Australian Government

Great Barrier Reef
Marine Park Authority

Plane Basin Assessment

Mackay Whitsunday Natural Resource Management Region

Assessment of ecological functions within the Plane basin focusing on understanding and improving the health and resilience of the Great Barrier Reef

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Great Barrier Reef Marine Park Authority

Department of Sustainability, Environment, Water, Population and Communities

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Great Barrier Reef Marine Park Authority
2-68 Flinders Street (PO Box 1379)
Townsville QLD 4810, Australia

Phone: (07) 4750 0700
Fax: (07) 4772 6093
Email: info@gbrmpa.gov.au

www.gbrmpa.gov.au

EXECUTIVE SUMMARY

Context

A healthy and resilient Great Barrier Reef World Heritage Area (the World Heritage Area) is reliant upon the ecological integrity of the adjacent Great Barrier Reef catchment and its coastal ecosystems.

The Plane basin provides habitat for many important marine, estuarine, freshwater and terrestrial species with lifecycles that have connections to the World Heritage Area. The coastal ecosystems in the basin also provide a range of ecological functions that support the health and resilience of the marine environment.

Within the marine environment, coastal waters provide high value marine areas including around islands and inshore coral reefs. To protect representations of these areas, there are many coastal and inshore Marine National Park Zones adjacent to this basin.

This Report is part of a series of similar reports investigating the nature, condition, connectivity and management of coastal ecosystems within basins that form the catchment of the World Heritage Area. The purpose of this report on the Plane basin is to:

- Review coastal ecosystems in the basin, assess their state and consider the pressures that they are facing now, and into the future.
- Understand the connections between coastal ecosystems and the World Heritage Area, and how changes to these connections are impacting on the ecological functions they provide to the Marine Park.
- Empower communities and stakeholders by providing information that can support on-ground actions.

Maps shown in this basin assessment were derived from a range of data sources, and should only be used as a guide.

The Plane basin

The Plane basin is located south of Mackay and covers an area of 254,010 hectares. The basin estuaries make up 4.6 per cent of the extent of estuaries in the Reef catchment. This amounts to an estimated $3.7 million worth of annual recreational and commercial fisheries catch*.

The coastal ecosystems in the Plane basin have changed significantly over the last century. Changes to hydrology, fish barriers, vegetation and the establishment of exotic weeds have altered the coastal ecosystems in most of this basin. New management designs are required to adapt to the changed hydrology and ecosystems. This needs to occur strategically at a whole of landscape scale.

Key issues

The Plane basin provides habitat for many important marine, estuarine, freshwater and terrestrial species with lifecycles that create connections to the World Heritage Area. Within the World Heritage Area marine environment, the coastal waters provide dugong habitat (protected under extensive dugong protection areas) and also high value marine areas including islands and inshore coral reefs. There are many coastal and inshore Marine National Park Zones adjacent to this basin.

Most of the Plane basin's original vegetation cover, namely forests and woodlands, have been heavily modified or removed. The changes to these ecosystems (and the ecological functions provided by them) have occurred over the last century. These changes include direct loss or clearing of coastal ecosystems, significant changes to overland hydrology, introduction of exotic species, and drainage and filling of wetland ecosystems. Ecosystems have been lost or modified as the result of social and economic development. Any future management needs to be adaptive and innovative to ensure no further loss to coastal ecosystems and the functions they deliver to the World Heritage Area. Though the southern catchment has undergone changes, there are areas of less development which are relatively unchanged (woodlands). These areas should be protected to prevent further decline in connectivity and coastal ecosystems. Inshore marine areas are under threat from anthropogenic impacts including increases in sediment, nutrient and contaminant loads delivered to the World Heritage Area from the Plane basin.

The changes in hydrology and in-stream ecology in the Plane basin are attributed to poor water quality and loss of ecosystem connectivity to the World Heritage Area. Since European settlement, the nature of nutrients and agrichemicals entering these coastal ecosystems has changed from slow release organic nutrients into rapidly assimilated inorganic nutrients. Pesticides and herbicides used on the land are now entering the sea. Inshore seagrass meadows are in decline, which affects dependent species such as vulnerable dugongs and endangered green turtles.

Many of the creeks and streams in this system have poor water quality year round, with weirs and road crossings creating barriers that prevent fish migrations to and from marine areas (for example mangrove jack, sea mullet and barramundi).

Potential management actions

This report has been developed as a baseline for the Plane basin. In order to ensure that the basin is best represented, consideration of additional finer scale data, local knowledge and information will further enhance this assessment.

Ensuring the long-term health of the Reef requires greater protection of, and restoration of important ecological processes and functions provided by Fitzroy basin coastal ecosystems. Actions that would increase protection and restore processes and function include:

1. The inclusion of rehabilitation plans into the life of a mining project and audited by management agencies to ensure compliance.

2. Greater protection, restoration and management of remnant and riparian vegetation to reduce bank erosion and to filter nutrients and sediments.
3. Greater protection, restoration and management of wetlands and their floodplains that recycle and trap nutrients and sediments and provide important nursery areas for fish species.
4. Restore connectivity of streams, rivers and waterways to promote hydrological connectivity and improve fish passage.
5. Manage modified coastal ecosystems to provide ecological functions and values that support the health of the World Heritage Area through the continued improvement in land management practices (grazing, dryland and irrigated production).
6. Encourage strategic vegetation management, including planting of climate change adapted species and plants designed to address the modified landscape (e.g. deep rooted trees planted on floodplain to assist in managing rising groundwater and salinity).
7. Plan and manage new land use to have no net impact on the World Heritage Area.

*This figure was derived from the annual catch in the Great Barrier Reef of fish and invertebrate species that use estuaries for part or all of their life histories. This amounted to approximately $20,000 per square kilometre of estuary (assuming all estuaries are equally productive and using Gross Value of Production figures from the east coast inshore finfish fishery, mud crab fishery and other trawl fishery).[1]

INTRODUCTION

Background

The Great Barrier Reef Marine Park (Marine Park) covers an area of approximately 348,000 km^2 and extends from Cape York in the north to Bundaberg in the south. The Great Barrier Reef World Heritage Area was accepted in 1981 for inclusion in the World Heritage List, meeting all four of the natural heritage criteria (aesthetics and natural phenomena; geological processes and significant geomorphic features representing major stages of earth's history; ecological and biological processes; and habitats for the conservation of biological diversity, including threatened species). The World Heritage Area includes additional areas outside of the Marine Park. The World Heritage Area extends from the low water mark on the Queensland coast to up to 250 km offshore past the edge of the continental shelf and includes coastal and island ecosystems, as well as some port and tidal areas, outside of the Marine Park.

The adjacent Great Barrier Reef catchment encompasses an area of 424,000 km^2 with all water flowing from the catchment into the World Heritage Area. The catchment contains a diverse range of terrestrial, freshwater and estuarine ecosystems. These coastal ecosystems include rainforests, forests, woodlands, forested floodplains, freshwater wetlands, heath and shrublands, grass and sedgelands, and estuaries.

Coastal ecosystems support the health and resilience of the World Heritage Area. The ecological functions provided by coastal ecosystems include physical processes (such as sediment and water distribution and cycling), biogeochemical processes (such as nutrient and chemical cycling) and biological processes (such as habitat and food provisioning).

This Report assesses the Plane basin's current land use, remaining extent and pressures on coastal ecosystems, and how this basin supports and maintains the health and resilience of the World Heritage Area.

Purpose

The purpose of a basin assessment is to assess at the landscape scale the ecological functions, the risks to these functions and the cumulative impacts that are affecting the long-term health of the World Heritage Area. The focus area for this Report is the Plane basin, which includes ecosystems extending from the inshore areas of the Marine Park to the upper extent of the Plane basin. The information collected, collated and analysed provides a rapid summary of the state of the basin's ecological assets and highlights pressures and threats, ecological condition, and social response to threats and pressures that are influencing the health of the World Heritage Area. More influencing factors – and consequently more pressures – are at work at finer scales of analysis and should be considered when planning or managing these areas.

The Great Barrier Reef catchment is made up of thirty-five basins draining directly into the World Heritage Area, as shown in Table 1.

Table 1: Basins in the Great Barrier Reef catchment

Great Barrier Reef catchment

NRM regions	Basins
Cape York NRM region (managed by Cape York NRM)	Jacky Jacky
	Olive-Pascoe
	Lockhart
	Stewart
	Normanby
	Jeanie
	Endeavour
Wet Tropics NRM region (managed by Terrain)	Daintree
	Mossman
	Barron
	Mulgrave-Russell
	Johnstone
	Tully
	Murray
	Herbert
Burdekin Dry Tropics NRM region (managed by NQ Dry Tropics)	Black
	Ross
	Haughton
	Burdekin
	Don
Mackay Whitsunday NRM region (managed by Reef Catchments)	Proserpine
	O'Connell
	Pioneer
	Plane
Fitzroy NRM region (managed by Fitzroy Basin Association)	Styx
	Shoalwater
	Waterpark
	Fitzroy
	Calliope
	Boyne
Burnett-Mary NRM region (managed by Burnett Mary Regional Group)	Baffle
	Kolan
	Burnett
	Burrum
	Mary

Coastal zone as defined by Queensland State Coastal Management Plan 2011

Methodology

The methods underpinning this basin assessment are detailed in the Coastal Ecosystems Assessment Framework[2], a tool developed in partnership with the Queensland Government (available at www.gbrmpa.gov.au). The Coastal Ecosystems Assessment Framework was developed and used as the basis of the *Informing the Outlook for Great Barrier Reef coastal ecosystems*[3] report, and provides a holistic approach to assessing and understanding ecological functions provided by coastal ecosystems and the pressures affecting them.

The catchment in its current state is a mosaic of natural and modified ecosystems with a suite of values and functions of importance to the World Heritage Area. The methodology used to understand the values and functions provided by natural and modified coastal ecosystems are outlined in the Coastal Ecosystem Assessment Framework[2] and have been used as a basis for the Plane basin assessment. Figure 1 below describes the methodology used to rapidly assess the ecological functions and values to conduct the Plane basin assessment.

Figure 1: Summary of the methodology for conducting a basin scale assessment

Stakeholder engagement and verification of assessment information has been crucial to the development of this basin assessment. Building on the information collected and collated for the *Informing the Outlook for coastal ecosystems*[3] report, the methodology for preparing this Report incorporated the following steps:

1. Local experts were consulted to identify areas of interest to visit in the field as part of a ‘rapid assessment’.
2. Research was conducted on the basin using available information.
3. Sites of interest were identified using coastal ecosystem maps and Google earth (GPS identification for sites to be visited for field work).
4. Collaboration with local stakeholders (i.e. consultants, natural resource management bodies, local land owners) helped to verify the issues affecting the basin, as well as additional field sites.
5. Field investigations were conducted using the field site assessment template forms (Appendix A) to capture site locations and reference photos at basin sites (Figure 2).
6. GPS coordinates from field assessments were imported into Google earth to assist with report preparation.
7. Preliminary basin assessments were compiled to facilitate stakeholder input.
8. Workshops were conducted to bring stakeholders together to present information and incorporate feedback into the basin assessment.
9. Draft basin assessments were prepared as a basis to further stakeholder input.
10. Basin assessments finalised and published.

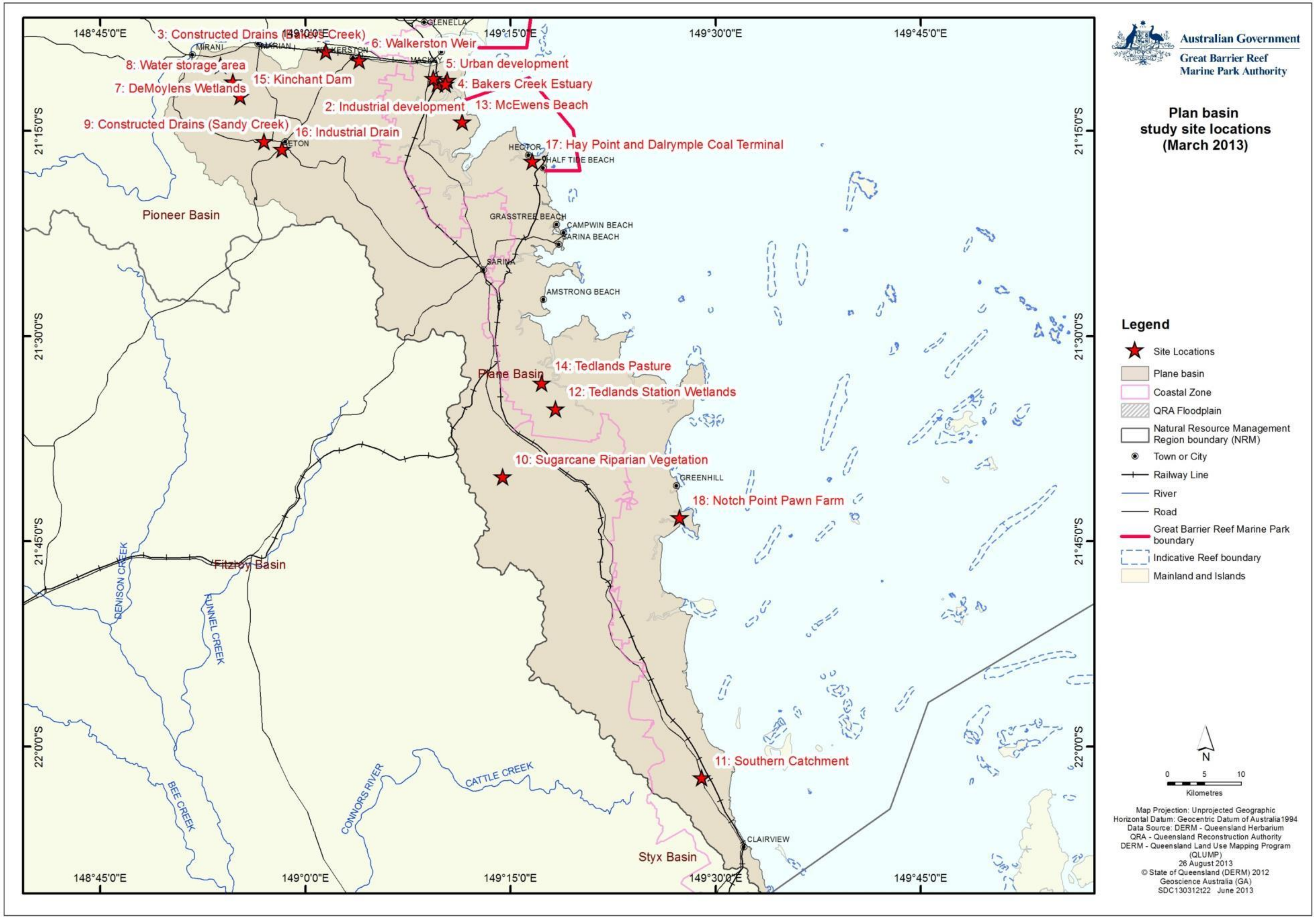

Figure 2: Study sites for the Plane basin assessment

PART A: VALUES OF THE GREAT BARRIER REEF REGION – PLANE BASIN

Chapter 1: Plane basin – background to changes affecting matters of national environmental significance

1.1 Background and history of the Plane basin

The Plane basin is located south of Mackay, extends just past the town of Clairview in the south, and is bounded by the Connors Range to the west (Figure 1.1.1). It is the southernmost basin within the Mackay Whitsunday Natural Resource Management Region and is managed by the Reef Catchment's Natural Resource Management Body. The Plane basin covers an area of 254,010 hectares. Annual rainfall varies north to south along the basin, with higher rainfall in the upper catchment (maximum 3000 mm) compared to the middle and lower (1200-2500 mm) regions.[4] The major creeks in the basin include Bakers Creek, Sandy Creek, Alligator Creek, Plane Creek, Cape Creek, Rocky Dam Creek, Marion Creek, Gillinbin Creek, West Hill Creek, Carmila Creek and Flaggy Rock Creek.

