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Mangroves and Saltmarshes

our great barrier reef
let's keep it great

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Mangroves and Saltmarshes

Summary

- Mangroves and saltmarshes are ecologically important habitats that link the marine and terrestrial environments and provide habitat for both marine and terrestrial organisms, including several threatened species.
- Along the Great Barrier Reef coast mangrove and saltmarsh habitats cover an area of approximately 3800 km^2.
- There are 39 mangrove species and hybrids in and adjacent to the Great Barrier Reef World Heritage Area, which represents almost all the species found in Australia and more than half the number of species in the world. Twenty-six species of saltmarsh plants also occur along the Great Barrier Reef coast.
- Mangrove and saltmarsh ecosystems are vital to the biological productivity and food webs of coastal waters and provide critical nursery areas for many fish and crustaceans, including commercially and recreationally important species.
- They provide an important buffer between land and reef, as they filter land runoff and improve the quality of water entering the Great Barrier Reef lagoon. They also serve to buffer the coastline from storms and cyclones.
- These intertidal ecosystems are subject to the effects of human activities, such as coastal development and declining water quality. A significant proportion of the Queensland coast has been developed since European settlement. However, due to the lack of historical data, the actual area of mangrove and saltmarsh habitat lost is unknown. The overall condition of remaining mangrove and saltmarsh areas along the Great Barrier Reef coast is relatively stable.
- The Queensland Government and local governments are responsible for the management of coastal areas of the Great Barrier Reef region, including wetland habitats such as mangroves and saltmarshes. The *Reef Water Quality Protection Plan*, released in October 2003, is aimed at halting and reversing the decline of water quality in the Great Barrier Reef within ten years.
- Mangrove and saltmarsh plants are protected under the *Queensland Fisheries Act 1994*, which includes the use of permits and Fish Habitat Areas to regulate activities that may disturb marine plants. There are 41 Fish Habitat Areas along the Great Barrier Reef coast, which afford a high level of protection to marine and estuarine ecosystems in these specific locations.
- Continued research and monitoring is required to provide up-to-date information on mangrove and saltmarsh habitat boundaries, and to improve our ability to detect subtle changes in the condition of these communities.
- Mangrove and saltmarsh habitats are often found growing close together in the intertidal zone and form important coastal communities that are interconnected with the Great Barrier Reef (GBR) ecosystem. Most of the mangrove and saltmarsh habitats are on the border of the Great Barrier Reef World Heritage Area (GBRWHA) and not actually inside it. However, they form a critical part of the GBR ecosystem.

Condition

Mangrove and saltmarsh diversity

Mangroves

Mangroves are flowering plants that inhabit inter-tidal* habitats along estuaries, rivers, bays and islands.[4,58,85] Mangrove communities are usually groups of trees and shrubs, growing in sheltered areas where fine sediments accumulate, and where they are inundated by seawater during the daily tidal cycle.

Mangrove and saltmarsh communities near Cape Palmerstone National Park. These two communities are interconnected and provide many ecological services that help to maintain the health of the Great Barrier Reef.

Mangroves occur in both tropical and temperate regions of Australia, although tropical regions have a higher species diversity.[11,29,32,42,43] For example, there are 31 species (including 1 hybrid†) of mangrove plants recorded in the Daintree region in northern Queensland, compared to eight species in southeast Queensland,[31,32] and two species in southern temperate Australia.[19]

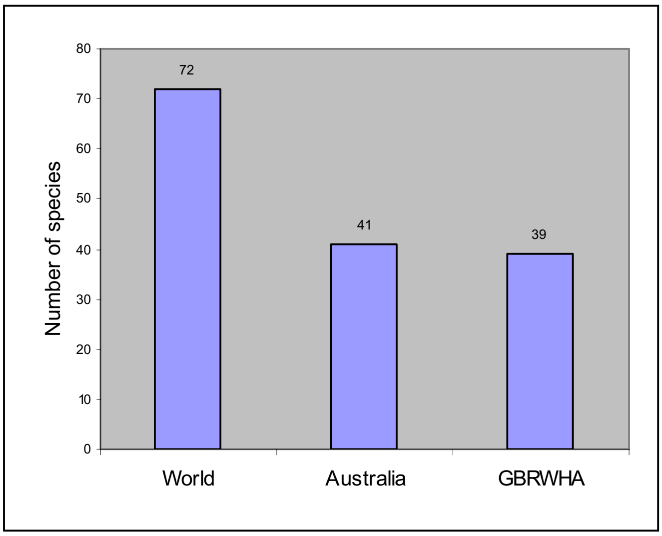

Figure 1. The comparison of the number of mangrove species found in the world, Australia and along the GBR coast.[32]

The mangrove forests along the GBR coast are very diverse, with at least 39 mangrove species and hybrids recorded.[32] This represents more than half the species found in the world and a significant proportion of the species that occur in Australia (see Figure 1). Australia has one endemic§ mangrove species (*Avicennia integra*) that is only found in the Northern Territory.[30] However, one hybrid species of mangrove (*Lumnitzera X rosea*) found in the northern GBR, is rarely found anywhere else in the world.[32,82]

Across Australia, mangroves occupy an estimated 11 500 km^2 of coastal foreshore and estuary areas,[44] including approximately 2140 km^2 along the GBR coast.[70]

Mangrove forests cover 2140 km^2 of the GBR coast, and play a vital role in the coastal ecosystem.

Saltmarshes

Saltmarshes tend to occupy the hyper-saline[‖] soils of the upper inter-tidal zone, where saltwater inundation occurs less frequently (usually only during high spring tides). These communities are generally found growing on the landward side of mangroves, and are made up of salt tolerant, flowering plants in the form of low growing shrubs, herbs and grasses.[2] The areas of bare ground found in and around saltmarsh habitats are known as 'saltpans' or 'saltflats', and are covered in mats of algae during the wet season. Throughout this chapter, saltpan habitats are included within saltmarshes.


Saltmarsh habitats cover 1660 km^2 of the Great Barrier Reef coast, and generally occur on the landward side of mangroves.

Saltmarsh communities occur in both tropical and temperate regions of Australia, with higher species diversity found in temperate regions. For example, there are approximately 26 saltmarsh species along the GBR coast[51] compared to approximately 50 saltmarsh species in temperate regions of Australia.[10]

The coastal areas in and adjacent to the World Heritage Area contain 1660 km^2 of saltmarsh habitat.[70] This represents over 40 per cent of the combined area of mangrove and saltmarsh found along the GBR coast, and approximately 12 per cent of Australia's saltmarsh habitats (13 595 km^2).[10]

Mangrove and saltmarsh distribution

Mangrove and saltmarsh habitats are unevenly distributed along the GBR coast, with most of the mangrove and saltmarsh habitats occur within five main areas:

- Princess Charlotte Bay (Figure 2)
- Hinchinbrook Island (Figure 4)
- Bowling Green Bay (Figure 4)
- Broadsound and Shoalwater Bay (Figure 5)
- Fitzroy River estuary (Figure 5).

Factors influencing mangrove and saltmarsh communities

Mangroves and saltmarsh species have specialised physiological adaptations (including the ability to exclude or secrete salt from their plant tissue), which allow them to survive and reproduce in these otherwise uninhabitable saline environments.[20,59] Different mangrove and saltmarsh species are able to tolerate these harsh environments to varying degrees, depending on the adaptations of each species.[11,75] In the dry tropical regions between Townsville and Mackay, low rainfall and limited freshwater runoff have given rise to hypersaline soils. Consequently, mangrove forests in this region comprise more salt tolerant species with extensive saltmarsh areas (for example, Fitzroy estuary; Figure 5). Saltmarsh plants are generally more tolerant of dry, saline conditions than mangroves.

The wet tropics regions, which experience higher rainfall, have reduced soil salinity because rain and runoff flush the salt from the soil. The reduced salinity can support a more diverse range of mangrove species (for example, Daintree estuary[11]). In some upstream areas, the presence of freshwater means the mangrove forests and the adjacent rainforests merge, to form unique plant communities.[47] Further, mangrove trees in the wet tropics can grow to heights of 30 metres, whereas mangroves in the dry tropics generally do not exceed five metres.[72]

The main environmental factors known to influence the distribution of particular mangrove and saltmarsh species along the GBR coast are climate (especially the duration and frequency of rain or freshwater input), evaporation rates, and the frequency of saltwater inundation (i.e. tidal regime).[33] A number of other factors also influence their distribution including:

- Hydrology (tides, currents, sea level, wave action)[11,33,80]
- Geomorphology (catchment size, estuary length, sediment type and depth, slope)[11,33,80]
- Exposure to freshwater (land runoff, groundwater seepage)[11,33,80]
- Land use in adjacent catchments (cleared catchments tend to have increased sediment runoff)[38]
- Oxygen availability (aerobic or anaerobic sediment)[4]
- Nutrient availability and pH (acid or alkaline sediment)[4]
- Feeding on seeds (crabs selectively eat the propagules[#] of certain mangrove species).[71,79]

Ecological roles

The mangrove forests in and adjacent to the GBR coast are some of the most healthy and diverse in the world, and are an integral part of the GBR ecosystem. These habitats support ecologically diverse communities of plants and animals that include fish, crustaceans, molluscs, insects, mammals and reptiles.[58] Mangroves and saltmarshes are particularly important as they form ecosystems that link the marine and terrestrial environments and provide habitat for both marine and terrestrial organisms. For example, mangroves are important habitats for fruit bats, which roost in mangroves during the day and fly out at night to forage in surrounding forests. Mangroves on Night Island (Far Northern Management Area) and in the Low Isles (Cairns/Cooktown Management Area) provide night–time roosts for Pied Imperial-Pigeons (*Ducula spilorrhoa*) that fly to coastal rainforests during the day to feed.

The ecological role of crabs

Crabs are the most abundant macro-invertebrates in mangrove and saltmarsh ecosystems. When building their burrows, crabs improve the infiltration of ground water, water from high tides and freshwater runoff. This helps to flush out excess salt and reduce soil salinity. The burrows also increase oxygen levels in the sediment by creating air spaces in otherwise oxygen deprived sediment.[29,85] Crab holes also provide refuges for many organisms, including fish, molluscs and worms.[47]

Research in mangrove and saltmarsh ecosystems in the Great Barrier Reef has found that crabs are vital to the recycling of nutrients, in particular nitrogen.[56,71] Many crabs eat large amounts of fallen mangrove leaves and propagules[71] while other species eat algae and detritus.[58] The presence of crabs in these ecosystems has been shown to improve the growth of mangrove and saltmarsh plants, and also increases the biomass and diversity of other organisms.[4,56]

