised. The ‘island’ (away from human influence) sites chosen to assess local climatic effects in each region were:

- **Port Curtis**: Endfield Creek on southern Curtis Island
- **Fitzroy**: Balaclava Island, east of Port Alma
- **Moreton Bay**: Cobby Cobby Island in southern Moreton Bay.

Change in area of intertidal vegetation, between 1940s and 1999, was calculated, using the methodology described in the previous section. In the island case studies, however, spatial and compositional analyses were performed on a much finer scale and in greater detail, differentiating between communities/ species within a vegetation type (e.g. mangroves). This approach allowed sensitive detection of change in wetland composition, change in relative dominance and area of zones (e.g. *Rhizophora* zone) within a forest and shifts in ecotones over time.

Again, field verification was conducted at the three locations. In addition, transects were performed measuring relative elevation at major ecotones within the intertidal wetland in order to establish whether a correlation exists between these parameters within a given region.

2.2 Outline of Report

This report presents findings for the three study regions, Port Curtis, Fitzroy River estuary, and Moreton Bay. For each area, there are regional assessments and detailed case studies (river and island) included. The regional assessments outline the general background of the area (location, land use, climate), its history (historical photographs and charts, timelines) and broad changes in regional coastal vegetation. The river (anthropogenic influence) and island (natural influence) case studies describe the study sites and methodologies in detail, and present and discuss the results of the vegetation change analyses. Broad implications of the findings, applications for environmental managers, as well as a synthesis and review of future mitigation actions are presented.

2.3 Publications in Preparation

The following publications arising from this project are currently in preparation:-

- **Changing tidal wetlands.** A popular book showing change over the last 150 years in 3 coastal regions of eastern Australia.

- **Interpreting Change in Tidal Wetlands.** Scientific book of methods and case studies describing tools to assess and interpret change in tidal wetlands along the eastern Australian coastline.

- **Using tidal wetlands to monitor climate change.** An article describing the Wetlands Cover Index (WCI) based initially on spatial data across northern Australia to being a predictor of change as ecotone shifts correlated with changing rainfall patterns over time.

- **Severe damage to tidal wetlands following a hail storm in southern Moreton Bay.** A description of the extensive hail storm damage which occurred in the region in 1997.

- **Indicators of local sea level rise in tidal wetlands in southern Moreton Bay.** A description of zonal shift where tidal wetlands migrate as sea level changes.

- **Climate change affecting mangroves of Luggage Point and Boondall wetlands Brisbane.** Case studies of climate affects on mangrove and salt marsh habitat cover.

- **Methods for mapping fine scale change in tidal wetland vegetation.** Descriptions.

- **Environmental history of Bulwer Island in the Brisbane River.** A BP initiative.

3. Methods

3.1 Aerial photography and change detection

Remote sensing and geographical information systems methodologies were applied to determine the historical change of the mangrove, salt marsh and saltpan in a spatial and numerical sense. The following will explain the processes applied.

3.1.1 Flow Chart

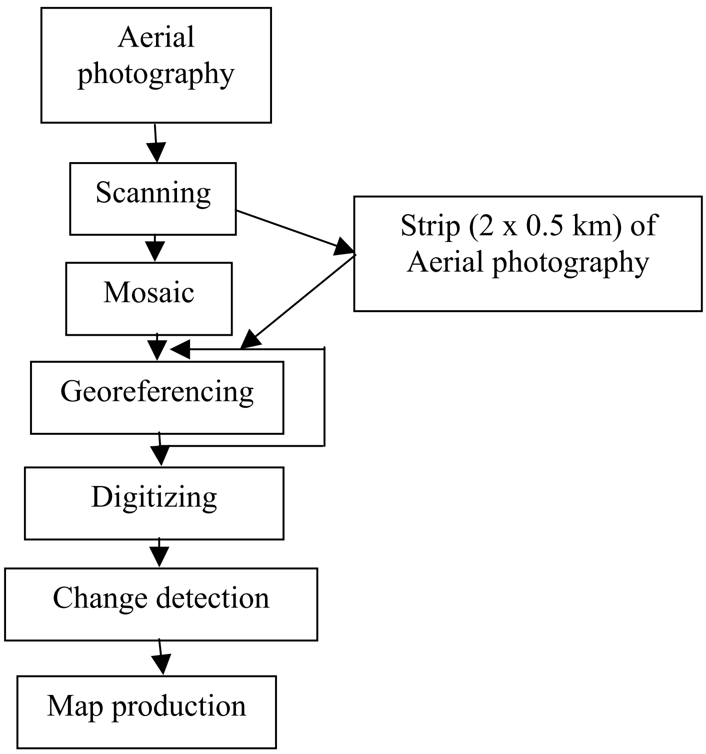


Figure 19. Analytical methods applied to produce the mosaic and tidal wetland maps, and calculate change of surface area over time, as seen in this report.

3.1.2 Acquisition

Historical aerial photographs were acquired for each area studied in this project, with the specific sources for each area and year listed in the relative chapters.

Historical aerial photo libraries were searched at local and national government and non government agencies such as: Department of Natural Resources and Mines (DNRM), Geoscience Australia and Central Queensland University. These agencies acquired the photos for a variety of purposes (e.g. vegetation mapping, beach protection, town planning)

The search prerequisites were that the aerial photos:

- Covered the complete or parts of the area of interest;
- Had a scale of at least 1:25000 so that single trees could be determined;
- Covered a large time period (e.g. 1940 till 2003); and
- Were in good condition.

3.1.3 Scanning

Scanning of the aerial photographs was needed to digitize the different vegetation types in the Areas Of Interest (AOI). The acquired images were scanned in at a resolution of 600 or 1200 dots per square inch (dpi).

Scanning resolution depended on a balance between;

- High quality digital imagery (for example, single trees were just visible) and
- Reduced image size so that image processing was still suitable with a desktop computer.

Images were scanned in using standard flat bed scanners such as the Canon D1250 U2 or Scanmaker Pro.

3.1.4 Mosaicing

Mosaics of the aerial photographs were made for the areas of interest or study areas that were covered by more than one photo. For some study areas, the area of interest was covered by one photo only, and thus a mosaic was not required for that area.

The electronic versions of the photos were imported into Adobe Photoshop (version 6.0). With this program's imaging tools a mosaic was created. The photos were then saved and reduced to below 150 mega bytes to keep an acceptable quality but also image processing speed. Desktop computers, such as a Pentium 4 with a 2 GHz CPU, 512 Ram and 40 Gigabytes hard drive, were shown to be sufficient for the processing. However, computers with less capabilities could still process the images, just with a delay in processing.

The photos were not corrected for flying height, pitch and roll of the plane. This was not conducted for a number of reasons:

- Appropriate camera and flying details were not available;
- And/or sufficient funding was not available for orthorectification;
- And/or no digital elevation model was available for the areas of interest;
- And/or insufficient skills and time were available to conduct a more thorough job.

As a result of the photos not being fully corrected, some mosaics did not have a perfect match between neighbouring photographs. Those areas of interest which had no high elevation differences were less affected.

3.1.5 Georeferencing

Images are georeferenced to calculate and compare changes in vegetation over time. This process required referencing the imagery to an earth coordinate system.

The digital images were imported into the image processing software package ERDAS Imagine 8.5. For this process, characteristic features were determined in the digital image and a reference image. The referenced image was fixed to an earth coordinate system, which was described by datum and projection (in this project AGD 84 and Universal Transfers Mercator Projection). The characteristic features consisted of approximately 20 control points (for example, jetties or houses and natural features, single trees or jetties) evenly spread across the base image. The program calculated a second order polynomial through these points to get the best match. Route mean square errors were improved by adding and/or deleting control points. After this iterative process, the polynomial was used to resample the base image to a new and more refined georeferenced image.

The most recent aerial images were georeferenced to appropriate reference satellite images (Landsat ETM 5 or 7). The resulting georeferenced image was then used to georeference the older aerial images. The aerial photographs had higher resolution than the satellite imagery (25 x 25 m) and satellite imagery did not show single trees, where aerial photographs did. Therefore, by georeferencing the older aerial images with the youngest georeferenced image (showing single trees), the error between these images was reduced.

3.1.6 Digitizing

Size and location of the mangrove, salt marsh and saltpan areas was determined after the boundaries of these areas were digitized using the georeferenced imagery.

The georeferenced images were imported into a GIS software package (Arcview 3.3). Polygons were drawn using the digitising options in the package and then labels were assigned to them. Labels varied from detailed (species level) to general (for example, mangrove). The labels consisted chiefly of three vegetation classes: mangrove, salt marsh plus saltpan). The location of the polygons were made with the help of the digital image as a backdrop on the screen and comparing with the hard copy aerial and terrestrial photographs. Field knowledge and experience about what mangrove, salt marsh and saltpan look like was essential for this process, and was backed up with selected ground observations. Depending on the quality of the images and the need, labels were assigned to each polygon.

3.1.7 Change analysis

Change analysis focussed on the actual number of changes in surface area and where these changes occurred spatially over the different time periods.

Surface area per polygon was calculated using ArcView tools. Total surface area per vegetation type was calculated in Excel by summarizing totals of surface area for those polygons with the same vegetation type. These total values were then compared over time with the results of aerial photographs from other time periods.

3.1.8 Strips

Strips (2 by 0.5 km) were extracted from the aerial photography. The strips characterise the areas of interest and do not have high elevation differences. The advantage of these strips was the higher accuracy achieved in these images.

The advantages with this technique when georeferencing the strip to another strip were:

- more details were visible as the strips could be scanned at higher resolution;
- the area size was smaller, which will contribute to a better fitting projection model; and
- the relief differences were small and the lack of ortho rectification had less influence.

These strips went through the same process as discussed in paragraphs 3.1.1 to 3.1.6.

3.1.9 Map production

Maps were produced using the GIS software package (ArcView 3.3). The digitised vegetation areas and areas of interest were presented on top of available aerial photography or satellite imagery. This was done to help understand the location of each vegetation type in relation to characteristic features in the imagery. All maps presented are in projection Universal Transverse Mercator and datum Australian Geodetic Datum 1984.

3.1.10 Accuracy assessment

Accuracy assessment was conducted on the georeferenced imagery from a large mosaic (1000 km^2), small area (~13 km^2) and a small strip (~0.6 km^2). These areas were chosen to demonstrate the influence of the size of the mosaic and scale on the georeferenced imagery. In each image, 10 natural control points (for example, trees) were located and the coordinates were recorded. The Root Mean Square Error (RMSE) was calculated for these points relative to a base image. The base image was the image used to georeference all the other images to, of the same area (see section 3.1.5).

Table 3. Accuracy assessment of an ad hoc selection of imagery used in this project. Root Mean Square Errors were calculated measuring the position of 10 different locations in the imagery for each time frame and image set.

Fitzroy Estuary				Luggage Point				Cobby strip			
Ave RMSE (m)	115.3	Area size (km2):	1142.0	Ave RMSE (m)	8.5	Area size (km2):	14.0	Ave RMSE (m)	2.6	Area size (km2):	0.6
Year	**RMSE (m)**	**Images**	**Image scale**	**Year**	**RMSE (m)**	**Images**	**Image scale**	**Year**	**RMSE (m)**	**Images**	**Image scale**
1999	Base	36	1:25000	1991	Base	1	1:25000	1997	Base	1	1:12500
1941	115.3	96	1:10000	2002	4.2	1	1:25000	1987	2.5	1	1:12500
				1981	6.0	1	1:25000	1974	2.0	1	1:12500
				1960	11.9	2	1:15000	1955	3.0	1	1:12500
				1951	10.4	2	1:15000	1944	2.7	1	1:12500
				1946	9.9	2	1:15000				

The results demonstrate that detailed imagery and the smaller area images had the greatest accuracy and were favoured in the assessment of change over time (Table 3).

The accuracy of the mosaics would have been improved if the images had been orthorectified appropriately before producing the mosaics. Such an extra process would have taken into account the position of the airplane, its pitch and roll.

3.1.11 Limitations

- Imagery was georeferenced with Landsat ETM 7 images, which had a pixel size of 25 m. The pixel size influenced the resolution and therefore how accurate features were used as natural control points. This influenced the quality of the georeferencing of the base aerial image. Using high resolution imagery or additional field control points would have improved the accuracy of the georeferencing.
- Size (bytes) of the images needed to be reduced to speed up image processing on the computer. However, this reduction in size caused the loss of accuracy leaving some features not clearly visible.
- Older aerial photographs were sometimes of poor quality. Therefore, some details may have been missed or inaccurately delineated.
- The operator who digitized the aerial imagery needed personal experience in field interpretation of mangrove, salt marsh and saltpan habitats. Since the drawing of lines delineating vegetation types depended on the operator's visual interpretation, this may also have affected comparability of the maps produced. This applies both within this project, and comparing among other studies.

3.1.12 Software, hardware and computer skills

Ability of equipment and skills may be a limiting factor to the work described above. The following is a list of minimum requirements for equipment required:

Software and Hardware	**Task**	**Minimum Requirements**	**Used in this project**
Computer	Conduct the processing	Windows based, Desktop or laptop, 250 Mb ram, 1 GHz processor, 20 Gb Hard drive	Pentium 4 with a 2 GHz CPU, 512 Ram and 40 Gigabytes hard drive
Flat bed scanner	Scan the aerial photographs	A3 size scans at 1200 dpi	Canon D1250 U2
Photo imaging software	Produce a mosaic of the scanned aerial photographs	Adobe Photoshop 6.0 or equivalent	Adobe Photoshop 6.0
Georefencing Software	Georeferencing of scanned aerial photographs	Basic GPS software such as FUGAWI 3.0 or equivalent	ERDAS Imagine 8.5 (high end remote sensing program)
Geographical Information System Software	Digitizing the imagery, calculate change detection and producing maps	ESRI ArcView 3.3 or equivalent	ESRI ArcView 3.3 with spatial analist and change detection extensions
Spreadsheet software	To calculate total surface area resulting from digitizing.	Microsoft Excel	Microsoft Excel

The following is a list of minimum requirements for skills and knowledge needed:

Task	Skill levels and knowledge needed	Qualification level
Acquisitioning	Basic knowledge of geographic area of interest for aerial photographs to be acquired. Basic knowledge and skills in aerial photograph interpretation.	BSc. major in botany and minor in GIS and Remote Sensing
Scanning	Basic scanning skills with standard flat bed scanner.	BSc. or equivalent
Mosaic production	Basic knowledge of the area of interest to identify overlapping imagery and basic skill using the imaging mosaic software.	BSc. major in botany and minor in GIS and Remote Sensing
Georeferencing	Advanced knowledge of wetland habitats to: Identify (natural) control points and understand how much natural control points can change over time in appearance. Advanced knowledge and skills in the principle of georeferencing software and analyzing the quality of the georeferencing.	BSc major GIS and Remote Sensing equivalent
Digitizing	Advanced knowledge of and experience in wetland vegetation and basic principles in digitizing using GIS software.	BSc.(Honours) major in botany and minor in GIS and Remote Sensing
Change detection	Advanced knowledge of and experience in wetland vegetation and advanced skill GIS software	BSc.(Honours) major in botany and minor in GIS and Remote Sensing
Analysis	Advanced knowledge of and experience in wetland vegetation and advanced skill GIS software	BSc.(Honours) major in botany and minor in GIS and Remote Sensing

In this project the team to conduct the process described above consisted of:

Title	**Degree**	**Experience**
1 x Principle Investigator	Post doc. in wetland vegetation	100 years
2 x Research Assistance in digitizing and aerial photo interpretation	BSc. (Honours) wetland vegetation mapping	1 year
1 x Research Assistance GIS and Remote Sensing	Masters in Remote Sensing and GIS and pgdip. in marine science	8 years
2 x BSc. (Honours) Students	BSc. Botany and/or Environmental Science	No experience

4. Port Curtis Region

4.1 Regional Assessment

4.1.1 Background: Port Curtis – an Industrial Centre

Port Curtis (approximately 23.8^{o}S, 151.5^{o}E) is located on the Central Queensland coast, near the Tropic of Capricorn (see Figure 20). The area borders on the tropical/ subtropical transition zone, and the climate is warm (average daily maximum: 27.6^{o}C, minimum: 18.5^{o}C) with moderate rainfall (mean annual rainfall: 928.4 mm) (Bureau of Meteorology Australia). Most of this rainfall occurs during summer months. The region comprises the coastal area east of the Calliope and Dawes ranges, and includes Gladstone City, Calliope Shire and part of Miriam Vale Shire. Calliope River and Auckland Inlet are dominant water courses within the region. The Port Curtis embayment, a natural, deepwater harbour, is protected from the open ocean by the large Curtis and Facing Islands.

Port Curtis is a major industrial centre. Industries include an aluminium refinery (Queensland Alumina Limited) and smelter (Boyne Smelters Limited), a cement production works (Queensland Cement and Lime), chemical plants (e.g. Orica and Ticor) and Queensland's largest power station (Gladstone Power Station). The area of state-owned industrial land measures over 10,000 hectares. Port Curtis also possesses a major, international harbour and is Queensland's largest multi-commodity port.

Issues in the region include harbour dredging, port development, industrial development, discharge of effluent and extensive reclamation of intertidal wetlands, including mangroves, mudflats, saltflats and marshes. Although intertidal wetlands are still prevalent along the Port Curtis coastline, they have been extensively cleared, filled or modified around Gladstone City. The area around Auckland Inlet has been particularly affected. This situation is likely to continue and increase, as further port and industrial development has been planned for the near future.

Another issue affecting the region involves increased urbanisation. The regional population of Port Curtis in 2001 was over 40,000, with 27,000 of these people residing in Gladstone City. It is predicted the population of Gladstone City will rise to 35,000 within the next decade, exerting further pressure on the region's resources and environment.

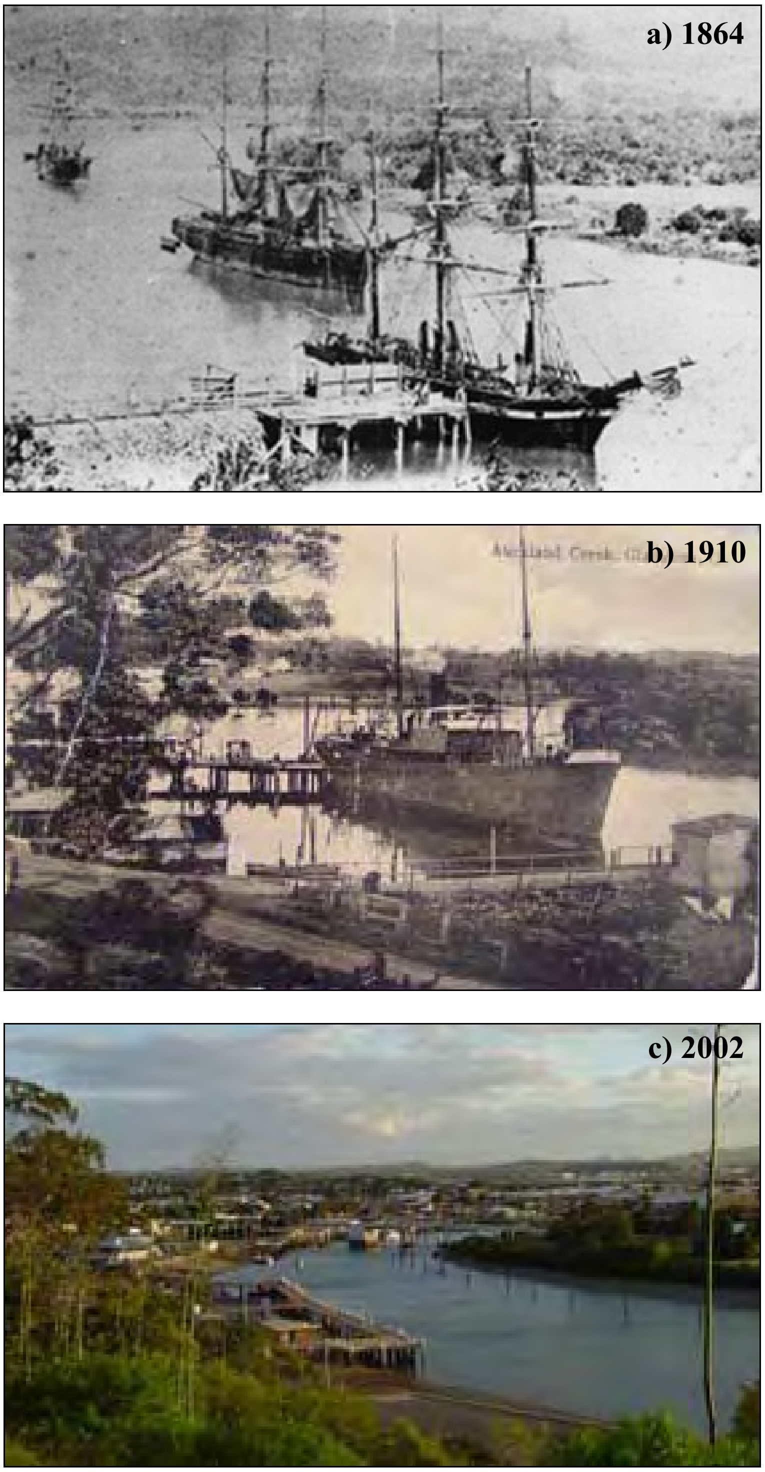
Figure 20. Map of the Port Curtis Region, showing Gladstone and the major creeks and islands.

4.1.2 History

Gladstone was originally settled by Europeans in 1846. Early in the colonisation of Australia, it had been destined to become the grand Northern Australian Colony. These plans were soon laid aside, however, and, after a brief period as a penal colony, it functioned largely as a cattle port up until the mid 20th century, with small-scale harbour developments at Auckland Point, Auckland Inlet and Parsons Point. In the 1960's, however, industrial, urban and port development accelerated. This trend has continued ever since, making Gladstone the major industrial centre and port it is today. Accompanying these developments, Port Curtis has undergone radical changes in coastline and coastal habitat from its original condition. Large areas of wetland have been 'reclaimed' and intertidal habitats cleared or modified. Some of these changes can be seen by comparing Figure 21, an early chart of the region (1853), with Figure 20, a line map created from 1999 data.

Figure 21. Early chart of the Port Curtis region, revealing a substantially different coastline from that which exists today. (Source: Department of Harbours and Marine, 1986)

The Historical Coastlines Project has collected a series of historical photographs from the Port Curtis region, which can be used as a visual representation of change (refer Figures 22-26).



Figures 22(a), (b) & (c). Views through time of Auckland Inlet, Gladstone: in 1864, loading cattle for international ports; in 1910, a motorised vessel of a new age; and in 2002, a relatively tranquil tourist and fishing port exists now that larger vessels load at the outer harbour wharves. Note that the same rock wall jetty features in all photos. (Sources: (a) & (b) Gladstone Port Authority; (c) Norm Duke)

Figures 22a), b) and c) show a view through time of Auckland Inlet, Gladstone, in 1884, 1910 and 2002, respectively. The 1884 image shows the loading of cattle for international ports onto tall ships. The 1910 photo shows the same, but upgraded wharves, with a motorised vessel of the new age. Today, a relatively tranquil tourist and fishing port exists, now that the larger vessels load at the outer harbour wharves.

Figure 23(a) & (b). Aerial views of Auckland Point in 1924 and 1952. Within this period, extensive reclamation of land surrounding the point may be observed (Source: Gladstone Port Authority)

Aerial views of Auckland Point in 1924 and 1952 and be seen in Figures 23a) and b), respectively. It can be seen from these photos that within this short time period, extensive reclamation of land surrounding the point, has taken place. Figure 24 shows a historical view of Auckland Inlet in 1907, with the commercial centre visible in the photo.

Figure 24. Historical view of Auckland Inlet in 1907, showing the commercial centre (Source: Gladstone Port Authority)

Figures 25a) and b) highlight the advancing developments that were taking place in Auckland Inlet between 1947 and 2002. In 1947, the Shell Terminal is visible on reclaimed land at Auckland Point. In the 2002 photo, it can be seen that there has been further reclamation, construction and modification, particularly opposite Auckland Hill, where the 'new' harbour and port developments can be seen.

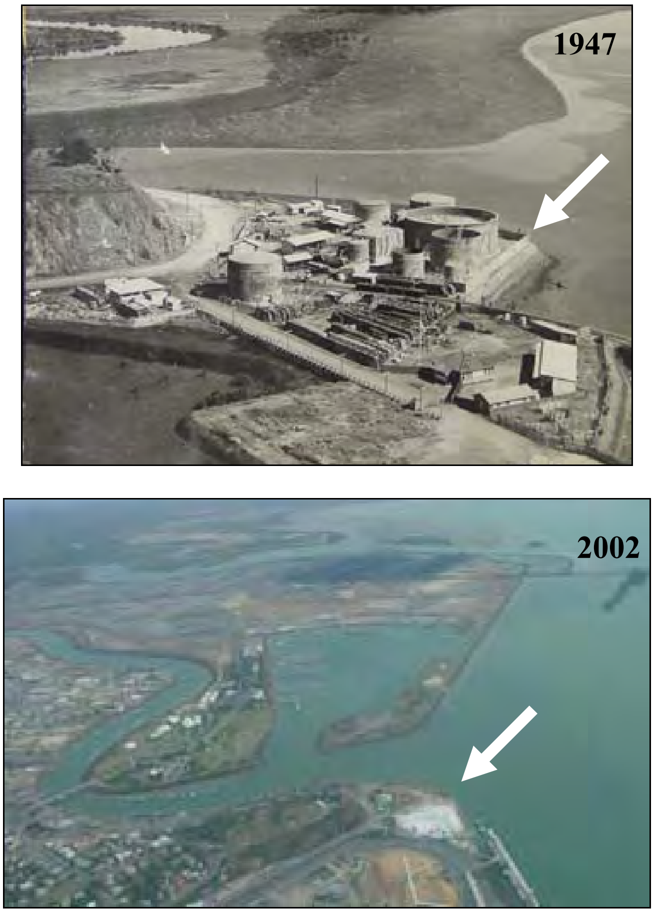


Figure 25(a) & (b). Oblique aerial photos showing the advancing developments in Auckland Inlet. The white arrow denotes the same point in both years. In 1947, the Shell Terminal is visible on reclaimed land, Auckland Point. In 2002, there has been further reclamation, construction and modification, particularly opposite Auckland Hill, where the 'new' harbour and port developments may be seen. (Source: (a) Gladstone Port Authority; (b) Norm Duke).

Figure 26. Sailing boats at the entrance of Auckland Inlet in 1912, showing a relatively undisturbed shoreline. (Source: Gladstone Port Authority)

Figure 26 displays and calming view of sailing boats at he entrance of Auckland Inlet in 1912, showing a relatively undisturbed shoreline.

A historical timeline of the Port Curtis region, outlining anthropogenically-driven actions and events contributing to these coastal changes, is provided in the appendix (Appendix 1).

4.1.3 Broad change in Regional Coastal Vegetation

Wetland vegetation change analysis has been undertaken previously for the Port Curtis region by Arnold (1995). In Arnold's (1995) study, based on aerial photography, it was found that 650 hectares of mangroves and 950 hectares of saltflat had been lost from the region between 1941 and 1988. This represented a loss of 17% and 24%, respectively. Most of this loss was attributed to industrial and urban development.

In this study, data was prepared for change analysis to compare tidal wetland vegetation areas of the total Port Curtis region and selected subregions between 1941, 1988 and 1999. The selected subregions, detailed in Figure 27, were: Gladstone, North Port Curtis, Boyne, South Curtis Island and Facing Island. The analysis was based upon digitised wetland distribution data from Arnold (for the 1941 and 1988 profiles) and the Department of Primary Industries (for the 1999 profile). The digitisations were overlaid onto Landsat imagery and change detection performed as described in the methods. Figures 27(a-f) show current distribution of mangrove and saltpan in 1999, using the DPI data. Table 4 presents the absolute areas of mangrove and salt marsh/saltpan in the different years for the different subregions.

Table 4. Area (in hectares) of tidal wetlands including mangrove, and salt marsh plus saltpan in five subregions of the Port Curtis region during 1941, 1988 and 1999. WCI = Wetlands Cover Index (% mangrove). Asterisks (*) indicate regions under significant anthropogenic influence. Sources of data include: DPI Fisheries, and EPA.

PC	Mangrove			Salt marsh/Saltpan			Total			WCI		
Subregions	**1941**	**1988**	**1999**	**1941**	**1988**	**1999**	**1941**	**1988**	**1999**	**1941**	**1988**	**1999**
North	298	261	183	374	381	114	672	642	297	44	41	62
South Curtis	834	819	647	724	707	741	1558	1526	1387	54	54	47
Facing	131	119	59	876	603	314	1007	722	373	13	16	16
Gladstone*	1135	821	635	561	428	439	1696	1249	1074	67	66	59
Boyne*	1445	1221	845	1316	799	903	27 61	2019	1748	52	60	48
TOTAL Region	**3842**	**3240**	**2369**	**3852**	**2918**	**2510**	**7694**	**6158**	**4879**	**50**	**53**	**49**
Human Affected Subregions*	2580	2042	1480	1877	1227	1342	4457	3269	2822	58	62	52
% Change*		-21	-27		-35	9		-27	-14			
Subregions Under Mostly Natural Influence	1262	1199	889	1975	1691	1168	3237	2889	2057	39	41	43
% Change		-5	-26		-14	-31		-11	-29			

The mangrove area has decreased in all subregions throughout the last 60 years, with a total regional decrease from 3842 hectares in 1941 to 3240 hectares in 1988 and 2370 hectares in 1999. This equates to a total loss in mangrove area of 1470 hectares (38%) between 1941 and 1999. In terms of absolute loss, most loss has occurred in the Gladstone subregion, and the Boyne subregion in recent years, although Facing Island has lost more in terms of percentage lost.

The area of salt marsh/saltpan has experienced a net decrease from 1941 to 1999 in all regions, except Southern Curtis Island. In the Boyne and Gladstone subregions, most of this loss occurred between 1941 and 1988, with small increases in the following decade. There was a total regional decrease from 3852 hectares in 1941 to 2918 hectares in 1988 and 2510 hectares in 1999. This equates to a total loss in salt marsh/saltpan area of 1342 hectares (34.8%) between 1941 and 1999.

It should be noted that error can arise when comparing data from different sources, due to factors such as differences in interpretation. For this reason, it is more reliable to compare original data generated by the same person using the same methods. This was one of the goals of the Historical Coastlines Project. This analysis has been used for the detailed assessment case studies.

Clearly, the coastal features and tidal wetlands of the Port Curtis region have changed dramatically over the last 60 years. Much of this was understandably due to reclamation around the mouths of the Calliope and Boyne Rivers, and particularly centred on Auckland Creek. However, some losses may be due to natural fluctuations in climate. Key ecological indicators are used in the following discussion to assess the situation and to evaluate the validity of the data used.

Overall, the region is characterised by at least 3 major categories of impact (refer to Table 5): reclamation loss, depositional gains & losses and ecotone shift. An assessment has been made for each using relevant indicators to characterise and possibly quantify the dominant influences.

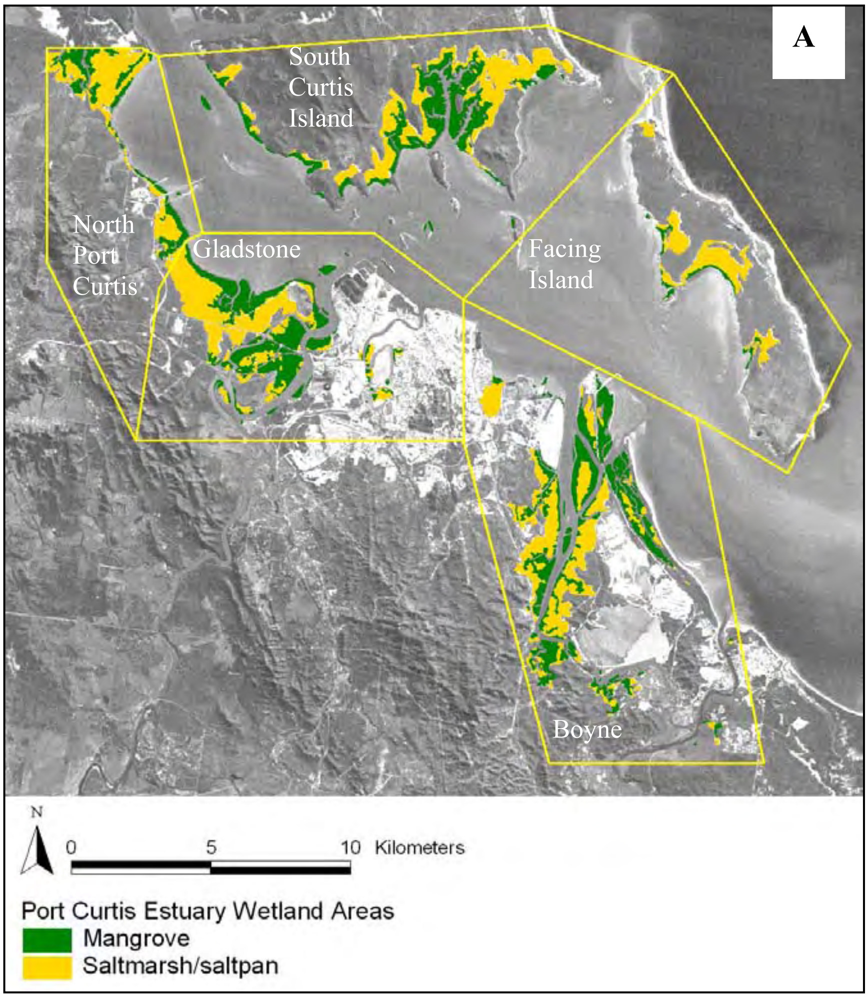
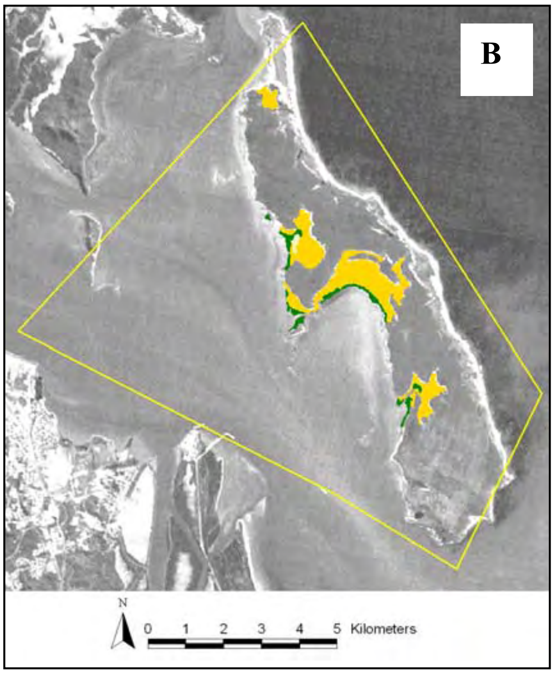
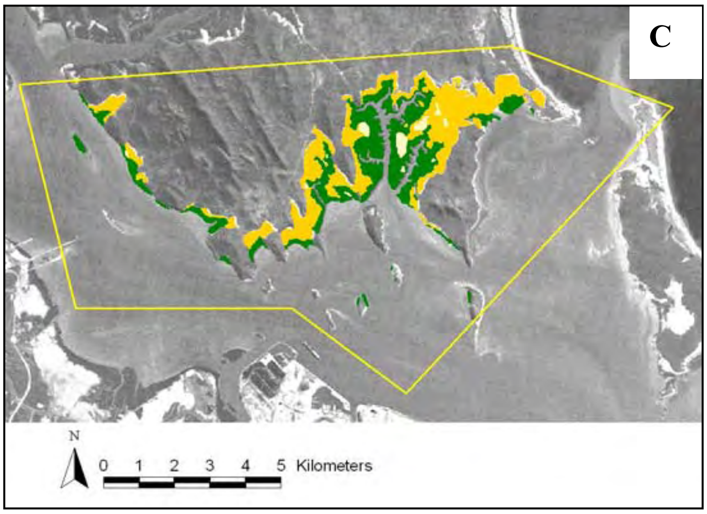


Figure 27. Distribution of mangrove and salt marsh/ saltpan in the five Port Curtis subregions, displayed on a 1995 Landsat image.
A: Map of Port Curtis detailing the eight selected subregions used in this assessment for comparison.
B: Facing Island subregion.
C: South Curtis Island subregion.
D: North Port Curtis subregion.
E: Gladstone subregion.
F: Boyne subregion.
(Landsar Source: ACRES, 1995).





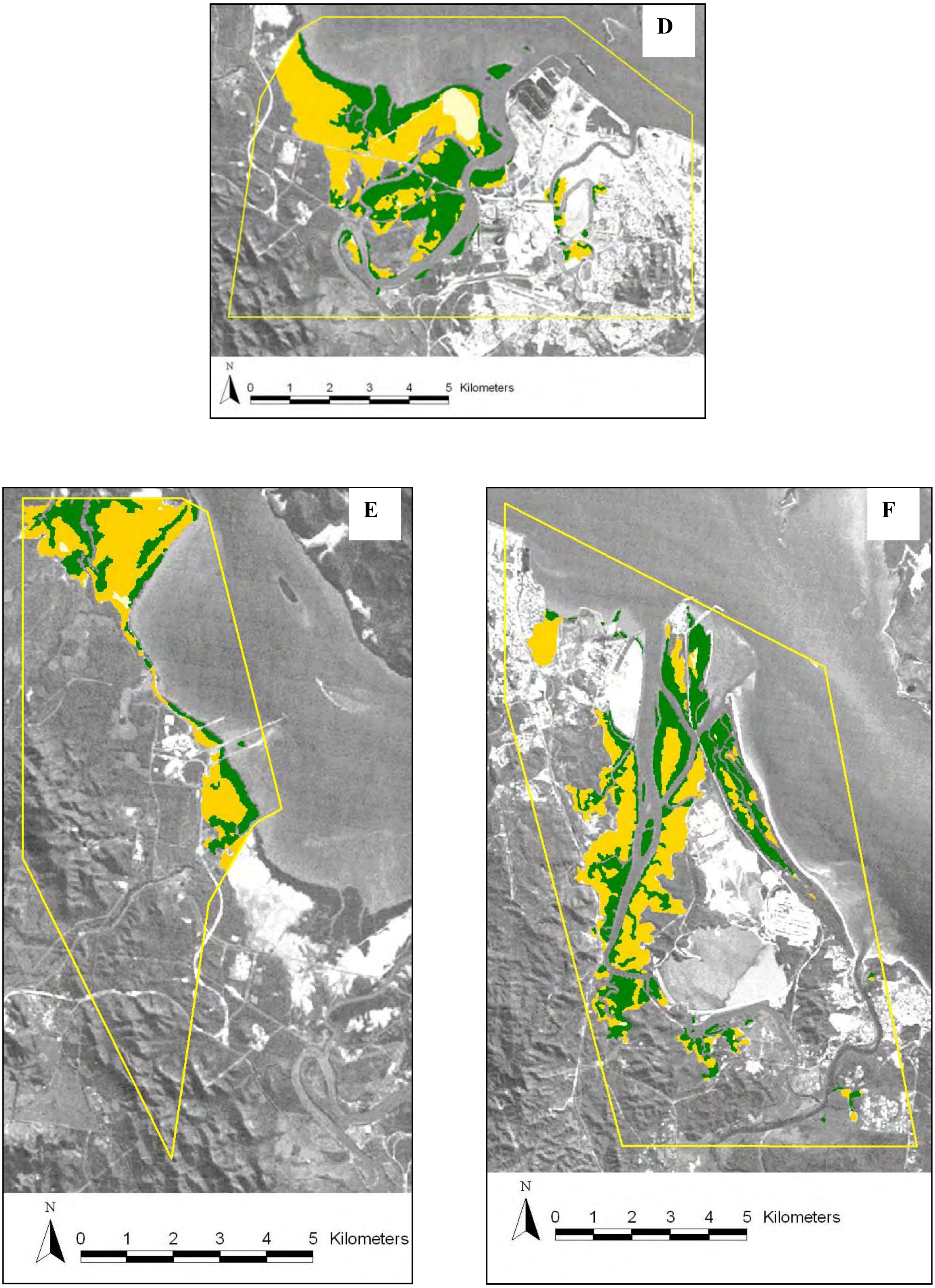

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Table 5. Effect levels and types of change affecting tidal wetlands of the Calliope River and Auckland Creek estuaries (Port Curtis) during three historical periods of the last two centuries. The 12 types of change are grouped into 4 categories (A-D) based on human and natural influences on coastal and estuarine habitat.

Type of Change	Pre 1860	1860 to 1946	1946 to 2002
A. Direct – Intended & obviously human related			
1. Reclamation loss	**Effect:** None	**Effect:** Minor **Driver:** Port development in Auckland Creek.	**Effect:** Dominant **Driver:** >1,600 ha lost to industrial and port development in Auckland Creek and toward Calliope River mouth.
2. Direct damage	**Effect:** Minor **Driver:** Occasional tree cutting, access paths & tracks.	**Effect:** Minor **Driver:** Occasional access paths, tree cutting, access paths, tracks, trampled roots.	**Effect:** Minor **Driver:** Occasional access paths, tree cutting, access paths, tracks, trampled roots.
B. Direct – Unintended & obviously human related			
3. Restricted tidal exchange	**Effect:** None	**Effect:** Minor **Driver:** Impoundment, built-up roads.	**Effect:** Minor **Driver:** Impoundment, built-up roads.
4. Spill damage	**Effect:** None	**Effect:** Minor **Driver:** Occasional small oil spills in Auckland Creek.	**Effect:** Minor **Driver:** Occasional small oil spills proportionate to shipping volume.
C. Indirect – Unintended & less obviously human related			
5. Depositional gains and losses	**Effect:** Minor **Driver:** Regular seasonal rainfall associated with occasional increased sediment in run-off.	**Effect:** Minor **Driver:** Clearing of catchment vegetation & increased crop agriculture increased sediment run-off, resulting in shallower waters around the river mouth.	**Effect:** Minor **Driver:** Clearing of catchment vegetation & increased crop agriculture increased sediment run-off, resulting in shallower waters around the river mouth.
6. Nutrient excess	**Effect:** None	**Effect:** None	**Effect:** None
7. Species-specific effect	**Effect:** None	**Effect:** None	**Effect:** Moderate **Driver:** Dieback in the 1970s of *Avicennia,* possibly associated with unidentified toxicants in run-off or industrial emissions.
D. Not obviously human related, if at all			
8. Wrack accumulation	**Effect:** None	**Effect:** None	**Effect:** Minor **Driver:** Litter debris, debris from blooms, storm waves.
9. Herbivore/insect attack	**Effect:** Minor **Driver:** Possible insect plagues, occasional.	**Effect:** Minor **Driver:** Possible insect plagues, occasional.	**Effect:** Moderate **Driver:** Insect plague depleted canopy foliage by 40% leaf area.
10. Storm damage	**Effect:** Minor **Driver:** Severe storm, hail, lightning, storm waves, occasional.	**Effect:** Minor **Driver:** Severe storms, hail, lightning, storm waves, occasional.	**Effect:** Moderate **Driver:** 291 ha affected by hail damage along Calliope River. Severe storms, lightning, storm waves - occasional
11. Ecotone shift	**Effect:** Minor **Driver:** Climate (rainfall) change, longer-term.	**Effect:** Minor **Driver:** Climate (rainfall) change, longer-term.	**Effect:** Minor **Driver:** Rainfall decline notable in recent decades, change, longer-term, causing dieback.
12. Zonal shift	**Effect:** None	**Effect:** None	**Effect:** None

Relative effect levels: None; Minor; Moderate; Dominant, based on relative extent and presence of changes observed.

Reclamation Loss

In Table 4, area estimates of tidal wetlands in Boyne and Gladstone subregions show marked declines between 1941 and 1988, and 1999. These are the areas dominated by past and current reclamation activity. However, quantifying the exact amount of loss attributable to reclamation was beyond the scope of this study, and would require intensive field surveys and a greater level of mapping detail. Loss of both mangrove and salt marsh/saltpan between 1941 and 1988 was approximately 1200 hectares, around 27 %, and a further 400 hectares was lost up to 1999.

Losses from reclamation appear to be higher for the salt marsh/saltpan compared to the mangroves, mostly based on the 1941-1988 period. These observations were checked during ground surveys and by inspecting the GIS data sets for each sector. Changes in these sectors were notably of two kinds, decreases due to reclamation and some increases due to relatively minor depositional gains in the Boyne subregion.

Depositional Gains & Losses

Some depositional gains (not quantified) were observed in the northern mouth of the Boyne subregion, namely South Trees Inlet. None were apparent at the mouths of the Calliope River and Auckland Inlet.

Ecotone Shift

Shifts in ecotones have been discussed in the first chapter. There is a clear correlation with rainfall patterns such that tidal wetland areas with greatest coverage of mangroves can be observed in wetter climates. The indicator used in this assessment is the Wetland Cover Index (WCI). The WCI may be used as a descriptor of the relationship between rainfall and wetland composition, and may be used to quantify this kind of change.

Estimates of WCI show some regional patterns correlated with climate. The WCI estimate for the region has been based on the three subregions where most changes might be considered natural, to minimise the confounding effect of human influence. The total tidal wetland area was estimated to be around 2,100 hectares in 1999 with a WCI of 43. Based on the relationship presented in Figure 1, this equates to a mean annual rainfall of around 997mm, an estimate slightly higher than the 872mm estimate for the Fitzroy River estuary (where WCI = 38). Both estimates compare well with actual rainfall records.

Estimates of WCI for the early periods might therefore also reflect respective prior rainfall levels. WCI values increased from 39 in 1941, to 41 in 1988, and then to 43 in 1999. This implies that rainfall has increased (from 897, to 947, to 997 mm, respectively) over the 60 year period. A check of the long term rainfall record for Gladstone (Figure 14) shows no clear pattern, although complex or lag effects may exist. Further detailed assessment is required to understand these possible influences. In any case, mangrove vegetation apparently integrates longer term change, making it a useful indicators of average climatic condition.

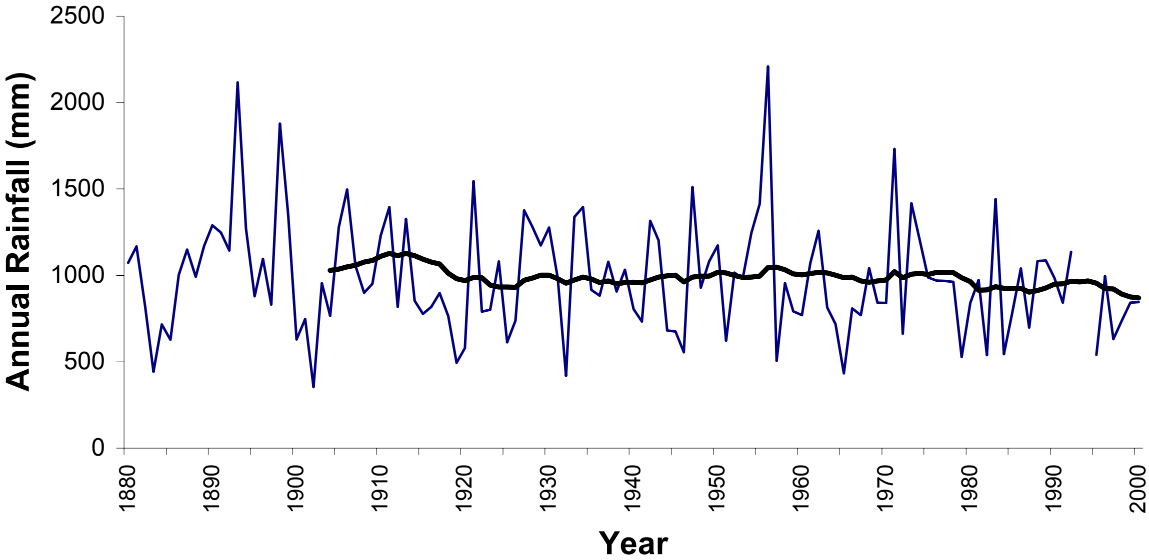


Figure 28. Annual Rainfall in Gladstone, 1940 to 2001. Black trendline represents the moving average over a 25-year time period. (Source: Bureau of Meteorology Australia).

Areas less affected by direct human influences also show declines in both mangrove and salt marsh/saltpan. However, there is good reason to question these differences since they may reflect inconsistencies in the data sets from year to year. Area estimates used here are based on maps using two different interpretations of wetland vegetation cover and mapping.

A more detailed analysis of vegetation change in Port Curtis is considered in the following case studies.

4.2 Detailed Assessment – Case Studies

4.2.1 Calliope River and Auckland Inlet – Area of Human Influence

The lower reaches of the Calliope River (23.84°S, 151.19°E) and the entire length of Auckland Inlet (23.84°S, 151.24°E) run through the heart of Gladstone City. Their relative locations are displayed in Figure 5. Both systems have been subjected to significant human influence, and both have experienced changes in coastal features and vegetation as a result.

Auckland Inlet is the most disturbed catchment in the Port Curtis region (Figure 29). In the past, the inlet served as a busy harbour and cattle port but, today, it is mainly used for local boat traffic, as a water supply for the power station, and to direct storm water away from the city. It has undergone substantial urban and industrial development, including modifications by the Gladstone Port Authority (coal terminals, reclaimed industrial estates and Gladstone Marina), Gladstone Power Station (Clinton Ash Pond reclamation) and Gladstone City Council (city tip and sporting fields). As a result of these activities, large areas of habitat have been removed. Between 1941 and 1988, for example, an estimated 90% of intertidal wetlands were lost (Arnold 1995). By 1988, nearly no saltpan and less than 50 hectares of mangroves remained (Arnold 1995).

Figure 29. Aerial view of Auckland Inlet, showing substantial industrial developments and influences. (Source: Norm Duke)

Calliope River supports the second largest mangrove area in Port Curtis (Arnold 1995). This system has also experienced significant impacts (Figure 30), although proportionally less than for Auckland Inlet. Between 1941 and 1988, an estimated 10% of mangroves and 12% of salt flats were lost as a result of dieback (possibly facilitated, although not caused, by a fungal pathogen) and industrial development (Gladstone Power Station, roading, RG Tanna Coal Terminal) (Arnold 1995). This impact is likely to continue, as further reclamation has been planned for the future (for example, Gladstone Port Authority).

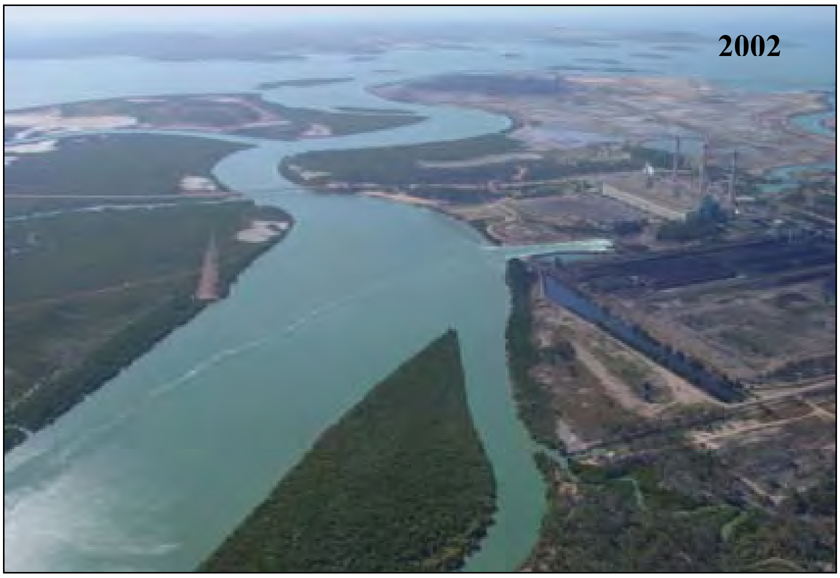


Figure 30. Aerial view of Calliope Creek and surrounding developments. Note the Gladstone Power Station on the right. (Source: Norm Duke)

The following case study presents a thorough investigation of change in these heavily-impacted systems, through the creation of digitised maps detailing coastal vegetation and features for each of the years, 1941 and 1999, and the use of change-detection analysis to calculate changes in the tidal wetland area. The methods used in this case study are outlined in Chapter 3. Aerial photography used was obtained from three sources. The 1941 aerial photography was purchased from United Photo and Graphic Services, Victoria and borrowed from Alistair Melzer, Central Queensland University, whilst the 1999 photography was obtained from the Department of Natural Resources and Mines (DNRM). The mosaics created were georeferenced to a Landsat TM 1995 image, which was obtained from the Biophysical Remote Sensing Group (Geographical Sciences and Planning Department, University of Queensland). The mosaics can be seen in Figures 17 and 18, and provide a visual comparison with Figures 19 and 20 showing the tidal wetland area coverage in 1941 and 1999. The vegetation categories used in this case study were mangrove and salt marsh/ saltpan.

Findings and Discussion

As noted in the regional assessment, the tidal wetlands in the vicinity of Gladstone and nearby areas of Port Curtis have been severely altered and damaged, particularly for estuarine areas of the Calliope River and Auckland Creek. There are several causes for the decline in these wetland areas and they can be usefully identified and grouped using the indicators discussed in this treatment. Much of the damage is related to development activities, but at least one major impact was natural.

Figure 31. Map of Gladstone, in 1853, showing adjacent features and suburban allotments. (Source: Barbara Webster).

The extent of change can be determined by comparing maps drawn from aerial photographs taken in 1941 and 1999 (Figures 32 and 33). Comparing these images with the 1853 image of Auckland Inlet (Figure 31), also provides an indication of changes in the shape of the creek.

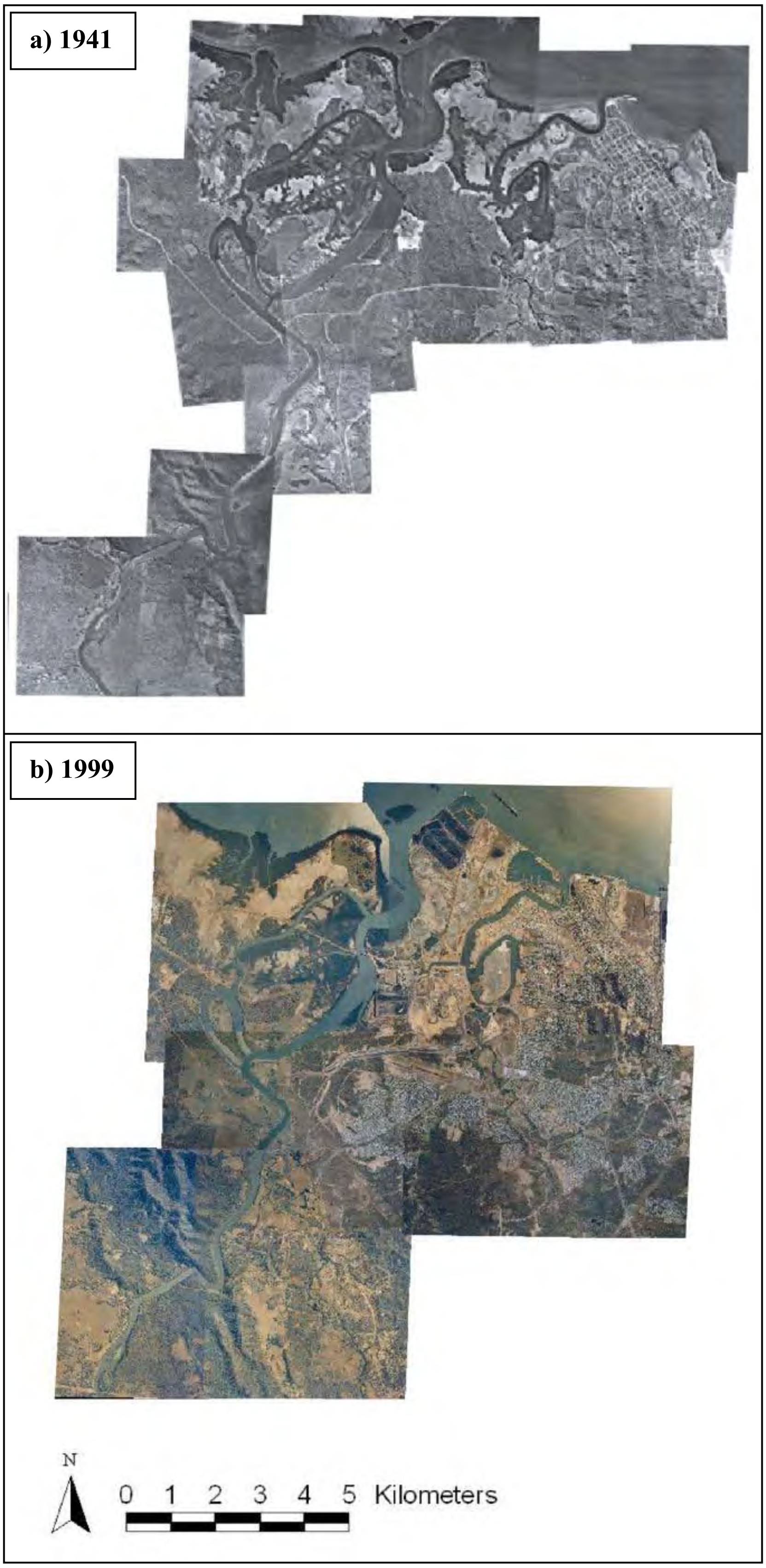
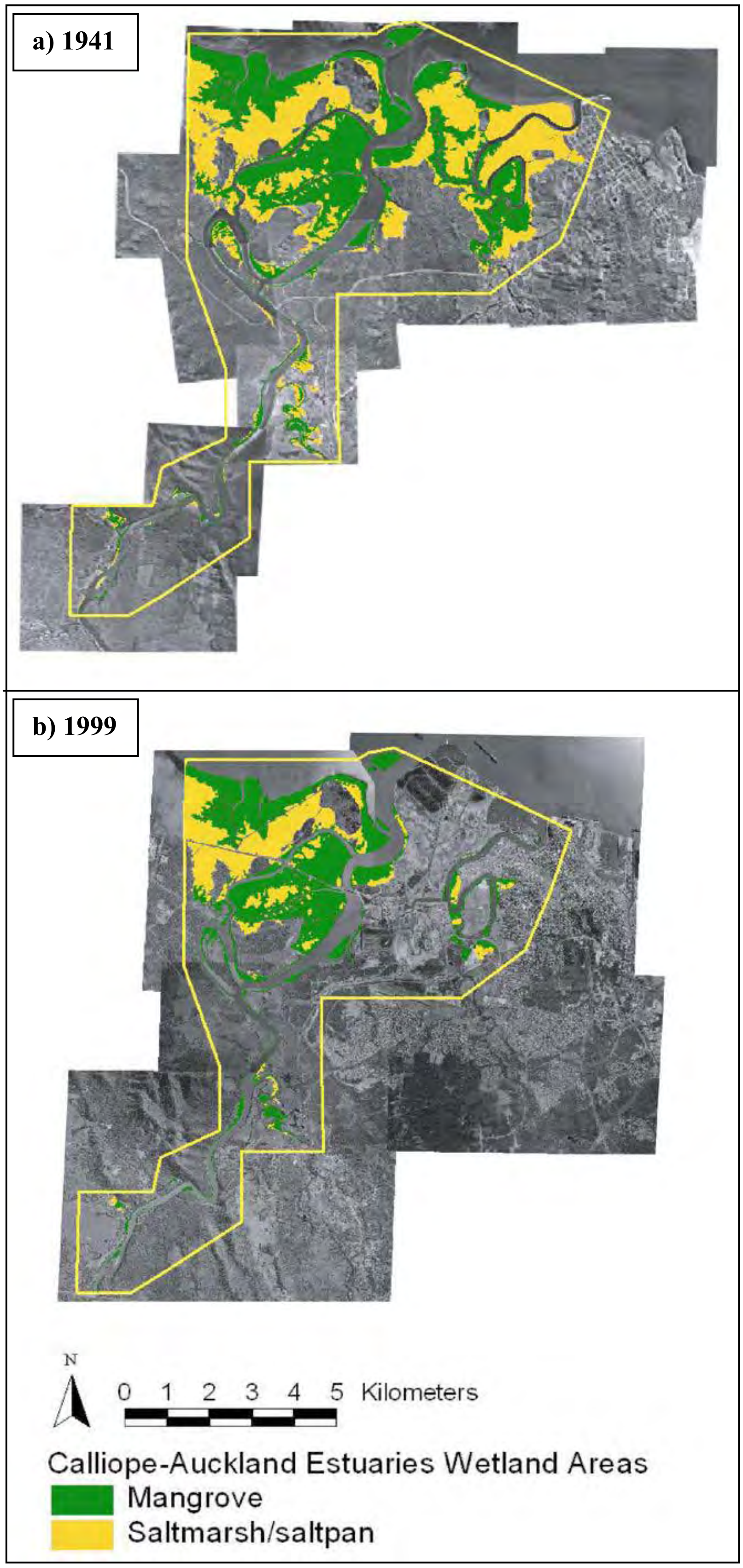


Figure 32a) and b). Mosaics of aerial photographs depicting Calliope Creek and Auckland Inlet, Port Curtis, in a) 1941 and b) 1999.



Figures 33a) and b). Vegetation map showing mangrove (green) and saltpan (yellow) areas surrounding Calliope River and Auckland Creek in a) 1941 and b) 1999. Yellow boundary marks area of interest.

Estimates of area are summarised in Table 6 along with corresponding estimates of percent change. It is significant that most change has occurred at the expense of the salt marsh/ saltpan. The loss was estimated at 516 hectares (approximately 52% change) between 1941 and 1999. There was, however, also a loss of 221 hectares of mangroves (approximately 21% change) from the region.

Table 6. Area (in hectares) of tidal wetlands including mangroves and salt marsh/ saltpan surrounding Calliope Creek and Auckland Inlet (Port Curtis) in 1941 and 1999. Data for 1999 from the DPI Fisheries (in brackets) for the same area are included for comparison. Other sources: this study.

	Mangrove			Salt marsh/ Saltpan			Total		
	1941	**1999**	**(1999)**	**1941**	**1999**	**(1999)**	**1941**	**1999**	**(1999)**
Area in ha	1061	840	(628)	981	465	(512)	2042	1305	(1140)
Change in ha from 1941-1999		-221			-516			-737	
% Change		-20.8			-52.3			-36.1	
Source			(DPI)			(DPI)			(DPI)

Storm Damage & Dieback

A notable and dominant feature of the Calliope River mangroves is the hail-affected area around the Anabranch. This area was struck by a severe storm in October 1994 and significant damage was recorded across a wide area (Houston, 1999). The types of damage sustained included: leaf damage and removal; bark shredding on one side of stems; and extensive small branch breakage. Recovery following the storm has been minor and current condition is clearly still showing signs of the impact. In the field survey of the current project, it was found that some species, like *A. marina*, had notable recovery, while other species, like *Ceriops* and *Rhizophora*, died over the large area affected.

Table 7. Extent of hail damaged area (in hectares) of mangroves and salt marsh (moderate, severe and total) as a result of a severe hail storm in the Port Curtis region during October 1994. The salt marsh category was used in this case instead of the salt marsh/ saltpan category, as the hail damage would only be occurring to the vegetation and would have minimal affect of the saltpan itself. (Source: Houston, 1999).

PC	Area of hail damage (ha)		
	Moderate	Severe	Total (mod+severe)
Mangroves	118	52	170
Salt marsh	24	17	41
TOTAL	**143**	**68**	**211**

Figure 34. Photograph of the hail-damaged area, showing dead C*eriops* in the foreground, with surviving *Avicennia marina* trees in behind the dead C*eriops*. This photo was taken in 2002, approximately 8 years after the hail storm occurred in 1994. (Source: Norm Duke)

Houston (1999), in his study, measured the area of hail-damaged mangroves and salt marsh and evaluated the degrees of damage as either moderate or severe. The total area of mangroves affected was 170 hectares, with 118 hectares experiencing moderate damage and 52 hectares experiencing severe damage (Table 7). There was a total of 41 hectares affected by hail-damage, with 24 hectares showing a moderate effect, and 17 hectares having severe damage. Overall, there was a total of 211 hectares of mangroves and salt marsh affected by the hail storm. Figure 35 shows the extent of the hail-affected area.

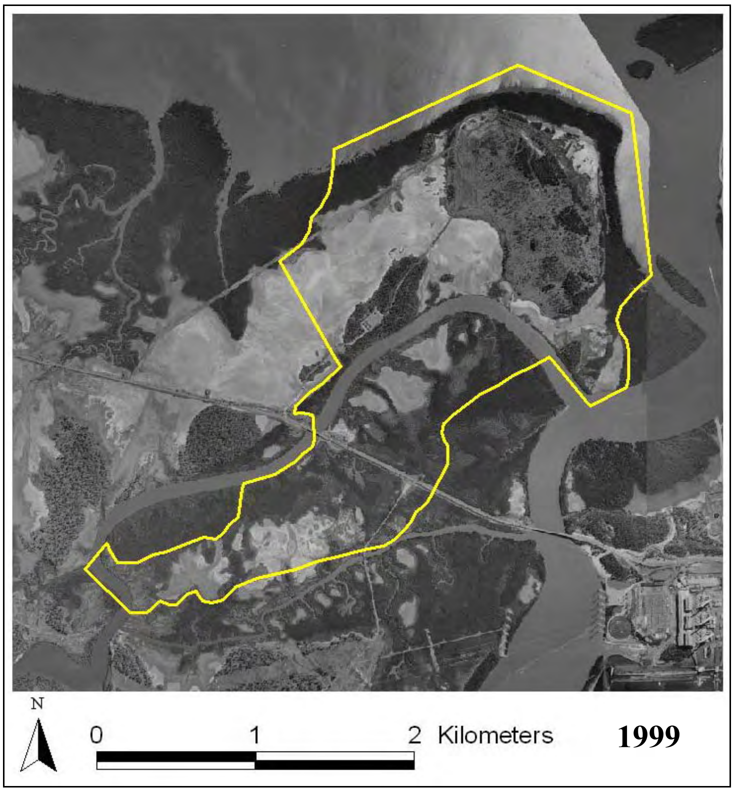


Figure 35. Close-up view of hail-damaged area (top left corner of previous picture), 1999. Mangrove and saltpan areas were calculated at 170 and 41 hectares, respectively. Yellow boundary marks hail-affected area as identified by Houston (1999).

Reclamation Loss

The bulk of tidal wetland loss is mostly due to reclamation associated with development of harbour-side land and facilities, industrial plant areas, urban sprawl, and roadways. The indicator tool used to identify this type of change relied on reported reclamation, geometric loss patterns in maps and photos, and observations of constructed retaining walls. The area of tidal wetland loss was around 1635 hectares for the 58 years up to 1999 (see Table 4). It is significant also that these losses had been incremental over several years while the damage from the hail storm happened after a single storm event.

The main site of loss was at Auckland Inlet, associated with large-scale reclamation for industrialisation, urbanisation, and port development. Approximately 593 hectares of tidal wetland area were reclaimed at Auckland Inlet in the period from 1941 to 1999, with approximately 205 hectares of mangrove and 388 hectares of salt marsh/saltpan being lost (see Table 8). In Figures 37(a) and 37(b) it can be seen that a large area of tidal wetland was reclaimed at Auckland Inlet, with only fragmented patches of the mangrove and salt marsh/saltpan remaining along the edges of the Creek.

Table 8. Area (in hectares) of tidal wetland including mangroves and salt marsh/ saltpan surrounding Auckland Inlet (Port Curtis) in 1941 and 1999. (Source: this study)

	Mangrove		Salt marsh/ Saltpan		Total	
	1941	**1999**	**1941**	**1999**	**1941**	**1999**
Area in ha	290	85	422	34	712	119
Change in ha from 1941-1999		-205		-388		-593
% Change		-70.7		-91.9		-83.3

Species-Specific Dieback

An incident of species-specific dieback of *Avicennia marina* in 1973-1974 was reported by Saenger (1988) for the Port Curtis region. There were strong suggestions at the time that this dieback was caused by a pathogen but this has since been rejected. Damage by a fungal pathogen is an unlikely cause of dieback based on detailed follow-up studies (Pegg and Forsberg, 1982; Pegg, Gillespie and Forsberg, 1980) and confirmed more recently by John Irwin and Andre Drenth (UQ CRC Plant Sciences), and Ken Pegg (DPI Plant Pathology). Current consensus is that the common fungal agent in mangroves, now known as *Halophytophthora* sp., is no longer considered pathogenic. While this fungal agent was ubiquitous throughout tidal mangrove areas, it was considered to affect and kill mangrove trees (and thus facilitate their loss) only after the plants were damaged or severely stressed for other reasons.

Figure 36(a) and 36(b). Auckland Inlet mosaics in a) 1941 and b) 1999, which can be used as a comparison with the tidal wetland maps in Figure 37.

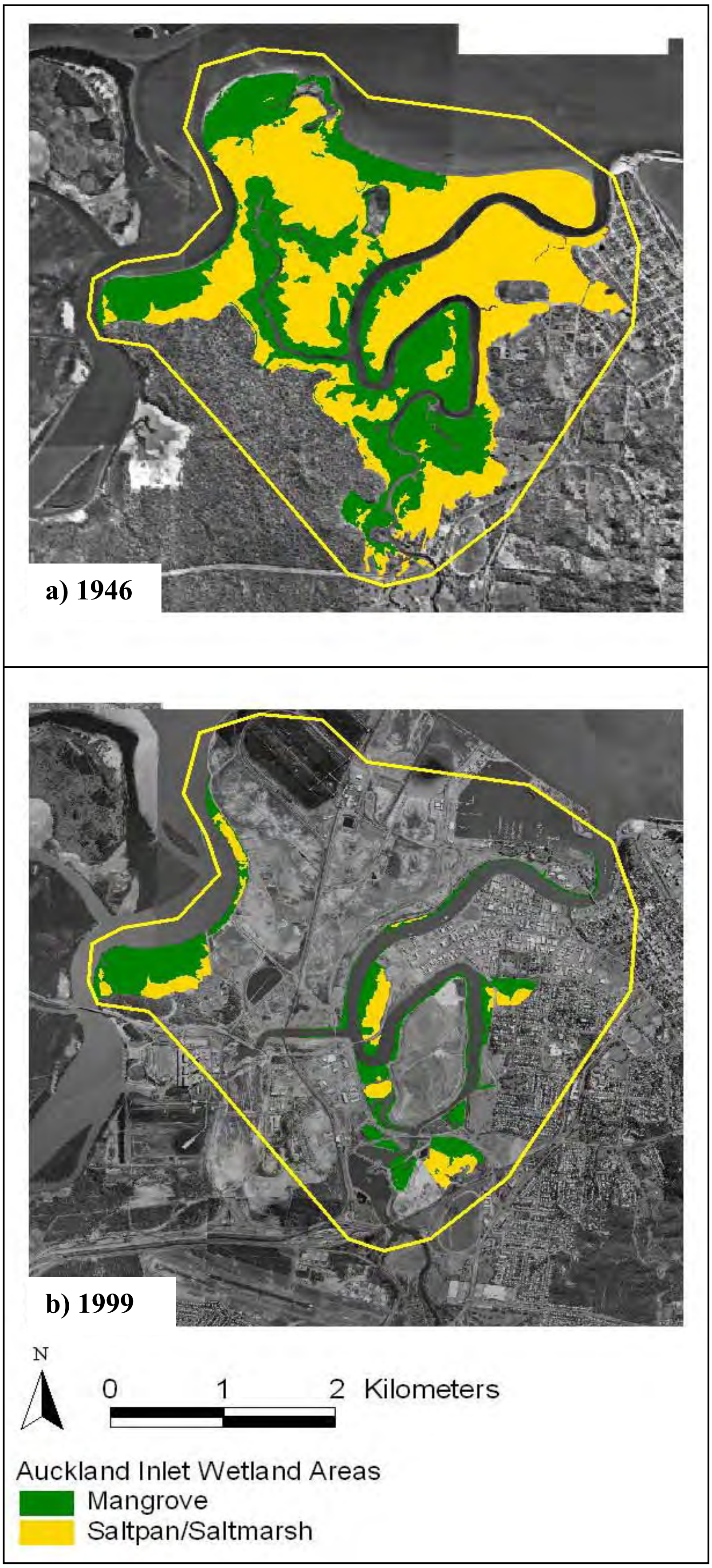


Figure 37(a) and 37(b). Auckland Inlet tidal wetland area in a) 1941 and b) 1999. Yellow boundary marks the area of interest. (Data source: this study)

This incident is comparable with only one other in the world, namely the dieback of *A. marina* currently taking place in the Pioneer River estuary and through the Mackay region. In the Port Curtis instance, no causative factor had been identified. The full extent of damage, notably of mangrove dieback, was not quantified either, although it was observed throughout the lower and middle estuary of the Calliope River (Saenger, 1988).

Zonal Shifts

There were no data available regarding the more subtle kinds of dieback associated with zonal shift for the Port Curtis region. If zonal shifts had occurred, they may have been masked in many cases by the reclamation losses in this area.

4.2.2 Endfield Creek, Curtis Island – Area of Natural Influence

Endfield Creek is situated at the Southern End of Curtis Island (23.76°S, 151.27°E). It was chosen for the case study investigating natural change, as it is an undeveloped, removed area, relatively free from direct human influence. In the past, one spot along the creek was used as a cattle landing, but such activity has long since ceased. Today, apart from the occasional visit by local fishermen, the creek and its surrounding intertidal vegetation remain undisturbed. This situation provides an opportunity to examine the role natural factors (e.g. climate change and sea level rise; see pg. 11 for description) may play in driving coastal vegetation change. Few previous studies have considered the impact of such factors on mangrove communities, despite their potential importance. Natural processes, both local and global, may indeed pose a significant risk to intertidal wetland habitats, especially when compounded by anthropogenic influences.

The study site was selected to encompass locations with a low, gradual rise in elevation, consisting of terrestrial 'islands' surrounded by salt marsh/ saltpan and completely fringed on the seaward edge by mangroves (Figure 38).

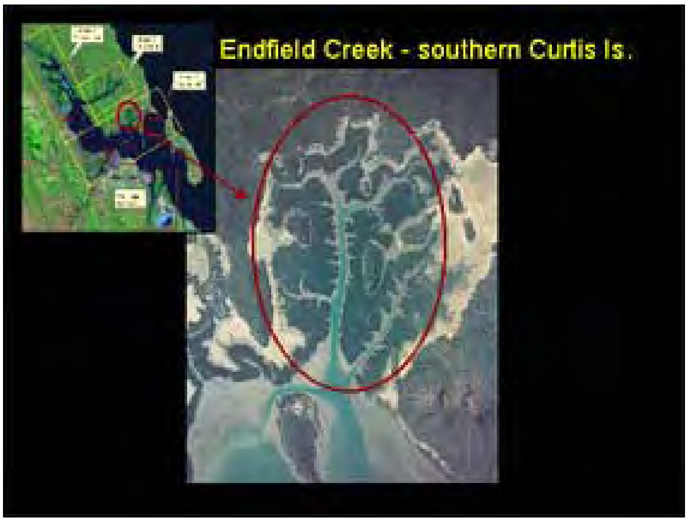


Figure 38. Location of Endfield Creek study site.