Figure 1.1.1: Map of the Plane basin and its proximity to the Great Barrier Reef catchment and the Great Barrier Reef Marine Park

The Plane basin has a long history of agriculture and port development (Table 1.1.1). The Plane basin's alluvial plain provides fertile soil that supports a prosperous farming industry. The dominant land use (by area) in the Plane basin today is grazing, followed by sugar cane cultivation.

Just south of Mackay is the Hay Point and Dalrymple Bay Coal Terminals. Together they make the world's largest coal export port. Coal is mined inland from the Bowen basin in Central Queensland coal fields and is exported to ports around the world including China and India. The port consists of purpose-built rail-loading facilities, onshore stock yards and offshore jetties leading to wharves. Coal is the only commodity exported from these port facilities.[5]

The hydrology and drainage of the Plane basin has been modified with the construction of drains, weirs and the Kinchant Dam. Kinchant Dam (Study Site 15) is built on upper Sandy Creek and is used to provide irrigation supplies to agriculture and water to surrounding areas.

Social and economic values of the Plane basin include recreation (boating and tourism), irrigation, stock watering, human consumption of aquatic food, and the cultural and spiritual values of Yuibera, Koinjmal, Ngaro and Gia Traditional Owners.[6]

Point sources of pollution within the Plane basin include the town of Sarina (5730 population), which is situated on the banks of Plane Creek, and contains a sewage treatment plant, alcohol distillery and sugar mill. Bakers Creek (770 population) contains an abattoir, a recycled water treatment plant and metal works. Aquaculture facilities can be found throughout the basin such as the prawn farm at Notch Point. Industrial sources of potential pollution include Hay Point and Dalrymple Bay coal-loading facilities and its associated vessels. Additionally, small settlements are found scattered along the coast. Inefficient management of the above mentioned facilities has the potential to cause detrimental impacts on the various creeks and coastal habitats within the region and the World Heritage Area.

The Plane basin has a long history of development that has altered coastal ecosystems (Table 1.1.1).

Table 1.1.1: Historical timeline for the Plane basin[7]

Year	Event
1864	Plane Creek (later Sarina) was established as a pastoral run by Henry Bell.
1894	A central sugar mill is built on Plane Creek, operation began in 1896.
1908	Plane Creek is renamed Sarina.
1913	Sarina was joined to Mackay by rail. Further extensions followed, in 1915 to Koumala and in 1921 to St Lawrence completing (that part of) the North Coast railway route down to Brisbane.
1958	An enhanced water supply for Middle Creek Dam was completed.
1965	Opening of Borthwick's Meatworks at Baker's Creek.
1969	Construction of the Hay Point coal facilities began along with major associated rail facilities at Yukan and Oonooie.
1981	Construction of the Dalrymple Bay Coal Terminal began.
1984	Dalrymple Bay Coal Terminal opens.

Chapter 2: Values and their current condition and trend

The values that are considered in this report include:

- Inshore marine ecosystems that underpin the outstanding universal value of the World Heritage Area (such as coral reefs, seagrasses and associated species).
- Terrestrial, freshwater and estuarine coastal ecosystems that provide ecological functions to the World Heritage Area and other matters of national environmental significance.

The ecosystems examined in this report also provide habitat for a range of other matters of national environmental significance. The matters of national environmental significance in the Plane basin are outlined in section 2.1 below and the values and their elements that underpin matters of national environmental significance for the Plane basin and adjacent waters are shown in Appendix C.

A conceptual model of these ecosystems and the functions they provide is shown in Figure 2.1.

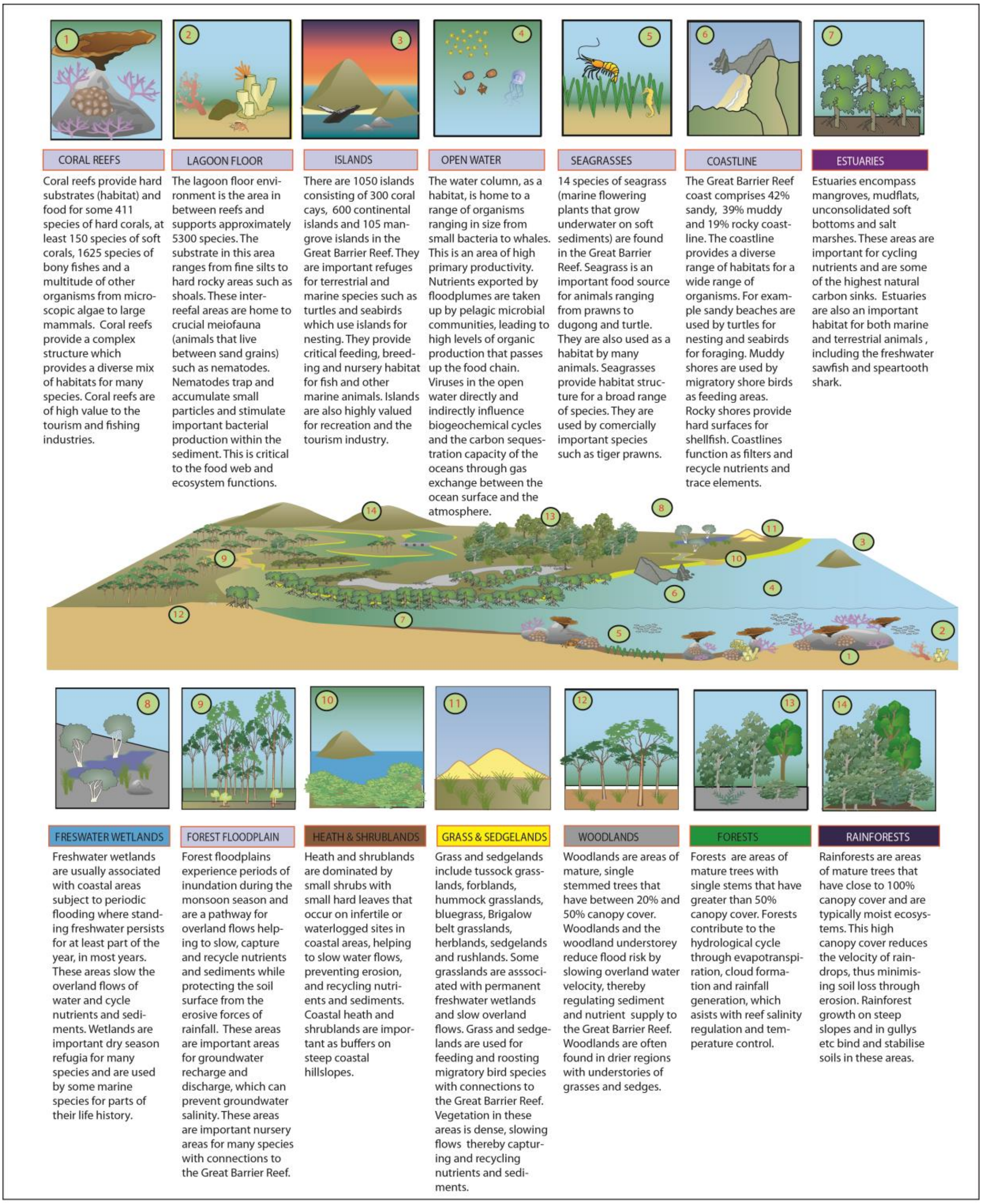

Figure 2.1: Conceptual model for categorizing the Great Barrier Reef coastal, catchment and inshore ecosystems and assessing the ecological functions and services of those ecosystems to the cumulative impacts of development[3]

2.1 Matters of National Environmental Significance in the basin

Under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), actions that have, or are likely to have, a significant impact on a matter of national environmental significance require referral to the Australian Government Environment Minister. The Minister will decide whether assessment and approval may be required under the EPBC Act. There are eight matters of national environmental significance protected under the EPBC Act. These are:

- World heritage properties
- National heritage places
- Wetlands of international importance (listed under the Ramsar Convention)
- Listed threatened species and ecological communities
- Migratory species protected under international agreements
- Commonwealth marine areas
- The Marine Park
- Nuclear actions (including uranium mines).

There are also a number of species that are not listed under the EPBC Act, including the snubfin dolphin which is of concern because of its limited home range.

Heritage properties

The Great Barrier Reef was inscribed in the World Heritage list in 1981 and meets all four natural criteria. Parts of the Plane basin and all of the adjacent marine areas fall within the World Heritage Area.

National heritage properties

The EPBC Act provides for the listing of natural, historic or indigenous places that are of outstanding national heritage value. Within the Plane basin only the Great Barrier Reef is listed as a National Heritage Property (for its natural values).

Wetlands of international importance (declared Ramsar wetlands)

The EPBC Act provides for the management and protection of Australia's Ramsar wetlands. There are no wetlands of international importance within the Plane basin.

Listed threatened species

Five species of bird, one species of frog, five species of mammal, seven species of plant, and seven species of reptiles have been identified as listed threatened species within the Plane and adjacent waters (Appendix D). Key threatened marine species in the World Heritage Area include six of the seven marine turtles and humpback whales.

Figure 2.1.1: The endangered Burdekin Duck (*Tadorna radjah*) is listed on both the ICUN Red List of Threatened Species and EPBC listed species (white head and belly, with dark back and neck ring - photo taken at the edge of an industrial estate adjacent to Mackay Airport, in the Plane basin, February 2013)

Ecological communities

There are two threatened ecological communities within the Plane basin. These are detailed in Table 2.1.1.

Table 2.1.1: Threatened ecological communities within the Plane basin

Community	Status	Occurrence
Littoral rainforest and coastal vine thickets of Eastern Australia	Critically endangered	Likely to occur
Broad leaf tea-tree (*Melaleuca viridiflora*) woodlands in high rainfall coastal north Queensland	Endangered	N/A

Listed migratory species

The lists of migratory species include those species listed in the:

- Japan-Australia Migratory Bird Agreement (JAMBA)
- China-Australia Migratory Bird Agreement (CAMBA)
- Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention).

The wetlands in this region represent important habitat and transport corridors for migratory bird species with the adjacent marine waters. There are 25 species of migratory marine birds, two species of migratory mammals (dugong and humpback whales), and seven species of migratory reptiles (marine turtles and saltwater crocodile) occurring within the Plane basin (Appendix E).

The Great Barrier Reef Marine Park

The Marine Park is recognised as a matter of national environmental significance under the EPBC Act to enhance the management and protection of the ecosystems in the Great Barrier Reef Region. The *Great Barrier Reef Marine Park Zoning Plan 2003* (the Zoning Plan) is the overarching plan that provides for a range of ecologically sustainable recreational, commercial, and research opportunities and for the continuation of traditional activities. Each zone has different rules for the activities that are allowed (as of right), prohibited, and those that require permission. Zones may also place restrictions on how some activities are conducted.

2.2 Other protected areas and values in the basin

Although not a matter of national environmental significance, there are other areas within the Plane basin that have intrinsic values and may also have significance for the long-term health and resilience of the World Heritage Area as detailed below.

Dugong Protection Areas

Dugong Protection Areas A and B occur in the coastal waters of the Plane basin (Figure 2.2.1). Zone ‘A’ Dugong Protection Areas include significant dugong habitats in the southern Reef (consistently contain over 50 per cent of dugong numbers). In these areas, the use of offshore set, foreshore set and drift nets are prohibited. The use of river set nets is allowed with modifications in Zone ‘A’ Dugong Protection Areas. Other netting practices such as ring, seine, tunnel and set pocket netting which are not considered to pose a serious threat to dugongs are unaffected.

In Zone ‘B’ Dugong Protection Areas mesh netting practices are allowed to continue, but with more rigorous safeguards and restrictions than before. Zone ‘B’ Dugong Protection Areas have been shown to contain about 22 per cent of dugongs in the southern Reef. These measures are being kept under review to ensure protection of dugongs in these areas.

Nationally important wetlands (Directory of Important Wetlands in Australia)

Nationally important wetlands in the Plane basin include:

- Broad Sound
- Four Mile Beach
- Great Barrier Reef Marine Park
- Sandringham Bay - Bakers Creek Aggregation
- Sarina Inlet – Ince Bay Aggregation

These are mapped, along with Conservation Parks, National Parks, Forest Reserves, Nature Reserves and Fish Habitat Protection areas in Figure 2.2.1.

Conservation parks, national parks and forest reserves

There are 22 protected areas covering 13 per cent of the Plane basin. These include:

- Bakers Creek Conservation Park
- Ben Mohr Forest Reserve
- Ben Mohr State Forest
- Cape Palmerston National Park
- Collaroy State Forest
- Connors Forest Reserve
- Eton Forest Reserve
- Kelvin Forest Reserve
- Kelvin National Park
- Kelvin State Forest
- Koumala Forest Reserve
- Mount Blarney Conservation Park
- Mount Bridgman Forest Reserve
- Mount Hector Conservation Park
- Mount Kinchant Conservation Park
- Porphyry Hill State Forest
- Sandringham Bay Conservation Park
- Spencer Gap Forest Reserve
- Spencer Gap State Forest
- West Hill Forest Reserve
- West Hill National Park
- West Hill State Forest.

These are shown in Figure 2.2.1.

Fish Habitat Areas

Declared fish habitat areas (FHA) are areas protected under the *Fisheries Act 1994* (Qld) against physical disturbance associated with coastal development and are selected on the basis of their respective values. There are three FHA within the Plane basin – Broad Sound[8], Cape Palmerston[9] (Rocky Dam) and West Hill.[10]These are described in Table 2.2.1.

Table 2.2.1: Fish Habitat Areas located in the Plane basin

FHA	Location	Habitat Values	Fisheries Value	Unique Values
Broad Sound[8] (declared in 1986)	125 km south-east of Mackay and is approximately 170,400 hectares in size.	Extensive mangroves and saltmarshes around the estuary, mangrove-lined creeks and seagrass beds, high tidal range with intertidal areas at low tides, sandy beaches and rocky structures.	Commercial and recreational fisheries.	Largest tidal range in Queensland, state's largest declared FHA.
Cape Palmerston	50 km south east of	Extensive mangrove forests, intertidal flats and saltmarsh	Commercial, recreational	

FHA	Location	Habitat Values	Fisheries Value	Unique Values
(Rocky Dam)[9] (declared in 1986)	Mackay and is approximately 21,500 hectares in size.	areas, fringing inshore reef and seagrass beds in Ince Bay, freshwater in Rocky Dam Creek, large sandy bay that at low tide reveals estuarine sandbars and channels.	and Indigenous fishing grounds.	
West Hill [10](declared in 1986)	It is located approximately 80 km south-east of Mackay.	Extensive mangrove stands, extensive saltmarshes and intertidal flats, salt flats, and seagrass beds.	Commercial and recreational fisheries.	