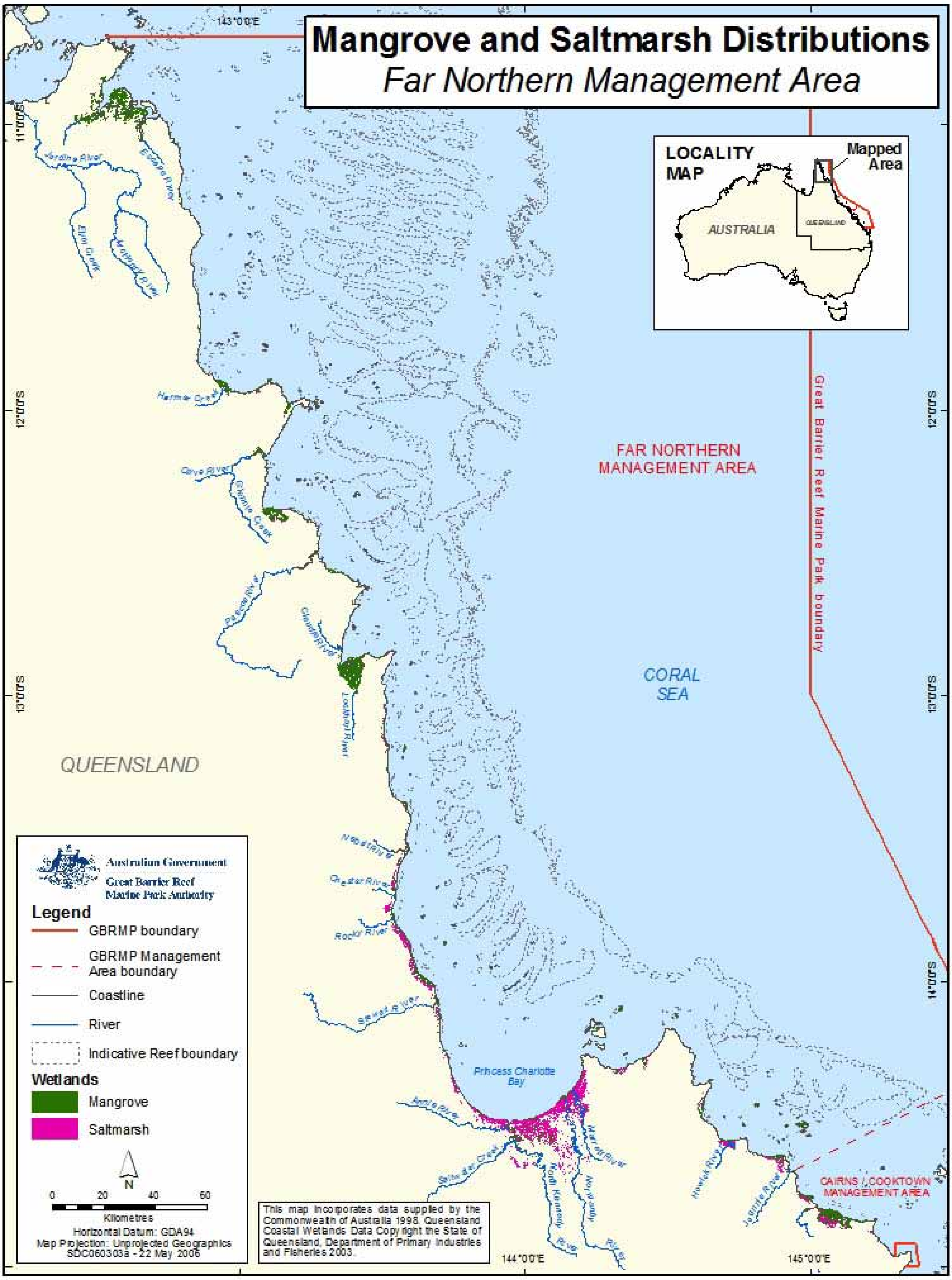

Figure 2. Mangrove and saltmarsh distribution along the coast of the Far Northern Management Area of the Great Barrier Reef World Heritage Area

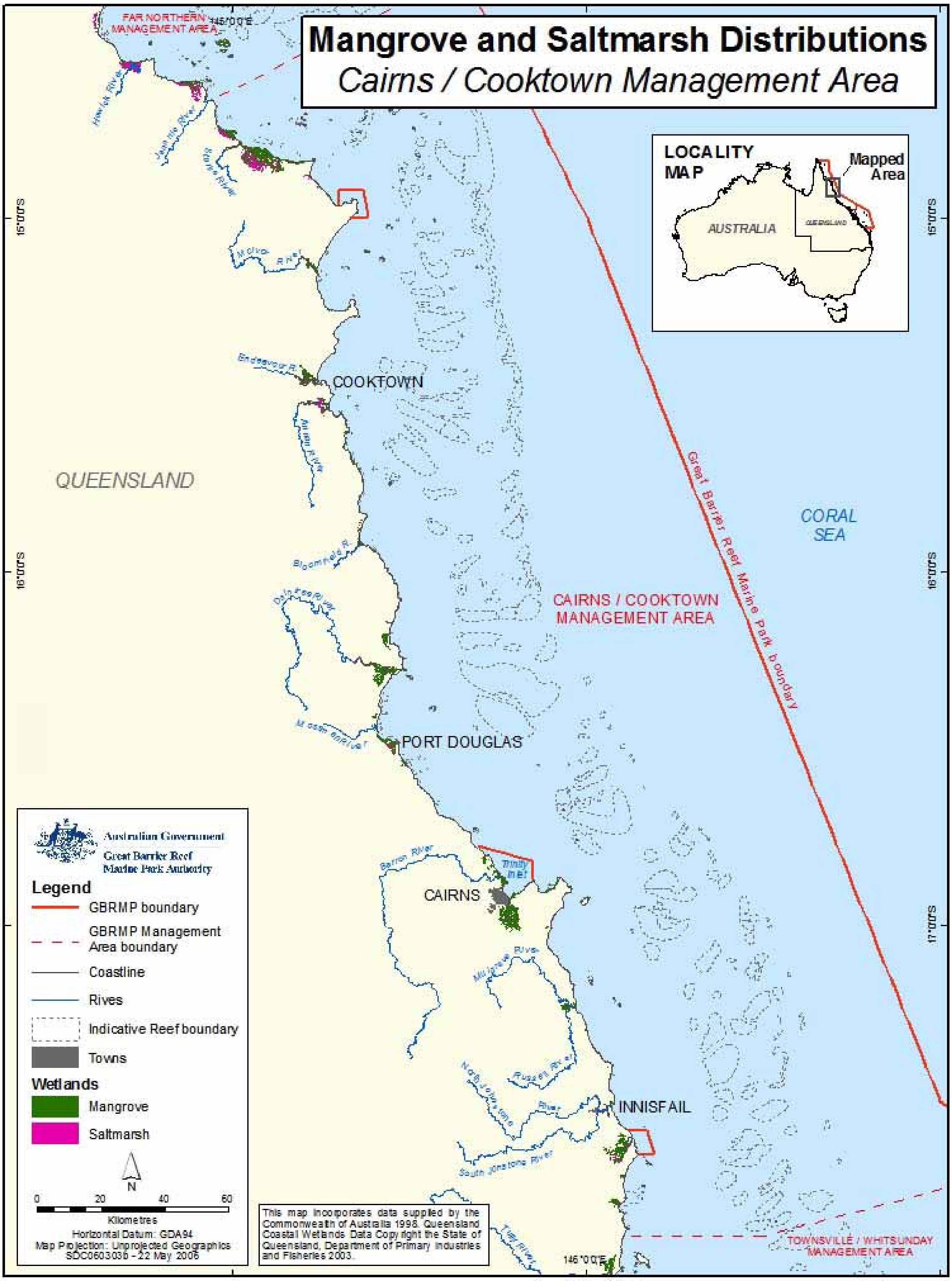

Figure 3. Mangrove and saltmarsh distribution along the coast of the Cairns/Cooktown Management Area of the Great Barrier Reef World Heritage Area

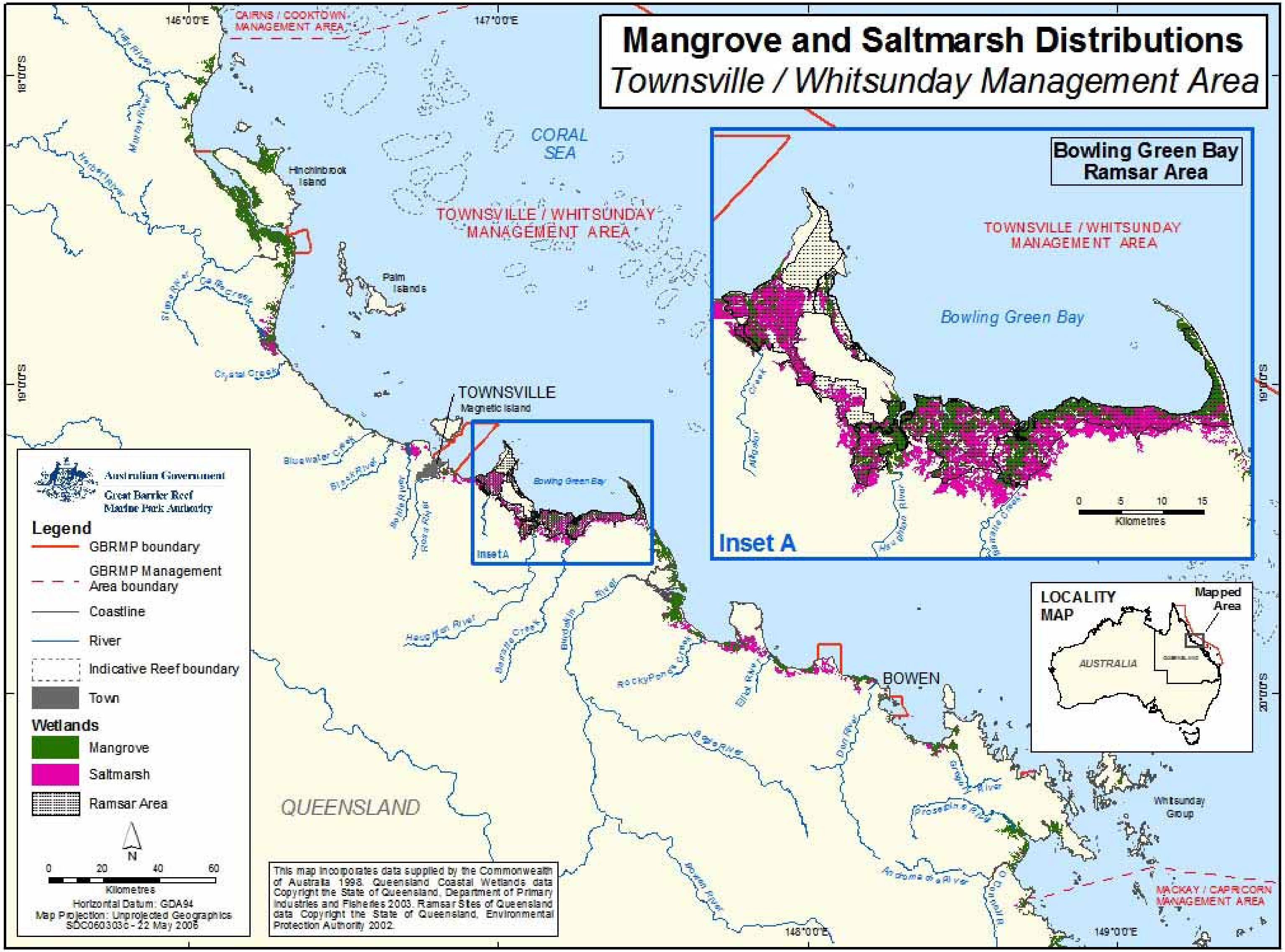

Figure 4. Mangrove and saltmarsh distribution along the coast of the Townsville/Whitsunday Management Area of the Great Barrier Reef World Heritage Area. Inset A shows the Bowling Green Bay Ramsar Site