These characteristics allowed detection of subtle shifts in ecotone and encroachment/ dieback processes. Historical aerial photographs of the site were collected for 1941, 1959, 1970, 1979, 1989 and 1999. The 1941 photography was purchased from United Photo and Graphic Services, Victoria. The 1959 photography was borrowed from Alistair Meltzer, Central Queensland University. The 1970, 1979 and 1999 photography was obtained from the Department of

Natural Resources and Mines, while the 1989 set was borrowed from Queensland Parks and Wildlife Service. The mosaic was then georeferenced to a Landsat TM 1995 image (datum: WGS 84 and projection: Transverse Mercator) of the region, which was obtained from the Biophysical Remote Sensing Group (Geographical Sciences and Planning Department, University of Queensland).

The vegetation types were divided into the following categories: *Avicennia marina* with *Ceriops australis* (AM/CA), *Avicennia marina* (AM), *Ceriops australis* (CA), *Rhizophora stylosa* (RS), salt marsh/saltpan (SP) and terrestrial (TR).

Findings and Discussion

For the study site at Endfield Creek, four maps at approximately 20 year time intervals were created, depicting the vegetation types (Figure 39). These sequential maps, whilst few major changes are immediately obvious, allow for the detection of small scale changes to the total areas of vegetation types. Information regarding the amount of mangrove and salt marsh in proportion to total area, and any changes to this, is also able to be taken from the images. The years that maps have been created for were 1941, 1959, 1979 and 1999, which also allows for the rate of any changes to be determined.

Careful examination of the maps shows that the wetland area usually consisted of several zones, from mean sea level up to the terrestrial sections of the islands. There were occasional areas of *Avicennia marina* fringing, with pure stands of *Rhizophora stylosa* forming a large, distinct zone behind. A mixed *Ceriops australis* and *A. marina* zone of varied widths usually occurred landward of the *R. stylosa*. Area of saltpan and salt marsh area is usually behind this zone, with another *C. australis* zone (usually pure stands) between the salt marsh and the terrestrial areas.

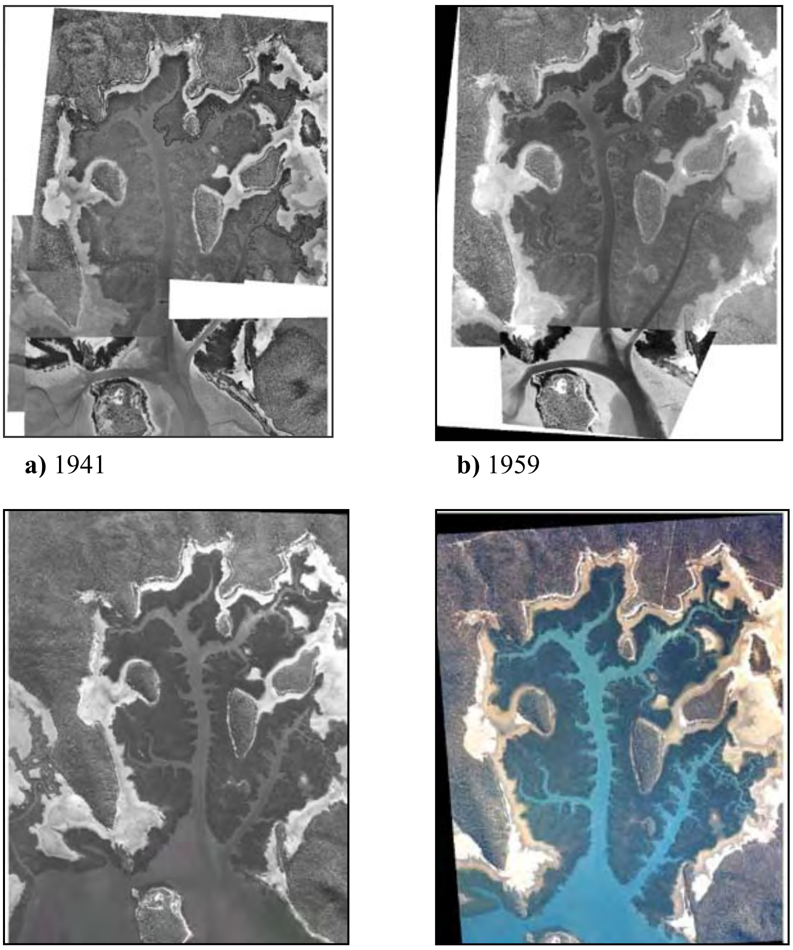
From the created maps, the total site area, and the area of each vegetation type, was able to be determined, and the change between each year calculated (see Table 9).

Overall, the greatest increase in area between 1941 and 1999 was in *R. stylosa* stands, with the mixed *C. australis* and *A. marina* vegetation type also increasing in area. *A. marina*, occurring as pure stands, decreased in area in the same time period. However, the incremental rates of change demonstrate that despite overall trends, the changes occurring were not constant and fluctuated between positive and negative shifts during different time periods. For example, over half of the loss of *A. marina* occurred between 1941 and 1959. The remainder of the overall loss occurred at a much slower rate, taking more than 40 years to lose less *A. marina* than was lost in the first 18 years studied. Due to a small total area of *A. marina*, the overall loss of approximately two and a half hectares accounts for more than half of the *A. marina* present initially. The trends of *R. stylosa* forests demonstrate the high variability in the overall loss values. The increase in *R. stylosa* between 1941 and 1959 was greater than any other change to vegetation type, during the study time frame, at an increase of 7.05 hectares. However, during the following time period, between 1959 and 1979 *R. stylosa* forest decreased, before increasing again slightly between 1979 and 1999. Due to the large overall area of the *R. stylosa* forests, however, the large area in hectares of change is actually equivalent to only a relatively small percentage of the forest, being only a 4.2% decrease overall. Of interest is the change to total area, with an overall increase. Much of this increase occurred during 1941 and 1959, but the following period recorded a loss of area, almost equivalent to the initial increase recorded.

The vegetation specific table has been summarised to determine the proportion of mangroves and salt marsh and saltpan in the total area, and also overall change to the two wetland ecosystems (Table 9). The total area consists mostly of mangrove vegetation, with the proportion of the total area being almost three quarters mangrove. An increase in the proportion of mangrove was also recorded, with losses to the total area of saltpan. This loss in saltpan area was compensated in part by the increase in the proportion of mangrove, and also with an increase in the proportion of terrestrial vegetation. However, the changes that were recorded represented only relatively small changes to the proportion of each ecosystem type.

Table 9. Area (in hectares) of tidal wetlands, including the general wetland vegetation categories as well as the mangrove species level vegetation categories for Endfield Creek, Curtis Island (Port Curtis) in 1941, 1959, 1979 and 1999. WCI = Wetland Cover Index (% mangroves).

PC – Endfield Creek	**Year**			
	1941	**1959**	**1979**	**1999**
Avicennia marina	3.79	2.15	1.99	1.26
A. marina with *Ceriops australis*	6.96	9.07	8.95	9.17
Ceriops australis	9.52	10.07	9.17	8.76
Rhizophora stylosa	114.01	121.06	117.08	118.78
Salt marsh/saltpan	23.44	24.90	22.18	22.61
Terrestrial	**24.65**	**25.70**	**25.06**	**25.81**
Total Mangrove	**134.28**	**142.35**	**137.19**	**137.97**
Total Salt marsh/saltpan	**23.44**	**24.90**	**22.18**	**22.61**
Total Tidal Wetland area	**157.72**	**167.25**	**159.37**	**160.58**
WCI (% mangroves)	**85.1**	**85.1**	**86.1**	**86.0**
Total terrestrial and Tidal wetland	**182.37**	**192.95**	**184.43**	**186.39**



a) 1941 **b)** 1959 **c)** 1979 **d)** 1999

Figures 39a), b), c) and d). Aerial photography of Endfield Creek for the years specified, to be used for comparison with the vegetation map in Figure 40 (Scale: 1:70 000).

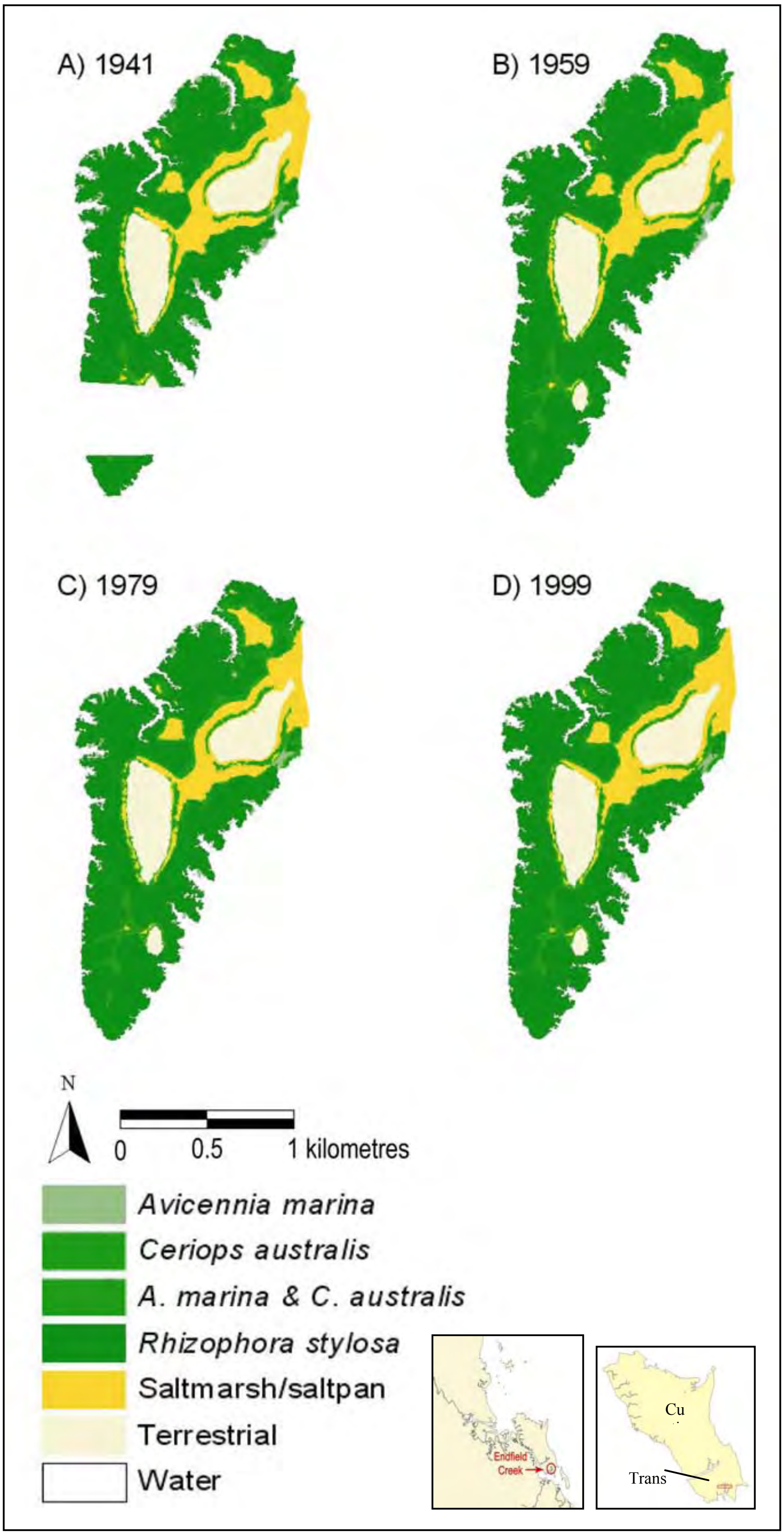


Figure 40. Vegetation map of the Endfield Creek study site depicting the relevant vegetation types, in a) 1941, b) 1959, c) 1979 and d) 1999. Inset shows the location of the Endfield Creek site.

4.2.2.1 Focal Point 1 – Strips

For the Endfield Creek study site, a strip, as mentioned in Chapter 3, was selected. The area used was chosen due to the location of water at either end of the strip, along with tidal wetland and terrestrial areas in between the water. The transect strips were created for six years, 1941, 1956, 1970, 1979, 1989 and 1999, the photography for which was obtained from the above, already mentioned sources. These strips were created to try and determine what small changes were taking place within a defined area. Specifically, it shows the change in water over time, an increase in water area indicating a retreating seaward edge.

Table 10 shows the area of tidal wetland, including water, for Endfield Creek, Curtis Island, for the six years that the transect strip was done for. As can be seen from this table, both the mangrove area and salt marsh/saltpan area over the 1941 to 1999 period was variable. From 1941 to 1970, mangrove area decreased by 5.34 hectares. This corresponded with an increase in the salt marsh/saltpan area of 5.93 hectares. From 1970 to 1979 the mangrove area increased by 6.14 hectares, with the salt marsh/saltpan area decreasing by 7.32 hectares. Mangrove area stabilized for 1989 and then increased 1.9 hectares by 1999, as did the salt marsh/saltpan area.

The area of water within the polygon strip experienced small changes throughout the 58-year period, with an overall increase of 0.73 hectares. There was a small increase of 0.13 hectares from 1941 to 1956, and then a decrease of 0.72 hectares from 1956 to 1970. By 1979 there was again an increase of 0.64 hectares, and then a reduction of 0.36 hectares by 1989. Between 1989 and 1999, there was a slightly higher increase of 1.04 hectares.

Table 10. Area (in hectares) of tidal wetlands including the different vegetation types within the transect strip selected at Endfield Creek, Curtis Island (Port Curtis) in 1941, 1956, 1970, 1979, 1989 and 1999. Transect strip location can be seen in figure 42.

PC - Strips	**Year**					
	1941	**1956**	**1970**	**1979**	**1989**	**1999**
Total Mangroves	83.77	81.38	78.43	84.57	84.56	82.68
Total Salt marsh/saltpan	46.37	48.55	52.30	44.98	45.32	47.26
Total Terrestrial vegetation	36.73	36.41	36.63	36.93	36.96	37.02
Water (increase indicates retreating seaward edge)	15.16	15.29	14.57	15.21	14.85	15.89

From this we can learn that there is a lot of variation in the water level. Some of these variations changes could have been due to the error experienced with georeferencing, even with the small error in this case (refer to Chapter 3 – Methods). Thus, it cannot be concluded as to whether the seaward edge was shifting. With the error taken into account, it appears that the seaward edge did not move.

Terrestrial vegetation had similar small variations over the 58-year period, which also may be due to the error experienced with georeferencing.

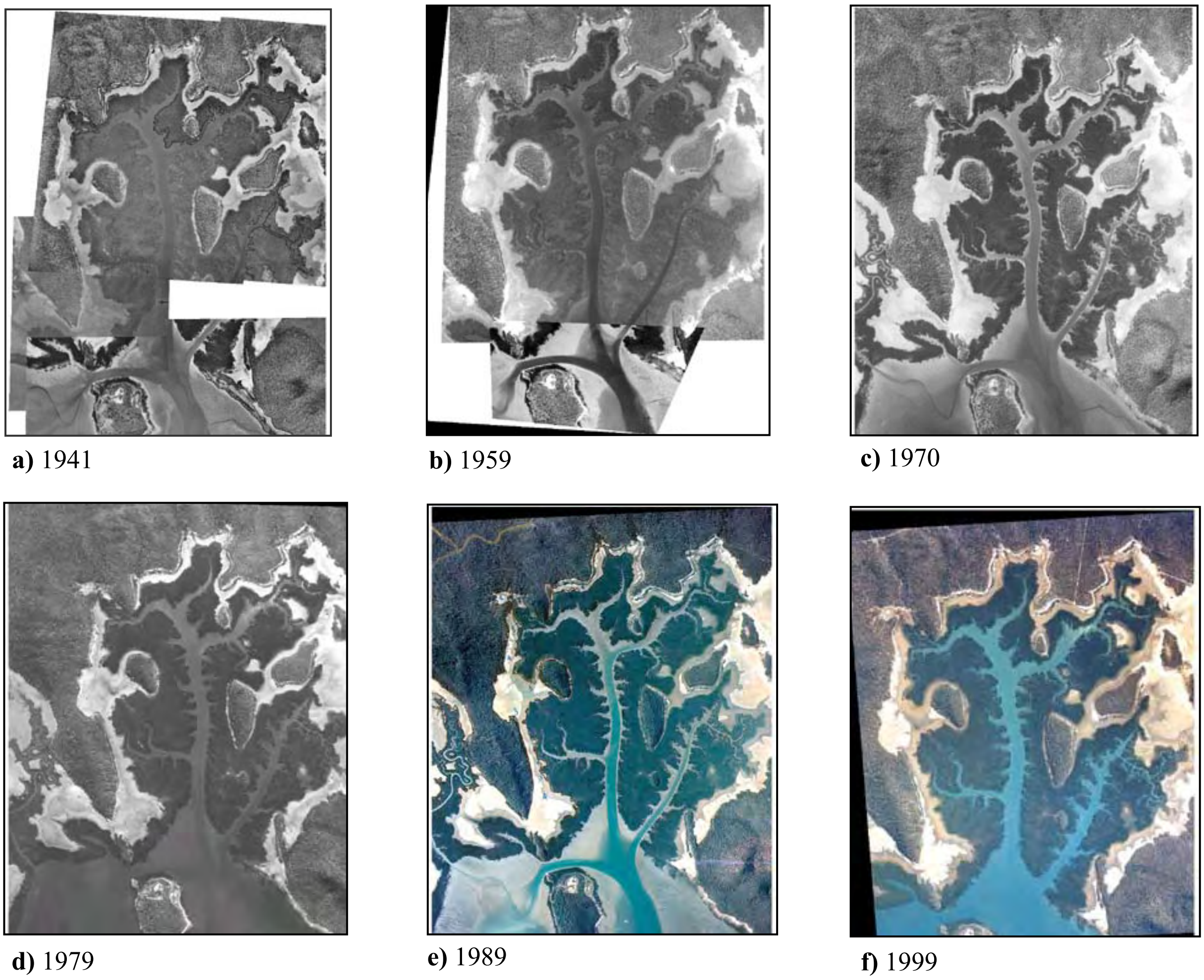


Figure 41. Mosaics of the Endfield Creek study site for the years listed. They can be used as a visual comparison with the vegetation map strips in Figure 42 (Scale: 1:70,000).

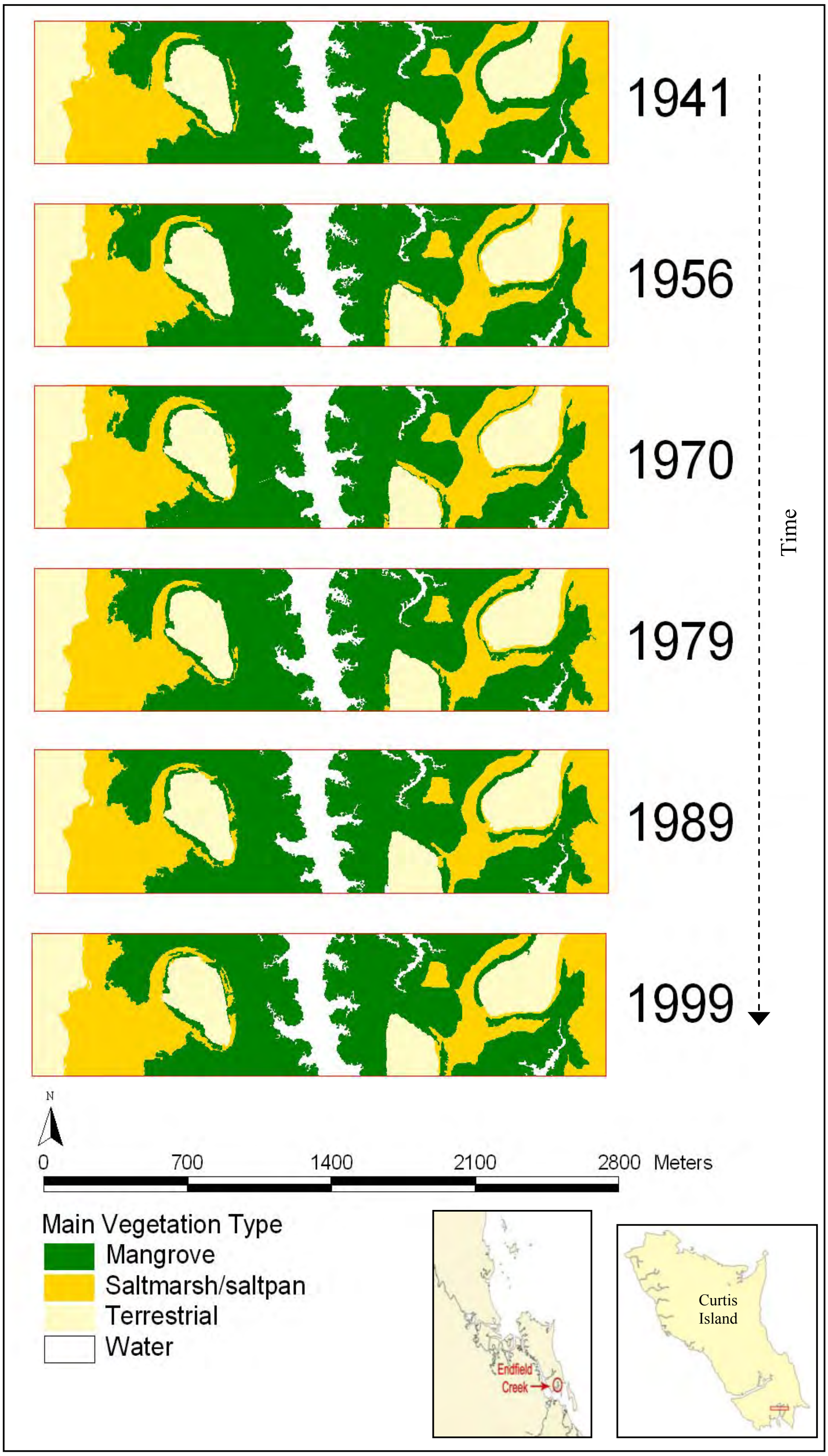


Figure 42. Time series of vegetation maps of transect strips from 1941 to 1999, running through a section of Endfield Creek (Curtis Island), showing the major vegetation categories of mangrove, salt marsh/ saltpan and terrestrial, along with water. Insets show the location of the transect in the region.

Mosaics of aerial photographic images of the site at Endfield Creek show few changes to tidal wetlands vegetation between 1941 and 1999 (see Figure 41). This general observation was assessed further and confirmed in the assessment of high scale strip images (Figure 42). Note that the study area in these strips included a wide mangrove stand, extensive salt marsh and saltpan, plus terrestrial parts, small islands and water. As with the mosaics, there was no obvious change in tidal wetland vegetation cover. Change detection was applied, where appropriate, to geo-referenced images.

This was better shown in the analysis of change detection (Figure 43). Here, there were small changes and shifts in ecotones. By contrast, there were no sea or land edge shifts which would marked changes in sea level. Small shifts were observed along the lower, top edge, and there were similar shifts along the upper edge. These are largely unexplained, although they may reflect smaller fluctuations in rainfall.

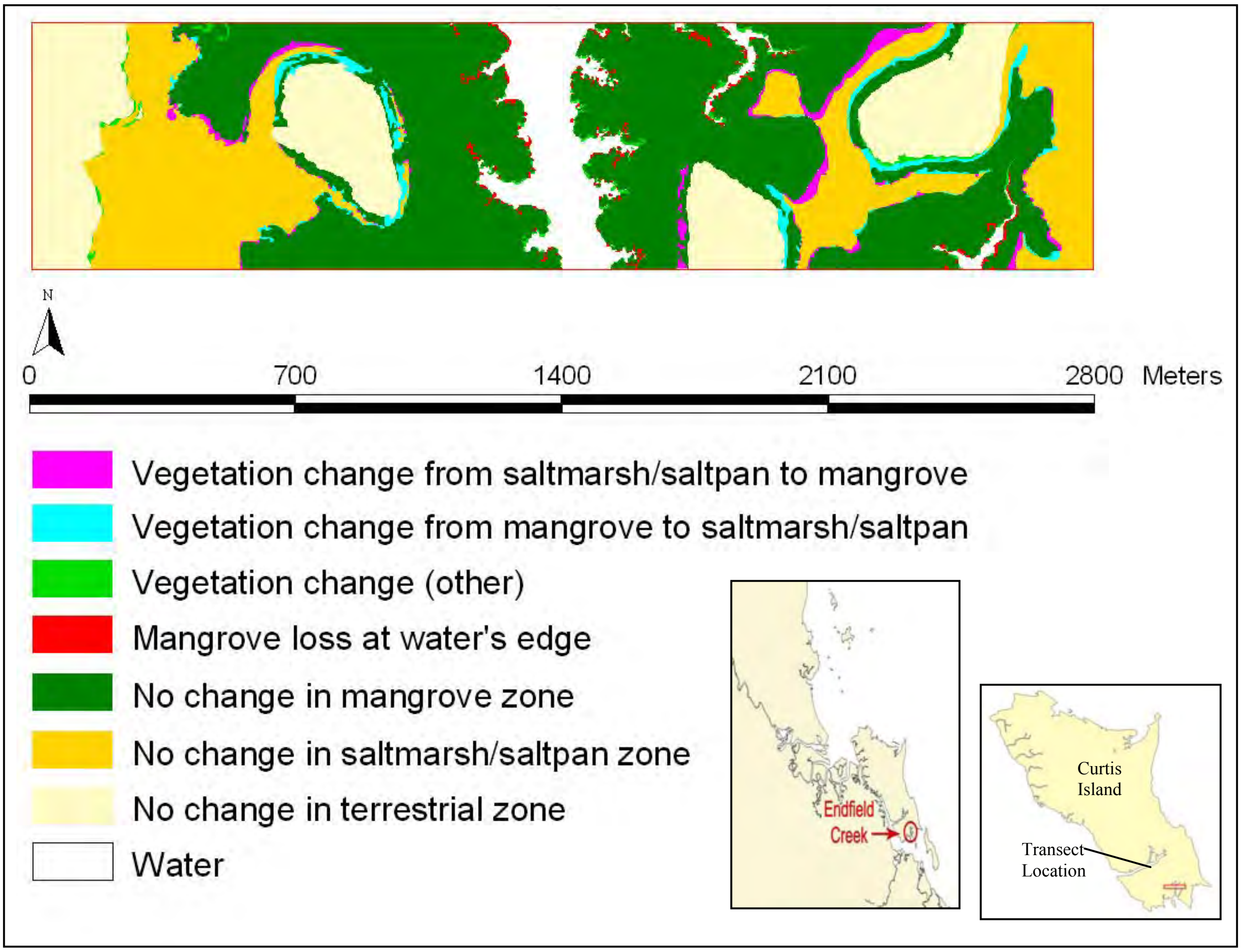


Figure 43. Vegetation change map for Endfield Creek (Curtis Island), from 1941 to 1999. Inset shows the transect location

4.2.2.2.Focal Point 2 – Transects

Four transects were studied in mangrove and salt marsh habitat around Endfield Creek, on the southern end of Curtis Island. Transects were used to describe and record variations in elevation with respect to ecotones – or between notable vegetation zones visible from aerial photographs. These were confirmed during field studies when a record was made describing species composition and vegetation structure. Transect sites were chosen to represent zones of vegetation in the region.

Field verification (ground truthing) was used to help interpret the imagery and define boundaries. This was achieved by setting transects through the vegetation from the seaward to the terrestrial fringe, and taking GPS coordinates at ecotones. Relative elevations at ecotones across the transects were also measured, using a combination of a dumpy level and staff, and a fluid-filled U-tube and ruler (Figures 44-46). This information was used to determine a possible correlation between elevation and ecotone.

Figure 44. Field survey: elevation readings using dumpy level.

Figure 45. Field survey: staff viewed with dumpy level.

Figure 46. U-tube and ruler used for elevation readings where dense vegetation restricted usage of dumpy and staff.

A primary objective for this section of the study was to link elevation heights with ecotones between chief vegetation types, and to present this as a generalised composite transect for the region (Figure 47). A schematic diagram of transects at Endfield Creek (Figure 48) shows the four transects placed relative to each other based principally on the high tide limit (HAT) and to a lesser extent on the lower intertidal limit of mangroves (~Mean Sea Level, marked by the lower wavy line).

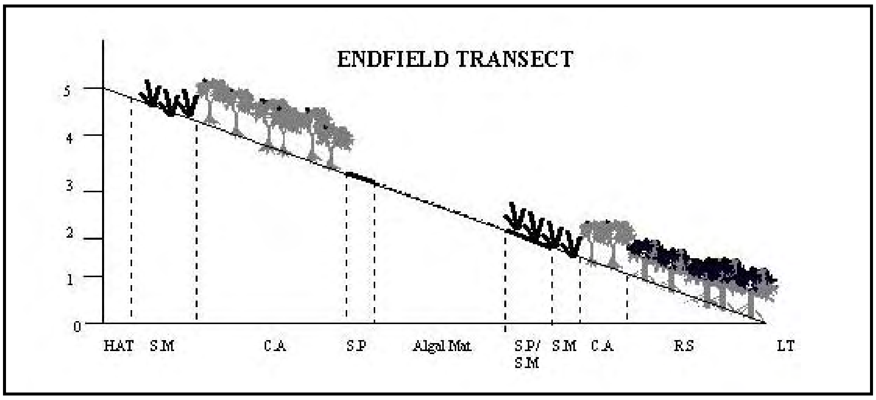


Figure 47. A schematic, generalised profile with tidal vegetation based on four transects in Endfield Creek. The vertical axis represents height in metres above LT. Elevation reference level was based on the high water mark determined from beach wash and debris. (HAT: High Tide, SM: Salt Marsh, CA: *Ceriops*, SP/SM: Saltpan/ Salt marsh, RS: *Rhizophora*, LT: Low tide.)

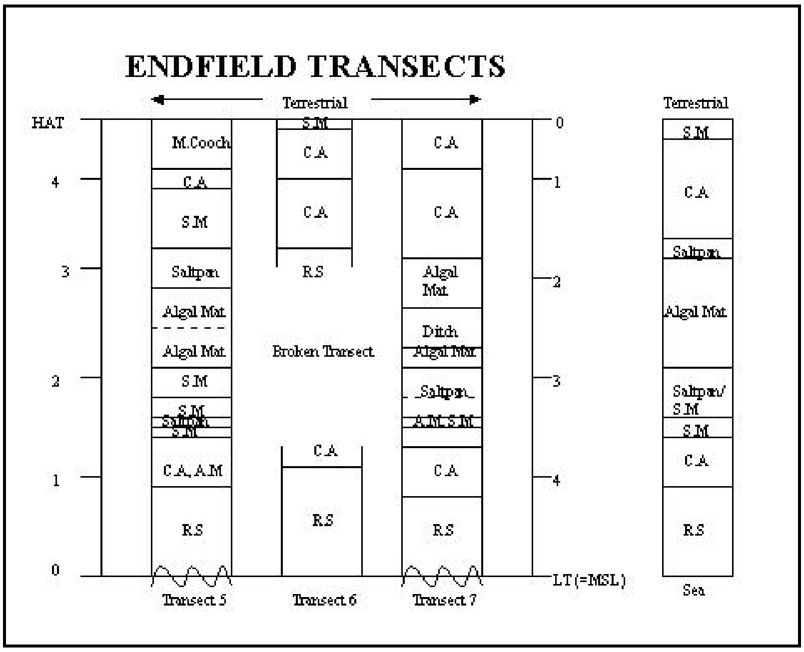


Figure 48. Incremental elevations (in metres) recorded for the four transects made in tidal flats at Endfield Creek. Note that transects were either scored from the low tide (MSL) or high tide (HAT) of the upper section of the intertidal range. Transects were termed 'floating' if they did not extend from high to low water limits. For codes, see Figure 32.

Avicennia marina was common within seaward and landward zones, while other species were more restricted. For example, *Excoecaria agallocha* was found mostly along terrestrial margins.

The five chief vegetation types include:

Seaward margin of *Avicennia marina* – sometimes dense stands around 5-8 m, sometimes scattered individual trees, and sometimes absent.

***Rhizophora stylosa* zone** – always present, ubiquitous, mostly monotypic with stands around 3-4m, usually very dense, forming a sturdy gnarled labyrinth of intertwined, above-ground prop roots. In many instances, these stands were not easily penetrable. This was the chief reason why transects were not all completed from HAT to MSL.

***Ceriops* zone** – can be a mixed zone or in specific associations of *Ceriops* around 1-2m with scattered solo emergent trees of *A. marina*, around 3-5m tall.

Saltpan/Salt marsh zone – comprises both vegetation-free zone and peripheral salt marsh at <0.5 m height at both high and low water marks.

Landward zone – This zone is also comprised of mixed species composition – for example, *Aegiceras corniculatum, Aegialitis annulata, Excoecaria agallocha*, etc.

The low intertidal position of some transacts were notably variable. This appeared due to a combination of factors, including slope, proximity of channel flows and erosion.

Elevational range for mangroves was around 4.5 metres between the approximate HAT and the seaward extent above MSL.

This information can be used as part of the indicator tool to check for the existence of zonal shifts (associated with sea level change) or ecotone shifts (associated with climate change) when compared to past imagery. At the ground level, there were no obvious indicators of this type of change taking place (e.g. dieback or encroachment at fringes). The information collected was also used in ground truthing, to verify the vegetation types and zones identified in the aerial photography.

5. Fitzroy River Estuary Region

5.1 Regional Assessment

5.1.1 Background: Fitzroy Estuary – A Rural Region

Fitzroy River Estuary (approximately 23.4°S, 150.7°E) is situated in Central Queensland, with its mouth meeting the coast near the north of Curtis Island (see Figure 35). Its catchment is the second largest in Australia, covering 142,537 km^2 (GBRMPA, 2001). The area borders on the tropical/ subtropical transition zone, and the climate is warm (average daily maximum: 28.2°C, minimum: 16.5°C) and relatively dry (mean annual rainfall: 820.1 mm) (Bureau of Meteorology Australia). The river has a long history of flooding during periods of episodic heavy rain, with the most recent major flood having taken place in 1991. The Fitzroy River estuary and delta are defined by Keppel Bay on the east and by the Rockhampton tidal barrage on the west, 59.6 km upstream from the river mouth. The delta includes the Fitzroy River, Casuarina Creek, Raglan Creek and Connor Creek.

The Fitzroy Estuary region is a major rural centre. An estimated 60% of the catchment area has been cleared, mostly for rural development (GBRMPA, 2001). The dominant land uses are agriculture (grazing and cropping) and mining. Grazing occupies approximately 124,732 km^2 of the catchment (GBRMPA, 2001). Intertidal wetlands are present in some areas, particularly around the lower reaches of the river and south of the mouth. These wetlands typically consist of extensive saltpans fringed by mangroves surrounding drainage creeks (Bruinsma, 2000).

Issues in the region include clearing for rural development, erosion and runoff of sediment, nutrients and pesticides. An estimated 2,635,882 tonnes of sediment, 6,579 tonnes of nitrogen and 1,440 tonnes of phosphorous are exported into the river per year (GBRMPA, 2001). The river is highly turbid, with substantial deposition near the mouth.

In addition to rural influences, urban pressure also exists from centres such as Rockhampton City (approximately 58,000 people (ABS 1996)). Rockhampton has impacted the system through clearing and urbanisation of the coastline and influx of nutrients and sewage.

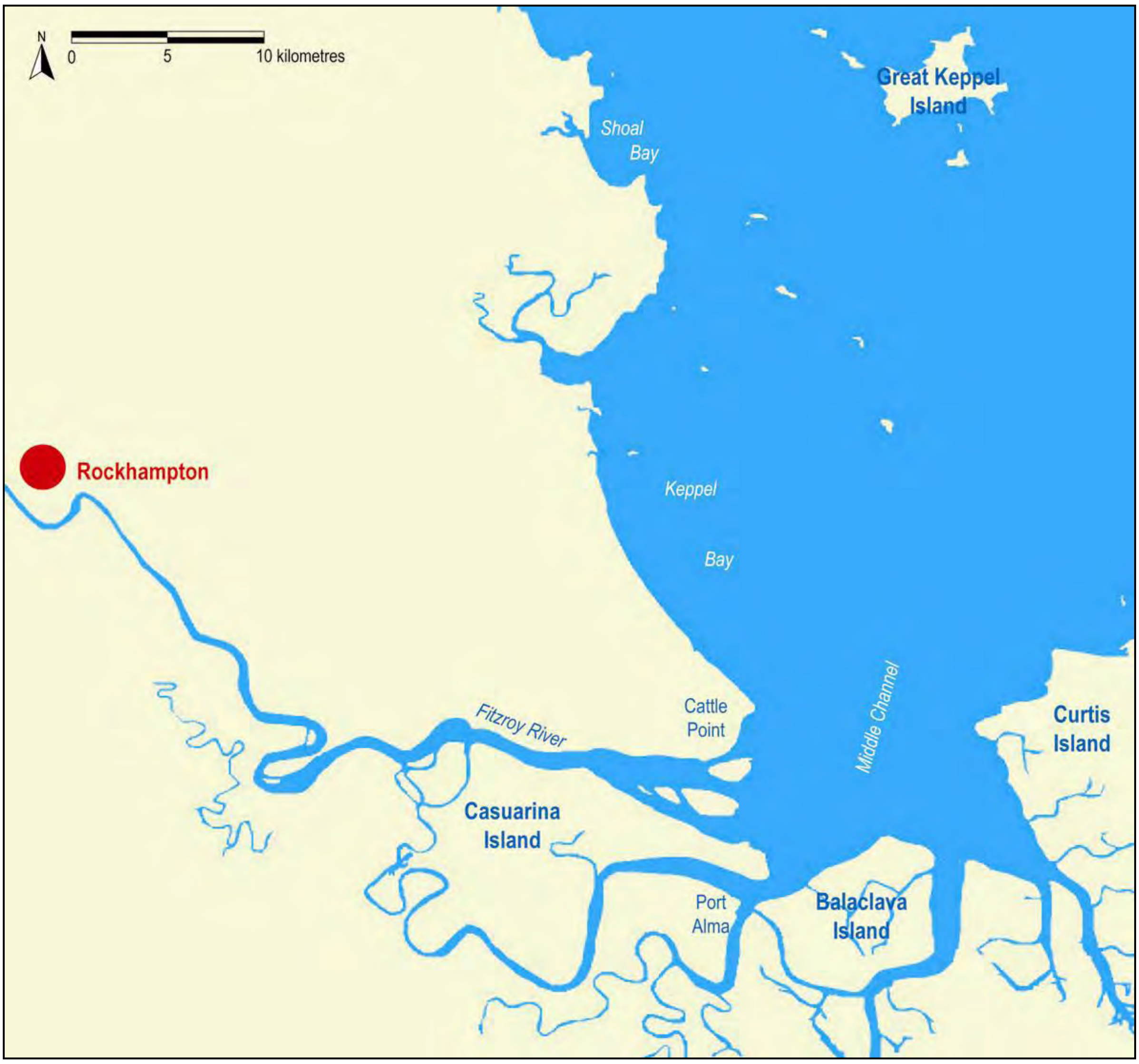


Figure 49. Map of the Fitzroy River Region, showing the city of Rockhampton and the major islands.

5.1.2 History

In 1853, William and Charles Archer established the first grazing property on the banks of the Fitzroy River. Since then, the region has developed into a thriving rural centre. Much of the early history of the area involved attempts to turn Rockhampton into a leading deep-water port, in the decades following the 1860's. To meet these ends, extensive effort and expenditure were directed towards 'engineering' the Fitzroy River, including such modifications as dredging, filling, construction of training walls and dykes. Figures 50 and 51 depict early charts and ‘improvement’ plans for the river. By the early 20th century, however, it became apparent that these dreams were unattainable. The river port was closed in 1965 and the wharves demolished in 1968 (Webster and Mullins, 2002). Today, the majority of incoming ships arrive instead at Port Alma, to the south of the Fitzroy River mouth.

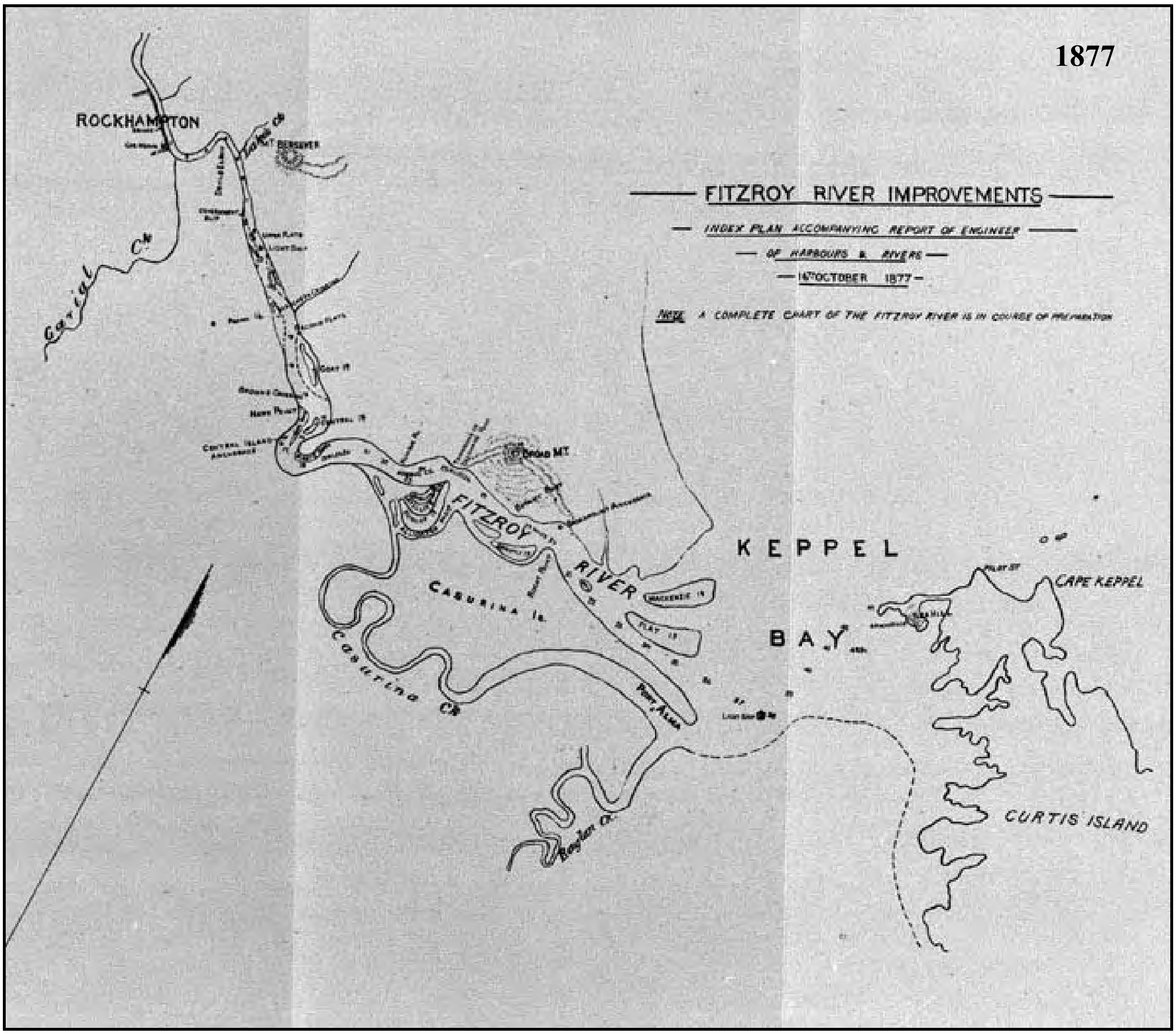


Figure 50. Chart of the Fitzroy River and its estuary as it appeared in 1877.

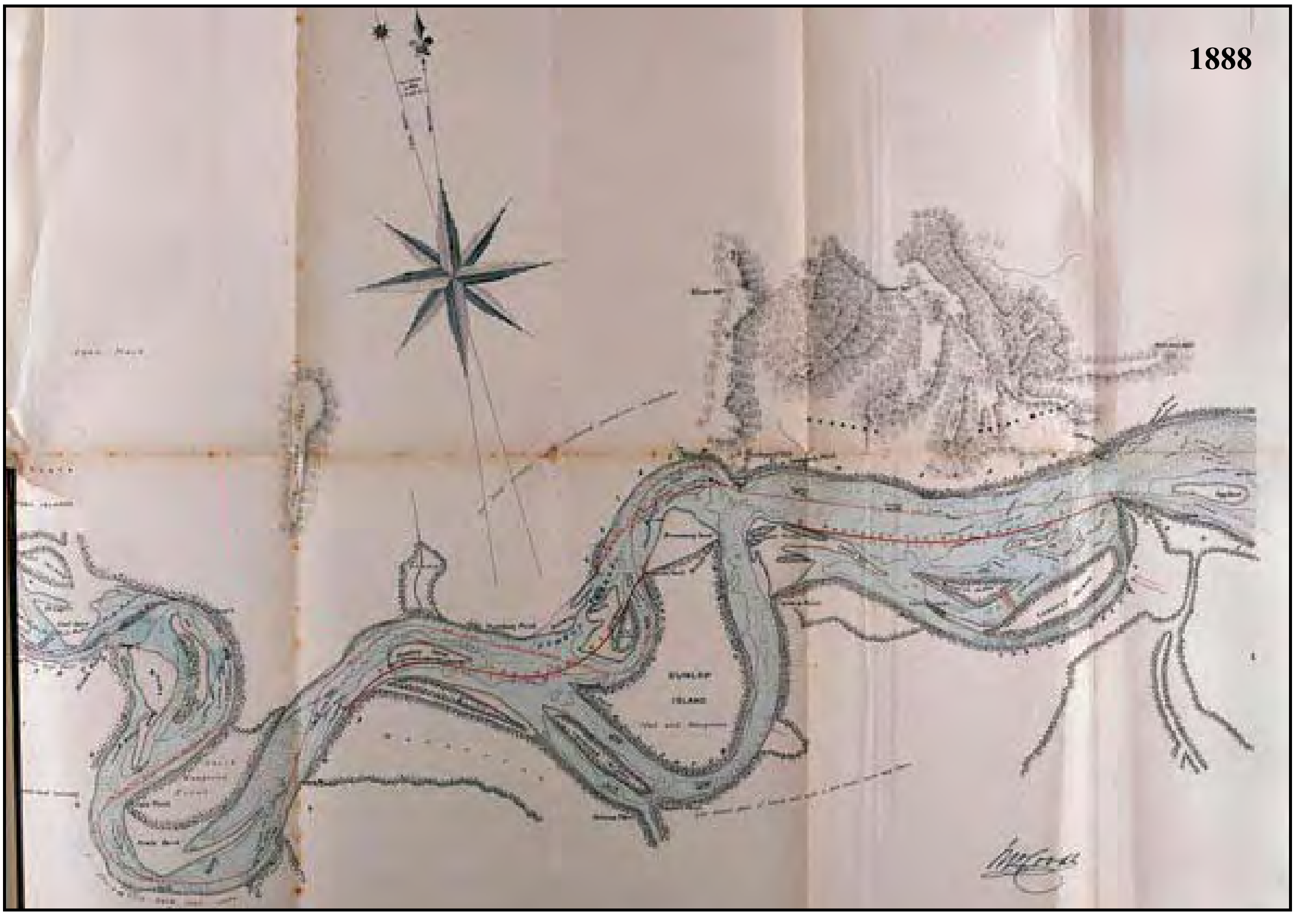


Figure 51. Chart of plans and improvements for a section of the Fitzroy River, 1888. Planned training walls are shown in red.

As part of the Historical Coastlines project, a series of historical photographs were collected from the Fitzroy River region, which can be used as a visual representation of historical change in the river (refer Figures 52 to 54).

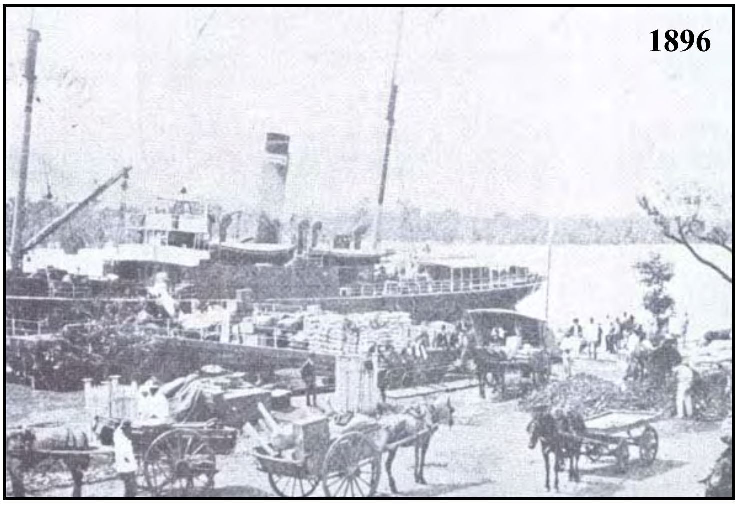
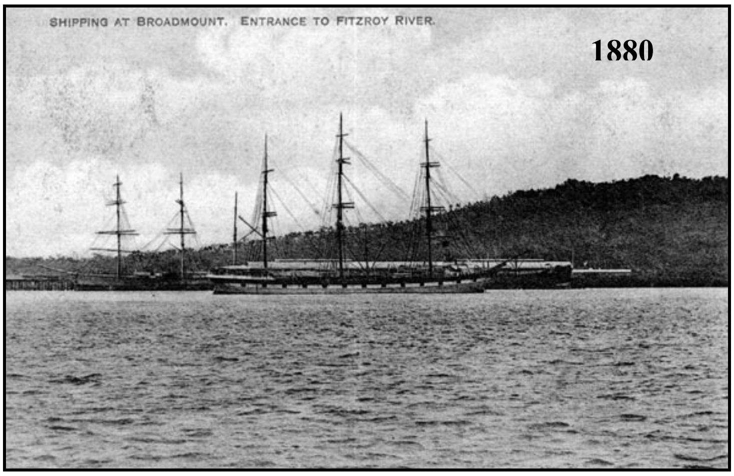


Figure 52. Rockhampton high-level wharf in 1896. (Source: John Oxley Library)



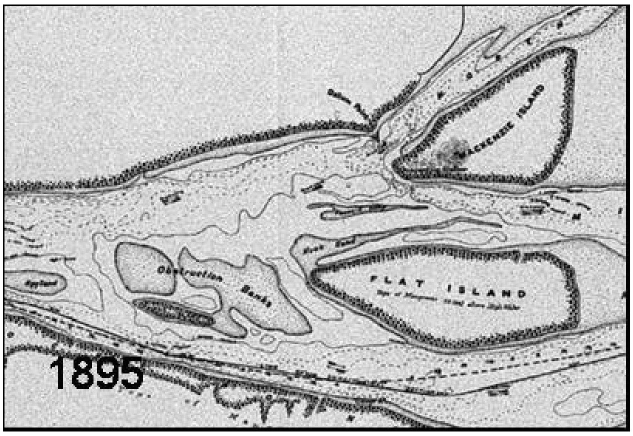
Figures 53(a), (b) & (c). Views of Broadmount harbour, Fitzroy River estuary, in 1880, 1910 and 2002. Today, the wharves have been demolished and the Broadmount 'port' abandoned. (Source: (a) & (b) Rockhampton District Historical Society; (c) Norm Duke)

Figure 52 shows a photo of Rockhampton's high-level wharf, in 1896, bustling with traders and their horse-drawn carts.

Figure 54(a) & (b). Early aerial views of the Fitzroy River, near Dunlop Island, in normal conditions (a), and during the 1928 flood (b). (Source: the Queenslander 1930)

Figures 53a), b) and c) display a view of Broadmount harbour, in the Fitzroy River estuary, in 1880, 1910, and 2002, respectively. What was a busy harbour in the late 1800s and early 1900s, is now deserted. Today, the wharves have been demolished and the Broadmount 'port' abandoned.

Figures 54a) and b) show early views of the Fitzroy River, near Dunlop Island, both normal conditions (54a) and during the 1928 Flood (54b).



a)

b)

c)

Figure 18. Time series showing development of mangrove islands in the mouth of the Fitzroy River for the years **a)** 1895, **b)** 1941 and **c)** 1999. A and B, shown in **c)**, are the two new mangrove islands that have formed since 1941, most likely as a result of sedimentation in the river mouth. Sand banks to the north of island B and Flat Island (the large Island in the bottom right) are also displaying signs of additional mangrove islands forming. (Scale 1:85,000). (Source: (a) Department of Harbours and Marine; (b) & (c) mosaics HC)

Another noteworthy event in the history of the Fitzroy River has been the formation of large mangrove islands near the river mouth. A time series of images, depicting this phenomenon is presented in Figures 55(a), (b) & (c). The 1895 image was taken from an old chart and the 1944 and 1999 photographs are a mosaic of aerial photographs. It is thought that the formation of these islands may have resulted from increased rates of sedimentary deposition, possibly due to increased clearing of catchment vegetation and/ or changes to estuarine hydrology (e.g. GBRMPA, 2001; Webster and Mullins, 2002; Fabbro and Duivenvoorden, 1996).

A historical timeline of the Fitzroy region, outlining anthropogenically-driven actions and events contributing to these coastal changes, is provided in the appendix (Appendix 2).

5.1.3 Broad change in Regional Coastal Vegetation

Wetland vegetation change analysis has not been previously undertaken for the Fitzroy River region. The Department of Primary Industries (DPI), however, classified and calculated the area of tidal wetlands for the Fitzroy River region in 1999.

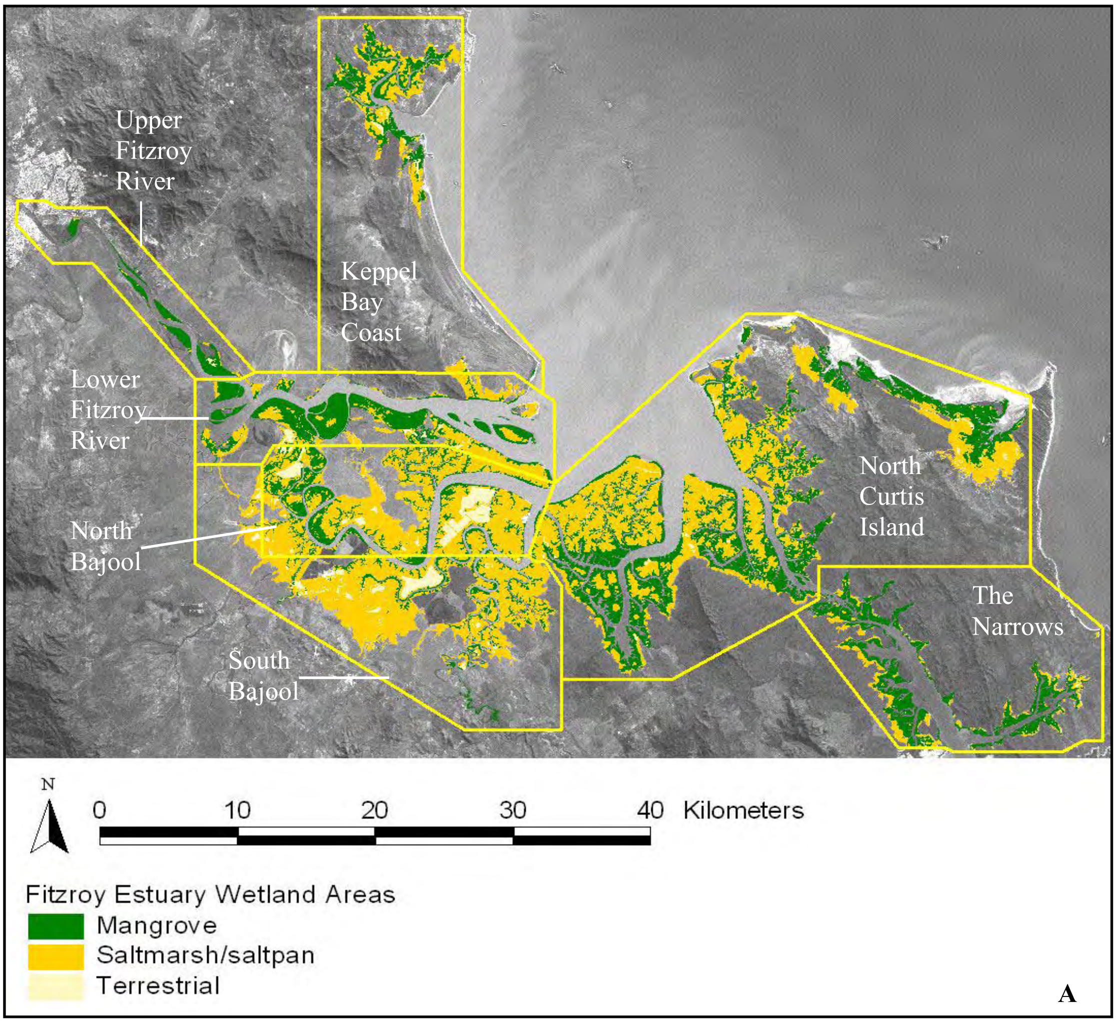
In this study, the Fitzroy River region was divided into 7 subregions, based on the river case study area of interest, the extent of tidal wetlands and the human influence on these areas. The selected subregions, detailed in Figure 56a), were: Keppel Bay Coast, Upper Fitzroy River, Lower Fitzroy River, North Bajool, South Bajool, North Curtis Island, and The Narrows. The area of tidal wetlands (mangrove and salt marsh and saltpan) can be seen in Table 11, and Figures 56a) –56g) show the distribution of these tidal wetlands in 1999, based on the DPI data.

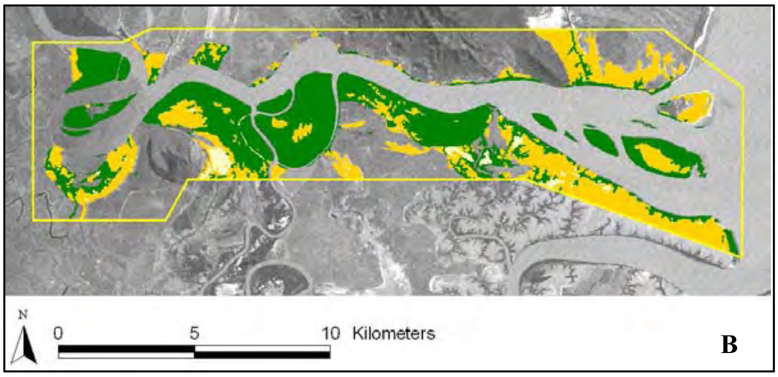
Overall change analysis could not be performed for the region as there was no historical data of tidal wetland cover to compare with the current cover estimates. The Fitzroy River region is an expansive area, that encompasses a number of different land uses. The total mangrove area in 1999, within the region was 20 801 hectares, with 30 158 hectares of salt marsh and saltpan, giving a total regional tidal wetland area of 50 959 hectares.

Table 11. Area (in hectares) of tidal wetlands including mangrove and salt marsh plus saltpan of the Fitzroy River estuary during 1999. WCI = Wetland Cover Index (% mangroves). The source of data was DPI Fisheries. Asterisk (*) denotes subregions under significant human influence.

FE	Mangrove	Salt marsh/Saltpan	Total	WCI
Subregions	**1999**	**1999**	**1999**	**1999**
Keppel Bay Coast	1566	1721	3287	47.6
Upper Fitzroy River*	762	2	764	99.7
Lower Fitzroy River*	3174	1787	4961	64.0
North Bajool*	2527	7166	9693	26.1
South Bajool	1200	7049	8249	14.5
North Curtis Island	8928	11,454	20,382	43.8
The Narrows	2644	979	3623	73.0
TOTAL Region	**20,801**	**30,158**	**50,959**	
Human Affected Subregions (*)	6463	8955	15,418	
Subregional Under Mostly Natural Influence	14,338	21,203	35,541	

The region was divided into distinct subregions specifically to isolate areas of known dominant influences. These subregions are shown in Table 11 and Figures 56a-h. The influencing factors will be discussed in the next section.





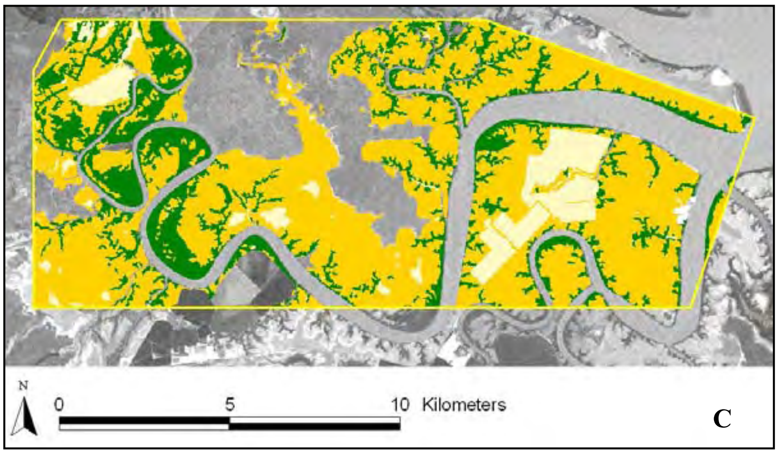
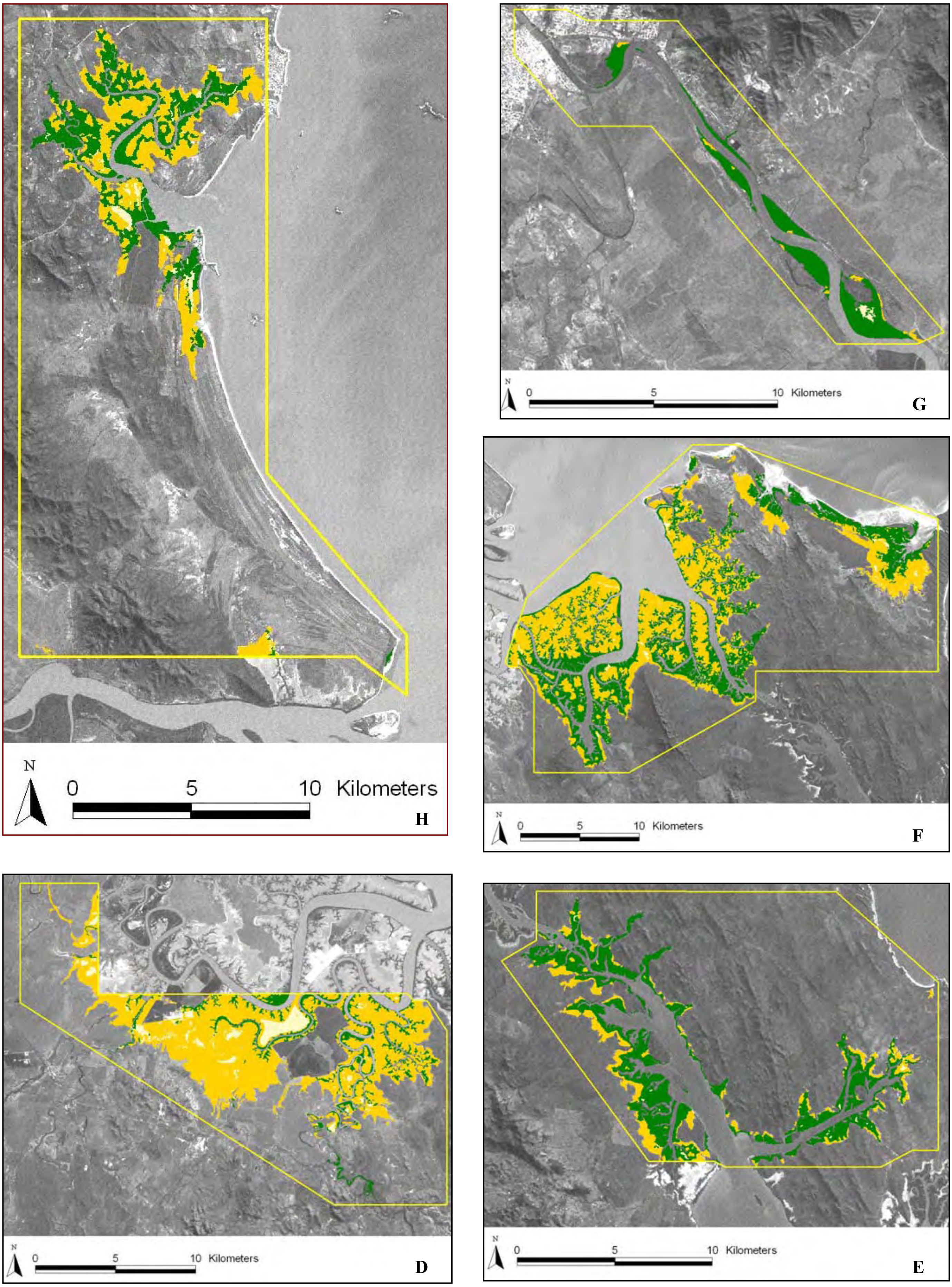


Figure 56. Distribution of mangrove and salt marsh/ saltpan in the seven Fitzroy River estuary subregions.
A: Map of Fitzroy River estuary region detailing the seven subregions used in this assessment for comparison.
B: Lower Fitzroy River
C: North Bajool
D: South Bajool
E: The Narrows
F: North Curtis Island
G: Upper Fitzroy River
H: Keppel Bay Coast
(Source: DPI Fisheries, 1999).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Types of change

Overall, the region is characterised by at least 7 categories of some impact (Table xx), with one relatively chief factor, namely ‘depositional gains and losses’. An assessment has been made for each using relevant indicators to characterise and where possible to quantify the more dominant influences.

Depositional Gains and Losses

The most dominant effect on tidal wetlands in the Fitzroy River Estuary region was shown with the formation of large mangrove islands at and near the river mouth. Although, there was a net gain of mangroves of around 210 ha, the effect is considered far greater since far greater areas were affected by both deposition and erosion. While large areas of tidal wetland were also lost, most gains were observed either with these ‘islands’, or behind river training walls. The latter constructions were made to assist redirection of river flows to maintain the navigation channels. This was not achieved, however, so the upstream port was abandoned around 1965. The chief driver for these depositional changes had been the regular high loads of sediment washed down the river estuary, especially during flood flow events (also see Duke and Wolanski, 2002). These flows have been associated with notable changes in hydrology, with indicative erosion and deposition of sediments. The changes to the hydrology have had important effects on the course of the river estuary, and they have changed its shape and character to some extent. These influencing factors are considered the ones most likely to have driven the formation of the depositional banks which had been rapidly colonised by mangroves once sediment levels exceeded mean sea level elevation. The progress of change appears to have accelerated in the recent period, noting that these mangrove islands only appeared around the 1960s, noting their absence in aerial photographs and old charts until then. It was also of interest that there does not appear to have been a progressive accumulation of mangrove area, but a dramatic change about 40 years ago. It would be of great interest to further investigate the appearance and formation of these ‘islands’ since there may be links with land use activities as well as construction efforts affecting the estuarine hydrology.

Reclamation Loss

A moderate but still important effect on tidal wetlands in the region has also been the losses resulting directly from reclamation. These losses amount to more than 833 ha, lost directly to both salt extraction ponds and the port facilities at Port Alma. The loss had increased substaintially with just 13 ha reclaimed by 1941 and the rest since then.

Other types of change

Other types of change are considered of less overall importance in the region. However, there have been some reports and indications of impacts caused by other factors.

The most notable of these would be the effects shown with 'ecotone shift' reflecting changes in rainfall patterns. As seen Figure X, rainfall in the region has declined progressively over the last 130 years with ~38% loss in rainfall during this period. This is expected to result in notable dieback of mangrove within the tidal wetland areas, with consequential gains in salt marsh and saltpan. The case study for Balaclava Island, reported later in this Chapter, was chosen to investigate this possible outcome.

During the aerial survey of the region, there were notable mangrove dieback patches observed on Balaclava Island. These were indicative of possible hail storm damage, like that observed in the Port Curtis region (Houston, 1991; and see Chapter 4), and in southern Moreton Bay (see Chapter 6). This effect was not quantified in this assessment.

The report by McKillup and McKillup (1997) indicates also the importance and presence of severe insect herbivore attacks on mangrove vegetation in the region. Such impacts, like with the hail damage have largely gone unnoticed in the mostly inaccessible parts of the tidal wetlands of this vaste estuary.

The above observations probably also apply to both 'direct damage' by people accessing the water edge and saltpans, coupled with the effects of 'restricted water flow' associated with road constructions and walls constructed to create ponded pastures. These impacts are more difficult to quantify but their effects are considered relatively minor in the region, although they may have important localised effects.

Table 12. Effect levels and types of change affecting tidal wetlands of the Fitzroy River estuary during three historical periods of the last two centuries. The 12 types of change are grouped into 4 categories (A-D) based on human and natural influences on coastal and estuarine habitat.

Type of Change	Pre 1860	1860 to 1946	1946 to 2002
A. Direct – Intended & obviously human related			
1. Reclamation loss	**Effect:** None	**Effect:** Minor **Driver:** Upstream port development & river channel, plus Broadmount port facilities.	**Effect:** Moderate **Driver:** Losses to ponded pasture, salt production & port development at Port Alma (~840 ha loss of wetlands).
2. Direct damage	**Effect:** Minor **Driver:** Occasional tree cutting, access paths & tracks.	**Effect:** Minor **Driver:** Occasional access paths, tree cutting, access paths, tracks, trampled roots.	**Effect:** Minor **Driver:** Occasional tree cutting, access paths & tracks.
B. Direct – Unintended & obviously human related			
3. Restricted tidal exchange	**Effect:** None	**Effect:** Minor **Driver:** Impoundment, river training walls.	**Effect:** Minor **Driver:** Impoundment, built-up roads.
4. Spill damage	**Effect:** None	**Effect:** None	**Effect:** None
C. Indirect – Unintended & less obviously human related			
5. Depositional gains and losses	**Effect:** Minor **Driver:** Regular seasonal rainfall associated with occasional increased sediment in run-off.	**Effect:** Moderate **Driver:** Clearing of catchment vegetation increased sediment run-off, plus construction of training walls, resulting in shallower waters around the mouth. Dredging of navigation channel.	**Effect:** Dominant **Driver:** Includes 210 ha new mangroves at river mouth due to increased sediment in run-off, plus construction of training walls. Dredging of the navigation channel until 1965.
6. Nutrient excess	**Effect:** None	**Effect:** None	**Effect:** None
7. Species-specific effect	**Effect:** None	**Effect:** None	**Effect:** None
D. Not obviously human related, if at all			
8. Wrack accumulation	**Effect:** None	**Effect:** None	**Effect:** None
9. Herbivore/insect attack	**Effect:** Minor **Driver:** Insect plagues - occasional.	**Effect:** Minor **Driver:** Insect plagues - occasional.	**Effect:** Minor **Driver:** Insect plagues - occasional. But notable in upper estuary.
10. Storm damage	**Effect:** Minor **Driver:** Severe storm, hail, lightning, storm waves - occasional.	**Effect:** Minor **Driver:** Severe storms, hail, lightning, storm waves - occasional.	**Effect:** Minor **Driver:** Severe storm, hail, lightning, storm waves – occasional in lower estuary.
11. Ecotone shift	**Effect:** Minor **Driver:** Climate (rainfall) change - longer-term	**Effect:** Minor **Driver:** Climate (rainfall) change - longer-term	**Effect:** Minor **Driver:** Climate (rainfall) change - longer-term
12. Zonal shift	**Effect:** None	**Effect:** None	**Effect:** None

Relative effect levels: None; Minor; Moderate; Dominant, based on relative extent and presence of changes observed.

5.2 Detailed Assessment – Case Studies

5.2.1 Fitzroy River – Area of Human Influence

The case study focuses on the Fitzroy River estuary, consisting of the tidal reaches of the river (i.e. the area between the river mouth and the tidal barrage in Rockhampton) and the surrounding intertidal wetlands. The approximate study area is shown in Figure 57.

The Fitzroy River estuary has been exposed to considerable human influence over the last 150 years. Anthropogenic impacts potentially driving coastal change have included dredging, construction of training walls, increased sediment export and the construction of the Rockhampton tidal barrage in 1970 (Fabbro and Duivenvoorden 1996). Although the lower reaches are largely abandoned today, they are still affected by activities upstream and in the surrounding catchment.

The case study presents a thorough investigation of historical change in the Fitzroy River estuary tidal wetland habitat between 1941 and 1999, using aerial photography (from Rockhampton and Bajool). This was achieved through the creation of digitised maps detailing coastal vegetation and features for each of the years and the use of change-detection analysis to calculate changes in the tidal wetland area.

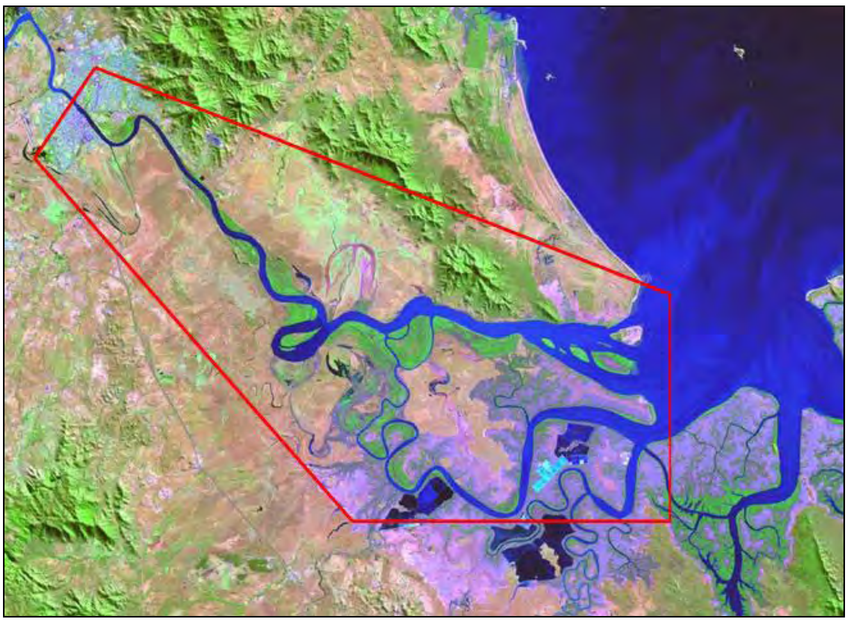


Figure 57. Location of Fitzroy River Estuary study site (Scale: 1:500,000).