Nature refuges

A nature refuge is a class of protected area under the *Nature Conservation Act 1992* that acknowledges a commitment to manage and preserve land with significant conservation values while allowing compatible and sustainable land uses to continue. Although a nature refuge agreement may be entered into voluntarily, a nature refuge agreement is legally binding. There are six nature refuges in the Plane basin (Figure 2.2.1).These are:

- Bakers Creek Nature Refuge
- Padaminka Nature Refuge
- Palm Valley Nature Refuge
- The Crossing Nature Refuge
- Thompson's Bush Nature Refuge
- Two Hills Nature Refuge.

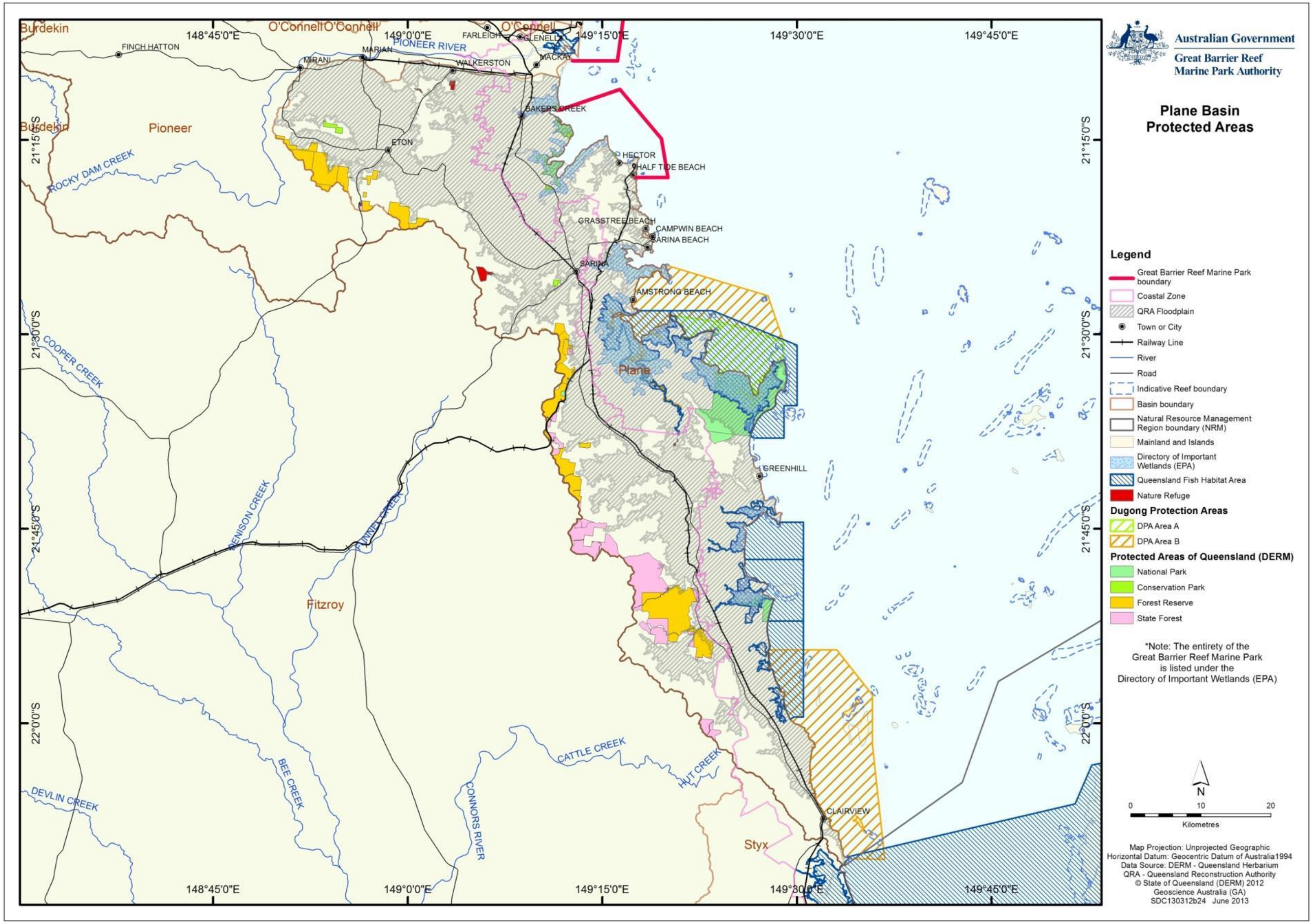

Figure 2.2.1: This map shows the spatial extent of some values in the Plane basin that may underpin matters of national environmental significance, including Nationally important wetlands, National Parks, Conservation Parks, forest reserves, Fish Habitat Areas and Nature Refuges

2.3 Coastal Ecosystems

The Great Barrier Reef inshore ecosystems are made up of many complex components, including estuarine and marine ecosystems such as mangroves, seagrasses and inshore coral reefs, which are closely linked to adjacent coastal ecosystems. These include coastal freshwater wetlands, coastlines and forested floodplains (Figure 2.3.1). These coastal ecosystems are interconnected and reliant on one another for their ongoing health and resilience. Species that form part of the amazing biodiversity of the Great Barrier Reef live in and move between these ecosystems throughout their life cycles.

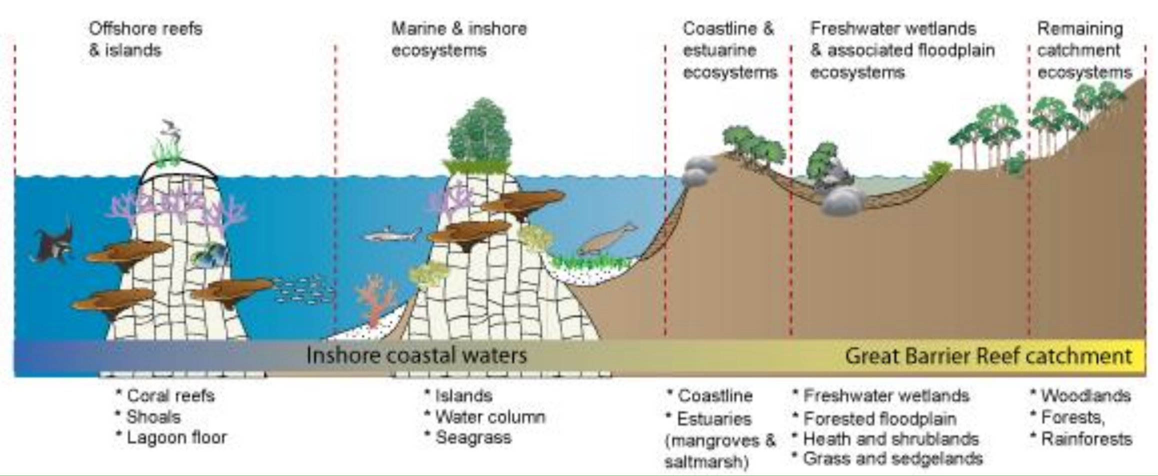

Figure 2.3.1: Broad groupings of coastal ecosystems illustrating the general level of importance for the ongoing health and resilience of the Great Barrier Reef

Coastal ecosystems are not easily separated and defined, as functionally they are all connected one way or another. Each component provides specific ecological functions that together make up and support the health and resilience of the ecosystem as a whole.

Inshore marine coastal ecosystems

The inshore coastal waters adjacent to the Plane basin are home to a range of marine flora and fauna, many of which are of conservation concern. Figure 2.3.4 shows the reefal and non-reefal bioregions in the area that were used as the basis for the Great Barrier Reef Marine Park Authority Zoning Plan (further information on bioregions and reefal and non-reefal areas can be found at http://www.gbrmpa.gov.au/zoning-permits-and-plans/rap). Figure 2.3.5 shows the Marine Park Zoning Plan, used to manage and conserve marine values.

The Great Barrier Reef Outlook Report[11] identified declining water quality as one of the greatest threats to the long-term health and resilience of the World Heritage Area. As a result, substantial investments have been made to improve land based practices with the goal of halting the decline in water quality. Development intensity (urban and agriculture) in the Plane basin is higher in the northern part of the catchment, in particular, Bakers Creek and Sandy Creek (Figure 2.3.3). These areas have considerable differences in the amount of sediment and nutrient loads entering the World Heritage Area due to the lack of riparian integrity and poor drainage design when compared to the southern Plane basin. Water quality in the Mackay Whitsunday region was classified as moderate while inshore areas had poorer water quality.[12] Chlorophyll *a* and total suspended solids were above Water Quality Guidelines.

A list of high profile water quality issues in the Mackay Whitsunday region was discussed in a report written by Brodie et al. 2003[4]. These issues include:

- A number of fish kills in various waterways including Alligator Creek.
- Blue-green algae (cyanobacteria) blooms in Kinchant Dam.
- Reviews suggesting a high rate of chemical use (particularly herbicides) in the region.
- Water quality assessments in which Sandy Creek and Plane Creek were suggested to have the poorest water quality of 18 sub-basins analysed.
- International scientific journal publications linking declining coral reef health in the Whitsundays to river pollutant discharge.
- Sewage treatment effluent discharge exceeding Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (ANZECC & ARMCANZ 2000) guidelines for total nitrogen (N), total phosphorus (P), ammonia and dissolved phosphorus.

Discharge from waterways into coastal waters is highly variable between and within years, and is dominated by large flood events associated with tropical cyclones and monsoonal rainfall.[13,14] It should be noted that during extreme weather conditions such as cyclones water quality in the Mackay Whitsunday region is influenced by flood plumes originating from the Fitzroy River, which is 350 km southeast of the Mackay Whitsunday area.[15] Within the Mackay Whitsunday region, large tides (approximately five metres) promote strong mixing of water within the Great Barrier Reef lagoon creating turbid conditions within shallow waters, especially between Mackay and Shoalwater (within the Plane River basin) (Appendix H). Inner shelf reef development is very limited south east of Mackay due to turbid conditions that negatively impact reef formation.[16]

Most exceedences of water quality guideline values occur during episodic flood events and may last from a period of days to weeks. The level of nutrients, sediments, pesticides and herbicides carried into inshore coastal waters at these times will vary according to the land use occurring within the sub-basin. The impacts on the World Heritage Area will also vary depending on the water quality, the size of the flood plumes, the flow duration, levels of mixing with coastal marine waters and the exposure time of organisms to the plume water.

Seagrass meadows occur in the waters adjacent to the Plane basin. Intertidal seagrass mapping is conducted under the Reef Plan Marine Monitoring Program.[12] Seagrass extent and health (reproductive effort) has been in decline over the last five years.[12] The decline in seagrass meadows is a result of poor abundance, very poor reproductive effort, and increased nutrient enrichment of seagrass tissue. Key environmental drivers of seagrass communities include exposure at low tides and variable catchment run-off.[12]

In 2009 the Reef Water Quality Protection Plan[12] baseline report stated that the inshore reefs in the Mackay Whitsunday region were in moderate condition. There was concern about the lack of recovery of these reefs as there had been no obvious natural disturbances since they were impacted by coral bleaching in 2002. Settlement of coral larvae was good in 2009 although recent data shows signs of decline. The numbers of juvenile corals are also in decline, which may be due to low coral cover limiting the availability of coral larvae. Reefs in the region have been impacted by Tropical Cyclone Hamish (March 2009), Ului (March 2010) and Yasi (February 2011).

The Plane basin contains a number of drainage depressions, which lack riparian vegetation, running through paddocks or a complete absence of remnant vegetation particularly in the northern part of the basin (Figure 2.3.2). An increase in turbidity of waterways was observed in the northern basin when compared to the southern basin which contributes to poor water quality.

Figure 2.3.2: Constructed drain located near Paget with no riparian vegetation (Study Site 5) (left); and a constructed drain running through sugar cane farm with no riparian vegetation (right)

The majority of areas where sugar cane is now grown were previously forests (Figure 3.2.1 and Figure 3.2.2). Forests provide a number of physical and biogeochemical processes to coastal ecosystems (Appendix F) these include:

- Regulating water flow
- Trapping sediment
- Stabilising sediment from erosion
- Assimilating sediment
- Regulating nutrient supply to the World Heritage Area.

The changes associated with the lack of physical and biogeochemical processes that were once provided by forests, in addition to the changes associated with modifying land use to sugar cane production, has resulted in the Plane basin having a very limited capacity to provide adequate coastal ecosystem services and functions.

Within the Mackay Whitsunday region, Bakers Creek is one of the most intensively cropped (61 per cent cane) catchments. During monitoring,[17] Bakers Creek exhibited the lowest minimum (1.2 per cent saturation), lowest median (19.25 per cent saturation) and lowest maximum (52.7 per cent saturation) dissolved oxygen values, indicating that Bakers Creek would not be able to support higher order aquatic taxa such as fish populations and would exhibit a very poor species diversity (Appendix H). Bakers and Sandy creeks did not reach the minimum central Queensland water quality guideline value of 80 per cent saturation.

Bakers Creek was found to be slightly acidic, which was attributed to dissolving organic matter, presence of nutrients and carbon, seasonal variation and melaleuca trees that dominate the riparian zone.[17]

Nutrient concentrations were highest in intensively cropped sites particularly after periods of high rainfall.[17] Sandy Creek and Bakers Creek (intensively cropped) exhibited the highest concentrations for most nitrogen and phosphorus species (for example total nitrogen).

High total phosphorus levels were measured at intensively cropped sites at Sandy Creek and Bakers Creek. These results indicate that P-based fertilisers are widely used throughout the Mackay Whitsunday region. P source available for transportation to the waterway from intensively cropped areas can be reduced with better nutrient management practices (Appendix H). High levels of phosphorus can have devastating impacts on aquatic life forms including eutrophication that can cause toxic algal blooms, resulting in lowered dissolved oxygen concentrations.[18]

Herbicide concentrations were highest in intensively cropped sites and highest values were often measured after heavy rainfall. The most commonly detected chemicals were emetryn, atrazine, hexazinone and diuron.[17] These herbicides commonly occur from cropping (cane and horticulture) and urban land use.[19] The lack of 'water sensitive' drainage designs, fragmented and cleared riparian vegetation, and limited wetland detention or retention areas contribute to the detection of the above herbicides found within the Marine Park.