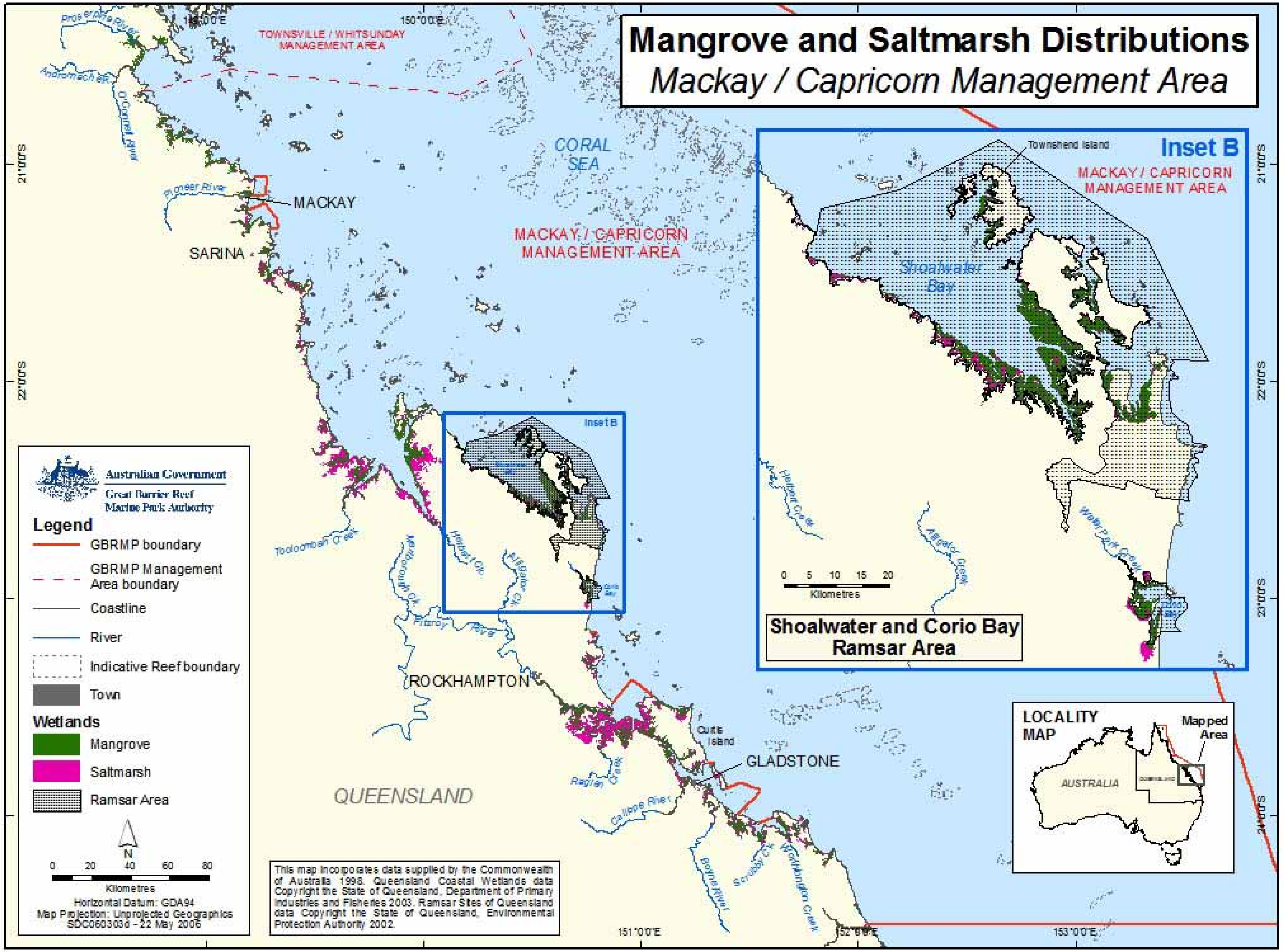

Figure 5. Mangrove and saltmarsh distribution along the coast of the Mackay/Capricorn Management Area of the Great Barrier Reef World Heritage Area. Inset B shows the Shoalwater and Corio Bay Ramsar Site

Mangroves and saltmarshes are also important habitats for several threatened species in and adjacent to the GBRWHA (Table 1). The Dawson Yellow Chat (*Ephthianura crocea macgregori*) is the most threatened bird in the GBRWHA. The population of the entire sub-species is very small and is only found in saltmarsh and swampy grassland on Curtis Island (Mackay/Capricorn Management Area), and a few sites on the adjacent mainland near Gladstone.

Table 1. Examples of threatened species in the GBRWHA that inhabit mangrove and saltmarshes. Information derived from[50,52,57]

Associated habitat	Common name	Scientific name	Taxon group	*Queensland Nature Conservation Act 1992*	*Environment Protection and Biodiversity Conservation Act 1999*	IUCN Red List of threatened species 2006
mangroves and saltmarshes	false water rat	*Xeromys myoides*	Mammal	Vulnerable	Vulnerable	Vulnerable
mangroves	green turtle	*Chelonia mydas*	Reptile	Vulnerable	Vulnerable	Endangered
mangroves	estuarine crocodile	*Crocodylus porosus*	Reptile	Vulnerable	Listed migratory species	-
mangroves	rusty monitor	*Varanus semiremex*	Reptile	Rare	-	-
mangroves and saltmarshes	beach stone curlew	*Esacus neglectus*	Bird	Vulnerable	-	-
saltmarshes	Australian painted snipe	*Rostratula benghalensis australis*	Bird	Vulnerable	Vulnerable	-
saltmarshes	yellow chat (Dawson)	*Ephthianura crocea macgregori*	Bird	Endangered	Critically endangered	-
mangroves	apollo jewel butterfly	*Hypochrysops apollo apollo*	Insect	Vulnerable	-	-
mangroves	Illidge's ant-blue butterfly	*Acrodipas illidgei*	Insect	Vulnerable	-	Endangered
mangroves	ant plant	*Myrmecodia beccarii*	Epiphyte	Vulnerable	Vulnerable	-
mangroves	mangrove orchid	*Dendrobium mirbelianum*	Orchid	Endangered	Endangered	-

Primary production and nutrient recycling

Mangrove and saltmarsh ecosystems are vital to the biological productivity of coastal waters.[4,55,85] Mangrove and saltmarsh plants produce large amounts of organic material (for example, leaves, seeds/propagules, flowers, wood) through primary production**. These intertidal ecosystems also support other primary producers such as algae.[4] The plant material (alive and dead) is consumed by other organisms and contributes to a nutrient cycle that sustains many other plants and animals. One GBR study recorded 120 species of insects, crustaceans, molluscs and worms in decaying mangrove wood.[24] These wood-dwelling organisms provide an important food source for many predatory animals, such as fish and birds.

Fisheries

Mangroves form important habitats for fish and crustaceans by providing food, and a canopy of foliage and extensive root systems for shelter.[60] Mangroves and saltmarshes provide critical nursery habitats for many juvenile fish and crustaceans, including commercially and recreationally important species:[18,45,55,60,66,68,73,76]

- Barramundi (*Lates calcariferi*)
- Grey mackerel (*Scomberomorus semifasciatus*)
- School mackerel (*Scomberomorus queenslandicus*)
- Sea mullet (*Mugil cephalus*)
- Whiting (*Sillago ciliata*)
- Mud crabs (*Scylla serrata*)
- Tiger prawns (*Penaeus esculentus*)
- Banana prawns (*Penaeus merguiensis*)

Connectivity

Many mangrove and saltmarsh-dependant organisms also depend on other adjacent habitats during the low tide. As the high tide moves out, they leave mangroves and saltmarshes to shelter in nearby seagrass beds and mudflats located in deeper water.[78] The organism's interdependency on different habitat types means that the abundance and diversity of life found across these habitats is much higher when the connections between them are maintained.[67]

Mangroves, like saltmarshes, are ecologically connected to seagrass beds and coral reefs and provide critical habitat for many juvenile fish species.

Studies in the Caribbean have found that fish populations on coral reefs are more diverse and abundant when these reefs are connected to mangrove systems.[65] In some cases, the biomass[††] of fish on these reefs was found to be double that of reefs that were not connected to mangrove systems.[66] This included commercially important fish, such as snappers and sweetlips. In the GBR, the connection between mangrove habitats, seagrass beds, and coral reefs is critical for the completion of some fishes' life cycles, such as the red emperor.

Sediment trapping and stabilisation

Mangroves and saltmarshes provide an important buffer between land and reef that can filter water flowing from the land into the GBR lagoon. Even though mangroves and saltmarshes occupy a relatively small area along the GBRWHA, they trap, process and store large amounts of sediment and organic matter.[5] They also filter out potential pollutants such as nutrients and pesticides. During the incoming tides, some suspended sediment carried into mangroves is trapped, reducing the amount of suspended sediment in the outgoing tide.[86]

Mangrove ecosystems also serve to buffer the coastline from storms and cyclones. Their extensive root systems stabilise the shoreline and protect the soil structure from wave action, currents and storm surges. This minimises the amount of soil that is removed and washed out into adjacent habitats. The physical height of mangroves also acts as a natural windbreak between the sea and the land.

Mangroves provide a buffer between the land and sea, and help to protect the coastline during storms and cyclones.

There is also some evidence that mangroves may provide some protection during tsunamis. The tsunami that swept through parts of Asia on Boxing Day in 2004 resulted in extensive damage to coastal areas and led to the death of over a quarter of million people while leaving millions homeless.[26] Post-tsunami surveys indicate that in some areas, mangroves provided some protection for coastal areas and villages[26] by absorbing some of the wave energy and thereby reducing the impact further inland. Some villages behind mangrove forests were barely affected, whereas villages located near exposed shores were completely destroyed.[28]

Traditional values

Mangroves and saltmarshes have significant traditional value to Indigenous Australians, as illustrated by the large number of mangrove-related words in traditional Indigenous languages.[12] The clan name Kanthanunpu, of the Kuku Yau tribe from the Lockhart River region, is the name of the mangrove palm that is endemic to that region (C Turner 2006, pers. comm., 2 August). There are also dreamtime stories about mangrove inhabitants, such as mudskippers and fiddler crabs. Mangroves are important cultural training grounds for teaching children about traditional fishing and collecting, and traditional ways to use these resources. This includes learning about cultural indicators or signs that show when certain fish and bivalve species are good to eat or when breeding seasons start (C Turner 2006, pers. comm., 2 August). Mangrove ecosystems, including the plants themselves, also provide medicines and raw materials for tool making, and are an important source of food.[63]

Trends in Great Barrier Reef mangrove and saltmarsh communities

Factors influencing mangrove and saltmarsh condition over time
Both natural and human related factors can cause changes in the condition of mangrove and saltmarsh communities over time (see *Mangrove and saltmarsh diversity and distribution*). In terms of natural factors, climatic variations (especially rainfall) have been known to cause changes in local mangrove and saltmarsh ecosystems. During drought conditions, increased soil salinity may cause die back of some mangrove species,[33] which are then replaced by more salt-tolerant saltmarsh species. In the Fitzroy river catchment of central Queensland, a long-term decline in rainfall over the last 130 years has been linked to the dieback of mangroves and expansion of saltmarshes in the region.[36] In contrast, a study undertaken in the Hinchinbrook region found that although the total vegetated inter-tidal area had not changed between 1941-1991, there was a shift in the vegetation type due to an increase in rainfall. It was estimated that over the 50-year period, mangroves had replaced 78 per cent of the saltmarshes.[39]

Mangrove and saltmarsh ecosystems are also affected by natural disturbances, such as storms and cyclones that generate strong winds and pulses of sediment-laden floodwater,[21,40,49] as well as pest outbreaks.[36,62] These disturbance events may cause death, dieback or impaired plant growth, but under ‘normal’ conditions recovery usually occurs within a few years. However, if the ecosystem is experiencing a decline in health or lack of resilience, and is stressed due to the exposure of other pressures, the ecosystem may fail to recover as expected after a disturbance event.

The current condition of mangroves and saltmarshes
While it is apparent that a significant area of the Queensland coast has been developed since European settlement, the actual area of mangrove and saltmarsh habitat lost since that time is unknown. Recent trends in mangrove and saltmarsh ecosystem condition (in terms of their distribution and plant species composition) can be obtained from satellite images. Although localised declines in mangrove[29] and saltmarsh[2] habitats have occurred (see *Pressure*), the available satellite imagery suggests that the overall condition of mangrove and saltmarsh

habitats in or adjacent to the GBRWHA are relatively stable. Nevertheless, in order to detect more subtle changes in condition and health within these ecosystems, there is an urgent need to establish baseline data at suitable scales, long-term monitoring and retrospective remote sensing.[36]

Pressure

Mangrove and saltmarsh ecosystems along the GBR coast experience pressures from both human activities and natural processes. Pressures facing mangrove and saltmarsh habitats do not occur in isolation. The impacts of cumulative pressure can reduce the ecosystem's ability or capacity to recover from otherwise minor disturbances and in some situations, may eventually result in a serious long-term decline, without recovery. Given the importance of mangroves and saltmarshes to the GBR ecosystem, the pressures facing these habitats are of significant concern to reef managers.

The main pressures facing mangrove and saltmarsh ecosystems along the GBR coast include:

- Coastal development (physical damage or removal, and changes in hydrology and salinity regimes)
- Declining water quality (increased levels in sediments, nutrients and pesticides)
- Shipping and oil spills (increased levels of petrochemicals)
- Aquaculture (increased siltation, erosion and nutrients)
- Disturbance events (severe weather events and invasion of pest species)
- Climate change (sea level rise and increase in storm/cyclone frequency and intensity)
- Human use (fishing and collecting).

In some circumstances, declining water quality may cause an increase in the area of mangroves. However, the expansions are essentially a symptom of an ecosystem imbalance and in the longer-term may cause a decline in the health of the ecosystem.