The 1941 photography was purchased from United Photo and Graphic Services, Victoria, and the 1999 photography was obtained from the Department of Natural Resources and Mines (DNRM). Mosaics that were created for this case study were georeferenced to a Landsat TM 1995 image (datum: WGS 84 and projection: Transverse Mercator) of the region. The Landsat TM 1995 image was obtained from the Biophysical Remote Sensing Group (Geographical Sciences and Planning Department). The mosaics can be seen in Figures 59a) and 59b), and provide a visual comparison with Figures 60a) and 60b) showing the tidal wetland area coverage in 1941 and 1999, respectively. The vegetation categories used in this case study were mangrove and salt marsh/ saltpan.

Early 1880s images, such as Figure 58, can be used to visually interpret what the shape of the river might have been like at that time.

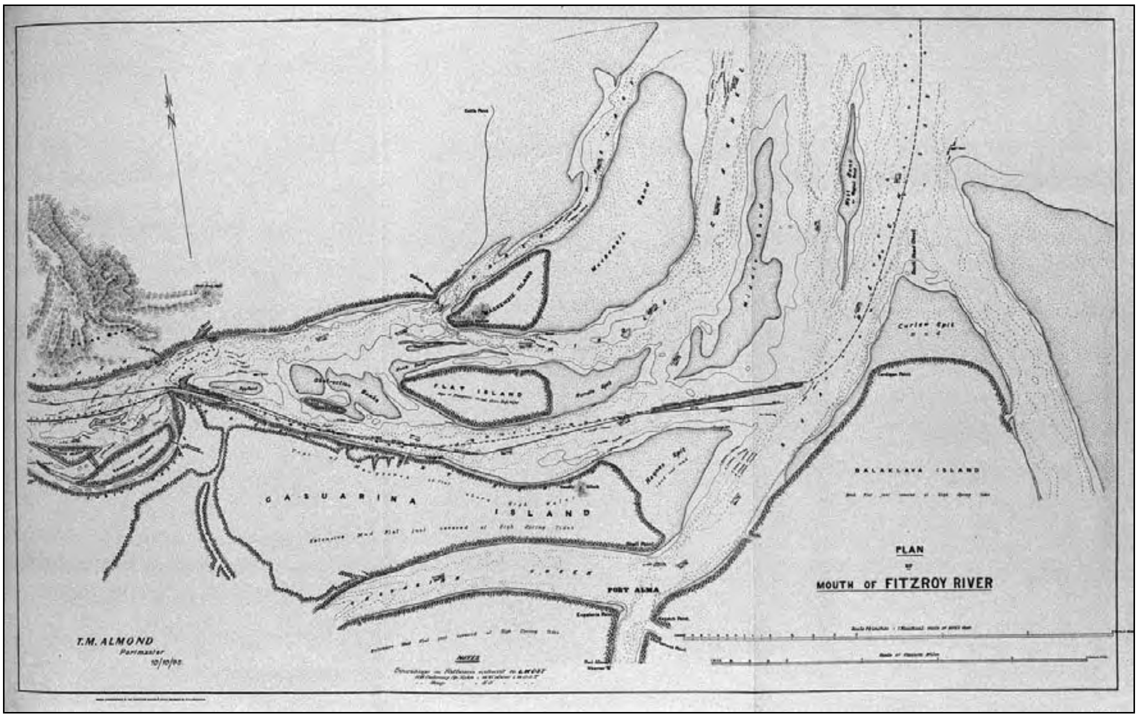


Figure 58. 1895 map of the Fitzroy River; one of the number of old historical maps used to interpret the 1880s tidal wetland area.

Findings and Discussion

In the Fitzroy River region, as noted in the regional assessment, there have been few major direct human influences (ie. reclamation, direct damage, restricted tidal exchange and spill damage; c.f. indirect human influences) over the last 60 years. However, there have been have some notable changes to mangrove areas around the mouth of the river and in the lower estuary.

There are three notable causes for change in the tidal wetland areas, and these have been identified and grouped using the indicators discussed in this treatment.

The extent of change can be seen by comparing the maps drawn from 1941 and 1999 aerial photography (Figures 60a) and 60b)). Estimates of tidal wetland areas are summarised in Table 13, along with corresponding estimates of percent change. It is significant that the change occurred at the expense of the salt marsh/ saltpan. The loss was estimated at 524 hectares (approximately 5.6% change) between 1941 and 1999. There was, however, an increase of 550 hectares of mangroves (approximately 9.7% change) from the region. Overall, the net change for the Fitzroy River was very small, with an increase of 26 hectares (only 0.17% change).

Table 13. Area (in hectares) of tidal wetlands including mangroves and salt marsh/ saltpan directly surrounding Fitzroy River Estuary in 1941 and 1999. Current (1999) wetland area for the greater Fitzroy region is included for comparison (Source: DPI Fisheries, and this study). WCI = Wetland Cover Index (% mangroves).

	Mangrove			Salt marsh/saltpan			Total			WCI		
	1941	**1999**	**(1999)**	**1941**	**1999**	**(1999)**	**1941**	**1999**	**(1999)**	**1941**	**1999**	**(1999)**
Area in ha for River (case study)	5691	6241	(6463)	9342	8818	(8955)	15 033	15 059	(15 418)	37.86	41.44	(41.92)
Change in ha 1941-1999		+550			-524			+26				
% Change		+9.7			-5.6			+0.17				
Source			(DPI)			(DPI)			(DPI)			(DPI)

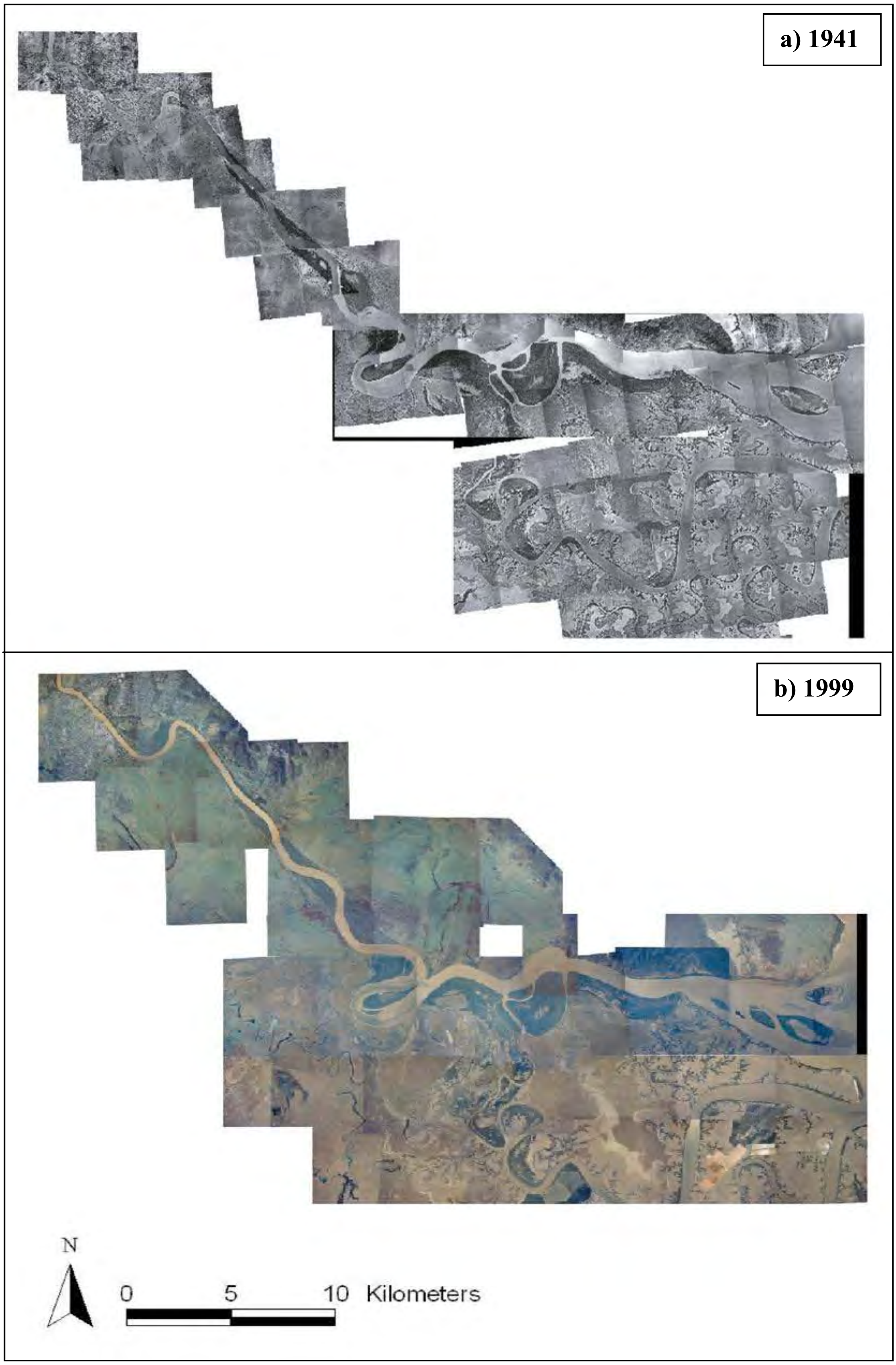


Figure 59a) and b). Mosaic of aerial photographs depicting Fitzroy River estuary in a) 1941 and b) 1999. These provide a visual comparison with the vegetation maps in Figure 60.

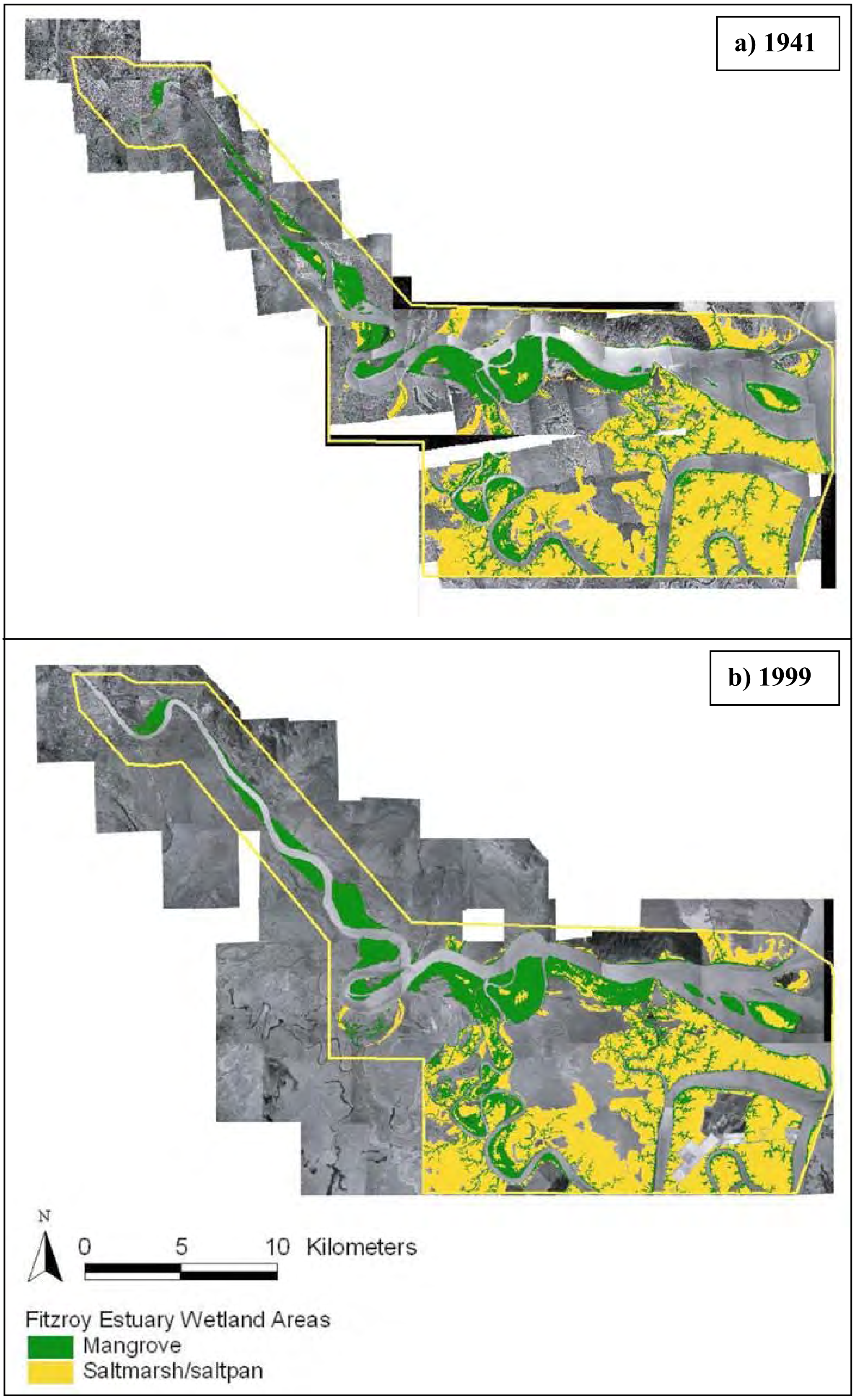


Figure 60. Vegetation map showing mangrove (green) and saltpan (yellow) areas directly surrounding the Fitzroy River Estuary in a) 1941 and b) 1999.

Drivers of change along the Fitzroy River lower estuary

There appears to be two main drivers of change evident within the Fitzroy River. These have been identified as natural change in river hydrology, and unintentional human change as a result of 1) river-altering structures being constructed, and 2) deposition of sediment in the mouth of the River. There are three separate case studies that have been identified that represent the two main proposed drivers of change, one showing natural change and two showing unintentional human changes, and these are outlined below. They are Pirate Point, Sandfly and Mosquito Islands and the River mouth islands (see Figure 61).

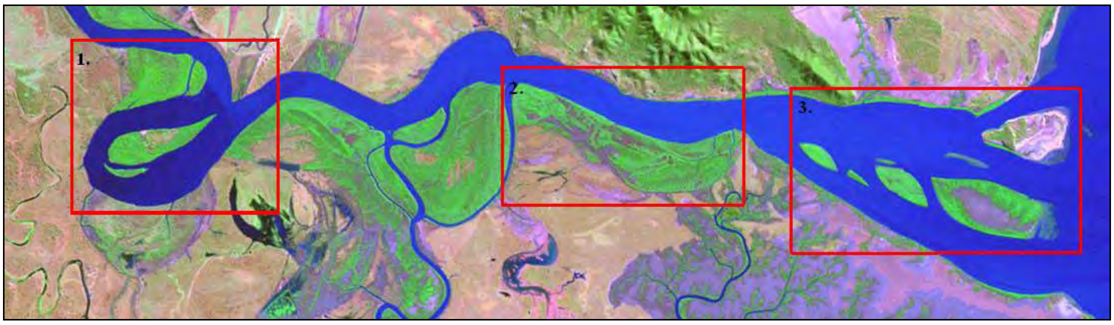


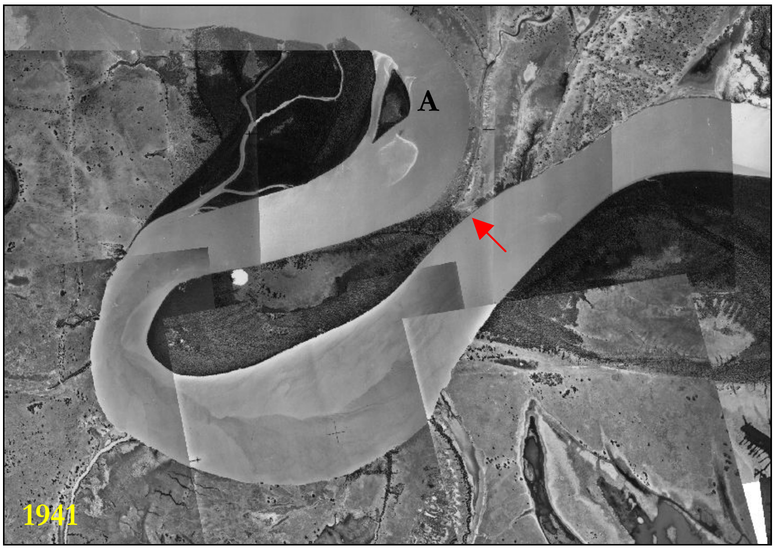
Figure 61. Location of the three case studies illustrating the three proposed drivers of change within the Fitzroy River. 1. Pirate Point; 2. Sandfly and Mosquito Islands; and 3. River mouth islands.

Changed hydrology

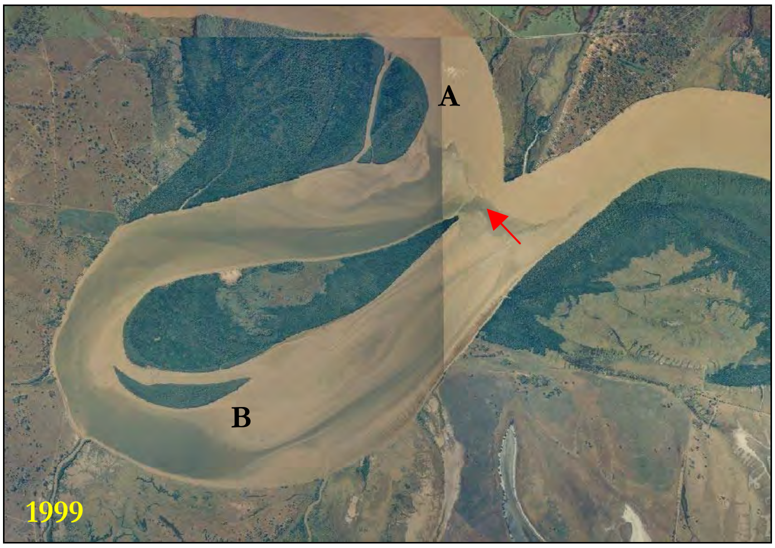
The first case study is located at Pirate Point (see Figure 62), where the River has cut through one of the bends in its course. In 1941 Pirate Point was a tight bend in the River with a spit through the middle of the bend (see Figure 62a). However, by 1999, the River had broken through the spit (where the red arrow is indicating in Figure 62b) and created an island in the bend, at the same time also creating a new flow path for the River (see Figure 62).

Not only had a large new island been created in the bend, but a smaller mangrove island (see Figure 62'B') to the south of the larger new island had also formed. Another change that occurred over these 60 years, was the growth of the mangrove knob, in the top left of the picture, indicated by 'A'. The mangrove island 'A' grew in size, while the creek within the mangrove knob was almost engulfed with mangroves.

The cause of this change has been proposed to be natural changes in river hydrology, such as meandering of the river course, through deposition of sediment on the inside bank of a bend and the erosion of the outside bank of the bend. However, there may also be secondary affects from unintentional human changes to the river, which alter the hydrology of the river, that have influenced this change.



a)



b)

Figures 62. Pirate Point **a)** in 1941 with spit still intact, and **b)** in 1999 after the formation of an island as a result of the River cutting through the spit. There is an increase in area in the mangrove island A, with that whole mangrove knob growing larger, subsuming part of the creeks within the mangroves here. By 1999 there is also the formation of a new mangrove island, B, along with the larger new mangrove island that made up the spit. The red arrows indicate the point where the River cut through the spit, both before and after it occurred.

Alteration to erosion and deposition

The second case study of change is proposed to be related to unintentional human changes that result in alteration of the hydrology of the river and erosion and deposition processes that occur. The case study is of Pugh Sand, Tait Islet, and Sandfly and Mosquito Islands, which is identified in Figure 61 above, and is an example of mangrove gain within the Fitzroy River.

In 1875 construction of training walls along the Fitzroy River began (see Figure 63) with a training wall constructed above Tait Islet and Mosquito and Sandfly Islands (from Shoal Island across to Rocky Point) starting in 1905. Construction of this wall allowed mangroves to establish, after both the deposition of sediments over time and the dumping of dredging spoil in behind the training walls. The three original islands have become engulfed by the deposition and subsequent colonisation, and are now connected to the mainland to the point where the islands are no longer recognisable.

In the 1895 chart there is a well defined water course between the mainland and Sandfly Island, as well as the presence of the three islands, Sandfly, Mosquito and Tait. By 1941 the training wall had almost been finished, and is indicated by the red arrows in Figure 64b. Sandfly, Mosquito and Tait Islands had all been subsumed by mangroves and were now joined to the mainland. The defined channel that was below Sandfly Island in the 1895 chart, had formed a creek (see Figure 64b). By 1941 there was also the development of another new mangrove island, indicated by A in Figure 64b. In 1895 there was the presence of a sand bar named Pugh Sand, which was drawn on the chart in a similar position to where the new 1941 mangrove island developed.

By 1999, the new mangrove island, A, had also been subsumed by mangroves. The creek present in 1941 had almost been closed in with the formation of another smaller creek along the eastern edge of the new mangrove island. There is also the encroachment of salt marsh/saltpan into the mangrove from the mainland direction, in Figure 64c, and in Figure 65.

1853	Archer Brothers established grazing property at Gracemere (near where Rockhampton is situated today).
1859	First recorded major flood to 8.23m
1862	Government constructs a public wharf
1864	Close survey of river recommended before proposed dykes and dredging Undertaken; Floods in February and March to 8.46m and 8.69m respectively
1865	Dredging begins - Upper Flats
1875	Training wall construction begins Heavy silting due to flood
1884	Blind channels on either side of the Fitzroy were closed with barriers to confine the current to the main channel of the river. Dredging to 12ft although quickly silted up again after floods.
1891	Most planned training walls had been completed
1896	Flood Feb 8.92m, 100 homes flooded
1897	Middle Channel dredged
1901	Dyke built between Shoal Island and Iguana Point
1905	Shoal Island training wall started
1913	South Channel opened
1914	South Cannel dredged to 17' and middle channel closed
1918	'The Great Flood' in Jan-Feb at 10.11m. Dredge cuttings silted up
1940	Dumping of dredge spoil behind training walls (459 600 tonnes)
1949	4 Acres of land at Port Alma reclaimed
1963	Fitzroy deemed un-navigable
1965	Rockhampton river port closes, and dredging stops.
1970	Barrage constructed
1991	Major flood.

Source: Compiled from timelines written by the author and a timeline by Barbara Weston, found in Appendix A.

Figure 63. Fitzroy River timeline of environmental factors. Dredging of the Fitzroy River began in 1865, with training wall construction beginning in 1875. After almost a century of trying to tame the Fitzroy River, it was claimed untameable and the River Port closed in 1965. Green indicates general or political happenings, blue indicates flood events, red indicates construction, orange indicates reclamation, and black indicates dredging and associated activity.

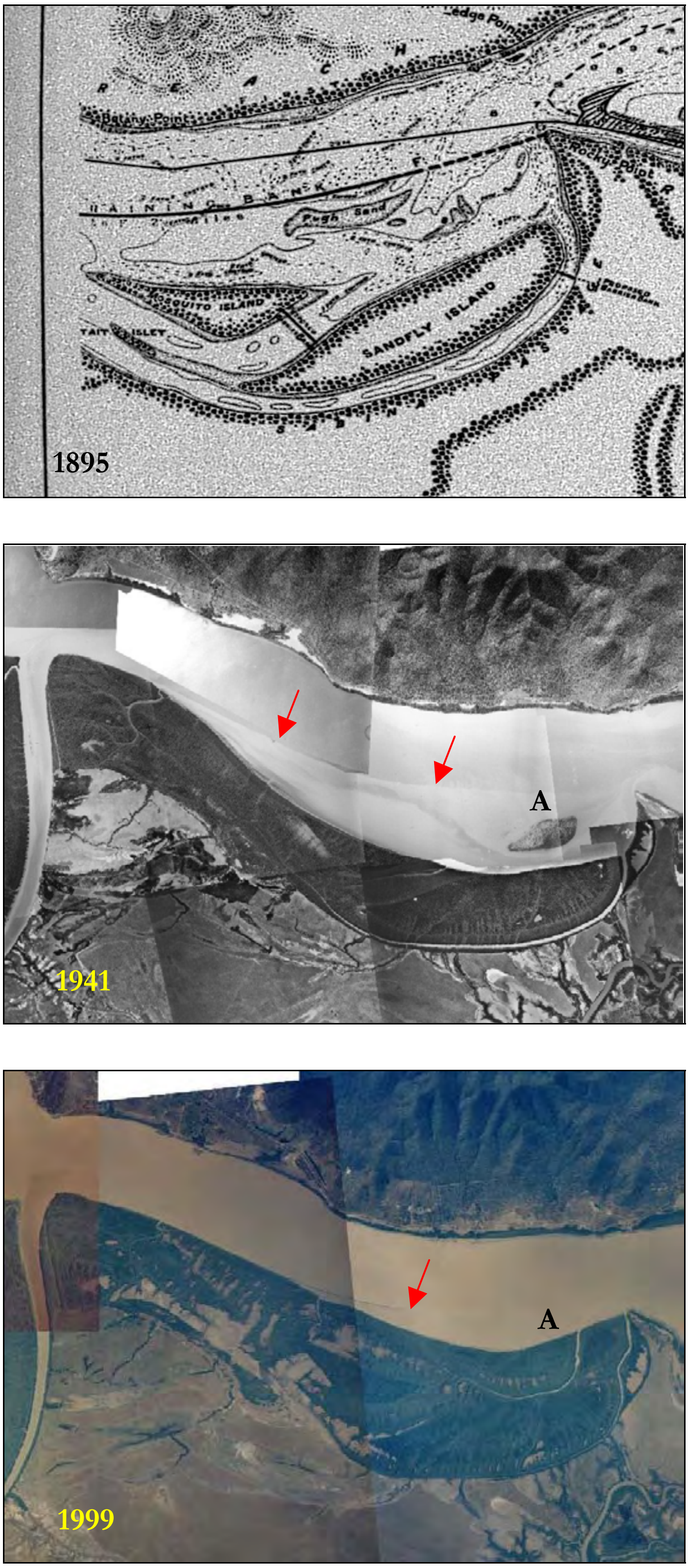


Figure 64. Time series showing mangrove encroachment on Sandfly Island, Mosquito Island, Tait Islet and Pugh Sand, along the Fitzroy River in **a)** 1895, **b)** 1941 and **c)** 1999. In **a)** the proposed training wall (from Shoal Island across to Rocky Point) is drawn on the chart, the position of which is then indicated in **b)** and **c)** by the red arrows. In 1941 a new mangrove island has formed and is indicated by A. By 1999 this new island has been subsumed by mangroves and now forms part of the mainland.

From 1895 to 1941, Mosquito and Sandfly Islands had been fully surrounded by mangroves, forming a one large patch of mangrove forest. In the 1941 figure, the presence of a small mangrove island can also be seen. This is what was referred to as Pugh Sand in the 1895 Figure, and is now forming a mangrove island. However, by 1999, this new mangrove island from 1941 had also been surrounded by mangroves and had become part of the large patch of mangrove that used to be Mosquito and Sandfly Islands.

Figure 65. Aerial view of saltpan encroachment into the mangrove forest between Shoal Island (in the top right corner of the photo) and Rocky Point, 2002. (Source: Katherine Zahmel)

Downstream sediment deposition

The third type of change that occurred in the Fitzroy River was what appears to be downstream deposition of sediment, resulting in the formation of two new mangrove islands in the mouth of the River.

From 1895 to 1941, there was little change observed in the islands at the mouth of the River. There was the larger Flat Island, to the bottom right (see Figure 55), and the smaller Egg Island on the left. However, between 1941 and 1999 there were two additional mangrove islands that formed, A and B, as shown in Figure 55c. Additionally, in the 1999 photo (Figure 55c), the banks to the north of Island B and Flat Island are showing signs of additional mangrove islands forming.

As can be seen, from 1895 to 1941 (46 years) there was little change in the mangrove island at the mouth of the River (see Figure 55a and 55b). However, over the period from 1941 to 1999 (58 years), two extra mangrove islands developed in the mouth (Figure 55b and 55c).

It has been proposed that this gain in mangroves was due to downstream deposition of sediment, most likely related to human activities occurring within the catchment, such as land clearing and construction of training walls within the River. There also may be a possible influence from natural occurrences such as floods.

Key ecological indicators and types of change

The region is characterised by at least three major categories of impact: depositional gains and losses, associated changes in species composition and ecotone shift. An assessment has been made for each using the relevant types of change.

Depositional Gains & Losses

Most depositional gains were observed in the mouth of the river, with the dramatic formation of mangrove islands occurring after the 1960's (Bob Packett, pers. com.). For a century prior to the 1960's, the islands had remained relatively unchanged, as seen in the 1895 chart (Figure 55a)) and the earliest aerial photographs taken in 1941 (Figure 55b)). In comparison, between 1941 and 1999 (e.g. Figure 55c)), there was a 15% net gain (around 40 ha) in mangrove area for all mouth islands.

However, these were not the only increases in mangrove area observed. An assessment of the broader mouth area (including the islands) for the same time interval found a net increase in mangrove area of 210 hectares, or around 11.5%. New mangrove areas had also formed along the sides of the river and further upstream. These occurrences may not be related to climate change but rather to changes in catchment sediment loads or in river flow and hydrology. Catchment changes might equate to catchment clearing, and loss of riparian vegetation. Hydrological changes might have arisen from the earlier dredging and construction of river training walls upstream, or with the installation of the barrage. For example, sections of the river cut off by river training walls constructed at least one or two decades earlier have been filled in by mangroves. As with the islands, most increases were due to formation of new intertidal habitat rather than through encroachment of existing intertidal habitat into saltpan or terrestrial areas.

Changes in Species Composition

Colonisation of sediments appears to have been rapid, with some islands apparently created at different periods. This is indicated by apparent differences in species composition and mangrove forest structure for some islands. For instance, during the field survey, it was noted that the island furthest upstream (Two Bob Island) was chiefly colonised by a closed forest of *Avicennia marina* around 5-6 metres tall with seedlings of *Rhizophora stylosa* underneath. By contrast, another new island, the larger one downstream, appeared to be at a more advanced successional stage. Fewer (but similarly sized) *A. marina* trees were being replaced by *R. stylosa*, generally around 3-4 metres. Mature stands were dominated by *R. stylosa*, with *A. marina* generally only found at the seaward margin or in upper saltpan areas.

Changes at the river mouth – timing of driving factors

The new mangrove areas are clear examples of depositional gains (see first chapter on indicators). It is unclear, however, which factors were the chief causes of increased sediment deposition, but they are expected to be fundamental since they appear to represent altered functionality and hydrodynamics of the estuary. There are some important clues to identifying the factors.

A first indication may be the timing. What has taken place in the estuary or catchment after the 1960's which might have affected estuarine hydrodynamics and sediment deposition? Major development projects may be relevant, for example: construction of the barrage just upstream of Rockhampton in the 1970's; clearing of catchment vegetation; increased surface mining; crop production; construction of river training walls; and/or other changes in the water course, like the cut-off of the ox bow (see Appendix 2).

A significant factor may be water flow of the river, shown in records of flood events. Figure 66 shows that flooding events appear to have increased in frequency since the 1850's. The maximum frequency was scored in the 25 years from 1950-1974, with 26 recorded instances. Maximum flood height was highest for the period 1900-1924, exceeding 10 metres in 1917-18. The second maximal height was scored in 1950-1974.

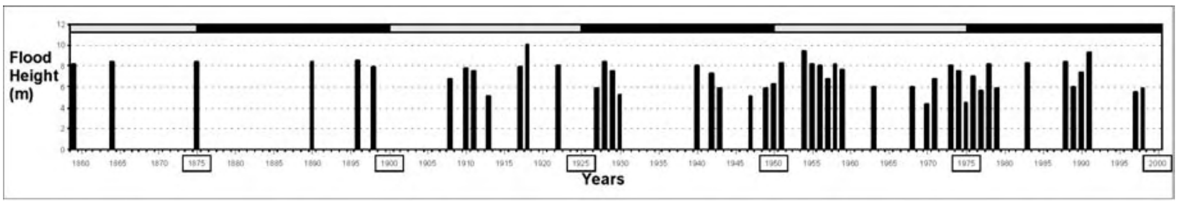


Figure 66. Maximum flood heights for Fitzroy River, 1860-1990. (Source: Bureau of Meteorology Australia).

A second clue may come from the special characteristics of the 'islands', in particular the observation that they are entirely comprised of mangroves, without terrestrial sections. The four clumps of mangroves indicate: firstly, that sediment deposition for these locations exceeded mean sea level but these did not exceed the highest tide level; and secondly, that the sediments were relatively stable for successful establishment of mangrove seedlings. Mangroves have opportunistically colonised the mud banks formed at the mouth of the river. The mangroves clearly aid in stabilising the banks, but the appearance of these banks is indicative of changes in river hydrodynamics.

In this way, the presence of mangrove plants on these mud banks provides a very useful indicator of sediment mud bank development. This tool can be used to assess changes in river function using remote sensing techniques, and estimates of change can be determined retrospectively where historical imagery, like aerial photographs, are available.

Ecotone Shift

Shift in ecotones has been discussed in the first chapter. There is a clear correlation with rainfall patterns such that tidal wetland areas with greatest coverage of mangroves are found in wetter climates. The indicator used in this assessment is the Wetland Cover Index (WCI).

Estimates of WCI show some regional patterns correlated with climate. Overall the best WCI estimate has been based on the 'total estuary' sector which encompassed the chief tidal wetland areas of the estuary. The total tidal wetland area was estimated to be around 500 km^2 in 1999 with a WCI of 40. Based on the relationship presented in Figure 67, this equates to a mean annual rainfall around 920 mm, an estimate less than that described above for the Port Curtis area. The estimate compares well with actual rainfall records.

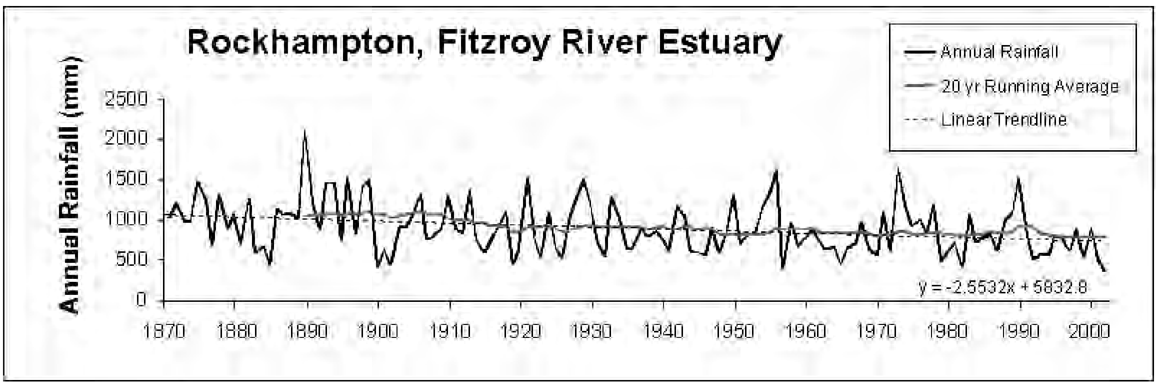


Figure 67. Annual Rainfall in Rockhampton, 1870 to 2001. (Source: Bureau of Meteorology Australia).

4.2.2 Balaclava Island – Area of Natural Influence

Balaclava Island is situated in the south-western section of Keppel Bay, just south of the mouth of the Fitzroy River. It is separated from the mainland by Kamlesh Passage and Connor Creek, and its western end is located at the mouths of the Raglan and Casuarina Creeks. It is an undeveloped, uninhabited mangrove and salt marsh island, relatively free from direct human influence. The area chosen for the case study was on its eastern seaward side, away from any surrounding rural or urban developments (23.56^{o}S, 150.95^{o}E) (Figure 68). The study examines the role natural factors (e.g. climate change and sea level rise) may play in driving coastal vegetation change.

Figure 68. Location of Balaclava Island study site.

The study site was selected to encompass locations with a low, gradual rise in elevation, consisting of terrestrial 'islands' surrounded by salt marsh/ saltpan and completely fringed on the seaward edge by mangroves. These characteristics allowed detection of subtle shifts in ecotone and encroachment/ dieback processes. Historical aerial photographs of the site were collected for 1941, 1956, 1979, 1990 and 1999. The 1941 photography was purchased from United Photo and Graphic Services, Victoria. The sets for the other years were borrowed from the Department of Natural Resources and Mines. The mosaic was then georeferenced to a Landsat TM 1995 image (datum: WGS 84 and projection: Transverse Mercator) of the region, which was obtained from the Biophysical Remote Sensing Group (Geophysical Sciences and Planning Department, University of Queensland).

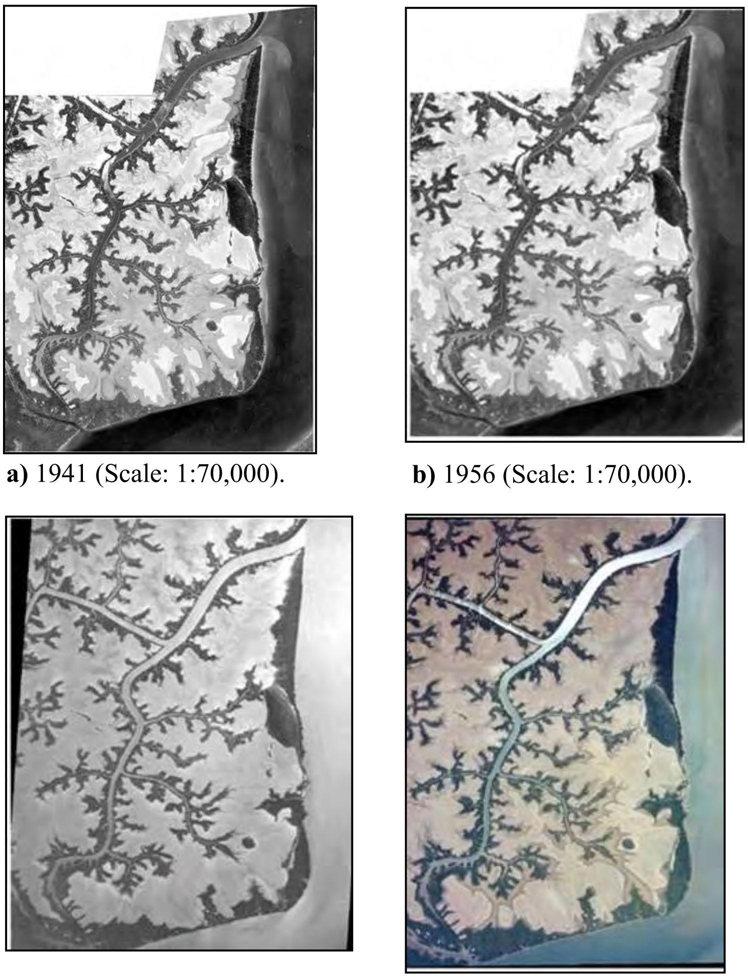
The vegetation types were divided into the following categories: *Avicennia marina* with *Ceriops australis* (AM/CA), *Avicennia marina* (AM), *Ceriops australis* (CA), *Rhizophora stylosa* (RS), salt marsh/saltpan (SP) and terrestrial (TR).

Field verification (ground truthing) was used to help interpret the imagery and define boundaries. This was achieved by setting transects through the vegetation from the seaward to the terrestrial fringe, and taking GPS coordinates at ecotones. Relative elevations at ecotones across the transects were also measured, using a combination of a dumpy and staff, and a fluid-filled U-tube and ruler. This information was used to determine a possible correlation between elevation and ecotone, as discussed in the transect focal point below.

Findings and Discussion

For the study site on Balaclava Island, the vegetation was interpreted from aerial photographs and mapped. The four resulting images, for the years 1941, 1956, 1979 and 1999, are illustrated in Figure 70. These maps provide an overall depiction of the extensive saltpans and salt marsh areas present in the region, with a narrow fringe of mangroves. Early in the study period, *Avicennia marina* formed a pure stand along one length of the island, but decreased in area, leaving a few *A. marina*, seaward of the *R. stylosa* stands. Mixed *C. australis* and *A. marina*, usually of short stature, were found to the landward side of the *R. stylosa*, bordering the extensive saltpan area. The specific details regarding the changes to the vegetation types and ecosystems are explored, considering the change of these parameters over time, and also examining the trends of the three small areas of the study site.

The results clearly demonstrate that there were some changes to the vegetation types recorded at the study site that occurred from 1941 to 1999. The overall change and the incremental rates of these changes have been presented in Table 14. The largest change as a percentage of each vegetation type's total area, was a loss of 95% of the *A. marina* from 1941 to 1999. Most of this loss occurred between 1941 and 1956, when there was also the greatest decrease in the area of the mixed *C. australis* and *A. marina* stands, which lost 4.12% of its total area. *R. stylosa* forests also decreased in area overall, but such decrease was not constant, with this vegetation type recording increases for the first 38 years of the study, to 1979, and then a large loss from 1979 to 1999. The only vegetation type that recorded consistent increases in total area is the salt marsh and saltpan category. The results also suggest that the greatest change to environmental conditions occurred between 1941 and 1956 and between 1979 and 1999, with the greatest rates of change being recorded for mangrove vegetation during these times.



a) 1941 (Scale: 1:70,000). **b)** 1956 (Scale: 1:70,000).

c) 1979 (Scale: 1:70,000). **e)** 1999 (Scale: 1:70,000).

Figure 69. Aerial photo mosaics of Balaclava Island, south of the Fitzroy River mouth, in a) 1941, b) 1956, c) 1979, d) 1999. These provide a visual comparison for the vegetation strips in Figure 69.

Table 14. Area (in ha) of tidal wetlands including mangroves and salt marsh/ saltpan within a section of Balaclava Island in 1941 and 1999. (Source: this study).

	Mangrove		Salt marsh/ Saltpan		Terrestrial		Total Wetland	
	1941	**1999**	**1941**	**1999**	**1941**	**1999**	**1941**	**1999**
Area in ha	101.84	91.54	225.94	235.21	27.98	28.34	327.78	326.75
Change in ha from 1941-1999		-10.30		+9.27		+0.36		-1.03
% Change		-10.1%		+4.1%		+1.3%		-0.3%

The overall change to the two main ecosystem types shows a reasonable decrease in the proportion of the area that is mangrove vegetation (Table 15). An increase in saltpan area, however, is almost equivalent to the area of mangrove lost.

Table 15. Area (in hectares) of tidal wetlands, including the general wetland vegetation categories as well as the mangrove species level vegetation categories on Balaclava Island (mouth of the Fitzroy River) in 1941, 1956, 1979 and 1999. WCI = Wetland Cover Index (% mangroves).

FE – Balaclava Island	**Year**			
	1941	**1956**	**1979**	**1999**
Avicennia marina	6.02	0.94	0.61	0.25
A. marina with *Ceriops australis*	29.80	25.22	23.57	28.57
Rhizophora stylosa	66.02	67.56	70.94	62.72
Salt marsh/saltpan	225.94	230.16	230.56	235.21
Terrestrial	**27.98**	**27.58**	**29.42**	**28.34**
Total Mangrove	**101.84**	**93.72**	**95.12**	**91.54**
Total Salt marsh/saltpan	**225.94**	**230.16**	**230.56**	**235.21**
Total Tidal Wetland area	**327.78**	**323.88**	**325.68**	**326.75**
WCI (% mangroves)	**31.1**	**28.9**	**29.2**	**28.0**
Total terrestrial and Tidal wetland	**355.76**	**351.46**	**355.1**	**355.09**

In summary, there was a small overall decrease in mangrove area and increase in saltpan area. No notable change was detected in terrestrial vegetation. At this location, it is possible that there has been a decrease in overall rainfall and/ or humidity over the past 43 years, resulting in an increase of salt marsh area, a vegetation type which is more dominant to mangroves in cooler and drier climates. Other potential causes include other climatic factors, particularly those influencing salinity.

5.2.2.1 *Focal Point 1 – Strips*

For Balaclava Island, transect strips were created for five years between 1941 and 1999, the photography for which was obtained from the above, already mentioned sources. These strips were created to try and determine what small changes were taking place within a defined, predominantly naturally influenced area. Specifically, it shows the change in water over time, an increase in water area indicating a retreating seaward edge.

As can be seen in Table 16 and the vegetation maps in figure x, in the decades following 1941, mangrove area progressively decreased over the 58-year period. The greatest change in wetland area occurred between 1979 and 1990, with a decrease of 2.5 hectares of mangrove area and an increase of 2.2 hectares of salt marsh/saltpan. Encroachment of the salt marsh/saltpan area into mangrove areas can be observed by comparing the vegetation maps.

Table 16. Area (in hectares) of tidal wetlands including the different vegetation types within the transect strip selected on Balaclava Island (Fitzroy River Estuary) in 1941, 1956, 1979, 1990 and 1999.

FE	Year				
	1941	**1956**	**1979**	**1990**	**1999**
Total Mangroves	32.4	31.9	31.5	29.0	28.8
Total Salt marsh/saltpan	62.5	62.9	61.7	64.0	64.7
Total Terrestrial vegetation	13.0	13.8	13.4	13.3	13.4
Water (increase indicates retreating seaward edge)	17.2	16.6	18.2	18.6	18.1
TOTAL strip area (ha)	125.1	125.2	124.8	124.9	125.0
WCI					

Another noteworthy change during the study period was the increase in the water zone, between 1956 and 1979, by 1.57 hectares. This corresponded with a decrease of 1.1 hectares in the salt marsh/saltpan area. From the vegetation maps it can be seen that there has been a loss of mangrove on the eastern seaward edge (Figure 71).

Between 1979 and 1999 the water zone increased slightly more, which also corresponded with a decrease in mangroves. The salt marsh/saltpan increase in the same period, was slightly less than the mangrove decrease. Terrestrial vegetation stayed relatively stable throughout the period, except for a small increase of 0.7 hectares between 1941 and 1956.

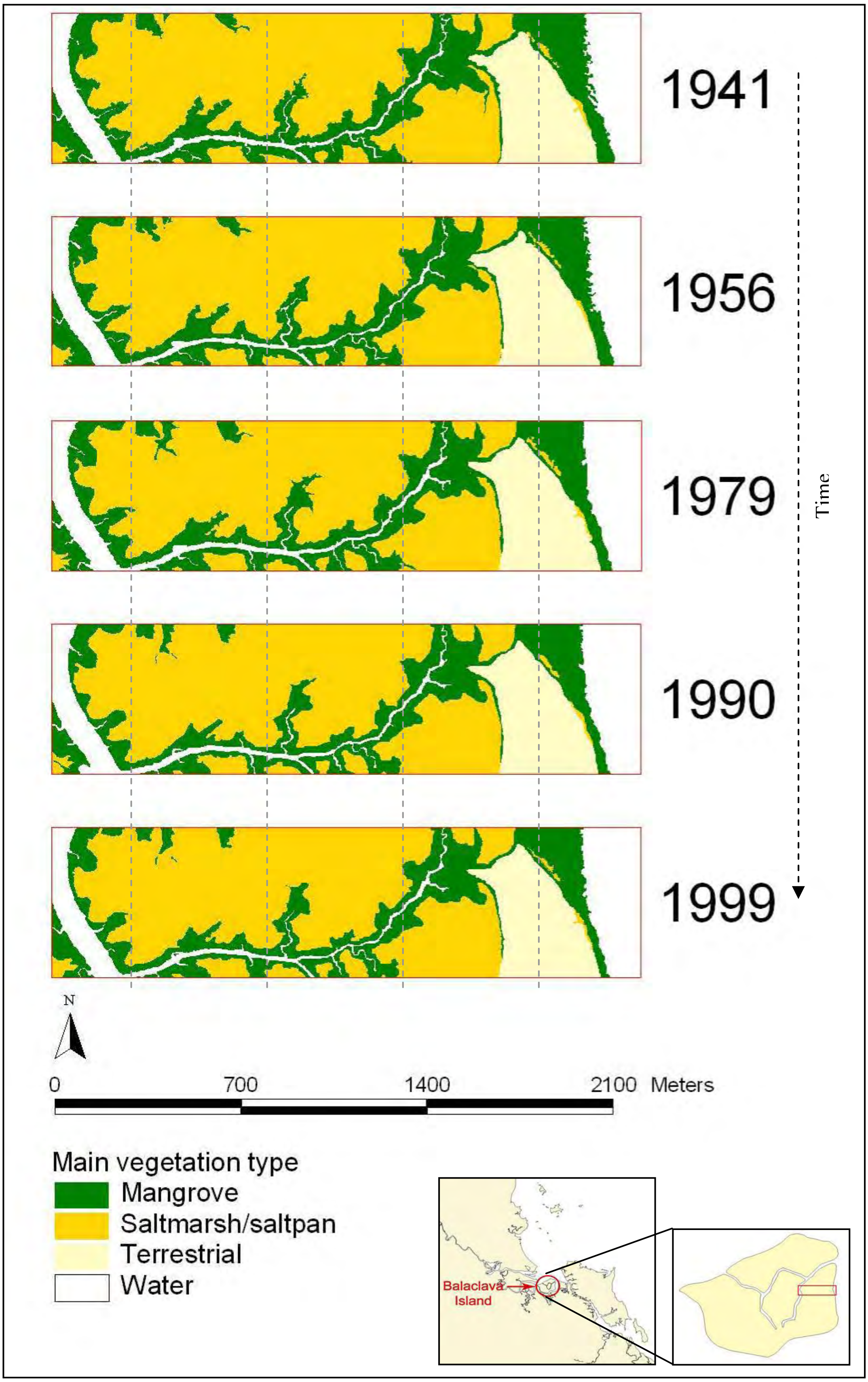


Figure71. Time series of vegetation maps of transect strips from 1941 to 1999, running through a section of Balaclava Island (south of the mouth of the Fitzroy River), showing the major vegetation categories of mangrove, salt marsh/ saltpan and terrestrial, along with water. The inset shows the location of the transect.

a) 1941 (Scale: 1:70,000).

b) 1956 (Scale: 1:70,000).

c) 1979 (Scale: 1:70,000).

d) 1990 (Scale: 1:70,000).

e) 1999 (Scale: 1:70,000).

Figure 72. Aerial photo mosaics of Balaclava Island, south of the Fitzroy River mouth, in a) 1941, b) 1956, c) 1979, d) 1990 and e) 1999. These provide a visual comparison with the vegetation strips in Figure 71.

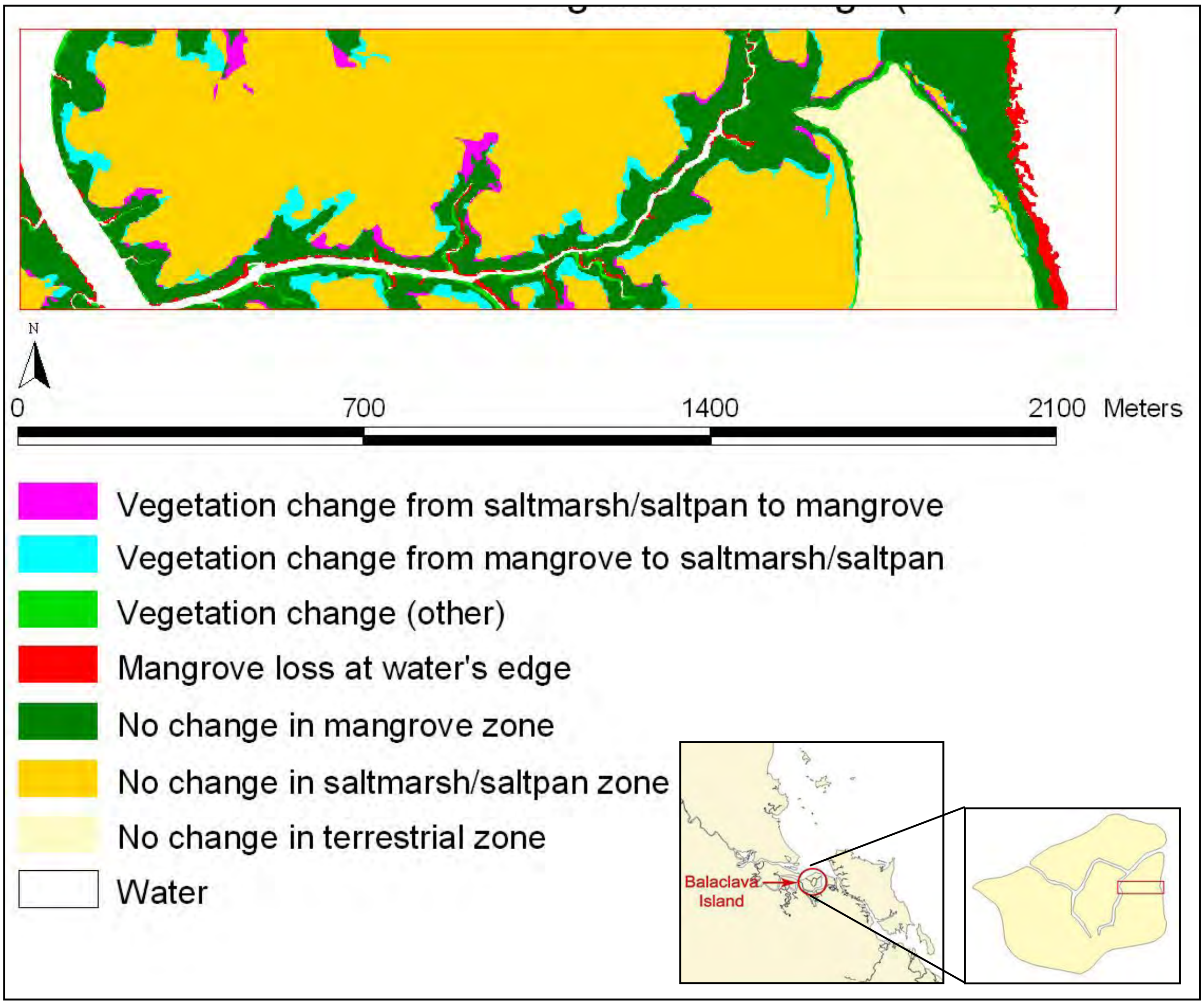


Figure 73. Vegetation change map for Balaclava Island (south of Fitzroy River mouth), from 1941 to 1999. Inset shows the transect location

Figure 73 shows a vegetation change analysis for the Balaclava Island transect strip. It can be seen that between 1941 and 1999 there was a loss of mangroves from the eastern edge of the strip. Salt marsh/ saltpan encroachment into mangrove area is also evident in this change analysis map.

5.2.2.2 Focal Point 2 – Transects

Eight transects were studied in mangrove and salt marsh habitat on Balaclava Island, south east of the Fitzroy River mouth. Transects were used to describe and record variations in elevation with respect to ecotones – or between notable vegetation zones visible from aerial photographs. These were confirmed during field studies when a record was made describing species composition and vegetation structure. Transect sites were chosen to represent zones of vegetation in the region.

A primary objective for this section of the study has been to link elevation heights with ecotones between chief vegetation types, and to present this as a generalised composite transect for the region (Figure 74). A schematic diagram of transects on the eastern side of Balaclava Island (Figure 75) shows the eight transects placed relative to each other based principally on the high tide limit (HAT) and to a lesser extent on the lower intertidal limit of mangroves (~Mean Sea Level, marked by the lower wavy line).

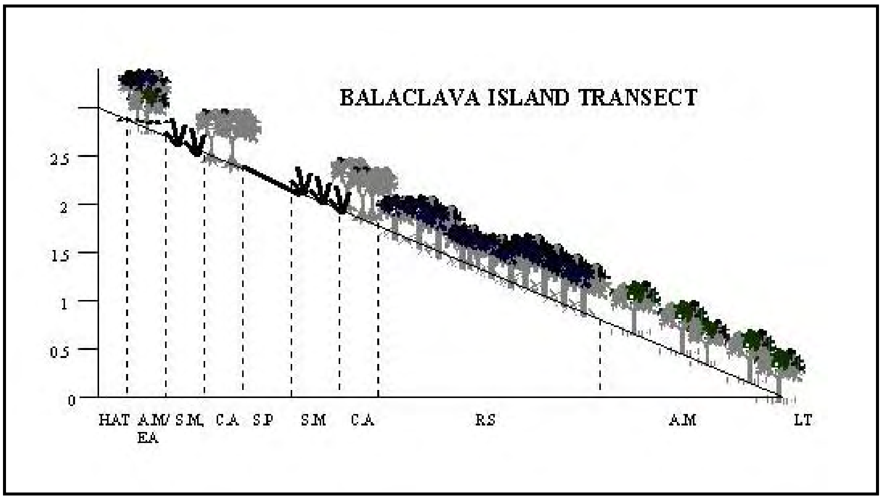


Figure 74. A schematic, generalised profile with tidal vegetation based on eight transects on Balaclava Island. The vertical axis represents height in metres above LT. Elevation reference level was based on the high water mark determined from beach wash and debris. (HAT: High Tide, SM: Salt Marsh, CA: *Ceriops*, SP/SM: Saltpan/ Salt marsh, RS: *Rhizophora*, AM: *Avicennia*, EA: *Exoecaria*, LT: Low tide.)

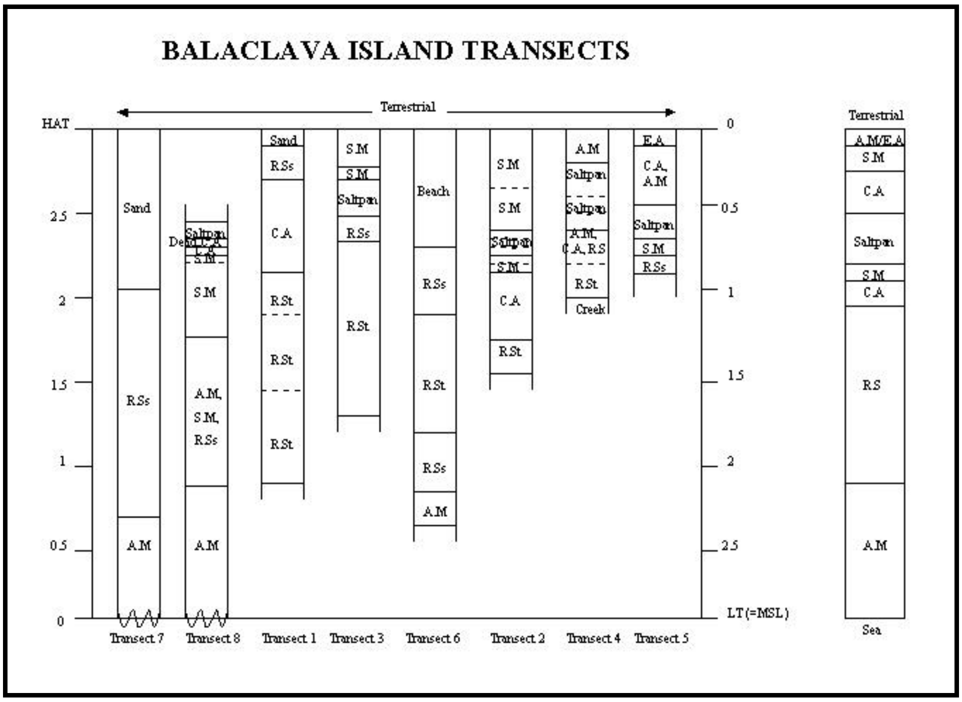


Figure 75. Incremental elevations (in metres) recorded for the eight transects made in tidal flats at Balaclava Island. Note that transects were either scored from the low tide (MSL) or high tide (HAT) of the upper section of the intertidal range. Transects were termed ‘floating’ if they did not extend from high to low water limits. For codes, see Figure 58.

Avicennia marina was common within seaward and landward zones, while other species were more restricted. For example, *Excoecaria agallocha* was found mostly along terrestrial margins.

The five chief vegetation types include:

Seaward margin of *Avicennia marina* – sometimes dense stands around 5-8 m, sometimes scattered individual trees, and sometimes absent. This zone was absent in all transects of this study, but it was present in the area mostly as scattered and occasional trees.

***Rhizophora stylosa* zone** – always present, ubiquitous, mostly monotypic with stands around 3-4m, usually very dense, forming a sturdy gnarled labyrinth of intertwined, above-ground prop roots. In many instances, these stands were not easily penetrable. This was the chief reason why transects were not all completed from HAT to MSL.

***Ceriops* zone** – can be a mixed zone or in specific associations of *Ceriops* around 1-2m with scattered solo emergent trees of *A. marina*, around 3-5m tall.

Saltpan/Salt marsh zone – comprises both vegetation-free zone and peripheral salt marsh at <0.5 m height at both high and low water marks. The saltpan may or may not have an algal mat across the surface.

Landward zone – This zone is also comprised of mixed species composition – for example, *Aegiceras corniculatum, Aegialitis annulata, Excoecaria agallocha*, etc.

The low intertidal position of some transacts were notably variable. This appeared due to a combination of factors, including slope, proximity of channel flows and erosion.

The elevational range of mangroves was around three metres between approximate HAT and the seaward margin above MSL.

During the field transects, evidence of longer term change in Balaclava Island was detected, revealed through effects such as dieback of mangroves at ecotone fringes. Figures 76, 77 and 78 provide visual examples of the effects observed.

Figure 76. Dieback at seaward fringe.

Figure 77. Dieback at inner, saltpan fringe: recent effect.

Figure 78. Dieback at inner, saltpan fringe: older effect.

5. Moreton Bay

5.1 Regional Assessment

5.1.1 Background: Brisbane River and Moreton Bay –an Urban Centre

Moreton Bay (approximately 27.5°S, 153.3°E) is located in southeast Queensland, about 450 kilometres south of the Tropic of Capricorn (see Figure 79). The climate is warm and subtropical (average daily maximum: 25.4°C, minimum: 15.7°C) with moderate to high rainfall (mean annual rainfall: 1185.4mm) and acute storm activity, mostly occurring during summer months (Bureau of Meteorology Australia). The region comprises five major catchments, the Brisbane River, Logan/Albert Rivers, Pine Rivers, Pumicestone Passage and Caboolture River catchments, with a total area of 21,220 km^2, and includes the heavily developed cities of Brisbane, Ipswich and Logan (Dennison and Abal, 1999). The Brisbane River is the largest of these catchments, measuring 13,100 km^2, and extends from Moreton Bay to the Great Dividing Range (Dennison and Abal, 1999). It includes the Upper Brisbane, Stanley, Lockyer and Bremer River subcatchments and 50 major creeks. The Brisbane River estuary is defined by the tidal portion of the river, extending from the mouth 90 km upstream to Mt Crosby. It has a long history of flooding, with 11 major floods recorded since 1840 (Bureau of Meteorology Australia). The next largest catchment is that of the Logan/Albert Rivers, which measures 3157 km^2, extending west to the Great Dividing Range and south to the Lamington Plateau (Dennison and Abal, 1999). This is followed by the Pine Rivers catchment (including North and South Pine Rivers), the Pumicestone Passage Catchment and the Caboolture River catchment, measuring 808 km^2, 761 km^2 and 354 km^2, respectively (Dennison and Abal, 1999). In comparison, the Bay measures 1,523 km^2, giving a total catchment to bay ratio of 14:1 (Dennison and Abal, 1999). Moreton Bay, a shallow, protected embayment, is largely enclosed to the east by Moreton and North Stradbroke Islands.

Figure 79. Current map of Moreton Bay, showing major rivers, cities and islands.

Western Moreton Bay is exposed to substantial urban influences. The lower catchment includes the heavily developed urban centres of Brisbane (State Capital), Ipswich and Logan Cities. Brisbane City is centred on the Brisbane River, Ipswich around the Bremer River (part of Brisbane River catchment) and Logan around the Logan River. The region has the largest population in Queensland, as well as the highest population growth rate in Australia (Skinner *et al.*, 1998). The population in the greater Brisbane area in 2001 was over 1,600,00 (898,380 in

Brisbane City) and could rise to 2,360,000 by 2021 (Australian Bureau of Statistics). As a consequence of this intense urbanisation and population pressure, large areas of the catchment have been modified for urban parkland, residential, commercial and industrial uses, particularly in the lower Brisbane River catchment. These activities, as well as port development and river 'improvements', have led to the replacement of large areas of coastal wetlands in the Western Bay. A current estimate for remaining mangrove area is 13,500 hectares (Dowling and Stephens, 1999).

In addition to urban and industrial land uses (dominant in the lower catchment), the other major land use in the region is rural, involving activities such as grazing, cropping and forestry (Capelin *et al.*, 1998). These activities dominate in the upper catchment areas, as well as in much of the Logan catchment area. In all, little of the Moreton Bay catchment, apart from isolated areas such as the Southern Bay Islands, remains unaltered. In the Brisbane River catchment, for example, only 14 % of the area remains uncleared (CRC for Catchment Hydrology, 2003).

Issues in the region, arising from the intense urbanisation and population pressure, include high levels of clearing and development. The area has undergone reclamation, modification and direct removal of wetland and clearing of catchment vegetation for marinas, real estate, canal estates, and port, airport, industrial and urban developments. The annual loss of riparian/ wetland habitat has been estimated at 94 hectares (EPA, 2001), while the overall clearing rate of catchment vegetation since 1820 has been estimated at 8450 hectares/year, with a lower annual clearing rate of 3,340 hectares/year calculated for more recent times (1987-1991) (Catterall *et al.*, 1996). This more recent clearing and land use change has been largely attributed to urban expansion and rural residential development.

Another issue in the region is the elevated discharge of sediment, nutrients and pollutants into waterways. This is of particular concern in the Brisbane River. The river, particularly in the middle reaches, experiences high turbidity, up to ten times greater than for other subtropical estuaries on the East Australian coast (EPA, 2001). Suspended sediment levels have increased four fold in the last 80 years, with current export from the catchment into the Bay estimated at 450,000 tonnes/year (Dennison and Abal, 1999; EPA, 2001). Contributing factors include increased runoff, erosion from both rural parts of the catchment, but also urban areas, and dredging. A further factor influencing this discharge is altered hydrology. Paving of the urban landscape has lead to an increase in the area of hard, non-porous surface, diverting greater volumes of storm water into sewage transportation systems and placing these under strain.

Brisbane City has greater than 2,100 km of enclosed urban stormwater drains and 8,200 km of kerb and channel drains (CRC for Catchment Hydrology, 2003).

Large quantities of nutrients are also introduced to the system via this stormwater input, sewage effluent, wastewater discharge and runoff, further degrading the river system and facilitating problematic algal blooms. There are 40 wastewater treatment plants in the catchment (CRC for Catchment Hydrology, 2003). Nitrate levels in the river have risen 22 fold, to 305 μM N, and phosphate levels 11 fold, to 42 μM P, in the last 50 years (EPA, 2001). Pollution levels have also risen, with an increase of heavy metals, hydrocarbons and other toxicants in the river and surrounding shores.

5.1.2 History

In 1823, while exploring Moreton Bay, John Oxley first charted the Brisbane River (Figure 80). The following year, a penal colony was established at Redcliffe Point. This was soon relocated upstream to North Quay, a site that would later become Brisbane's Central Business District. By 1842, the Moreton Bay penal colony was closed and the area opened for free settlement. In the decades following the separation of Queensland (1859), Brisbane experienced rapid population growth, expansion and urban, industrial and commercial development, a trend which accelerated after World War II, despite periodic setbacks afforded by droughts, floods and economic depressions. Today, Brisbane is Australia's third largest capital city, and a major urban centre with a busy, international port. Accompanying these developments, the region, particularly the Brisbane River, has undergone major changes in form, shoreline and coastal habitat. Construction of bridges, wharves and training walls, dredging, channel improvements, deepening of the Bar at the river mouth, removal of obstacles and points hazardous to navigation, reclamation, and port development have all acted to modify the river and its surrounding environment. Some of these changes, such as the straightening of the river and the developments near the mouth, can be seen by comparing Figure 81 (an early chart of the river from 1823), with Figure 92 (a map from 1998). In the recent map (Figure 92), the port can be observed at Fisherman Islands, near the mouth of the river. This was not always the case, and represents the end point of a series of shifts that saw the port move upstream from its initial position near the mouth, to the Town Reach, and then progressively back downstream to its current location. In the early and mid 1800's, obstacles, bars and shallow stretches in the river forced most large vessels to anchor outside the mouth, where cargo was transferred to smaller boats for transport upstream. Subsequent deepening of the river and channel improvements allowed these large vessels to travel upstream, facilitating a shift to a Town Port in the late

1800's and early 1900's. From the mid 1900's, however, the port was once again shifted progressively towards the mouth, due to the difficulties in accommodating heavy trade, the ever-increasing size of ships, and the development of commercial infrastructure facilities downstream.

Figure 80: Chart of Moreton Bay from 1823. (Source: John Oxley Library)

The Historical Coastlines Project has collected a series of historical photographs of the river, which can be used as a visual representation of change to the river (refer to Figures 82-90).

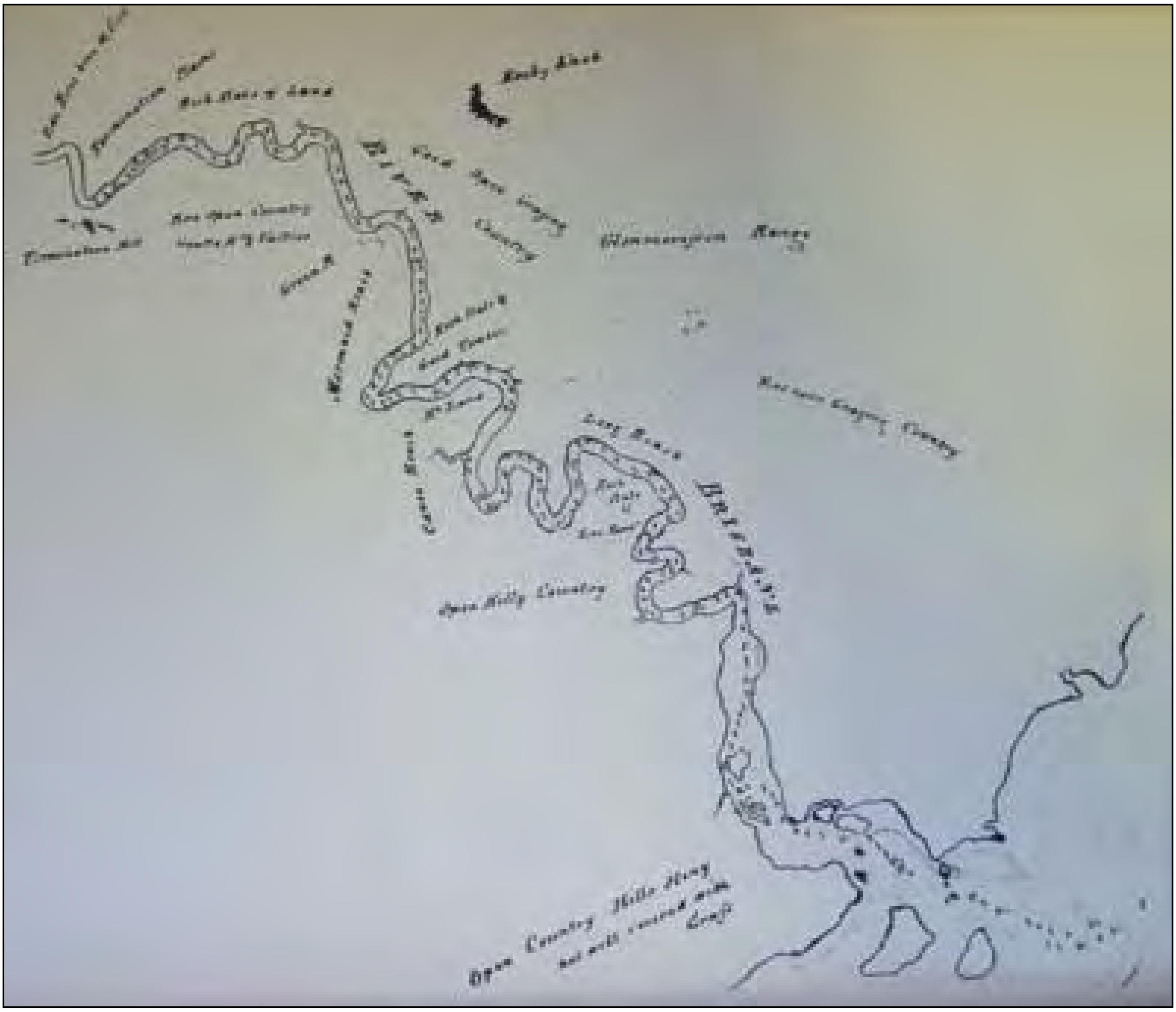
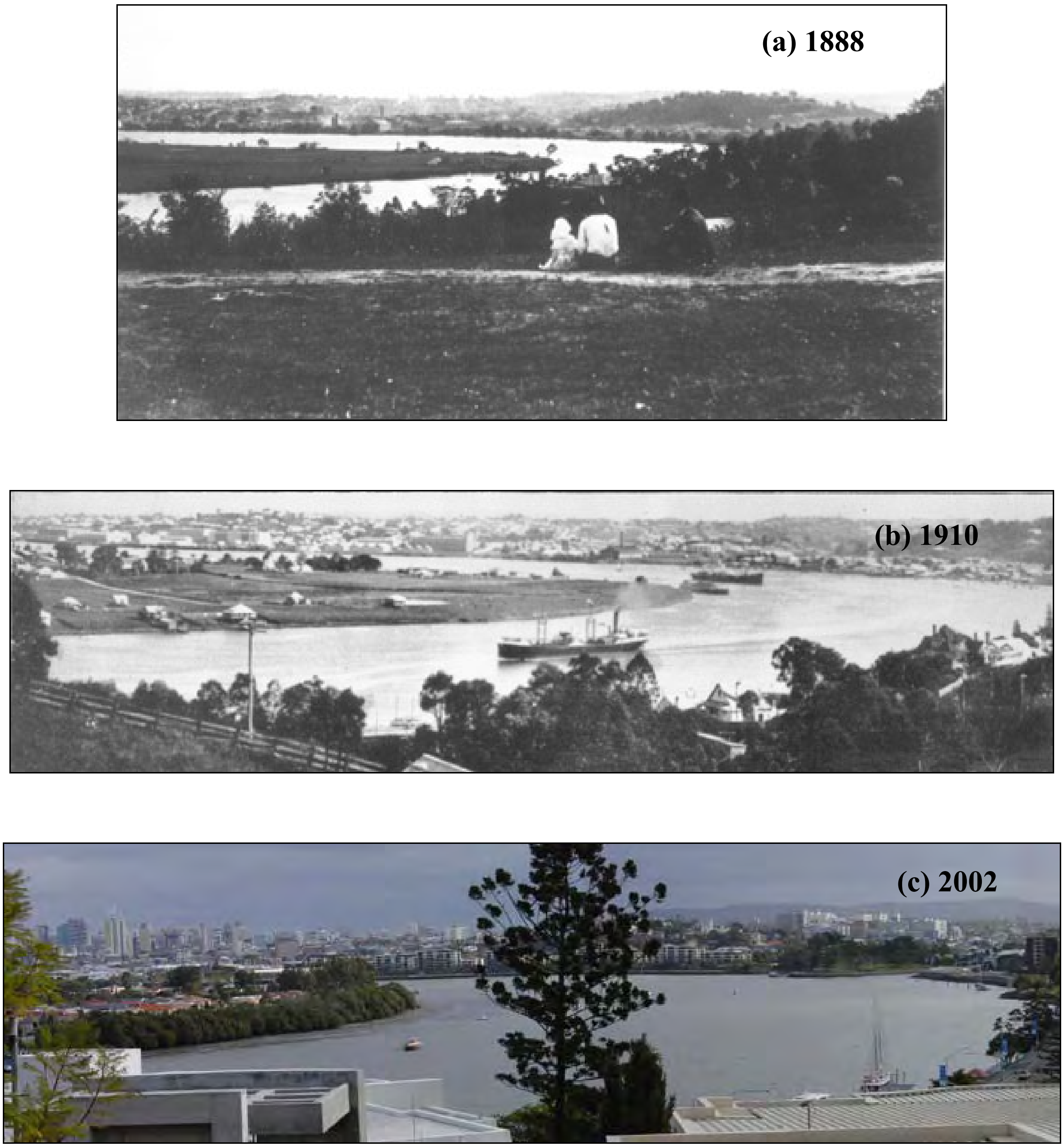


Figure 81: Chart of the Brisbane River, as surveyed by John Oxley in 1823. (Source: Survey Office Brisbane)

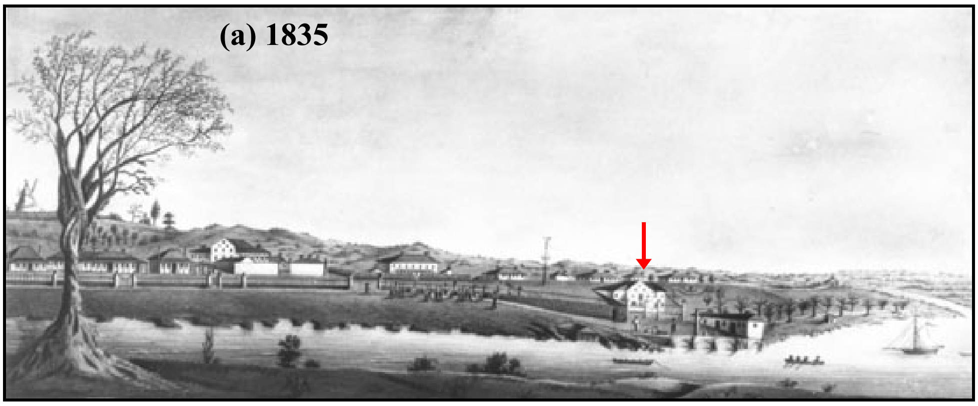
Figures 82a), b) and c) show the changing view of Bulimba reach, in 1888, 1910 and 2002, respectively. The photo time series shows increasing urban development and construction occurring, changing from a rural town, by today's standards, to a built-up city that we see today.