Figure 2.3.3: Water storage areas function as run-off detention basins in the upper Sandy Creek catchment (Study Site 8)

Reef Catchments have been managing to improve farming practices, lower pollutant loads and remove associated threats to the Reef. The Reef Plan's second report card[16] stated that improved land management practices have been taken up by 17 per cent of sugar cane growers, 41 per cent of horticulture producers and 17 per cent of graziers. Improved land management practices have reduced the annual loads for nutrient (four per cent), phosphorus (one per cent), pesticides (18 per cent) and sediment (three per cent).[16]

The Mackay Whitsunday Water Quality Improvement Plan (WQIP)[19] has developed management interventions for the rehabilitation of priority habitats and the reduction of pollutant loads from diffuse and point sources. Implementation of the WQIP will take place until 2014 and involves management intervention, monitoring and modelling, planning and legislation.[19]

A natural resource management plan was produced by Reef Catchments with aims of protection and restoration of natural and cultural assets. This plan outlines goals for the protection and management of waterways throughout the region with the goals of conserving biodiversity and developing the sustainable use of natural resources.[17]

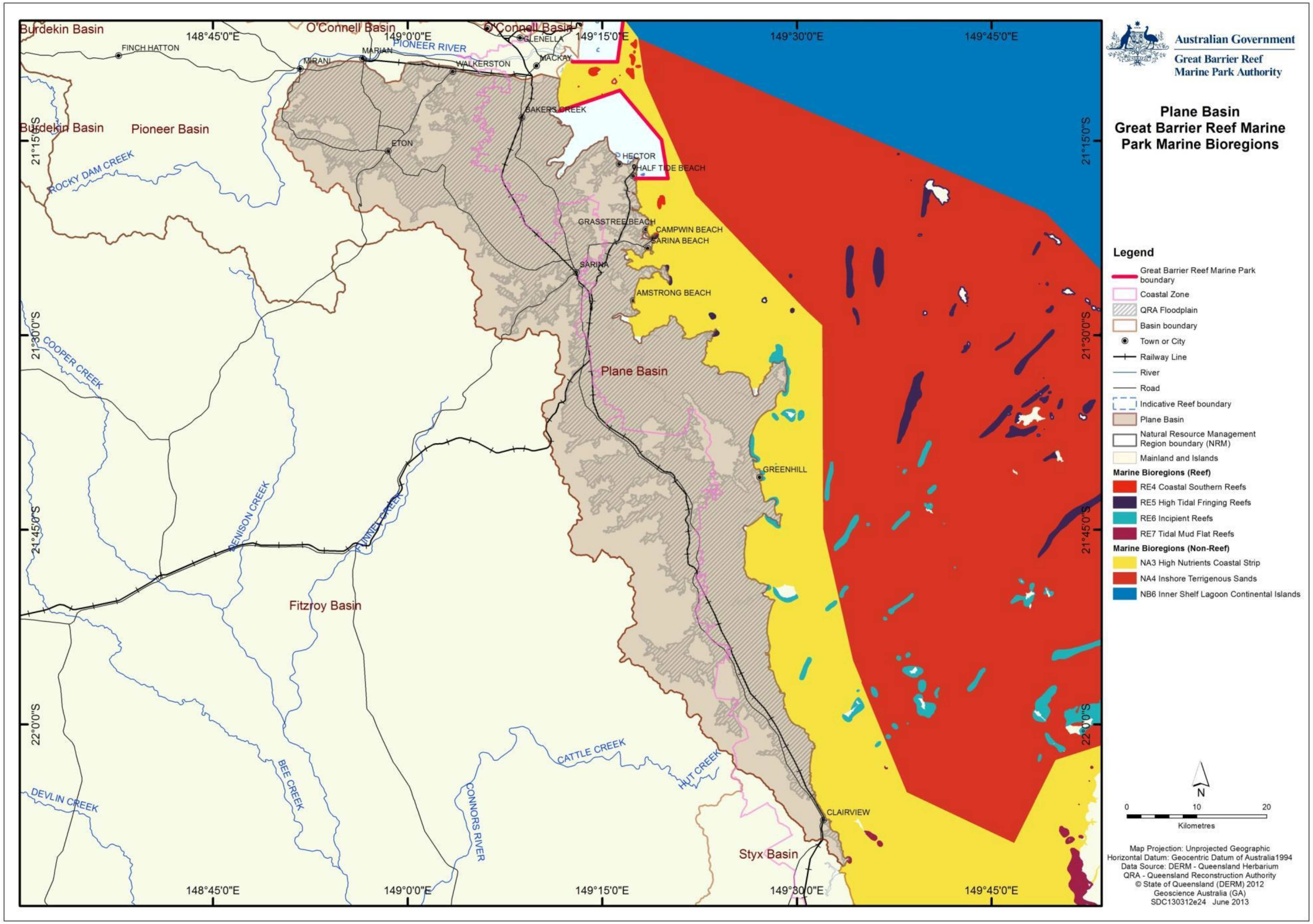

Figure 2.3.4: Marine bioregions adjacent to the Plane basin

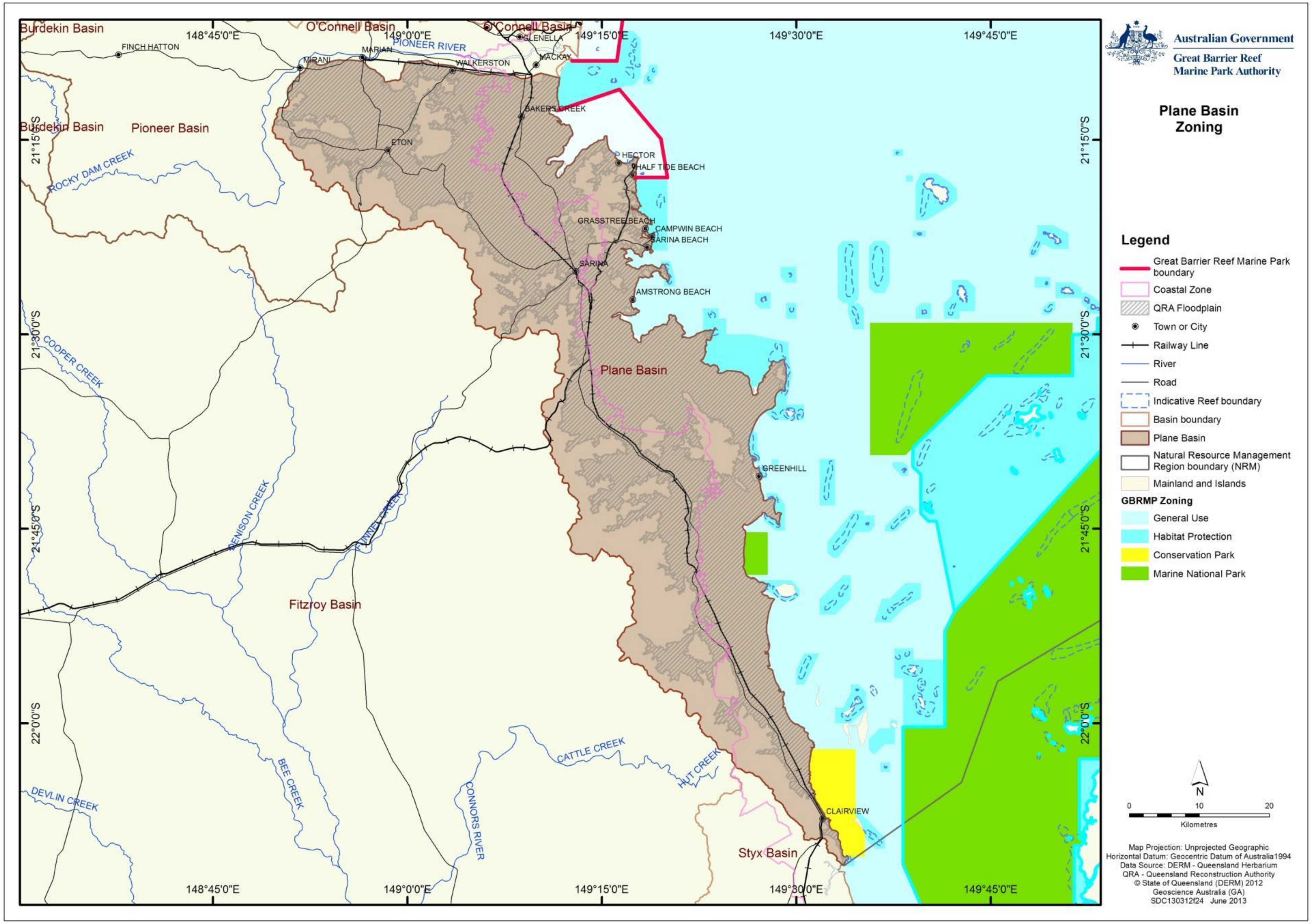

Figure 2.3.5: Zoning within the Marine Park adjacent to the Plane basin

Changes to coastal ecosystems

Coastal ecosystems in the Plane basin have been substantially modified or cleared (Table 2.3.1). Significant changes include:

- Broadscale clearing of forests (103,593 hectares) and woodlands (24,171 hectares).
- Construction of drains to remove water from floodplain wetlands.
- Modifications to river banks topology form including straightening, channelisation and removal of riparian vegetation (these have impacted upon terrestrial and aquatic biodiversity).
- Introduction of pasture grasses that have irreversibly altered the flora biodiversity and natural fire regimes. These introduced grasses often burn hotter and faster causing habitat loss and subsequent changes to biodiversity (including species loss) and lead to loss of soils. The risk to biodiversity can be reduced through sustainable grazing management.
- Aquatic biodiversity has declined in some parts of the basin as a result of landscape changes, fish barriers, in-stream structures and land use. The coastal region of the Plane basin is dominated by grazing and sugar cane cultivation.

Land development patterns have left ongoing legacy issues (such as ponded pastures, elevated export of sediment loads, stream channel habitat losses), which continue to impact on the life cycle of local aquatic and terrestrial species with connections to the World Heritage Area (such as migratory fish and migratory birds). This has led to an ongoing decline in populations of key species, such as mangrove jack and barramundi, due to reduced resilience.[3]

In pre-European times, the Plane basin was dominated by forests and woodlands (Figure 2.3.6). Since European settlement, these woodlands and forested areas have been thinned for grazing and cleared for agricultural production (Figure 2.3.7).

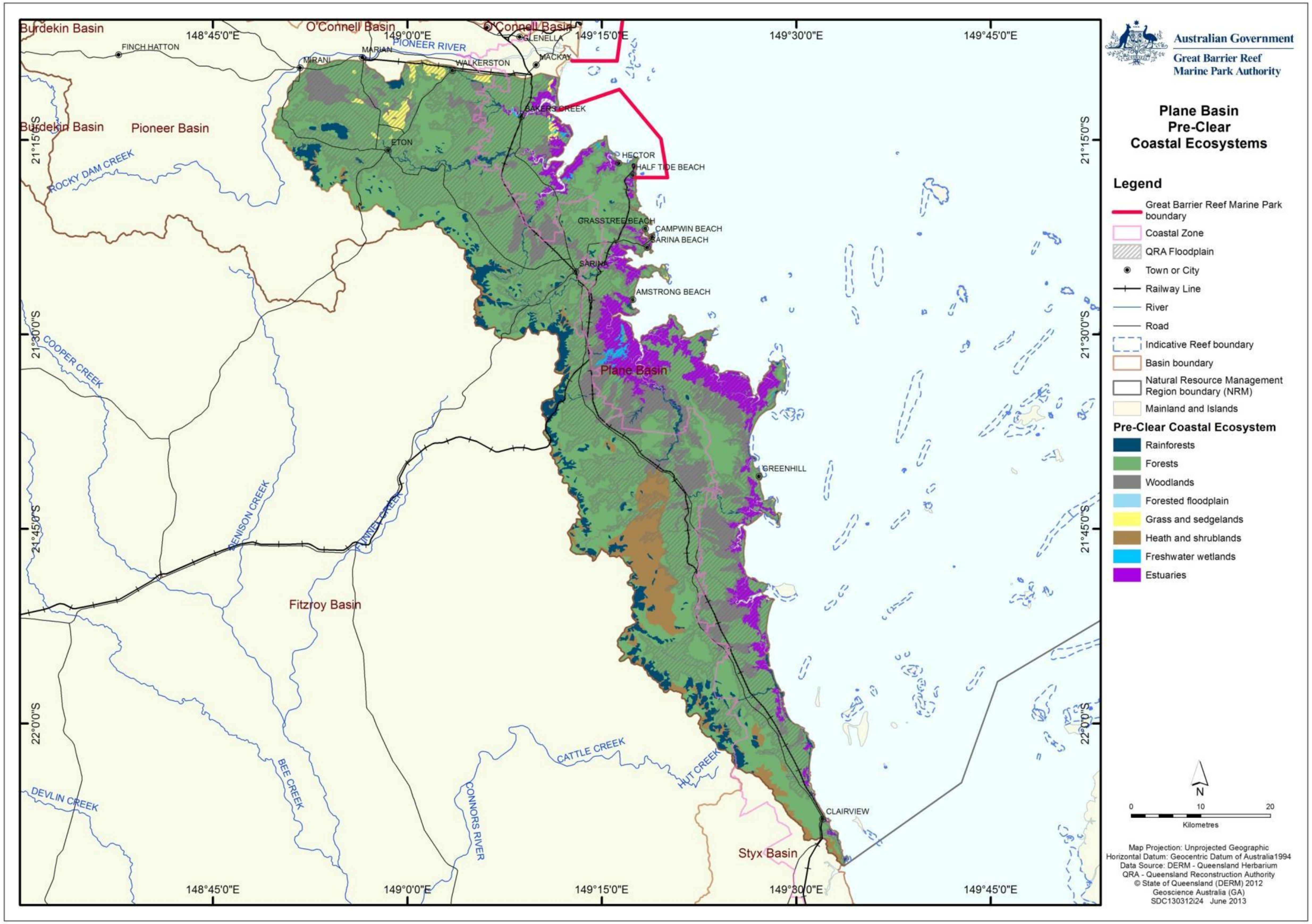

Figure 2.3.6: This map shows the pre-clear coastal ecosystems in the Plane basin

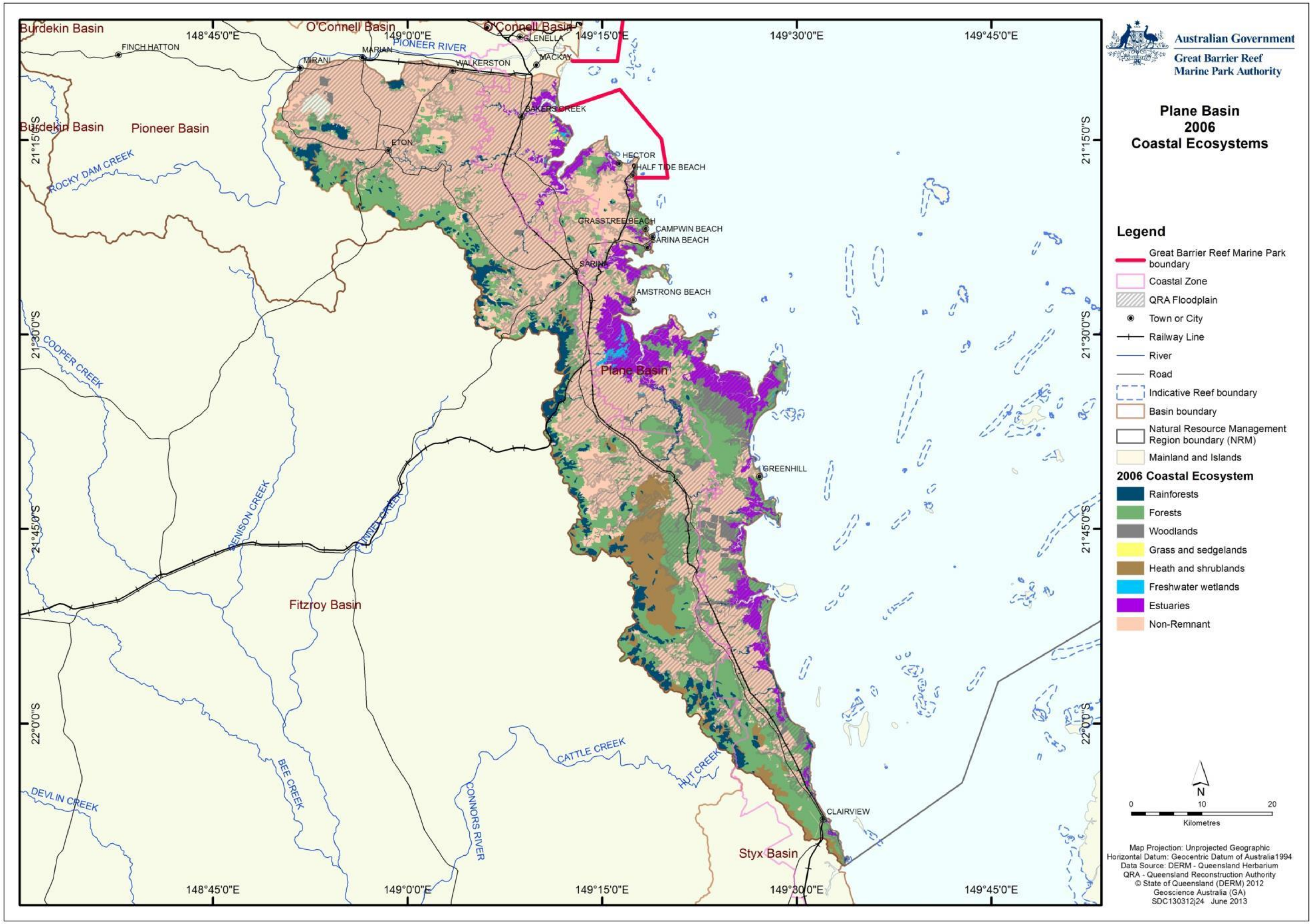

Figure 2.3.7: This map shows the post-clear coastal ecosystem assemblages in the Plane basin (derived from 2006 Queensland Government Regional Ecosystem data)