Pressure: coastal development and declining water quality

In and adjacent to the GBRWHA, coastal development and declining water quality are the most significant pressures on mangroves and saltmarshes.[29]

Coastal development
Over the last 150 years, the removal of mangrove and saltmarsh habitats in some areas of the GBR coast has been recorded. This removal has primarily been undertaken to reclaim land for urban and industrial development, port expansion, salt farms, mining, aquaculture, and agriculture.[6,7,15,36,38,77] Some examples include:

- Gladstone and Boyne region: between 1941 and 1999, 1,470 ha of mangroves and 1342 ha of saltmarshes were cleared.[36] Most of the inter-tidal wetland loss was experienced in the Port Curtis region. Between 1941 and 1989, approximately 650 ha of mangroves and 950 ha of saltmarshes were cleared mainly for industrial and urban development.[7] Further clearing of 520 ha was permitted in the mid 1990s for expansion of the port.[88]
- Fitzroy estuary: between 1946 and 2002, approximately 840 ha of mangroves and saltmarshes were reclaimed for salt farms, agriculture and the expansion of Port Alma.[36] An estimated 2700 ha of salt evaporation ponds occupy inter-tidal areas near Raglan Creek.[17]

- Mackay region: between 1953 – 1995, approximately nine per cent of mangroves and 43 per cent of saltmarsh originally in the region were cleared.[16]
- Cairns regions: during the 1970s, 700 ha of mangroves and saltmarshes were cleared in Trinity Inlet for sugarcane production.[6]
- Mossman region: approximately 30 years ago, 10 ha of mangroves were reclaimed for agriculture.[74]

Salt farms, along with a number of other land-use practices, place pressure on mangrove and saltmarsh habitats.

Even when relatively small areas of mangroves and saltmarshes are removed from the GBR coast and estuaries, the impact of these changes on the surrounding environment may accumulate over time.[29]

Coastal development continues to place pressure on mangrove and saltmarsh ecosystems along the GBR coast. The Port of Gladstone is currently undergoing an extensive expansion programme that may result in the removal of mangroves and saltmarshes. The development of marinas and resorts may also be a threat to mangrove and saltmarsh habitats, especially where areas need to be reclaimed. Further, the construction of infrastructure such as bridges, causeways and pontoons that service these developments may pose secondary pressure from increased vehicle traffic (that causes soil compaction), physical damage to plants, and changes in drainage patterns (see *Changes in Hydrology*). Vehicle traffic, especially 4WDs, have been linked to the degradation of saltmarshes.[14,41]

Acid Sulfate Soils

Acid Sulfate Soils contain iron sulfide (pyrite) and when exposed to air, toxic sulfuric acid is formed. As a result, a highly acidic discharge (pH<4), containing significant levels of aluminium and iron, is released into surrounding waterways.

Acid Sulfate Soils occur naturally in coastal areas of Australia. However, they pose serious risk to the surrounding environment when they are disturbed or drained. The acidification of water is known to cause fish mortality and disease (such as 'red spot' disease). Further, the increase of dissolved iron in coastal waters from Acid Sulfate Soils discharge has been linked to toxic algal blooms, such as *Lyngbya majuscula*.[69]

Approximately 666 000 ha of Acid Sulfate Soil is present throughout the GBR coastal region and poses a potential threat to the surrounding environment if the soil is disturbed or drained (that is exposed to air).[69] The disturbance of Acid Sulfate Soils in East Trinity Inlet, due to vegetation clearing and the construction of a bund wall and floodgates in 1971, has caused significant ecological damage to the area. Periodic fish kills have been reported since 1972[61] and the acid runoff has caused substantial mangrove mortality on the tidal side of the bund wall.[69] The Acid Sulfate Soil problem in East Trinity Inlet has been identified as a serious problem with a costly remediation strategy now in place to manage the acidification problem. For more information about the remediation of East Trinity Inlet see: www.epa.qld.gov.au/publications/p01939aa.pdf/East_Trinity_Newsletter_Edition_4_2006.pdf

Changes in hydrology
Structures such as break walls or bund walls, causeways and roads can change tidal flow and currents. Disruption and alteration to water flow are known to change sediment deposition and erosion patterns and affect the distribution and function of mangroves and saltmarshes.[36] The development of Clinton Wharf, near Port Curtis, altered the local hydrodynamics, resulting in mangrove dieback.[7] Changes in river channels have also caused extensive losses of saltmarsh habitats in other parts of Australia.[2]

Freshwater input from urban storm water drains has also been identified as a threat to saltmarshes and may affect the community composition, due to changes in the salinity regime.[2] Storm water is also likely to deliver increased nutrients and pollutants into saltmarsh habitats, and may increase the spread of potential weed species.[1] Little is known about these impacts on saltmarshes along the GBR coast.

Agriculture
Saltmarshes are particularly sensitive to impacts associated with some agricultural practices such as increased drainage, ponded pastures[§§], and physical damage from livestock.[14] Levee banks or bund walls have been built to restrict tidal flow to certain areas, which reduces the salinity of the soils on the landward side. Between 1971 and 1975, a 7.2 km long bund wall with tidal floodgates and a network of deep drains was constructed in East Trinity Inlet, Cairns. The construction was designed to reclaim inter-tidal land for sugarcane production. In 1977, 18 ha of mangroves in East Trinity Inlet (predominantly *Rhizophora stylosa*) died due to the dramatic change in the salinity regime as a direct result of the bund wall.[48] More recently, mortality of mangroves in East Trinity Inlet has been associated with the disturbance of Acid Sulfate Soils[69] (see *Coastal development*). East Trinity Inlet has not been used for sugarcane production since 1998, as the area produced low crop yields.

Bund walls have also been built throughout the inter-tidal areas of the Queensland coast in order to increase useable land for livestock. There has been extensive construction of ponded pastures in the Broadsound and Fitzroy River region.[17] Ponded pastures transform areas of saltmarsh habitats into less saline habitat to make it more suitable for pasture.[41] Saltmarshes are critical habitats for many juvenile species, such as barramundi, mullet and penaeid prawns and the construction of bund walls restricts their movement and access to these habitats.[17] In central Queensland, ponded pastures have been reported to trap and kill barramundi and can promote the growth of pest grasses.[18]

Declining water quality
Sediment and nutrients
Since European settlement, large proportions of the natural vegetation in the GBR catchments have been cleared or thinned for grazing, agricultural cultivation, mining, aquaculture, and industrial and urban development.[15] Clearing vegetation in catchments significantly increases the amount of sediment and nutrients flowing into rivers, estuaries and the GBR lagoon.[16,36,77] It has been estimated that the GBR receives approximately 15 million tonnes of sediment per year (four to five times the pre-1850 levels) and approximately 77 000 tonnes of nitrogen and 11 000 tonnes of phosphorus per year (three to five times the pre-1850 levels).[64]

Increased sedimentation in the last 40 years has been linked to significant changes in mangrove distribution in some areas of the GBR coast.[36] In all of the estuaries that have been investigated for changes in sedimentation, mangroves have expanded. These include:[38]
- Trinity Inlet

- Johnstone River estuary
- Pioneer River estuary
- Fitzroy River estuary
- Moresby River estuary

These changes are not considered as signs of improved estuarine health, as these expansions are responses to unnatural increases in sedimentation.[38]

In established mangrove forests, increased sedimentation can reduce mangrove health and growth, and lead to mangrove dieback. Tides, cyclones and floods bring sediment-laden water into mangrove habitats, and during these events excessive sediment can bury the mangrove roots. There have been reports of sedimentation leading to mangrove stress or mortality in several areas along the GBR coast, including Bowen, Gladstone[40] and Princess Charlotte Bay.[21]

The loss or removal of mangroves and saltmarshes affects not only the immediate area, but can lead to increased sedimentation and loss of other ecosystem functions in adjacent habitats, such as seagrass meadows and inshore coral reefs. It has been estimated that if there had been no removal of mangroves and saltmarshes within Trinity Inlet, these communities would have trapped more than half a million tonnes of sediment that has been discharged into surrounding marine habitats in the last 40 years.[84]

Increased sedimentation may arise from many causes. In 1875, a river training wall was constructed in the Fitzroy River. The change in river hydrology resulted in the accumulation of sediment behind the training wall (also used to dump dredging spoil) and the area is now colonised by mangroves.[36] Two new mangrove islands also formed between 1941 and 1999, at the mouth of the Fitzroy River. This is thought to be caused by the combined effect of the construction of the river training wall, and increased sediment deposition in the river, due to land clearing in the Fitzroy catchment.[36]

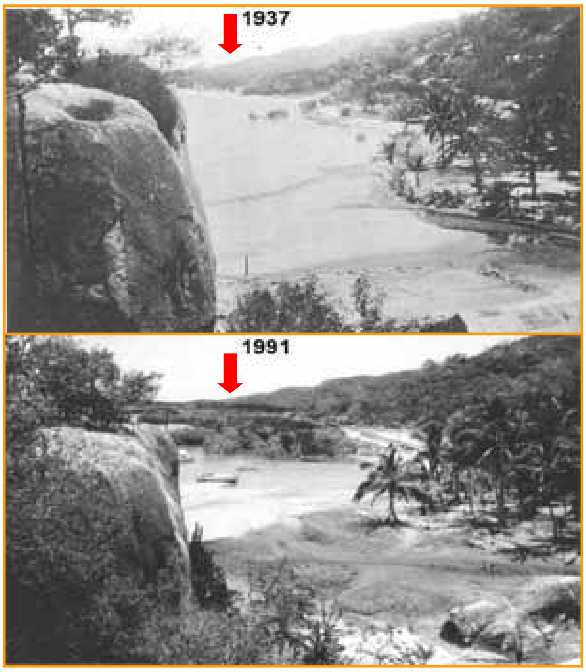

Figure 6. Cockle Bay, Magnetic Island – a comparison through time. Photos courtesy of Norm Duke and Eric Wolanski.[38]

Dredging activities can also generate large amounts of suspended sediment that may accumulate in nearby areas, particularly near where dredge-spoil is dumped. This is evident in Cockle Bay on Magnetic Island where dredging and spoil disposal between 1937 and 1991 have been linked to significant increases in the mangroves in areas that originally had little fine sediment and few mangroves (Figure 6).[38]
Mangrove and saltmarsh systems are generally low in nitrogen and phosphorus and in some cases, increased nutrient levels can enhance mangrove growth and reproduction.[22] However, excessive levels of nutrients, such as nitrogen and phosphorus, can result in eutrophication[llll]. This can cause a change in food webs and microbial communities, resulting in a shift from healthy to unhealthy ecosystems.[3] In some cases fish–kills may occur. Increased nutrients can also fuel algal blooms that smother the breathing roots of the mangroves and cause extensive dieback. In Moreton Bay, southeast

Queensland, algal blooms have been linked to extensive mangrove dieback,[53] and in other parts of Australia, nutrient related dieback of saltmarshes has been recorded.[2] Reports of eutrophication in the GBR mangrove and saltmarsh habitats are rare.[16]

Pesticides

Mangroves may be directly affected by agricultural herbicides[##] such as diuron. Recent research has determined that herbicides, especially diuron, have a greater affect on salt-excreting species, particularly the grey mangrove (*Avicennia marina*), than salt-excluding species such as the red mangrove (*Rhizophora stylosa*).[13] In 2002, more than 30 km^2 of the grey mangrove in at least five adjacent estuaries in the Mackay region, showed signs of significant dieback. Surveys conducted in these estuaries suggest that diuron, from adjacent agricultural areas, has caused the extensive dieback of grey mangroves.[34] The effects of pesticides from agricultural runoff on saltmarsh communities are currently unknown.

Pressure: shipping and oil spills

The majority of oil spills that have occurred in Australia have resulted from shipping incidents.[35] Although major shipping incidents and oil spills are actually rare, they can be catastrophic events with long-term impacts. Three of the most significant oil spills in the GBRWHA include spills near Cape Flattery (December 1991), Yorkeys Knob (December 1994) and more recently in Gladstone Harbour (January 2006).

The Cape Flattery oil spill resulted in the loss of approximately three hectares of mangrove forests and five years after the oil spill the mangroves showed little sign of recovery.[35] In Gladstone Harbour, although surveys by the Queensland Environmental Protection Agency (QEPA) and Queensland Department of Primary Industries and Fisheries (QDPI&F) found that most mangroves appeared intact following the 2006 spill, leaf loss and dieback was found in isolated patches. Further, impacts of oil spills on mangroves may take months to appear (see *Management Status: Shipping and oil spills*).