Figures 83a) and b) show a view of the Town Reach, in 1835 and 2002, respectively. The Commissariat building can be seen in both photos and is indicated by the arrows in both photos. In 1835, the Commissariat building was one of the few present on the bank of the river, while in 2002, it is almost lost amongst the skyscrapers that form part of Brisbane's CBD.



Figures 82(a), (b) & (c): The changing view of Bulimba Reach, showing increases in urban development and construction. (Sources: (a) & (b) John Oxley Library; (c) Norm Duke)

Figure 84 shows a view of the South Brisbane coaling wharves in 1889, where trains delivered coal to service the steamship trade. Large ships were a regular site at the Town Reach at this time.



Figures 83(a) & (b): View of the Town Reach in 1835 and 2002. The Commissariat building is visible in both pictures (red arrow). In 1835, it was one of the few buildings present on the bank of the river while, in 2002, it is almost lost amongst the city skyscrapers. (Source: (a) John Oxley Library; (b) Norm Duke)

A view of the Brisbane River during the major flood of 1931, from North Quay, can be seen in Figure 85. Figure 86 shows a view of the Old Victoria Bridge, when it was under construction, in 1872.

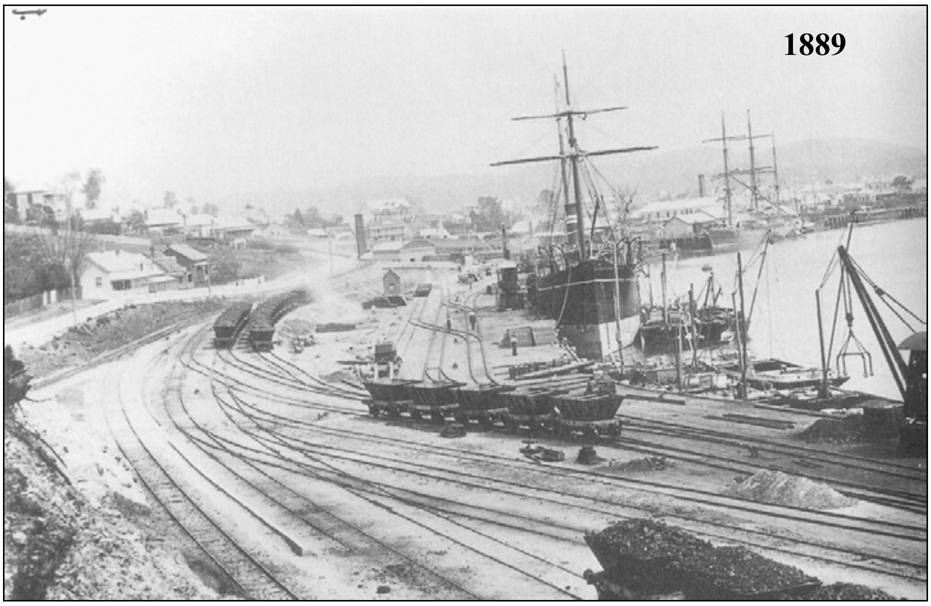


Figure 84: View of the South Brisbane coaling wharves in 1889, where trains delivered coal to service the steamship trade. Large ships were a regular sight at the Town Reach during this time. (Source: Private Collection)

A photo of the South Brisbane Baths, from 1910, can be seen in Figure 87. The baths were filled and emptied by the tidal movement of the Brisbane River. This was at a time when people used to swim frequently in the Brisbane River.

Figure 85: View of the river from North Quay during the major flood of 1931. (Source: Fryer Library, UQ)

Figure 86: Old Victoria Bridge, under construction in 1872. (Source: Fryer Library, UQ)

A photo of the Hamilton Training Wall under construction, in 1934, can be seen Figure 88, whilst Figure 89 shows the construction taking place on swampland at Pinkenba in 1936.

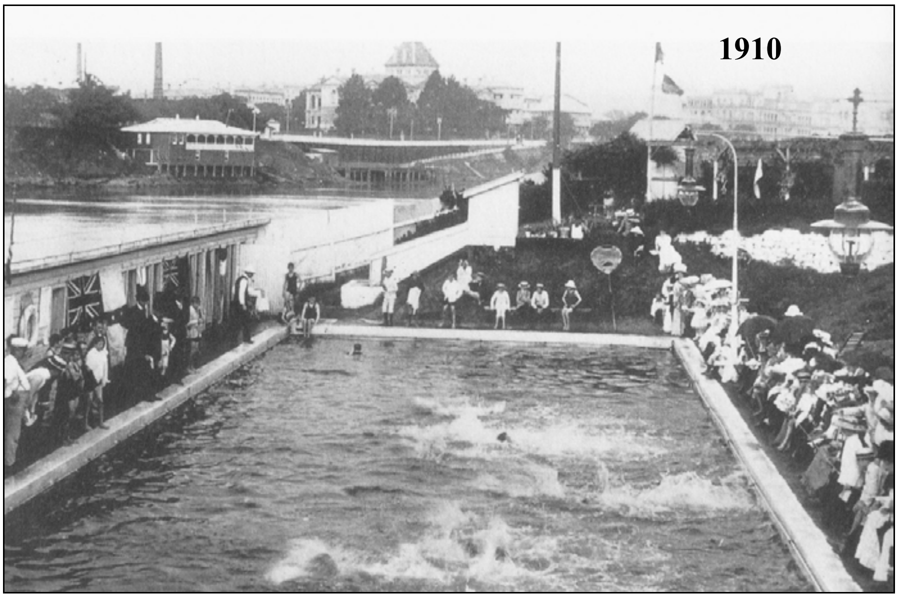


Figure 87: South Brisbane Baths, 1910. The baths were filled and emptied by the tidal movement of the Brisbane River, at a time when people used to swim frequently in the Brisbane River. (Source: Brisbane City Council)

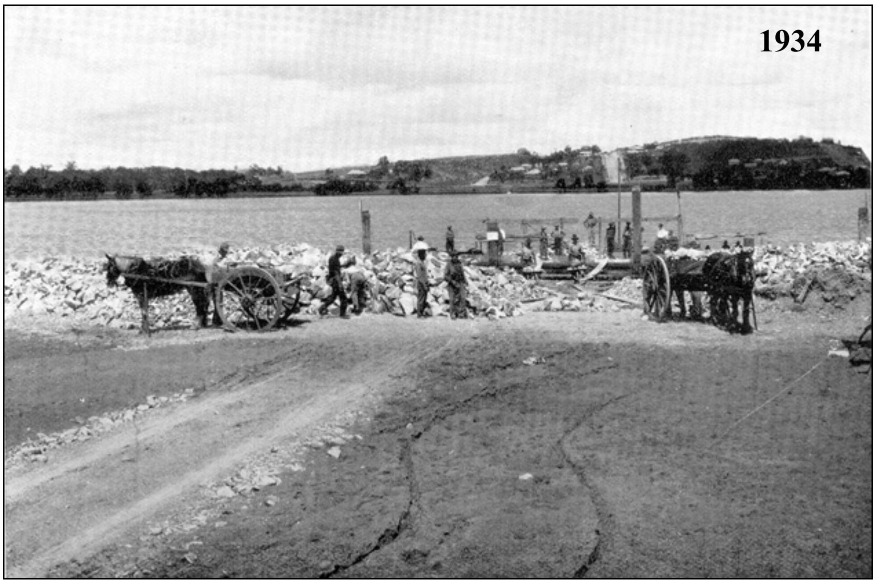


Figure 88. Hamilton Training Wall under construction in 1934.
(Source: Brisbane City Council)

Figure 90 shows a view of the mouth of the Brisbane River in 1969, prior to the major development of the Fisherman Islands by the Port of Brisbane Authority.

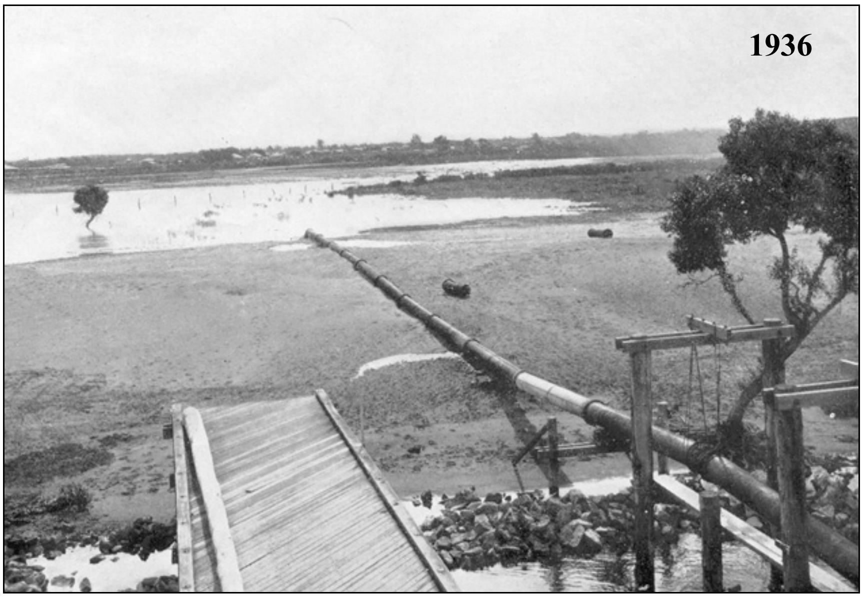


Figure 89: Construction on swampland at Pinkenba in 1936. (Source: Brisbane City Council)

Figure 90: The mouth of the Brisbane River in 1969, prior to major development of Fisherman Islands by the Port of Brisbane Authority. (Source: Brisbane City Council)

A historical timeline of the Brisbane River, outlining anthropogenically driven actions and events contributing to these coastal changes, is provided in Appendix 3.

5.1.3 Broad Change in Regional Coastal Vegetation

Currently, there are approximately 15,000 hectares of mangrove and 2,500 hectares of salt marsh/ saltpan in the Moreton Bay region, which extends from Caloundra to Coolangatta (Manson *et al.*, *in press*). The most extensive stands of these mangroves, and other wetland vegetation types (e.g. salt marsh/saltpan), occur in Southern Moreton Bay, on the numerous mangrove islands. Substantial stands also exist in some of the estuaries within the region (e.g. Caboolture River, Pine Rivers, Hays Inlet and the mouth of the Brisbane River). Of the 8 species of mangroves found within the Bay, *Avicennia marina* dominates, comprising 75% of the community (Dowling and Stephens, 1999). In the western side of the Bay, expansive areas of wetland habitat have been replaced, largely due to reclamation activities for urban, industrial and port development (e.g. Durrington, 1977; Hyland and Butler, 1989; Dowling and Stephens, 1999; Manson, *in press*).

Mangrove change analysis has been undertaken previously for the region in several studies. In Dowling and Stephen's (1999) study, based on digitised aerial photography, mangrove coverage in 1974 and 1998 were compared. The total mangrove area calculated for 1974 was 15,496 hectares, compared with 15,275 hectares in 1998, giving a net loss of 221 hectares (1.3%) in 24 years. Actual loss over this time period was much greater, measured at 3,806 hectares, but this was offset by gains of new mangroves, measured at 3,589 hectares (Manson *et al.*, *in press*). A change detection analysis, performed by Manson *et al.* (*in press*) on the Dowling and Stephens (1999) digitised data sets, revealed the spatial characteristics of these losses and gains. Large losses were detected for the western, mainland side of the Bay. Major causes were identified as the Brisbane Airport expansion (12.5% of loss), industrial development (~6%), agriculture/ aquaculture (~6%) and canal estates/ marinas (~6%). The cause of 60-70% of the total loss in the region, however, remained unidentified (Manson *et al.*, *in press*). Mangrove gains over the period mainly occurred on the islands in the Southern Bay region, to the landward edge of existing mangrove stands (Manson *et al.*, *in press*). For all these figures (Dowling and Stephens, 1999; Manson *et al.*, *in press*), however, there may be an element of error, due to misregistration between the 1974 and 1998 coverages, resulting in misalignment (Manson *et al.*, *in press*). Little geographical referencing was performed on the original maps, making comparisons with 1998 data difficult (Dowling and Stephens, 1999). Furthermore, the vegetation classification systems used for the 1974 and 1998 data sets are not directly comparable, potentially introducing further error. Finally, change in wetland habitat other than mangrove (e.g. saltpan), was not provided.

Another study of change was conducted by Hyland and Butler (1988), in this case comparing mangrove coverage between 1974 and 1987. During this period, it was estimated that 1361 hectares (8.4%) of mangroves in Moreton Bay were lost. This was largely attributed to reclamation, including 5 large-scale wetland developments at Dux Creek, Serpentine Creek, Fisherman Islands, Jacobs Well and Hope Island (total loss of 1207 ha) and 28 smaller-scale developments (total loss of 154 ha).

In addition to these intentional anthropogenic losses (i.e. reclamation and direct damage), some of the historical mangrove losses in the region can be attributed to unintentional anthropogenic (e.g. restricted tidal exchange) and natural causes. Table 9 lists and quantifies reported mangrove loss events over the past 70 years, and differentiates these as due to reclamation, unintentional anthropogenic factors or natural causes. Prior to 1997, loss was dominated by anthropogenic impacts (i.e. reclamation and unintentional anthropogenic loss) whereas in the last five years, loss was dominated by natural impacts. This was due to a severe hailstorm event in 1997, which damaged 191 hectares of wetland in the Southern Bay area. The sum of losses over the 70-year period attributable to reclamation, unintentional anthropogenic and natural causes were calculated at 1574, 163 and 159 hectares, respectively. However, it should be noted that the list is not comprehensive and simply represents a compilation of figures reported in the literature for clearly quantified and identified loss events. Actual losses, therefore, would be much higher. Consequently, these totals are much lower than the total regional loss calculated from aerial photography over shorter time periods (e.g. Manson *et al.*, *in press*).

In the current study, a change analysis was performed to compare wetland vegetation areas of the total Moreton Bay region and selected subregions between 1974, 1998 and 2000. The selected subregions, detailed in Figure 91, were: Pumicestone Passage, Caboolture/ Pine Rivers, Northern Bay Islands, Greater Brisbane River, Waterloo Bay, Southern Bay Islands, Logan River and Coomera River. These subregions were selected based on whether they were human influenced or less-obviously human influenced, and to separate the dominant drivers of change, within these subregions.

Pumicestone Passage and Caboolture/ Pine River wetlands were categorised as being under predominantly unintentionally anthropogenic influence (e.g. anthropogenic effects other than reclamation). Tidal wetlands in the Northern and Southern Bay Islands were categorised as being under predominantly natural influence (e.g. climate change, sea level rise, storm damage) and the Greater Brisbane River, Waterloo Bay, Logan River and Coomera River wetlands were categorised as being dominated by intentional anthropogenic influence (e.g. reclamation).

The analysis was based upon digitised wetland distribution data from Dowling (for the 1974 profile), Dowling and Stephens (for the 1998 profile) and the Department of Primary Industries (for the 2000 profile). The 1974 and 1998 data were directly comparable (same source) and were used to calculate change over the period, while the 2000 data (different source) was used as a validation for the 1998 data, to check for intra-source variability and margin of error, as it was taken at a similar time point during which changes were minimal and wetland coverages should have been approximately equivalent (refer, for example, to Table 17). The regional analysis presented in this study differs from previous analyses (e.g. Dowling and Stephens, 1999; Manson *et al.*, *in press*) by including estimates for salt marsh/ saltpan, extending the comparison to include DPI data from 2000, and splitting the areas into subregions that can be categorised as influenced by certain factors (e.g. natural, unintentional anthropogenic and intentional anthropogenic). The areas for the subregions were calculated, as described in Chapter 3. The DPI polygon data was overlaid onto Landsat TM imagery to provide a visual representation of current distribution of mangrove and salt marsh/ saltpan in 2000, shown in Figures 91a)-i). Table 18 presents the absolute areas of mangrove and salt marsh/ saltpan in the different years for the different subregions. The salt marsh/ saltpan figures for 1974 are approximations only, as Dowling and Stephens (1999) reported that this wetland vegetation type was not mapped in a consistent manner over the study area in 1974. The 1974 figures were taken from Dowling's (1986) 'tidal inundation' classification, which he defined as comprising samphire flats (salt marsh), marine clays (saltpan) and saltwater couch.

Table 17. Timeline of disturbance to mangrove communities in Moreton Bay, differentiating loss events into those due to reclamation, unintentional anthropogenic factors or natural causes. List is not comprehensive but represents a compilation of figures reported in literature for clearly quantified and identified loss events. Letter in brackets following location refers to subregion (see Figure 76): B = Greater Brisbane River, W = Waterloo Bay, L = Logan River, CM = Coomera River, P = Pumicestone Passage, CP = Caboolture/ Pine Rivers, N = Northern Bay Islands, and S = Southern Bay Islands.

Year	Location	Reclamation Loss (Ha)	Natural Loss (Ha)	Unintentional Loss (Ha) (Dieback)	Comment	Source
1937	Mud Island (W)	-	-	22	Dredging occurred between the period 1937-1993 on the Island leading to long-term supratidal deposition of coral rubble and creation of shingle ridges and sediment crests. These have accumulated on the open reef flat with ridges entering parts of the inner reef flat and destroying mangroves by burial, impoundment and abrasion. Dieback is ongoing from this event.	Allingham & Neil (1995)
1958 to today	Fisherman Islands (B)	100 (146 total wetland)	-	23	Reclamation of tidal wetlands, predominately mangroves to allow port construction and expansion. Adjacent mangroves suffered loss largely due to the hydrological changes associated with the amalgamation of the several islands now collectively known as Fisherman Islands. Port expansion and reclamation is ongoing to date.	HC, Current Study
1958 to 1997	Whyte Island (B)	22 (70 total wetland)	-	23	Reclamation of tidal wetlands began in 1958 and ceased in 1984, and has resulted in the intentional and unintentional loss of a large expanse of mangroves and salt marsh. Of the 37 hectares that have died (possibly as a result of elevated nutrients and large scale changes to hydrological regimes), 17 hectares have died since1997.	HC, Current Study
1964	Bulwer Island (B)	81	-	-	Mangroves were removed for the construction of Oil Refineries, now the site for British Petroleum (BP) Refinery	Harris (2001)
1965	Redcliffe (CP)	Unknown	-	22	Construction of the Redcliffe Aerodrome began in 1965. The land was privately owned before being handed over to the local council, then to the Aerodrome. The construction of bund walls, drainage channels and large scale changes to the drainage patterns from the infilling of the airport itself is believed responsible for the dieback.	Pedersen (2002)
1970	Wynnum (W)	-	-	3	Modification of drainage system when the access road was constructed during the late 1960's, early 1970's, accelerated by changes in salinity or other anthropogenic changes. Various heavy metals have been recorded in sediments of these impounded mangroves.	Saenger *et al.* (1991); Clark *et al.* (1997)
1974 to 1987	Runaway Bay (CM)	15.2 (28.8 total wetland)	-	-	Reclamation of mangroves for a Canal Estate development north of Runaway Bay.	Hyland & Butler (1988)
	Hollywell (CM)	9.4 (19.4 total wetland)	-	-	Canal Estate development	
	Sovereign Islands (CM)	18.1	-	-	Development of an artificial waterway and amalgamation of two islands (Griffin and Andy's) in 1974 resulting in the loss of mangroves.	
	Boykambil (CM)	8.8	-	-	Construction of artificial waterway north of Boykambil.	
	Coomera River (CM)	96.3 (131.9 total wetland)	-	-	Reclaimed for construction of canal estate "Hope Island" (including Sanctuary Cove and Boykambil)	

Year	Location	Reclamation Loss (Ha)	Natural Loss (Ha)	Unintentional Loss (Ha) (Dieback)	Comment	Source
	Southern Moreton Bay (CM, CM, L)	96.6	-	-	Mangroves reclaimed for farmland and marina development.	
		10.6 (23.1 total wetland)	-	-	Mangroves reclaimed for development of McLaren Marine Village	
		2.5	-	-	Various residential developments between the mouth of the Logan River and Victoria Point.	
	Cleveland Point (W)	22.8 (44.7 total wetland)	-	-	Construction of Raby Bay Point Halloran canal estate developments	Manson *et al.* (*in press*)
	Deception Bay (CP)	1	-	-	Construction of Canal Estate "Newport Waters"	Hyland & Butler (1988)
	Pumicestone Passage (P)	115.2 (151.9 total wetland)	-	-	Mangroves lost at Dux Creek (Canal Estate), Solander Lake (Canal Estate) and Spinnaker Sound (Marina) developments.	Hyland & Butler (1988)
1975 (~)	Hayes Inlet (CP)	-	-	44	Sediment deposition and large-scale change to hydrology creating conditions of impoundment and desiccation. Unknown source of hydrological change, but sediment deposition could be resulting from flood events depositing large amounts of sediment.	Pedersen (2002)
1977	Brisbane Airport (B)	850 (1190 total wetland)	-	-	Airport construction occurred after the Environmental Impact Statement was collated during the period between 1973 and 1977. Reclamation of mangroves (total of 850 hectares) occurred between 1977 and 1980, where the partially artificial channel (Serpentine Creek) was constructed and opened.	Durrington (1977), Hyland & Butler (1988)
1978	Stradbroke Island (N)	-	-	5	Sand mining south of Amity Point, North Stradbroke Island, required 'make-up' water when these operations were undertaken in areas above the existing water table. This water was pumped from a small impoundment created from the construction of a bund wall across Wallum Creek. Prior to the bund wall construction, an area of mangroves, in the Wallum Creek drainage basin was reclaimed by sand mining tailings. As a result of the stressful conditions created by the impoundment, large-scale dieback of these species occurred. To date, recovery is dominated by *Avicennia marina* since resumption of tidal flow in late January 1979.	Quinn & Beumer (1984)
1983 to 1987	Luggage Point (B)	-	-	14.5	The mangroves are impounded in this region and the effect appears localised. No definitive cause has been attributed to the event at present, but it is believed to have occurred between these dates due to the presence of large algal mats visible in aerial photos at these times.	Current study, HC, Laegdsgaard & Morton (1998)
1987 to 1990	Logan River (L)	124	-	-	Between 1987 and 1990 this area was reclaimed for sugar cane field construction.	Manson *et al* (*in press*)
1995	Coombabah Lake (CM)	-	8	-	A hailstorm around this period is suspected to have caused the dieback of several species of mangrove adjacent to a golf course development on the lake.	Pedersen (2002)
1997	Southern Moreton Bay and Islands	-	~150 (191 total	-	Physical damage resulting in widespread, species-specific death to mangrove and salt marsh communities resulted from a severe hailstorm in September of this year. A significant	Current Study, HC

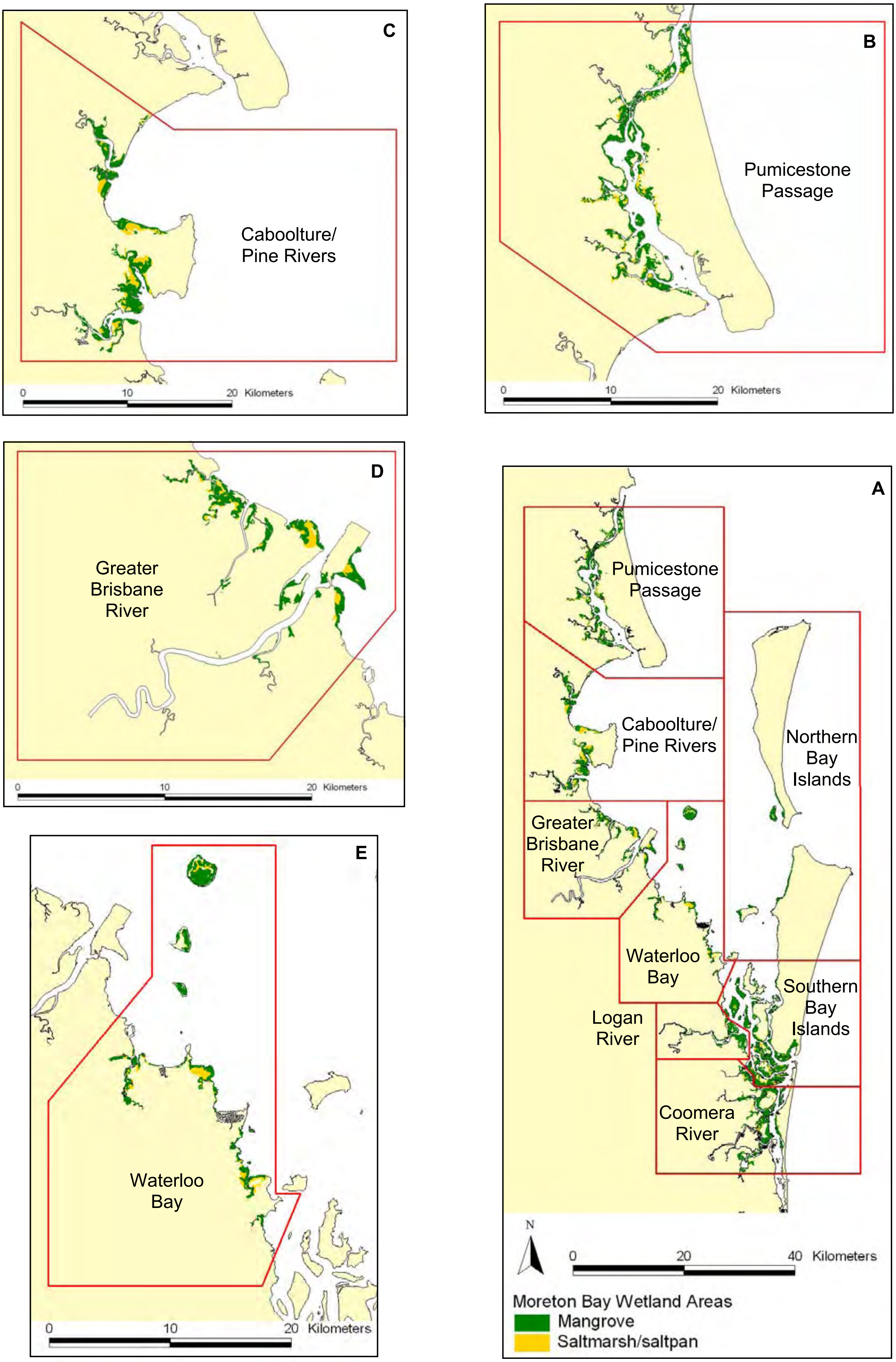
Year	Location	Reclamation Loss (Ha)	Natural Loss (Ha)	Unintentional Loss (Ha) (Dieback)	Comment	Source
	(S)		wetland)		portion of this dieback occurs on Cobby Cobby Island, where approximately 44 hectares of salt marsh and mangrove communities were damaged. Recovery is limited to only a few species.	
1998	Coombabah Lake (CM)	-	-	3	This mangrove dieback has not been associated with a known cause, and occurs adjacent to the Sewerage Treatment Plant on Coombabah Lake	Pedersen (2002)
	Sandstone Point (P)	-	1	-	Severe cyanobacterial blooms in December suspected to have caused small-scale dieback as a result of pneumatophore smothering.	Pedersen (2002)
	Caboolture River Mouth (CP)	-	-	3	Severe dieback occurred at the northern mouth of the Caboolture River as a result of impoundment. A further 13 hectares of circumscribing mangroves appear affected by this impoundment, however the effects are not quite as severe. No recovery has taken place to date.	Pedersen (2002)
2002	Adams Beach (N)	-	<0.1	-	Cyanobacterial blooms appear to be the cause of blockage in a small stream supplying tidal water to a small stand of mangroves. This has resulted in the water being impounded and subsequent death of mangroves.	Pedersen (2002)
Total	**Moreton Bay**	**1573.5**	**159**	**162.5**		

Table 18: Area (in hectares) of tidal wetlands including mangrove and salt marsh/ saltpan in eight subregions of the Moreton Bay region during 1974 and 1998. Data for 2000 from the DPI for the same areas are included for comparison (in brackets). Greater Brisbane River, Waterloo Bay, Logan River and Coomera River subregions were categorised as being under major intentional human influence; Pumicestone Passage and Caboolture/ Pine Rivers subregions were categorised as being under mostly unintentional human influence; and Northern Bay Islands and Southern Bay Islands were categorised as being under mostly natural influence. Sources of data were Dowling (1986) for 1974, Dowling and Stephens (1999) for 1998, and DPI (2000) for 2000.

MB	Mangrove			Salt marsh/ Saltpan			Total Tidal Wetland Area		
Subregions	**1974**	**1998**	**(2000)**	**1974***	**1998**	**(2000)**	**1974***	**1998**	**(2000)**
Greater Brisbane River	1758	1078	(1012)	771	262	(279)	2529	1340	(1291)
Waterloo Bay	1183	1124	(1102)	529	365	(318)	1712	1489	(1421)
Logan River	1040	929	(906)	205	64	(44)	1245	993	(951)
Coomera River	2561	2486	(2429)	1132	263	(258)	3693	2750	(2687)
Pumicestone Passage	2184	2228	(2471)	1046	485	(458)	3230	2713	(2929)
Caboolture/ Pine Rivers	1733	1978	(1895)	835	703	(697)	2568	2682	(2592)
Northern Bay Islands	621	749	(683)	18	13	(3)	638	762	(685)
Southern Bay Islands	3896	4091	(3888)	1037	377	(465)	4933	4468	(4353)
TOTAL Region	**14976**	**14663**	**(14386)**	**5573**	**2532**	**(2522)**	**20548**	**17195**	**(16908)**
Subregions Under Major Intentional Human Influence *Change in ha 1974-1998* *% Change*	6542	5617 *-925* *-14.1%*	(5449)	2637	954 *-1683* *-63.8%*	(899)	9179	6572 *-2607* *-28.4%*	(6350)
Subregions Under Mostly Unintentional Human Influence *Change in ha 1974-1998* *% Change*	3917	4206 *+289* *+7.4%*	(4366)	1881	1188 *-693* *-36.8%*	(1155)	5798	5395 *-403* *-7.0%*	(5521)
Subregions Under Mostly Natural Influence *Change in ha 1974-1998* *% Change*	4517	4840 *+323* *+7.2%*	(4571)	1055	390 *-665* *-63%*	(468)	5571	5230 *-341* *-6.1%*	(5038)

*The salt marsh/ saltpan figures for 1974 are approximations only, and may not be reliable, as Dowling and Stephens (1999) reported that this wetland vegetation type was not mapped in a consistent manner over the study area in 1974. The 1974 figures were taken from Dowling's (1986) 'tidal inundation' classification, which he defined as comprising samphire flats (salt marsh), marine clays (saltpan) and saltwater couch.

Mangrove area has decreased in all the subregions under intentional human influence (Brisbane River, Waterloo Bay, Logan River, Coomera River) between 1974 and 1998, with the greatest loss recorded for the Greater Brisbane River subregion (680 ha or 38.7% of the subregion). The combined loss for these four subregions was 925 hectares (14.1% in the four regions). In contrast, mangrove area increased over the period in all the subregions under mostly natural influence (Northern and Southern Bay Islands) and mostly unintentional human influence (Pumicestone Passage and Caboolture/ Pine Rivers). These categories experienced combined increases of 323 hectares (7.2%) and 289 hectares (7.4%), respectively. The total Moreton Bay region experienced a net loss in mangrove area of 313 hectares (2.1%) between 1974 and 1998.


C
Caboolture/
Pine Rivers
0 10 20 Kilometers
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A
Pumicestone
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Pine Rivers
Northern
Bay
Islands
Greater
Brisbane
River
Waterloo
Bay
Southern
Bay
Islands
Logan
River
Coomera
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Moreton Bay Wetland Areas
Mangrove
Saltmarsh/saltpan
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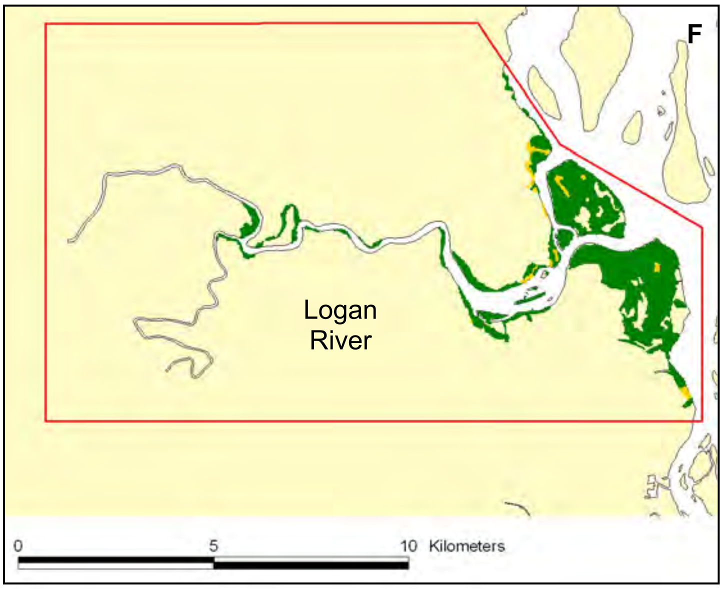
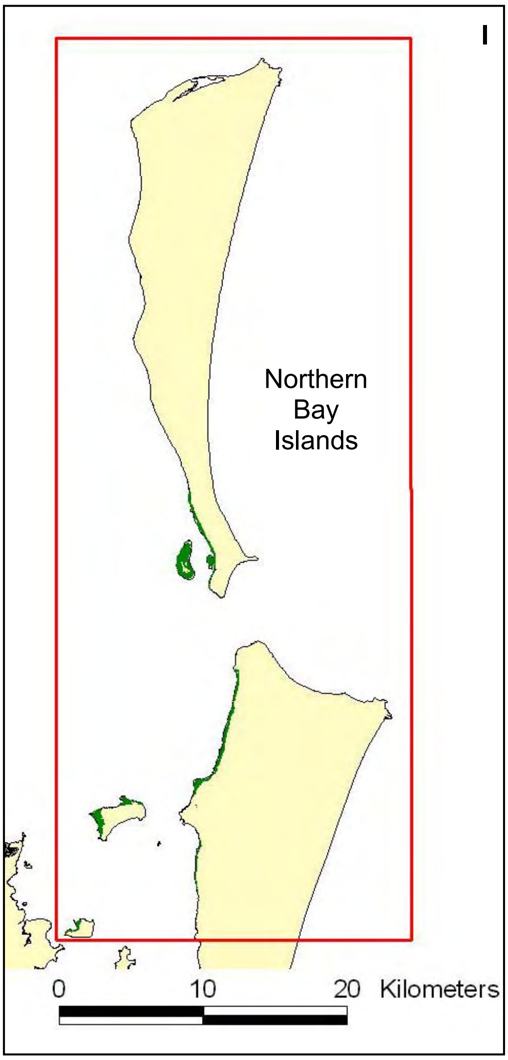
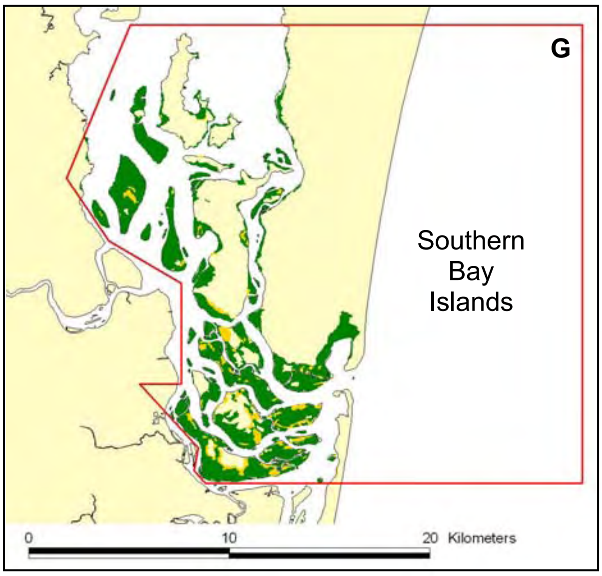
Waterloo
Bay
0 10 20 Kilometers







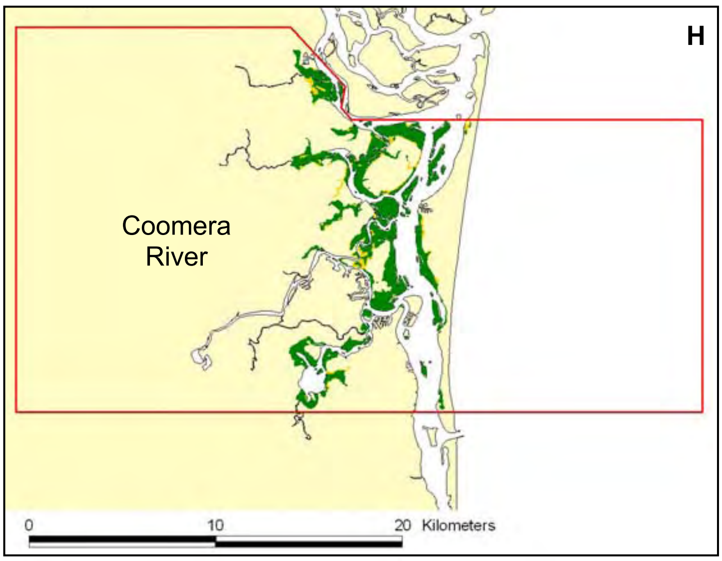


Figure 91. Distribution of mangrove and salt marsh/saltpan in the eight Moreton Bay subregions. (Source: DPI Fisheries, 1999).
A: Map of Moreton Bay detailing the eight selected subregions used in this assessment for comparison.
B: Pumicestone Passage subregion.
C: Caboolture/Pine Rivers subregion.
D: Greater Brisbane River subregion.
E: Waterloo Bay subregion.
F: Logan River subregion.
G: Southern Bay Islands subregion.
H: Coomera River subregion.
I: Northern Bay Islands subregion.

Salt marsh/ saltpan area has decreased in all subregions between 1974 and 1998, with the greatest decrease in the Coomera River subregion (869 ha or 76.8%). The highest combined loss occurred in subregions under major intentional human influence, with a loss of 1683 hectares (63.8%), compared with losses of 665 hectares (63 %) in subregions under mostly natural influence and 693 hectares (36.8%) in subregions under mostly unintentional human influence. The total Moreton Bay region experienced a net loss in salt marsh/ saltpan area of 3041 hectares (54.6%) between 1974 and 1998. It should be noted, however, that the salt marsh/ saltpan coverage figures for 1974 are approximations only, as this vegetation type was 'not mapped in a consistent manner over the current study area in 1974' (Dowling and Stephens, 1999). Also, salt marsh, saltpan and saltwater couch were grouped together in the 1974 classification, introducing a margin of error, as the inclusion of saltwater couch would make the figures somewhat higher than actual values. Nevertheless, the general trend is probably reliable and, by all indications, it seems there was a net loss of salt marsh/ saltpan in these areas over the period. Major causes for this loss would include reclamation, and encroachment by mangroves. In the case of encroachment, this could be related to sea level rise or climate change. These drivers are discussed later in this section (under Ecotone and Zonal Shifts) and in more detail in the Cobby Cobby Island case study.

Total wetland area experienced a net decrease from 1974 to 1998 in all subregions, except in the Caboolture/ Pine River and Northern Bay Islands subregions. The greatest loss was recorded in the Brisbane River subregion, where total wetland area decreased by 1189 hectares (47%). The highest combined loss occurred in subregions under major intentional human influence, with a loss of 2607 hectares (28.4%), compared with losses of 341 hectares (6.1%) in subregions under mostly natural influence and 403 hectares (7%) in subregions under mostly unintentional human influence. The total Moreton Bay region experienced a net loss in wetland area of 3,353 hectares (16.3%) between 1974 and 1998. Again, these figures should be viewed as approximations only, due to the questionable accuracy of the 1974 salt marsh/ saltpan areas.

Generally, the areas from the DPI (2000) data were roughly similar to those measured by Dowling and Stephens in 1998. In some cases, however, there is more variability between the Dowling and Stephens 1998 and DPI 2000 data than between the 1974 and 1998 data (e.g. mangroves in the Pumicestone Passage and Southern Bay Island subregions). It is unlikely, for example, that Pumicestone Passage experienced a 243 hectare gain in mangrove area over the 2-year period. It is likely that this does not reflect actual vegetation change. This may be attributable to the resolution differences between Landsat TM and Aerial Photograph images. This discrepancy both casts question on the reliability of the source data and demonstrates the importance of comparing original data generated by the same person using the same methods, as error can arise when comparing data from different sources, due to factors such as differences in interpretation.

It is clear, however, that the coastal features and tidal wetlands of the Moreton Bay region have undergone large-scale change over the last 24 years. A lot of this change occurred in subregions under intentional anthropogenic influence, due to activities such as reclamation. However, some changes would most likely to have been due to natural factors, such as climate change and storm activity. Key types of wetland change are used in the following discussion to evaluate the situation in the Moreton Bay region.

Overall, the region is characterised by at least 10 categories of change (refer to Table 1), with varying impact levels: reclamation loss, direct damage (minor), restricted tidal exchange, spill damage, depositional gains, nutrient excess, wrack accumulation, storm damage, ecotone shift and zonal shift.

Reclamation loss

In Table 18, area estimates of wetlands in the subregions under intentional anthropogenic influence showed marked declines over the period 1974-1998, particularly in the Greater Brisbane River, Logan River and Coomera River subregions. These areas are dominated by past and current reclamation activity. Although quantifying the exact amount of loss attributable to reclamation was beyond the scope of this study, and would require intensive field surveys and a greater level of mapping detail, estimates can be obtained from Table 17. According to this, at least 1,574 hectares of mangrove have been reclaimed in the region in the last 70 years, with up to 1493 hectares reclaimed in the period 1974-2000. The main drivers of change were airport, industrial and canal estate developments. Brisbane Airport construction in the late 1970's and early 1980's, in the Greater Brisbane River subregion, was the largest reclamation of wetland in Moreton Bay, leading to the loss of 850 hectares of mangroves and 340 hectares of salt marsh/ saltpan (Durrington, 1977; Hyland and Butler, 1988). Other major reclamations in the Greater Brisbane River subregion, partly occurring within the study period, included Fisherman Islands and Whyte Island. Bulwer Island experienced a loss of 81 hectares of mangroves in a clearing event, but this was prior to 1974. In the Coomera subregion, reclamation within the 1974-2000 study period occurred at Runaway Bay, Hollywell, Sovereign Islands, Boykambil, Coomera River, Southern Moreton Bay and McLaren Marine Village, mostly for canal estate developments. In the Logan River subregion, reclamation losses occurred at Logan River for sugar cane field construction and between the Logan River mouth and Victoria point for residential developments, while in the Waterloo Bay subregion, reclamation losses took place in the Raby Bay and Point Halloran canal estate developments. Based on this information, reclamation seems to be a major cause of wetland loss in subregions under intentional human influence. Only minor reclamation losses have occurred in the subregions under mostly unintentional human influence, except at the Dux Creek Canal Estate, Solander Lake Canal Estate and Spinnaker Sound marina developments in the Pumicestone Passage subregion. No reclamation losses have been recorded for those subregions under mostly natural influence (Table 17).

Direct damage

Wetland loss due to direct damage is a moderate type of change in the region, although it is not quantified. For example, there is a notable impact on the health on a small patch of mangroves at Myora Springs, North Stradbroke Island, resulting from excessive human access and trampling. A possible remedy for this would be to install a walkway through the mangroves, like those at Wynuum and Boondal wetlands, elsewhere in Moreton Bay region.

Restricted tidal exchange

Loss of wetland area due to restricted tidal exchange has occurred extensively in the region. Up to at least 113 hectares of mangrove dieback documented within the 1974-2000 period was attributable to this type of change (Table 17). Almost all of this occurred at locations within subregions under intentional and unintentional anthropogenic influence. This could have contributed to the large area of net mangrove loss calculated for the subregions under major intentional anthropogenic influence, while being offset by gains in the subregions under mainly unintentional anthropogenic influence (Table 18). Major incidents of this type of change have occurred at Fisherman Islands (23 ha mangrove lost) and Whyte Island (23 ha mangrove lost) in the Greater Brisbane River subregion, and at Hayes Inlet (44 ha mangrove lost) in the Caboolture/ Pine Rivers subregion.

Table 19. Effect levels and types of change affecting tidal wetlands of the Brisbane River estuary during three historical periods of the last two centuries. The 12 types of change are grouped into 4 categories (A-D) based on human and natural influences on coastal and estuarine habitat.

Type of Change	Pre 1860	1860 to 1946	1946 to 2002
A. Direct – Intended & obviously human related			
1. Reclamation loss	**Effect:** None	**Effect:** Moderate **Driver:** Chiefly industrial, upstream port development & river channel.	**Effect:** Dominant **Driver:** >2,200 ha of wetlands lost to industry, airport & seaport development plus urban, canal estates & agriculture.
2. Direct damage	**Effect:** Minor **Driver:** Occasional tree cutting, access paths & tracks.	**Effect:** Moderate **Driver:** Numerous access paths, tree cutting, access paths, tracks, trampled roots.	**Effect:** Moderate **Driver:** Numerous access paths, trampled roots, although areas generally protected under law.
B. Direct – Unintended & obviously human related			
3. Restricted tidal exchange	**Effect:** None	**Effect:** Minor **Driver:** Impoundment, built-up roads.	**Effect:** Moderate **Driver:** Impoundment, built-up roads - proportionate to population size.
4. Spill damage	**Effect:** None	**Effect:** Minor **Driver:** Occasional oil spills proportionate to shipping volume.	**Effect:** Minor **Driver:** Oil spill incidents proportionate to shipping volume - accumulation may exceed toxicant degradation rates.
C. Indirect – Unintended & less obviously human related			
5. Depositional gains and losses	**Effect:** Minor **Driver:** Increased frequency of fires in catchment reduced ground vegetation and increased sediment in run-off.	**Effect:** Minor **Driver:** Clearing of catchment vegetation & increased crop agriculture increased sediment run-off, resulting in shallower waters around the mouth. Dredging maintained channel	**Effect:** Minor **Driver:** Site hardening with city-urban roads and built-up areas and reduction in catchment croplands, altered & decreased sediment run-off. Dredging maintained the navigation channel.
6. Nutrient excess	**Effect:** None	**Effect:** None	**Effect:** Minor **Driver:** Possible dieback of mangroves resulting from impoundment caused by blooms of algae attached to roots.
7. Species-specific effect	**Effect:** None	**Effect:** None	**Effect:** Minor **Driver:** Minor dieback associated with toxicants in apparent run-off, & with application of herbicides along drains.
D. Not obviously human related, if at all			
8. Wrack accumulation	**Effect:** Minor **Driver:** Debris from blooms, storm waves - occasional.	**Effect:** Minor **Driver:** Litter debris, debris from increased number of blooms, storm waves.	**Effect:** Minor **Driver:** Litter debris, debris from increased number of blooms, storm waves. Recent *Lyngbya* blooms.
9. Herbivore/insect attack	**Effect:** Minor **Driver:** Insect plagues, occasional.	**Effect:** Minor **Driver:** Insect plagues, occasional.	**Effect:** Minor **Driver:** Insect plagues, occasional.
10. Storm damage	**Effect:** Minor **Driver:** Severe storm, hail, lightning, storm waves - occasional.	**Effect:** Minor **Driver:** Severe storms, hail, lightning, storm waves - occasional.	**Effect:** Minor **Driver:**Severe storms, lightning, storm waves - occasional. Notable hail damage (190ha) in South Moreton Bay region.
11. Ecotone shift	**Effect:** Minor **Driver:** Climate change - longer-term	**Effect:** Minor **Driver:** Climate change - longer-term	**Effect:** Moderate **Driver:** Rainfall fluctuations notable over period, climate corresponds with mangrove increase & recent dieback.
12. Zonal shift	**Effect:** Minor **Driver:** Sea level change - longer-term.	**Effect:** Minor **Driver:** Sea level change - longer-term.	**Effect:** Minor **Driver:** Sea level change - longer-term.

Relative effect levels: None; Minor; Moderate; Dominant, based on relative extent and presence of changes observed.

Spill damage

Minor oil spills have occurred around the Port of Brisbane, but have not resulted in significant or obvious mangrove dieback. The exception is a recent leak of 1.2 million litres of crude oil at Lytton in March 2003, which caused dieback of mangroves surrounding drainage channels. There is evidence of longer term genetic deterioration observed as chlorophyll deficient mutation (albino propagules), correlated with petroleum hydrocarbons in the sediments surrounding areas of greater shipping activity (Duke and Watkinson, 2002).

Depositional Gains

Depositional gains in the region were not quantified, but heavy upstream catchment use has resulted in large plumes of sediment at the mouths of the Brisbane, Pine, Caboolture and Logan Rivers. Deposition and accumulation of this sediment may have contributed to some of the mangrove gains in the Caboolture/ Pine River subregions. It would not have been a major type of change in the mouth of the Brisbane River, as constant heavy dredging has quickly removed any build-up of sediment in this area.

Nutrient Excess

Nutrient excess, caused by indirect human factors, may have contributed to several instances of minor mangrove dieback in the subregions under direct and indirect anthropogenic influence (not quantified). In some cases, elevated nutrients from sources such as wastewater outlets have led to excessive algal growth, smothering breathing roots or blocking water exchange. For example, at Luggage Point, a location adjacent to a wastewater treatment plant and point source outlet, the formation of large algal mats is thought to have smothered pneumatophores of *Avicennia marina* and impounded a localised area through the formation of an algal bund wall, possibly contributing to the dieback observed in this area between 1983 and 1987 (Laegdsgaard and Morton 1998).

Large algal mats have also been observed associated with recent dieback areas adjacent to the wastewater treatment plant outlet at Hayes Inlet, in the Caboolture/ Pine Rivers subregion (Pedersen, 2002).

Wrack accumulation

At least 1 hectare of mangrove loss in the region within the study period can be attributed to wrack accumulation, classified as a 'natural' impact. Severe cyanobacterial blooms in 1998 at Sandstone Point (Pumicestone Passage subregion) and in 2002 at Adams Beach on North Stradbroke Island are suspected to have caused small-scale dieback (1ha) of mangrove stands as a consequence of pneumatophore smothering and restricted tidal flow, respectively.

Storm damage

This type of change heavily impacted wetland areas in the Southern Bay Island subregion. A major hailstorm in southern Moreton Bay in 1997 resulted in dieback of 191 hectares of wetland area across several islands, including Cobby Cobby Island. This will be discussed in more detail in the Cobby Cobby Island case study. The large documented area of hailstorm-related dieback is not seen as a decrease in wetland area in the subregion in Table 10. This may be due to the loss being offset by greater amounts of natural wetland gain, or reflect inaccuracies in the data.

Another hailstorm, in 1995, is suspected to have caused dieback of 8 hectares of mangrove at Coombabah Lake, in the Coomera River subregion.

Ecotone Shift

Wetland Cover Index (WCI) could not be used to reveal shifts in ecotone in the regional assessment, as salt marsh/ saltpan figures were unreliable and the time period very short. Apart from using the WCI, however, ecotone shifts due to climate change may also be revealed through observation of mangroves moving into or out of salt marsh/ saltpan areas. In Moreton Bay, several authors have reported landwards encroachment and expansion of mangroves at the expense of contracting salt marsh/ saltpan area (e.g. Flood and Grant, 1984; Wetherall, 1993; Morton, 1993; Manson *et al.*, *in press*), indicative of a warmer, wetter environment. This shift was also observed and quantified in this study, on Cobby Cobby Island, and will be discussed further in Section 5.2.2. Increases in mangrove area due to climate change could potentially explain the increases recorded for the subregions under mostly natural and unintentional anthropogenic influence (Table 18).

Zonal shift

Zonal shifts, due to localised sea level rise, appear to be taking place at some sites within the study region (not quantified). This type of change would be most readily examined in subregions under mostly natural influence. Encroachment of wetlands into historically terrestrial environment has been observed in Southern Moreton Bay, resulting in *Casuarina* and *Melaleuca* dieback. This type of change will be discussed further in the Cobby Cobby Island case study.

Overall, based on the available information, wetland change in the Moreton Bay region has been dominated by reclamation loss (especially in subregions under major intentional human influence), hail storm damage (especially in subregions under mostly natural influence), restricted tidal exchange (especially in subregions under intentional and unintentional human influence) and ecotone shifts (regional, but more apparent in subregions with little or no human influence).

A more detailed and longer-term analysis of vegetation change in Moreton Bay is considered in the following case studies.

5.2 Detailed Assessment – Case Studies

5.2.1 Brisbane River – Area of Human Influence

The case study focuses on the Brisbane River estuary and its surrounding intertidal wetlands, from the river mouth to the Brisbane City Centre, 25 km upstream. The study area is shown in Figure 85.

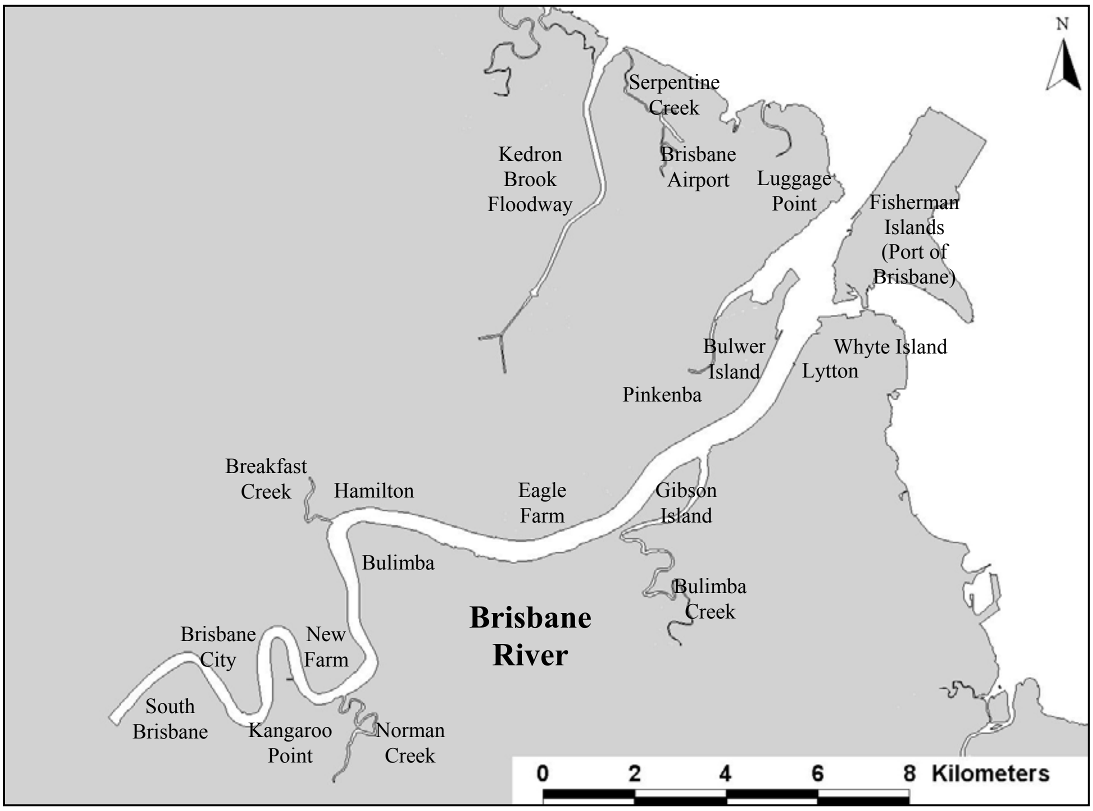


Figure 92. Brisbane River Estuary Study Site, showing location of major points of interest.

The Brisbane River estuary runs through the heart of Brisbane City, Australia's third largest capital city, and is an area of intense urban, industrial and port activity (Figure 93 & 94). Anthropogenic impacts include population pressure, sewage inputs, sediment and nutrient loads, 'paving' of the landscape, reclamation activities, dredging and modification of the river, urban and industrial expansion and port developments at the river mouth.

Figure 93: Aerial view of Brisbane River at the Brisbane City Centre, showing substantial urban developments and influences. (Source: Brisbane City Council)

Figure 94: Aerial view of the Port of Brisbane at Fisherman Islands, at the river mouth. (Source: Norm Duke)

The system has been subjected to significant human influence, and has experienced major changes in coastal features and vegetation as a result. Substantial areas of wetland habitat have been lost since European settlement in 1824, although mangroves have colonised further upstream, probably due to changes in hydrology. At the time of settlement, the Brisbane River mouth was characterised by numerous 'mangrove' islands and shallow channels with slow river flow. Anthropogenic development has modified the shape and hydrological regimes of the river and it is now a walled, straightened, high-flow watercourse. However, currently extensive and diverse mangroves exist in the region, including communities on Fisherman, Whyte and Bulwer Islands, and those adjacent to the Brisbane Airport and Luggage Point.

Four major reclamation events dominate the history of development and disturbance to mangroves at the Brisbane River Mouth. The redevelopment of Brisbane Airport at Serpentine Creek in 1979 comprised the largest destruction of wetlands in southeast Queensland. 1190 hectares of salt marsh and mangrove were destroyed, 850 hectares of which comprised mangrove vegetation (Durrington, 1977; Hyland and Butler, 1988). In 1964, approximately 81 hectares of mangroves were reclaimed prior to the construction of the Amoco/BP Oil refinery at Bulwer Island (Harris, 2001). Reclamation of tidal wetlands began in 1958 to make way for construction of the Port of Brisbane, amalgamating several small mangrove dominated islands now collectively known as the Fisherman Islands.

Within the last decade, the port has further expanded, now bringing the amount of reclaimed mangroves to ~150 hectares (Catchpoole, 1994). On adjacent Whyte Island, various industrial and port related developments also beginning in 1958 resulted in the reclamation of ~60 hectares of mangrove and salt marsh vegetation. (Catchpoole, 1994). These operations ceased in 1984.

As well as mangrove removal and altered hydrology, a number of polluting industries are based on the river, including petrochemical refining waste dumping and shipping. Elevated concentrations of heavy metals (Mackey *et al*., 1992; Clark *et al*., 1997), elevated nutrients (Mackey *et al*., 1992) and hydrocarbons (Godson, 2002) have been recorded in sediments within mangrove forests in the vicinity of the mouth of the Brisbane River associated with these anthropogenic industries.

The following case study presents a thorough investigation of historical change in the Brisbane River estuary tidal wetland habitat between 1946 and 2002, using aerial photography. This was achieved through the creation of digitised maps detailing coastal vegetation and features for each of the years and the calculation of change in wetland area over the time period. In addition, within the case study area, two focal points, Bulwer Island and Luggage Point, will be examined in greater detail and specific events driving the change observed at these locations discussed.

The methods used in this case study are outlined in Chapter 3. Historical aerial photographs of the Brisbane River estuary were collected for 1946 and 2002. Both sets of photography were obtained from the Department of Natural Resources and Mines (DNRM). The mosaics created were georeferenced to a Landsat TM 2002 image (datum: WGS 84 and projection: Universal

Transverse Mercator) of the region, which was obtained from the Biophysical Remote Sensing Group (Geographical Sciences and Planning Department, The University of Queensland).

The mosaics can be seen in Figures 98a) and 98b), and provide a visual comparison with Figures 99a) and 99b) showing the tidal wetland area coverage in 1946 and 2002. The vegetation categories used in this case study were mangrove and salt marsh/ saltpan.

Within the study site, two focal points, Bulwer Island and Luggage Point, were chosen for more detailed examination. Vegetation maps for 1946 and 2002 were produced for these sub-regions, using the methodology described above and in Chapter 3, and tidal wetland areas and change calculated. Historical information was collected on anthropogenic activities and events potentially contributing to the changes observed. Field verification was also conducted. For the Bulwer Island focal point, additional visual comparisons of mangrove coverage were made using a historical map from 1898 (Queensland Department of Transport (QDT)) and aerial photography from 1960 (DNRM) and 1997 (DNRM). Due to the diversity and abundance of source materials available on the history of Bulwer Island, a comprehensive, in-depth timeline could be collated, using photographs, maps, discussions with long-time residents and information from BP, whose refinery is presently located on the island. The timeline was used to detail anthropogenic events relevant to change on the island, including river development, dredging, filling, clearing and, consequently, the building of the BP (originally Amoco Oil) refinery. This was illustrated with maps from 1898 (QDT), 1963 (QDT) and 1974 (Dowling), and aerial imagery from 1961-1964 (BP), 1960 (DNRM), 1967 (BP), 1972 (DNRM), 1978 (DNRM), 1981 (DNRM), 1991 (DNRM) and 1997 (DNRM).

Findings and Discussion

Types of change in tidal wetlands of the Brisbane River estuary

This account describes the historical extent and types of changes affecting tidal wetlands of the Brisbane River estuary from 1823 to 2002. A revision and listing of available information on the diverse range of factors influencing this estuarine environment and setting are compiled in the timeline (Appendix 3). This timeline, while not intended to be complete, does include major events and circumstances surrounding most changes affecting the river estuary since it was first explored by John Oxley in 1823. The timeline is planned as a public resource available on the web where additional information can be added, as appropriate, by anyone with due acknowledgment and recognition of original sources. Within the framework and context of this historical resource and database, we further present an assessment of spatial change in tidal wetlands with new maps of the Brisbane River estuary for three representative periods, including 1860, 1946 and 2002.

The 1860 map of the Brisbane River (see Figure 96) shows the water course and tidal wetlands as they were prior to European settlement and before extensive alterations were applied over the next century and a half. The estuary at that time had what might be considered a classic funnel-shape. The mouth was broad, around three kilometers wide, and filled with various mud banks, low islands, and mangrove-lined creeks. These tidal wetland areas extended a considerable distance upstream, at least 10 kilometers. Key features were named at the time based on respective features, noting in particular, the islands of Gibson and Bulwer, which remain in name only today. Other islands, mud banks and rock shoals were present within the estuary creating challenges to navigation. These ‘obstacles’ were deemed as seriously limiting access to the growing town and port on the Town Reach further upstream, so extensive engineering of the river estuary was begun around this time (DHM, 1986). Most navigation obstacles have since been removed or incorporated into claimed river shorelands. For example, Parker Island was joined with Pinkenba lands, and Egg Island was removed altogether. The area of tidal wetlands at the time exceeded 2,900 hectares in our study area, as interpreted from early charts (Figure 95) and 1946 aerial photographs (Figure 91a; also see Table 20).

Clearly, around this time, as shown in the 1860 map (Figure 95), development was targeted upstream on riparian lands, particularly those associated with the rapidly expanding town site (Figure 91a).

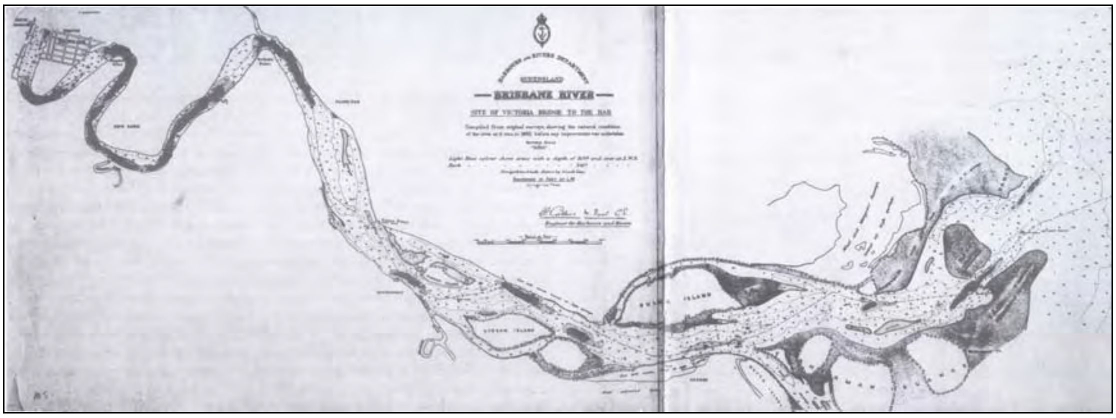


Figure 95: 1860s marine chart of the Brisbane River, from Victoria Bridge to the Brisbane Bar. (Source: Department of Harbours and Marine (DHM), 1986)

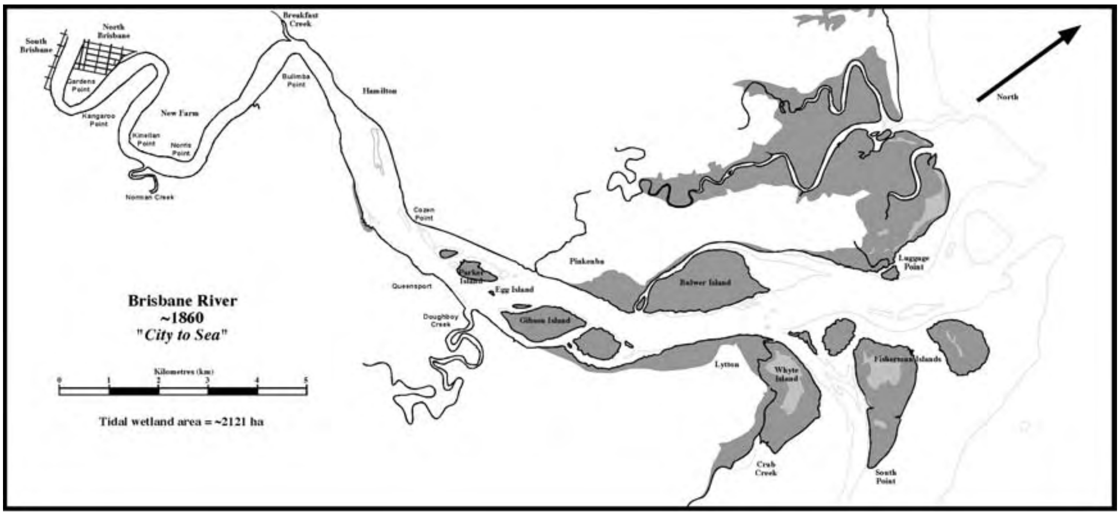
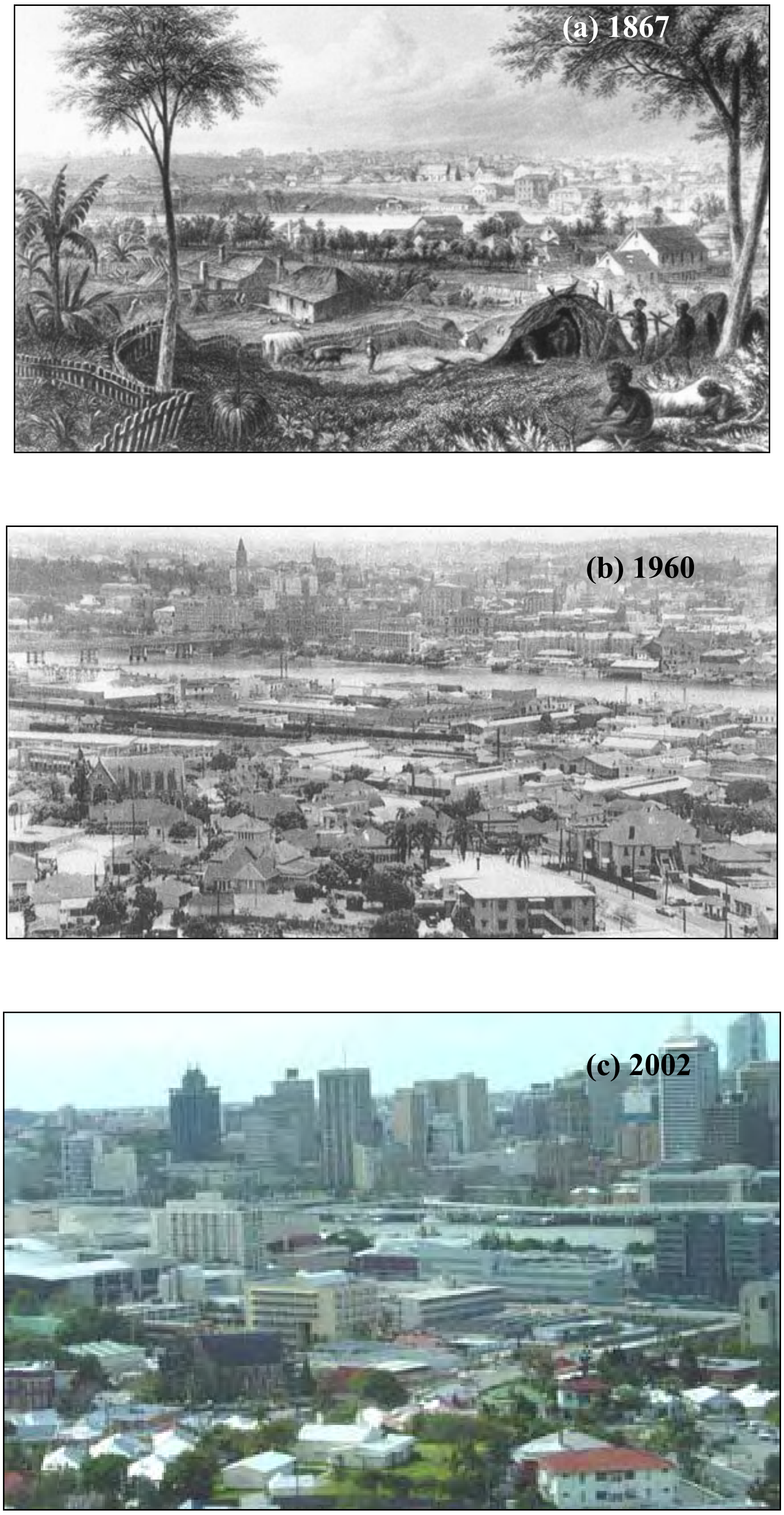


Figure 96. The approximated tidal wetland area along the Brisbane River in 1860. Tidal wetland coverage was estimated using an old 1860 chart (Figure 89) and extrapolation from the 1946 wetland area.

The river estuary was a vital conduit for increased shipping traffic during this time, so major long term plans for engineering and modifying the river were drafted and ground works initiated. The chief aim was to make the river more navigable for larger shipping to encourage greater trade for the region and its hinterlands.