Changes to coastal ecosystems (Table 2.3.1) show that the greatest proportion of modification to terrestrial biodiversity has occurred to grass and sedgelands (loss of 87 per cent), woodlands (loss of 72 per cent) and forests (loss of 62 per cent). Forests have had the greatest area of loss (103,593 hectares) while woodlands have lost a total area of 24,171 hectares. The combined loss of forests and woodlands and the reduction of the ecological values and functions provided by them have the greatest impact on the World Heritage Area. These ecosystems are important in controlling the erosion of sediments, protecting soil from erosive impacts of raindrops and in-trapping sediments. They also recharge groundwater resources and replenish natural river flows.[3]

For information in regard to the categorisation of the Reef's coastal, catchment and inshore ecosystems and the ecological functions and services of those ecosystems please refer to Figure 2.1.

The floodplain extent for the Plane basin is 168,732 hectares (Queensland floodplain mapping). The Coastal Ecosystems data has been derived using the broadscale vegetation grouping from Queensland Government Regional Ecosystem mapping.[20] This data may not accurately represent areas of forested floodplains and other species that exist in this floodplain area. It is recommended that further fine scale mapping is completed to ensure management decisions are considered.

Table 2.3.1: Area (ha) of pre-clear and post-clear coastal ecosystems based upon Queensland Government Regional Ecosystem mapping

	Ecosystem	Pre-clear (ha)	2006	2009	% remaining
	Rainforests	15,156	13,941	13,940	92
	Forests	165,792	62,607	62,199	38
	Woodlands	33,593	9,434	9,422	28
	Forested floodplain	2	0	0	0
	Grass and sedgelands	2,493	319	319	13
	Heath and shrublands	14,039	13,685	13,666	97
	Freshwater wetlands	845	724	724	86
	Estuaries	19,890	18,826	18,826	95
	Non Remnant	0	131,445	131,885	N/A
	Not Mapped	2,200	3,028	3,030	N/A

Coastline and estuarine coastal ecosystems

Estuaries are highly productive fish nursery areas and provide a range of ecological functions for species with connections to the World Heritage Area. Animals such as prawns, crabs and many popular commercially and recreationally fished species (such as barramundi and mangrove jack) use estuaries for part of their life history. Approximately 4.6 per cent of the estuaries in the World Heritage Area occur in the Plane basin which equates to $3.7 million of gross value of production of fisheries harvest.

The extent of estuaries in the Plane basin has remained relatively unchanged (five per cent loss) according to Queensland Government Regional Ecosystem mapping (Table 2.3.1). The current health of these ecosystems has not been assessed since a study on the condition of estuaries within the Plane basin was completed in 2000 as part of the Australian Estuarine Database Survey.[21] Results of some of the estuary assessments by Australian Natural Resource Atlas within the Plane are shown in Table 2.3.2.

Table 2.3.2: Australian Natural Resource Atlas (ANRA) classification of estuaries for the Plane basin[21]

Name of Estuary	Class	Sub-class	Condition
Bakers Creek	Tide Dominated	Tide-Dominated Estuary	Modified
Sandy Creek	Tide Dominated	Tide-Dominated Estuary	Largely Unmodified
Louisa Creek	Tide Dominated	Tide-Dominated Estuary	Largely Unmodified
Castrades Inlet	Wave Dominated	Wave-Dominated Estuary	Largely Unmodified
Sarina Inlet	Tide Dominated	Tide-Dominated Estuary	Largely Unmodified
Rocky Dam Creek	Tide Dominated	Tide-Dominated Estuary	Modified
Coconut Creek	Tide Dominated	Tidal Flat/Creek	Largely Unmodified
Cape Creek	Tide Dominated	Tide-Dominated Estuary	Largely Unmodified
Knobler Creek	Tide Dominated	Tidal Flat/Creek	Largely Unmodified
Walter Hall Creek	Tide Dominated	Tidal Flat/Creek	Largely Unmodified
Marion Creek	Tide Dominated	Tidal Flat/Creek	Largely Unmodified
Basin Creek	River Dominated	Tide-Dominated Delta	Largely Unmodified
West Hill Creek	Tide Dominated	Tide-Dominated Estuary	Largely Unmodified
Feather Creek	River Dominated	Tide-Dominated Delta	Largely Unmodified
Carmila Creek	Tide Dominated	Tidal Flat/Creek	Largely Unmodified

The condition of the 15 estuaries was assessed by the Australian Natural Resource Atlas in 2000.[21] None of these estuaries was identified as in pristine condition. Bakers Creek (Study Site 4) and Rocky Dam Creek (Figure 2.3.2) were found to be modified (indicating modification of coastal ecosystems in the vicinity of the system) while the remainder were found to be largely unmodified. In terms of estuarine conditions, Sandy Creek was rated the worst followed by Plane and Bakers creeks. Water quality was rated as poor in Rocky Dam Creek and Flaggy Rock Creek, while mangroves and saltmarshes were in poor condition in Carmila Creek as well as Sandy and Alligator creeks.[19]

Freshwater wetlands and associated floodplain coastal ecosystems

Freshwater wetlands across the Plane basin have been reduced to approximately 89 per cent of the pre-European extent. The mapped extent of freshwater wetlands often underestimates losses, especially in those wetlands that are infrequently inundated. Palustrine (Ephermeral) wetlands are periodically dry and are often not recognised as wetland areas. They can be ones that are most vulnerable to being lost or degraded. They are also often the ones that provide connections for species movement within catchments and to the World Heritage Area.[3]

Many otherwise intact wetlands are suffering a range of health problems associated with loss of connectivity, hydrological modification, sedimentation, nutrient overload and weed infestations. The loss of functions therefore may be much greater than changes in extent might imply.

The Queensland and Australian governments, through the Queensland Wetlands Program, have mapped wetlands at a finer scale than the current regional ecosystems mapping. Through this mapping, approximately 281 lacustrine/palustrine wetlands were identified in the Plane basin. The extent and classification types of wetlands within the Plane basin are shown below at Table 2.3.3.

Table 2.3.3: Queensland Wetlands Program data for the freshwater wetlands of the Plane basin[22]

System as defined by the Queensland Wetlands Program	Area (km²)	Wetlands area (%)	Total area of basin (%)
Artificial and highly modified	16.20	5.9	0.6
Estuarine	188.39	68.5	7.4
Lacustrine	0.00	0.00	0.00
Palustrine	22.60	8.2	0.9
Riverine	47.65	17.3	1.9
Total	274.85	100	10.8

The Plane basin contains a wide variety of streams and wetlands that provide habitat for numerous fish species, including endemic, vulnerable and threatened fish species. The streams, wetlands, floodplains and lagoon systems in the Plane basin are fertile nursery areas for fish species including barramundi and mangrove jack (Study Sites 12, 7 and 13).

Study Site 12 - Tedlands Station wetlands

Tedlands Station wetlands are located south of Sarina and are located on Tedlands Station, a working cane and cattle producing property. The wetland consists of riparian vegetated stream channels, lagoons, melaleuca and palm swamp forests, woodlands and bunded inter-tidal areas that were once mangroves and salt couch grasslands. The Tedlands (Figure 2.3.8) consists of a number of significant environmental values including:

- Good condition riparian stream corridors due to the retention of vegetation beyond the immediate stream bank when cleared.
- One of the best remnant deep water floodplain lagoons complete with adjoining riparian vegetation and native macrophyte communities and barramundi and crocodile population.
- Treed swamps that are full of ponded pastures (some loss of biodiversity value) but maintain function as silt retention basins and floodwater retention areas.
- Bunded ex-tidal area wetlands that due to intensive late dry season grazing regimes maintain open water areas and function as fish nursery swamps (barramundi).

Significant values of Tedlands Station for the World Heritage Area include:

- Coastal swamps provide important fish habitat.
- Provide catchment water quality functions (filtering services).
- Detain flow, processing nutrients and retaining sediment and other contaminant loads.
- Protecting endangered and of concern wetland regional ecosystems.[23]

Tedlands Station has implemented a number of best practice management strategies which are maintaining wetland habitat values, including:

- Grazing regimes including stock rotation, and seasonal grazing management can reduce exotic weeds, reduce fuel loads and associated impacts.[23,24]
- Grazing also maintains open water conditions and native submerged and emergent aquatic plant communities and fish and water bird habitat values.[23]
- Late dry season burning can promote a more open and diverse wetland plant community.[23]

Throughout the Mackay Whitsunday region development on the coastal lowlands has impacted on the productivity of fish habitat and nursery areas.[25] Tedlands Station wetlands consist of coastal swamps and deep water lagoons which have significant value for fish habitats.

Tedlands Station demonstrates that the management of nature conservation does not need to compromise production outcomes.[26]

Figure 2.3.8: Tedlands Station wetlands deep water lagoon (left), ungrazed portion of the Tedlands wetland is dominated by exotic pasture (right)

Study Site 7 - DeMoylens Wetlands

DeMoylens wetlands are located approximately 40 kilometres west of Mackay and flows into Sandy Creek. Reef Catchments, Queensland Wetlands Program, Mackay Regional Council and Department of Agriculture, Fisheries and Forestry are collaboratively planning rehabilitation for the area (Figure 2.3.9). Currently, this wetland is full of water hyacinth and Hymenachne grass, and has guinea grass in adjoining riparian vegetation stands. With aquatic weed management and targeted controlled grazing, this area could become a healthy freshwater wetland with open water habitat and minimal impacts from introduced pasture. It could provide a wide range of wetland habitats and, if fish passage connectivity was re-established, provide important food resources, nursery and feeding habitats for key recreational and commercial fish species linked to the World Heritage Area.

Figure 2.3.9: Wetland managed by Reef Catchments, Queensland Wetlands Program, Mackay Regional Council and Department of Agriculture, Fisheries and Forestry for rehabilitation. Hymenachne understory (left) and floating rafts of water hyacinth (right)

Study Site 13 – McEwens Beach

McEwens Beach is a good example of a healthy coastal wetland (Figure 2.3.10). The wetland contains permanent water, along with a wide range of habitats which provide important food sources and shelter for roosting and breeding waterbirds. The wetland is backed by elevated woodlands, surrounded by mangroves, and contains a diverse range of native vegetation. The wetland is an important detention area and settling pond which helps improve water quality, nutrient and sediment loads entering the World Heritage Area, and provides good passage for fish migrations.

Figure 2.3.10: Mangrove vegetation along McEwens Beach wetland (left). Healthy wetland backed by woodlands and an important detention and fish productivity area (McEwens Beach, Study Site 13) (middle and right)

Forested coastal ecosystems

Grass and sedgelands, woodlands, and forests have been subjected to the greatest modifications within the Plane basin. Though the loss measured as a percentage is lowest for forests (62 per cent) when compared with grass and sedgelands (87 per cent) and woodlands (72 per cent), the actual area of land lost from forest is greatest at 103,593 hectares (Table 2.3.1). The loss of these coastal ecosystems will largely drive sediment and nutrient loads, along with the altered hydrology (from clearing and drainage) that more readily transports available loads, and the decreased interception capacity of the denuded riparian zone.

Much of this loss has been from river floodplains where the vegetation has been completely cleared or thinned and replaced by agriculture. Sugar cane cultivation dominates the coastal regions of the basin with grazing being the other significant agricultural practice. In the northern area of the Plane basin, only small areas of remnant vegetation remain whereas, in the southern basin area, land and riparian vegetation is only cleared if rich alluvial soil used in sugar cane production is present. In the southern area (Study Site 11) of the Plane basin there are good riparian zones, estuaries are generally intact, there are no bund walls, and woodlands are still present. The southern Plane basin area has undergone changes, however there are still many areas which are relatively unchanged (woodlands) and these areas must be protected to prevent further decline in connectivity and coastal ecosystems (Figure 2.3.11).

Figure 2.3.11: Very little riparian vegetation in the northern area of the Plane Creek (Sandy Creek) (Study Site 10) (left) and the healthy riparian vegetation in the southern Plane Creek (Oke Creek) (Study Site 11) (right). The difference in the turbidity levels is visible indicating the increasing sediment load received by the basin in lower catchment reaches

The Queensland Government has assigned regional ecosystems a conservation status which is based on its current remnant extent (how much of it remains) in a bioregion (Figure 2.3.12). Regional ecosystems were originally defined by Sattler and Williams (1999)[27] as vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil. Vegetation that is classified as endangered is afforded most protection in Queensland; however some industries such as mining, transport, electricity and community infrastructure may be exempt. Lesser protection is afforded by the other categories. However regional ecosystem conservation classification is based on the remaining terrestrial extent of these ecosystems, and does not take into account their functional linkage to the World Heritage Area. For example, forested flood plains that have been significantly lost already and play a limited role in trapping sediment, removing nutrient and recycling water, have protection limited to the riparian zone. Therefore regional ecosystem conservation classifications most likely do not protect coastal ecosystems most important to maintaining the health and resilience of the World Heritage Area.