Oil in mangrove and saltmarsh ecosystems can persist and remain toxic for decades.[2,35] The effects of oil on mangroves depend on the type of oil. Thick, heavy oil tends to smother the breathing roots of mangroves causing them to die slowly. In contrast, thinner, lighter oil dissolves the protective layer on the leaves and bark, allowing toxic chemicals to penetrate the plant's tissue, resulting in rapid death. The severity of an oil spill also depends on the extent of oil coverage, the time of year the spill occurs (plants are more vulnerable during their main growing season), the species involved (some plants are more sensitive than others), and tides and currents.[89]

If the effects of an oil spill on mangroves are not lethal, plant growth, and in some cases reproduction, are seriously impaired and the amount of leaf litter they produce is significantly reduced.[35,37] This has a negative effect on primary and secondary production, in turn affecting many organisms in and adjacent to these inter-tidal habitats. Research undertaken in Moreton Bay and Port Curtis, suggests that significant levels of petroleum hydrocarbons may increase the level of mutation in mangrove propagules.[35,37] This loss in mangrove reproductive viability could have serious implications on the long-term health of mangrove ecosystems that have been exposed to oil.

Pressure: aquaculture

Coastal pond-based aquaculture for species like prawns and barramundi is a growing industry that occupies about 450 ha on the GBR coast.[46] Apart from the immediate loss of mangrove and saltmarsh habitats to aquaculture development, aquaculture operations may increase nutrient and suspended sediment levels in surrounding areas. The creeks that receive effluent may experience increased erosion, while creeks that are pumped for clean water may be exposed to increased siltation.[81] Eutrophication of the habitats downstream from aquaculture effluent discharge may also occur.[87] However, there have been no reported cases of eutrophication due to aquaculture along the GBR coast, reflecting the careful management of these operations.

Some aquaculture ponds along the Great Barrier Reef coast are constructed in mangrove and saltmarsh habitats.

Pressure: disturbance events (storms, cyclones, outbreaks and invasions)

From time-to-time, mangroves and saltmarshes may be affected by disturbance events that cause significant damage over a relatively short time frame. Disturbance events can include storms and weather events, outbreaks of herbivorous insects and invasions by pest species. Under normal conditions, these habitats recover over subsequent years. In general, recovery of mangroves and saltmarshes from disturbances will depend on the nature and extent of the disturbance, the resilience of the mangrove and saltmarsh habitats involved, the impacts of other pressures, and the subsequent environmental conditions.

Storms, cyclones and floods

Disturbance events such as storms, cyclones and floods can cause widespread mortality of mangroves and saltmarshes. In Port Curtis during October 1994, a hailstorm affected approximately 170 ha of mangroves and 41 ha of saltmarshes. The yellow mangrove (*Ceriops tagal*) experienced higher mortality than other species such as the red mangrove (*Rhizophora stylosa*) and grey mangrove (*Avicennia marina*). Surveys two years later found that the canopy cover and species composition had changed, and some saltmarsh plants such as *Sporobolus virginicus* had died.[49]

Weeds and pest species

Mangrove and saltmarsh ecosystems can be greatly affected by weeds and pests. Some of these are native species that only become problems under certain conditions, while others are non-native species that have been brought into Australia. Rubbervine (*Cryptostegia grandiflora*) is a major introduced pest in many regions bordering the GBRWHA and is a particular threat to mangroves and saltmarshes as it can tolerate the saline conditions. Rubbervine infestations have been reported in:

- Port Curtis - currently only found in adjacent freshwater riparian vegetation[83]
- Fitzroy River - currently only found in adjacent freshwater riparian vegetation[17]
- Burdekin River to Molongle Creek.[27]

Pond apple (*Annona glabra*) is also considered to be a potential threat to the inter-tidal ecosystems along the GBR coast.[54]

Under certain conditions insects can have significant effects on mangroves. A herbivorous insect outbreak was reported in Port Curtis during the 1970s, where 30-40 per cent of the *Rhizophora* canopy (an area greater than 200 ha) was affected.[36] In the Rockhampton region during 1995, an outbreak of the moth *Achaea serva* defoliated a 10 km strip of blind-your-eye mangrove (*Excoecaria agallocha*). The moth outbreak coincided with a widespread drought in the region. It is thought that during dry periods, the amount of latex sap (natural defence against predators) present in mangrove leaves is significantly reduced, leaving them more vulnerable to insect attack. After the region received some rain a few months later, surveys of the affected mangroves found that the mangroves had grown new foliage with no further sign of moth damage.[62]

Pressure: climate change

Climate change may have significant effects on mangroves and saltmarsh ecosystems, through the impacts of oceanic circulation patterns and El Nino-Southern Oscillation events, an increase in the frequency and intensity of severe storms, changes in rainfall patterns and rising sea levels.[8] Changes in rainfall patterns could alter the community composition and species diversity of mangrove and saltmarsh ecosystems, and increases in the frequency and intensity of severe storm and extreme weather events will mean more frequent and larger disturbance events.

Rising sea levels are likely to have the greatest effect on mangroves and saltmarshes. Current predictions suggest that climate change may cause the sea level to rise by 0.9 metres in the next 100 years. This rise in sea level will flood the narrow mangroves and saltmarsh habitat zone. In time, as the sea level rises, the inter-tidal zone will move inland creating new areas suitable for mangrove and saltmarsh plants to colonise. However, their ability to colonise these areas may be severely reduced if natural land barriers or human structures (such as levee banks, break-walls, and towns/cities) restrict their migration.

The impact of climate change on mangroves and saltmarshes will be magnified if they are faced with other pressures. Accumulative pressure can cause a decline in the health and resilience of these inter-tidal ecosystems, reducing their ability to recover from the more frequent and severe disturbance events, or adapt to changing conditions.

Pressure: traditional use

The traditional use of mangroves and saltmarshes is not considered as a significant pressure. The historical and cultural significance of mangrove-related food sources is evident in Princess Charlotte Bay, on the east coast of Cape York Peninsula, where extensive shell middens remain.[12] The traditional owners of Princess Charlotte Bay are known to have roasted and eaten the hypocotyl[***] of the orange mangrove (*Bruguiera gymnorhiza*).[25] Mangrove plant extracts are also used as a source of dye.[9] Further, coastal Indigenous Australians used mangrove wood to make spears, spear tips, shields, boomerangs, fire sticks, canoes and paddles. Mangrove plants are also known to Indigenous Australians for their various medicinal purposes.[63]

Traditional foods collected in mangrove habitats include teredos††† (*Teredo sp.)*, oysters (Ostreidae), mud clams (*Geloina sp.*), mud crabs (*Scylla serrata*), and many species of fish.[10] The Kanthanunpu people, a clan of the Kuku Yau tribe from the Lockhart River region, call mud clams 'accul' and treat them as a delicacy. The Kuku Yau men also use large accul shells as a traditional necklace ornament in dance ceremonies (C Turner 2006, pers. comm., 2 August).

The current level of mangrove resources used by indigenous communities in the GBR is undocumented. However, it is clear that mangrove species continue to be an important part of the culture and diet of Indigenous Australians. The *National Recreational and Indigenous Fishing Survey 2003* found that many indigenous communities rely on mangrove species for food. The most important foods are mussels, yabbies, mud crabs, prawns and oysters.[23] Fish such as mullet, catfish, barramundi, snapper, perch and bream taken from mangroves are also important sources of food with over 50 000 fish of each group harvested every year by Indigenous groups in northern Australia.[23]

Response

Response: marine plant protection

The Australian Government and Queensland Government jointly manage the GBR region. The Great Barrier Reef Marine Park Authority (GBRMPA) is the Australian Government agency responsible for managing the Great Barrier Reef Marine Park (Marine Park), which extends from the low tide mark to the continental shelf. The Queensland Government manages internal waters (for example, Hinchinbrook Channel), the inter-tidal zone and other coastal habitats, which include the vast majority of mangrove and saltmarsh habitats (see *Response: coastal development and water quality*).

In Queensland, all mangrove and saltmarsh plants, along with all other marine plants, are protected under the *Queensland Fisheries Act 1994*, which is administered by the Queensland Department of Primary Industries and Fisheries (QDPI&F). The department has a comprehensive policy for addressing a wide range of potential impacts on marine plants, and importantly, the policy also considers pressures arising from cumulative impacts.

Under the *Queensland Fisheries Act 1994*, all marine plants are protected from 'unlawful' damage, disturbance or removal. This means that it is illegal to damage marine plants unless the QDPI&F has issued a permit to do so. Applications for permits to remove, damage or disturb marine plants are assessed against the objectives and provisions of the *Queensland Fisheries Act 1994* and policies. In most cases, permits are only issued if the disturbance to marine plants and tidal lands is minimised. In some instances 'offsets' for impacts are negotiated with the applicants. These offsets can involve requiring the permit holder to provide support for research and education, or to surrender privately owned land to the State for environmental protection. In this way, areas of important habitat, including some freshwater wetlands that are otherwise not protected, have been protected as they have been transferred from private ownership to State ownership. Offsets may also be arranged where the permit holder revegetates an area of marine plants equal to that being removed. This strategy has had mixed success in the past and today is only used when it is considered likely to be more successful than natural colonisation, such as within a degraded area.

The QDPI&F also declares Fish Habitat Areas throughout tidal areas of Queensland. Their purpose is to protect and manage fish habitats that are vital for fisheries productivity to ensure sustainable fishing into the future. Declaration as a Fish Habitat Area affords a high level of protection to marine and estuarine ecosystems in specific locations, as the *Fisheries Regulation 1995* restricts the activities (such as development related activities) that can be authorised in those areas. Therefore, marine plants, including mangroves and saltmarsh plants, in Fish Habitat Areas receive higher protection than under the general marine plant protection provisions of the *Queensland Fisheries Act 1994*. There are currently 41 Fish Habitat Areas, covering a total of 649,889 ha adjacent to and within the GBRWHA. Where marine plants occur within the Marine Park, protection is also regulated under the *Great Barrier Reef Marine Park Zoning Plan 2003*. This plan regulates the type of activities that can occur in different zones, and highly sensitive or ecologically important species are protected.

Maintaining ecosystem resilience
Preserving ecosystem resilience requires an integration of management responses across the entire GBR ecosystem. Consequently, to maintain ecosystem resilience, it is essential to reduce the overall human pressure on these systems, and ensure key ecosystem components and processes remain intact. Some of the Commonwealth Government and State Government initiatives that will help to maintain mangrove and saltmarsh ecosystem resilience include: the *Reef Water Quality Protection Plan* (Reef Plan) *(*see *Response Coastal Development and Water Quality)*; the *Great Barrier Reef Marine Park Zoning Plan 2003* (Zoning Plan) and the *Marine Parks (Great Barrier Reef coast) Zoning Plan 2004*. These initiatives complement other State Government measures to protect these inter-tidal habitats and ensure that the GBR and its components are managed at an ecosystem level. Together, these measures protect the various ecosystem components, and processes, such as reproduction, and the biological connections that link the different habitats. Maintaining these ecological connections and processes is vital to the healthy functioning and resilience of mangrove and saltmarsh ecosystems, as well as the GBR as a whole.

Response: coastal development and water quality

Protection under Queensland legislation
The management of coastal areas of the GBR region, including wetland habitats such as mangroves and saltmarshes, is primarily the responsibility of the Queensland Government and local governments. The state government agencies responsible for managing these areas include the Queensland Environmental Protection Agency, Queensland Department of Natural Resources, Mines and Water, and Queensland Department of Primary Industries and Fisheries. These agencies oversee several articles of legislation that deal with regional planning of development, protection of natural resources, land use, water allocation and activities such as vegetation clearing. As well as being declared Fish Habitat Areas, mangroves and saltmarshes may be included in state National Parks. For example, Bowling Green Bay National Park, Hinchinbrook Island National Park and Edmund Kennedy National Park contain large areas of mangrove forest and other coastal wetlands. As National parks, these areas are protected under the Queensland *Nature Conservation Act 1992*.

The Queensland Government has implemented a policy for *Development and Use of Ponded Pasture 2001* to reduce the impact of ponded pastures on inter-tidal wetlands and fish habitats. This policy, along with the *Queensland Fisheries Act 1994*, means that the construction of new barriers or raising of existing structures across waterways will first need to be assessed through the Waterway Barrier Works Approval framework. This is intended to maximise water flow through these barriers to allow fish to move between areas. In doing so, the policy will help to reduce changes in hydrology that could affect mangroves and saltmarshes.