Figures 97(a), (b) & (c): The changing view from Highgate Hill, South Brisbane: in 1867, with scattered housing; in 1960, where the town hall dominates the city centre; and in 2002, where the town hall is no longer visible behind towering high rises.
(Sources: (a) & (b) John Oxley Library; (c) Norm Duke)

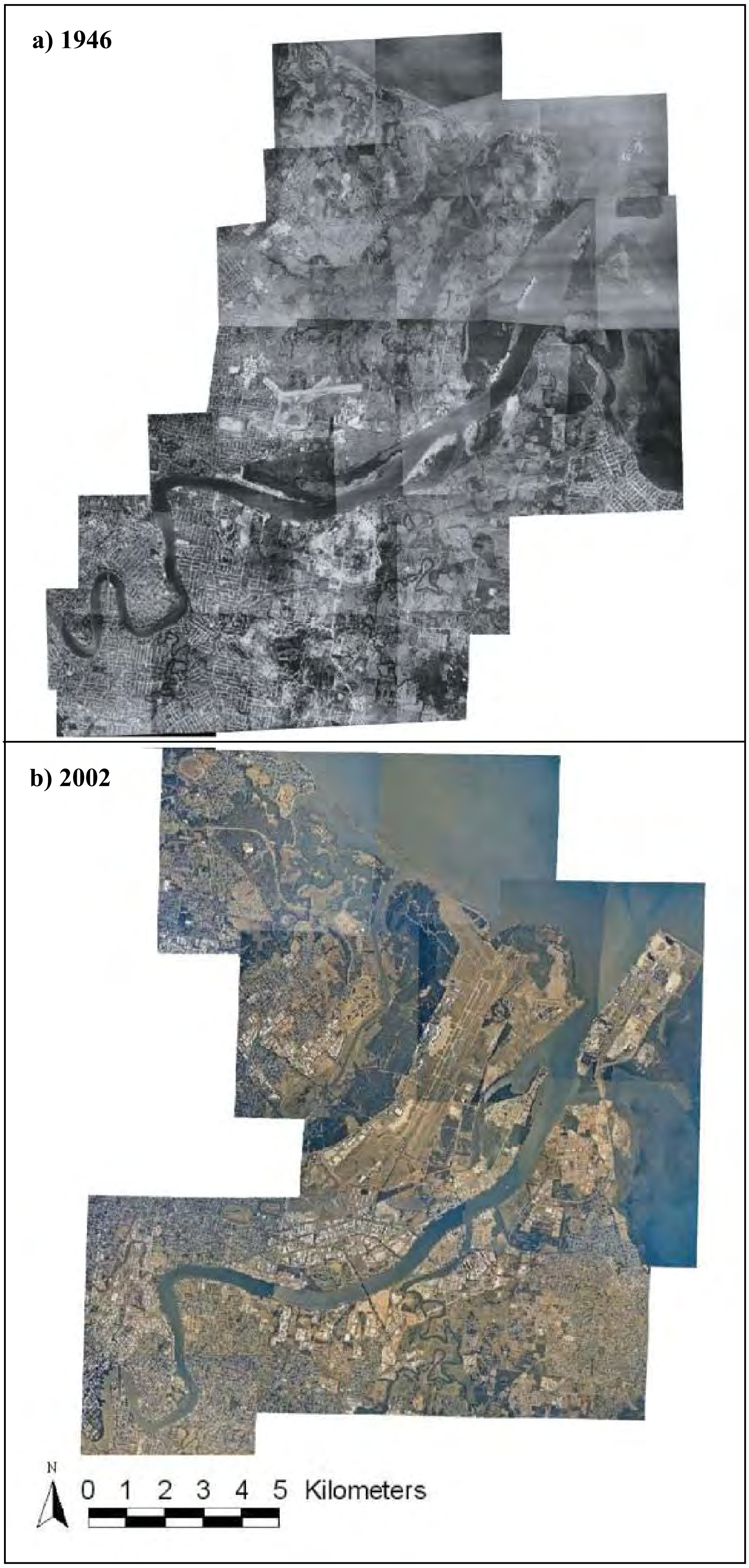
The 1946 map of the Brisbane River (Figure 99a) shows relatively few overall changes to the tidal wetland area, with a total of 2,895 hectares and 1,665 hectares of mangroves (Table 20). However, there were notable changes to the river channel and main watercourse. Immediately apparent are changes to the funnel-shape of the original estuary, with its narrowing, straightening, and losses of the islands identified above. By comparison, the estuary had become more closely resembling a straightened drain, with much less shoreline and tidal vegetation to stop the export of sediments downstream. In several instances, creeks were redirected and straightened, although Bulimba (ex Doughboy) Creek was made longer by passing around Gibson Island through Aquarium Passage. The width of the main river channel generally was reduced to less than one kilometer, and straightened to further aid navigation (DHM, 1986). As part of this process, a considerable section of the river from Hamilton to Coxen Point and Pinkenba was claimed with landfill, incorporating Parker Island plus other mangrove islands and mud banks to add to Eagle Farm and Hamilton Lands. Installation of training walls were well-advanced since they were constructed early to define the water course and areas for dumping dredge spoil. Overall construction and engineering activities included point excavation (involving the shortening of upstream points like Kangaroo Point, to allow longer ships to navigate the sharp corners), alignment works (to straighten the navigation channel), training walls (to harden the sides of the river bank and channel to direct and concentrate water flows), reclamation and straightening of drainage inflow channels (to facilitate run-off from claimed riverside lands for occupation and use), accompanied by dredging along the river and across the bar at the mouth (to allow larger shipping to pass into protected waters of the river and port at any tide). These construction efforts collectively resulted in massive changes to the character and natural function of the river, especially notable with changes in sediment transport and deposition.

From early times, recorded in early charts of the day, it was acknowledged that sediment deposition had increased significantly at the mouth. This was apparently exacerbated by the clearing of terrestrial and riparian vegetation upstream, hardening of city surfaces (Figure 97b), and increased run-off flows. The impact of this kind of disturbance on coastal processes has no equal in past times. For instance, Neil and Yu (1996) showed a relationship between catchment run-off and unit sediment yield in Queensland coastal catchments. When this model was applied to geological data of deteriorating late Holocene climate over 6-7 thousand years ago in the Brisbane River area, it showed mean flow-weighted sediment concentrations increased from about 90 mg/L to 150 mg/L (Capelin et al., 1998). By contrast, mean flow-weighted sediment concentrations increased to 525 mg/L as a consequence of land use intensification following European settlement over the last 200 years. For any particular level of runoff, based on data from a number of coastal river systems in Queensland (Neil and Yu, 1996), the change from natural to disturbed systems involved an increase of 3.5 times the sediment load observed prior to catchment disturbance. Johnson *et al*. (2002) quantified current catchment condition in Moreton Region as less than 26% of remaining natural vegetation, which is among the most impacted in the state.

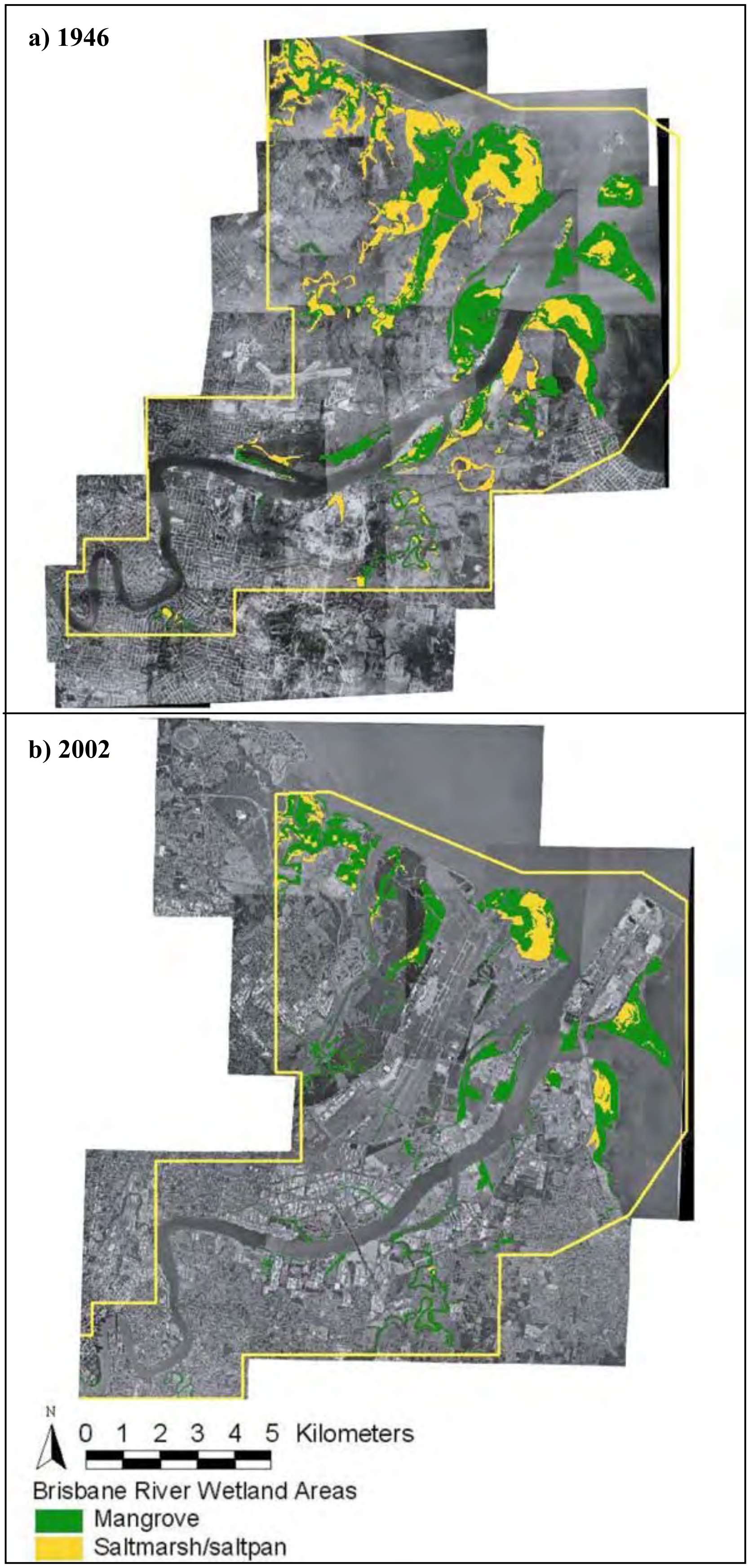
By around the middle of the 20th century, plans to alter and develop the river estuary were well-advanced and targeted on river channel development. As noted, these changes did effect river function and sediment deposition, but they had relatively little apparent impact on the extent tidal wetlands surrounded the estuary. By contrast, however, the next phase of development projects were to have a profound and catastrophic impact on these wetlands.

Table 20: Area (in hectares) of tidal wetlands including mangroves and salt marsh/ saltpan surrounding the Brisbane River (Moreton Bay) in 1946 and 2002. Data for 1998 from Dowling and Stephens and for 2000 from the DPI for the same area of interest are included for comparison. Details on sources stated in methods.

	Mangrove				Salt marsh/ Saltpan				Total Tidal Wetland Area			
	1946	**2002**	**(1998)**	**(2000)**	**1946**	**2002**	**(1998)**	**(2000)**	**1946**	**2002**	**(1998)**	**(2000)**
Area in ha	1165	1122	(993)	(933)	1230	257	(248)	(260)	2895	1379	(1241)	(1193)
Change in ha 1946-2002		-543				-973				-1516		
% Change		-32.6				-79.1				-52.4		
Source	HC	HC	Dowling/ Stephens	DPI	HC	HC	Dowling/ Stephens	DPI	HC	HC	Dowling/ Stephens	DPI



Figures 98a) and b). Mosaic of aerial photographs depicting the Brisbane River in a) 1946 and b) 2002.



Figures 99a) and b). Vegetation maps showing mangrove and salt marsh/ saltpan areas surrounding the Brisbane River in a) 1946 and b) 2002. Yellow boundary marks area of interest.

The 2002 map of the Brisbane River (Figure 99b) shows immense losses (>52%) in tidal wetland area since 1946 down to 1,379 hectares – identifying a net loss of 1,516 hectares. Changes in tidal wetland area are presented in Table 20, noting 33% net loss in mangrove and an incredible 79% net loss in salt marsh and saltpan. Remaining remnant areas exist today as relatively isolated reduced plots and marginal stands surrounded predominantly by intensive industry and port developments. The bulk of wetland losses were directly associated with two major development projects, including the progressive re-location of seaport facilities to the river mouth, plus the construction of the new international and domestic airport on northern wetlands during the early 1980s (Saenger, 1996). Airport construction alone accounted for the destruction of around 600 hectares of tidal wetlands, marked by the loss of almost an entire estuarine system, Serpentine Creek, and the township of Cribb Island on its northern side. Specific changes to the river estuary include further consolidation of main river channel narrowing and straightening, filling of tidal lands associated with Gibson and Bulwer Islands, the filling and development of new port facilities and infrastructure on Whyte and Fisherman Islands. The filling of lands around Eagle Farm was completed.

Given there are significant goods and services benefits to be derived from tidal wetlands (for example, Duke, 1997), it is expected that substantial losses in wetland cover will correlate with a notable decline in water quality and fishery production along the western side of the bay. Despite the extensive losses identified in this latter period, and the likely implications on bay health and fisheries, there has been no systematic evaluation of further impacts of additional works being planned. Such an assessment need be conducted as a matter of urgency if we are to preserve the benefits of the relatively small remaining tidal wetland area in this region.

Types of changes to tidal wetlands of Brisbane River estuary

Both natural and human events have had notable influences on the river estuary. In the first instance, natural factors defined the funnel-shape of the estuary prior to 1860, along with the extent and composition of tidal wetlands. A dynamic equilibrium may also have existed between such estuarine ecosystems and with both those upstream in the catchment and those in the bay, like seagrasses and corals (Duke and Wolanski, 2001). The arrival of Europeans heralded the beginning of dramatic changes to the estuary, upsetting the previous equilibrium where nearshore ecosystems were forced to readjust. These changes usually receive the most attention, recorded as losses whether they be due to reclamation affecting mangroves, or flood events causing losses in seagrass (Dennison and Abal, 1999). But, there are likely to be a range of different factors involved and it would be useful to evaluate each of them in an assessment following the guidelines established in this project.

By reviewing the 12 types of change described in Chapter 1, it is possible to identify and quantify the chief drivers or factors influencing change over the last two centuries in tidal wetlands of the Brisbane River estuary. The period is conveniently considered in three sections, prior to 1860, 1860 to 1946, and 1946 to 2002. The assessment results are summarised in Table 12 with the 12 types of change and 3 time periods with estimated impact levels and brief observations of the chief drivers, or influencing factors. Levels of effect were ranked as ‘none’, ‘minor’, ‘moderate’, or ‘dominant’, depending on the relative extent and presence of the effects observed.

Reclamation loss

The major type of change affecting tidal wetlands around the Brisbane River over the last century and a half has been due to losses in reclamation. All these changes began post-European arrival, and in this estuary the level of impact reached a moderate level by 1946, affecting possibly around 200 ha. By 2002, however, the impact was classified as dominant, since more than half (52% net, Table 11) of tidal wetlands remaining in 1946 had been removed, notably around 1,516 ha. The chief drivers of change were port and airport development in conjunction with expansion of industrial facilities toward the river mouth.

Direct damage

There was a probably a minor impact prior to 1860 with walking access tracks and light cutting by both Aboriginal people and early European arrivals. In 1946, the apparent level of impact had reached moderate levels based on aerial photograph interpretations and population numbers. The level of impact in this category appears to have remained the same although the population had increased, so had the level of protection restricting general access. The types of damage observed include tracks and paths which would have included trampling of roots and cutting of stems.

Restricted tidal exchange

It is expected there would have been no restricted tidal exchange dieback prior to 1860. However, by 1946, there was instances associated with the installation of training walls and access roads to the river. Damage was observed behind training walls at Bulwer Island, and other areas were impounded. The extent of this kind of damage had increased to moderate levels by 2002.

Spill damage

There was no spill damage expected prior to 1860. Up to 1946, there is expected to have been a minor amount, although there are no records of spill incidents. Up to 2002, the level has remained at minor since there had been no obvious spill damage or dieback recorded. The most severe incident recorded in Brisbane occurred recently in April 2003 when a pipe burst at Lytton and spilled into a mangrove lined channel. There was severe dieback of mangroves along the channel. However, other more subtle impacts have been reported where petroleum hydrocarbons appear to cause lethal genetic mutations in mangroves (Duke and Watkinson, 2002). There are also worrying observations that benthic macrofauna biomass and diversity has declined in recent decades suggesting that the health of mangrove ecosystems in the port area has been seriously affected. It seems likely that in some areas the accumulation of oil in sediments from chronic small spills may have exceeded degradation rates of such toxicants in sediments.

Depositional gains and losses

This type of change appears to have remained at a minor level over all three periods. Prior to 1860, it was likely to have been driven by fires in catchment areas leading to more erosion where the frequency of fires increased. The number of fires may have increased with increasing numbers of people, but certainly after 1860 there was massive clearing of catchment vegetation, and development of crop farming involving soil tillage – all leading to increased erosion and run-off of sediment into the estuary. However, it is expected these effects were obscured by the reclamation losses and channel dredging. Some areas around Fisherman Islands by 2002 showed areas of new mangroves fitting the expected pattern but the changes in area were relatively minor.

Nutrient excess

This type of change remains unproven. It seems likely, in any case, that no instances occurred prior to 1946. The reported instance at Luggage Point, at the mouth of the river, appears to be the only occurrence so far. The level of impact is recorded as minor.

Specifies-specific effect

This type of change had not been shown until recently in 2003. There were no apparent instances prior to 1946. The recent instance at Luggage Point, at the mouth of the river, appears to be an isolated case involving herbicides in run-off, which appear to have killed a hectare of mangrove trees. The level of impact is recorded as minor. It is possible there might be more cases of this type of change but surveys of toxicant chemicals in the environment are expensive, and rarely done. Sampling for toxicants in the recent case was only conducted since the dieback was in an isolated area, and there were no other possible causes observed.

Wrack accumulation

This type of change has not been observed in the estuary but minor levels are likely.

Herbivore/insect attack

This type of change has not been observed in the estuary but minor levels are likely.

Storm damage

This type of change has not been observed in the estuary but minor levels are likely.

Ecotone shift

Changes in rainfall patterns may have significantly affected mangrove vegetation cover in tidal wetlands around the Brisbane River estuary. The Wetland Cover Index, described in Chapter 1, is the chief tool in showing this type of change and the importance of longer term patterns in rainfall. The trend shown in Figure 121 indicated the probable rainfall effect on vegetation had increased from quite dry conditions in the 1940s, to wetter conditions in the 1970s after which rainfall had declined again although not reaching the conditions seen earlier.

Zonal shift

This type of change has not been observed in the estuary but minor levels are likely.

5.2.1.1 Focal Point 1 – Bulwer Island

Bulwer Island is located at the mouth of the Brisbane River (153°08'E, 27°24'S), which flows into Moreton Bay (Figure 92). The chief industry occupant of the island is the Bulwer Island BP Refinery. The refinery is in close proximity to residential areas of Pinkenba, and major industry areas including the Caltex Oil Refinery, ACL (concrete), the Port of Brisbane, Luggage Point Wastewater Treatment Plant, and Brisbane International Airport (Figure 100).

Figure 100. Bulwer Island, at the mouth of the Brisbane River, and the surrounding industries. (Source: DNRM)

Bulwer Island is an island in name only today. The changes that joined this piece of land, originally a mangrove island, to the mainland commenced a century ago, as part of a series of planned development projects to improve the Brisbane River and surrounding wetlands for major port and harbour usage. The history of this site reflects the dramatic changes, which have occurred along much, if not all, of the lower estuarine reaches of the Brisbane River since European discovery in 1823 (Davenport, 1986). Since this time, the natural shape and function of the river has changed from a large, meandering inlet with many small mangrove islands and channels to a walled, deep flowing, straight watercourse through hardened built-up surroundings.

Major events

In 1860, Bulwer Island was an island around 700 hectares in area and totally covered with mangroves. The dominance of mangrove vegetation is indicative that all parts of the island were flooded by regular tidal inundation and there was no terrestrial vegetation. As the population of Brisbane increased, the island was altered as part of various port development projects planned to improve the overall port and harbour facilities. In the later part of the 19th century, the island was eventually joined to the mainland with the construction of the Bulwer Island training wall, being a continuation of the wall commencing further upstream. Immediately following wall construction in 1903, sand from ongoing dredging of the river was used to fill low-lying areas between the island and the training wall. This took place progressively further north and continued downstream from Pinkenba. The island was accordingly enlarged to the training wall from the southern end, and at this time, the north-eastern spit was also created to provide locations for navigation beacons.

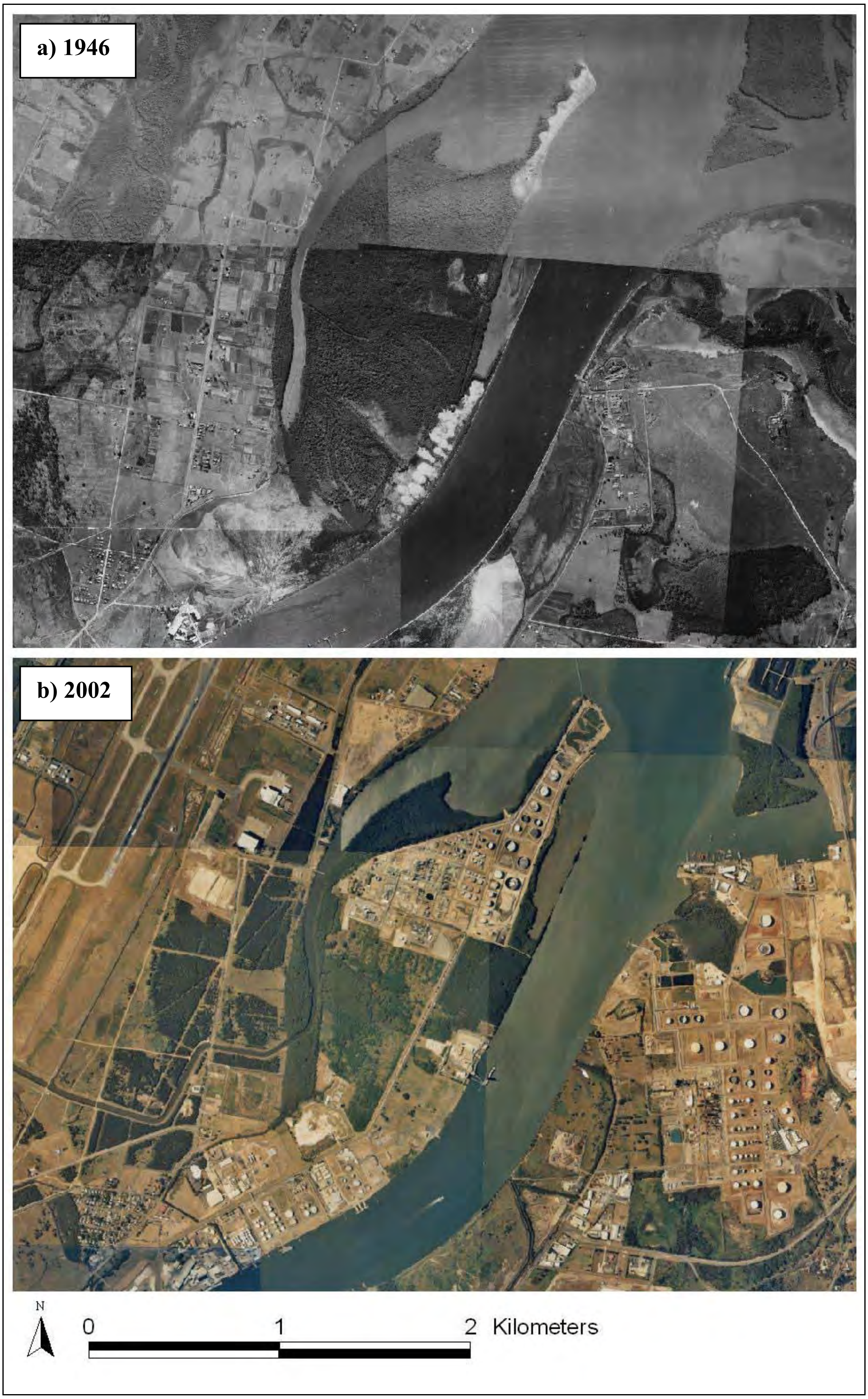
In 1962, approximately 81 hectares of mangroves were cleared to make way for the Amoco Oil Refinery, built in 1964. In the 1970s other areas of mangroves were cleared to the south of the island. In general, landfill operations on Bulwer Island increased general sediment elevations above high water, to a height of around 2-4 m above Australian Height Datum (AHD) for the refinery site. BP acquired the refinery in July 1984, and today the other chief industrial occupants include Shell and ACL Concrete.

Changes to wetland habitat

Table 21: Area (in hectares) of tidal wetlands including mangroves and salt marsh/ saltpan at the Bulwer Island focal point (Brisbane River) in 1946 and 2002.

	Mangrove		Salt marsh/ Saltpan		Total Tidal Wetland Area	
	1946	**2002**	**1946**	**2002**	**1946**	**2002**
Area in ha	200	86	22	0	222	86
Change in ha from 1946-2002		-114		-22		-136
% Change		-57.0%		-100.0%		-61.3%
Source	HC	HC	HC	HC	HC	HC

Many changes have occurred to the wetland communities once present on Bulwer Island. A detailed timeline of this change, incorporating historical events, maps and photographs, is provided as Appendix 4. Figures 101a) and b) show close-up aerial photographs of the island in 1946 and 2002, respectively. Figures 102a) and b) are vegetation maps of the location, while Table 21 gives the comparative areas of wetland coverage. Over the period, net losses of 114



Figures 101a) and b). Mosaics of aerial photographs depicting Bulwer Island, Brisbane River, in a) 1946 and b) 2002.

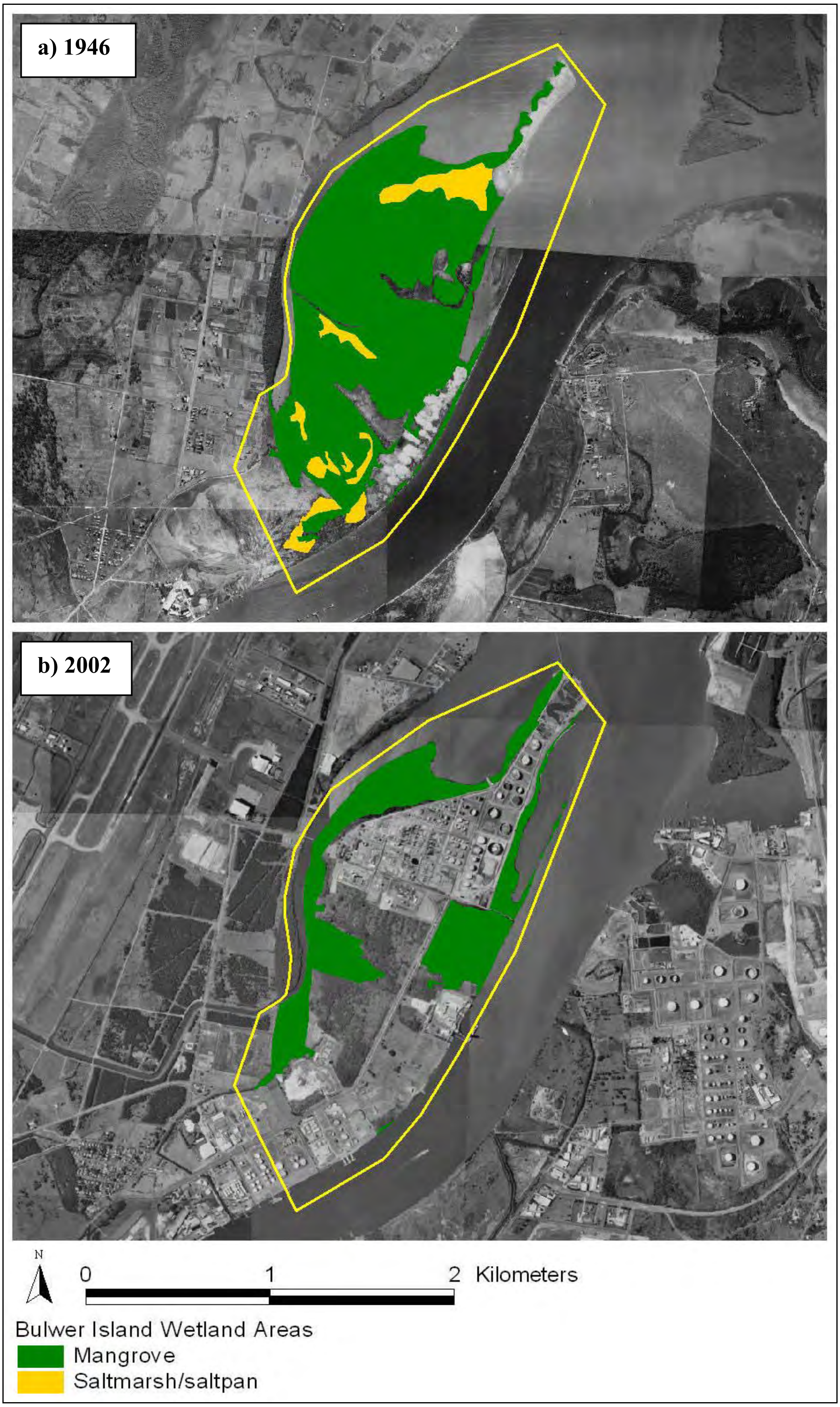


Figure 102a) and b). Vegetation map showing mangrove and salt marsh/ saltpan area on Bulwer Island in a)1946 and b) 2002. Yellow boundary marks area of interest.

hectares (57%) of mangroves and 22 hectares (100%) of salt marsh were recorded, giving a combined net loss of 136 hectares (61%). An additional visual comparison is provided in Figure 98, where details from an 1898 map and 1960 and 1997 aerial photographs were overlaid onto a recent aerial photograph (1997), to illustrate changes in mangrove distribution and coastline. In 1898, Bulwer Island was a distinct island, completely covered in mangroves. By 1960, an altered, straightened river course can be observed, with Bulwer Island joined to the mainland via a training wall (built 1903). The island had been enlarged from its original condition, with new land apparent at the northern spit and between the island and the training wall at the southern end. Major human intervention (e.g. clearing) on the island was yet to take place, and extensive mangrove communities still existed, similar to those visible in the 1898 image. In the 1997 image, a substantially reduced area of mangrove vegetation can be observed. The losses occurred as a result of reclamation, involving clearing, land fill burial, dredging excavation and refinery construction. New areas of mangrove are also visible, along the southern end of the training wall and the eastern edge of the island. From this, it is evident that remaining mangroves were able to rapidly colonise new areas built-up with dredge spoil from the river. They appear to have colonised opportunistically, becoming established where landfill raised sediment elevations above mean sea level but not above maximal high water spring tide levels.

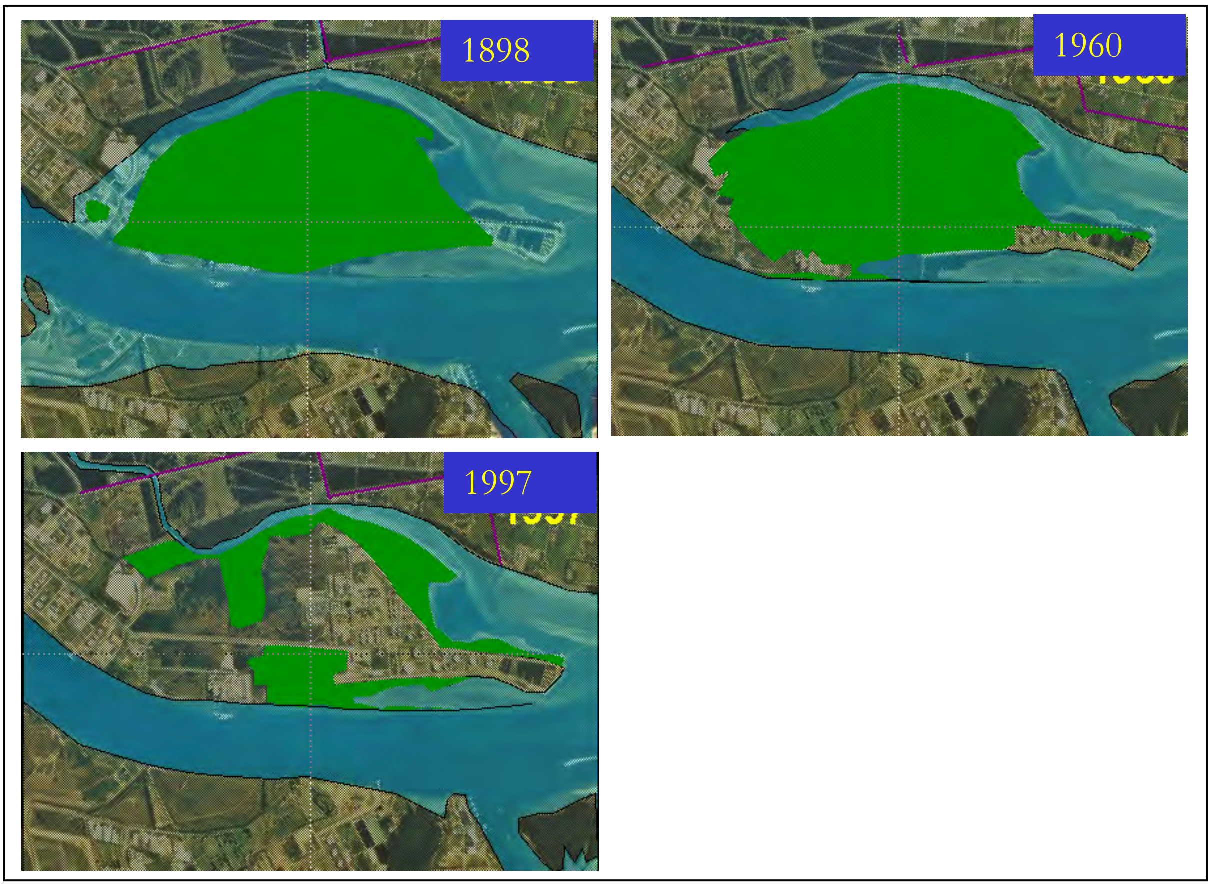


Figure 103: A visual comparison of mangrove change on Bulwer Island, where details from an 1898 map and 1960 and 1997 aerial photographs were overlaid onto a recent aerial photograph (1997), to illustrate changes in mangrove distribution and coastline. (Source: DNRM, QDT & HC)

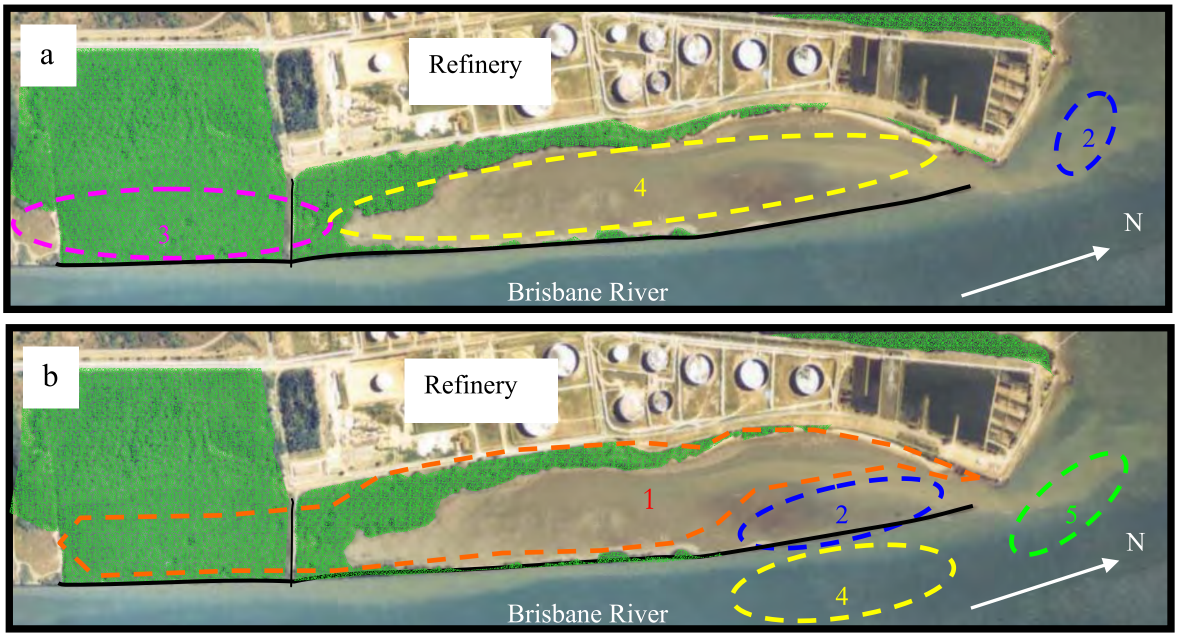
From the changes observed in the aerial photographs (Figure 103), combined with a knowledge of the history of the area, two major types of wetland change can be identified for Bulwer Island. These are: reclamation loss and depositional gains (intentional).

Reclamation loss

The net loss of 136 hectares of wetland between 1946 and 2002 can be attributed to reclamation. The actual loss from reclamation would be slightly higher, as the 'net loss' figure incorporates the small gains in mangrove area on the southern and eastern edges. The greatest change to the original mangrove community occurred in 1962 when the entire northern end of Bulwer Island was reclaimed for construction of the Amoco refinery. The clearing process removed 81 hectares of mangroves and involved two bulldozers with chains dragged between them to completely fell all vegetation. The mangrove vegetation was left on site and fallen trees were covered with sand. Additional areas on the southern end of the island were reclaimed in the 1970's.

Depositional gains (intentional)

This type of change was a variation on the category described in Table 1 in that, at this location, depositional gains were intentional and directly human-related. From the time the training wall was constructed in 1903 until the late 1960's, dredge spoil was used to progressively fill in the areas behind the wall with sediment. Following this active infilling, the land was stabilised and mangroves were able to colonise the new intertidal areas created between the wall and the island (small areas at southern end and eastern edge) and in the passage behind the island that is now known as Boggy Creek. Mangroves that already existed in original stands evidently expanded rapidly into these new sites. Mangroves occupying these areas today were up to around 8-12 m tall and dominated by one species, *Avicennia marina*. Not all of the areas behind the training wall were colonised by mangroves, however, as infilling did not extend to the northern end of the wall as was planned in the early 1900's. This left the intertidal mud flat area readily observed today. In 1898, it appeared that there were natural depth fluctuations of 0.3-2 m below low water (covered at low tide) with very shallow natural mudflats in some areas (Figure 99). As some areas of the mudflat were filled in (Figure 99(b)), mangrove colonisation occurred. Dredging in 1963 reduced the elevation in the northern area of the mud flat to 4 m below low water to provide sand for the filling in of Bulwer Island.



Mangrove

0m 500 m

1	2	3	4	5
▪ 0m + above LWD ▪ Mud at low tide	▪ 0 – 1m below LWD ▪ Water at low tide	▪ 1 – 1.5m below LWD	• 2 – 3m below LWD	• 3.5 – 5.5m below LWD

Figure 104: Depth measurements recorded in: a) 1898 and b) 1963 and applied over a 1997 aerial photograph. (Source: DNRM)

In addition to these two broad types of wetland change detected for the location using aerial photography, more subtle changes to ecological health were observed during field visits to the island. Two different types of sublethal effects were encountered, abnormal root growth forms and albino propagules. Branched pneumatophores, as well as adventitious roots and buttress trunks, were observed to be moderately frequent in mangroves at Bulwer Island, compared to other mangrove forests in Moreton Bay. These root forms could be a result of past oil contamination (Boer, 1993). Buttress roots are often found in areas of increased sediment accumulation (Ellison, 1998) but, at this site, they could be a residual characteristic from when the site was filled in. During another field visit, mutated, ‘albino’ propagules of *A. marina* were identified. This was the first documented observation of mutation for this species and prompted detailed study into the potential genetic degradation in mangrove species following exposure to polycyclic aromatic hydrocarbons (PAH’s). A study by Duke and Watkinson (2002) discussed the high probability of petroleum oil affecting genetic make-up through direct mutation or genetic selection.

5.5.1.2 Focal Point 2 – Luggage Point

Luggage Point is located on the northern tip of the mouth of the Brisbane River (Figure 92). The area is occupied by Luggage Point Wastewater Treatment Plant and point source outlet and Brisbane Airport (Figure 104). The Luggage Point Wastewater Treatment Plant, which discharges its treated effluent into the Brisbane River to the south of the study area, is the largest wastewater treatment plant in Brisbane. Luggage Point also contains areas of wetland habitat. The largest area of mangrove vegetation is located around Jubilee Creek, a small tributary of the Brisbane River, which enters the region from the north. The dominant species of mangrove is *A. marina*, although the occasional *A. corniculatum* is also present. Inland from Jubilee Creek, to the east, there is an extensive saltpan. The saltpan is fringed on its outer edges by salt marsh and then mangrove vegetation. Several patches of these mangroves fringing the saltpan are currently dead or dying. Pools of impounded water have been observed on the outer edges of the saltpan, and large algal mats have been present since 1981 (e.g. Laegdsgaard and Morton, 1998).

Figure 104: Luggage Point, at the mouth of the Brisbane River, is adjacent to a sewage treatment plant and Brisbane Airport.

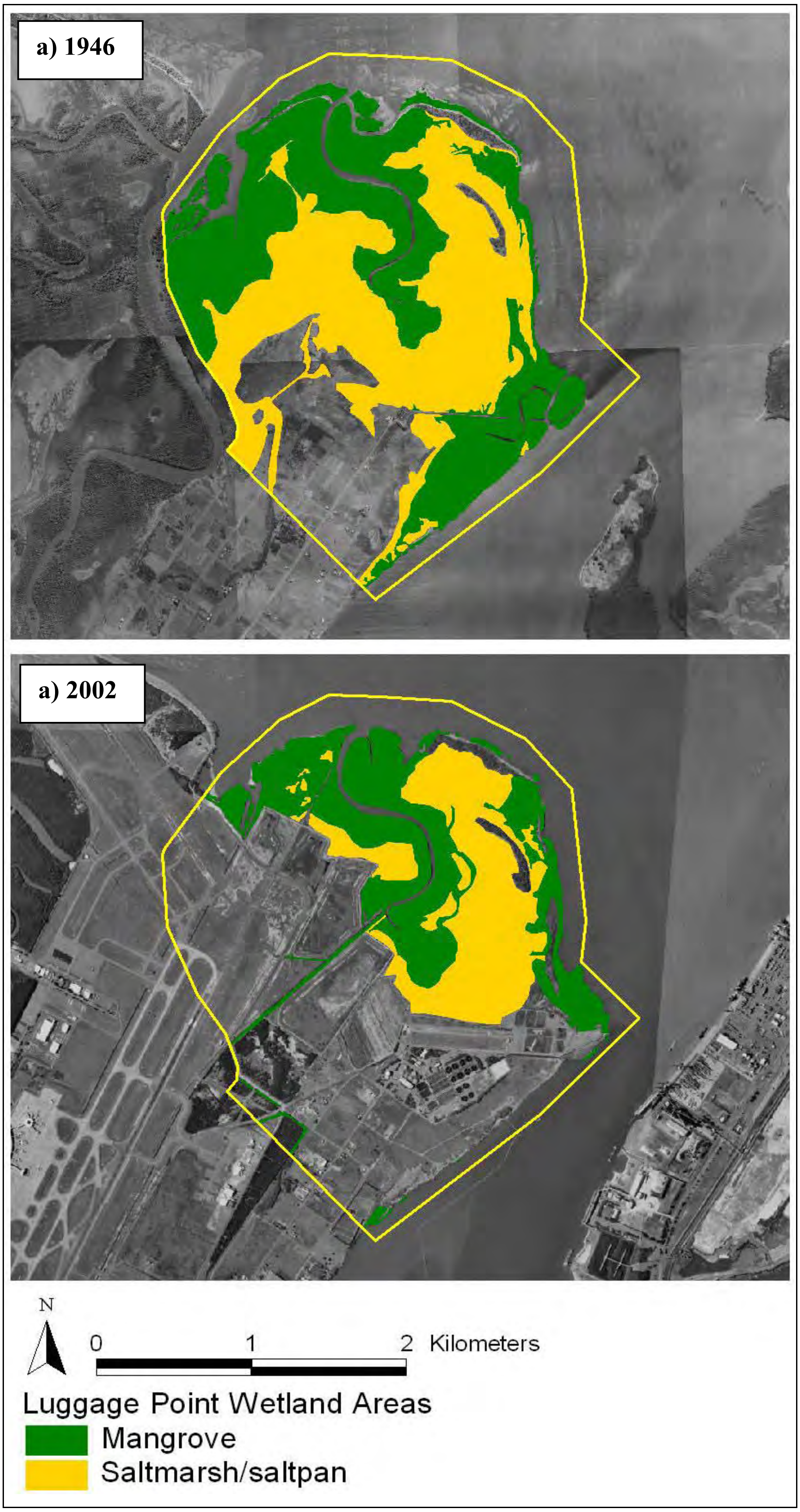
The wetlands at Luggage Point have undergone major change due to development and expansion. Most of this change has occurred since 1981. Major reclamation works for the Brisbane airport began at this time, removing Serpantine Creek and large amounts of mangrove and salt marsh/ saltpan on the northern side of the study area (Laegdsgaard and Morton, 1998). Removal of wetland vegetation on the southern side of the study area took place in the early 1970's, due to reclamation for the augmentation of the wastewater treatment plant (Laegdsgaard and Morton, 1998). The upgraded Sewage Treatment Plant was completed in the early 1980's. Dieback of mangroves to the east of Jubilee Creek, around the saltpan, was reported as especially severe in the period 1983-1987 (Laegdsgaard and Morton, 1998).

Changes to mangroves

Figures 105a) and b) show aerial photographs of Luggage Point in 1946 and 2002 respectively. Figures 106a) and b) are vegetation maps of the location, while Table 22 gives the comparative areas of wetland coverage. Areas of mangrove 'dieback' (losses due to unintentional factors) were identified in the 2002 vegetation map, and were used to differentiate total mangrove loss into that attributable to unintentional factors and that attributable to reclamation. Over the period, net losses of 96 hectares (42%) of mangroves and 177 hectares (65%) of salt marsh/ saltpan were recorded, giving a combined net loss of 273 hectares (54%). The mangrove loss of 81.5 hectares was due to reclamation, while 14.5 hectares was due to dieback (unintentional factors). All of the salt marsh/ saltpan loss was due to reclamation.

From the changes observed in the aerial photography, combined with knowledge of the history of the area, three types of wetland change can be identified for Luggage Point. These are: reclamation loss, restricted tidal exchange and nutrient excess.

Figure 105a) and b). Mosaics of aerial photographs depicting Luggage Point, Brisbane River, in a) 1946 and b) 2002.



Figures 106a) and b). Vegetation map showing mangrove and salt marsh/ saltpan areas at Luggage Point, Brisbane River, in a) 1946 and b) 2002.

Table 22: Area (in hectares) of tidal wetlands including mangroves and salt marsh/ saltpan at the Luggage Point focal point (Brisbane River) in 1946 and 2002.

	Mangrove		Salt marsh/ Saltpan		Total Tidal Wetland Area	
	1946	**2002**	**1946**	**2002**	**1946**	**2002**
Area in ha	231	135	272	95	503	230
Total change in ha from 1946-2002		-96		-177		-273
% Change		-41.6%		-65.1%		-54.3%
Change in ha due to reclamation		-81.5		-177		-258.5
Change in ha due to dieback* (unintentional)		-14.5				-14.5
Source	HC	HC	HC	HC	HC	HC

*The term dieback in this case refers to mangrove dieback that was observed and quantified in the field, from mangroves that have grown since 1946.

Reclamation loss

Loss due to reclamation is the dominant driver of wetland change at this location. Most of the mangrove loss (81.5 ha) and all of the salt marsh/ saltpan loss (177 ha) recorded between 1946 and 2002 were a result of reclamation activities. Major reclamation works for the Brisbane Airport commenced in 1981, and led to large-scale removal of mangroves and salt marsh/ saltpan on the northern side of the study area. Reclamation for the augmentation of the Luggage Point Wastewater Treatment Plant took place in the early 1970s, removing wetland on the southern end of the study area, adjacent to the wastewater treatment plant outlet.

Restricted tidal exchange

The dieback of mangroves that occurred within the period has been attributed to restricted tidal exchange, or impoundment. This amounted to a loss of 14.5 hectares of mangrove. The wetland indicator tool used to identify this type of change relied on both the aerial imagery and field observations. On the aerial photography, mangrove dieback (dead stumps) was apparent in localised upper intertidal pockets, near reclaimed areas. In the field, pooled, impounded water was observed around the dead trees (Figure 107). Signs of a few recently dead trees were evident, although most of the dieback appeared to be part of one, older cohort. The impoundment is believed to have occurred between 1983 and 1987, due to the presence of large algal mats visible in aerial photographs taken at this time (Laegdsgaard and Morton, 1998) and age of the dead trees (Pedersen, 2002).

Figure 107: Pooled, impounded water surrounding dead mangroves at Luggage Point. (Source: Dan Pedersen)

Nutrient excess

The cause of dieback of the mangroves in the impounded areas has been associated with excessive algal growth (Laegdsgaard and Moreton, 1998). As mentioned above, extensive algal mats were evident in aerial photographs taken between 1983 and 1987 (Laegdsgaard and Morton, 1998). The formation of these mats is thought to have smothered pneumatophores of *A. marina* and impounded a localised area through the formation of an algal bund wall, possibly contributing to the dieback, although this has not been confirmed (circumstantial). Mats were also observed during the field visit, covering the water and sediment surfaces around the perimeter of dead areas (Figure 108). It is likely this algal growth was enhanced by the high nitrogen inputs in the area, from the Luggage Point Wastewater Treatment Plant point source outlet.

Figure 108: Extensive algal mats on the surface of the water and covering mangrove pneumatophores at Luggage Point. (Source: Dan Pedersen)

5.2.2 Cobby Cobby Island – Area of Natural Influence

Cobby Cobby Island (27°43'S, 153°23'E) is situated at the southern end of Moreton Bay, southwest of North Stradbroke Island and directly south of Russel Island (Figure 109). The island is approximately 305 hectares in area, of which wetland comprises 240 hectares. The north-western end of the island was hit by a severe hailstorm on September 20, 1997, causing damage to a large amount of vegetation. Hail pellet size ranged between 2-5 cm in diameter. Cobby Cobby Island was chosen for the case study investigating natural change, as it is an undeveloped, removed area, relatively free from direct human influence. The study examines the role natural factors, such as climate change, seal level rise and storm damage, may play in driving coastal vegetation change.

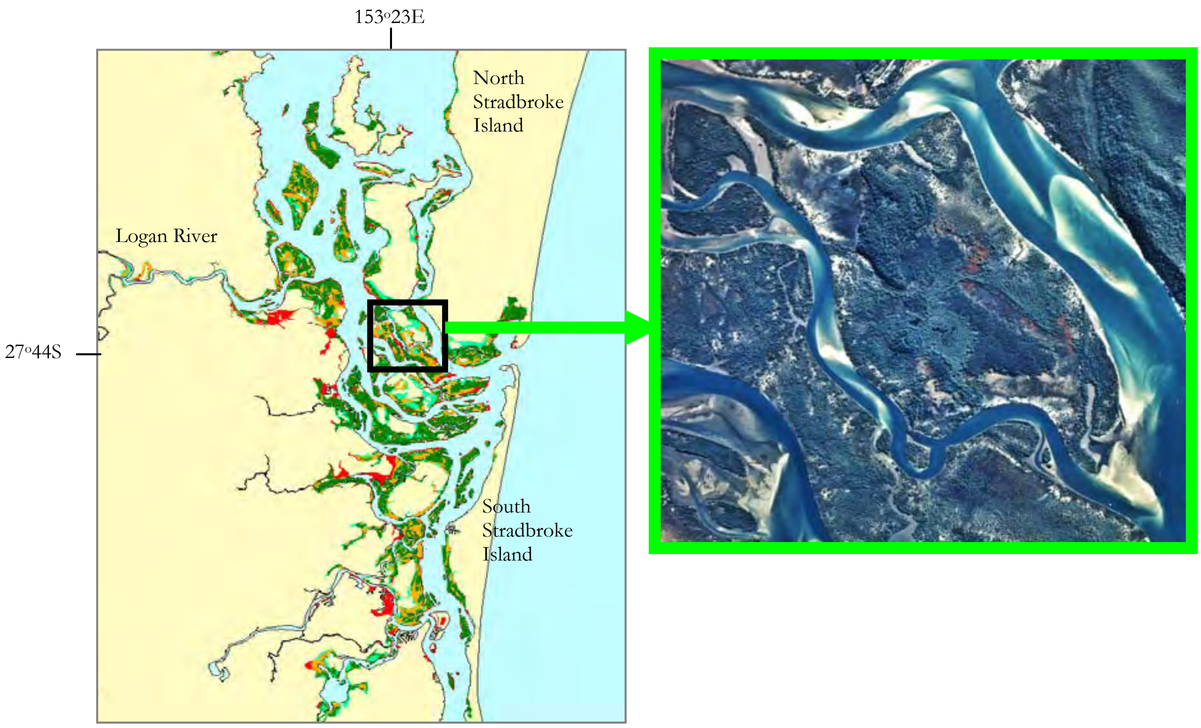


Figure 109: Location of Cobby Cobby Island within Moreton Bay and aerial photograph of the island in 1997.

The study site was selected to encompass a location with a low, gradual rise in elevation, consisting of a terrestrial ‘island’ surrounded by salt marsh/ saltpan and mangrove vegetation. These characteristics allowed detection of subtle shifts in ecotone and encroachment/ dieback processes. Historical aerial photographs of the site were collected for 1944, 1955, 1967, 1973, 1987 and 1997. The 1955, 1967, 1987 and 1997 photography was obtained from the Department of Natural Resources and Mines, while the 1944 photography was purchased from AUSLIG, Victoria. The 1973 photography was obtained from the Queensland Herbarium (Department of Primary Industries). The images were georeferenced to a 1987 geo-rectified image (datum: WGS 84 and projection: Universal Transverse Mercator) of the region, which was obtained from the Queensland Herbarium.

The vegetation categories that were used in this case study were *Avicennia marina* and *Aegiceras corniculatum* (AM//AC), *Avicennia marina* with *Ceriops australis* (AM/ CA), *Aegiceras corniculatum* (AC), *Avicennia marina* (AM), *Ceriops australis* (CA), *Rhizophora stylosa* (RS), salt marsh/ saltpan (SP), *Casuarina* forest (terrestrial) (CR), and terrestrial (except *Casuarina*) (TR).

Field verification (ground truthing) was used to help interpret the imagery and define boundaries (2001). This was achieved by setting transects through the vegetation, and taking GPS coordinates at sites situated on ecotones. In total, 6 transects were conducted, encompassing the widest range of vegetation types possible and representing areas of dynamic change observed in aerial photographs.

As the 1997 hailstorm occurred after the aerial photograph for that year was taken, and no new aerial photographs of the island are yet available, Landsat TM satellite imagery (1999) and hyperspectral imagery (2000) were used to map the extent of damage caused by this event. The total area impacted was calculated by a ground survey, as hyperspectral imagery lacks the fine-scale resolution required for accurate remote analysis. The ground survey involved walking along the perimeter of the hail-damaged area, using hand-held GPS technology to track the entire route. These coordinates were later downloaded and plotted onto a 1997 aerial photograph image of the Island. Area of dieback was determined in ArcView 3.2, using the same technique applied to the digitised aerial photographs (described in Chapter 3).

Findings and Discussion

Figure 110 provides an overall view of all the vegetation maps from 1944-1997, while Figures 111-116 display each map separately, facilitation finer-scale examination and identifying regions of extensive change. Figure 117 shows the extent of damage caused by the hailstorm in September 1997. Table 23(a) presents the areas of the different vegetation types for each year, while Table 23(b) provides a more general comparison by combining the vegetation types into the simplified categories of mangrove, salt marsh/ saltpan and terrestrial.

The maps and areas can be compared to reveal changes in vegetation cover over the period, at intervals of approximately a decade. Between the years of 1944 and 1955, the main change was seen in *A. marina* mangrove coverage, which increased in total area by 8.6 hectares. This occurred through expansion of existing areas and colonisation of a new area on the south-eastern end of the island, shown in Figure 112. Overall, the total areas of the major wetland categories (e.g. mangrove) remained relatively stable over the period, although salt marsh/ saltpan experienced a small decrease in area of 3.4 hectares.

Table 23**a):** Area (in hectares) of tidal wetlands including the different vegetation types on Cobby Cobby Island (Moreton Bay) in 1944, 1955, 1967, 1973, 1987 and 1997.

	Year					
	1944	**1955**	**1967**	**1973**	**1987**	**1997**
Avicennia marina	92.7	101.3	94.1	89.5	98.9	124.3
Aegiceras corniculatum	12.0	11.9	12.7	14.6	9.9	12.7
Ceriops australis	10.9	8.6	8.6	8.7	7.0	7.6
A. marina with *A. corniculatum*	20.9	15.1	15.1	8.7	17.5	11.7
A. marina with *C. australis*	12.5	12.2	9.8	10.7	17.8	12.6
Rhizophora stylosa	4.0	4.7	4.5	4.7	5.0	4.6
Salt marsh/ saltpan	71.6	68.3	86.9	92.2	67.1	64.2
Casuarina (terrestrial)	68.4	67.3	54.2	53.3	48.9	40.4
Terrestrial (except *Casuarina*)	26.4	27.7	27.5	26.8	29.3	26.1

Table 23(b): Area (in hectares) of tidal wetlands including the simplified vegetation categories of mangrove, salt marsh/ saltpan and terrestrial on Cobby Cobby Island (Moreton Bay) in 1944, 1955, 1967, 1973, 1987 and 1997. WCI = Wetland Cover Index (% mangroves).

	Year					
	1944	**1955**	**1967**	**1973**	**1987**	**1997**
Mangrove	152.9	153.8	144.8	136.8	156.1	173.5
Salt marsh/ Saltpan	71.6	68.3	86.9	92.2	67.1	64.2
Terrestrial (*Casuarina* and non-*Casuarina*)	94.8	94.9	81.7	80.1	78.2	66.5
Total Wetland	224.6	222.0	231.6	229.0	223.2	237.7
WCI	68.1	69.3	62.5	59.7	69.9	73.0
Total Terrestrial & Tidal Wetland	319.3	317.0	313.4	309.1	301.4	304.2

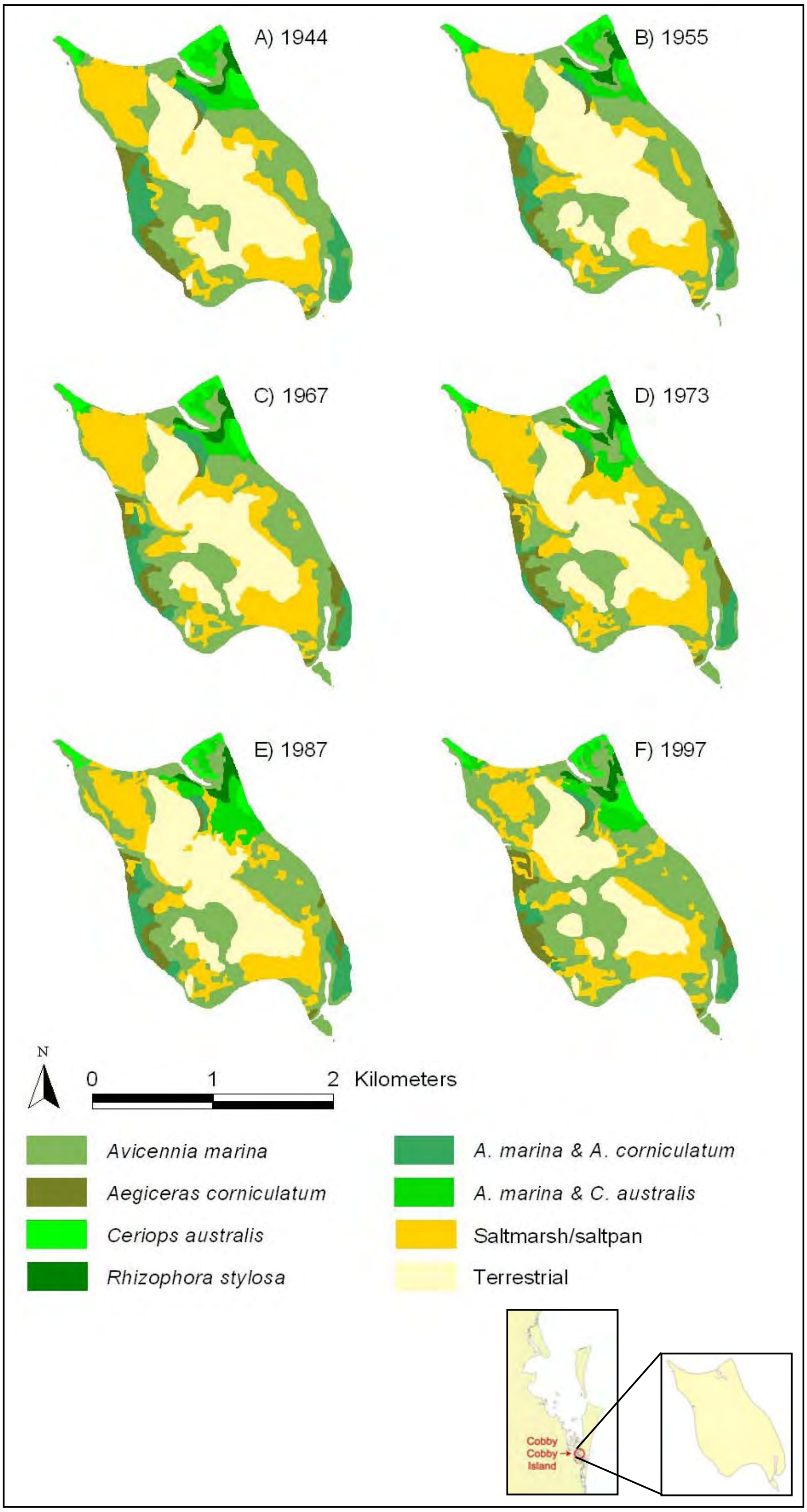


Figure 110: Time series of vegetation maps, showing different vegetation types on Cobby Cobby Island in 1944, 1955, 1967, 1973, 1987 and 1997.

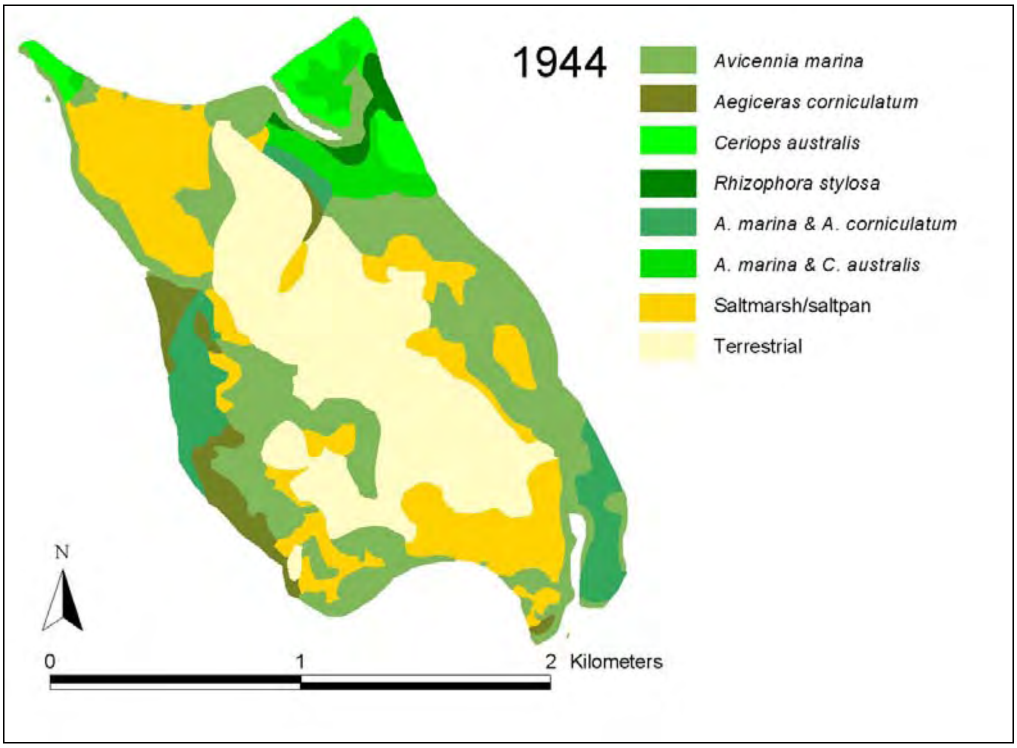


Figure 111: Vegetation map of Cobby Cobby Island in 1944, showing the different vegetation types.

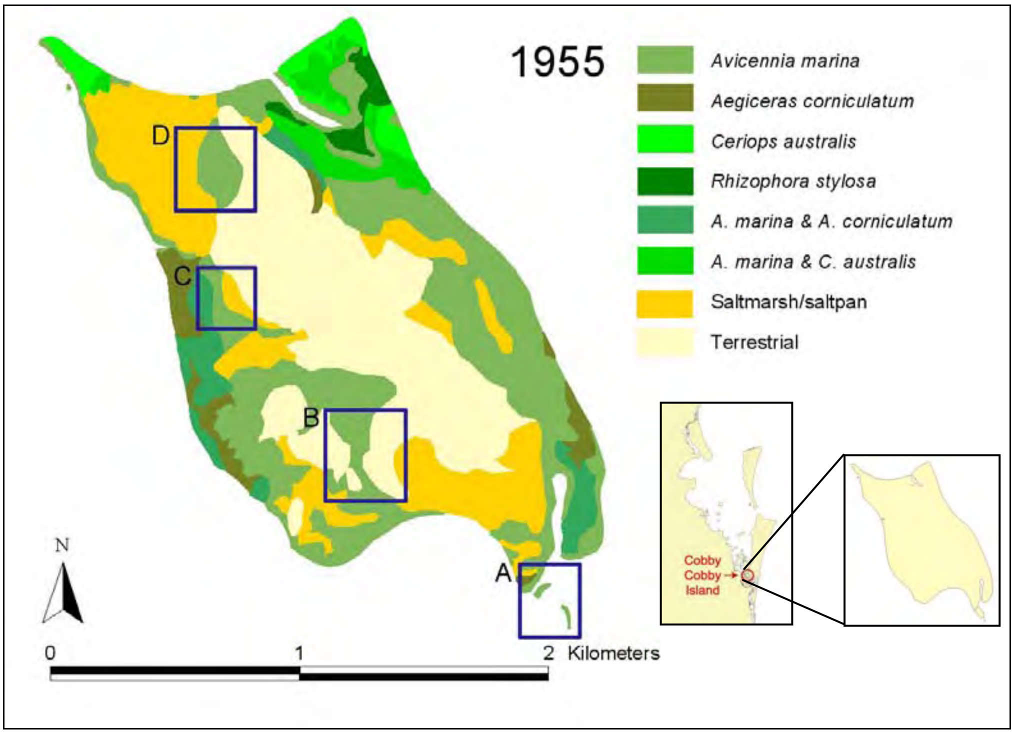


Figure 112: Vegetation map of Cobby Cobby Island in 1955, showing the different vegetation types. Blue-boxed areas indicate regions of extensive change from 1944 until 1955. (A) represents region of colonised *Avicennia marina* - previously this area was unvegetated; (B) represents region of *Avicennia marina* spread through previously salt marsh vegetation; (C) represents region of increased *Avicennia marina*; (D) represents region of increased *Avicennia marina*.

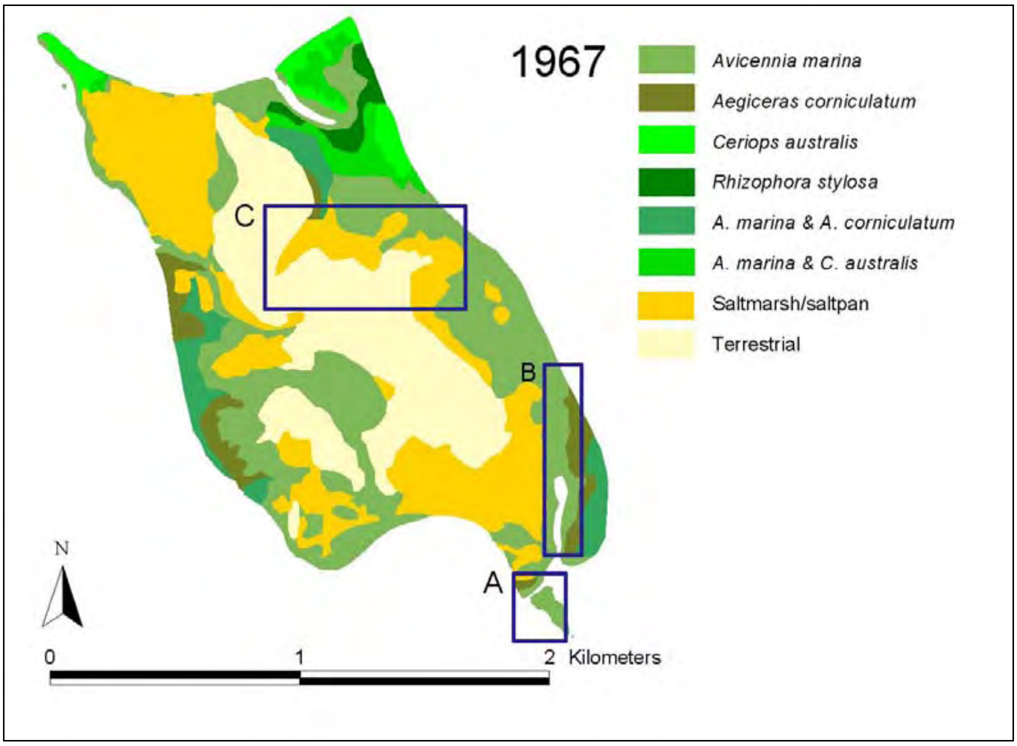


Figure 113: Vegetation map of Cobby Cobby Island in 1967, showing the different vegetation types. Blue-boxed areas indicate regions of extensive change from 1955 until 1967. (A) represents an increase in *Avicennia marina* colonised in this region between 1944 and 1955; (B) represents an increase in the proportion of *Avicennia marina* in a previously predominately mixed *A. marina* and *Aegiceras corniculatum* forest; (C) represents the first evidence of landward intrusion of *Avicennia marina* into terrestrial and salt marsh vegetation

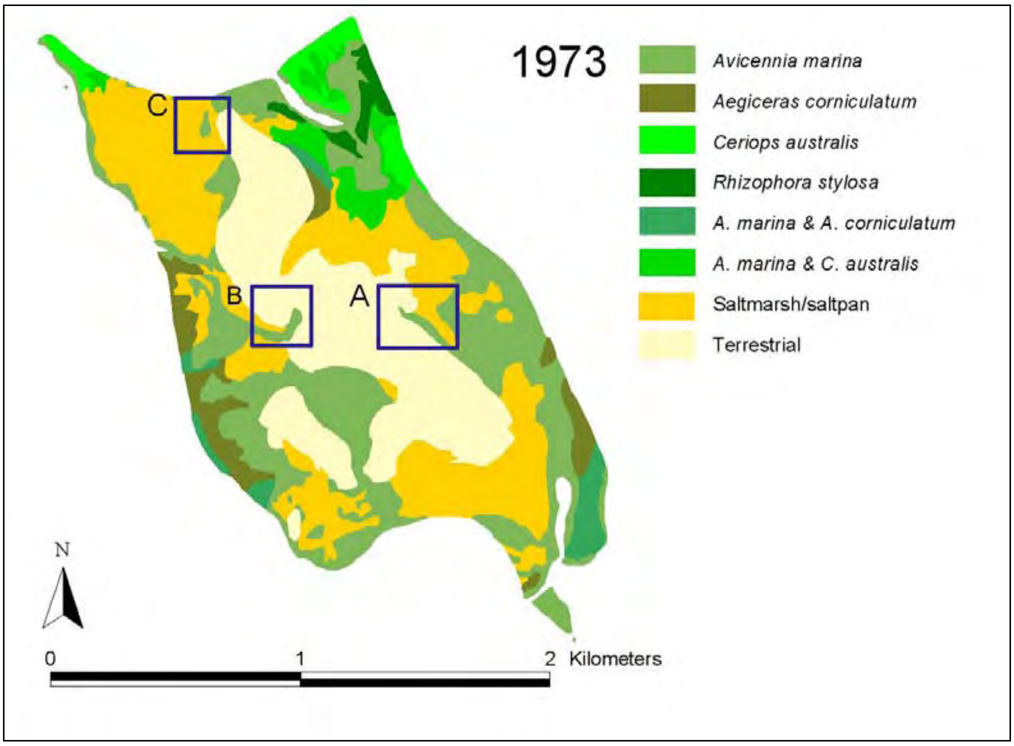


Figure 114: Vegetation map of Cobby Cobby Island in 1973, showing the different vegetation types. Blue-boxed areas indicate regions of extensive change from 1967 until 1973. (A) and (B) represents the continuing central spread of *Avicennia marina* into terrestrial and salt marsh species; (C) represents the increase in *Avicennia marina* into salt marsh regions.

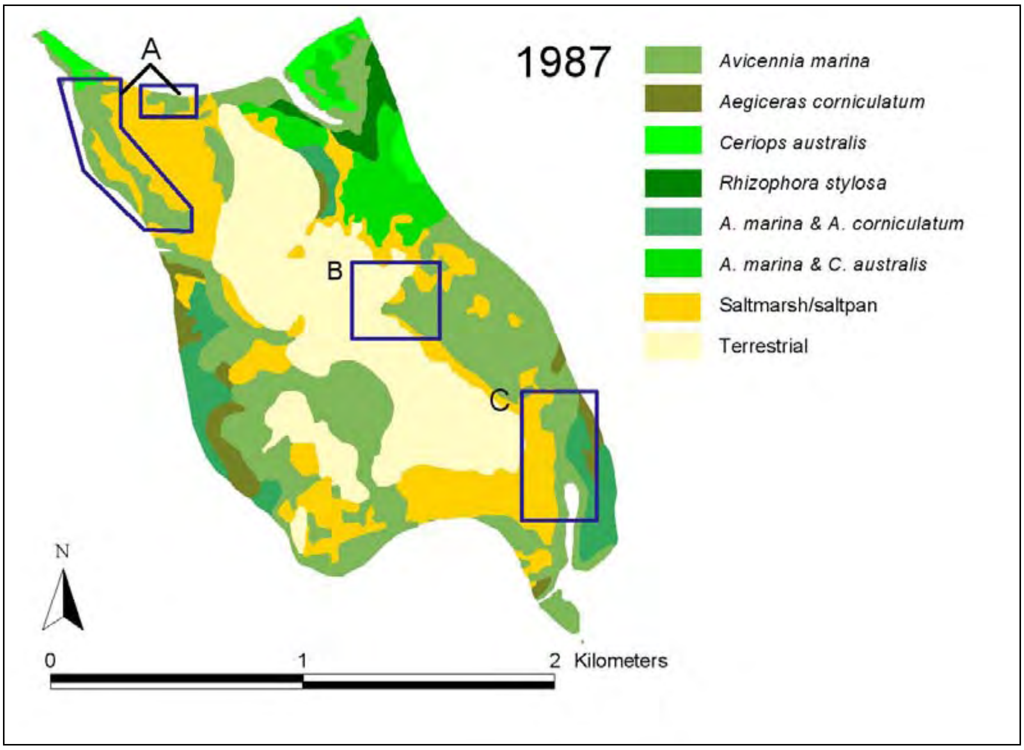


Figure 115: Vegetation map of Cobby Cobby Island in 1987, showing the different vegetation types. Blue-boxed areas indicate regions of extensive change from 1973 until 1987. (A) represents continuation of the intrusion of *Avicennia marina* into salt marsh species also documented between 1967 and 1973; (B) represents the continuing central spread of *Avicennia marina* into terrestrial and salt marsh species; (C) represents the continuation of the increase in *Avicennia marina* composition of the mixed *A. marina* and *Aegiceras corniculatum* forest.