Figure 2.3.12 shows the gradient of remnant vegetation retention and connectivity found in the north compared to the south of the Plane basin. To the west of Hector (northern basin), a small area of remnant vegetation can be seen, however the *Vegetation Management Act Regulation 2000* has classified the area as 'not of concern'. This area is important from a conservation and functional perspective for the Plane basin, being the last stand of vegetation in that part of the coastal zone. The area should be protected from further decline or degradation in connectivity or coastal ecosystems.

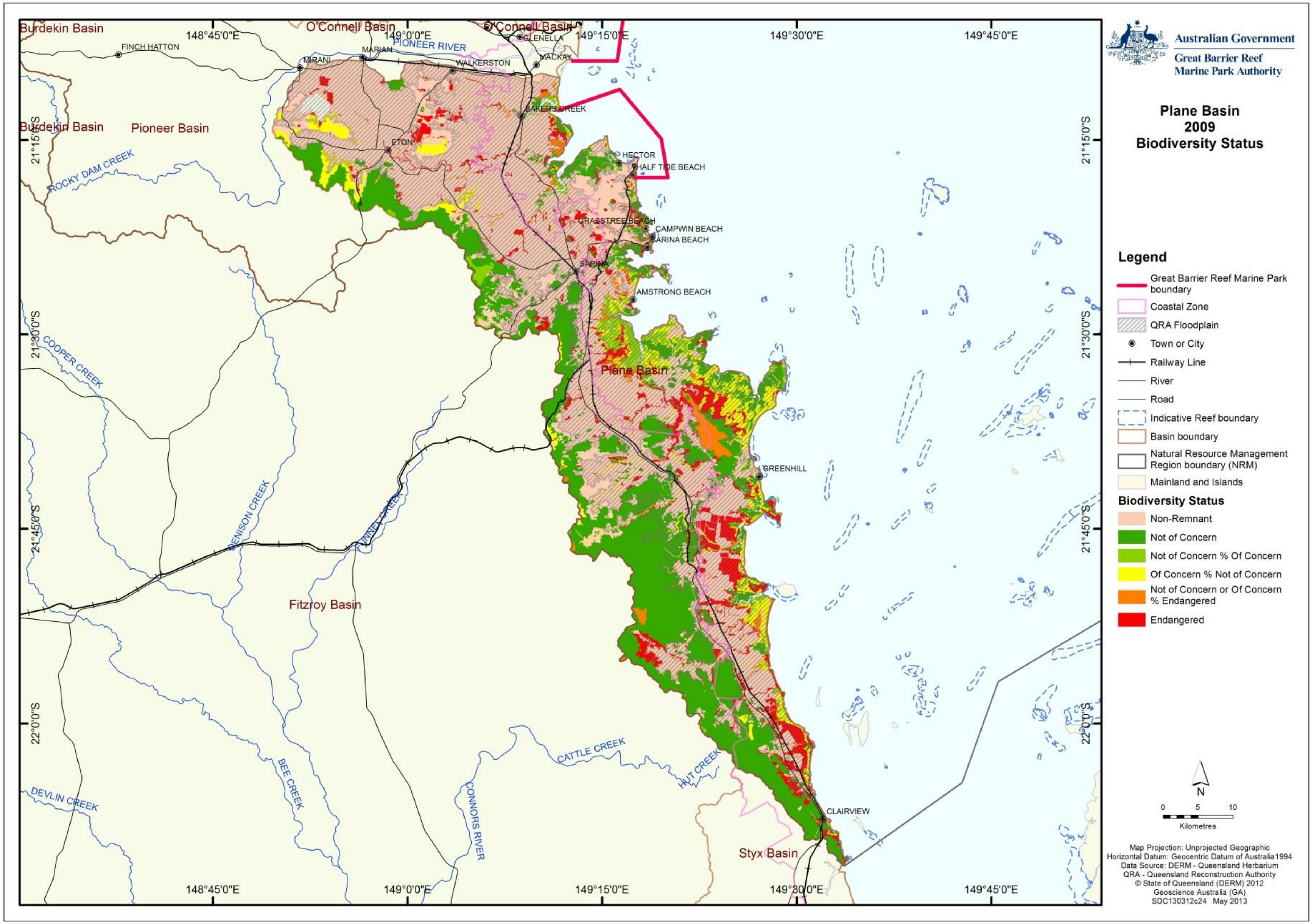

Figure 2.3.12: Regional ecosystem conservation status map for the Plane basin

2.4 Ecosystem processes

The condition of ecosystem processes in the Plane basin varies both spatially and temporally. Areas that have been highly modified from the natural coastal ecosystems that were once there show the greatest degree of change in processes. For example, rivers that have been modified into water distribution channels offer limited capacity for biological processes for fish species such as reproduction, dispersal recruitment and migration and are often nutrient enriched.

Appendix F contains a list of coastal ecosystems and some of the ecological processes they deliver for the health and resilience of the World Heritage Area.

Physical processes

Physical processes are those that transport and mobilise elements such as water, sediments and minerals. They include groundwater recharge/discharge, sedimentation/erosion of soils and deposition and mobilisation processes.[3] All coastal ecosystems provide these services, some more effectively than others.

Changes in hydrology have occurred as a result of land use change (such as land clearing, grazing and urbanisation, leading to surface compaction and reducing soil porosity, and increased sediment loss to erosion in streams), barriers (such as dams, weirs and road/rail crossings), groundwater extraction, floodplain drainage networks and changing rainfall patterns as a result of climate change. These actions have irreversibly altered run-off quality, quantity and seasonality of flows, and sediment build up in river beds. Storm intensity in recent years has delivered sudden large pulsed flows of freshwater into the World Heritage Area. These flows often have reduced residence times in the basin and the supporting coastal ecosystems sufficient for many ecological processes to occur. As a result, freshwater induced coral bleaching and smothering of corals and seagrass by sediments is occurring more frequently.[28] Water extraction has reduced flows and also resulted in increasing sedimentation of rivers. Reduced high velocity flows inhibit sediment movement along these watercourses. As these rivers fill with sediment (sand) they become shallower and wider. This changed hydrology results in scouring and erosion of banks during pulses from storm events, which impacts on World Heritage Area inshore ecosystems by increasing turbidity.

Physical processes such as sediment delivery have changed considerably in the Plane basin as a result of land use change. The reduction in the delivery of sediments to estuaries and the coast as a result of dams, weirs and water extraction (which reduces water quantity and hence velocity) can lead to or enhance shoreline erosion and change estuary dynamics.[29]

Wetlands are ecologically important ecosystems as they perform a number of functions such as nutrient removal and transformation, sediment/toxicant retention, shoreline stabilisation, flood flow alteration, groundwater recharge, groundwater discharge, enhance wildlife diversity and abundance.[30] Both riparian vegetation and wetlands have been reduced in the Mackay Whitsunday region and the efficiency of these systems to perform the above mentioned functions has thus declined.[4] Surveys of vegetation have been carried out in a number of sub-basins in the area surrounding the Sarina sub-basin, including Carmila Creek (by Sarina Landcare Catchment Management Association),[31] Rocky Dam Creek (by Sarina

Landcare Catchment Management Association),[32] and Plane Creek (by Department of Natural Resource and Mines and Sarina Landcare Catchment Management Association).[33] Riparian vegetation for Carmila Creek, Rocky Dam Creek and Plane Creek (weeds and exotics were also classified for Plane Creek) are presented in Table 2.4.1.

Table 2.4.1: Riparian classification for Carmila Creek, Rocky Dam Creek and Plane Creek[31,32,33]

Sub-basin	Good (%)	Moderate (%)	Fair (%)	Poor (%)
Carmila Creek (18 sites)	6	83	0	11
Rocky Dam Creek (19 sites)	47	37	0	16
Plane Creek	8	39	45	8

Pre-European clearance, riparian vegetation in the Plane basin was dominated by rainforests, estuaries and woodlands (Figure 2.3.6). Woodlands and rainforests provide a number of ecological processes for coastal ecosystems including: regulating water flow (groundwater and overland flow), trapping sediment, stabilising sediments from erosion, and assimilating sediment (Appendix F). Estuaries also trap sediment, stabilise sediment from erosion and assimilate sediment, however they also detain water, mitigate floods, connect ecosystems and regulate water flow (Appendix F). The loss of these ecological functions and drain construction results in loss of detention, increases in peak water flows, greater generation and transport of sediment and nutrients and other contaminant loads.

Biogeochemical processes

Biogeochemical processes revolve around energy and nutrient dynamics. Biogeochemical processes include production, nutrient cycling, carbon cycling, decomposition, oxidation-reduction, regulation processes and chemical/heavy metal modification. Wetland and associated floodplain ecosystems offer the greatest capacity for maintaining biogeochemical processes as these ecosystems slow the flow of water and allow the processes to occur. For example, Sandringham lagoon is located approximately 15 km south of Mackay. Reef Catchments, Department of Primary Industries and Fisheries, Natural Resources and Water, Pioneer Catchment and Landcare Group, the Mackay Bird Observers Club of Australia, and local landholders with funding from both the Australian and Queensland governments rehabilitated the Sandringham Lagoon.[34] The lagoon was inundated with hymenachne and hyacinth. The removal of weed infestations is important to restore important habitat values of wetlands[35]. Hymenachne and hyacinth can create poor water quality, invade sugar cane crops and cause the loss of native flora and fauna habitats.[36] Sandringham Lagoon has been successfully cleared of hymenachne and 15 fish species now inhabit the area compared to the previous five (T Marsden (Reef Catchments) 2013, pers. comm., 9 May).

During large flood events, biogeochemical processes in coastal ecosystems often do not occur as water flows at high volume and velocity directly into inshore coastal waters. In more developed basins, the volume of nutrients is often higher as a result of fertiliser use and point source discharges. These processes then generally occur in the inshore coastal waters. Impacts of elevated nutrients on the marine environment are outlined in Table 2.4.2.

Elevated nutrients in inshore coastal waters indicate that the coastal ecosystems are not able to regulate the biogeochemical processes. This is likely due to elevated inorganic nutrients from agricultural and urban sources which often discharge directly into waterways.

Table 2.4.2: Forms of nutrients and their impact on the aquatic environment

Term	Description/source	Impact on aquatic environment
Particulate organic matter	Large particles of organic matter (e.g. dead plants and animals) that get broken down by decomposers into smaller dissolved organic matter.	Not available for uptake by plants and animals.
Dissolved organic matter (DOM)	Large molecules of organic matter (nitrogen, carbon, phosphorus etc.) produced as a result of decomposition.	Not biologically available until broken down by bacteria.
Dissolved inorganic matter	By-product of bacterial decomposition of DOM or applied in this form as fertilisers.	Nutrients such as nitrogen and phosphorus are freely available in this form for uptake by cyanobacteria, plants and animals. This results in low oxygen levels leading to fish kills.

Biological processes

Biological processes are the processes that maintain animal and plant populations. These include survival/reproduction mechanisms, dispersal/migration/regeneration, pollination and recruitment. Wetland and associated floodplain ecosystems offer the greatest capacity for maintaining biological processes.

Fish communities inhabiting the rivers and creeks of the Plane basin are being negatively impacted by hydrological changes creating fish barriers and habitat loss, and water quality. Constructed ponded pastures for cattle grazing have caused disturbances to coastal wetland vegetation in addition to hydrology and salinity regimes.[37] The location of pondage banks on or adjacent to barramundi nurseries will likely result in the restriction of barramundi movement and increase the risk of entrapment under specific flow regimes.[38] An additional stress to fish is increased coastal erosion from sugar cane production on floodplains situated along the coast, which is especially high during periods of high rainfall.[39] Erosion can result in the siltation of waterways and estuaries, altering water flow and environmental characteristics for fish communities and habitats.[37]

The majority of environmental monitoring of coastal ecosystems such as benthic communities (coral reefs and seagrasses) has been conducted north of the Plane basin in Mackay and the Whitsunday area.[40] However, there are Dugong Protection Areas within the Plane basin, such as Llewellyn Bay, Ince Bay and the Clairview region. Llewellyn and Ince Bays are potentially influenced by Plane Creek, which enters the sea at Sarina Inlet just north of Llewellyn Bay. The Styx and Fitzroy rivers located to the south of Clairview (both outside of the Plane Creek basin) influence all Dugong Protection Areas in the Plane basin region. Another important local waterway is Carmila Creek, which drains into the Clairview Dugong Protection Areas. A risk assessment of impacts influencing Dugong Protection Areas was created and is summarised for the Plane Creek area in Table 2.4.3. The risk analysis of Plane Creek Dugong Protection Areas (Llewellyn and Ince Bay) shows that Plane Creek is an area requiring special management focus. Measures to reduce pollutant loads, such as improving riparian vegetation and reducing erosion, are critical to maintaining and preserving water quality health in the World Heritage Area.[40]

Table 2.4.3: Risk assessment of impacts by catchment activities on water and habitat quality in Dugong Protection Areas (DPA) in the World Heritage Area. This table has been modified from Schaffelke 2001[40]

DPA	Adjacent Catchments	Significant Local Watercourse	Development Close to DPA	Fertiliser use	Pesticide use	Sediment export	Summary risk rating
Llewellyn Bay	Plane Creek	-	Hay Point Port	High/mod. high	High	High	High
Ince Bay	Plane Creek	-	Hay Point Port	High/mod. high	High	High	High
Clairview	Styx River	Carmila Creek	-	Low	Low	High	Moderate

Seagrass in the Plane basin is monitored in the Sarina Inlet. Coastal and estuarine seagrass abundance has varied over time in the Mackay Whitsunday Region; however Reef sites have been declining since 2007. It has also been found that estuarine meadows exhibit a low ability to recover from disturbances as no seed was recorded in 2009 after large declines were measured the previous year. The estuarine intertidal seagrasses Z*. capricorni, H. ovalis* and *H. uninervis* in Sarina Inlet have been highly variable.[41]

2.5 Connectivity

Aquatic ecosystem connectivity refers to how ecosystem components are linked, whether through air, water or overland. Disruptions to connectivity between different areas where fish breed and grow can lead to a reduction in population resilience, or even localised extinctions of some species. Figure 2.5.3 shows the sub-basin waterways that were considered by this assessment. Figure 2.5.4 shows the stream orders (classification system where waterways are given an 'order' according to the number of additional tributaries associated with each waterway) combined with land zones and elevation. These tools were used to assess connectivity.

The hydrology and drainage of the Plane basin has been highly modified with the construction of dams and weirs that provide water for agriculture, industrial and urban uses (Figure 2.5.1) but are also barriers to fish movement. The connectivity between marine, freshwater lagoons and wetland habitats are vitally important to life cycles and the productivity of natural population.[42] Fish barriers also include water quality, chemicals, culverts, road crossings and bund walls.

Figure 2.5.1: Walkerston Weir can act as a fish barrier for fish migration (Study Site 6)

Ponded pastures are found along the coastal areas of the Plane basin, in particular, Rocky Dam Creek, Plane Creek and Bakers Creek (Figure 2.5.2). Although ponded pastures maintain some of the existing wetland values, ponded pasture can also interfere with natural water flow, cause loss of fish habitat and fish connectivity.