Protection under the *EPBC Act 1999*

Whilst the Queensland Government is primarily responsible for managing land use along the coast adjacent to the Marine Park, the Australian Government has a responsibility to ensure that the principles of ecologically sustainable development are implemented. Developments and activities that could threaten natural heritage values or matters of 'national environmental significance' may also need to be assessed under the Australian Government *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act 1999*).

Bowling Green Bay and Shoalwater/Corio Bay contain two of the largest areas of mangrove and saltmarsh habitat along the GBR coast. These areas are internationally recognised migratory bird habitats and have been declared as wetlands of international importance under the Ramsar Convention (see Figure 4 and 5). Listing under the Ramsar Convention means that they are recognised as matters of 'national environmental significance' and protected under the *EPBC Act 1999*. The Shoalwater Bay Military Training Area, with its extensive mangrove and saltmarsh habitats, is also recognised as a Commonwealth Heritage Place under the Commonwealth Heritage List protected under the EPBC Act 1999. Certain activities may also be listed under the *EPBC Act 1999*. For example, land clearing has been listed as a *Key Threatening Process* under the *EPBC Act 1999* and the Australian Government has committed support for habitat conservation, planning and land management at the State level.

Improved protection through the *Reef Water Quality Protection Plan*

Another major initiative that will help protect mangroves and saltmarshes is the *Reef Water Quality Protection Plan* (Reef Plan). Launched in December 2003, the Reef Plan is a joint Australian Government and Queensland Government initiative that aims to halt and reverse the decline of water quality entering the GBR, within ten years. The Reef Plan's two main objectives are to reduce the amount of pollutants running from the land to the reef, and to rehabilitate and conserve coastal habitats that play a role in removing water borne pollutants. These coastal habitats include wetlands such as mangroves and saltmarshes. As water quality is one of the main pressures facing these intertidal ecosystems, the Reef Plan should help to reduce the associated pressure.

In 2003, the Australian Government launched the Great Barrier Reef Coastal Wetlands Protection Programme, which will assist in achieving the goals of the Reef Plan. The programme will identify priority wetlands that play a significant role in improving water quality entering the GBR lagoon and provide habitats for flora and fauna. The Queensland Natural Heritage Trust Wetlands Programme is a joint Queensland Government and Australian Government initiative to drive institutional reforms to better protect, conserve and manage wetlands. Some of the projects include state-wide mapping and inventory (*see Response: research and monitoring*), management profiles, and information and education initiatives, which will help land managers and communities, preserve or restore wetlands in their areas. For more information about the protection of wetland habitats (see *Environmental status – coastal birds*).

Education and community awareness
The Australian Government and Queensland Government recognise the need to better educate the community about the value of wetlands and the need for their conservation. As part of the Queensland Wetland Programme, the GBRMPA has undertaken a range of initiatives to help educate the community about the importance of wetlands, particularly to the GBR ecosystem. The initiatives include:

- A new wetlands exhibit at Reef HQ
- Interactive wetlands information kiosks
- Reef Beat poster series
- An interactive web quest for school students
- A wetlands curriculum unit for school teachers.

For more information on the management of land use in the GBR catchment and wetland protection, see:

- *Environmental status – water quality*
- The GBRMPA Water Quality and Coastal Development website
- *Environmental status – coastal birds*
- *Reef Water Quality Protection Plan*.

Response: shipping and oil spills

The management arrangements for shipping in the GBR are designed to reduce the risk of a shipping incident, by maximising shipping and navigational safety. Shipping in the GBR is managed at one of the highest levels of protection in the world (see *Management status: shipping and oil spills*). Should an oil spill occur, the *National Plan to Combat the Pollution of the Sea by Oil and Other Noxious and Hazardous Substances* (the National Plan) and State level contingency plans are activated to coordinate the response. There are several options available for responding to an oil spill. However, the response must consider a large number of factors, including the type of oil involved, weather conditions, the type of environment and the resources available. The costs and benefits of the various options also need to be considered when initiating a response (for more information, see *Management status: shipping and oil spills*).

Mangrove and saltmarsh habitats are high priorities for protection from oil and where possible, efforts are focused on preventing oil from reaching them. This is because removing oil from mangrove and saltmarsh habitats is very difficult and cleaning efforts can result in serious physical damage to the plant roots and branches. Further, oil maybe trampled deeper into the sediment where it continues to impact on plants and animals for extended periods. If oil does enter these inter-tidal habitats, leaving the oil to breakdown naturally maybe considered as the best response option in some instances. Oil, in contact with air and water, will eventually be decomposed by bacteria into less harmful substances through a process known as bio-remediation.

Response: aquaculture

The GBRMPA introduced the Great Barrier Reef Marine Park (*Aquaculture*) Regulations 2000 (Aquaculture Regulations) to address potential environmental impacts associated with the discharge of aquaculture waste to waterways that lead to the Marine Park. In March 2005, the Australian Government accredited Queensland law under the Aquaculture Regulations, meaning that the GBRMPA regulations were incorporated into Queensland law, and ceased to exist as a separate article of legislation. As long as the accreditation remains in place, aquaculture operations are managed under Queensland law and the Queensland Government is responsible for granting permits, monitoring and auditing aquaculture facilities. However, aquaculture operations may require approvals from the Australian Government under the *EPBC Act 1999* where these operations trigger the Act. Such triggers might include potential impacts on threatened species, migratory species or impacts on a listed Heritage Place (see *Response: water quality and coastal development*).

Response: disturbance events (storms, cyclones, outbreaks and invasions)

Storms and disturbance events are part of the natural cycle of disturbance and recovery. These events cannot be managed or controlled so management efforts are focused on maintaining the resilience or health of the ecosystem to ensure that these systems can recover and return to their original state. Maintaining the resilience of mangrove and saltmarsh ecosystems requires minimising pressures that otherwise reduce their ability to recover from disturbance. Consequently, management actions are focused on addressing key pressures such as coastal development and water quality, and preserving the healthy functioning of the GBR ecosystem (see *Response: climate change*).

Response: climate change

Storms and climate events like El Niño are part of natural cycles. However, the potential for climate change to magnify the impact of these events is a significant concern. Climate change is a global issue that is beyond the scope of the GBRMPA to manage directly. At a national level, the Australian Government has committed $1.8 billion to address climate change issues, including investment in climate change research in national programmes to reduce greenhouse gas emissions and to support low emissions technology, renewable energy and energy efficiency initiatives. Within the GBR, the GBRMPA has forged a partnership with the Australian Greenhouse Office to develop and implement a Climate Change Response Programme. The programme aims to identify the potential impacts of climate change on the animals, plants and habitats of the GBR to identify strategies to mitigate these impacts, and to develop a Climate Change Action Plan for the GBR. The vulnerability of mangroves to climate change is being assessed through the programme.

Response: traditional values and use

Traditional use in the GBR is managed through the *Great Barrier Reef Marine Park Act 1975* and the *Nature Conservation Act 1992*. However, these Acts are subject to the provisions of the *Native Title Act 1993* that recognises ‘the rights and interests over land and water possessed by indigenous people in Australia under their traditional laws and customs’. In doing so, the *Native Title Act 1993* makes allowances for traditional use of habitats such as mangroves and saltmarshes. Consequently, most traditional activities are ‘as of right’ and do not require permits.

The GBRMPA works with traditional owners and other agencies to manage the traditional use of marine resources. In July 2004, a new system for managing traditional use of marine resources in the Marine Park came into effect as part of new Marine Park zoning provisions. Under the new system, some traditional use will continue to be ‘as of right’. Other traditional use of marine resources may be conducted through a permit where necessary, or a traditional owner–developed and GBRMPA–accredited '*Traditional Use of Marine Resources Agreement*' (TUMRAs). A TUMRA is a formal agreement relating to the traditional use of marine resources prepared by traditional owners. As TUMRA's are legal instruments recognised by both *Great Barrier Reef Marine Park Act 1975* and the *Queensland Nature Conservation Act 1992*, a TUMRA can be developed that includes traditional use of mangrove and saltmarsh habitats that lie outside the Marine Park.

The GBRMPA is currently working closely with traditional owner groups to assist the implementation of the TUMRAs. In December 2005, the GBRMPA and the Environmental Protection Agency - Queensland Parks and Wildlife Service (QPWS) accredited the Girringun TUMRA and in doing so, ratified the first legal arrangement concerning the traditional use of marine resources between Traditional Owners within the GBR Region. This has set an important precedent and many other traditional owner groups have expressed interest in developing TUMRAs for their areas. For more information on the management of traditional use, see *Management status – Indigenous connections with the Great Barrier Reef*.

Further Reading:

Information on mangroves and saltmarshes

- Wetlands and the Great Barrier Reef
  http://www.gbrmpa.gov.au/corp_site/key_issues/water_quality/wetlands
- Profile of Queensland saltmarshes
  http://www.epa.qld.gov.au/publications/p01719aa.pdf/Saltmarsh_wetlands.pdf
- Profile of Queensland mangroves
  http://www.epa.qld.gov.au/publications/p01867aa.pdf/Mangrove_wetlands.pdf
- Mangrove fact sheets
  http://www2.dpi.qld.gov.au/fishweb/2618.html
- Saltmarsh fact sheets
  http://www2.dpi.qld.gov.au/fishweb/17196.html
- Mangrove physiology and zonation (includes links to facts sheets about specific types of mangroves in Queensland)
  http://www2.dpi.qld.gov.au/fishweb/2623.html
- General information about mangroves
  http://www.epa.qld.gov.au/nature_conservation/habitats/wetlands/wetlands_habitats/mangroves/
- Conceptual models and diagrams of wetlands including mangroves and saltmarshes
  http://www.coastal.crc.org.au/wetlands/conceptual.html
- Mangrove field guide to mangroves of Queensland
  http://www.aims.gov.au/pages/reflib/fg-mangroves/pages/fgm-qld-index.html
- Mangrove State of the Marine Environment Report for Australia
  http://www.deh.gov.au/coasts/publications/somer/annex1/mangrove.html
- General information about mangroves
  http://www.wettropics.gov.au/pa/pa_mangroves.html
- Information about mangroves (Ozestuaries)
  http://www.ozestuaries.org/indicators/intertidal_invertebrates.jsp
- General information about mangroves
  http://www.reefed.edu.au/explorer/plants/mangroves/index.html
- Information about wetlands
  http://www.deh.gov.au/water/wetlands/index.html

- For students – ‘Exploring wetlands’ on-line activities
  http://www.reefed.edu.au/students/reef_quest/wetlands.html
- For teachers – Educational materials and teaching units about mangroves
  http://www.reefed.edu.au/teaching/primary/mangroves/index.html

About management and conservation

- About Fish Habitat Areas
  http://www.dpi.qld.gov.au/cps/rde/xchg/dpi/hs.xsl/28_1238_ENA_HTML.htm
- About protecting marine plants
  http://www.dpi.qld.gov.au/cps/rde/xchg/dpi/hs.xsl/28_1239_ENA_HTML.htm

About wetlands and Ramsar

- About Ramsar in Australia
  http://www.deh.gov.au/water/wetlands/ramsar/index.html
- The Bowling Green Bay Ramsar site
  http://www.epa.qld.gov.au/nature_conservation/habitats/wetlands/wetlands_habitats/bowling_green_bay/
- The Shoalwater/Corio Bay Ramsar site
  http://www.epa.qld.gov.au/nature_conservation/habitats/wetlands/wetlands_habitats/shoalwater_and_corio_bays/

Books

- The field guide to saltmarsh plants can be ordered on-line from the QDPI&F
  http://www2.dpi.qld.gov.au/fishweb/18539.html

End notes

[*] The area of the shore between the high tide and low tide marks

[†] A cross-breed between two or more species

[§] A ‘native’ species that is only found in a given region

[‖] Higher salt concentration in the soil compared with seawater. Hyper-saline conditions tend to exist in areas where saltwater inundation occurs only during the spring tides, rainfall and freshwater input is low, and evaporation rates are high

[#] Seed of a mangrove

[**] Using photosynthesis to produce organic material from chemical elements and energy from the sun

[††] Total weight, volume or energy equivalent of organisms in a given area

[§§] Modification to the natural hydrology in order to increase the production of agricultural plant species

[‖‖] Increased nutrient exposure leading to increases in primary productivity and depletion of oxygen

[##] Chemicals used to control plants such as weeds

[***] The part of the propagule which eventually bears the roots

[†††] A type of bivalve that is often found burrowing in decaying wood

Bibliography

1.Adam, P. 2000, 'Saltmarsh', in *State of the Marine Environment Report for Australia: Technical Annex 1 - The Marine Environment*, eds L.P. Zann and P. Kailola, Department of the Environment, Sport and Territories, Ocean Rescue 2000 Program, Canberra, http://www.deh/gov.au/coasts/publications/somer/annex1/saltmarsh.html

2.Adam, P. 2002, 'Saltmarshes in a time of change', *Environmental Conservation* 29 (1): 39-61.