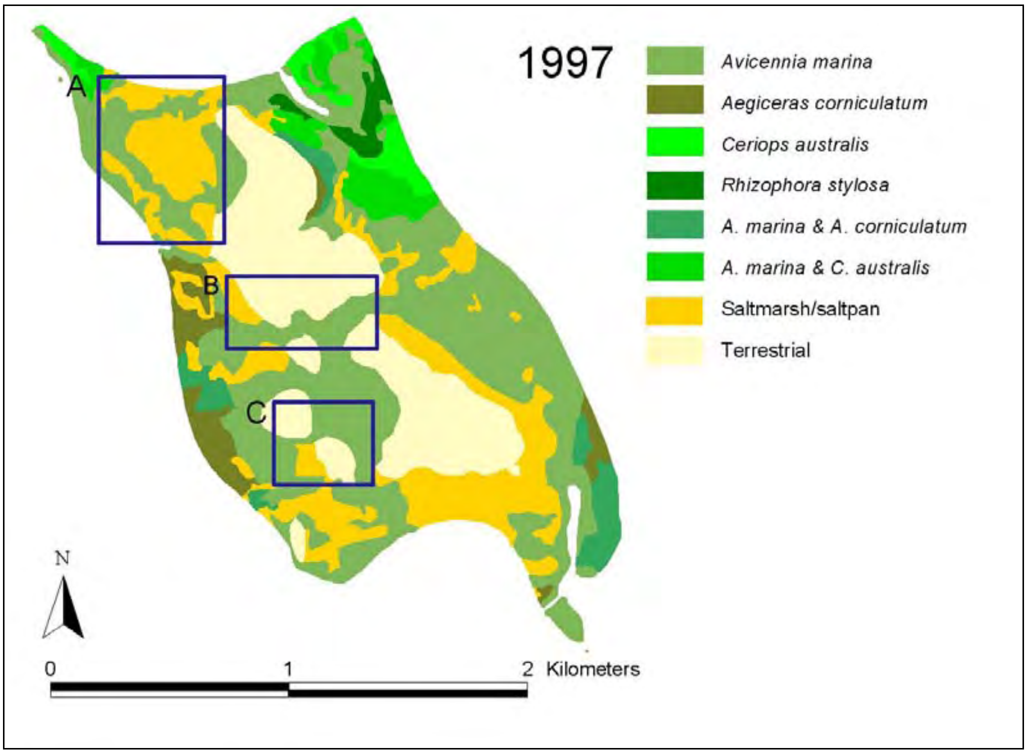


Figure 116: Vegetation map of Cobby Cobby Island in 1997, showing the different vegetation types. Blue-boxed areas indicate regions of extensive change from 1987 until 1997. (A), (B), and (C) represent the continuing central spread of *Avicennia marina* into terrestrial and salt marsh species.

Between the years of 1955 and 1967, a net loss of 7.2 hectares of *A. marina* was recorded, contributing to the overall loss of 9.0 hectares of mangrove vegetation, largely due to replacement by salt marsh species. Nevertheless, increases in *A. marina* were observed in some localised areas, such as in forests located at the south-eastern point of the island. The first evidence of encroachment of *A. marina* into salt marsh and terrestrial environments was also observed over this period. (Figure 113). Salt marsh/ saltpan experienced a large increase in area of 18.6 hectares, also leading to an increase in total wetland area from 222 hectares to 2331 hectares. Most of the increase in salt marsh/ saltpan area occurred at the expense of *Casuarina* vegetation (terrestrial), which experienced a loss of 13.1 hectares.

Again, between 1967 and 1973, there was a net increase in salt marsh/ saltpan area (5.3 ha) and a net decrease in mangrove area (7.9 ha). In terms of species, the main mangrove losses were recorded for *A. marina* (4.6 ha) and *A. marina*/ *A. corniculatum* mixed forests (6.4 ha). Despite these overall losses, there was further encroachment of *A. marina* into central salt marsh/ saltpan and terrestrial areas, and appearance of a mangrove 'pocket' in one of the salt marsh/ saltpan areas (Figure 114).

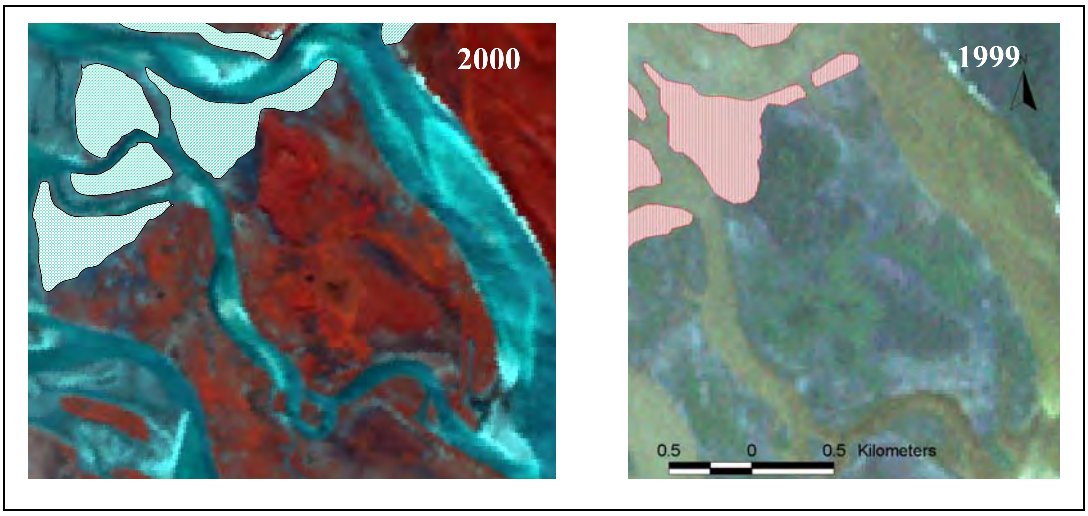


Figure 117: Extent of vegetation affected by the hailstorm that hit Cobby Cobby Island in September, 1997, as shown by airborne hyperspectral MASTER data (August 2000) and satellite multispectral Landsat ETM 7 (December 1999) imagery.

The trend of increasing salt marsh/ saltpan and decreasing mangrove was reversed in the period from 1973 to 1987. A large decrease in salt marsh/ saltpan area (25.1 ha) and a large increase in mangrove area (19.3 ha) were recorded. There was also a large increase in *Casuarina* (terrestrial) area (45.6 ha). Most of the increase in total mangrove area was caused by expansion of *A. marina* and *A. marina* mixed forests. *A. marina*, *A. marina*/ *A. corniculatum* and *A. marina*/ *C. australis* increased by 9.4, 8.8 and 7.2 hectares, respectively. This period saw further intrusion of *A. marina* into salt marsh/ saltpan areas and continuing encroachment of *A. marina* into central salt marsh/ saltpan and terrestrial zones. On the south-eastern side of the island, *A. marina* also spread into areas previously dominated by *A. corniculatum*, leading to an expansion of the *A. marina*/ *A. corniculatum* mixed forest.

Between 1987 and 1997, mangrove area continued to increase, with a net gain of 17.3 hectares. This was mainly due to the large increase in *A. marina* area recorded for this decade (25.5 ha). Salt marsh/ saltpan area experienced a small decrease (2.9 ha), while large losses were recorded for *Casuarina* (terrestrial) area (58.5 ha). Overall, wetland area increased by 14.4 hectares. Examination of the 1987 and 1997 vegetation maps revealed the continued encroachment of *A. marina* into the central salt marsh/ saltpan and terrestrial vegetation. By 1997, *A. marina* had extended all the way through the *Casuarina* forest in the middle of the island, fragmenting the terrestrial zone. Mangrove species also dominated areas along the north-western end of the island, a region previously vegetated by salt marsh species.

Overall, in the entire period between 1944 and 1997, Cobby Cobby Island has experienced a large increase in mangrove area (20.5 ha), a large increase in total wetland area (13.1 ha), a small decrease in salt marsh/ saltpan area (7.4 ha) and a large decrease in *Casuarina* area (28.0 ha). The general trend involved a decrease in mangrove area and increase in salt marsh/ saltpan area until 1973, followed by a large increase in mangrove area and decrease in salt marsh/ saltpan area in the last two decades. *Casuarina* vegetation (terrestrial) decreased gradually until 1973, increased between 1973 and 1987, and then decreased and fragmented greatly in the last decade.

In September 1997, several months after the aerial photograph for that year had been taken, a severe hailstorm impacted a large area of vegetation on the north-western side of the island (Figure 115). Physical effects ranged from leaf damage to tree death. The area of wetland vegetation lost directly from this hailstorm, measured during the field survey, was approximately 44 hectares, comprising 34 hectares of mangrove and 10 hectares of salt marsh. Vegetation affected by the storm included the salt marsh species *Sarcocornia quinqueflora* and *Juncus kraussii*, and the mangrove species *A. marina*, *C. australis* and *R. stylosa*. Approximately 20% of the total mangrove area was damaged on Cobby Cobby Island, with *A. marina* being the species most affected. The damaged sites included both newly developed forest stands of *A. marina* on the central northern area of the island, and mature stands of *C.*

australis and *A. marina* on the north-eastern point. Little or no regeneration of the damaged mangrove vegetation has occurred between 1997 and the present day. Bark damage, dead branches and dead trees remain a substantial characteristic of the affected forest condition and structure.

5.2.2.1 Focal Point 1 – Strips

For the 1944-1997 aerial imagery, vegetation maps were compared between years to detect any incremental or overall landwards or seawards shift in vegetation type. In order to determine more precisely where these shifts had occurred, a remote transect technique was applied. For each of the aerial photographs, a latitudinal strip, approximately 200 m in diameter, was cropped from the photo across the centre of the island. The location of the strip was chosen to encompass a transect carried out by Davies in 1979 (Davies, 1985). Each strip of photograph was georeferenced to another photograph strip georeferenced to the 1997 aerial photograph image (Datum AMG 84, Transverse Mercator).

The categories used were the same as the ones previously for the vegetation maps of the whole island. Separate vegetation maps, using the simplified classifications of mangrove, saltpan/ salt marsh and terrestrial, were also produced, to more clearly depict general trends.

Field verification (ground truthing) was again used to help interpret the imagery and define boundaries (December 2002). This was achieved by setting a transect through the vegetation from the seaward edge to the terrestrial fringe, recording vegetation details and taking GPS coordinates at ecotones. The transect was placed within the area covered by the photographic strips, and along the same path as the 1979 Davies transect, allowing direct comparison of the vegetation profiles.

A change detection analysis, using the simplified vegetation categories of mangrove, salt marsh/ saltpan and terrestrial, was also performed. This identified the location and spatial dynamics of vegetation losses and gains between the years.

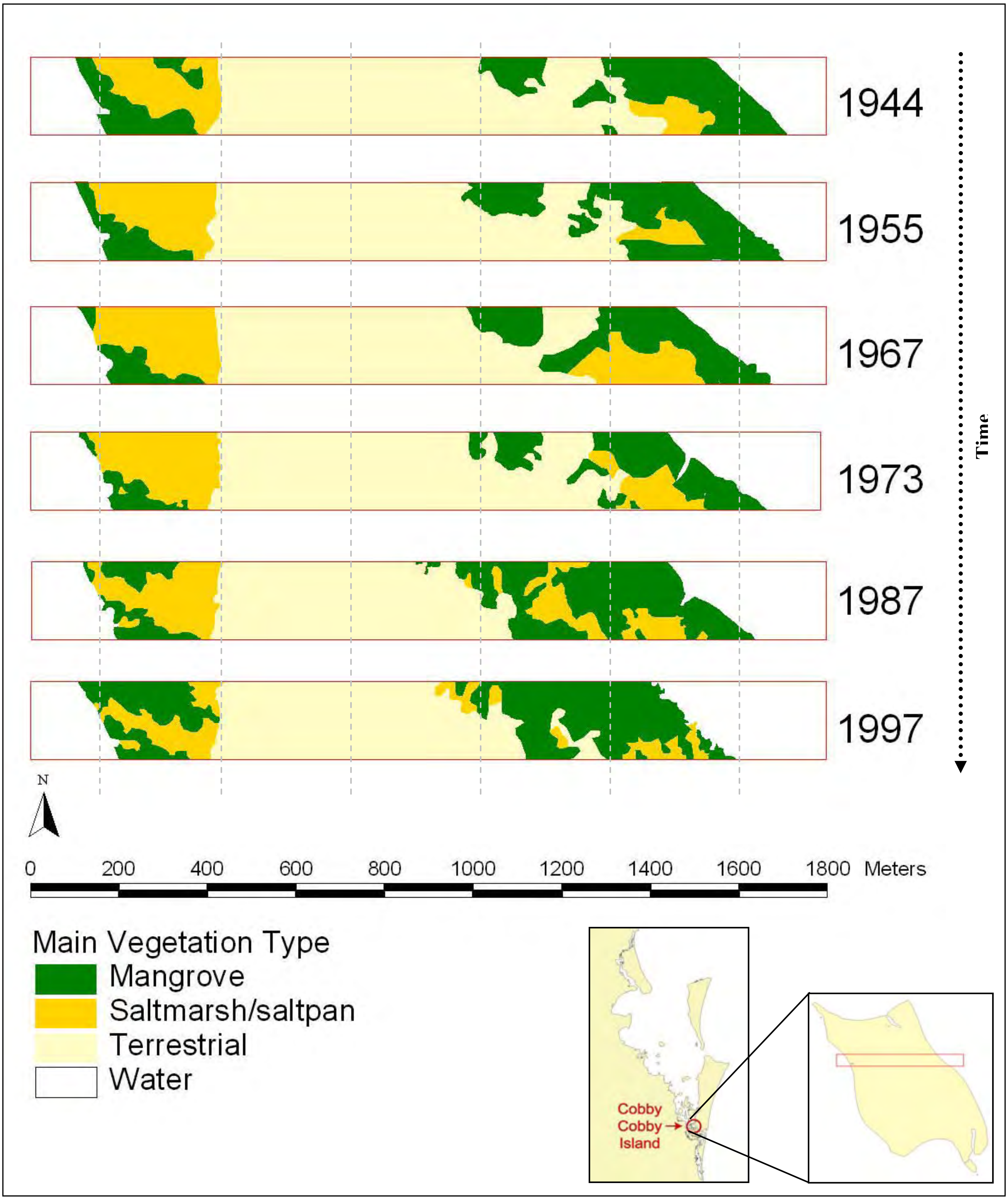


Figure 118: Time series of vegetation maps of transect strips, running through Cobby Cobby Island from western to eastern edge, showing the major vegetation categories of mangrove, salt marsh/ saltpan and terrestrial. Refer to inset for location of transect strip.

Table 24: Area (in hectares) of tidal wetlands including the different vegetation types within the transect strip selected on Cobby Cobby Island (Moreton Bay) in 1944, 1955, 1967, 1973, 1987 and 1997.

	Year					
	1944	**1955**	**1967**	**1973**	**1987**	**1997**
Avicennia marina	5.47	5.84	4.94	3.62	7.63	8.85
A. marina with *A. corniculatum*	1.25	0.93	0.63	1.06	0.48	0.13
Rhizophora stylosa	0.56	0.37	0.48	0.32	0	0
Salt marsh/ Saltpan	3.83	4.10	5.82	5.25	5.18	3.09
Grass (terrestrial)	4.06	0	1.38	2.28	0.90	0.65
Grass/ *Casuarina* (terrestrial)	0	3.43	5.53	5.97	0	0
Casuarina (terrestrial)	4.85	4.80	0	0	3.72	4.51
Eucalyptus (terrestrial)	6.21	6.41	6.24	6.19	6.29	6.31
Water (increase indicates retreating seaward edge)	5.39	5.72	6.79	7.19	7.64	8.31
Total Mangroves	**7.27**	**7.14**	**6.04**	**4.99**	**8.11**	**8.99**
Total Salt marsh/ Saltpan	**3.83**	**4.10**	**5.82**	**5.25**	**5.18**	**3.09**
Total Terrestrial	**15.11**	**14.63**	**13.14**	**14.44**	**10.90**	**11.47**

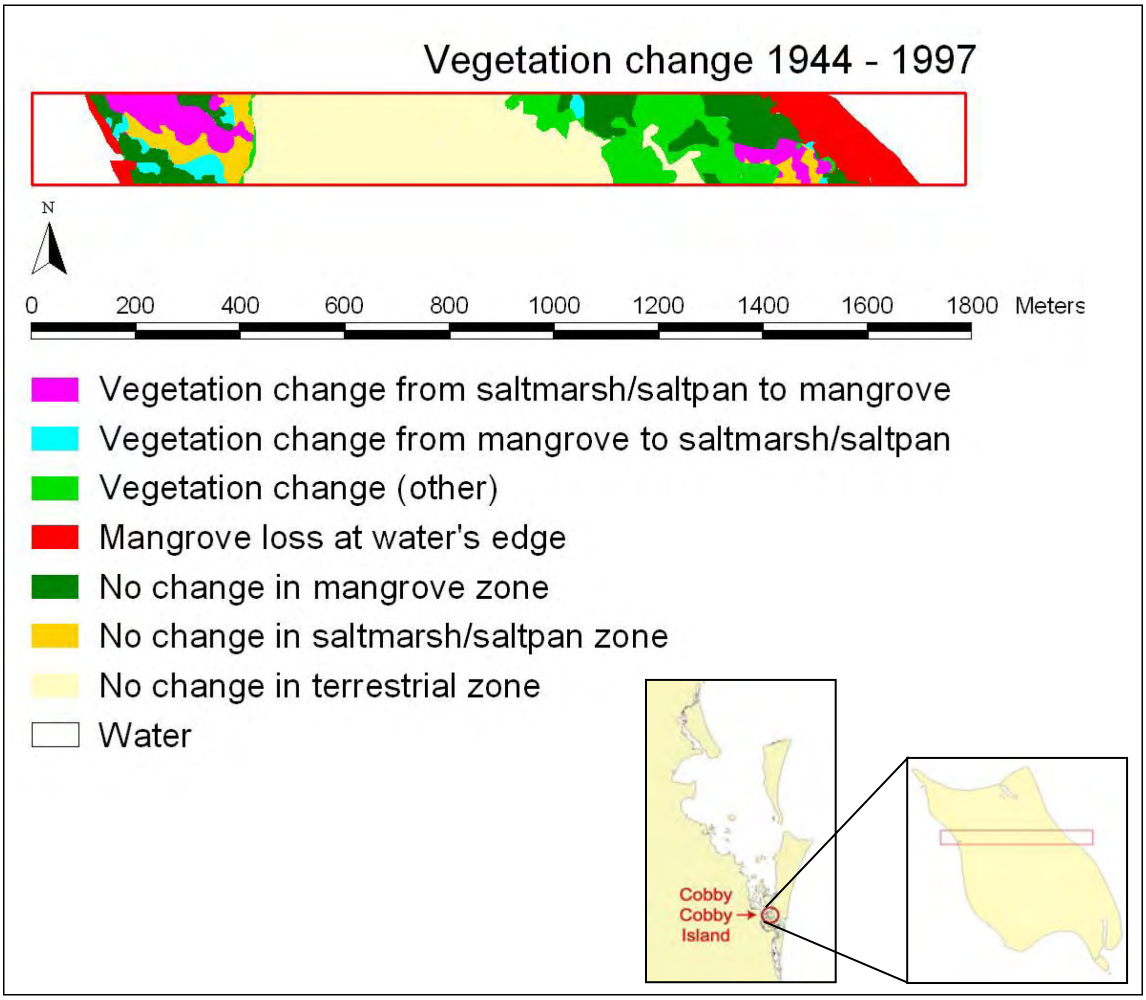


Figure 119: Change detection analysis of transect strips, running through Cobby Cobby Island from western to eastern edge, showing the areas of losses and gains between 1944 and 1997. There was substantial loss of mangrove vegetation from the seaward fringe, particularly on the eastern side of the island. Refer to Figure 119 for location of transect strip.

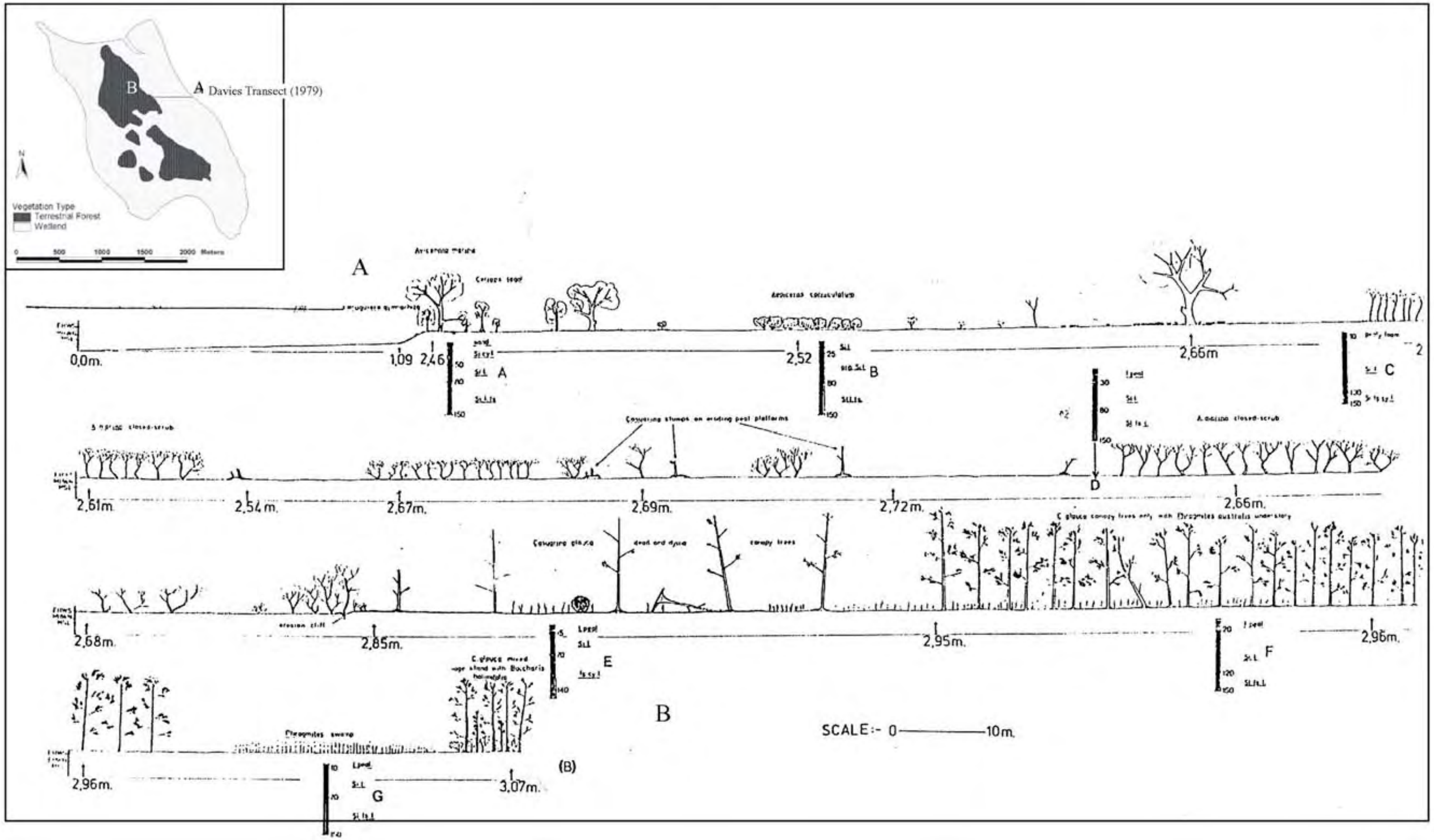


Figure 120(a): Conceptual diagram of a transect conducted in 1979 by Jim Davies depicting wetland and terrestrial vegetation types and zone boundaries on the eastern side of Cobby Cobby Island. (Source: Davies, 1985)

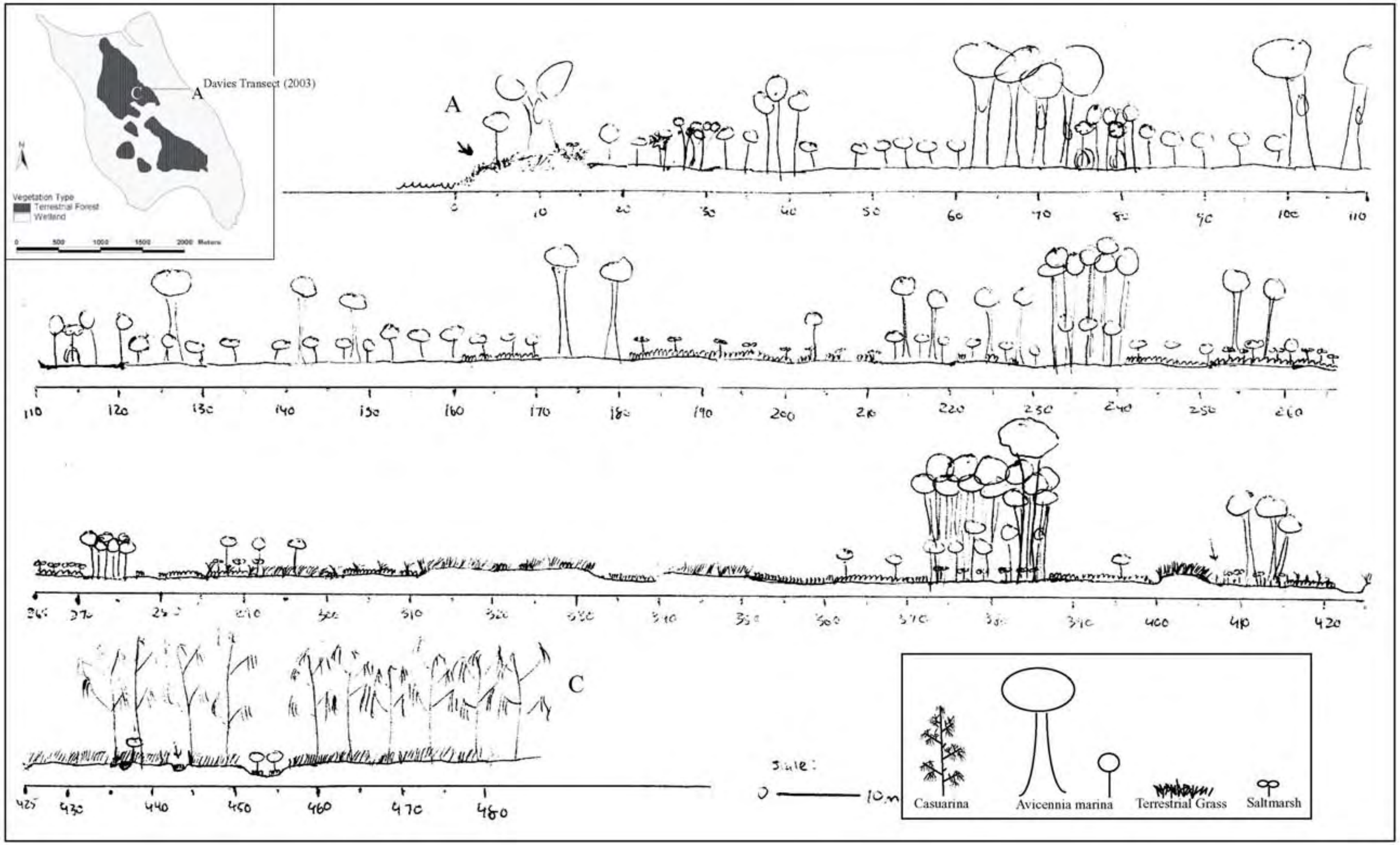


Figure 120(b) Conceptual diagram of a transect conducted in December 2002 along approximately the same path as the Davies (1979) transect, depicting wetland and terrestrial vegetation types and zone boundaries on the eastern side of Cobby Cobby Island, Southern Moreton Bay. This transect differs only slightly from Davies (1979) in its end point (C) – within 50 metres. (Source: Pippi Lawn)

Figure 118 presents vegetation maps of comparable transect strips taken at the same location for the different years, 1944-1997. Table 24 compares areas of each vegetation type within the strips. Figure 119 presents the results of a change detection analysis, showing areas of loss and gain, while Figure 120 compares the 1979 Davies transect with the 2002 Historical Coastlines transect from the same location.

As can be seen from the vegetation maps and table, in the decades following 1944, mangrove area decreased until 1973 and then increased greatly. The greatest change in wetland can be seen in the last two decades, with the large increase in mangrove area, decrease in terrestrial area and small decrease in salt marsh/ saltpan. Encroachment of mangroves at the expense of the other vegetation types can be observed by comparing the vegetation maps.

Another noteworthy change during the study period, revealed by the change detection analysis (Figure 119) and the steady increase in the water zone (Table 24), was the loss of mangrove area from the seaward edge. This loss occurred on both sides of the island, although the loss was greater on the eastern side, where the edge retreated approximately 100 m between 1944 and 1997. Over the same period, the area of terrestrial vegetation steadily decreased (Table 24).

In summary, the chief changes occurring between 1944 and 1997 were: (1) the loss of terrestrial vegetation to mangrove matched with losses of mangrove from seaward margins, and (2) an increase in mangrove vegetation overall.

These findings were also supported by the field data, comparing the 1979 Davies transect with the 2002 HC transect. The profiles were centred relative to each other around the small stand of *A. corniculatum* shrubs, the only clump of this species in the area. Between 1979 and 2002, land was lost from the seaward edge and in 2002, the edge was located inland relative to its original position. Evidence of erosion (e.g. exposed cable roots) was observed at the water-land interface. Near the middle of the transect, areas with dead *Casuarina* stumps in the 1979 profile had been completely taken over by salt marsh and mangrove seedlings by 2002, with no *Casuarina* remaining. Salt marsh and mangrove vegetation extended much further inland in the 2002 profile, having replaced areas previously occupied by *Casuarina* (both dying and healthy in 1979). During the 2002 field survey, mangrove shrubs and salt marsh pockets were observed growing up amongst *Casuarina* trees in the outer edge of the terrestrial forest. Evidence of the continued dieback of the terrestrial fringe was also found, with dying and dead *Casuarina* trees photographed at the wetland-terrestrial interface near the transect site (Figure 121).

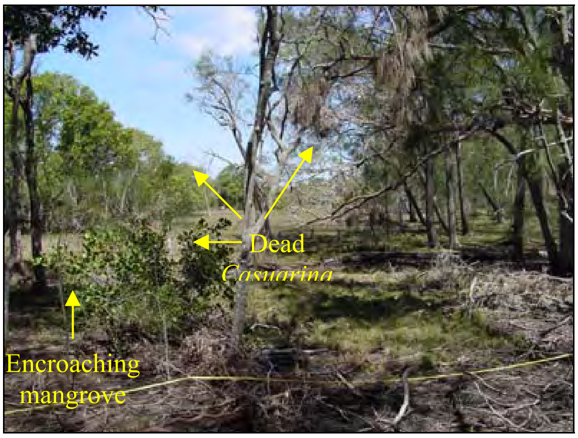


Figure 121: Dying and dead *Casuarina* trees were observed at the wetland-terrestrial interface on Cobby Cobby Island.

Types of change

The current study has presented specific and detailed evidence of change in mangrove and associated vegetation on Cobby Cobby Island over the period 1944 to 1997. Analysis of the dynamic shifts in vegetation that have occurred on the island has provided the rare opportunity to study the effects of natural factors on wetland change. Overall, three main types of change have been identified for the location. These are: storm damage, ecotone shift and zonal shift.

Storm damage

Loss of wetland due to storm damage resulted from a severe hailstorm, which hit Cobby Cobby Island on September 20, 1997. The storm was sufficiently forceful to remove in one day the same area of mangroves gained over the previous 50 years by 'natural' accretion and progressive long-term change. In total, 44 hectares of wetland were damaged on the northern end of the island, comprising 34 hectares of mangroves and 10 hectares of salt marsh. Impacted mangrove areas on the island showed few signs of recovery after five years and there was little or no recruitment. This illustrates the dramatic, sudden and localised impact that storms can have on wetland habitats.

Ecotone shift

Shifts in ecotones, due to changes in climate, have been discussed in the first chapter. A correlation between rainfall and proportion of mangroves was described, such that tidal wetland areas with the greatest proportion of mangroves are found in wetter climates. The wetland cover index (WCI), a measure of the percentage of total wetland are occupied by mangroves, is used as the indicator in this assessment. The WCI may be used as a descriptor of the relationship between rainfall and wetland composition, and may explain the driver of some types of natural change. As shown in Table 16, over the entire 1944-1997 period, there was a net expansion of the mangrove component within the intertidal zone, and the WCI increased from 68.1 in 1944 to 73.0 in 1997. This implies there may have been a trend towards wetter conditions in the region. Long-term rainfall data from the region shows a long-term increase in average annual rainfall between the 1940's and the 1990's when examining the moving average (based on a 30-year time period) (Figure 122).

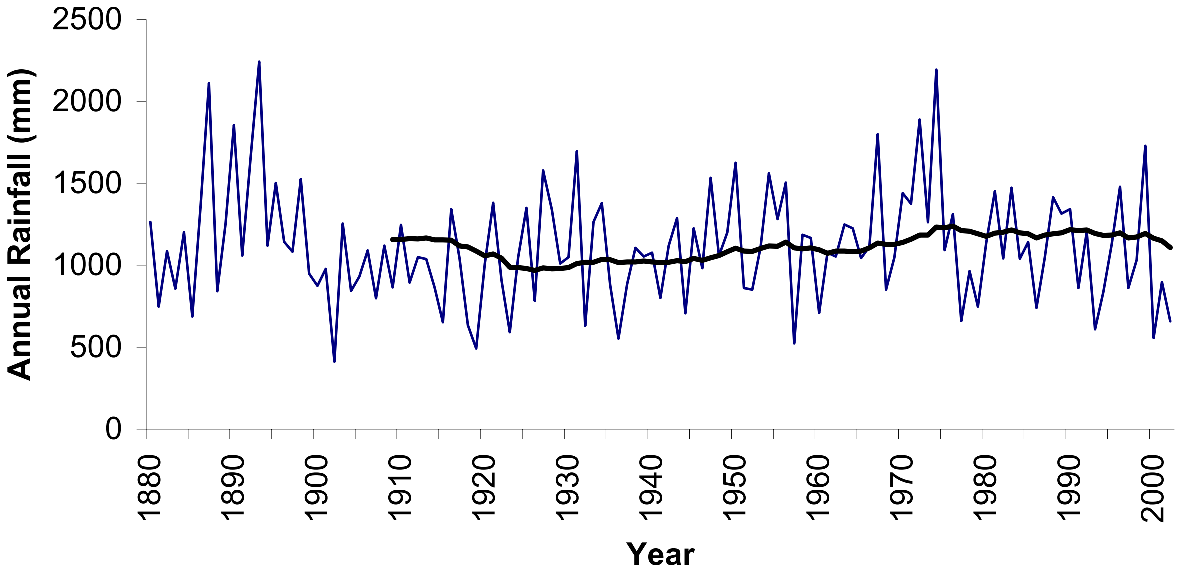


Figure 122: Annual rainfall in Brisbane, 1880 to 2002. Black trendline represents the moving average over a 30-year time period. (Source: Bureau of Meteorology Australia)

A period of drier years preceded the 1940's and a period of wetter years preceded the 1990's. If the data are grouped over 50 year periods, the average annual rainfall for the 50 years preceding 1944 was 1022 mm, compared with 1163 mm for the 50 years preceding 1997. This overall trend supports the hypothesis that the increase in the proportion of mangroves over the period may be linked to climate change, in this case an increase in rainfall. The trend is not so apparent, however, on a finer scale, when comparing WCI and rainfall patterns at each interval between 1944 and 1997. Figure 123 shows average annual rainfall, based on a 30-year moving average, plotted with WCI values for each of the years examined between 1944 and 1997. The pattern of WCI values commences with moderately high values in the 1940's and 1950's, followed by a decrease, followed by a large increase in the last two decades. Although this roughly follows the same pattern as average annual rainfall (small peak, trough, large peak), it does not fit exactly, particularly at the 1973 point, where a low WCI coincides with high average annual rainfall.

Figure 123: Average annual rainfall in Brisbane (black trendline), based on a 30-year moving average, plotted with WCI values (pink dots) for each of the years examined between 1944 and 1997. (Source: Bureau of Meteorology Australia; HC)

The lack of a straightforward relationship may be due to interference by other factors at this location, such as latitude and temperature. The WCI-rainfall relationship has been developed based on data from lower (more tropical) latitudes, and may not be directly transferable to locations at higher latitudes, such as Cobby Cobby Island. Furthermore, the relative proportion of mangrove vegetation within the wetland zone is thought to be influenced not only by rainfall, but also by temperature (Fosberg, 1961; Hutchings and Saenger, 1987). Relatively greater proportions of mangrove and less salt marsh are found in both wetter and warmer environments of the wet tropics. A check of the long-term temperature record for the region shows a gradual increase in minimum temperature (Figure 124). Finally, the relationship between ecotone shifts and climate change is further complicated at this location, due to the co-existence of zonal shifts. The effects of zonal shifts, caused by sea level change, will be discussed below.

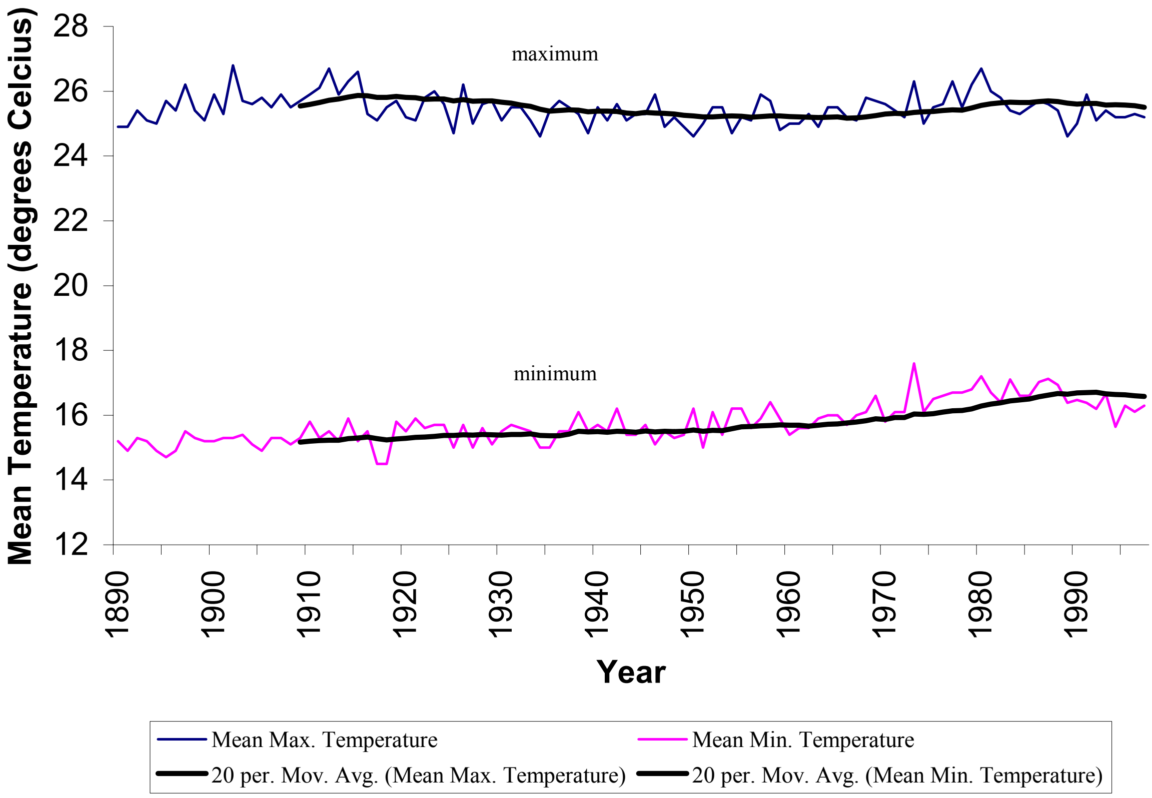


Figure 124: Average annual maximum and minimum temperature for Brisbane, 1890-1997. Black trendlines represent the moving averages over a 20-year time period. (Source: Bureau of Meteorology Australia; HC)

Zonal shifts

Zonal shifts in wetland vegetation, suggestive of sea level rise, were detected on Cobby Cobby Island. Wetland habitat was lost from the seaward margin, while mangrove encroachment and terrestrial dieback was observed at the landward fringe of the tidal zone. Admittedly, some of the loss of the seaward margin could be alternately explained by erosion from boat wash, particularly on the north-eastern side of the island. However, the occurrence of comparable losses on the western and southern sides of the island, where there is less boat traffic, and the accompanying inland shift of wetland at terrestrial margins as observed in the transects, lends support to the sea level rise hypothesis (Figure 125). In all, there was a net shift inland of the mangrove/ salt marsh zone, although the landward margin shifted proportionally further inland, with extensive encroachment into low lying terrestrial habitat, increasing the area of the wetland zone. Differences in the extent of the shifts may be explained by the variability in topographic profiles, where a steeper profile will show less of a spatial change in remote imagery (Figure 119).

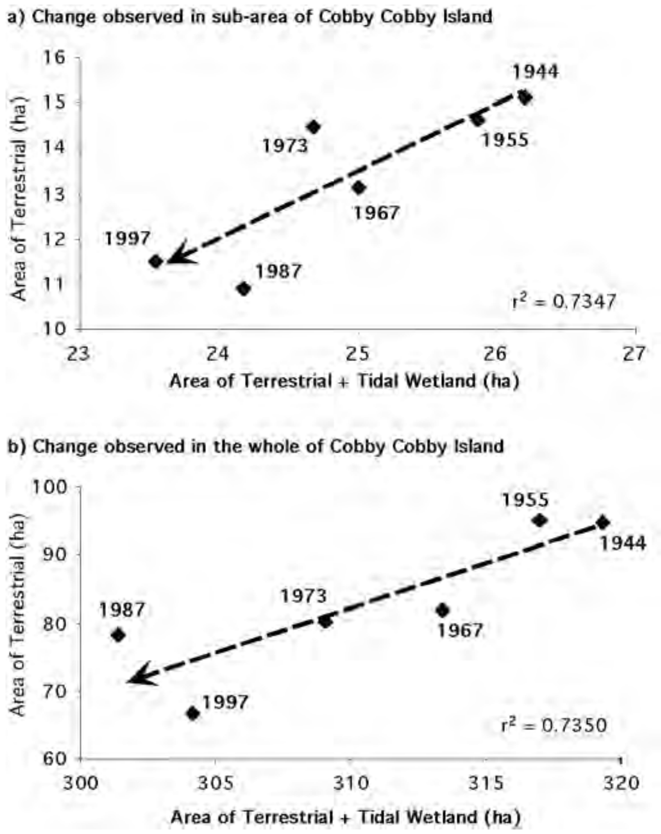


Figure 125: Evidence supporting possible local sea level rise in southern Moreton Bay, on Cobby Cobby Island, from 1944 to 1997; **(a)** shows changes observed in the sub area of Cobby Cobby Island (strips), and **(b)** shows the changes over the whole of Cobby Cobby Island. Both (a) and (b) demonstrate progressive and corresponding shifts in both seaward and landward margins of the tidal wetland (mangrove-salt marsh-saltpan zone).

It is not clear whether the effects observed on Cobby Cobby Island are localised or characteristic of the wider region. If the trend of increase in sea level is, indeed, regional, the implications are immense. Currently, there are no comparable observations published from studies elsewhere.

7. Conclusion

Comparing Tidal Wetlands of the three Regional Study Areas

Tidal wetlands of Moreton Bay, Port Curtis and Fitzroy River regions are characterised and influenced by different environmental and climatic conditions. The chief characteristics of the three study regions are listed in Table 25. Each have quite different sized catchments varying from the vaste Fitzroy River Basin catchment in central Queensland, to the moderately large area of the Moreton Bay region catchment (consisting chiefly of 4 distinct river catchments – Brisbane, Logan, Pine, Caboolture), to the much smaller catchment of the Port Curtis region (consisting chiefly of 2 distinct river catchments – Calliope, Boyne). Despite these differences, there are notable patterns which reflect both natural and human influences on tidal wetland vegetation. It is important to distinguish between these types of change and their relative importance so adaptive management strategies might be applied effectively both ecologically, socially and economically.

Table 25. Current extent of tidal wetlands of Moreton Bay, Port Curtis and Fitzroy River regions around 2000. Area estimates based on DPI data for specific regional areas defined in the study area assessments (Chapters 4, 5 & 6).

	Fitzroy River Estuary	Port Curtis	Moreton Bay SE Queensland
Major Catchment Area (km^2)	+145,205	+4,374	+21,220
Latitude South for general area	23.4° S	23.8° S	27.5° S
Average Max. Temperature (°C)	28.2	27.6	25.4
Average Min. Temperature (°C)	16.5	18.5	15.7
Mean Annual Rainfall (mm)	820	928	1185
Mangrove Taxa	16	14	8
Mangrove (ha)	20,800	2,369	14,386
Saltmarsh/Saltpan (ha)	30,158	2,510	2,522
Total Tidal Wetlands (ha)	50,959	4,879	16,908
WCI	40.8*	48.6*	85.1*

Genetic diversity, measured in terms of species numbers, is notably highest in the warmer latitude regions. Lower temperatures generally limit genotypic diversity, notable with the fewer species the Moreton region (Duke et al., 1998; also see Table 25) compared with the other two regional areas. There has been no evidence of genetic decline, or loss of diversity of vegetated cover in any of the three study regions. However, is it of notable interest in the Moreton Bay Region of two indications of potential effects on diversity from both natural factor and a human related factors. In the first case, severe storm effects may have influenced species composition of mangrove forests. This is evident where *Avicennia marina* was favoured over many other mangrove species since it can respond and recover more readily from serious physical damage. This species dominates the region, and other species which dominate elsewhere, like *Rhizophora stylosa*, are both poorly represented and have more diminutive growth forms. Secondly, *Avicennia marina* and other species there, have a lethal genetic mutation correlated with the presence of hydrocarbons in the sediments.

Table 26. Diversity of mangrove species in tidal wetlands of Moreton Bay, Port Curtis and Fitzroy River regions (see Duke et al., 1998). Dominant taxa in each region are indicated with bold underline.

	Fitzroy River Estuary	Port Curtis	Moreton Bay SE Queensland
Acanthus ilicifolius	X		
Acrostichum speciosum	X	X	X
Aegialitis annulata	X	X	
Aegiceras corniculatum	X	X	X
Avicennia marina	X	X	**X**
Bruguiera exaristata	X		
Bruguiera gymnorrhiza	X	X	X
Ceriops australis	**X**	**X**	X
Excoecaria agallocha	X	X	X
Lumnitzera racemosa	X	X	X
Rhizophora stylosa	**X**	**X**	X
Osbornia octodonta	X	X	
Pemphis acidula	X	X	
Scyphiphora hydrophyllacea	X	X	
Xylocarpus granatum	X	X	
Xylocarpus mekongensis	X	X	

The tidal wetlands of Moreton Bay, Port Curtis and Fitzroy River regions have different complements of mangrove species. This is shown in Table 26 comparing lists of mangrove species in each region. Generally, species numbers follow a decline from northern to southern locations, generally acknowledged to be influenced by corresponding declines in air temperature. Dominant taxa also vary from *R. stylosa*-*C. australis* in northern regions to *A. marina* in the south.

Rainfall amounts and longer-term patterns varied between regions (Fig. 126). Reported mean annual rainfall was least in the Fitzroy region and greatest in the Moreton Bay region. A longer term decline was evident in the Fitzroy region and was supported by the linear trendline with slope of -2.55 overall, and closely corresponding with the 20 year running average. The decline was therefore progressive over the last century. Other regions showed only slight if any overall declines in rainfall. Rainfall was more or less constant in the Port Curtis region, however in the Moreton Bay region , the 20 year running average rainfall showed relatively broad fluctuations. These data identify a long dry period from 1910 to 1945 to a period of relatively high rainfall from 1970 to 1995. The variation from high to low levels of rainfall in the 20 year running average amount to around 500 mm, being ~38% of the total rainfall for the region.

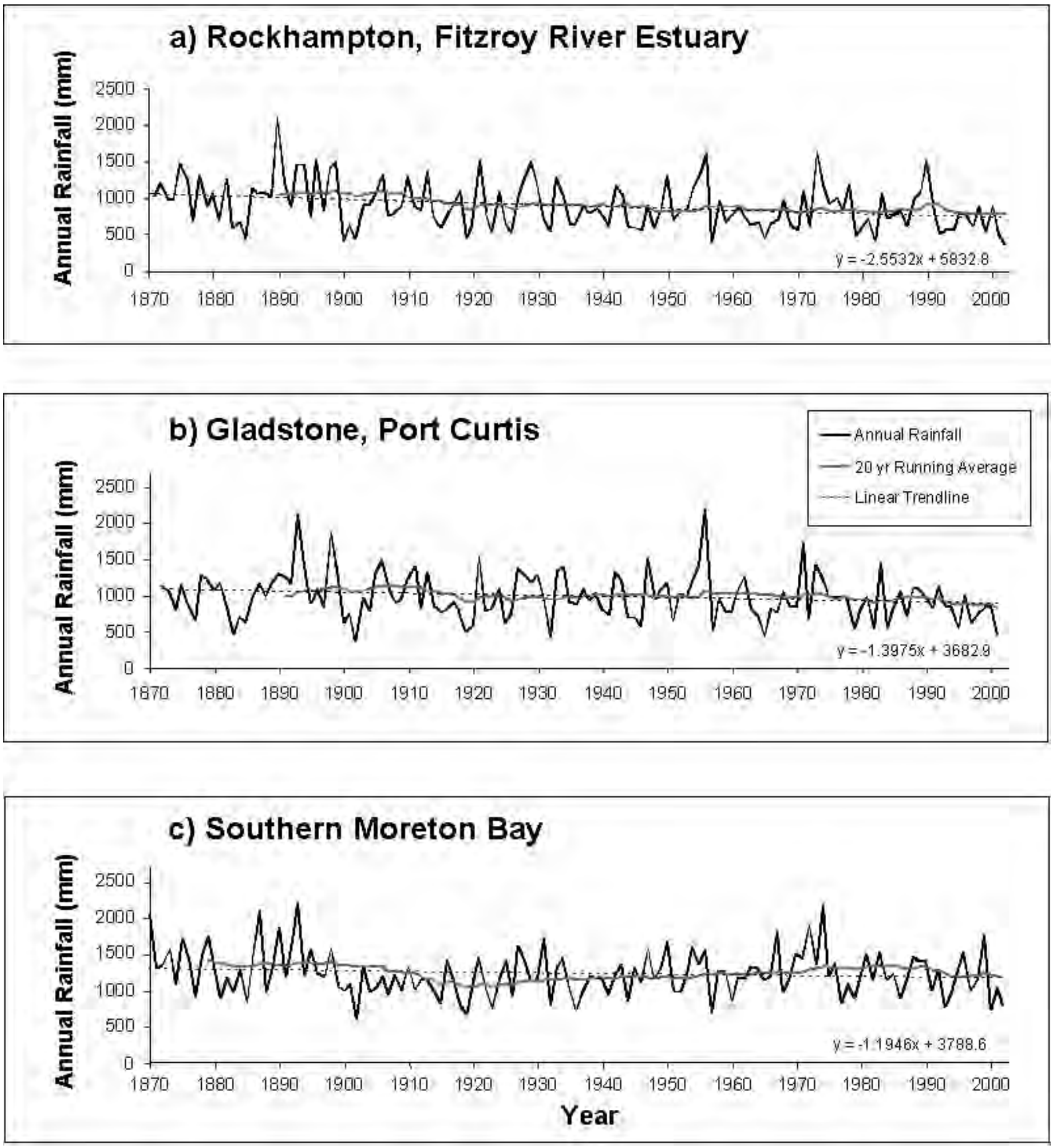


Figure 126. Plots of annual rainfall (1870-2002) for the study regions of (a) Fitzroy River Estuary (Rockhampton Aero, Rockhampton PO & Port Alma), (b) Port Curtis (Gladstone Aero) and (c) Southern Moreton Bay (Russell Island, Rocky Point & Brisbane) assessed in this report. Data was supplied by the Bureau of Meteorology, Brisbane Office.

The extent of tidal wetlands is largely dependant on the respective catchment size, but the biomass of vegetation depends more on annual rainfall. The amount of biomass was chiefly correlated with the extent of mangrove vegetation since trees have greater mass than the more diminutive saltmarsh, consisting of shrubby monocots and grasses. In the classification used in this assessment, saltmarsh has been grouped with saltpan areas. Saltpans have been nominally classified as vegetation-free zones in the past (ala. Fosberg, 1961), but this does not account for the prolific benthic microalgae which inhabit the surface layers. These algae flourish seasonally during periods of higher rainfall when they form extensive green mats up to 1 cm thick.

The larger catchment of the Fitzroy may also have some influence on the higher number of species, but the catchment size factor was considered of secondary importance regards the amount of vegetative cover. Vegetative cover appears to depend more on rainfall. As part of this assessment, the relationship between mean annual rainfall and the Wetland Cover Index (WCI) was proposed as a convenient quantitative measure of vegetative condition for tidal wetlands. Index estimates were positively correlated with rainfall, as discussed previously (see Chapter 1). However, overall regional estimates, shown in Table 1, were not considered accurate indicators of rainfall condition since other important types of change, like 'reclamation loss', and 'depositional gains and losses' would effect the proportions of vegetative cover. The combination of types of change in these wetlands provide insights into the different drivers acting in respective regional areas.

In this treatment, we introduce and propose a selection of indicators for evaluation of the types of change. These indicators include field observations in combination with remote sensing parameters. The key indicators most relevant to change in each region were identified. Some may apply more widely, but in most cases, the types of change may be ranked based on the area or percent coverage. For ecotone shift, we have quantified this effect using the Wetland Cover Index for areas of little or no human influence (direct or indirect). Wetland habitats were expected to integrate and combine a variety of influencing factors over longer-term periods in their composition, structure and distribution.

The indicators described in this study take advantage of the special characteristics of tidal wetlands in general. For instance, mangroves were expected to show their response to climate change in fluctuations in vegetative ecotones, or zonation patterns, across tidal profiles. Furthermore, tidal wetlands might also show their response to sea level change with corresponding and unidirectional shifts in sea and land margins. For instance, an appropriate research and monitoring strategy might use mangrove forest transect plots to quantify human impacts and changes in climate and sea level. Quantification will be supported further by using remote sensing

– comparing historical aerial photographs retrospectively to assess change over the last half century, and to link these findings with current imagery confirming prior condition as the baseline for future ongoing monitoring and assessment.

The relative extent and importance of the major types of change are shown in Table 3 comparing each of the three regional study areas. There were both human and natural disturbances affecting tidal wetland habitats of each region. Each may have notable longer term consequences. Changes were observed as both overall gains and losses in wetland habitat. The benefits of distinguishing between the different impacts and types of changes aids quantification of the dominant and moderate drivers of change which characterize each region.

Dominant influences

The dominant driver of change in tidal wetlands in Moreton Bay and Port Curtis regions has been Reclamation Loss, directly affecting more than 2,200 ha and 1,600 ha respectively. This shows that ~13% and ~33% of tidal wetlands in these regions have been converted to other use over the last 60 years. These other uses is partially location dependant where losses were largely due to port and industrial development in the Port Curtis region, while in the Moreton Bay region losses included airport construction and canal estates. By contrast, the dominant driver in the Fitzroy River estuary region had been Depositional Losses and Gains which increased the net area of tidal wetlands by 860 ha, or ~2% of the total. These changes were likely due to land use changes in the catchment, in conjunction with changes to the hydrology of the river. Considerable efforts were made to improve the navigation of the river from the late 1800s up until the 1960s (Webster and Mullins, 2002). These efforts involved the construction of river training walls, channel dredging, bank excavation and landfill. The combination of these alterations to the river channel are expected to have changed the hydrology, affecting both depositional and erosion sites along the lower estuary. It was notable that several large mangrove islands formed in the estuary mouth between 1950 and 1970 (see Chapter 5).

Moderate influences

Moderate, or secondary, drivers of change were notable also in each region. In Fitzroy River Estuary, ~830 ha (~2%) were lost to reclamation of tidal wetlands chiefly for conversion to port facilities and salt works near Port Alma. The impact of these changes were not expected to extend beyond the immediate areas affected.

Table 27. Effect levels for types of change influencing tidal wetlands of Moreton Bay, Port Curtis and Fitzroy River regions over the last two centuries until 2000. The 12 types of change are grouped into 4 categories (A-D) for human and natural influences. Refer also to Table X (1st Chap 1).

Type of Change	Fitzroy River Estuary	Port Curtis	Moreton Bay SE Queensland
A. Direct – Intended & obviously human related			
1. Reclamation loss	**Effect:** Moderate **Driver:** >830 ha lost to ponded pasture, salt production & development around Port Alma.	**Effect:** Dominant **Driver:** >1,600 ha lost to industrial and port development in Auckland Creek and toward Calliope River mouth.	**Effect:** Dominant **Driver:** >2,200 ha of wetlands lost to industry, airport & seaport development plus urban, canal estates & agriculture.
2. Direct damage	**Effect:** Minor **Driver:** Occasional tree cutting, access paths & tracks.	**Effect:** Minor **Driver:** Occasional access paths, tree cutting, access paths, tracks, trampled roots.	**Effect:** Moderate **Driver:** Numerous access paths, trampled roots, although areas generally protected under law & with walkways.
B. Direct – Unintended & obviously human related			
3. Restricted tidal exchange	**Effect:** Minor **Driver:** Impoundment, built-up roads.	**Effect:** Minor **Driver:** Impoundment, built-up roads.	**Effect:** Moderate **Driver:** Impoundment, built-up roads - proportionate to population size.
4. Spill damage	**Effect:** None	**Effect:** Minor **Driver:** Occasional small oil spills proportionate to shipping volume.	**Effect:** Minor **Driver:** Oil spill incidents proportionate to shipping volume - accumulation may exceed toxicant degradation rates.
C. Indirect – Unintended & less obviously human related			
5. Depositional gains and losses	**Effect:** Dominant **Driver:** Net gain of ~860 ha around river mouth due to increased sediment in run-off, plus construction of training walls. River channel dredging ceased in 1965.	**Effect:** Minor **Driver:** Clearing of catchment vegetation & increased crop agriculture increased sediment run-off, resulting in shallower waters around the river mouth.	**Effect:** Minor **Driver:** Site hardening with city-urban roads and built-up areas and reduction in catchment croplands, altered & decreased sediment run-off. Dredging maintained the navigation channel.
6. Nutrient excess	**Effect:** None	**Effect:** None	**Effect:** Minor **Driver:** Possible dieback of mangroves resulting from impoundment caused by blooms of algae attached to roots.
7. Species-specific effect	**Effect:** None	**Effect:** Moderate **Driver:** *Avicennia* dieback in early 1970s affecting ~500 ha of mangroves. Apparent toxicant in run-off, or industrial emission.	**Effect:** Minor **Driver:** Minor dieback associated with toxicants in apparent run-off, & with application of herbicides along drains.
D. Not obviously human related, if at all			
8. Wrack accumulation	**Effect:** None	**Effect:** Minor **Driver:** Litter debris, debris from blooms, storm waves.	**Effect:** Minor **Driver:** Litter debris, debris from blooms, storm waves. Recent *Lyngbya*.
9. Herbivore/insect attack	**Effect:** Minor **Driver:** Insect plagues - occasional in upper estuary.	**Effect:** Moderate **Driver:** Insect plague depleted canopy foliage by 40% leaf area.	**Effect:** Minor **Driver:** Insect plagues - occasional.
10. Storm damage	**Effect:** Minor **Driver:** Severe storm, hail, lightning, storm waves - occasional.	**Effect:** Moderate **Driver:** >210 ha affected by hail damage along Calliope River. Severe storms, lightning, storm waves - occasional	**Effect:** Moderate **Driver:** >190 ha affected by hail damage around Cobby Cobby Island, southern Moreton Bay. Severe storms, lightning, storm waves - occasional
11. Ecotone shift	**Effect:** Minor **Driver:** Climate change - longer-term	**Effect:** Minor **Driver:** Overall rainfall decline notable, longer-term change, causing some dieback.	**Effect:** Moderate **Driver:** Rainfall fluctuations notable over period, climate corresponds with mangrove increase & recent dieback.
12. Zonal shift	**Effect:** None	**Effect:** None	**Effect:** Moderate **Driver:** Sea level increase - notable local effect in southern Moreton Bay.

Relative effect levels: None; Minor; Moderate; Dominant, based on relative extent and presence of changes observed.

In Port Curtis region, ~500 ha were apparently affected by an unidentified toxicant, causing dieback of only *Avicennia marina* in the early 1970s (cp. Duke et al., Mackay report, 2002) while other species appeared unaffected. Much of this damage has since recovered apparently, although the proportion of *A. marina* in the region may have remained relatively low. Further losses in Port Curtis region include damage caused by insect herbivores removing 30-40% of canopy foliage of *Rhizophora* stands across an area of >200 ha. No dieback or tree death was observed in this case. Additionally, in Port Curtis region, there was a significant damage and dieback of trees caused by a severe hail storm in 1994 (Houston, 2000). Tree damage was selective chiefly killing *Rhizophora* and *Ceriops* species while *Avicennia* trees were able to recover.

In Moreton Bay region, many areas have been affected by Direct Damage caused by people walking through mangrove areas trampling above ground roots, disturbing below ground roots and crab burrows, causing erosion, breaking branches, and preventing establishment and growth of new seedling recruits. Such sites were eroded as sediment binding the roots broke down. With erosion, any recruitment was undermined, as well as the undermining of mature trees. The site generally deteriorates from this point, and such changes are expected to be irreversible. Damage caused by a hail storm was also observed in Southern Moreton Bay. In one storm, ~190 ha were killed and severely damaged. As observed in Port Curtis region, *Avicennia* was able to recover from this severe physical damage, while other species like *Rhizophora*, *Ceriops* and *Bruguiera* were slower to recover, if at all.

Additional apparent natural factors have also affected tidal wetlands of the Moreton Bay Region indicating notable trends in climate-related factors. Ecotone shift had occurred in southern Moreton Bay, corresponding to fluctuations in annual rainfall. Zonal shift was also described in the case study of Cobby Cobby Island, indicating apparent sea level rise in southern Moreton Bay. It is yet to be determined whether this effect was a regional or localised, although it appears to be the latter. Both these shifts in vegetation components of tidal wetlands where influenced and partially obscured by significant erosion over the last 20-30 years of the mangrove fringe (depositional losses and gains) apparently caused by dredging and wave action of vessels navigating Canaipa Passage along the eastern side of Cobby Cobby Island (Andrews, 1997; Morton *et al*., 1999).

Benefits in identifying drivers of change

By identifying the types of changes affecting tidal wetlands, it has been possible to quantify and compare their combined influences on tidal wetlands for each study region. Knowing the relative importance of such factors affecting coastal areas provides distinct advantages for those deciding on management options which would be most effective. For example, this information would be useful in an evaluation of management options and actions in response to clear indications of environmental degradation, like mangrove dieback. An assessment of the chief drivers of change, provides information for cost effective management actions. These actions might also be socially acceptable provided people are advised of the assessment outcomes in popular media and education. In the instances where changes might be related to human activities, mitigation efforts may be directed effectively to respective levels of government to implement appropriate remedial actions. For example, local government might direct effects might respond to direct effects from land use, while national government might deal with indirect factors like national emission controls. For changes related to fluctuations in climate, including sea level change, it may also be necessary to implement 'accommodation' measures where predicted changes might be anticipated while planning for future development in coastal areas.

The strategies proposed in this report offer a means to systematically assess and evaluate the types of change in tidal wetlands, and to identify the relative importance of the dominant drivers of change. The advantage in having this knowledge is that effective management options can be applied to preserve environmental health of protected tidal wetland habitat, and to sustain the acknowledged benefits of these valuable natural ecosystems.

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8. Appendices

Appendix 1

Timeline for Port Curtis, Auckland Creek and Calliope River

Appendix 2

Timeline of Rockhampton area, Fitzroy River

Appendix 3

Timeline of Brisbane River Region

Appendix 4

Timeline of Bulwer Island

Appendix 5

Metadata for Reference Sources

Appendix 6

Port Curtis Industrial Centre

Appendix 7

Fitzroy River Estuary Rural Region

Appendix 8

Brisbane River Capital City and Port

Appendix 9

Assessing Historical Change in Coastal Environments

Appendix 1 - Timeline for Port Curtis

Year	**General**	**Navigation/Construction/ Dredging – wharf/dam/weir/wall**	**Land tenure and Land use**	**Reclamation/ Restoration**	**Political/Legislation/ Administration**
Unknown	John Oxley examined Port Curtis when looking for suitable penal settlement sites in the ship *Mermaid*				
Prior Sept 1824	Robert Hoddle carried out surveys at Port Curtis (PC)				
1846	Mr W.E. Gladstone (secretary of State for the colonies) approved establishment of a new colony for better type convicts, on the shores of Port Curtis – 'Gladstone'; Scheme to rid English gaols of less serious offenders; Prisoners to be labour for new settlement; Town officially settled at Barney Point facing the harbour. Port established in a small creek running into it.	The port creek was 300 ft. wide, & apart from small bar inside was between 12 and 24 ft. at low water. Was chosen because of tidal stream, which ran at 1.5 – 2 knots 1/3 mile off Observation Point (used as anchorage for wanting to proceed to sea). Larger vessels anchored in 6 fathoms between Barney and Auckland Points. Early wharfage built all around the creek.			Earl Grey formed new ministry in England - ordered Sir Charles Fitzroy (Gov of NSW) to abandon establishing even before the 1st ships arrived. Abandoned 2 months after the settlement was started. Some free settlers stayed on the banks of Auckland Creek (Barney Point), but the settlement was already set back. Not much expansion because ringed by mountains.
1854	First wool exported to Gladstone.				

1859	Separation of Qld from NSW (Dec 10)				
1862					Jan: George Poynter Heath appointed as Portmaster of Harbour Master's Department – became known as D. Ports and Harbours. 2 July: Marine Board Act of 1862 passed.
1864	Select committee appointed by Legislative Assembly inquired into the state of ports – Gatcombe Head (PC) light needed to prevent vessels running past port.				
1867	Cattle trade from the port temporarily ceased. Shipping decreased – pilot and crew of the pilot vessel helped with the Bustard Head (BH) Lighthouse, as it approached completion. Led to establishment at BH.	Port not buoyed correctly (although not many dangers) – only 1 buoy in shipping channel and 1 in the North Channel by 1867. Passage through The Narrows beaconed – vessels could get between Rocky and Gladstone where enough water.			
1868	Two vessels arrived, 1 from New Zealand and 1 from New Caledonia.	Larger and additional buoys required in the shipping channel for arrival of ships in port. Light also erected on Bustard			

		Head and Oyster Point.			
1870	C.W. Rich was Harbour Master from 1870 to 1882.				
1874	George Seeds appointed as pilot.				
1876	Pilot replaced by Robert J. Belbin – only there for 3 months. Seeds continued in an acting capacity.				
1879	Pilot's cottage on Gatcombe Head was completed.				
1881	Pilot establishment at PC reduced to min.; Pilot had been dismissed.				
1882	W. Whitfield appointed as pilot (February). New Harbour Master – H.M. Cockburn.	North Channel into port continued to deteriorate, due to growth of sand spit at inner end of channel.			
1885		Deepwater jetty at Auckland Creek completed (started 1882). Site for the jetty was mostly stiff clay overlying soft rock – good foundation or the work. Jetty head was 125ft. by 50t. with large closed shed for cargo. Depth of 22ft. at low water at the head, and 34ft. at high water. (Jetty construction info in book p 221).			

1890		Dredging of The Narrows was started. Due to the excavation being difficult the operation was suspended after 16 months.			
1892	Cattle trade between Gladstone and New Caledonia had increased considerably – steamers used being of large tonnage.	Passage between end of the Spit off Gatcombe Head and nth-west of East Bank only a cable width – navigation difficult. Cannel had shoaled to 10 ft. Southern approach still a deep, large channel. Auckland Creek only suitable for moderate tonnage vessels, as was rapidly shoaling at wharves and at entrance. 1100ft. from entrance to leading lights only 7.5 ft. at low water.			
1893	Gladstone could be approached by either the North or South Channels, which were both buoyed and beaconed for night use.				
1895		Floating light placed to mark inner end of North Channel, and small white light placed at East Point on Facing Island, so vessels could avoid the shoal water off			

		Settlement Point. Depth of Auckland point jetty was not enough for very large vessels, so berth was deepened to not less then 20ft. at LWST. Cattle-race constructed along jetty & receiving yards for cattle and horses at inner end of jetty.			
1896		Navigation in The Narrows was still a problem, due to lack of water (lights well maintained). Dredging contracted out to dredge channel 80ft. wide, and 3ft. deep at low water. Dredging started but not completed due to contractors building a dredge that was unsuitable. So, arrangements were made for a deeper channel for the mail steamer *Premier* (which regularly went between Rockhampton and Gladstone) by removing 2 – 3ft. from shallow parts by hand labour (15 – 20 men employed). Only suitable for vessels up to the size of the *Premier*.			

1897		Trade to the port by large vessels was increasing, thus realised would need to beacon and light the South Channel, as the North Channel (only 8ft. at low spring tides and narrow in some parts) was unsafe for large tonnage vessels.			
1899		Tridacna removed 702 cubic yards of mud and shell from jetty berth to give depth of 21ft.			
1900		Water main from the railway dam connected with jetty.			
1901	Schooner *Enid* (built 1866), that was working in Gladstone, replaced but new cutter, *Jessie*, until 1902 ,when sold. *Enid* became barge for carrying gasholders for Rockhampton's gas buoys.				
1902	*Jessie* sold.	Due to further silting up of the North Channel, by 1902 navigation was closed, in the interests of safety, and the South Channel became the only recognised port entrance.			
1903		Tridacna dredged a channel 100ft. wide by 10ft.deep			

		below low water spring tides into Auckland Creek.			
1904	For communication between Gladstone and the pilot station at Gatcombe Head, a flagstaff was erected at the station and on Auckland Hill. Using the disc and cone system of signalling, arrivals and departures were communicated to Gladstone.				
1907					Explosives Act passed. All explosive magazines put under control of the Marine Department.
1909		New berth completed, increasing the wharf frontage at Auckland Point by 200ft.			
1916	Light at Gatcombe Head taken over by Commonwealth Lighthouse Service.				
1917		Depth in South Channel in low water spring tides 26 ft. Meatworks Jetty, Parson's Point was 20 ft. at the upstream end to 24 ft. at the lower end. .Auckland Point Jetty was 22 ft., but sand was encroaching from the shore			
1923		450ft. extension of the Auckland Point Jetty, with a			

		width of 26ft., completed. Railway extended to the end of wharf, 15t crane built 14ft. above deck built on wharf. Whole berthage, now 1000ft long, dredged to 26ft. at LWST.			
1924	Larger ships gradually came to the port and a variety of cargo was exported. From Auckland Point Jetty, 738 cotton bales were loaded for Great Britain.				
1925	Three shipments of wool (1791 bales), as well as five shipments of cotton left from Gladstone. Communication between Gladstone and pilot station at Gatcombe Head still a problem. At this stage they were using Morse lamp, which could only be used at night.				
1927	31 overseas vessels called into the port, loading horses, wool, frozen meat and other products.				
1928		By this year navigation lights had been replaced by flashing lights, and electric lights were installed at			1928 Harbour Board completed negotiations with British Imperial Oil Company to use site on

		Auckland Point.			Auckland Point. Set up tanks for petroleum products.
1931				Many navigation aids lost in cyclonic blow in Feb., South Trees Light Beacon demolished. This and Rocky Point Beacon had to be replaced.	
1932	Heliographic apparatus provided to pilot station at Gatcombe Head for communication with Gladstone during daylight hours.				
1934	Gladstone still "deep water" port, at LWST still 25ft of water at Auckland Point.				
1936	Wireless telephonic equipment for pilot station and Gladstone.				
1938		New lighted Fairway Buoy established.			
1943		Lighted Fairway Buoy removed.			

1944		Old timber decking of timber wharf from 1919 being covered with reinforced concrete slab.			
1947		Lighted Fairway Buoy replaced, repairs to underneath portion of No.2 concrete wharf at Auckland Point jetty			
1948		40 bays of South End Jetty at Curtis Island washed away due to cyclonic weather and abnormal tides			
1951	81 arrivals at port in year ending 30th of June. Entrance channel was 25ft., except on night course on Gatcombe Head Leads, being 22ft. there.				
1952		Completed new jetty to replace one destroyed in 1948 by cyclonic weather.			
1954		Wharf constructed in Auckland Creek for use of fishermen and fish board.			
1955	Gatcombe Head pilot station discontinued. Positions of harbour master and pilot were combined.	Platypus II deepened coal loading berth, dredged berth for 223ft. extension, extended dredged area for an additional 250ft., and removed all clay for preparation for further			

		extension and for tanker berth. In June maintenance dredging of Auckl. Point berth to 28ft. LWST carried out by Echenis.			
1956		223ft. extension to Auckland Point jetty completed, and coal loading facilities upgraded to 400t per hour by fixed head conveyor system			
1958		Construction of a further 225ft. extension, providing a total of 1224 ft. at Auckland Point wharf.			
1961		Main port facilities centred around Auckland Point, where lowest water depth was 25ft. at outer section and 32ft. at inner section; wharf extension built on Auckland Point, 225ft by 83ft.			
1964	Major growth and development commenced which was to make Gladstone into one of the busiest and biggest QLD ports.				
1966		Further extension of reinforced concrete, 306 ft x 83ft wide, at eastern end of Auckland Point jetty.			
1967		Development dredging, to			

		permit use by ships of 25.000 D.W.T., completed. Entrance depth: 31ft. 6in., Auckland Point coal berth: 37ft., Auckland Point swinging basin: 30ft.			
1969		New concrete pilot station jetty on Auckland Creek, equipped with 10t electric crane.			
1970		Reconstruction of old No.2 wharf from 1923, with new wharf comprising 125ft. x 61ft. extension to the coal wharf, the two being joined by a 203ft. x 6ft. bridge section.			
1971		New receival facilities and duplication of the ship loader.			
1972		New pyrites handling facility.			
1984		Further extension of Auckland Point jetty of 233ft, with storage shed, 100ft. x 300ft. at Auckland Point.			