Figure 2.5.2: Ponded pasture located on Tedlands Station. Road crossing creating a fish barrier (left) and wetland inundated with hymenachne (right) (Study Site 14)

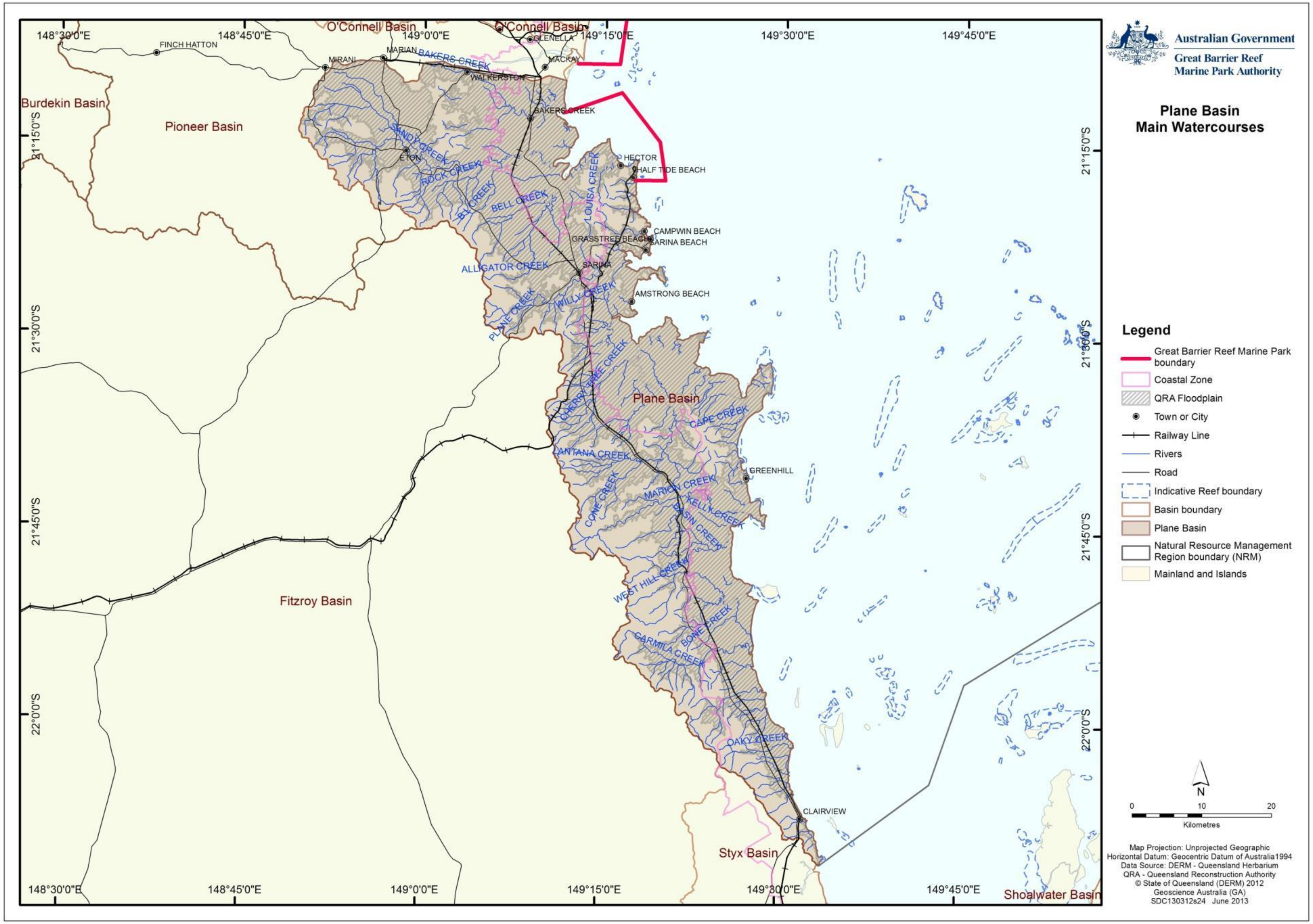

Figure 2.5.3: Major waterways in the Plane basin considered in this assessment

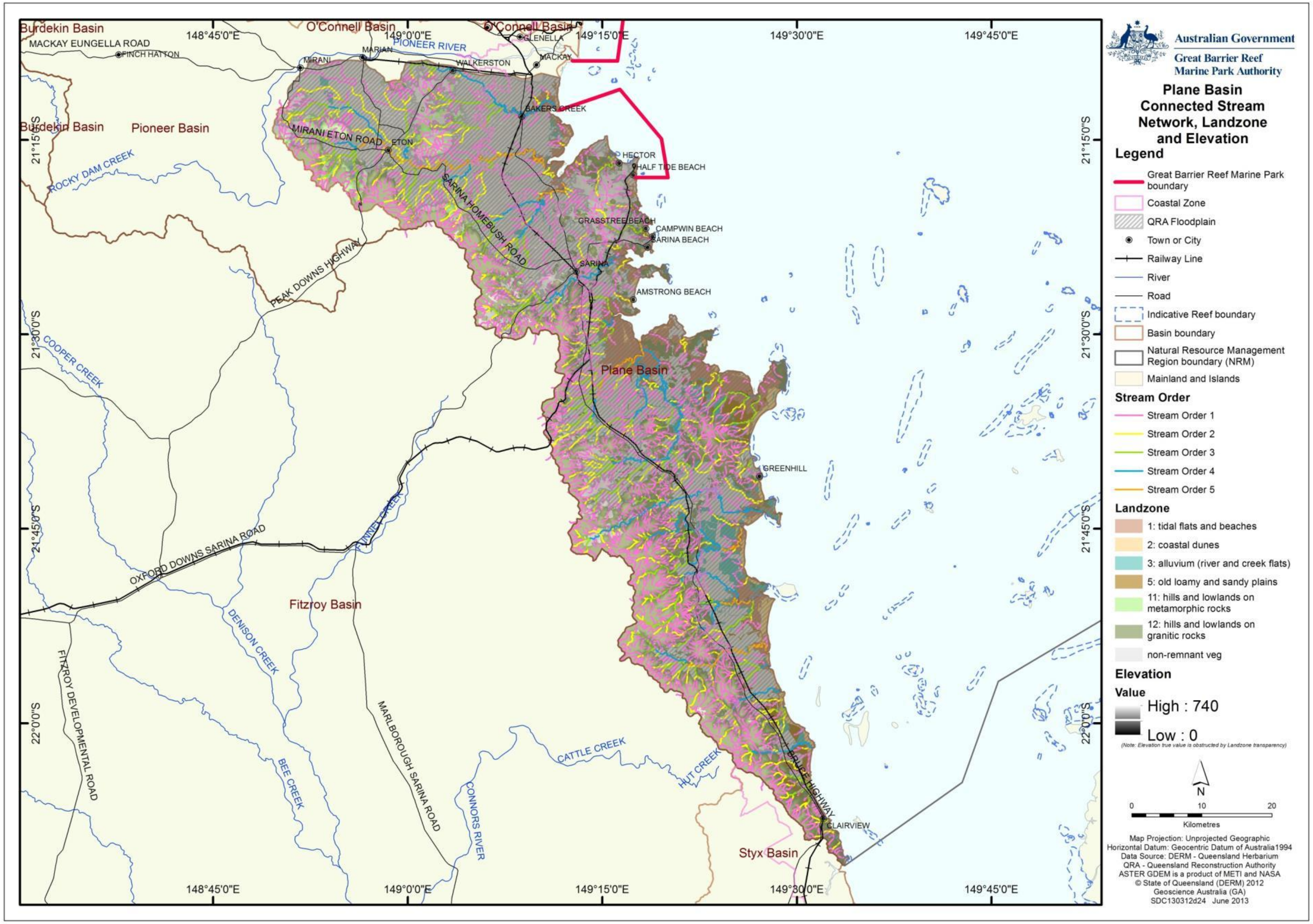

Figure 2.5.4: Stream order and elevation map showing the floodplain of the Plane basin

Surface hydrology

Plane, Sandy and Bakers creeks have undergone large hydrological modifications. The natural flows of Sandy Creek and Bakers Creek have been largely impacted from modifications to the Pioneer River to the north. Pioneer River contains two major water storages (Kinchant Dam and Teemburra Dam) and three weirs (Mirani, Marian and Dumbleton). The water stored in these dams and weirs is predominantly used for irrigation of sugar cane and drinking water supply to a lesser extent.[4] Water is diverted from Mirani Weir into Kinchant Dam (storage volume 62,800 ML) where it is retained.[4] Kinchant Dam (Study Site 15) (situated in the Sandy Creek catchment) releases water for irrigation, after which tailwater eventually enters into the lower course of Sandy and Bakers creeks, creating an artificial flow (Figure 2.5.5).

Figure 2.5.5: Kinchant Dam (Study Site 15) located in the Sandy Creek catchment, is used for irrigation and creates an artificial flow in Sandy and Bakers creeks

Within the 35 km length of Plane Creek there is one dam (Middle Creek Dam) and four weirs (Jackson's Weir, Council Dam, Mill Dam and CSR Dam), which highly regulate the flow of the creek.[33] Middle Creek Dam is a small drinking supply dam (1365 ML).[4] Dams and weirs can create fish barriers which impact on fish migrating between marine and freshwater habitats. These barriers can contribute to the loss of species diversity within fish communities and severely impact the health of the region's aquatic ecosystems.[42]

Road crossings are also common throughout the Plane basin and act as barriers for fish migrations. Constructed drains which are found throughout the basin create large water flows (Figure 2.5.6). These large water flows create higher velocity and volume resulting in less residence time within natural systems, such as mangroves and wetlands. Less resident time means the system cannot treat the water effectively before it is washed out into the World Heritage Area.

Figure 2.5.6: Industrial drain in Paget near Mackay (Study Site 2) (left). Industrial drain built by SunWater in Paget (Study Site 16) (right)

Groundwater hydrology

Groundwater dependent ecosystems are affected by a range of natural and anthropogenic related drivers. Changes in rainfall patterns, evaporation and temperature can all impact on groundwater recharge. Declines in groundwater recharge can lead to seawater incursion in coastal aquifers, affecting coastal wetland ecosystems. Seawater incursion can also be amplified by sea-level rise, storm surge and over extraction of groundwater. In some areas (such as the Haughton basin) groundwater is now intensively managed through groundwater replenishment infrastructure. Climate change will exacerbate these impacts, especially in low lying coastal areas, although the true impacts in the Plane basin are not known.

Extensive modification has occurred in many areas within the Plane basin, they have (in general) increased overland flow, floods with higher peaks but short duration and a reduction in groundwater discharge. Groundwater extraction at Sandy Creek and Alligator Creek has lowered the watertable resulting in declining wetlands and dead trees. The northern Plane basin is a highly modified system, groundwater recharge is down and therefore the catchment acts as a big storm drain, picking up loads of nutrients bound to sediment which discharges straight into the World Heritage Area for some distance. The floodplain coastal ecosystem no longer functions to slow flow, deposit sediments and allow for sediment and nutrient cycling.

Chapter 3: Impacts on the values

3.1 Drivers of change

The primary drivers of change for the Plane basin are climate change, economic growth, population growth and technical development.

Climate change

The Queensland Government has carried out extensive mapping of coastal areas projected to be at risk based on climate change predictions up until the year 2070. The maps factor in climate change impacts including sea-level rise of 30 centimetres and a 10 per cent increase in the maximum potential intensity of cyclones and associated storm surge at-risk areas and erosion prone areas.

Information on climate change impacts is based on the most recent report from the Intergovernmental Panel on Climate Change (IPCC) – the international scientific authority on climate change. Property scale and area-based coastal hazard maps are available from the Department of Environment and Heritage Protection website at http://www.ehp.gov.au/coastal/management/maps/index.html. Table 3.1.1 shows the regional climate change predictions that will apply to temperature, rainfall, evaporation and extreme events.

Woodlands and forests in the Plane basin will be most affected by invasive vegetation, changed fire regimes and extreme weather events that will become more commonplace as a result of climate change. Coastal wetland ecosystems will be impacted by sea-level rise, extreme weather events and changes in the water balance and hydrology.[43]

One of the greatest risks associated with climate change will be the exacerbation of catchment ecosystem process failings, already apparent under current stressed conditions. Catchments are already experiencing low dissolved oxygen levels in stream and the increase in temperatures reduces the dissolved oxygen carrying capacity. The Plane basin already has poor integrity of the riparian system and elevated sediment and nutrient exports. More extreme rainfall events under climate change scenarios will increase these exports and further erode stream channels and banks. Additionally, more extreme dry seasons will reduce viability of aquatic refuge in streams and floodplain wetlands.

The impacts of climate change will vary across the basin, with the highest threats to low-lying coastal areas and the floodplain. Future development planning needs to map and consider the risks of sea-level rise, storm surge and flooding before allowing for development in the coastal zone and floodplain. The interaction of rising sea temperatures and ocean acidification will exacerbate the impacts from catchment run-off on inshore coral reef ecosystems

Table 3.1.1: The regional climate change predictions for the Whitsunday, Hinterland and Mackay (WHM) region for temperature, rainfall, evaporation and extreme events[44]

Element	Prediction
Temperature	Average annual temperature in the WHM region has increased 0.3°C over the last decade (from 22.7°C to 23.0°C). Projections indicate an increase of up to 4.2°C by 2070, leading to annual temperatures well beyond those experienced over the last 50 years. By 2070, Mackay may have 12 times the number of days over 35°C (increasing from an average of one per year to an average of 12 per year by 2070).
Rainfall	Average annual rainfall in the last decade fell nearly 14 per cent compared with the previous 30 years. This is generally consistent with natural variability experienced over the last 110 years, which makes it difficult to detect any influence of climate change at this stage. Models have projected a range of rainfall changes from an annual increase of 17 per cent to a decrease of 35 per cent by 2070. The 'best estimate' of projected rainfall change shows a decrease under all emissions scenarios.
Evaporation	Projections indicate annual potential evaporation could increase 7–15 per cent by 2070.
Extreme events	The 1-in-100-year storm tide event is projected to increase by 36 cm in Mackay if certain conditions eventuate. These conditions are a 30 cm sea-level rise, a 10 per cent increase in cyclone intensity and frequency, as well as a 130 km shift southwards in cyclone tracks.

Economic growth

Economic growth has been the driver for much of the land use change that has occurred in the Plane basin.

The Mackay population is growing rapidly due to the expansion of the mining industry inland of the basin. This increase in population means there is likely to be an increase in industrial areas (Figure 3.1.1). Industrial and urban areas in Mackay are being built in low-lying coastal floodplain and wetland areas including Melaleuca swamps, salt marsh and mangroves, requiring major drainage infrastructure to support it. Lack of water sensitive design principles in construction of this infrastructure is leading to large drains conveying rapid, high volume flows with an increased transport capacity for sediments, nutrients and other contaminants directly to receiving estuaries and ultimately near-shore marine waters.

Currently, there is a proposal for a port expansion at Hay Point Coal Terminal (Study Site 17) which will generate more employment opportunities and promote expansions of some local industries.

Figure 3.1.1: Mackay city is expanding and as a result industrial areas are extending into low lying freshwater and estuarine wetlands, necessitating large capacity drains such as these near Paget (Study Site 5)

Population growth

Population growth in response to the fly-in/fly-out industry has been the driver for the expansion of the Mackay region.[45] The Mackay population is projected to increase between 2006 and 2031. As of 30 June 2011, the population of Mackay Regional Local Government Area was 121,397. By 2031 the population is expected to be 187,367.[46]

The Queensland Government is expecting the average annual population increase for Mackay to be 2.3 per cent per annum. Intensive urban residential development is mostly confined to the northern end of the basin and linked to the city of Mackay.