3.Alongi, D. 1994, 'The role of bacteria in nutrient recycling in tropical mangrove and other coastal benthic ecosystems', *Hydrobiologia* 285: 19-32.

4.Alongi, D. 1998, *Coastal Ecosystem Processes*, CRC Press LLC, p419.

5.Alongi, D.M. and McKinnon, A.D. 2005, 'The cycling and fate of terrestrially-derived sediments and nutrients in the coastal zone of the Great Barrier Reef shelf', in *Marine Pollution Bulletin, Catchment to Reef: Water Quality Issues in the Great Barrier Reef Region*, eds P.A. Hutchings and D. Haynes, 51, 239-252pp.

6.Armour, J., Cogle, L., Rasiah, V. and Russell, J. 2004, 'Sustaining the Wet Tropics: A Regional Plan for Natural Resource Management', in *Volume 2B Condition Report: Sustainable Use*, Rainforest CRC and FNQ NRM Ltd, Cairns.

7.Arnold, D.P. 1995, 'Changes to mangrove ecosystem distribution: Port Curtis 1941 to 1989', in *Mangroves - A resource under threat?: An issue of the central Queensland coast, Gladstone Campus, Central Queensland University*, eds D. Hopley and L. Warner, James Cook University of North Queensland, 41-56pp.

8.Australian Greenhouse Office 2005, *Climate Change Risk and Vulnerability: Promoting an efficient adaptation response in Australia*, Australian Greenhouse Office, Department of Environment and Heritage. Written by the Allen Consulting Group, Canberra. p159. http://www.greenhouse.gov.au/impacts/publications/risk-vulnerability.html

9.Australian Institute of Marine Science, *The uses of mangroves*, Australian Institute of Marine Science, viewed on 3 May 2006: http://www.aims.gov.au/pages/research/mangroves/mangrove-uses.html.

10.Australian State of the Environment Committee 2001, 'Coasts and Oceans', in *Australia State of the Environment Report 2001 (Theme Report)*, CSIRO Publishing on behalf of the Department of the Environment and Heritage, Canberra.

11.Ball, M.C. 1998, 'Mangrove species richness in relation to salinity and waterlogging: a case study along the Adelaide River Floodplain, northern Australia', *Global Ecology and Biogeography Letters* 7: 73-82.

12.Bandaranayake, W.M. 1999, 'Economic, traditional and medicinal uses of mangroves', in *AIMS Report 28*, Australian Institute of Marine Science, Townsville.

13.Bell, A.M. and Duke, N.C. 2005, 'Effects of Photosystem II inhibiting herbicides on mangroves - preliminary toxicology trials', in *Marine Pollution Bulletin, Catchment to Reef:*

Water Quality Issues in the Great Barrier Reef Region, eds P.A. Hutchings and D. Haynes, 51, 297-307pp.

14.Bridgewater, P.B. and Cresswell, I.D. 1999, 'Biogeography of mangrove and saltmarsh vegetation: implications for conservation and management in Australia', *Mangroves and Salt Marshes* 3: 117-125.

15.Brodie, J.E. 2002, 'Keeping the wolf from the door: managing land-based threats to the Great Barrier Reef', in *Proceedings of the Ninth International Coral Reef Symposium, Bali, Indonesia. 23-27 October 2000*, eds D. Hopley, P.M. Hopley, J. Tamelander and T. Done, State Ministry of the Environment, Indonesia, Indonesian Institute of Sciences, International Society for Reef Studies, 2, 705-714pp.

16.Brodie, J.E. and Mitchell, A.W. 2005, 'Nutrients in Australia tropical rivers: changes with agricultural development and implications for receiving environments', *Marine and Freshwater Research* 56: 279-302.

17.Bruinsma, C. 2000, 'Queensland Coastal Wetland Resources: Sand Bay to Keppel Bay', in *Information Series QI00100*, Department of Primary Industries Queensland, Brisbane.

18.Cappo, M., Alongi, D.M., Williams, D.M. and Duke, N.C. 1998, 'A Review and Synthesis of Australian Fisheries Habitat Research', in *Major Threats, Issues and Gaps in Knowledge of Coastal and Marine Fisheries Habitats - A Prospectus of Opportunities for the FRDC "Ecosystem Protection Program" Volume 2: Scoping Review*, Fisheries Research & Development Corporation, http://www.reeffutures.org/topics/publications/afhr-vol2.pdf

19.Chapman, M.G. and Underwood, A.J. 1995, 'Mangrove Forests', in *Coastal Marine Ecology of Temperate Australia*, eds A.J. Underwood and M.G. Chapman, University of New South Wales Press Ltd, Sydney, 187-204pp.

20.Chapman, V.J. 1974, *Salt Marshes and Salt Deserts of the World*, Cramer, J. (ed 2), supplemented reprint. Lehre.

21.Chappell, J. and Grindrod, J. 1984, 'Chenier Plain Formation in Northern Australia', in *Coastal Geomorphology in Australia*, eds B.G. Thom, Academic Press, 197-231pp.

22.Clough, B.F., Boto, K.G. and Attiwill, P.M. 1983, 'Mangroves and sewage: a re-evaluation', in *Biology and Ecology of Mangroves*, eds H.J. Teas, Junk Publishers, The Hague, 151-162pp. Cited in: Schaffelke, B., Mellors, J. and Duke, N.C. 2005, 'Water quality in the Great Barrier Reef region: responses of mangrove, seagrass and macroalgal communities', in *Marine Pollution Bulletin, Catchment to Reef: Water Quality Issues in the Great Barrier Reef Region*, eds P.A. Hutchings and D. Haynes, 51, 279-296pp.

23.Coleman, A.P.M., Henry, G.W., D.D., R. and J.J., M. 2003, 'Indigenous Fishing Survey of Northern Australia', in *The National Recreational and Indigenous Fishing Survey July 2003*, eds G.W. Henry and J.M. Lyle, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra,

24.Cragg, S.M. and Robertson, A.I. 1989, 'Unpublished study of wood-dwelling fauna in north Queensland'. Cited in: Robertson, A.I. and Alongi, D.M. 2000, 'Mangrove ecosystems in Australia: structure, function and status', in *State of the Marine Environment Report for*

Australia: Technical Annex: 1 - The Marine Environment, eds Z. L.P. and P. Kailola, Department of the Environment, Sport and Territories, Ocean Rescue 2000 Program, Canberra, http://www.deh.gov.au/coasts/publications/somer/annex1/mangrove.html

25.Cribb, A.B. and Cribb, J.W. 1975, *Wild Food in Australia*, Collins, Sydney. p240. Cited in: Hegerl, E.J. 1982, 'Mangrove Management in Australia', in *Mangrove Ecosystems in Australia: structure, function and management*, eds B.F. Clough, Australian Institute of Marine Science, 275-288pp.

26.Dahdouh-Guebas, F., Jayatissa, L.P., Di Nitto, D., Bosire, J.O., Lo Seen, D. and Koedam, N. 2005, 'How effective were mangroves as a defence against the recent tsunami?' *Current Biology* 15 (12): R443-R447.

27.Danaher, K. 1995, 'Coastal wetlands resources investigation of the Burdekin delta for declaration as fisheries reserves', in *Report to Ocean Rescue 2000*, Fisheries Division, Queensland Department of Primary Industries, http://www2.dpi.qld.gov.au/extra/pdf/fishweb/burdekin_report.pdf

28.Danielsen, F., Sorensen, M.K., Olwig, M.F., Selvam, V., Parish, F., Burgess, N.D., Hiraishi, T., Karunagaran, V.M., Rasmussen, M.S., Hansen, L.B., Quarto, A. and Suryadiputra, N. 2005, 'The Asian Tsunami: A Protective Role for Coastal Vegetation', *Science* 310: 643-643.

29.Duke, N. 1997, 'Mangroves in the Great Barrier Reef World Heritage Area: current status, long-term trends, management implications and research', in *State of the Great Barrier Reef World Heritage Area Workshop*, eds D. Wachenfeld, J. Oliver and K. Davis, Great Barrier Reef Marine Park Authority, 288-299pp.

30.Duke, N.C. 1988, 'An endemic mangrove species, *Avicennia integra* sp. nov. (Avicenniaceae), in northern Australia', *Australian Systematic Botany* 1 (2): 177-180.

31.Duke, N.C., *Daintree Mangroves*, Centre for Marine Studies, University of Queensland, Brisbane, viewed on 04 January 2006:
http://www.marine.uq.edu.au/marbot/publications/daintree1and4.pdf
http://www.marine.uq.edu.au/marbot/publications/daintree2and3.pdf.

32.Duke, N.C. 2006, *Australia's mangroves. The authoritative guide to Australia's mangrove plants*, The University of Queensland and Norman C Duke, Brisbane. p200.

33.Duke, N.C., Ball, M.C. and Ellison, J. 1998, 'Factors influencing biodiversity and distributional gradients in mangroves', *Global Ecology and Biogeography Letters* 7: 27-47.

34.Duke, N.C., Bell, A.M., Pederson, D.K., Roelfsema, C.M. and Bengston Nash, S. 2005, 'Herbicides implicated as the cause of servere mangrove dieback in the Mackay region, NE Australia: consequences for marine plant habitats of the GBR World Heritage Area', in *Marine Pollution Bulletin, Catchment to Reef: Water Quality Issues in the Great Barrier Reef Region*, eds P.A. Hutchings and D. Haynes, 51, 308-324pp.

35.Duke, N.C. and Burns, K.A. 1999, *Fate and effects of oil and dispersed oil on mangrove ecosystems in Australia*, Australian Institute of Marine Science and CRC Reef Research Centre, http://www.aims.gov.au/pages/research/mangroves/fae/fae03.html

36.Duke, N.C., Lawn, P., Roelfsema, C.M., Zahmel, K.N., Pederson, 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*, Historical Coastlines, CRC for Coastal Zone Estuary & Waterways Management, Brisbane.
http://www.coastal.crc.org.au/Publications/HistoricalCoastlines.html

37.Duke, N.C. and Watkinson, A.J. 2002, 'Chlorohyll-deficient propagules of *Avicennia marina* and apparent longer term deterioration of mangrove fitness in oil-polluted sediment', *Marine Pollution Bulletin* 44: 1269-1276.

38.Duke, N.C. and Wolanski, E. 2001, 'Muddy Coastal Waters and Depleted Mangrove Coastlines - Depleted Seagrass and Coral Reefs', in *Oceanographic Processes of Coral Reefs: Physical and Biological Links in the Great Barrier Reef*, eds E. Wolanski, CRC Press LLC, 77-88pp.

39.Ebert, S.P. 1995, *The geomorphological response to sediment discharge from the Herbert River, north Queensland, 1943-1991*, Honours Thesis, James Cook University of North Queensland, Townsville. Cited in: Duke, N. 1997, 'Mangroves in the Great Barrier Reef World Heritage Area: current status, long-term trends, management implications and research', in *State of the Great Barrier Reef World Heritage Area Workshop*, eds D. Wachenfeld, J. Oliver and K. Davis, Great Barrier Reef Marine Park Authority, 288-299pp.

40.Ellison, J.C. 1998, 'Impacts of Sediment Burial on Mangroves', *Marine Pollution Bulletin* 37 (8-12): 420-426.

41.Environmental Protection Agency/Queensland Parks and Wildlife Service, *Managing the saltmarsh wetlands*, Environmental Protection Agency/Queensland Parks and Wildlife Services, viewed on 11 May 2006:
http://www.epa.qld.gov.au/nature_conservation/habitats/wetlands/wetland_management_profiles/saltmarsh_wetlands/managing_the_saltmarsh_wetlands/#gen7.