Reference: Department of Harbours and Marine (1986), *Harbours and Marine: Port and Harbour Development in Queensland from 1824 to 1985*, Department of Harbours and Marine, Brisbane.

Appendix 2 - Timeline for Fitzroy Estuary

Year	General	Navigation/Construction/ Dredging - wharf/dam/weir/wall	Land tenure and Land use	Reclamation/ Restoration	Political/Legislation/ Administration
1853	Archer Bros. Charles and William found and named Fitzroy R., and chose a farming site at Gracemere (near where Rocky is today) and a station was established				
1855	Sept 1: Cutter *Elida* anchored in Fitzroy R. near Archer property – unloaded stores; Nov: transported wool (from Gracemere flock) to Gladstone to be shipped to Sydney. Dec 28: Mr C. Archer chartered another schooner *Albion* (85 tonnes) – sailed from Gladstone to Gracemere (through The Narrows) and went to Sydney with the wool.				
1857	Shipwrecks 3 buildings in Rockhampton: bush inn, Palmer's store and a hut.		Hinterland populated by graziers.		
1858	Discovery of gold at Canoona – rush to the Fitzroy R. Only port accommodation was a rickety wharf at the bottom Fitzroy Street, Rockhampton. 16000 people	Increase of ships that were overcrowded and mostly inexperienced seafarers. Captain M.S. Rundle was sent north in *Satellite* to survey the			Influx of ships led to Rocky being declared Port of Entry. Mr H. Lumsden 1st sub-collector of customs.

	which led to the birth of the town of Rockhampton.	Fitzroy R., The Narrows, & the North Coast.			19th Oct – Arthur Vyner appointed Harbour master for Port of Rocky. Charles Haynes later became pilot for Port of Rocky.
1959	Separation of Qld from NSW (Dec 10).	M. Rundle acted as Harbour Master and Pilot from Jun till officially appointed in April 1860.	Primitive form of marking navigation channels in Fitzroy R. was carried out to decrease the number of vessels getting stranded. Used oil drums for buoys and old packing crates for beacons		
1861	Pilots houses tendered to be erected at Cape Capricorn on Curtis Island at northern entrance to Keppel Bay (March).	24000 pounds($) set aside for harbour work in Qld ports. An extra 258 pounds. 2s. 2d was provided to buy new buoys, anchors, chains, and repairs to buoys in the Fitzroy R. port.			
1862	Squatters were occupying land at Rocky.				Jan: George Poynter Heath appointed as Portmaster of Harbour

					Master’s Department – became known as D. Ports and Harbours. 2 July: Marine Board Act of 1862 passed.
1863	Northern limits of the Port of Rockhampton moved to 42 miles south of Cape Manifold 5 Feb (from Lat 22. deg. S.).				
1864	Select committee appointed by Legislative Assembly inquired into the state of ports – Fitzroy R. needed 2 kerosene lights on Upper Flats. Tender for erection of pilot houses on new pilot station, Keppel Bay.	Being entered by overseas and coastal vessels – realised that navigation channels needed to be improved or another site for a deep water port found. Staff Commander Jeffrey, assisted by Master H.J. Stanley, survey Keppel Bay.			
1865		Port Master, Lieutenant Heath, carried out thorough surveys and charted the river before dredging and clearing Upper Flats channel in 1865 (reported to have made it worse). By the time it was finished in May, it had started silting up at the other end. Dredged alternative channel, 150ft. wide, parallel to and within 150ft. of north bank of the river (6ft. at low water) –			

		completed 1866.			
1866		A lightship placed to mark the Upper Flats – marked the crossing place as well as showing depth of water across the Flats, by shapes during the day and lights at night.			
1867	Telegraph line connecting Rockhampton to Keppel Bay Pilot Station completed. Trade carried out almost entirely by steamers.	34 beacons and 28 buoys marking 60 miles of channel.			
1868	Dredge channel at the Flats was 1 ft. deeper than the natural channel. Was as narrow as 80 ft. in one place so only available for steamers and sailing vessels with a fair wind.	From 1864-68 at low water at Second Flats was 4ft. deep and 12ft. at Brown's Crossing, to 6ft. at low water at Second Flats and only 3ft. 6in. at Brown's Crossing.			
1869	Depth of the channels not much improvement - some of the wool being exported sent overland via Dalby to Brisbane				
1871	*Mary*, a 24 h.p. steamer, used for towing vessels up and down the long intricate channels of the Fitzroy R.				
1874	Engineer for Harbours and Rivers appointed – dredging again then cam under the Engineers control.				

	Fitzroy had an Engineer-in-Charge and one boatman.				
1875	Flooding caused considerable silting in Fitzroy R.	This led to a dredger, the *Bremer*, brought in to dredge it out. Depth reduced to 4ft. 6in. from 1ft. 8in. at low water at the upper and lower ends of the Upper Flats cutting.			
1877					The Navigation Act of 1876 was given royal assent. It consolidated and amended the Laws relating to Navigation harbour lights and keeping and carriage of gunpowder.
1879	The *Fitzroy* arrived, a steamer that was constructed for service in the port, and to attend North Reef and Cape Capricorn lighthouses. Land bought and plans for replacing old slipway prepared, but nothing done. Old slipway repaired.	In Keppel Bay, the Timandra Buoy was pointed out by line of lights at Sea Hill. Lights for Brown's Crossing (Fitzroy R) set up and lightkeeper's cottage completed. Dredge *Bremer* started dredging at Upper Flats. Encountered problems.			
1880		Dredge *Lytton* took over from *Bremer*, and soon the depth over most of Upper Flats was 7ft. (in Fitzroy till 1882).			

		Training walls built along the Fitzroy River, total distance of 12330 linear ft. below the Government slip. Width of river through the Upper Flats dropped from 2500 ft. to 1500 ft. (details of walls p221).			
1881	Pilot buildings on Curtis Is in poor state. Floating magazine in Rockhampton sank without evident cause. [was originally *Ben Bolt* and bought by govt for magazine purposes in 1869]	Six pairs of lights in the lower reaches of the Fitzroy R. aided navigation at night.			
1882		*Lytton* finished dredging.			
1883	Rapidly growing port – meant that *Fitzroy* and the port staff spent most time towing; therefore not enough time to complete dept work.				
1884	Town Council of Rocky applied for govt loan to carry out wharf, river bank protection and drainage works. Loan refused as considered already enough wharfage in the river.	Dredge *Saurian* commenced work in Upper Flats, then moved to lower end of the shallow water at Central Island, deepening it to 12ft. 6in. in a 200ft. wide channel. Then shifted to Brown's Crossing, Archer's Crossing and the Upper Flats and dredged to	Blind channels on either side of the Fitzroy R were gradually closed with barriers to confine the current to the main channel of the river. Spaces		

		depth of 12ft. 6in. in 200ft wide channel. *Saurian* cont. dredging to 12ft. although quickly silted up again after floods.	behind barriers filled with dredged material.		
1886	Half time school estd at pilot stations at Keppel Bay and Sea Hill, teacher alternating between the two.				
1890	Yeppon had become small outport; Had one small steamer and a few small craft trading to it occasionally.				
1891		Most planned training walls had been completed. However, not all were finished due to stop in funding as a result of depression. Oct: *Saurian* and plant laid up. Avg accumulation after 12mths was 2ft. Beyond the walls, avg was 5ft.			
1894		Beacons on Balaclava Island mounted on towers and elevated so could be seen 2-3 miles outside Timandra Bank.			
1895	Harbour board was formed at Rocky when an Act was passed in this year. Rocky harbour board received: steam dredge *Saurian*,	New light established at Sea hill on Curtis Island.			

	steam tugs *Hawk* and *Curlew*, 6 iron side delivery punts, steam launch *Wallaby*, and steam engine and boiler *Fern*. Causeway formed between Sea Hill light and the Pilot Station at Grassy Hill.				
1899	Middle Channel into Broadmount Harbour formally opened to traffic.	Marking in the Middle Channel at mouth of the Fitzroy – 15 beacons, 10 buoys, 16 lights; made easy navigation.			
1900	*Fitzroy* temporarily replaced by *Albatross* from Brisbane, while being overhauled. By this stage,				By this year, magazines situated in Rockhampton
1902	Quarantine station on Mackenzie Island closed. Retrenchment within the Marine Department.				
1903	Grassy Hill pilot station house painted, and stores boat beyond repair. Built new boat 'carriage' to launch boats.				
1907	*Constance* attended lights and dolphins in Middle Channel and at Broadmount until 1914 when replaced by a motor launch.	Tide gauges established along the river.			Explosives Act passed. All explosive magazines put under control of the Marine Department.
1908	Carrying capacity of magazine at Rockhampton led to explosives				

	being stored in sheds on the jetty at Port Alma.				
1910	*Fitzroy* replaced by *Woy Woy*, a wooden single screw steamer.				
1911	Due to railway construction progess, explosives' imports increased, and explosives thus taxed to provide room for explosives imported from overseas.				
1912	Light stations at Kazatch and Eupatoria Points erected.	Lights put on wharf and dolphin placed off Chersonese Point to mark shallow patch.			
1913	Violent storms and south-east gales caused damage to structures in Keppel Bay. Land resumed at Bajool to build new magazine. Explosives transported directly form Port Alma to Bajool by rail.				
Early 1900s	It appeared that Broadmount would be the deepwater port for Rockhampton. Little mention made of Port Alma, but navigation was still maintained.				
1914	By this stage shipping into Port Alma had started to increased. Most overseas and interstate shipping went to Port Alma wharf.	Due to problems with the Middle Channel into port, Harbour Board started dredging the South Channel to 17 ft. at low water.			

	However, it was a few years before considered a port of any importance. Vessels calling for meat were expected to go direct to Broadmount. Gas buoys used in navigation increased in power with introduction of incandescent mantles.	Middle Channel to be closed as South Channel deemed best and easiest entrance to Fitzroy River and Broadmount. Middle Channel closed to navigation and all lights, buoys etc. removed.			
1918	Large flood occurred – 31 ft. 11 in. in the Fitzroy River.	Dredged cuttings silted up as result of flood and navigation aids temporarily suspended.			
1919	Pilot station at Grassy Hill moved to Little Sea Hill				

Reference: Department of Harbours and Marine (1986), *Harbours and Marine: Port and Harbour Development in Queensland from 1824 to 1985*, Department of Harbours and Marine, Brisbane.

Appendix 3 – Timeline for Brisbane River

Timeline is a summary of literature reviewed and is not intended to be comprehensive. Rather, it represents the start to a continuing process, whereby others will be able to add historical events via an interactive webpage.

1823—1860	*White settlement – Town landing*
1860—1945	*Rapid early expansion - Town port*
1945—1984	*Post war development – Lytton port*
1984—2001	*Consolidation – Lytton bulk port*

Year	General	Navigation/Construction/ Dredging - wharf/dam/weir/wall	Land tenure & land use	Reclamation/ Restoration	Political/Legislation/Administration
1799	Matthew Flinders explored Moreton Bay, and landed at Woody Point, Redcliffe.[3]				
1823	Arrival of John Oxley on HMS *Mermaid*. River charted as far upstream as Goodna.[1] The Brisbane River was named after Sir Thomas Brisbane, governor of New South Wales.[6]	The Brisbane River bed, except for the upper reaches and on the bar, consisted almost entirely of sand, mud and silt, to a depth of about 15' below datum. Below this, stiff mud and hard clays existed for the most part. Gravel areas occurred in the upper reaches and there were rock areas around Lytton and at one or two other patches upstream.[1]			

1824	Return of John Oxley on HMS *Amity* colonial brig with the first shipload of troops and convicts. Initial settlement at Redcliffe moved to Brisbane town. Previous charts were revised, updated and extended.[1] September- Oxley and Cunningham noted signs of drought above College's Crossing.[7]	Establishment of landing sites in the river at Brisbane town. The river banks were notoriously sticky black mud. The bar at the mouth was a nuisance to shipping, also, but it did put off illegal entry to the colony.[1]	Government owned penal colony which included settlement accommodation area, small crop farms and quarries.[1] First penal colony was established at Redcliffe.[6]		The first white settlement in the region was a penal colony. Free trade and settlement was not allowed.[1]
1825	Arrival of Edmund Lockyer on HMS *Mermaid* to further examine the river – 'Eden Glassie' (=Brisbane). The river was surveyed up to the mountains and source.[1] Lockyer explored the middle section	*Mermaid* was the first sea going vessel to enter the river and, after dropping supplies, to leave with a cargo of pine logs, 7 Sept. Most shipping in the river was, however, small shallow draft vessels ferrying passengers and cargo from drop-off points at Dunwich and Amity.[1]	Exports were timber cut from along the banks of the river and floated to a pick-up point outside the bar.[1] Redcliffe penal colony was moved to North Quay.[6]		

	of the Brisbane River.[8]				
1826		The first wooden wharf constructed was ~300 yds downstream of where the northern end of Victoria Bridge is located today. Bar at river mouth was an obstruction to normal-sized vessels.[1]	As the settlement became well-established wheat production flourished and shiploads were sent to Sydney in Government vessels.[1]		
1827	Discovery of limestone on the Bremer near Ipswich.[1]	Flat bottom barges, operated by the settlement at Brisbane town, carried limestone for building purposes from Ipswich.[1] Bridge built across Wheat Creek from corner of Adelaide and Albert Streets.[3]			First pilot appointed – John Tosh.[1]
1828		Alan Cunningham reported a stone wharf used for landing stone ferried across the river from Kangaroo Point for construction of buildings in the settlement. This wharf was located at the Edward Street ferry landing.[1]			
1829	Explorer Cunningham traversed the	A wharf was constructed to service the Eagle Farm agricultural area, but this wharf			

	country to the north- Linville.[8]	was not used much since it had a sand bar in front.[1] Commissariat Stores with retaining wall completed at Queens Wharf.[3]			
1835		Another bridge constructed across Wheat Creek, near corner of Queen and Creek Streets.[3]			
1836	Major flood.[3]	Bridge constructed over Breakfast Creek.[3]			
1838	Severe drought.[3]				
1841	Squatters (sheep farmers) on the Darling Downs given permission to land and pick-up supplies at Brisbane. Flood height at the Port Office gauge = 31’5”, Jan 14; swept away bridges.[1, 3]				
1842	Proclamation declaring Moreton Bay was no longer a penal settlement and it was now		Moreton Bay open for settlement and free trade. Building		Harbour Master, appointed from Sydney.[1]

	open for free settlement.[1] (A) The road from the north marked out.[9]		allotments in the Town of Brisbane sold at auction in Sydney.[1]		
1843	Flood height at the Port Office gauge = 12’10”, Jun 9.[1]				
1844	Flood height at the Port Office gauge = 26’10”, Jan 10.[1]	HRSN Co. wharf and stores built at South Brisbane.[3]			
1845		A rapid increase in shipping to Moreton Bay with smaller ships crossing the bar and anchoring in the South Brisbane Reach. Larger ships anchored off the river mouth and received cargo from small tenders and lighters.[1]	*Eliza Kincaid* took on the first cargo of wool from the Moreton hinterland for sale in Sydney.[1]		
1846	Brisbane declared a Port of Entry.[1]		Moreton Bay is inhabited by approximately 4000 Aborigines and 2257 migrants.[10]		
1848	*Artemisia* was the first immigrant ship to Brisbane and Moreton Bay bringing over 200 people from	Tonnage of shipping entering the Port of Moreton Bay was 8,000 tons.[1] Bridge for traffic opened over Breakfast Creek (collapsed the following year).[2]	*Artemisia* departed within a month laden with a cargo of wool.[1]		

	overseas.[1]				
1849	Brisbane declared a Warehousing Port.[1]	Shipping companies built commercial wharves and warehouses along the south bank, opposite the township.[1]			
1850	Customs House erected in 1850.[1]	First survey of the navigation of the River Brisbane with a view to removal of the natural obstacles, especially at the river bar and at Eagle Farm Flats. The survey identified the works and cost but little was done until after Separation.[1] Tender accepted for new Breakfast Creek bridge.[3]	Agriculture and grazing activities spread beyond inner Brisbane, to areas such as Bulimba, Coorparoo, Enoggera, Nundah, Sherwood and Stafford.[10] The Brisbane River valley sheep grazing was starting to cause erosion problems. After flooding rains, considerable soil was eroded and later deposited on sand river banks.[8]	Areas outside inner suburbs largely used for agricultural and pastoral purposes until 1880's (e.g. Bulimba, Coorparoo, Enoggera, Nundah, Sherwood and Stafford).[3]	
1851		Customs Wharf constructed at Petrie Bight.[3]			

1852	Flood height at the Port Office gauge = 13’4”, Apr 16.[1]	Eagle Street warehouse and wharf constructed.[3]			
1853		Tonnage of shipping entering the Port of Moreton Bay was 16,800 tons.[1] Bridge built across Cabbage Tree Creek and improvement to the Brisbane road undertaken.[9]			Steam Navigation Board of Moreton Bay (SNBMB).[1]
1857	Flood height at the Port Office gauge = 14’6”, May 19.[1]	Three bridges built at Milton.[3]			
1858		Some obstructions removed from Brisbane and Bremer Rivers. First permanent bridge constructed over Breakfast Creek.[3]			
1859	Separation of Queensland from NSW.[1] Queensland became its own state, with its own local government.[6]	Tonnage of shipping entering the Port of Moreton Bay was 40,000 tons. Feasibility of dredging the mouth bar and upstream to Lytton, and removing rock bars above Lytton up to Eagle Farm Flats. Most ships had to anchor outside Brisbane River Bar and transfer cargo to and from smaller vessels – dredging of channel through Bar was of	The municipality of Brisbane consisted of ridges and swamps, the rainfall runoff finding its way naturally to the swamps without need of man-made drains, and then via a series	Large influx of immigrants.[3]	Water supply and drainage were considered most urgent jobs for the government.[1]

		importance to trade economy.[1] ASN new wharf below Mary Street.[3]	of swamps and lagoons to the river. Spring high tides or flooding in the river flowed back into, and banked up, the natural runoff to these swamps, causing much of the surrounding land to be impassable in wet weather.[1]		
1860	Tenders for steam dredge called.[1]	Money available for clearing obstructions in Brisbane and Bremer Rivers.[1]	The first drainage system was constructed from Elizabeth Street down Albert Street to the creek at Margaret Street, which, although above ground level, had a very flat grade.[1]		
1861	The first census taken in Queensland in April. Population of				

	30,059.[1]				
1862	Severe drought.[3]	The steam dredge *Lytton* arrived in Brisbane under the direction of Thomas Francis. It was used to cut a channel through the bar at the mouth of the river – channel would be 300' wide and 9' deep at LW. Work was needed on inner and outer ends. Material dredged in the inner cut was sand, shell and vegetable matter while it was sand and mud in the outer.[1]			SNBMB becomes the Marine Board.[1]
1863	Flood height at the Port Office gauge = 14'8", Feb 16.[1]	Improvements of channel at Seventeen Mile Rocks, but this resulted in blocking one of the channels, creating shoal across River below rocks.[1]	An18' brick drain was built from Edward Street to Eagle Street.[1]		Oyster Fisheries Act 1863, reacting to the depletion of oysters on the banks in Moreton Bay, forbade the burning of live oysters for making lime, and issued permits for oyster beds.[1]
1864	Construction of the Enoggera Dam. Flood height at the Port Office gauge = 16'2", Mar 20.[1] Construction of railway from Ipswich began.[3]	Work on inner end of Bar channel completed and work started on outer end. Brady given contract to deepen shallow parts of Brisbane and Bremer Rivers.[1] Qld Steam Navigation Co. wharf constructed.[3]			
1865	The first railway opened from	Investigation revealed bar of coarse shingle at mouth of			

	Ipswich to Grandchester. Rail and roads were used to ferry produce and supplies between the hinterland and port.[1]	Bremer River, and rocky obstructions at Five Mile Rocks, Mile and a Half Rocks and Seventeen Mile Rocks in the Brisbane River. Rock obstructions were removed in the Brisbane and Bremer Rivers. A breakwater constructed at the junction of these rivers was designed to divert tidal waters into the Bremer leaving the upper Brisbane River fresh. Cutting commenced at Seventeen Mile Rocks. Channel cut through rock in Bremer from Basin to wharves at Ipswich. Obstructions at Two Mile Rocks, Five Mile Rocks and others removed. Construction of new timber jetty at Cleveland commenced. A wood pile bridge, Victoria Bridge, was built across the river from the town to the south bank.[1] First bridge constructed over Cabbage Tree Creek to Sandgate. Temporary wooden bridge constructed between North and South Brisbane (collapsed 1867).[3]			

1866	A severe economic depression lasting until 1873. No money for construction or dredging besides essential. Dept. of Harbours and Rivers discontinued.[1] Storm and flooding 27 Oct. Floods 10 December.[4]	The steam dredge *Fitzroy* arrived in Brisbane to dig and maintain channels in Brisbane and Bremer Rivers. Dredging and construction works were discontinued due to the collapse of financial institutions in Great Britain. Work stopped at Seventeen Mile Rocks due to lack of funds. Much rock and shingle had been removed but obstacles dangerous to navigation still existed. A wharf at Lytton was constructed to tranship railway stores and plant. Queen's wharf in Brisbane was renewed.[1] Construction of Brisbane Bridge started.[3]	Large areas owned by the St Vincent's Orphanage (over 3000 acres), including the Boondall Wetlands, Dinah Beach and Nudgee Beach (cleared due to increasing timber needs).[9]		
1867	Flooding destroyed the original Victoria Bridge. This was replaced. Flood height at the Port Office gauge = 11'10", Apr 2. Tonnage arriving/ leaving port decreased by almost a third.[1]	Dredging and cutting of the Francis channel and two smaller channels in the river (Fisherman Channel: cutting through sandbank to remove 40,000 cubic yards of sand; and Pelican Channel: shoal) by the dredge *Lytton* were completed allowing vessels of 16-17' draft to reach Lytton and Eagle Farm. Lanterns were used for lighting			

		up the channel beacons through Eagle Farm Flats. Breakwater completed at junction of Bremer and Brisbane Rivers. By this time, 56 buoys and 120 beacons marked the 170 miles of channel in the port.[1]			
1868	Lytton designated as Brisbane's port.[1]	It was possible to wade at LW across the river in Quarries Reach along a sand bar from near Colmslie to Hamilton. The greatest depth on this bar was around 3'6" at LW. The flood in 1873 changed this to 6'.[1]			
1870	Oyster industry flourishing. Included harvesting of shallow and deepwater beds. Flood height at the Port Office gauge = 13'3", Mar 10.[1]	The whole of the cuttings in the Brisbane River were cleared out to width of 200' and a depth of 10'6" at LW, except in Francis Channel, where inner cutting was cleared to 250' wide and outer cutting to 175'. Part of dredging plant sold, part turned over to Dept. Ports and Harbours.[1]			
1873	End of the economic depression. Flooding of the river noted through	Dredging continued also in the Upper Brisbane River, particularly Cockatoo Shoals. Minimum depths for river sections (in brackets): The Bar	The pastoral industry was still the mainstay and the first wool sales were held in		

	the city area including Edward Street and the Botanic Gardens. Flood height at the Port Office gauge = 12'7", Jun 18.[1]	(4'). Inner Bar (9'), Luggage Point (18'), Pelican Bank (9'), Lytton Rocks (15'), Above Lytton (17'), Eagle Farm Flats (7'), Quarries Reach (13'), Hamilton Reach (6'), Town Reach (15') and South Brisbane Reach (14'). Flood removed Quarries Reach sand bar to 6'' and washed away Egg Islet (small islet mid channel off Parker Island).[1]	Brisbane. Sugar cane was first grown on the banks of the Brisbane River but disastrous frosts in three successive years caused a decline in this area.[1]		
1874	Financial situation improved. Engineer Francis Rose appointed to take care of dredging, wharf construction and harbour works. Re-establishment of Dept. of Harbours and Rivers. Increase in overseas and coastal vessels visiting Brisbane.[1]	Dredging of Brisbane River recommenced with upturn of economy. Cutting of a channel through Cockatoo Shoal (gravel), above Brisbane, was completed by the dredge *Cockatoo* in 1875.[1] Iron Victoria Bridge opened between North and South Brisbane, but collapsed 1893.[3]			The Oyster Act of 1874 extended granting of licences to dredge sections where oysters grew below 2' at LW. All vessels engaged in collection were to be identified with the word "OYSTER". Those on the banks were identified with "O.B." Report on the oyster Fisheries of Queensland.[1]
1875	Construction of the government wharves at Petrie's	The old bucket dredge *Lytton* was overhauled and recommissioned for work in the	Initial concerns primarily with the creek downstream		The Brisbane Drainage Act of 1875 sought to address the urgent need for controlling water supply and

	Bight commenced in September, completed in 1877. Flood height at the Port Office gauge = 12'4", Mar 1.[1]	Francis Channel (10'6" at LW) and Petrie's Bight (16-17' at LW). Further work was done in the Francis Channel, as well as the Hamilton Reach in 1876. Contract for South Brisbane Dock.[1] Construction of Indooroopilly railway bridge (collapsed 1893). Construction of new government wharves at Petrie Bight began.[3]	of the Albert Street/ Adelaide Street intersection which was then the only open area developed, and in the knowledge that the Makerston Street culvert would be built as part of the Roma Street Railway project.[1]		drainage.[1]
1876		*Lytton* works on dredging Francis Channel and improving No. 2 Cutting, Hamilton Reach. Work commenced on the South Brisbane Dock, the graving dock, and completed in 1881. Much of excavated material deposited on streets of South Brisbane (which needed raising, widening, etc.). A wharf and approaches were constructed near the mouth of Doughboy Creek.[1] Albert railway bridge linking Brisbane and Ipswich opened at Indooroopilly.[3]	Small crop farming and dairying popular on city periphery.[3]		The Navigation Act of 1876.[1]

1877		The new bucket dredge *Groper* was used extensively on permanent navigation channels in the river commencing at Pinkenba Flats. All channels were dredged to 10' below LW to Brisbane. Once this was completed work started on deepening the river channels to 15' below LW, and widening to 250'. By now, Lytton had removed a total of 59,672 cubic yards from Brisbane River. Spoil from dredging was mainly deposited in the bay, 12 miles offshore, and the rest in the blind channel behind Parker Island.[1] Kennedy Wharf at Petrie Bight constructed.[3]	Storm culverts built along Adelaide and Creek Streets included a 9' by 9' masonry tunnel. Various other site drainage systems installed in the town area.[1]		The Queensland Fisheries Act of 1877 sought to control commercial fishing and preserve some breeding and feeding grounds.[1]
1878		Six tide gauges were installed between Brisbane and Lytton, and the marked high water datum supposedly represented a horizontal line between the beacons.[1] Construction of South Brisbane Graving Dock commenced.[3]			
1879	Flood height at the	Previously, there was a lack of			

	Port Office gauge = 11'10", Oct 16.[1]	suitable wharfage – vessels arriving in Town Reach had to anchor in the stream. Five moorings were installed in Town Reach for vessels waiting to unload or load. Survey of foreshores of Wynnum-Manly, and plans for proposed seawall.[1]			
1880		Countess St railway bridge completed.[3]			
1881	The 'Queensland Navy' was equipped to fight off a possible threat from the Russians.[1]	Work completed deepening the river channels from Brisbane to Lytton to 15' below LW. Cuttings were made in the line of the river and siltation was a problem only in three places – Hamilton, Eagle Farm and the Francis Channel. South Brisbane Graving Dock completed and opened.[1]			
1882		A new straight channel across the Brisbane bar was completed by *Groper* and the new dredge *Octopus* (previously, the tortuous Francis Channel had given difficulty). Two lighthouses were erected in the middle of the mangroves on Fisherman Islands. A gangway			The Port Dues Revision Act of 1882.[1]

		was constructed between the two islands to allow access to the back light positioned in soft mud.[1]			
1883	Severe drought. Heavy gale January.[1]	Construction of the Pile Light marking the outer edge of the Brisbane Bar (16' at LW) and eastside of the entrance to the straight channel. This replaced the lightship. The structure originally included the lightkeepers house and telegraph station, and was only demolished in 1970. *Duke of Westminster*, 3,726 tons and 400', was the largest vessel to reach the town. The curve around Kangaroo Point was less than some vessels could turn unassisted, so controls and procedures were adopted for general navigation.[1]	Drought brought about a sustained decline in pastoral expansion until around 1886.[1]		
1884	Swamps drained around Kangaroo Point, Petrie Terrace and New Farm.[3]	The new hopper dredge *Platypus* worked in the river and deposited spoil at Mud Island, a shallow mud island at the mouth of the river. The *Groper*, deepened the Bar Cutting channel to 15' below LW and a			

		width of 200'. The Inner Bar Cutting was dredged to the same depth but a width of 150'. The cutting through the Flats at Eagle Farm and Pinkenba was dredged to the same depth and a width of 200'. The *Octopus* deepened the Rocky Channel below Lytton to the same depth and width of 100'. After this it was decided to widen the channel cuttings to 300'. By now, nearby places for deposit of dredged spoil from the *Groper* were becoming limited – spoil to be dumped on the SE side of Mud Island.[1] Coal wharf opened at South Brisbane bight (demolished 1974). Wharf built at Kangaroo Point by Gibbs Bright and Co. Moar slip built at Kangaroo Point. Alterations to ASN Co. wharves at Eagle Street. Construction of new South Brisbane municipal wharves began.[3]			
1885		The *Octopus* was used to clear a swing basin in the South Brisbane Reach to a depth of 16'	A scheme for diverting flood waters of Victoria		

		below LW. The Groper continued widening channels.[1]	Park and Spring Hollow into Breakfast Creek included a culvert of 660' and 8' in diameter running through Bowen Hills. This was expected to greatly improve drainage from Fortitude Valley. Other drainage works were undertaken near Milton, South Brisbane, New Farm, Kangaroo Point and Fortitude Valley.[1]		
1886	Drought ended.[1]	Boats plying between Brisbane and Ipswich included 18 steamers, 18 sailing vessels, 23 barges and ~70 market boats. Due to river works, boats drawing 21' water could go up with tide without problems.[1] South Brisbane Council's Musgrave Wharf completed. Stanley Bridge constructed	As the drought ended, pastoral expansion increased again along with mining.[1] Stormwater drainage at Spring Hill, Fortitude Valley,		The Oyster Act of 1886 repealed and updated the 1874 Act.[1]

		across Norman Creek.[3]	New Farm and Petrie Terrace completed.[3]		
1887	Flooding of the river in February deposited soft material in the lower reaches of the river, as well as snags, and created shoals in the upper reaches. Flood height at the Port Office gauge = 16'2", Jan 23. Gale January.[1] Closure to net fishing of the Brisbane river upstream from Bulimba Ck for 3 years.[2]	The full channel depth of 15' below LW and width of 300' was obtained in all river sections from Brisbane to the mouth. Considered deepening channel to 20' below LW, and Harbour of Brisbane needed further deepening. The SS *Jumna* with a draft of 21'4" came up to Brisbane and left largely unassisted. However, there were problems because of the limited berthing facilities for these larger vessels up river. Work commenced on cutting a central channel of 20' depth at LW. Additional moorings were installed abreast of the Botanic Gardens for vessels waiting to unload or load. Dredge *Hydra* recommissioned, deepening of Bulimba Reach Channel to 20' started.[1] South Brisbane Graving Dock extended. North Quay embankment collapsed, mass concrete retaining wall			First Inspector of Fisheries appointed. The Queensland Fisheries Act of 1887 sought to better manage fisheries and preserve fish breeding and feeding grounds.[1, 2]

		constructed along Coronation Drive.[3]			
1888		New bridge at Breakfast Creek started.[3]	Stormwater drainage of South Brisbane constructed.[3]		
1889	Flood height at the Port Office gauge = 16'1", Jul 20.[1]	Two clam shell dredges cleared various wharves and removed silt/ blasted rock from Dock entrance.[1] New Breakfast Creek Bridge completed.[3]			
1890	Flooding of the river in March. Flood height at the Port Office gauge = 21'3", Mar 13. Heavy gales damage navigation aids.[1]	A measured mile (6,080'), used to check speed of vessels, was set out in Bulimba Reach. Navigation lights burnt oil and this required a light keeper. Clam-shell dredges cleared Websters Wharf, South Brisbane, and also ferry approach of Creek Street, and Harbours and Rivers and Port Office wharves. *Hydra* and *Groper* dredged berths of South Brisbane Reach, and then started deepening cuttings to 20'.[1]			
1891	Fish caught in Moreton Bay were brought up the river	First tables of predicted tide levels for the Brisbane River.[1]	First wool sales held in Brisbane.[1]		

	to Breakfast Creek where fish were distributed. Gales and heavy seas damaged buoys, etc.[1]				
1892	A cyclonic gale struck Brisbane with unusual violence on April 2nd with wind gusts ~70-75 mph.[1]	Brisbane River had a dredged channel 300' wide and 15' deep at LW with the central channel of 100' width having a depth of 18' at LW. All back channels had been filled with dredge spoil so shore sites were investigated. Dredging plant were laid up and port work greatly reduced as economic conditions worsened.[1] Norman Wharf built for ASN Co. at Eagle Street.[3]			The Harbour Boards Act 1892 sought to control and administer the ports in Queensland. The Act made provision for the construction, regulation, management and improvement of harbours by local authorities constituted for that purpose. The Harbour Dues Act of 1892 made temporary provision for the management and improvement of harbours while providing funds for the new Board when constituted.[1]
1893	Crisis and disaster. Eight of the eleven banks in the colony closed and there was general economic collapse. Depression. Flooding of the river in February was the worst ever rising to at least	Severe flooding almost obliterated the dredged channels and closed the port to all but small craft. Minimum depths for cuttings (in brackets): Outer Bar (8'6"). Inner Bar (15'), Pelican Reach (12'), Lytton Rocks (13'6"), Above Lytton (15'), Eagle Farm Flats (6'), Quarries Reach (12'), and Hamilton Reach (8'). After			Harbour Dues Act of 1893. At this time, control of tidal waters remained with the Crown. Reclamation required an Act of Parliament. This was later amended to Governor in Council approval and the issue of an Order in Council. A Board was granted tenure over port lands for the purpose of wharfage or port purposes, and the power to levy harbour dues on all goods discharged

	30’4” above LW twice in 2 weeks. River flooding left the gunship *Paluma* high and dry in the Botanic Gardens. Flood rose to 36’ above LW at Victoria Bridge. Flood height at the Port Office gauge = 31’2”, Feb 5. Flood height at the Port Office gauge = 10’10”, Feb 12. Flood height at the Port Office gauge = 30’4”, Feb 19. Flood height at the Port Office gauge = 15’8”, Jun 12.[1]	considerable effort all channel cuttings were re-established by dredges *Hydra*, *Groper* and *Platypus*. Port works later ceased again due to the poor economic conditions. The small dredge *Bremer* was used in the Upper Brisbane River including Pullen Pullen Creek, Gogg’s Reach, Cockatoo Island, Moggill Race, Bremer River Basin and at the junction of the Bremer and Brisbane Rivers.[1] Indooroopilly railway bridge and N end of Victoria Bridge destroyed in floods.[3]			or shipped within the harbour together with the right to lease land and facilities.[1]
1894	Strong gales and heavy rain occurred in January to March. The river remained closed to net fishing from the Magazine and Doughboy Creek upstream,	The small dredge *Bremer* was used to clear a minimum depth of 6-7’ at HW between Victoria Bridge and the mouth of the Bremer. The river on the whole carried much less water than before. Most dredge plant were laid up again due to poor economic circumstances.[1]			The amalgamation of the Marine Department. An amended regulation limited the speed of vessels within the river sought to protect the cutting.[1]

	reportedly providing a nursery for young fry. At least 12 boats fished the river and Boat Passage taking mullet, whiting, bream, tailor and jewfish.[1]				
1895	The Great Drought (until 1903).[3]	Construction commenced on the new steel arch Victoria Bridge, and continued until 1896. Number of vessels using South Brisbane Dry Dock decreased: needed lengthening and entrance widened for larger vessels. All cuttings up to Hamilton restored (after flood) to depth of 16', width 300' (except Lytton Rocks Cutting, 200' wide). Town and South Brisbane Reaches also dredged.[1] New Albert railway bridge opened, linking Indooroopilly and Chelmer.[3]	Recovery of commercial and industrial building activity after Depression.[3]		
1896	Mud worm disease found in oysters of Moreton Bay. The oyster industry was	The first gas buoys and transporters were used. The gas was produced locally from the refuse from shale oil plants.			

	in bad shape and getting worse. Flood height at the Port Office gauge = 10’4”, Feb 14. Flood height at the Port Office gauge = 6’7”, Feb 22. Flood height at the Port Office gauge = 9’10”, Feb 29.[1] Tidal separation of North and South Stradbroke Islands (to 1898).[3]	These lasted until the 1960s. Dredges *Hydra* and *Groper* maintained and deepened the river channels from the bar to Hamilton Reach. *Bonito* worked in the reaches above Hamilton up to South Brisbane Reach. *Bremer* was refitted with drilling equipment and used to break up rock in the Lytton Rocks cutting. Rock was removed by the dredge *Groper*. This rock was used to construct the training wall about 6 mi above Lytton. By 1899, this cutting was completed.[1] New Indooroopilly railway bridge opened. First half of Victoria Bridge opened.[3]			
1897		To assist compass adjusters, beacons were erected at Mud Island indicating the cardinal and quadrantal points of the compass. The suction dredge *Bonito* commenced dredging in the South Brisbane Reach and then went to Bulimba Reach dumping sand at Eagle Farm Flats which was then pumped ashore by the pump dredge		Future spoil from dredging to be deposited behind training walls to reduce carrying distance and allow for land reclamation.[1]	The Navigation Act of 1897.[1]

		stationed there. Work commenced on scheme to improve river, including training and regulation of lower reaches, dredging and cutting off certain points.[1] Bridge over Brisbane River at Mt Crosby finished (destroyed 1898). Lytton Rocks blasted. By this time, South Brisbane wharves stretched from Kangaroo Point to Victoria Bridge. New Victoria Bridge opened (replaced 1969).[3]			
1898	Flooding of the river during the early part of the year. Flood height at the Port Office gauge = 20'3", Jan 13. Flood height at the Port Office gauge = 14'6", Mar 9.[1] Drought until 1903 (A).	In conjunction with dredging, and to direct and regulate water flow in the lower portion of the river, training walls were constructed and certain points were cut off. Construction of training walls commenced in March with the first wall at Hamilton. Walls had a top width of 4' with a 1.25-1 slope and comprised of one-man sized stone pieces. A trench 6-8' deep was dredged through the sand bank to receive the stone. Stone came from the Kangaroo Point quarry and with footing support		The suction dredge *Cleveland* pumped silt behind Hamilton training walls.[1]	

		using Lytton Rock cutting spoil. The growth of the River Bar seaward had been rapid. This was shown at the Pile Light which was built on the 18' contour in 1884, and in 1898 it stood on the 11' contour. [1]			
1899		A floating navigation light was placed at the turning point between the Inner Bar and Pelican Bank cutting. The Lytton Rocks cutting was completed with a width of 300' and depth of 20' at LW. River channels deepened to 20' below LW and 200' wide, so large vessels could reach wharves at Town and other Reaches easily.[1]		Low lying areas behind many of the training walls afforded admirable receptacles for large quantities of dredge spoil.[1]	
1900	A Marine Biologist, James Tosh, was appointed by the Marine Board to advise on all matters in connection with pearl shell and edible oysters, and on the fisheries of the colony.	As there was insufficient water at most wharves in Pinkenba Reach, large vessels used to moor nearby where the depth was dredged to 24' below LW. Kangaroo Point was cut back to allow safer navigation around this point. The Hamilton training wall was completed at 8,600' in length. The Doughboy wall was commenced. New	Coal was becoming an important item for export.[1]	Some spoil from Kangaroo Point was dumped at Coxen Point Wall while the bulk was dumped in the bay.[1]	Pressure from ship owners and masters of overseas vessels called for: 1) provision at wharves for vessels to lie afloat at all stages of the tide; 2) increased wharf and shed accommodation and modern loading appliances; and, 3) provision of better facilities for loading of coal.[1]

	Increase in the market for Moreton Bay oysters. Water hyacinth became a troublesome pest in the Brisbane and Bremer Rivers. The weed interfered with navigation and stopped traffic in the Bremer. The only control was to physically remove the vegetation and dry it on the river bank.[1] Attempts to revive the dugong industry at Amity Point in the period 1901-1910 were hampered as numbers were so low.[2]	wharf completed to replace old Port Office wharves. Every effort was made, by the construction of training walls and dredging, to bring ships up river to established wharves in Town and South Brisbane Reaches. However, as ships increased in size the difficulties increased in getting them upstream for depth and manoeuvrability. Wharf space and shore access was also increasingly congested. For these reasons, gradually new facilities were built downstream in Bulimba and Hamilton Reaches.[1] River widening since 1900 to improve navigation & flood mitigation has removed about 22ha of river bank.[2] Temporary sandbag weir built across river due to drought.[3]			
1901	On January 1 the Commonwealth of Australia was proclaimed.[1]	At Lytton Rocks cutting, drilling and blasting was done to increase the depth to 26'. Gardens Point was cut back to allow safer navigation around the point, increasing width to			Proclamation for the implementation of fishing exclusion zones at certain months in Moreton Bay to protect spawning fish.[1]

		250'. Work then ceased here until 1913. Training walls were constructed through and along Parker Island. Preliminary work for removing part of SE side of Parker Island for better navigation started. Work included: cutting mangroves (used for mattresses for river improvements) and opportunistic dredging. The SE side of the island had to be dredged away over the next eight years. The Coxen wall extending to Parker Island was commenced in February. Two small dredge plant jetties were erected in front of Marine Dept. at Hamilton. Timber wharf constructed at Pinkenba Wharf. Part of bottom of South Brisbane Dry Dock concreted over (previously, natural rock surface).[1]			
1902	Brisbane was declared a city.[6]	The Parker wall was commenced in January and completed by September with length of 2,890'. The Doughboy wall was completed in June with a length of 7,040'.			Regulations stipulated minimum length for controlling fish size of marketed product.[1]

		The Coxen wall was completed in June with a length of 3,200'. Mangrove 'mattresses' were used to reduce subsidence. The Lytton wall was commenced in September.[1] First concrete weir for town water supply constructed at Mt. Crosby and introduction of river gauges.[2, 3] Temporary sandbag weir rebuilt across river due to drought.[3]			
1903	Great Drought ended.[3]	The channel depth up to Pinkenba was increased to 24' at LW. The new cutter-suction dredge, *Hercules*, pumped stiff solidified mud together with clay in many parts of the river and in the new bar cutting. At Hamilton the dredge encountered clay which proved too hard for the machine and she was re-assigned to work at Eagle Farm cutting, then Queensport, and then Quarries Reach. The dredge had trouble there also with coarse sand overlying mud and hard dry clay. The Bulwer wall commenced in July but then discontinued (resumed		*Hercules* was frequently used to pump ashore spoil dumped previously in the dump hole at Coxen Point.[1] Following construction of the Bulwer wall, sand was progressively pumped to fill the space between Bulwer Island and Pinkenba, eventually joining the island to the mainland. Also, filling was commenced to expand the island out towards the training wall (until 1946).[5]	

		1905). Lytton wall discontinued.[1]			
1904	Prawn trawling was fairly successful in the river, as well as collection of mud crabs.[1]	The grab dredge restored the upper river depth to 4’ at LW at Daly’s Flats, Junction Shoal, the Moggill Race and Cockatoo Island Crossing to assist the considerable number of barges using the river, chiefly carrying coal. Many of the dredge plant were laid up and little work was done. *Hydra* recommissioned to clean up old Quarries Reach Cutting.[1] Even by 1904 combined effects of dredging the mouth of the river and constructing training walls increased mean tidal range by 0.25 m.[2]			The Fisheries Act of 1904-7 sought to provide for the marketing of fish.[1]
1905		To facilitate access to wharves in South Brisbane and Town Reaches, a considerable area was dredged to a depth of 20-24’ at LW. Siltation was rapid in these so on-going maintenance was essential. The Lytton wall was completed and raised to 6’ above LW. Bulwer wall resumed. *Hydra*			

		successfully cleared clay from Hamilton Reach. *Hercules* worked on new Quarries Reach Cutting, where there was hard dry clay in places, difficult to dredge.[1]			
1906	Water hyacinth again became a troublesome pest in the Brisbane and Bremer Rivers. A lack of flooding had apparently led to its accumulation. The same method was used to control it.[1]	Almost all dredges in operation. A 24' channel had been dredged from the Bar to Kangaroo Point – "a truly memorable achievement fully deserving of perpetuation in the maritime annals of this city and state'. The dredge *Cleveland* was refitted for submarine rock drilling and operated in Lytton Rocks Cutting. Bulimba Point was cut back to allow safer navigation around the point. Spoil removed was mostly clay. Channel width increased from 500' to 700'. The Hamilton wall was raised to 10' above LW. The Bulwer wall was completed with an upper level of 6' above LW.[1] First Bulimba wharf constructed at Teneriffe.[3]			
1907	Size and number of	Removal of part of Bulimba			Legislation gave the Dept. of

	vessels visiting port had increased beyond available wharf accommodation.[1]	Point continued. Depth of 24' LW and width 300' available from Bay to Town Reach. South Brisbane and Town Reaches experienced rapid silt deposition, making it difficult to retain depth. Large wharf (Dalgety's) erected on New Farm side of Bulimba Reach, helping to relieve congestion of the Town and South Brisbane Reaches. Banks were protected with light random stone revetment. Work was carried out by the Dept. at cost to the owners.[1]			Harbours and Marine the authority to force land owners to protect their river banks.[1]
1908	Flooding of the river in March but recorded as slight. This flood brought down enormous amounts of hyacinth. Again the control was removal and drying. Shire Councils in the upper catchments were urged to control the weed in the small water	Lytton Rocks cutting was widened to 400' and depth of 26' at LW with further drilling and blasting up to 1911. Rock blasted and removed from Custom House Rocks. Further work in 1910 and 1911. Work commenced on a new cutting (and pile light) across the Bar. The Old Bar was being lengthened considerably with increased depths since axis was tangential to the 26' contour and the only way to get to that depth			

	courses upstream. Flood height at the Port Office gauge = 14’9”, Mar 15.[1]	would have been to make a bend. Furthermore, the Old Bar Cutting required considerable maintenance. Dredges *Maryborough*, *Hydra* and *Hercules* were used to dig a channel 400’ wide and 24’ deep at LW. The New Bar Cutting was completed in 1912.[1] Bishop Island formed by dredging at the Brisbane River mouth (to 1910).[3]			
1909		*Groper* worked at removing silt deposits from dredged area at Kangaroo Point. Much of SE side of Parker Island cut back.[1] Railway Wharf constructed at Pinkenba.[1, 3] Capricorn Wharf built at New Farm.[3]			
1910		With the exception of the Outer Bar Cutting and Lytton Rocks Cutting which were 300’ wide, the dredged channels of over 15 mi had a depth of 24’ at LW and minimum width of 400’. Bulimba Point was cut back further to allow safer navigation around the point. Borthwick’s		Since hopper barges were not equipped to pump spoil ashore, the spoil was dumped in ‘dump holes’ in the river or in the bay. These holes in the river were dredged out once or twice a year and the spoil pumped to	

		wharves in course of erection near Queensport. Further drilling and blasting of rock for deepwater berth at Kennedy Wharves, Petrie's Bight and at Doughboy Rock patch.[1]		reclamation areas behind the river walls.[1]	
1911		Further width of 100' was removed from Parker Island to facilitate the swing of large vessels berthing at Borthwicks Wharf. Lytton Rocks Cutting finally cleared to depth of 26', width 400'. Concrete section of Pinkenba wharf constructed.[1]	Brisbane area population 175,487 in 36,502 dwellings (city census total 146,991).[3]		
1912	Dredging operations were affected by major industrial action at the time.[1]	The new stern suction dredge *Remora* assisted in dredging the new bar cutting. The New Bar Cutting was open for navigation providing a straight outlet to the sea. The Pile Lighthouse was re-positioned on new piles at the 5 fathom (30') contour at LW outside the bar. The bottom was soft mud down to 35' noted by the piles being installed sinking 20' under their own weight. The site was supported by 5,000 tons of coarse sand dredged from near Garden Point. The	Town planning movement became influential.[3]	Dredge spoil from the inner end was pumped above HW to form Bishop Island which acted as partial protection to the cut from S-SE wave action.[1] Construction of training walls, reclamation works and removal of points and restrictions along lower reaches to city reach completed.[2] Bulwer Island spit reclaimed until 1929	

		lighthouse was equipped as a signal and telephone station. New channel leads on Bulwer Island consisted of two lighthouses. Bulimba Point was cut back still further to allow safer navigation around the point. River width was increased from 600' to 1000' between LW lines.[1] Construction of retaining walls along Breakfast Creek started by Town of Hamilton.[3]		(previously, it had been without spit and covered with dense low mangroves).[5]	
1913	The largest steamer to have visited Australia, *Nestor*, safely berthed at Bulimba. The port of Brisbane was considered equal to any in the country. Rains early in the year again brought down enormous amounts of hyacinth. Again there was serious impediment to navigation downstream.[1]	The old Pile Light was discontinued and the new one put in use in February. Large vessels in excess of 14,000 tons and 500' long were able to safely make their way unassisted up the river and berth at Bulimba Point. Gardens Point was cut back further to allow safer navigation around the point. Bulimba Point cut completed.[1]			

1914	Australia at war until 1918 resulted in a decline in overseas and coastal trade until 1920. Rains early in the year brought down additional large amounts of hyacinth. River navigation was seriously affected where 12 miles of the river was covered from bank to bank concealing large logs and snakes. Physical removal was the only control used.[1]	Minor dredging was done in the upper river with a grab dredger. Lack of resources and supplies made it almost impossible to maintain the dredge plant and to maintain channel maintenance.[1]		The Coxen Point 'dump hole' was abandoned after extensive use. A new dump hole was dredged out by *Hercules* in Aquarium Passage to receive spoil from Town and Upper Reaches. This spoil was to be used to reclaim nearby mangrove flats, and behind the Bulwer Island wall.[1]	The Fish and Oyster Act of 1914 sought to close loop holes evident in the old Acts, and to stipulate that everyone taking fish with a net, for sale or not, was required to have a licence.[1]
1915		The *Remora* was used to deepen the New Bar Cutting to 26' at LW. Gardens Point was cut back still further to allow safer navigation around the point.[1] Bowen Bridge reconstructed in reinforced concrete. Dredging and walling of Gardens Reach boundary of Botanic Gardens. Construction of Lytton jetty	Tar sealing of city streets commenced. Residential growth stimulated by tramways in outer areas.[3]	Spoil was dumped in the Aquarium Passage dump hole.[1]	

		commenced.[3]			
1916		Further works on the removal of Parker Island were done by the hydraulic dredger *Casuarina* and the *Platypus* up to 1918. The width of river was increased by 350'. The small grab dredge was used in the upper river particularly in Pope's Reach to 6' at LW. Reinforced concrete wharf and retaining wall for Fish Market at South Brisbane commenced.[1] BCC concrete wharf built at Petrie Bight between Boundary St and Kennedy wharves.[3]	Work commenced on building sewers in city and inner suburbs.[3]		
1917	Water discolouration in the river was thought due to wave action disturbing fine sediment on the outer bar and spring tides carrying the suspended matter upstream. Observations were started to determine the amount of	After excavation of Gardens Point, the river was widened from 500' to 800'. The South Brisbane Fish Market and wharf was completed.[1] Creation of Mt Crosby sedimentation basin to improve water quality.[3]	Saltwater cleansing of Brisbane streets commenced.[3]		

	suspended sediment in the river, sampling during winter in calm weather.[1]				
1918	Storm water and street runoff entering river through various sewers. Observations of suspended sediments showed larger amounts were along the wharves in Town Reach. The clearness of the water for most of the time was described as sufficient to permit an object to be seen at depths up to 2' under the surface in Town Reach. Some sewers at low water discharged a black offensive liquid but its effect was reportedly confined	Seawall construction at Sutton's beach, Redcliffe Peninsula.[2] Trenches dug in river to maintain water supply during drought.[3]			The Fish and Oyster Amendments Acts of 1918.[1]

	to small areas. At Hamilton objects were visible at 4' below the surface.[1]				
1919		River straightening works substantially completed. In the Brisbane River, the points were controlled by dredging and the banks by walls. Thus, the lower reaches of the river from Brisbane to the bay were confined.[1]			
1920		Of the 21.4 statute miles of waterway from the 5 fathom contour in Moreton Bay at the entrance to the Brisbane River to Victoria Bridge, 16.4 miles was dredged. Over half the dredge spoil was dumped in Moreton Bay. The new Bar Cut and Lytton Rock Cutting had widths of 400' while all other cuttings were from 450-600' wide. Depths below LW datum were between 26-28' up to and including Bulimba Reach while above that depths were around 24'.[1]	Medium to highrise buildings constructed for commercial and residential purposes (to World War II, then recommenced after war).[3]	Just less than half the amount dredged from the river was pumped ashore in reclamation areas along the river.[1]	
1921			Brisbane area		

			population 257,905 in 53,648 dwellings (city census total 220,371).[3]		
1922		The Cold Stores Wharf was completed at Hamilton.[1]	Reconstruction of Central and South Brisbane streets in concrete began.[3]		
1923		The depth of the Lytton Rocks cutting was increased to 27' using the dredge *Hydra*. A berth at Pinkenba was dredged for an oil company. This was the first record of an oil company proposing to operate in the area. The Department of Health, concerned about the enormity of the rat population inhabiting the stone walls, attempted to have them rat proofed by grouting the spaces with cement. Work started on the Hamilton wall.[1] First wharf constructed downstream at Hamilton.[3]	Sewerage system operated in city centre.[3]		
1924	A special punt, the *Hyacinth*, was used to control water				City of Brisbane Act established the Greater Brisbane.[6]

	hyacinth in the river. The coastal railway from Cairns to Coolangatta was completed.[1] Mosquito fish were relocated to the Brisbane River to try and alleviate mosquito larvae using these biological controls.[8]				
1925	In December 1924, there was no hyacinth in the tidal portions of the river but by May the river was thickly covered in the weed from Indooroopilly Bridge to Ipswich, a distance of around 32 miles. Rain in June flushed out the bulk into the sea where it died quickly. Number of overseas vessels to Brisbane increasing.[1]	Commonwealth standard tide and dredger signals were adopted and used from November 1st. The channel depth was increased to 26' at LW from the Pile Light to New Farm with a minimum width of 400'. New wharf attached to Hamilton Cold Stores and several wharves in Bulimba Reach enlarged.[1]	South Brisbane connected to sewerage scheme via siphon pipes on the riverbed.[3]		

1926	Failure of summer rain brought on drought.[1]	The width of the Lytton Rocks cutting was increased to 500'. Plant was used then to clear Doughboy rocks below Queensport which had a minimum depth of 8'6" at LW. This was deepened to 20'. Next were Hawthorn rocks and deepening in front of the Railway Wharf at South Brisbane. Breakfast Creek was made navigable and provide a sheltered mooring basin for small craft by clearing of obstacles and dredging to 4'6" at LW. Hamilton dredge plant jetties rebuilt.[1] Second (present) weir constructed at Mt. Crosby.[2]			
1927	Moreton Bay was patrolled by two vessels with Fishing Inspectors to make sure fisherman complied with the Fisheries Act and regulations. Flood height at the Port Office gauge = 9'4", Jan 28.[1]	Mt Crosby weir abutment washed out with flood.[3]			An Order in Council was issued under the provisions of the Fish and Oyster Act of 1914, increasing the minimum size at which all fish could be taken.[1] Brisbane River Tidal Lands Improvement Act.[3]

1928	Strong freshwater flows in the early part of the year caused deposits of silt in dredged channels as far down as Pinkenba. Flood height at the Port Office gauge = 9'3", Feb 22. Flood height at the Port Office gauge = 10'10", Apr 21. The first Australian Fisheries Conference. The review by TC Roughley on the oyster grounds and industry in Queensland. UQ postgraduate, FW Moorehouse was specially commissioned by the Marine Dept to join the British Royal Society Expedition to Low Isles.[1]	Dredges *Remora*, *Hydra*, *Maryborough* and *Platypus II* were used to restore navigational depths after the wet season. Similar work was required after each wet season. The points, Gardens, Kangaroo and Bulimba, had extended mud banks after the strong wet flows. These also needed to be dredged regularly to maintain channel depth and width.[1] Construction of Grey St Bridge commenced. Bretts Wharf constructed at Hamilton (re-developed 1994).[3]	Sealing of Pacific Highway was underway.[3]		

1929	Downturn in the economy again. Some dugongs were still being caught in the bay mainly for oil. Mr Moorehouse appointed as Marine Biologist to investigate marine problems in Queensland fisheries. The focus was on trochus, sponges, good fish, turtles and oysters. Flood height at the Port Office gauge = 9'10", Jan 24.[1]	By this time, the Port of Brisbane was well marked for navigation and few new lights or buoys were required. The river was still being developed and regulated. By 1959, training wall phase was drawing to a close, and removal of backwaters and preparation of lower reaches for commercial use was almost complete. Reportedly, the placement of training walls had removed backwaters that had sapped the energy of the tidal and flood flow and the river was now both navigable and virtually self flushing. At this time, the depth was 26' at LW from the bay to Bulimba, and 24' up to Victoria Bridge. Dredging in entrance to Wynnum Creek.[1] Bulwer Island lighthouses built.[5]		The Dept of Harbours and Marine realised that new lands around the lower reaches of the river would increase in value over the years, especially since there was a growing demand for berths for larger and larger vessels. The reclamation of lands around Pinkenba and Hamilton were the first step in this process. Just over a third of dredge spoil was pumped ashore by the *Remora* mostly into the reclamation area above Lytton where the training wall had to be raised from 5 to 10' above LW. The rest of the spoil was dumped in the bay.[1]	Dept. of Harbours and Marine was formed in January amalgamating the earlier departments of Marine, and Harbours and Rivers.[1]
1930	The standard gauge railway from NSW to South Brisbane was opened in September. Interstate transport	Lighting of buoys was converted from carbide gas to acetylene gas.[1] In 1930's, relief work in Sandgate included construction of retaining walls, concrete		New jetty and dolphin for pumping station just below Cold Stores Wharf built to enable *Remora* to discharge ashore and reclaim land there.[1]	

	of goods was no longer solely taken by sea. The relationship between railways and ports was no longer solely compatible, and it had become competitive both for interstate and within-state transport. This applied more broadly again considering the comparable increase in road transport. A regular air service was established by ANA between Sydney and Brisbane. Mud worm disease still badly affected oyster production. A Marine Biologist, FW Moorehouse, was commissioned to investigate the	seawall, shark-proofing and mangrove reclamation.[3]			

	problem and provide recommendations. He established a station on Stradbroke Island in March until July.[1]				
1931	The worldwide economic depression seriously affected local economies, employment and trade. Flood height at the Port Office gauge = 14'8", Feb 7.[1]	Hamilton training wall repaired. It had been damaged by the public who had removed large amounts of stone.[1] Pacific Highway bridge across Logan River.[3]			
1932	Large numbers of turtles were captured during the breeding season on islands off Gladstone and shipped to Brisbane for use in soup manufacture. This industry died out after 1933.[1]	The dredge *Platypus II* in conjunction with *Hydra* commenced deepening the Bar Cutting, Pelican Bank Cutting and Lytton Cutting to 30' at LW. Rat proofing of training wall fronting Botanical Gardens.[1] Grey St Bridge (later renamed William Jolly Bridge) opened, connecting North Quay and South Brisbane.[3, 6]		Lytton wall was raised in preparation for future reclamation. The mangrove and saltpan behind the Hamilton wall and below the Cold Stores was rapidly converted into dry land.[1]	The Fish and Oyster Amendment Act of 1932 sought to control fishing using explosives and noxious chemicals. About this time, push nets for catching prawns in the Brisbane River were made legal.[1]

1933	Gale conditions experienced during February.[1]	In Quarries Reach, *Maryborough* and *Hydra* dredged a depth of 29' at LW.[1] Planning for construction of Story Bridge commenced.[3]	Brisbane area population 341,625 in 79,232 dwellings (city census total 299,748).[3]	Reclamation fronting Hemmant was faced with stone which improved the appearance of Lytton Reach. Reclamation and log walling at Wellington Point.[1]	
1934	In January, a public scare occurred with people fearing that oysters caught off the mouth of the river were infected with typhoid bacteria. Although no evidence was found connecting to the oysters, it was of concern that the farm beds were about one mile from Luggage Point and the sewer outfall. This scare and the already depressed market made it very difficult for the local oyster industry. Unusually large catches of sea	The *Maryborough* made two cuts through the South Brisbane and Town Reaches to clear a depth of 26' at LW with a width of 200'. Silting in these reaches had always been heavy. *Remora* was used almost exclusively on maintenance dredging in the three upper reaches. Late in the year, point cutting was undertaken at Kangaroo Point to create a regularised bend with 800' width of river around the curve. New bridge (Story Bridge) to cross bend almost symmetrically. Cutoff completed 1938.[1] Petrie Bight wharves rebuilt as Brisbane Central Wharves, forming a curve know as Circular Quay.[3]		Protective work was done on Bishop Island where the northerly foreshore had eroded with the high summer tides. Special leases were issued for reclaimed lands around the Hamilton wall for river frontage properties. A large amount leased to wool dumping company – constructed wharfage and accommodation.[1]	To allay fears about contamination of oysters near the Luggage Point sewer outfall, this and adjacent banks were no longer granted a license and removal of oysters in the vicinity was prohibited under penalty. Fisherman were concerned at the time that Moreton Bay was being overfished, and called for controls to net fishing and area closures. By Order in Council net fishing was prohibited in the Port of Brisbane including Moreton Bay on Saturday to Sunday each week.[1]

	mullet were taken in the bay. Brisbane River flood study.[1]				
1935	A severe cyclone was experienced. After a period of nearly 10 years, water hyacinth, reappeared in the Bremer River after rains flushed it downstream.[1]	Berth at Abattoirs Wharf cut down to 30' LW and Borthwick's Wharf berth to 26' by chiselling sandstone rock.[1] Construction of Story Bridge.[3]		Occupation of the Hamilton lands was rapid with the installation of roads, roadside trees, water mains, power and lighting.[1]	The Fish and Oyster Amendments Acts of 1935. The Fish Board was constituted by the Fish Supply Management Act of 1935. The Whaling Act of 1935 made provision for the regulation of whaling in Queensland waters from shore stations in Queensland. The licence allowed the taking of 600 whales in the season over 5 years commencing in 1952.[1]
1936	By this time, line fishing had become very popular as recreation and sport. This resulted in several fishing clubs, and fishing competitions were extremely popular. This included big game fishing. The sale and marketing of fish in the Brisbane area was transferred to the	By this time, the depth of 30' at LW was obtained from the Bar Cutting up as far Upper Lytton Cutting. The diorite dyke at Lytton Rocks would take a bit more time. The Platypus II was able to remove very hard material. Realignment of wharves at Petrie's Bight and construction of central wharves.[1] Coral dredging began at Mud Island.[2] Breakfast Creek straightened and canalised for flood mitigation. Walter Taylor's		By this time, stone had been deposited and walls formed along the whole length as far up as Pinkenba. There was about 8,550' of wall planned. A new pumping station was established at Pinkenba by arrangement with the Shell Company of Australia for the use of their wharf to pump dredge spoil from Eagle Farm Flats, Pinkenba and Hamilton Reaches onto	Strict size limits were enforced on recreational fisherman as well as commercial operators, according to the Fish and Oyster Acts.[1] Queensland Fish Board established.[11]

	Fish Board in July. Water hyacinth was extremely plentiful in the upper reaches of Bremer and Brisbane Rivers.[1]	bridge over Brisbane River between Indooroopilly and Chelmer opened.[3]		low lying land at Pinkenba.[1]	
1937	Gale force winds and cyclonic conditions were experienced in February. Freshwater flows carried water hyacinth downstream where it was killed in the salty water of the estuary around March. The Queensland Game Fishing Association was formed in August. A weighing station was established at Hamilton.[1]	Trench dredged in Norman Creek for City Council sewerage pipes. Berths at new wharves at Newstead dredged to 29' in hard clay. Berth dredged for Hornibrook in Town Reach. Over 100,000 tons of maintenance dredging at private wharves over the year.[1]		Unloading the steam hopper of spoil for reclamation took the same time as driving the hopper offshore and dumping the contents in the bay. An additional cost in reclamation was therefore the cost of plant to pump the spoil ashore. From 1937 to 1938, greater than 50% of dredge spoil from the river was pumped to reclamation of tidal lands at Pinkenba, Hemmant and Lytton. The area reclaimed at Hemmant of 144 acres was surrounded by levees and ditches and was almost above HW but experienced subsidence due to water being squeezed from the	The previous order prohibiting net fishing in Moreton Bay on Saturday and Sunday was repealed as it did not produce an appreciable benefit and increase in the supply of marketable fish.[1]

				deposited material which was mostly mud.[1]	
1938	In July, a mail and passenger flying boat service was extended to Australia connecting to Europe and America via Singapore. The first records of sand crab fishing were presented, at least for commercial fisherman.[1] Queensland state population passed over 1 million.[11]	By this time, the Brisbane River cuttings from the bar to Pinkenba had been cut down to 30' at LW, with the exception of Lytton Rocks where the depth was 28' at LW. From Pinkenba to New Farm the depth was at 28' at LW. A small basin at the end of the Parker Island wall was excavated for the Commonwealth Government moorings for flying boats. This was soon moved however. Wynnum Creek dredged again and protective wall built on E side of entrance channel to stop sand and mud being washed from nearby beach into cutting (completed 1940). Construction of training wall at Hamilton Golf Links, Brisbane River.[1]		More dredging spoil pumped to Hemmant reclamation.[1]	
1939	Australia at war in World War II until 1945. Initially this was a war in Europe. A cyclone occurred in March.	In Brisbane River, electric navigation lights were established in the upper reaches at Oxley Creek and Carrington Rocks. Leads at crossover below Indooroopilly Bridge.		By this time, the general layout of the reclaimed Hamilton lands had taken place. Operations were commenced late in the year on drainage of the	

	A fertiliser and fish meal stock feed production industry was established on the south bank of the river using surplus and non-edible fish and fish offal.[1]	The Mount Crosby Weir was found to prevent movement of mullet and other fish upstream, causing a serious decline in fish numbers above the weir. The Brisbane City Council was persuaded to build a fish ladder at the weir. A complete examination of the river cuttings showed that dredged channels to 30' had deteriorated very little although no recent maintenance had been done. There was no flooding during this period however.[1]		tidal lands between Whinstanes and Meeandah which had been resumed for port purposes in 1910-1913.[1]	
1940	There was a marked increase in turbidity in the Brisbane River. The shortage of edible fish oils in Australia increased demand for oil from dugong and other sources.[1] Main sewer at Pinkenba collapsed, sewerage diverted at Eagle Arm into tidal channel until 1945.[3]	Deepening of the cutting at Lytton Rocks was begun late in the year, but work was not completed due to commitments with the Defence Department. Many naval wharves built over next couple of years in Brisbane River (10 by 1945). Swinging area abreast Abattoirs Wharf completed to 30' LW, 800' clear room. Work began at Moar's Slip, Kangaroo Point, constructing buildings, slipways and wharves for shipbuilding, demolishing old wharves,	1940's rapid urban development and land clearing for agriculture and grazing in upper reaches caused increased siltation.[2]	Sub-divisional roads were constructed, leases negotiated and construction of further industrial facilities were commenced. Reclaimed land between Hamilton training walls and Eagle Farm Road used extensively for US army and navy during war. Some reclaimed land at Hamilton Wharf region leased to Wool Appraisement	

		grading the riverbank, and building retaining wall and storm water drainage system.[1] The Story Bridge was completed and opened.[1, 3].		Committee: wool shed constructed. Also cold store and road construction.[1]	
1941	Japanese air strikes on Pearl Harbour brought the war to the Pacific and Australia in December.[1]	The flying boat moorings were re-laid in the Hamilton Reach. The cutting back of Kinellan Point (5.5 acres dry land) was begun. 300' fitting out wharf built at Moar's Slip, Kangaroo Point. Middle berth at Brisbane Central Wharves, Petrie's Bight, completed.[1]			
1942	A huge influx in troops, ships and aircraft from the USA for the war in the Pacific continued until 1945.[1]	Anti-submarine boom constructed across lower reaches near Lytton. Work on training wall construction ceased in March but recommenced 1946.[1] Port facilities at Pinkenba and Hamilton expanded.[3]			
1943	Fisheries research was carried out in Moreton Bay by the Fisheries Division of the Council for Scientific and Industrial Research. One investigation	By this time, the lack of maintenance dredging had resulted in significant siltation of the channels. In the Town Reach, the depth was only 20' at LW.[1]	Beginning of the Somerset's dam use in flood mitigation (B)		

	was of *Gracilaria* in the hope it may lead to a new industry. The algae is found commonly at the mouth of the Brisbane River.[1]				
1944		Hamilton and Bulimba Reaches had silted badly and depths could only be maintained at 28' at LW. New 600' fitting out wharf built at Kangaroo Point for shipbuilders. Brisbane Graving Dock (Cairncross Dock, for ship repairing) built, dredged and opened at Colmslie (S side of lower end of Hamilton Reach).[1]			
1945	Around this time, an Economic Museum organised by TC Marshall was established to show edible fishes of Queensland.[1]		High-level sewer built linking Eagle Farm and Luggage Point.[3]	The reclaimed land between Hamilton wall and the backwater had been extensively developed by 1945 for the use of the Royal Navy. The land had been given extensive top dressing, buildings and wharves erected and the area transformed into a	The Fish and Oyster Amendments Acts of 1945.[1]

				naval repair base.[1]	
1946	A cyclonic disturbance occurred in March causing a standstill to traffic in and around Moreton Bay for several days.[1] Drought.[3]	By this time, most leading lights in the river had been converted to electric neon lights. Work recommenced at Lytton Rocks Cutting and a depth of 33' was obtained with a width of 100'. *Morwong* and *Remora* were returned to maintenance dredging up to Hamilton Reach. *Maryborough* worked on Bulimba Reach and Town Reach. *Hydra* and *Maryborough* commenced restoration of Bulimba Point. Further dredging upstream involved the blasting and dredging of a rock bar to 9' at LW (completed 1948). Further dredging in Wynnum Creek. Breast wharf at Brisbane Graving Dock extended and berth extended further, with drilling and widening. One jetty built at Hamilton for dredges, 2 at Parker Island. Wall construction recommenced with walls at Lytton and Bulwer being extended and raised. A		Two more pumping stations built at Hamilton reach and Parker Island. Pumping stations at Pinkenba and Lytton continued to be used by dredges when in that part of river.[1]	

		wall around Kinellan Point was made to face off the cut made earlier, and to beautify the site with graded lawns and trees. [1]			
1947	Three periods of strong freshwater flow were experienced. The Harbours and Marine Department in conjunction with the CSIRO established a Fisheries Research Station at Dunwich.[1]	New leads with neon lights were built at the lower end of the Eagle Farm Flats Reach. Additions to South Brisbane Dry Dock to increase berthing space. Wall construction was done from Lytton Wharf to Crab Creek and Whyte Island, and on Bishop Island. Further deepening of the river was in progress at Lytton Rocks and Parker Island to achieve a depth of 33' at LW. There was a great effort put into maintenance dredging after the freshes, especially around Hamilton Reach. All point cuttings had to be restored again. However, large ships were no longer coming up to Town and South Brisbane Reaches.[1]	The Naval wharves D, E and F built on reclaimed lands by Allied Works Council for the Naval Authorities during the war were purchased by the H&M. These were then modified for commercial purposes.[1] Brisbane area population 457,462 in 113,797 dwellings (city census total 402,030).[3]	Levee banks to contain spoil from pumping were formed by bulldozer. This greatly accelerated work previously done by horse and scoop.[1]	
1948	In last years of 1940's, Brisbane assumed role of major port.[1]	Wall construction, as designed by EA Cullen with Harbours and Marine, were all but completed although work	In the 1940s, the levels of siltation had increased alarmingly	Dredges *Remora* and *Morwong* pumped large amounts of dredge spoil onto reclamation areas	

		continued for several years raising, upgrading and maintaining lengths. *Maryborough* dredged the Town Reach. By this time, the blasting and dredging of the Lytton Rocks Cutting with a depth of 34' and 450' wide was completed. Less follow-up dredging in Town Reach and South Brisbane Wharves as large ships no longer came up this far.[1]	possibly due to removal of trees and land clearing along the riverside for farms and housing development coupled with the heavy rains in the years 1947 to 1950.[1]	behind the training walls. Large quantities of spoil were pumped ashore to reclaim the area between the old north bank of the river and Parker Island. Large section of land below Hamilton area was raised to 16' above LW.[1]	
1949		The Pile Light was completely demolished in October when a tanker collided with the structure when entering the bar cutting. A temporary signal and telephone station was established on Bishop Island. Housing was provided with the buildings from Bulwer Island since the lights there had been converted to automatic gas lights. The damaged Pile Light was rebuilt with only a light and no accommodation. An automatic flashing light was established at Six Mile Rocks in the upper reaches opposite		Two more pumping stations were established in Hamilton Reach and Parker Island. These and the earlier stations were used to pump spoil ashore where it was convenient to the dredging at the time.[1]	A special committee, the Hamilton Lands Committee, was formed to investigate the layout of wharves, roads and railway lines from Hamilton to Pinkenba.[1]

		Dutton Park. Many large and small jetties built in Brisbane. Maintenance dredging was unable to keep up with the siltation which had reduced channel depths by one to two feet in some reaches. Dredging in Hamilton and Bulimba Reaches, but difficulty maintaining depth. Borthwick's Wharf berth blasted and deepened to 28' LW to accommodate larger vessels loading frozen meat.[1]			
1950	For the first time a 4 fathom otter trawl was used in Moreton Bay.[1]	The main aim at this time was to get the channel cuttings back to pre-war depths. Siltation was a grave concern. Caisson of South Brisbane Dock repaired.[1]			By an Order in Council, green turtles (*Chleonia mydas*) were declared protected in Queensland waters. However it was still legal to collect turtle eggs. Net staking was legalised for the foreshores of Fisherman Islands and Mud Island.[1]
1951	Heavy rains and run off in February. The water was charged with silt and with the faster velocity of the river in recent years silt was deposited	An automatic electric light replaced the fixed oil light in front of the beacon in lower Hamilton Reach. A uniform system of buoyage and dredger signals for use in Australian ports was adopted in June. Lower reaches deepened to 31'		Reclamation works were still being done at Parker Island, Hamilton and Pinkenba with suction dredges pumping into the head of Hamilton Inlet.[1]	