42.Environmental Protection Agency/Queensland Parks and Wildlife Service, *Mangroves*, Queensland Government, viewed on 11 April 2006:
http://www.epa.qld.gov.au/nature_conservation/habitats/wetlands/wetlands_habitats/mangroves/.

43.EPA/QPWS, *Mangroves*, Queensland Government, viewed on 11 April 2005:

44.Galloway, R.W. 1982, 'Distribution and physiographic patterns of Australian mangroves', in *Mangrove Ecosystems in Australia: structure, function and management*, eds B.F. Clough, Australian Institute of Marine Science and Australian National University Press, Canberra, 31-54pp.

45.Halliday, I.A. and Young, W.R. 1996, 'Density, Biomass and Species Composition of Fish in a Subtropical *Rhizophora stylosa* Mangrove Forest', *Marine and Freshwater Research* 47: 609-615.

46.Haynes, D. and Morris, S., *Water Quality*, Great Barrier Reef Marine Park Authority, Townsville, viewed on 17 March 2006:

http://www.gbrmpa.gov.au/corp_site/info_services/publications/sotr/water_quality/index.html.

47.Hegerl, E.J. 1997, 'The Ecological Benefits of Wetland Protection', in *Protection of Wetlands adjacent to the Great Barrier Reef, Babinda, Queensland, Australia, 25-26 September 1997*, eds D. Haynes, D. Kellaway and K. Davis, Great Barrier Reef Marine Park Authority, 77-81pp.

48.Hegerl, E.J. and Davies, J.D. 1977, 'The mangrove forests of Cairns, northern Australia', *Marine Research in Indonesia* 18: 23-57.

49.Houston, W.A. 1999, 'Severe hail damage to mangroves at Port Curtis, Australia', *Mangroves and Salt Marshes* 3: 29-40.

50.Jaensch, R., *Saltmarsh Wetlands*, Ecosystem Conservation Branch, Environmental Protection Agency, Brisbane, viewed on 12 April 2006: http://www.epa.qld.gov.au/publications?id=1719.

51.Johns, L. 2006, *Field guide to Common Saltmarsh Plants of Queensland*, Department of Primary Industries and Fisheries, p76.

52.Joyce, K., *Mangrove Wetlands*, Ecosystem Conservation Branch, Environmental Protection Agency, Brisbane, viewed on 12 April 2006: http://www.epa.qld.gov.au/publications?id=1867.

53.Laegdsgarrd, P. and Morton, R. 1998, *Assessment of health, viability and sustainability of mangrove community at Luggage Point*, Report by WBM Oceanics Australia to Brisbane City Council, Brisbane. Cited in: Schaffelke, B., Mellors, J. and Duke, N.C. 2005, 'Water quality in the Great Barrier Reef region: responses of mangrove, seagrass and macroalgal communities', in *Marine Pollution Bulletin, Catchment to Reef: Water Quality Issues in the Great Barrier Reef Region*, eds P.A. Hutchings and D. Haynes, 51, 279-296pp.

54.Le Cussan, J. 1991, *A report on the intertidal vegetation of the Daintree, Endeavour and Russell/Mulgrave Rivers*, Internal Report, Queensland Department of Environment and Heritage, Brisbane. p139. Cited in: Zeller, B. 1998, *Queensland's fisheries habitats: current condition and recent trends*, Information Series Q198025, Department of Primary Industries, Queensland, Brisbane. p211.

55.Lee, S.Y. 1995, 'Mangrove outwelling: a review', *Hydrobiologia* 295: 203-212.

56.Lee, S.Y. 1998, 'Ecological role of grapsid crabs in mangrove ecosystems: a review', *Marine and Freshwater Research* 49: 335-349.

57.Limpus, C.J. and Limpus, D.J. 2000, 'Mangroves in the diet of *Chelonia mydas* in Queensland, Australia', *Marine Turtle Newsletter* 89: 13-15.

58.Lovelock, C. 1993, *Field Guide to the Mangroves of Queensland*, Australian Institute of Marine Science, Townsville. p72. http://www.aims.gov.au/pages/reflib/fg-mangroves/pages/fgm-qld-index.html

59.Lugo, A.E. and Snedaker, S.C. 1974, 'The Ecology of mangroves', *Annual Review of Ecology and Systematics* 5: 39-64.

60.Manson, F.J., Loneragan, N.R., Skilleter, G.A. and Phinn, S.R. 2005, 'An evaluation of the evidence for linkages between mangroves and fisheries: a synthesis of the literature and identification of research directions', *Oceanography and Marine Biology: An Annual Review* 43: 483-513.

61.Martens, M.A., McElnea, A.E., Ahern, C.A. and Hopgood, G.L. 2004, 'Remediating the severe acid sulfate soil problem at East Trinity, Cairns, Australia', in *13th International Soil Conservation Organisation Conference, Conserving Soil and Water for Society: Sharing Solutions*, *Brisbane*, *July 2004*, eds

62.McKillup, S.C. and McKillup, R.V. 1997, 'An outbreak of the moth *Achaea serva* (Febr.) on the mangrove *Excoecaria agallocha* (L.)', *Pan-pacific Entomologist* 73 (3): 184-185.

63.Michie, M., *Aboriginal Use of Mangroves*, viewed on 12 May 2006: http://members.ozemail.com.au/~mmichie/mangr5.htm.

64.Moss, A.J., Rayment, G.E., Reilly, N. and Best, E.K. 1992, *Sediment and nutrient exports from Queensland coastal catchments, a desk study*, Department of Environment and Heritage, Brisbane.

65.Mumby, P.J. 2006, 'Connectivity of reef fish between mangroves and coral reefs: Algorithms for the design of marine reserves at seascape scales', *Biological Conservation* 128: 215-222.

66.Mumby, P.J., Edwards, A.J., Arias-Gonzalez, J.E., Lindeman, K.C., Blackwell, P.G., Gall, A., Gorczynska, M.I., Harborne, A.R., Pescod, C.L., Renken, H., Wabnitz, C.C.C. and Llewellyn, G. 2004, 'Mangroves enhance the biomass of coral reef fish communities in the Caribbean', *Nature* 427: 533-536.

67.Nagelkerken, I., Kleijnen, S., Klop, T., van den Brand, R.A.C.J., Cocheret de la Morinière, E. and van der Velde, G. 2001, 'Dependence of Caribbean reef fishes on mangroves and seagrass beds as nursery habitats: a comparison of fish faunas between bays with and without mangroves/seagrass beds', *Marine Ecology Progress Series* 214: 225-235.

68.Nagelkerken, I., Roberts, C.M., van der Velde, G., Doerenbosch, M., van Riel, M.C., Cocheret de la Moriniere, E. and Nienhuis, P.H. 2002, 'How important are mangroves and seagrass beds for coral-reef fish? The nursery hypothesis tested on an island scale.' *Marine Ecology Progress Series* 244: 299-305.

69.Powell, B. and Martens, M. 2005, 'A review of acid sulfate soil impacts, actions and policies that impact on water quality in the Great Barrier Reef catchments, including a case study on remediation at East Trinity', *Marine Pollution Bulletin* 51: 149-164.

70.Queensland Department of Primary Industries and Fisheries, *Coastal Habitat Resources Information System (CHRIS)*, viewed on March 2005: http://chrisweb.dpi.qld.gov.au/chris/.

71.Robertson, A.I. 1991, 'Plant-animal interactions and the structure and function of mangrove forest ecosystems', *Australian Journal of Ecology* 16: 433-443.

72.Robertson, A.I. and Alongi, D.M. 2000, 'Mangrove ecosystems in Australia: structure, function and status', in *State of the Marine Environment Report for Australia: Technical Annex: 1 - The Marine Environment*, eds Z. L.P. and P. Kailola, Department of the Environment, Sport and Territories, Ocean Rescue 2000 Program, Canberra, http://www.deh.gov.au/coasts/publications/somer/annex1/mangrove.html

73.Robertson, A.I. and Duke, N.C. 1987, 'Mangroves as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia', *Marine Biology* 96: 193-205.

74.Russell, D.J., McDougall, A.J. and Kistle, S.E. 1998, *Fish Resources and Stream Habitat of the Daintree, Saltwater, Mossman and Mowbray Catchments*, Northern Fisheries Centre, Department of Primary Industries, Queensland, Cairns. p72.

75.Saenger, P. 1982, 'Morphological, Anatomical and Productive Adaptations of Australian Mangroves', in *Mangrove Ecosystems in Australia: structure, function and management*, eds B.F. Clough, Australian Institute of Marine Science, 302pp.

76.Sasekumar, A., Chong, V.C., Leh, M.U. and Cruz, R.D. 1992, 'Mangroves as a habitat for fish and prawns', *Hydrobiologia* 247 (1-3): 195-207.

77.Schaffelke, B., Mellors, J. and Duke, N.C. 2005, 'Water quality in the Great Barrier Reef region: responses of mangrove, seagrass and macroalgal communities', in *Marine Pollution Bulletin, Catchment to Reef: Water Quality Issues in the Great Barrier Reef Region*, eds P.A. Hutchings and D. Haynes, 51, 279-296pp.

78.Skilleter, G.A. and Loneragan, N.R. 2002, 'Assessing the Importance of Coastal Habitats for Fisheries, Biodiversity and Marine Reserves: A New Approach Taking into Account "Habitat Mosaic"', in *Aquatic Protected Areas. What works best and how do we know? Proceedings of the World Congress on Aquatic Protected Areas*, eds J. Beumer, A. Grant and D.C. Smith, Cairns, Australia, 240-249pp.

79.Smith, I.T.J. 1988, 'The influence of seed predators on structure and succession in tropical tidal forests', *Proceedings of the Ecological Society of Australia* 15: 203-211.

80.Smith, I.T.J. 1992, 'Forest Structure', in *Tropical Mangrove Ecosystems*, eds A.I. Robertson and D.M. Alongi, American Geophysical Union, Washington, 101-136pp.

81.Talbot, F.H. 2001, 'Will the Great Barrier Reef Survive Human Impact?' in *Oceanographic Processes of Coral Reefs: Physical and Biological Links in the Great Barrier Reef*, eds E. Wolanski, CRC Press LLC, 331-348pp.

82.Tomlinson, P.B., Bunt, J.S., Primack, R.B. and Duke, N.C. 1978, 'Lumnitzera rosea (Combretaceae) - its status and floral morphology', *Journal of the Arnold Arboretum* 59: 342-351.

83.Walker, M.H. 1997, *Fisheries resources of Port Curtis and Capricorn regions*, Queensland Fisheries Management Authority, 84.Wolanski, E. and Duke, N. 2002, 'Mud threat to the Great Barrier Reef of Australia', in *Muddy Coasts of the World: Processes, Deposits and Function*, eds T.R. Healy, Y. Wang and J.A. Healy, Elsevier Science B.V., Amsterdam, 533-542pp.

85.Wolanski, E., Mazda, Y., Furukawa, K., Ridd, P., Kitheka, J., Spagnol, S. and Stieglitz, T. 2001, 'Water Circulation in Mangroves, and Its Implications for Biodiversity', in *Oceanographic Processes of Coral Reefs: Physical and Biological Links in the Great Barrier Reef*, eds E. Wolanski, CRC Press LLC, Townsville, 53-76pp.

86.Wolanski, E., Spagnol, S. and Ayukai, T. 1999, 'Field and model studies of the fate of particulate carbon in mangrove-fringed Hinchinbrook Channel, Australia', *Mangroves and Salt Marshes* 2: 205-221.

87.Wolanski, E., Spagnol, S., Thomas, S., Moore, K., Alongi, D., Trott, L. and Davidson, A. 2000, 'Modelling and Visualizing the Fate of Shrimp Pond Effluent in a Mangrove fringed Tidal Creek', *Estuarine Coastal and Shelf Science* 50 (1): 85-97.

88.Zeller, B. 1998, *Queensland's fisheries habitats: current condition and recent trends*, Information Series Q198025 Department of Primary Industries, Queensland, Brisbane. p211.

89.Zhu, X., Venosa, A.D., Suidan, M.T. and Le, K. 2004, *Guidelines for the bioremediation of oil-contaminated salt marshes*, United States Environmental Protection Agency, Cincinnati. p66.