	Quarries and Eagle Farm Reaches instead of Pinkenba as was the usual case.[1]	at LW.[1]			
1952	A whaling industry and factory was established at Tangalooma and licensed to catch 600 whales in the season. The first whale was killed in June. Oil was brought to storage tanks in the lower reaches of the Brisbane River. The industry collapsed after a few years.[1] Otter trawling was introduced widely for catching prawns.[2]	The Pile Light was automated with an acetylene light in October. The signal station at Bishop Island was retained. BHP's wharf extended upstream. Temporary wheat handling facilities installed at Pinkenba Railway Wharf. Ampol started using M-Wharf at Parker Island as tanker berth.[1] Victoria Bridge to be replaced.[3]		A further pumping station was set up at wharf F to facilitate reclamation of Hamilton Inlet.[1]	An Order in Council in June authorised the use of otter trawl nets for taking prawns in Queensland waters.[1]
1953	River water silt content and salinity were examined and recorded. Monthly	Dredging was done at 17 Mile Rocks Reach to clear a shoal patch which had developed below the rocks. *Echeneis*			

	samples were collected at Lytton, Hamilton and Town Reach. It was believed that silt was coming upstream from the river mouth. This was contrary to expectation that silt might come from upstream with the flow. Silt loads were found to be highest during high tide rather than low tide periods. Therefore silt dumped out in the bay could find its way back into the river.[1]	joined *Remora* and *Morwong* dredging Town Reach to Hamilton. Parker Island M-wharf extended to suit tankers. Vacuum Oil company built modern tanker berth at Colmslie, just upstream from Abattoirs.[1] Lighthouses on Bulwer Island converted to automatic gas flashing lights.[5]			
1954	A cyclone hit SE Queensland in February and caused severe damage and loss to the prawn fishery fleet. The GBR Committee	A wireless station was erected at Lytton for use of the pilot service and the Bishop Island station was closed. This station was later designated as the Control Tower for the Port of Brisbane. Only maintenance dredging was carried out in the	Brisbane area population 575,205 in 152,798 dwellings (city census total 502,320).[3]	Another pumping station was set up at Pinkenba to facilitate reclamation works. At this time, around 73% of dredge spoil was being used for reclamation with the rest being dumped in the	By this time, there were three fulltime Fisheries Inspectors stationed in Brisbane. In September, the Fish Board assumed some measure of control over the marketing of prawns.[1]

	conducted a survey of Low Isles comparing results with the 1928 expedition.[1]	river cuttings and berths, as well as the points upstream. Maintenance dredging at Pinkenba Wharf, Hamilton Reach, Bulimba Reach, Town Reach, Bulimba Point and Kangaroo Point.[1] New Norman Creek Bridge opened.[3] Bulwer Island training wall built up (rocks cemented to keep rats out) and extended.[5]		bay.[1]	
1955	Frequent heavy rains were experienced in March (flood: 11'6''), and these carried particularly high silt loads from cultivation on banks in upper reaches, dumping sediment in the upper reaches.[1] Eagle Farm sewerage pumping station and outlet operated at Luggage Point.[3]	A black buoy was placed near the Clara Rock buoy to mark the southern extent of the shallow water in the Lytton Rocks Cutting. Much dredging after flood. Removal of 15,000 tons per day was not sufficient to reverse a decrease in depth in the Hamilton Reach. Construction of Shell oil terminal at Pinkenba with berth 33', plans for 800' wharf.[1]			The Harbours Act of 1955 consolidated and amended earlier laws, and among other things sought to control reclamation, dredging & structures below high water mark. Foreshores and land lying under the sea within Queensland waters as well as lying under harbours were deemed to be the property of the Crown. Special leases for land lying below high water mark could be granted by the Governor in Council. The Fish and Oyster Amendments Acts of 1955 prohibited jags, gaffs and like apparatus from being used solely to catch fish. The Commonwealth Fisheries Acts of 1952 and 1953 were enacted. These

					sought to regulate and control Australian fisheries, defining territorial limits of the states.[1]
1956	Very wet period in early part of year.[1]	The western and eastern Bar Beacons were replaced with a pile structure and automatic light. Dredges busy removing silt. Navigation depth from mouth to Pinkenba still only 24' LW: claimed not safe, too shallow. Cable trench dredged in Canoe Reach (up-river). [1]		Dredged sand pumped ashore at Pinkenba.[1]	
1957		Eagle Farm Flats and Parker Island Cuttings had been widened to 450' and swinging basins enlarged. Further dredging by *Tridacna* in Wynnum Creek and Seventeen Mile Rocks, as well as approach and basin at Manly in preparation for small harbour.[1] New bridge constructed at Breakfast Creek. New Indooroopilly railway bridge completed.[3]			Licenses were issued for the removal of shell grit and coral, restricting the location and types of equipment used. In February, an exclusive licence was granted to QCL to take coral from Mud Island which it did do until 1983. After this it moved this operation to St Helena Island, where it continued until 1988. The Fisheries Act of 1957 sought to consolidate and update all Queensland fisheries namely, whaling, pearling, oystering and others.[1]
1958	An exceptionally dry early summer meant that there	Pinkenba and Upper Lytton Cuttings were widened by bucket dredges, *Groper* and			The Queensland Marine Act of 1958 sought to control and regulate merchant shipping. The Canals Act

	was some cessation to channel siltation.[1]	*Platypus II*. Installation for bulk handling of wheat completed at Pinkenba Railway Wharf.[1]			1958 sought to control canal developments.[1]
1959		Somerset Dam completed.[2]			There continued to be three fulltime Fisheries Inspectors stationed in Brisbane.[1]
1960	The use of ports had changed. Passengers were far fewer and trade was more international with bulk cargos. Ports had to change to meet this new demand.[1] During February and March, diatom (*Melosirag ranulata*) blooms were recorded in the upper estuary. Later that same year and again in 1963, very large blooms of the diatom (*Coscinodiscus centralis*) were recorded in the estuary.[8]	The least depth of water in the river channel up to New Farm was 26' at LW. Rock removed from Seventeen Mile Rocks and placed along banks as river wall. Two walls (Bulwer Island and Fisherman Islands) remaining to complete wall development of lower Brisbane River, although some others needed raising and finishing. South Brisbane Railway Wharf (coal wharf) demolished in 1960's to make way for Captain Cook Bridge.[1]		Active filling and mangrove expansion towards Bulwer Island training wall.[5]	The Pollution of Water by Oil Acts of 1960 to 1961 provided penalties for oil spillage in Queensland.[1]

1961	The 1961 census taken in Queensland. Population of 1,518,828.[1] Closure of the Tangalooma whaling station.[2]	Commencement of considerable development and wharf construction. Extension to Stevedoring and Wool Dumping general cargo wharf in Hamilton.[1] Moogerah Dam completed.[2]	Dispersal of industry from CBD to outer industrial areas and estates (60's and 70's).[3]	Much reclamation of tidal wetland started at Bulwer Island, from spoil adjacent to site, and from various cuttings. Total area of 500 acres to be made available to Amoco for tanker terminal and refinery. Before reclamation, 170 acres of mangroves had to be cleared, and sand pumped to raise level. Amoco to build refinery on reclaimed land on N bank of Bulwer Island. This required extensive reclamation, with fill pumped to island by suction dredges.[1] By this time, 260,000 cubic yards of fill had been pumped onto Bulwer Island.[5]	
1962		Seventeen Mile Rocks cutting deepened to 5'6'' in LW and 90' wide. Amoco and Phillips Petroleum built oil terminal in Pinkenba Reach. Wharves constructed by Ampol and		200 acres of Bulwer Island cleared for future Amoco refinery.[5] First areas of Amoco refinery property on Bulwer Island filled.[5]	

		Amoco to serve oil refineries at river mouth. Many old unsightly wharves removed along river.[1]			
1963		New suction dredge *Saurian* commenced work. Rehabilitation of South Brisbane Graving Dock commenced.[1]		*Saurian* worked on reclamation at Bulwer Island and then reclamation in vicinity of river for wharf and industry.[1] Entire northern end of Bulwer Island cleared of mangroves. Felled mangroves left on site and covered with sand.[5]	
1964		Developmental dredging and maintenance dredging up to and including Bulimba Reach, approaches to Amoco Wharf, deepening of Parker Island Cutting and Hamilton Reach, and new berth for BHP wharf extension at Hamilton. Dredging of Bay channels and swing basin at Luggage Point. Construction of Ampol product wharf at Lytton. Upstream section of South Brisbane Railway Wharf reconstructed.[1]	New BCC building code facilitated highrise development. Centenary Bridge opened Jindalee area up for suburban development.[3]	Further 200 acres of reclamation at Bulwer Island pumped from river deposits. Approximately half of spoil from river dredging works pumped ashore, half dumped in Bay. Dredge spoil from Bar Cutting and Luggage Point swing basin pumped to reclamation on Fisherman Islands. Spoil from Ampol Terminal Berth pumped	

		Centenary Bridge over river in Jindalee area.[3]		to reclamation on Ampol Refinery site.[1] Major construction of refinery on Bulwer Island began (completed 1965).[5]	
1965	Planning for future development of Port of Brisbane from Bulimba Reach to mouth. Needed larger dredge fleet to keep up with maintenance dredging. Cabinet decided South Brisbane Dock to be closed, transferring activities to Cairncross Dock. Operations ceased 1972.[1]	Further removal of the Seventeen-Mile-Rocks, dredging new channel on S side to 12' LW. The port was prepared for the larger modern ships, especially tankers. From the Pile Light to Luggage Point depth of 38', Luggage Point to Pinkenba depth of 28', Pinkenba to Norris Point depth of 27', Norris to Circular Quay depth 22', and Circular Quay to Victoria Bridge depth of 17'. Cairncross Dockyard (Brisbane Graving Dock) upgraded. Improvements to M-Berth at Pinkenba but major reconstruction required. Old Redbank Wharf demolished in Quarries Reach.[1] Ampol oil refinery opened at Lytton.[3]		Area (1 acre) upstream of ACF and Shirley's Wharf and downstream of Pinkenba Wharf reclaimed by landfill of ash and breeze – leased to ACF and Shirley's. Dredges continued to pump ashore to reclamation at Hamilton, Parker Island and Lytton. Stone and gravel revetment of river frontage completed to prevent erosion of sand reclamation of Amoco tank farm area. Final section of refinery lease reclaimed at Bulwer Island, pumping sand from Boggy Creek. Further reclamation in area until 1967 for road access, Brisbane City Council Park, etc. Little	

				sand for reclamation left in lower Brisbane River. Sand for Imperial Chemical Industries ammonia and fertiliser plant reclamation at Pinkenba taken from Moreton Bay, as not enough left in river.[1]	
1966		Construction of Ampol crude oil wharf on N bank at Luggage Point. Department's old dredge wharf at Hamilton had deteriorated and was demolished, making way for new extensions to Brett's Wharf. Demolition of D-Berth downstream from Messageries Wharf and old wharf at Colmslie Fish Board site to make way for new jetties.[1]	Brisbane area population 778,193 in 215,668 dwellings (city census total 593,668). CBD building boom in highrise construction until 1971.[3]	Another substantial pump out station constructed at Fisherman Islands to allow progressive reclamation of valuable area in development of Port of Brisbane. New jetties (at old D-Berth and Colmslie Fish Board Site) to be main discharge point for dredge *Sir Thomas Hiley.* Also used for *Morwong* in 1969/ 1970 for spoil from Fisherman Islands swinging basins, and lower reaches and berths. Reclamation of 300 acres progressively carried out (ultimately 2000 acres required). Spoil from	

				Ampol and Amoco oil berths and the deepwater Fisherman Islands swing basin.[1]	
1967	Floods in June.[1]	New beacons replacing old at outer Bar Cutting entrance. Pile Light at Bar Cutting demolished. Brisbane River wooden leading beacons replaced with steel structures. *Groper* excavated rock at Lytton Rocks cutting, deepening it to 34' LW. Australian National Line roll-on roll-off terminal at Newstead. Extension of berth at Bretts Wharf, Hamilton. Cairnscross Dockyard to undergo improvements (starting 1969, completed 1972).[1] Construction of new Victoria Bridge commenced.[3] Bulwer Island training wall extended to tip of island (work until 1972).[5]	First CBD highrise to exceed height of City Hall (MMI building, Queen Street).[3]	Saurian completed land reclamation for Amoco refinery on Bulwer Island.[5]	
1968	Jan 28 announcement of State Government plan to allow the construction of	No difficulties were experienced in handling the large oil tankers following the construction of two oil refineries in the lower reaches of the river. Increased		Parker Island reclamation area closed and pump out jetty demolished. Dredges upstream then had to discharge most	The Beach Protection Act of 1968 enabled the creation of the Authority responsible for investigations into coastal erosion problems and providing advice on mitigation to

	"Alberta City" on Coomera island. Strongly opposed by the Australian Littoral Society and Wildlife Preservation Society. Project abandoned. Start of 15 yr campaign to have area protected. Minor flood January.[2]	rate of siltation (from flood) in lower reaches required maintenance dredging. Main overseas terminal constructed by Brisbane Wharves and wool dumping company at their Hamilton No. 2 Wharf.[1]		spoil at Lytton/ Fisherman Islands pump outs. Approximately 65 acres at Lytton acquired from Commonwealth for filling by reclamation: bundwall constructed with imported solid fill, and diversion drainage channel excavated.[1]	local authorities.[1] Protection of all species of sea turtles in Queensland since 1968 under the Fisheries Act.[2]
1969		*Groper* and *Morwong* dredged Outer Bar Cutting where shoaling had decreased depth. Channels to Hamilton Reach dredged to 28'. Container load facility and roll-on roll-off terminal at Newstead completed, with wharf, crane and ramp. Austral Pacific Fertilizers completed complex at Gibson Island, with wharf and dredged berths.[1] Modern container facilities for Stevedoring built at Pinkenba. New Victoria Bridge opened.[3]		An area of almost 50 acres at Parker Island reclamation topped with sand to permit early leasing for industry. Development of Hemmant Industrial lands: reclamation with sand from Aquarium Passage started, a long-term project.[1]	Fisheries Section. Declaration of Pumicestone Passage, Deception Bay, Kippa-Ring, Hay's Inlet, Moreton Banks, Myora and Jumpinpin - Broadwater Fish Habitat Areas.[2]
1970	1970's large scale	*Saurian* dredged river to		By this time, a large part	

	seagrass loss in Deception Bay area.[2]	Cairncross Slipway. Preparation work commenced for deepening river channels to 30'. Deep trench excavated across Town Reach opposite Creek Street for telephone cable conduit.[1] Between 1900 & 1970 at least 12 million cubic metres of gravel & sand had been removed from the Brisbane river for local construction industry. Extraction peaked in the 1970's at 1.45M cubic metres per year. Annual production now is ~1Mcubic metres.[2]		of the original Parker Island reclamation had been developed for industry. Filling commences at Lytton reclamation: initial reclamation was 125 acres.[1]	
1971	Flooding, heavy rainfall runoff and siltation in February.[1]	Siltation (from flood) leaves Bulimba to Fisherman Islands seriously affected and heavy maintenance dredging carried out. *Saurian* used for developmental dredging in Scarborough Boat Harbour. Second grain terminal to be built at Pinkenba. *Tridacna* maintenance dredging at various points, e.g. Cairncross Dock and Wynnum Creek. *Sir Thomas Hiley* started dredging channels.[1]	Brisbane area population 867,794 in 251,037 dwellings (city census total 717,330).[3]	Over half spoil from Brisbane River Reaches pumped ashore. Spoil from channels dredged by *Sir Thomas Hiley* pumped to reclamation on Fisherman Islands or dumped in bay. Spoil from Scarborough Boat Harbour dredged by *Saurian* used in reclamation of tidal flats on Boat Harbour frontage.[1]	Beach Protection Authority. Clean waters Act 1971. Declaration of Peel Island Fish Habitat Area.[2]

1972	South Brisbane Dock ceases operation.[1] Flood February.[4]	Improvements of Cairncross Dockyard completed and new complex opened. *Sir Thomas Hiley* dredged reaches from Fisherman Islands to Hamilton to 30'. Blasting of bedrock at Pelican Banks Reach. Dredging of Qld Cement and Lime Co. berth and approaches at Bulwer Island for new clinker plant.[1] Captain Cook Bridge opened.[3]	Most Brisbane streets were now sealed.[3]	Dredged mud, clay and rock pumped ashore at Fisherman Islands, Lytton and Hamilton reclamation, and the rest dumped in Moreton Bay. Spoil from new Qld Cement and Lime Co. berth at Bulwer Island pumped to reclamation.[1]	
1973	Queensland state population reaches over 2 million.[11] South-east freeway-Juliette to Springwood opens.[12]	*Mourilyan* removed some of displaced mud of N bank of South Brisbane Reach caused by construction of Riverside Expressway. Three dolphins at M-berth and old coal berth at South Brisbane demolished.[1] Maroon Dam completed.[2]			The Pollution of Waters by Oil Act of 1973 enabled action to be taken against the owner or master of any ship or occupier of land where a discharge of oil occurred into the water.[1]
1974	Flooding of the river in January.[1] 1:100 year flood associated with reported loss of coral communities from Raby and Waterloo Bays.[2] The 5.5m flood caused an estimated	Powerful day and night lights established on shoulder beacons at Bulwer Island. New leads marking cuttings at upper Quarries Reach. Heavy siltation, dredging to regain depths. Dolphin-type wharf built at Pinkenba Wharves Wheat Board Bulk Handling area to serve larger grain ships.	1974 study by QDPI found 14% rural land in the catchment subject to severe soil erosion as a result of agricultural practices, 73% less severe erosion & 13%	Spoil from Fisherman Islands dredging (*Saurian*) pumped to adjacent reclamations.[1]	Environment Protection (Impact and Proposals) Act 1974 – ensures that matters significantly affecting the environment are fully taken into account by or on behalf of Aust. Gov.[2]

	$200 million dollars of damage and 14 lives were lost.[4]	Maynegrain completed and commissioned second grain storage and loading facility at Pinkenba. Maynegrain commenced construction of silica sand export complex at Pinkenba, with large shed, wharf and dredged berth. Oil seeds processing plant constructed at Pinkenba. *Saurian* dredged at Fisherman Islands, extending approaches to pump-out stations downstream from Ampol Crude Oil Wharf.[1]	negligible erosion. Report of the working committee on long term planning between Jumpinpin Bar & the Nerang river bridge. 1974 Moreton region non-urban land suitability study.[2]		
1975	1975 Coastal management investigation.[2]	Maynegrain large silica sand storage shed and barge unloading wharf completed in Pinkenba wharf area. *Saurian* dredged Cairncross Dockyard Slipway to remove flood siltation. New road built at Bulwer Island to service development of Queensland Cement and Lime Company's new mill complex on waterfront lease land.[1]			Australian Heritage Commission Act 1975 inventory of Australia's natural and cultural heritage. Great Barrier Reef Marine Park Act 1975 – establishment, control, care and development of marine parks in the Great Barrier Reef Region. National Parks and Wildlife Act 1975.[2]
1976	Port of Brisbane Authority took over full control and	Construction of service roads and associated underground drainage works for Hemmant	Brisbane city census population 724,801.[3]	Port of Brisbane Authority initiated development of	Port of Brisbane Authority Act of 1976 established the Authority as a separate and autonomous body.[1]

	management of port. Soil investigation work at new port complex site, Fisherman Islands.[1] 1976 Moreton region growth strategy investigation.[2] The Riverside Expressway was completed, which was part of the developing South-East Freeway.[6]	Industrial Port Land completed.[1] North Pine Dam completed. Hinze Dam completed. Bulwer Island grinding plant completed.[2] Last cargo ship used Newstead wharf, as port moved downstream to service larger container ships.[3]		Fisherman Islands near river mouth (until 1978).[3] Spoil from SE side of Inner Bar Cutting pumped onto Fisherman Islands for reclamation.[1]	Fisheries Act 1976. Historic Shipwrecks Act 1976. Fauna Conservation Act 1976.[2]
1977	Design work for Port of Brisbane Fisherman Islands container wharves.[1]				AMSA guidelines for protection and management of estuaries & estuarine wetlands.[2] Inaugural Brisbane River Symposium.[8]
1978	1978 study delineated mangrove & saltmarsh distribution on a 1:1000 000 scale vegetation map.[2]	Following successful field trials in 1975, the first conversions of navigation light systems to solar power were made.[1]		Section of mangroves cleared on Bulwer Island. Boggy Creek redirected to connect with airport drainage channels (work until 1981).[5]	The National Plan to Combat Pollution of the Sea by Oil was presented in June 1978 to the Commonwealth Parliament. This Act provided an effective administrative environment under which first response equipment, personnel and training were

					described.[1]
1979	The 1979 census taken in Queensland. Population of 2,222,700.[1] Olsen brief description of habitat reserves & maps indicating boundaries. 1979 Dowling provided a field key and generalised account of Moreton Bay mangroves.[2]			Pilot project revegetating Bulimba Creek began by Australian Littoral Society.[3]	
1980		New Brisbane Airport developments relocated last resident from Cribb Island community and redevelopment occurred near the mouth of the river. Wharves on Fisherman Islands were opened by the Port of Brisbane Authority.[3, 12] New lights on limit leads at Bulwer Island and swing basin leads for new wharves at Fisherman Islands.[1]			Trawlers >14m length with Moreton Bay permits were restricted to fishing grounds south of Sandy Cape.[2] St Helena Island was gazetted as a historic area. Moreton Island was listed on the National Heritage register.[12]

1981			Brisbane city census population 731,230.[3]		Environment Protection (Sea Dumping) Act 1981 – disposal of dredge spoil from Queensland's major trading ports.[2]
1982	Cited study of Southern Moreton Bay measured mangroves as 6950 ha and saltmarshes 2870 ha.[2]				Queensland Marine Parks Act 1982.[2]
1983	Main trade: import of crude oil and general cargo; and export of grain, meat, coal and refined petroleum products.[1] Economic boom.[3]	New oil storage tank erected at Amoco Oil Refinery obscured rear Bulwer Island lead so new higher leading beacon erected. By this time, Port of Brisbane Authority completed construction of 2 container terminals, bulk coal export facility and bulk cement import installation at Fisherman Islands and were constructing a bulk grain installation.[1]		Hamilton and Pinkenba reclamations were completed. Last pump-out was pulled down, ending 85 years of pumping fill to these reclamations. Pinkenba and Hamilton were rapidly developing into industrial estates.[1]	World Heritage Properties Conservation Act 1983 – protects and conserves those places under Aust. control which contain outstanding universal values. Declaration of Bribie Island, Pimpama, Coomera and Coombabah Fish Habitat Areas. Nov 19, threatened tidal wetlands became protected as Coomera Island Wetland Reserve.[2]
1984			158 blocks of land for sale at the controversial Raby Bay Canal.[12]	BP acquired Amoco refinery on Bulwer Island.[5]	Aboriginal and Torres Strait Island Heritage Protection Act 1984 protecting Aboriginal and Torres Strait Islander archaeological sites and traditional places.[2]
1985	Gold Coast Seaway	Wivenhoe Dam completed on			

	opened.[2]	the Brisbane River.[3] Dredging for airport work in Boggy Creek.[5]			
1986		Gateway Bridge finished and opened over river between Eagle Farm and Murrarrie.[3]			
1987	Reported loss of 8.4% of mangrove and 10.5% of saltmarsh/ claypan communities since1973. Reported return of seagrass to Deception Bay since 1975.[2]	Max dimensions of shipping channel reached 11.6m deep, 180m wide at river mouth; 9.1m deep, 120m wide at Hamilton.[2]	Brisbane city population 736,080.[3]		
1988	Coral dredging at St Helena Is ceased.[3]				
1989	Reported 38% loss of Melaleuca wetland in SE Qld since 1974.[2]	The operation of Wivenhoe Dam helped mitigate moderate flood levels in April. However, after the dam water flow was shut off there was massive riverbank slumping downstream. Rates were slowed down to try a fix the problem and no major riverbank slumping was recorded after a second flood later that year.[8]	Brisbane city population 744,828.[3]		

		Admiralty Wharf development with boardwalk access.[3]			
1990		1990's Cleveland Point and Raby Bay entirely enclosed by seawalls.[2] Crude oil pipeline construction commences on Bulwer Island (until 1994).[5]		Approval given for R/O marine plant regrowth from 80 ha reclaimed tidal land at Lamerough Ck, Caloundra.[2]	Dugong listed as vulnerable to extinction.[2]
1991	Flash flood Feb 8.[3]		Brisbane city census population 763,038.[3]	Approval given for reclamation of 150 ha of tidal land at Dux Ck, Pumicestone Passage.[2]	
1992		Dredging of Cabbage Tree Creek with spoil disposal at Dynah Island.[2]	Brisbane city population 767,324.[3]	Approval given for reclamation of 145 ha of tidal land at Fisherman Islands, Brisbane River.[2]	Nature conservation Act 1992. Declaration of Extension to Myora Fish Habitat Area.[2]
1993			Brisbane city population 777,280.[3]		Government establishment of the Brisbane River Management Group. Moreton Bay Marine Park declared.[2, 3] Land claims prepared for Peel Islands and North Stradbroke Islands.[12]
1994			Brisbane city population 786,442.[3]		Environmental Protection Act 1994.[2]
1995	Reported 38% gain of seagrass and some loss of species		Brisbane city population 801,879.[3]		Moreton Island declared a National Park.[12]

	since 1987 in Southport Broadwater.[2]				
1996	Reported approval given for removal or disturbance of 4 ha of mangroves and saltmarsh in Moreton Bay region. Reported complete loss of seagrass from mouth of Logan River since 1987. May 1996 flood significant. Affected coral and seagrass communities. Rated as 1 in 20 year event resulting in medium to high flows & flushing pollutants out of the estuaries into the bay. Resulting algal blooms may be linked back to mainly Brisbane river.[2]		Brisbane city census population 819,592.[3]		Coastal Protection Act of 1996.[2]

	All the seagrass from Southern Deception Bay was lost.[7] Queensland state population of 3,374,000.[11] Brisbane City Council first high speed city cat commenced at Bulimba.[6].				
1997	Dieback of 280 ha of mangroves associated with hail storm damage reported for southern Bay islands. Moreton Bay Trawl Discussion Paper released.[2]	75% of residential properties "protected" by seawalls. [2]	Heavy metals and hydrocarbons in sediments from urban runoff were recorded in some urban creeks after heavy rain. Recent tests on mud crabs showed only low levels of metals and persistent insecticides. However, a broader analysis of all intertidal fish and crustaceans has		Moreton Bay Marine Park extended.[2]

			not been undertaken.[2]		
1998		Extractive dredging in the Brisbane river ceased in December, 1998, however, on-going navigational dredging in the lower reach continues.[2]			
2000/ 2001	Mangrove dieback, possibly from altered drainage patterns, under investigation at Hay's Inlet, Luggage Point and Fisherman Islands. Start of nutrient removal upgrades for municipal waste water processing units (Logan, Brisbane, Pine Rivers, Caboolture and Redcliffe).[2]				The amended East Coast Trawl Fishery Management Plan comes into force.[2]
2003	Major oil spill (~ 1.2 million litres) in mangrove-lined channels and drains in the Lytton area. Approximately 1-2				

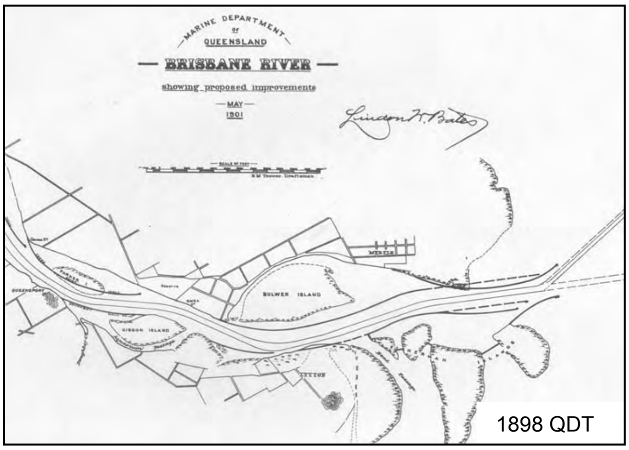
	hectares of mangrove dieback as a result.				

(1) Department of Harbours and Marine (1986). Harbours and Marine: Port and Harbour Development in Queensland from 1824 to 1985. Department of Harbours and Marine, Brisbane.
(2) DPI Fisheries (2002). HC3 Timeline.
(3) Fisher, R. (1999). Brisbane Timeline: From Captain Cook to City Cat. Brisbane History Group, Brisbane.
(4). Commonwealth Bureau of Meteorology (2003). Known Floods in the Brisbane and Bremer River Basin.
http://www.bom.gov.au/hydro/flood/qld/fld_history/brisbane_history.shtml
(5) Harris, C. (2001). A Scoping Study: Mangrove Rehabilitation at BP, Brisbane, Queensland. Hons. Thesis. The University of Queensland, Brisbane.
(6) Brisbane City Council (2003). Our City and Suburbs: History of Brisbane.
http://www.brisbane.qld.gov.au/ourcity_andsuburbs/about_brisbane/history.shtml
(7) Moreton Bay Catchment Water Quality Management Strategy Team (1998). The Crew Member's Guide to the Health of our Waterways. Moreton Bay Catchment Water Quality Management Strategy Team, Brisbane.
(8) Davie, P., Stock, E. & Low-Choy, D. (1990). The Brisbane River: A Source Book for the Future. The Australian Littoral Society Inc., Brisbane.
(9) Brisbane City Council (2003). Boondall Wetland Site.
http://brisbane-stories.powerup.com.au/boondall/boondall_pages/history/hist.htm
(10) The Courier Mail (2002). Our Queenslander, Book 2 – The Great Unknown: Tyrants and Triumphs of Settlement, May 12-24. The Courier Mail, Brisbane.
(11) The Courier Mail (2002). Our Queenslander, Book 11 – Fortune and Fame: Money and the Wealth to Come, May 12-24. The Courier Mail, Brisbane.
(12) The Courier Mail (2001). Birth of our Nation: Timeline – Greater Brisbane.
http://www.thecouriermail.com.au/extras/federation/

Appendix 4 - Historical Timeline for Bulwer Island

(note: feet distances have been converted to metres)

1898	Plans were laid out for proposed training of the river. These plans showed that small islands along the Brisbane River, such as Gibson, Parker and Bulwer Islands, were to be joined to the main land to enable the formation of a smooth riverbank Initial construction of the training wall began upriver (Davenport 1986)



1898 QDT

1903	The training wall was begun along the eastern side of Bulwer Island and known as the Bulwer Training Wall. It was completed in 1906 (to a level of about 2m above low water mark) therefore closing off the connection of what is now Boggy Creek to the Brisbane River.
1903-1946	Active filling to expand island to the training wall
1912	Bulwer still without spit, described as being covered with “dense low mangroves”, mud covers at ¼ flood Middle of the river sounded at 23ft (about 8m) at the deepest
1912-1929	Spit reclaimed
< 1929	Lighthouses built by 1929 (Davenport 1986)

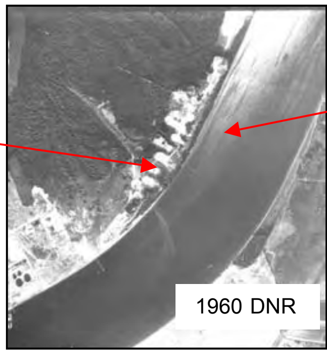
1936 — Reference to cotton bush and grass inland of training wall, to the south of the island.

1953 — Lighthouses converted to automatic gas flashing lights so people moved on and houses moved to Bishop Island for lightkeepers’ cottages. (Davenport 1986)

1954 — Transect across mud in line with the lighthouse → -1 to -3ft depth for mud, 3-7ft for mangroves then 10-12ft height on sand and grass to the lighthouse

The training wall was built up (rocks cemented to keep out rats) and extended

1960 — Filling taking place (began between 1903 and 1946), land heights of about 3 to 4.5m above Low Water Datum in three different areas of the island (1961 map). Area behind where pipe is now still below low tide mark.

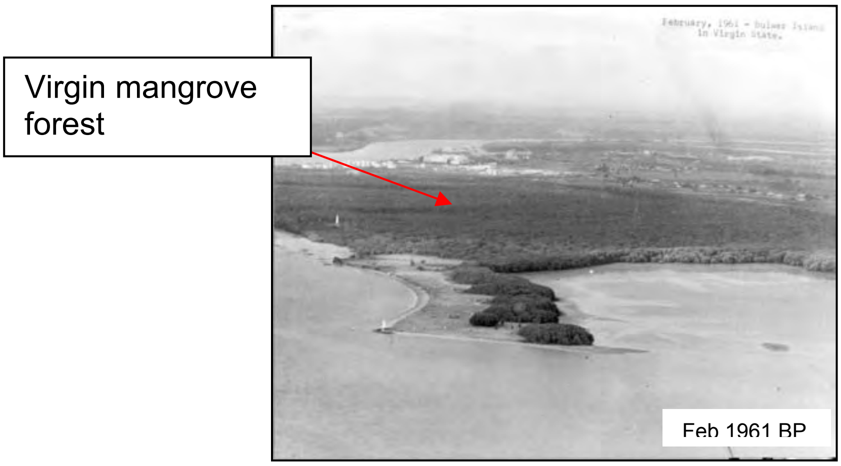


1961 — Bulwer Island described as “tidal swamp, dense mangroves”
Area of mudflats sounded between 0.5 and 1m below low water datum (3/61)

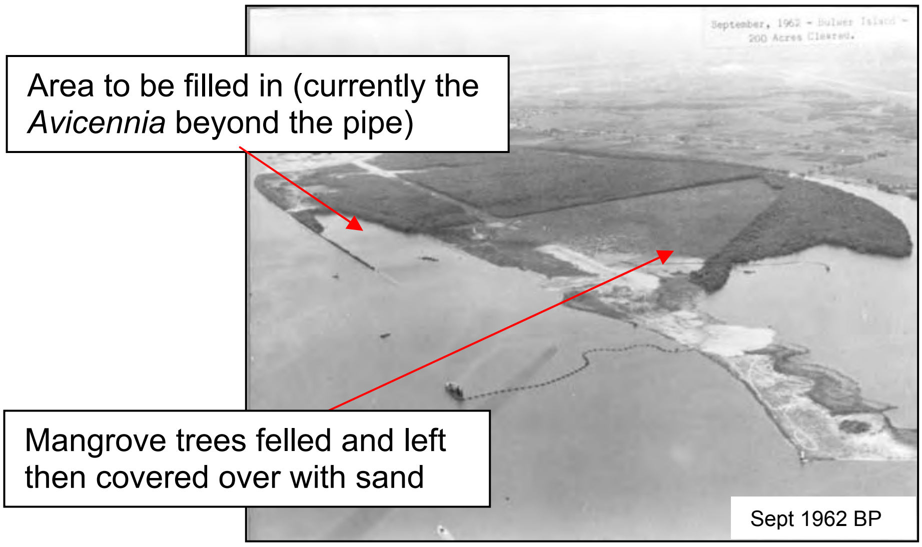
Bores by “Tridacna” showed mud to depth of 1m, then sand until 3m depth, at 3.8m mud and 4.7m sand again. Others with 1m mud then sand until 6.4m depth, then clay. (Tridacna in operation from 1894 to 1975.)

By June (1961) 260 000 cubic yards of fill had been pumped onto the island (Davenport 1986)

Tip of Bulwer reclamation described as sand partially grassed.

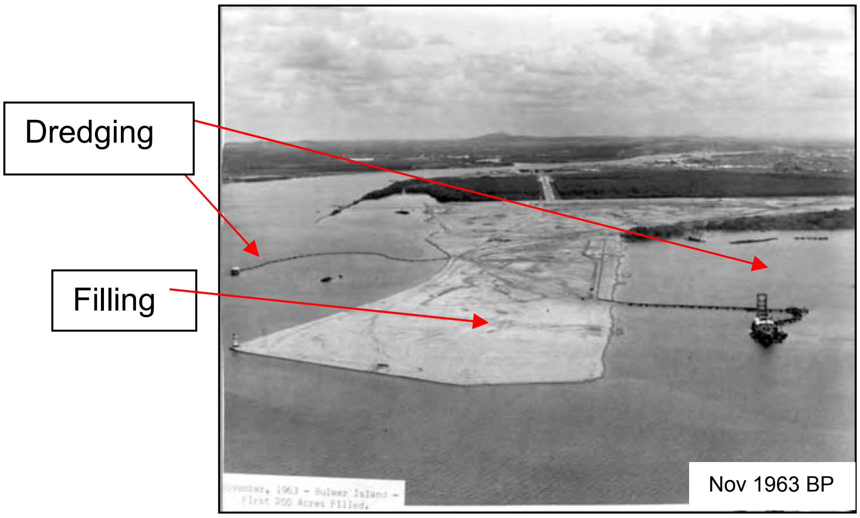


1962 200 acres of island cleared for future refinery using tractors with chains attached between them (9/62)



Plans for further wall construction laid out with bores done showing depths of water and sediment types. 0 - 2m water, then 2m – 5.5m depth silt and sand, then sand layer to about 12.2m then clay to around 33m. The very bottom samples showed shale or clay of basaltic origin.

1963 | First areas of refinery property filled (November)



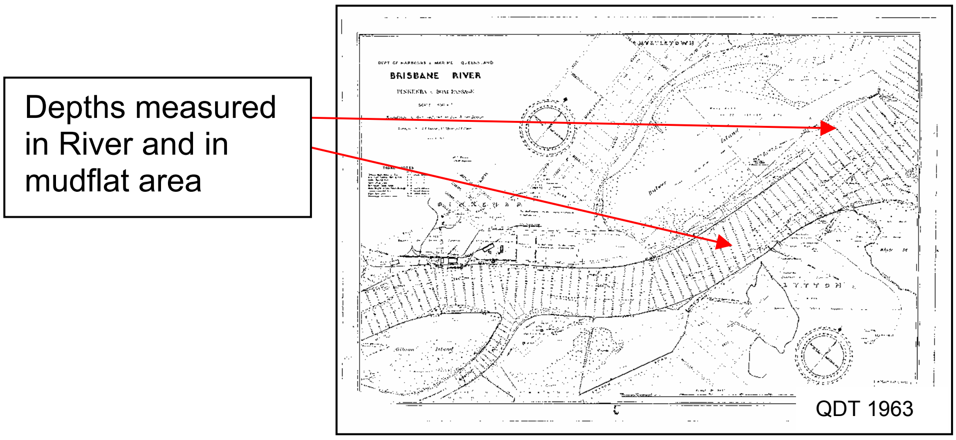
Rock wall only at middle length as shown in 9/62 photo above

Dredging done near the tip (before wall extended) by Sandpiper and main dredging from Boggy Creek

Dredging done by “Sandpiper”, “Kaione”, “Kawana Island” and “Queen of Holland” to a depth of around 5m below low water datum.

Bore holes done at the same time showed 1.5m of mud then from 1.5m to 3.6m was sand. At the deepest, clay or sand and gravel found. (17/11/63).

Limits of dredging set at 200ft or about 70m from land boundaries



Lytton Rocks cutting mapped – depths of 30ft below low water datum at deepest (18/10/63)

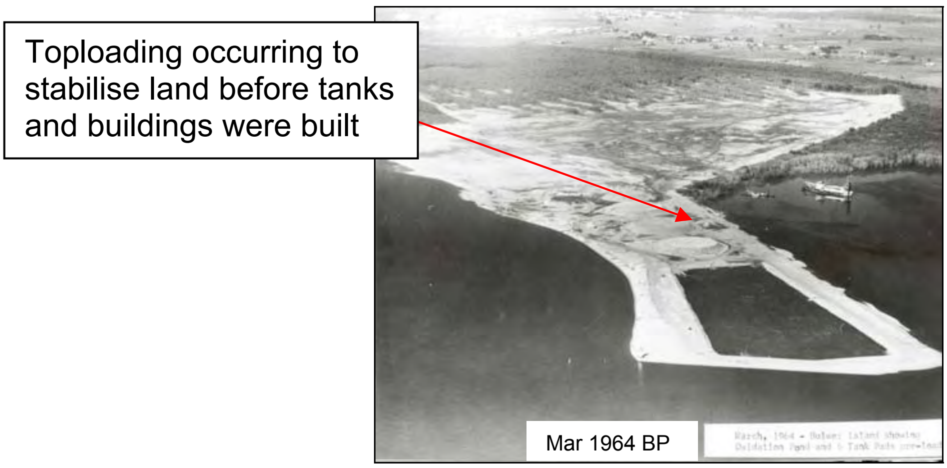
Levels mapped over whole island

1964 Major construction for the refinery began and was completed in 1965. $25 million spent on initial construction.

Soundings done across mud flats with shallow depths of 0.3 – 1m below low water datum then in deeper parts 3.8 – 7m depths recorded.

Water areas being filled in (compare 1962 photo above) land at about 3ft above low water datum by this stage. It seems that mangroves have colonised very quickly since the area was filled in between 1962 and 1964 (21/10/1964).

Lytton rock cutting mapped – 200 m wide by this stage to provide safe boat passage down the River.

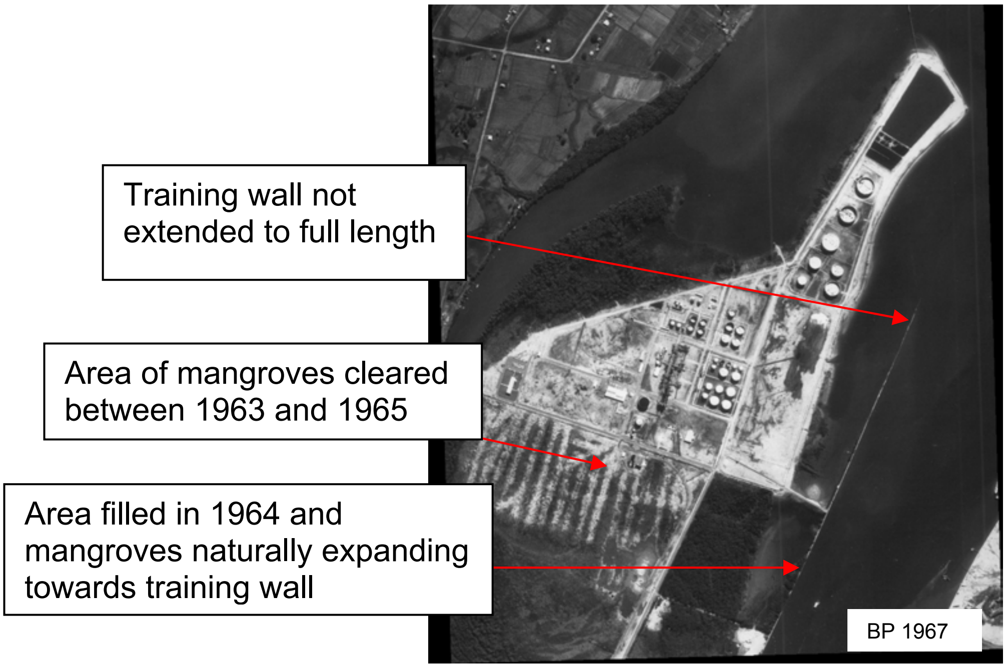


1965 "Queen of Holland" pumped sand from Boggy Creek onto final areas of the refinery property (Davenport 1986)

1966 Low water mark calculated from property boundaries. Usually low water was about 50 to 70m from the fenceline. (16/9/66)

1967 “Saurian” completed land reclamation for Amoco refinery on Bulwer Island

1967-1972 Training wall extended to tip of island and wall work completed



1968 Dredging in the Brisbane River, just outside BP training wall

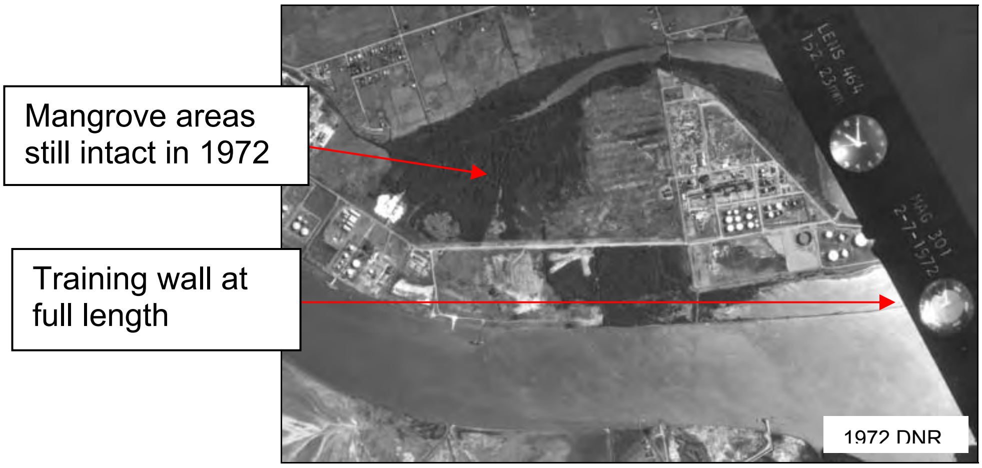
1968-1996 Expansion and upgrades by BP including Bitumen Unit and Sulphur Recovery Unit

1969 Plans for the further construction of the rock wall. Rock wall is concreted about half way up the island then left as loose stone.

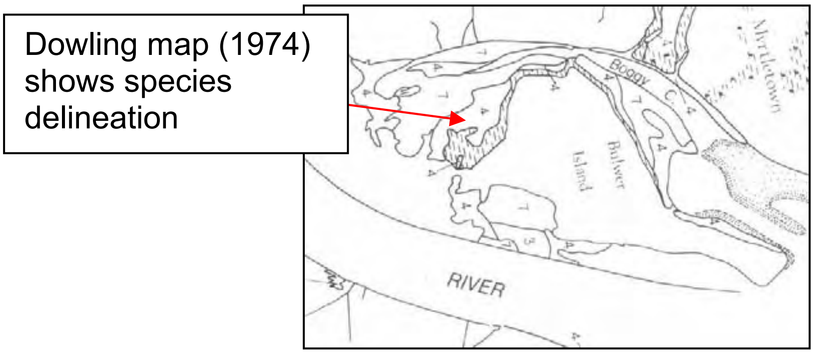
Low water mark again mapped outwards from property boundary for refinery. (13/2/69)

1972 Dumping of dredge spoil and wreck, ‘the Hulk’, in the site.

Large area of mangroves uncleared in 1972 photo. Also the mangroves in the study site are established



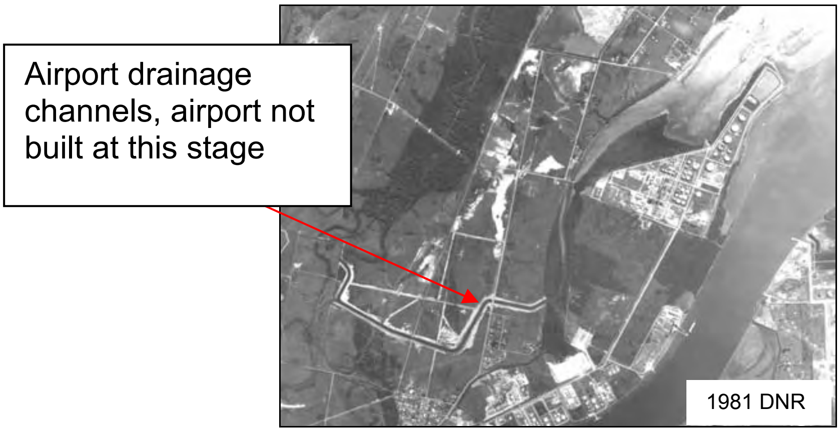
1974 Mangroves on Bulwer Island studied in 1974 by Dowling. Study site mangroves classified as *Avicennia* open forest



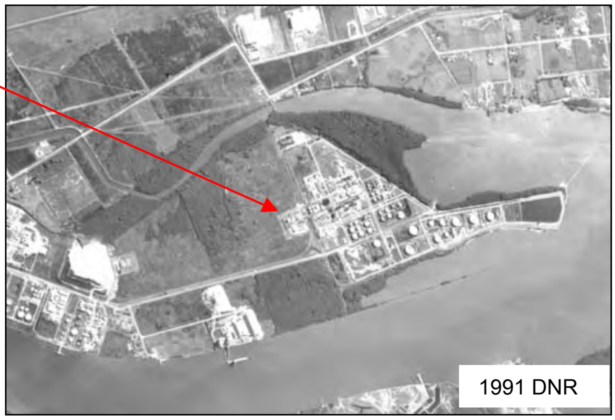
1975 Extensive mud flats around tip of Bulwer, evident at low tide

1978 Bottom area of mangroves extensively cleared

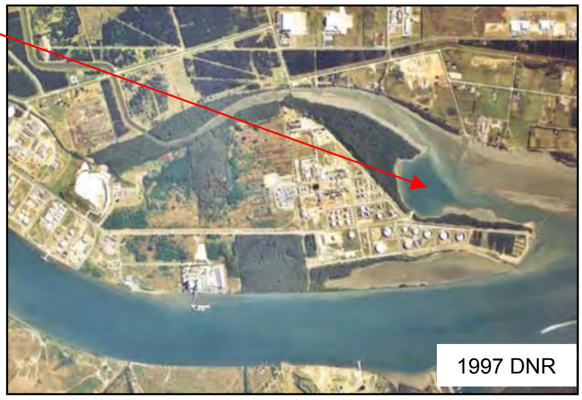
1978–1981 Boggy Creek redirected to connect with airport drainage channels



1985? Bitumen plant built



1985-1987 Dredging operation for airport work in Boggy Creek, dredged to 20m deep as a handling basin for dredge material from Middle Banks (1.4 million m^3)



1990-1994 Crude oil pipeline built

2000 Low tide mark located about 15m out from the lighthouse or 25m from the fence beyond the lighthouse (front lead)

There are many QDT maps that refer to the dredging and filling activities in the study site. The majority of these date between 1960 and 1963 with the following dates recorded as most relevant:

3/60	Depths shallowest at 0.3 to 1m below low water datum, deepest at about 1.5 – 2.2m
3/61	Depths of mudflat (ranging from 1.25 to 2.7m in middle)
1961	Filling towards south of island into the original water areas.
1963	Bores show depths of 1 – 2.2m water next to training wall then mud to 3 or 3.7m below low water datum then sand and clay at deepest (in some instances)
	Dredging (Sandpiper) – depth of 4m (filling inland areas within refinery boundary)
	Levels taken in 3 areas in mud and mangroves
	Land area of tip described as sand

Appendix 5 - Metadata

Entry	Title	Description	Source
1	Of Proposed for town of Glastone, showing adjacent features and position of suburban allotments, Port Curtis 1853'	Map: from Auckland Inlet to across to South Trees Inlet	Gladstone Port Authority (GPA)
2	Reclamation area Auckland Point - 1958'	Town plan drawing of reclamation area at Auckland Point	GPA
3	Gladstone Harbour - Soundings taken in December 1945'	Sounding depths from Barney Point across to Auckland Point Jetty, along proposed training wall	GPA
4	Gladstone - Auckland Point'	Town plan drawing of reclamation area at Auckland Point and proposed extension walls and harbour works	GPA
5	Soundings - Auckland Ck to Q.C.L. Wharf'	Map: showing soundings from Auckland Ck. to Q.C.L. wharf. Also, types of sediment found from cores taken.	GPA
6	Soundings - Auckland Ck to Q.C.L.'	Map (similar to entry 5 above): showing soundings from Auckland Ck. to Q.C.L. wharf. Also, H&M datum included.	GPA
7	Port Curtis - Plan of Auckland Creek and Barney Point Approaches - Soundings'	Plan of soundings from Auckland Inlet to Barney Point	GPA
8	Smith, More and Keown Surveyors - Soundings and bore holes - Auckland Ck. to Graham Ck. - 1969'	Map: showing soundings from Auckland Ck. to Graham Ck. Also, types of sediment found from bore holes taken.	GPA
9	Smith, More and Keown Surveyors - Soundings and bore holes - Auckland Ck. to Graham Ck. - 1969'	Map: showing soundings from Auckland Ck. to Graham Ck. Also, types of sediment found from bore holes taken, plus H&M datum taken.	GPA
10	Gladstone Harbour (Port Curtis) Soundings reduced to L.W.S.T. - 1923'	Map: from Auckland Inlet to across to Barney Point	GPA

11	Bruinsma, C (2000) 'Queensland Coastal Wetland Resources: Sand Bay to Keppel Bay.' Information Series QI00100. Department of Primary Industries Queensland, Brisbane.	Book	Department of Primary Industries Queensland (DPI)
12	QDEH (1994) *Curtis Coast Study Resource Report*. Queensland Department of Environment and Heritage, Rockhampton.	Book	Norm C. Duke
13	Department of Harbours and Marine (1986), *Harbours and Marine: Port and Harbour Development in Queensland from 1824 to 1985*, Department of Harbours and Marine, Brisbane.	Book: History of Port Development in Queensland	University of Queensland Physical Sciences and Engineering Library
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22	Gladstone 1999 QAP 5719 Run 10: 110-112	Aerial Photos	Department of Natural Resources and Mines, Queensland (DNRM)

23	Gladstone 1999 QAP 5713 Run 11: 72, 74	Aerial Photos	DNRM
24	Gladstone 1999 QAP 5719 Run 12: 47, 49	Aerial Photos	DNRM
25	Gladstone 1941 MAP 1426 Run 4E: 72181	Aerial Photos	GeoScience Australia
26	Gladstone 1941 MAP 309 Run 4EA: 72395, 72397	Aerial Photos	GeoScience Australia
27	Gladstone 1941 MAP 1425 Run 5: 35676	Aerial Photos	GeoScience Australia
28	Gladstone 1941 MAP 1428 Run 6: 35713, 35715	Aerial Photos	GeoScience Australia
29	Gladstone 1941 MAP 1427 Run 6A: 35483-35489 alt	Aerial Photos	GeoScience Australia
30	Gladstone 1941 MAP 1427 Run 7: 35519-35529 alt	Aerial Photos	GeoScience Australia
31	Gladstone 1941 MAP 1429 Run 9: 35401-35405 alt	Aerial Photos	GeoScience Australia
32	Gladstone 1941 MAP 1429 Run 11: 35317, 35318 alt	Aerial Photos	Queensland Parks and Wildlife Service (QPWS)
33	Gladstone 1941 MAP 1432 E Key: 69411-69413	Aerial Photos	GeoScience Australia
34	Gladstone 1941 MAP 1430 Run 13: 35933, 35934	Aerial Photos	QPWS
35	Gladstone 1959 Q925 Run 1: 26	Aerial Photos	Alistair Meltzer
36	Gladstone 1959 Q958 Run 2: 7	Aerial Photos	Alistair Meltzer
37	Gladstone 1970 Q2093 Run 1: 41	Aerial Photos	DNRM
38	Gladstone 1979 Q3064 Run 8: 8556	Aerial Photos	DNRM
39	Gladstone 1989 Q4831 Run 8: 80	Aerial Photos	DNRM
40	Gladstone 1999 QAP 5719 Run 8: 194	Aerial Photos	DNRM
41	Bajool 1941 QAP 5718 Run 3: 169	Aerial Photos	DNRM
42	Bajool 1941 QAP 5717 Run 4: 64, 65-69 alt	Aerial Photos	DNRM
43	Bajool 1941 QAP 5720 Run 5: 149	Aerial Photos	DNRM
44	Rockhampton 1999 QAP 5711 Run 11: 132, 134	Aerial Photos	DNRM
45	Rockhampton 1999 QAP 5711 Run 12: 117, 119, 120, 122	Aerial Photos	DNRM
46	Rockhampton 1999 QAP 5711 Run 13: 093-099 alt	Aerial Photos	DNRM
47	Rockhampton 1999 QAP 5711 Run 14: 070, 072, 076-082 alt	Aerial Photos	DNRM
48	Rockhampton 1941 QAP 1468 Run 9: 46883-46905 alt	Aerial Photos	Alistair Meltzer
49	Rockhampton 1941 QAP 1469 Run 10: 47131-47157 alt	Aerial Photos	Alistair Meltzer
50	Rockhampton 1941 QAP 1469 Run 11: 47159-47185 alt	Aerial Photos	Alistair Meltzer
51	Rockhampton 1941 QAP 1469 Run 12: 47187-47199 alt, 47200-47236 alt	Aerial Photos	Alistair Meltzer
52	Rockhampton 1941 QAP 1469 Run 13W: 47244-47258 alt	Aerial Photos	Alistair Meltzer

53	Rockhampton 1941 QAP 1470 Run 13E: 56470-56482 alt	Aerial Photos	Alistair Meltzer
54	Rockhampton 1941 QAP 1471 Run 14A: 69818-69842 alt	Aerial Photos	Alistair Meltzer
55	Rockhampton 1941 QAP 1470 Run 15E: 56549-56514 alt	Aerial Photos	Alistair Meltzer
56	Rockhampton 1941 QAP 1426 Run 15: 72081-72107 alt	Aerial Photos	Alistair Meltzer
57	Rockhampton 1941 QAP 1426 Run 16: 69786-69814 alt	Aerial Photos	Alistair Meltzer
58	Bajool 1941 MAP 1254 Run 1: 43637-43641 alt	Aerial Photos	GeoScience Australia
59	Bajool 1941 MAP 1254 Run 2: 43579-43597 alt	Aerial Photos	GeoScience Australia
60	Bajool 1941 MAP 1254 Run 4: 42627-62649 alt	Aerial Photos	GeoScience Australia
61	Bajool 1941 MAP 1256 Run 6: 43440, 43441, 43525-43547 alt	Aerial Photos	GeoScience Australia
62	Bajool 1941 MAP 1256 Run 7: 43414-43432 alt, 43555	Aerial Photos	GeoScience Australia
63	Bajool 1941 MAP 1257 Run 8: 42488. 42490, 42491	Aerial Photos	GeoScience Australia
64	Bajool 1941 MAP 1256 Run 9: 43454, 43456, 43470-43478 alt	Aerial Photos	GeoScience Australia
65	Bajool 1941 MAP 1257 Run 11: 42403-42409 alt	Aerial Photos	GeoScience Australia
66	Bajool 1941 MAP 1138 Run 12: 72365-72367 alt	Aerial Photos	GeoScience Australia
67	Bajool 1956 Q617 Run 2: 144	Aerial Photos	DNRM
68	Bajool 1956 Q618 Run 3: 28	Aerial Photos	DNRM
69	Bajool 1961 CAB 205 Run 6: 5006	Aerial Photos	DNRM
70	Bajool 1973 Q2693 Run 2: 144	Aerial Photos	DNRM
71	Bajool 1973 Q2695 Run 3: 9	Aerial Photos	DNRM
72	Bajool 1979 Q3063 Run 3: 8295	Aerial Photos	DNRM
73	Bajool 1990 Q4889 Run 3: 58	Aerial Photos	DNRM
74	Bajool 1999 QAP 5718 Run 3: 156	Aerial Photos	DNRM
75	Beenleigh 1997 QC5553 Run 7:149	Aerial Photos	DNRM
76	Beenleigh 1987 PC4616 Run 7:30	Aerial Photos	DNRM
77	Beenleigh 1973 Q2655 Run 6: 180	Aerial Photos	DNRM
78	Beenleigh 1955 Q543 Run 7: 111	Aerial Photos	DNRM
79	Beenleigh 1944 KD1049 Run 6: 412	Aerial Photos	DNRM
80	Brisbane 2002 QAP 5931 Run 10: 123, 125	Aerial Photos	DNRM
81	Brisbane 2002 QAP 5931 Run 11: 89-93 alt	Aerial Photos	DNRM
82	Brisbane 2002 QAP 5931 Run 12: 73, 75	Aerial Photos	DNRM
83	Brisbane 2002 QAP 5931 Run 13: 33-37 alt	Aerial Photos	DNRM
84	Brisbane 2002 QAP 5931 Run 14: 24	Aerial Photos	DNRM
85	Brisbane 1946 Run 4: 34800-34802 alt	Aerial Photos	DNRM

86	Brisbane 1946 Run 7: 34849, 34851-34853, 34855	Aerial Photos	DNRM
87	Brisbane 1946 Run 8: 34762-34766 alt, 34767, 34769	Aerial Photos	DNRM
88	Brisbane 1946 Run 9: 35249-35257 alt	Aerial Photos	DNRM
89	Brisbane 1946 Run 14: 34735-34736, 34738-34739, 34741-34743 alt	Aerial Photos	DNRM
90	Brisbane 1946 Run 16: 34723-34729 alt	Aerial Photos	DNRM
91	Brisbane 1946 Run 19: 35210	Aerial Photos	DNRM
92	Brisbane 1946 Run 20: 347680-34681, 34684-34685, 34687	Aerial Photos	DNRM

Changes in Coastal Ecosystems

Historical Coastlines

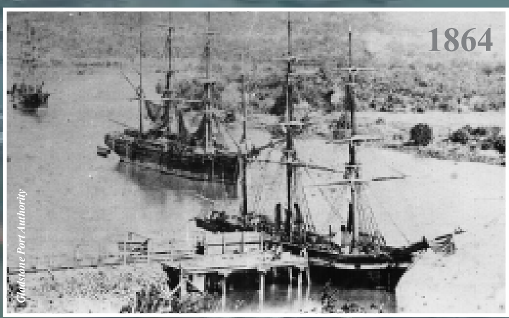
Port Curtis Industrial Centre

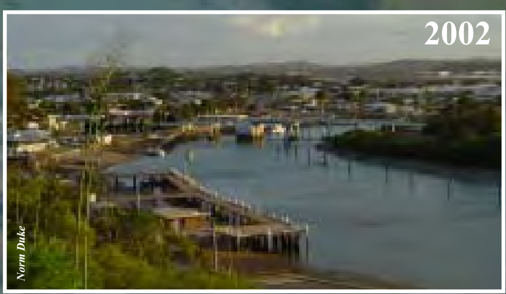
Early in the colonisation of Australia, Port Curtis was touted to become the grand Northern Australian Colony. By 1846, however, such dreams and schemes were dashed, albeit temporarily, for lack of freshwater and ill-conceived adventures. Despite such early set backs, the region and its township, Gladstone, have since developed into a major shipping port and industrial centre, with the pace of change accelerating in recent decades.

Port and industrial development have resulted in considerable alterations to landscape and coastal features in an effort to accommodate ever-growing demands of industry, trade and population. But, what are the effects of these changes? Are they sustainable? Does it matter? How much is the quality of our lives linked with that of the wider port area and associated marine wetland environments? How much do you value our coastal location?

The time is right to take stock and evaluate. The Coastal CRC's Historical Coastlines Project is gathering knowledge and comparing current indicators of ecological condition with those from the past, using photographs, maps and memories. In this phase of the project, the team is focusing on changes in coastal features and intertidal wetlands of the Calliope River, Auckland Creek and Endfield Creek in Port Curtis region.

Early chart of Port Curtis, revealing a substantially different coastline from that which exists today.





Timebights of Auckland Creek, Gladstone: in 1864, loading cattle for international ports; in 1910, tending to the naval defense of Northern Australia; and in 2002, the relative calm of moorings and local tourism.

Early aerial view of Shell Terminal on reclaimed land, Auckland Point Wharf.

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Norm Duke

Background: aerial view of Gladstone Harbour and Port Curtis in 2002

Text: Norm Duke/ Pippi Lawn
Design: Pippi Lawn/ Diana Kleine

Changes in Coastal Ecosystems

Historical Coastlines

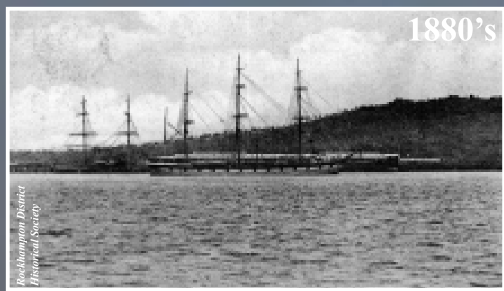
Fitzroy River Estuary Rural Region

In 1853, the Archer Brothers established the first grazing property on the banks of the Fitzroy River. With the river at its heart the region has since become a thriving rural centre, . Agricultural, mining and pastoral pursuits dominate the catchment and are likely to have a broad influence on the river and its coastline.

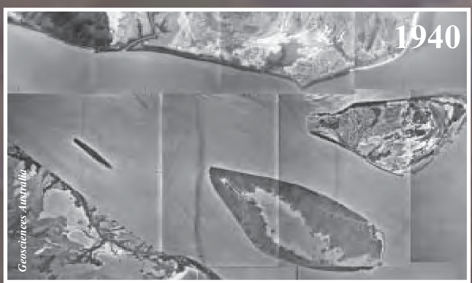
Past land management practices, in combination with natural geographic and climatic factors, have contributed to considerable alterations to downstream riparian and coastal ecosystems. A dramatic example of this involves the formation of new mangrove islands near the river mouth. Can we separate human influences from natural ones? What are the effects of these changes? Does it matter? How much is the quality of our lives linked with that of the river and its wetland environments?

The time is right to take stock and evaluate. The Coastal CRC's Historical Coastlines Project is gathering knowledge and comparing current indicators of ecological condition with those from the past, using photographs, maps and memories. In this phase of the project, the team is focusing on changes in coastal features and intertidal wetlands of the Fitzroy River.

Chart of the Fitzroy River and its estuary as it appeared in 1877.



Tall ships at Broadmount, near the mouth of the Fitzroy River.



Changing view of river mouth from 1864 to 2002, showing the formation of new mangrove islands.

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Background: aerial view of Fitzroy River mouth in 2002

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Changes in Coastal Ecosystems

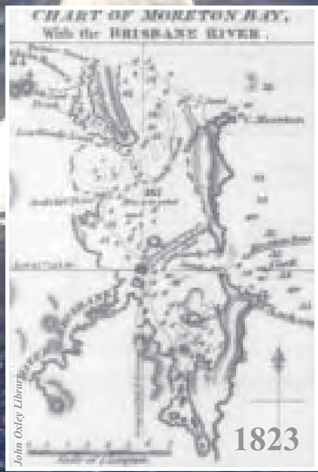
Historical Coastlines

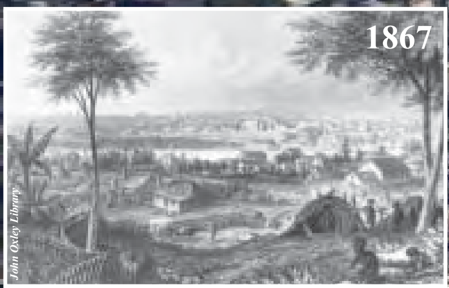
Brisbane River
Capital City and Port

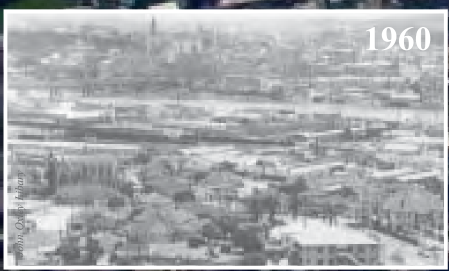
In 1823, John Oxley first charted the Brisbane River and, by 1842, Brisbane township was established. Since then Brisbane City has expanded and spread across surrounding riverside lands. The area has undergone extensive urbanisation with rapid population growth and industrial expansion to become Australia's third largest capital city with its busy, international port.

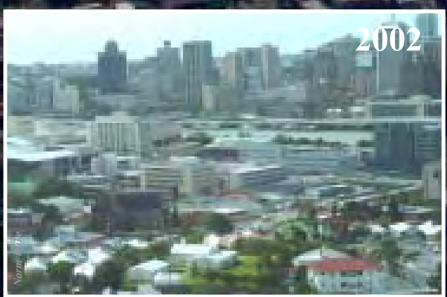
The river and fringing lands have been altered from their pre-white settlement condition. The river is now much narrower, its margins hardened with rock walls, roads and buildings, and it is much deeper after dredging to accommodate the largest vessels. But what are the effects of such changes on riparian ecosystems and the ecological functioning of the river? Are they sustainable? How much is the quality of our lives linked with the river and neighbouring marine wetland environments? How much do you value our river and coastal location?

The Coastal CRC is gathering knowledge and comparing current indicators of ecological condition with those from the past, using photographs, maps and memories. In the project, the team is focused on changes in coastal features and intertidal wetlands of the Brisbane River and Moreton Bay region.









The changing view from Highgate Hill, South Brisbane: in 1867, with scattered housing; in 1960, where the town hall and its chiming dominate the city centre; and in 2002, where the town hall is no longer visible behind towering skyrises.

Early view of Bulimba Reach

Background: view from Brisbane River mouth in 2002

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Assessing Historical Change in Coastal Environments

During the last two centuries, human progress and development in Australia have increased dramatically. These activities have resulted in massive alterations to landscape and coastal features to accommodate seemingly ever-growing demands of industry, trade and population. Notable significant losses have been observed for seagrass and mangrove habitats in some areas. But what are the longer term effects of such changes? Are they sustainable? Will our quality of life and the environment be affected? How much do we value natural environments and do they need to be managed? Is it important to record environmental history, and does it matter how things might have changed?

Historical information is our chart to the future

Historical information is like a chart used by sailors to navigate. In the absence of a chart, sailors would be unable to travel without continually testing the water ahead. A chart therefore represents the accumulated knowledge and observations of earlier sailors, making it a functional historical document. In some ways, a good navigation chart is analogous to a sound historical assessment of change and current health of ecosystems. Prior knowledge and accumulated observations of habitat condition will help us avoid striking ecological hazards and creating environmental disasters in the future.

Bulimba Reach, 1910

Dynamic, ever-changing coastal environments

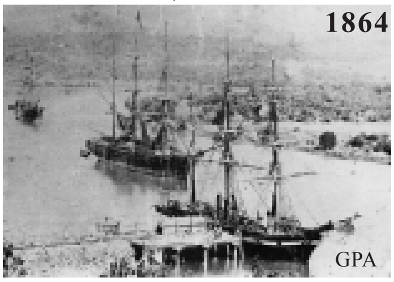
Coastal areas are naturally dynamic and ever-changing, and responsive to periodic fluctuations in climate and sea level over hundreds of years – and geological time. However, these effects are compounded with localised and increasing human influences which limit and determine current–day ecological diversity, health and coverage. Change in ecological habitats, like tidal wetlands, are clearly affected by both human and natural disturbances. Future global climate change is also predicted to be more rapid, with increases in severity of storms, and rapidly rising sea levels. In order to manage such anticipated change, it is essential we define and understand past conditions in order to quantify the rate of change, as well as to evaluate the capacity of coastal habitats and ecosystems to adapt and respond in the future.

Historical Coastlines Project

The Historical Coastlines project with the Coastal CRC was specifically set up to assess change in coastal habitat over the last 150 years, and specifically during the last 60 years. Study locations in the first triennium (2001-2003) of the project, include: Moreton Region, Port Curtis and the Fitzroy River Estuary.

Changing face of our coastlines

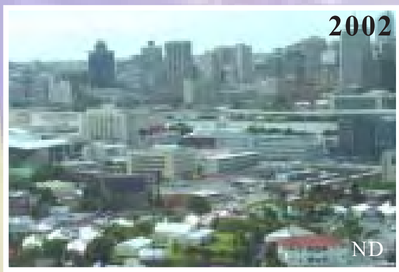
Auckland Creek, Gladstone



The Historical Coastlines project is using a variety of assessment tools to quantify key aspects of change related to coastal landscape and tidal vegetation like mangroves. One of the tools is to compare historical photographs with current images in selected locations. For example, changes surrounding the Brisbane River are aptly illustrated in the series of views of Brisbane city centre from Highgate Hill (right): in 1876, the semi-rural landscape surrounding the township officially established in 1842; in 1960, the area was transformed into a paved and hardened city environment a century later; and in 2002, further dramatic changes include riverside traffic flyovers constructed during recent decades.

In another example, changes around Auckland Creek, Gladstone, are viewed from Auckland Hill (left): in 1869, sailing trade vessels loaded cattle for international ports; in 1921, a motorised vessel of a new age; and in 2002, a relatively tranquil tourist and fishing port exists now that much larger trading ships load at the outer harbour wharves. Notice the stone rampart to the jetty and creek alone appear to have survived unchanged from 1869.

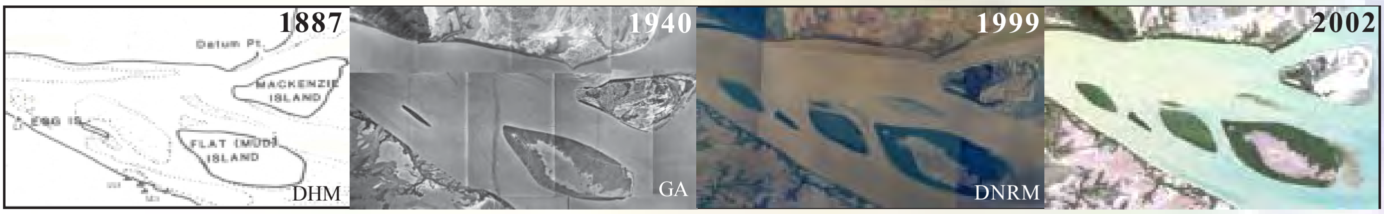
Highgate Hill, Brisbane



From Crow's Nest to Satellite Technology

To quantify changes in landscape, the Historical Coastlines project is also mapping coastal features and wetland vegetation in current and past times. Today, digital images taken from satellites are used to create maps. However, before our digital age, maps were hand drawn from aerial photographs from the 1940s, and before then, from visual observation and trigonomic measurements. The earliest maps were also drawn without the benefit of aerial viewing – apart from some highpoint like a hill, or the crow's nest of a tall ship.

Maps will be drawn from images and charts of the day based on GIS (Geographic Information System) format as far as possible for detection and quantification of change. In some instances, there have been dramatic changes within the last century like the appearance of new mangrove islands in the mouth of the Fitzroy River (images below). The rate of deposition appears to have increased with the clearing of catchment vegetation but this question can only be answered with historical studies like this one.



Appearance of new islands in the mouth of the Fitzroy River, revealed through comparison of an early chart (1887), early aerial photography (1940), modern aerial photography (1999) and satellite imagery (2002).

Our knowledge of the past is our insight of the future

If changes in the past can be identified and quantified in terms of extent and rate of change, this will help predict future trends. Reasonable predictions of future trends are possible providing the historical information they are based on is soundly based and accurately quantified. So, just like those who depend on maps for navigation, we also rely on accurate historical assessments to help protect and promote the survival of threatened natural coastal ecosystems. This becomes especially poignant where the health of these systems might be linked to our own health and sense of well-being.

Marine Botany
The University of Queensland
Coastal CRC

September 2002
Text: Norm Duke
Photos: John Oxley Library (JOL), Norm Duke (ND), Gladstone Port Authority (GPA), Department of Harbours and Marine (DHM), Geosciences Australia (GA), Deparrtment of Natural Resources and Mines (DNRM)
Design: Diana Kleine/ Pippi Lawn