Technological development

Historically, the major land use in the Plane basin was grazing and agriculture. These continue to be the primary land use with figures remaining fairly constant between 1999 and 2009 (Table 3.2.1). Most of the current extent of horticulture is irrigated, obtaining water supply from large rivers and purpose built dams (Kinchant Dam). As a result, the ecological impacts from irrigated horticulture in the Plane basin are significantly changing the floodplain.

The availability of low cost heavy earthmoving equipment has forever changed the Plane basin floodplain. This has provided capacity to build extensive drainage networks, transforming wetlands and parts of the river floodplains into areas with the capacity to grow sugar cane. This has resulted in a loss of the ecosystem values and services these environments once provided. Small streams and seasonal creeks have been developed and channelised, increasing flow rates, decreasing run-off detention times and the opportunity for processing or settlement of contaminant loads before discharge into the World Heritage Area.

3.2 Activities and impacts

Historically, the dominant land use in the Plane basin was grazing. As irrigation technology and availability improved in the early 20th Century, a shift towards irrigated sugar cane plantations emerged. Today, the dominant land uses within the Plane basin remain grazing and irrigated sugar. These industries support the urban centres of Bakers Creek, Sarina and

Walkerston. Land use for 1999 and 2009 is shown in Table 3.2.1 and Figures 3.2.1 and 3.2.2. Note that the appearance of water-marsh/wetland production is a result of the recognition of this land use in 2009.

Table 3.2.1: Major land use categories (hectares) for the Plane basin in 1999 and 2009 based on Queensland Land Use Mapping Program data

	Land use area (ha) - Plane	**1999**	**2009**
	Conservation, natural environments (inc. wetlands)	31,345	33,496
	Forestry - production	12,415	17,373
	Grazing natural vegetation	129,603	115,837
	Intensive animal production	109	204
	Intensive commercial	2,286	1,945
	Intensive mining	192	182
	Intensive urban residential	3,467	4,267
	Production - dryland	317	257
	Production - irrigated	70,354	70,744
	Water - production ponded pastures	0	5,479
	Water storage and transport	3,511	3,776
	Not Mapped	410	449
	Total Area (h)	**254,010**	**254,010**

Figure 3.2.2 shows the extent of land use changes which have occurred from 1999 and 2009. Grazing occurs throughout the basin with the majority of irrigated production occurring around central areas. The extent of ponded pasture (water – marsh/wetland production) (Study Site 14) can be seen south of Armstrong Beach close to the coast in Figure 3.2.1.

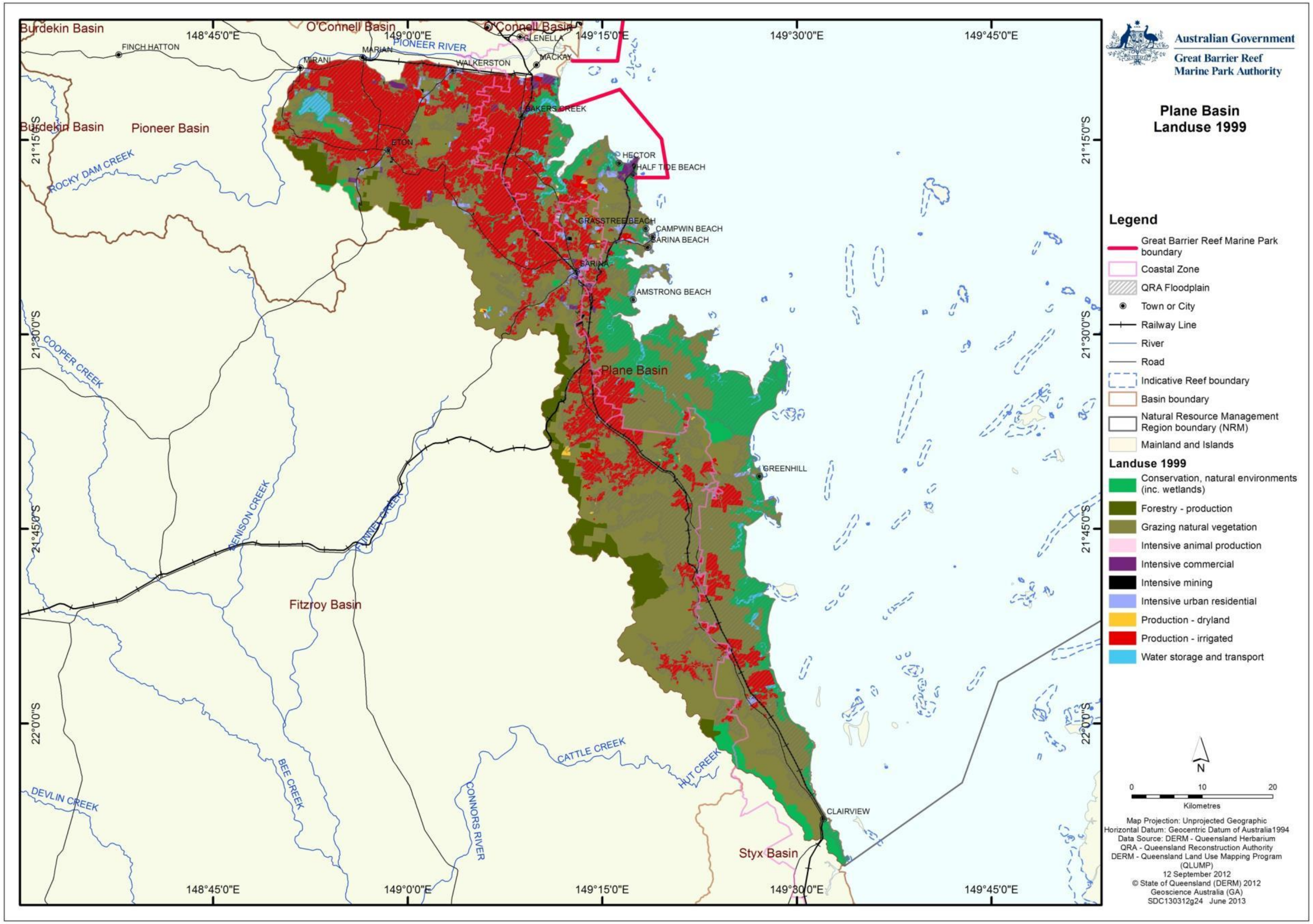

Figure 3.2.1: Map of land use for the Plane basin based on 1999 QLUMP data

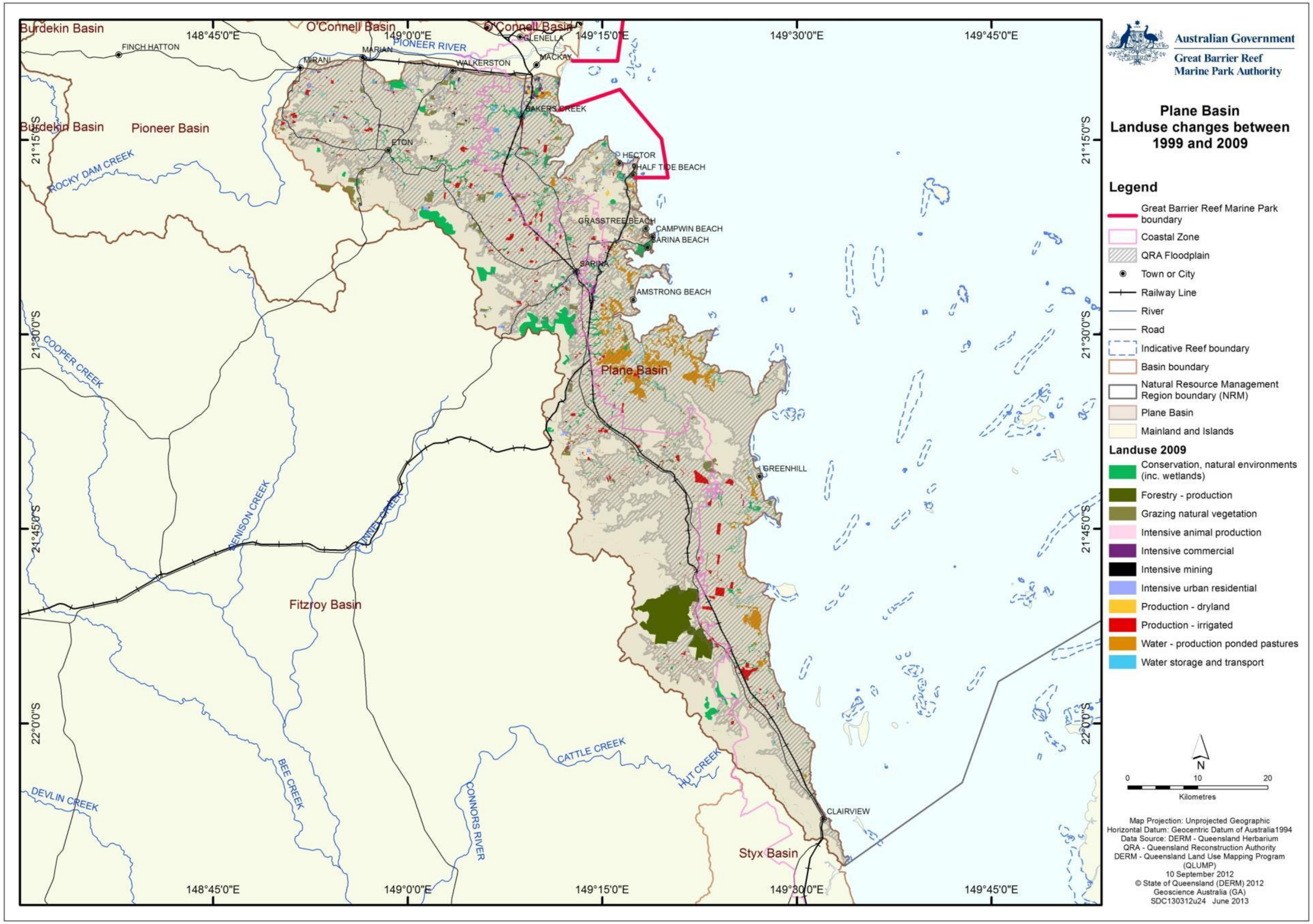

Figure 3.2.2: Map showing areas of changed land use in the Plane basin based on 1999 and 2009 QLUMP data

Land use within the coastal zone

Land use adjacent to the coast (the coastal zone) can have the greatest impact on the World Heritage Area's inshore waters. The coastal zone includes Queensland's coastal waters (which extend three nautical miles out to sea), coastal islands and land below 10 metres Australian Height Datum or within five kilometers of the coastline, whichever is greater. The land use occurring within the coastal zone for 1999 and 2009 are shown in Table 3.2.2 and Figure 3.2.1 and Figure 3.2.2.

Table 3.2.2: Major land use categories (hectares) for the Plane basin coastal zone in 1999 and 2009 based on Queensland Land Use Mapping Program data. Note the decline in Conservation, natural environments is due to greater resolution of mapping which has delineated the water-marsh/wetland production areas (ponded pastures)

	Land use area (ha) - Plane Coastal Zone	1999	2009
	Conservation, natural environments (inc. wetlands)	29,053	27,010
	Forestry - production	0	0
	Grazing natural vegetation	49,541	45,214
	Intensive animal production	72	162
	Intensive commercial	1,357	1,472
	Intensive mining	78	65
	Intensive urban residential	1,556	1,712
	Production - dryland	62	162
	Production - irrigated	21,537	22,070
	Water - production ponded pastures	0	5,479
	Water storage and transport	2,282	2,152
	Not Mapped	410	449

3.3 Actual and potential impacts from key activities

There have been some major landscape scale changes within the Plane basin which have been shown to impact on the receiving marine environment. Other developments in the basin may be relatively small in area however may contribute significantly to the cumulative impacts on the World Heritage Area.

Forestry

There is 17,373 hectares of forest and rainforest allocated for production forestry in the Plane basin. Forestry areas only pose a risk to the World Heritage Area during harvest when clearing may lead to erosion and increased sediment run-off, however this is dependent on forestry practices and is not as substantial as the impacts from grazing and intensive agriculture.

Grazing natural vegetation

There is 115,837 hectares of dryland grazing in the Plane basin making it the highest land use in the area. However, there has been a decrease in grazing between 1999 (129,603 hectares) and 2009 (115,837 hectares). This has occurred where there has been a shift from grazing to other land use activities such as forestry and conservation. It is expected that as irrigation becomes available further south, more farmers will change land use to irrigated cropping (sugar cane).

Grazing can impact water quality by altering vegetation in catchments and, where cattle drink directly from natural waters, by increasing erosion turbidity and nutrient inputs. In the short term, grazing reduces ground cover and overgrazing can leave the soil disturbed, with minimal cover and vulnerable to erosion when it rains, resulting in increased movement of sediment into waterways. Longer term impacts of overgrazing are a decline of perennial grasses in pasture leaving it less resilient to dry periods (i.e susceptible to greater decline in ground cover), vulnerable to invasion by weed species and reduced diversity and health of riparian vegetation.

Grazing in the Plane basin remains a source of sediment and nutrient loss during peak rain periods. Nutrients have increased due to the increased use of fertilisers and accelerated erosion whereas sediment loads have increased due to extensive land clearing and subsequent land uses. Stock access to riparian vegetation can contribute to poor riparian condition and increases in erosion.

The introduction of exotic grasses from Africa and South America, including guinea grass and para grass are highly flammable. These grasses have a higher fuel load than our native grasses. When they burn, they burn hotter, killing trees that would otherwise have survived traditional burns. Fires late in the dry season leave bare scorched ground vulnerable to erosion at the commencement of the wet season. In areas where well managed grazing occurs, fire loads are often greatly reduced.

The introduction of best management practices by graziers (17 per cent) has helped to reduce sediment, nutrient loads and erosion, and there have been good annual rains since 2008. Management focuses on increasing and maintaining ground cover, water infrastructure for cattle, and reducing fertiliser and chemical application.

Intensive animal production

There is 204 hectares of intensive animal production in the Plane basin. There is an aquaculture facility in the Plane basin coastal zone at Notch Point (Study Site 18) which produces prawns.

There is also a possibility of increased coastal aquaculture, which could alter coastal foreshore, estuarine, mangrove, salt marsh and marine and other aquatic environments.[47] Environmental impacts associated with aquaculture are water pollution, pest species, strain placed on wild fish populations for feeding and breeding, as well as the culling of natural predators.[47]

Intensive commercial

The city of Mackay and its associated urban and industrial areas occupies the northern part of the Plane basin, and was originally wetlands and saltpans. An ongoing issue within the Mackay Whitsunday region is the drainage of wetlands. There is currently a lack of 'water sensitive' drainage design and unsustainable expansion of inappropriate land use into low-lying wetland areas (Study Site 5 and Study Site 2). Drainage networks that are being developed have a large capacity, lack detention areas, have limited habitat value and discharge their increased capacity contaminant loads directly into receiving estuaries creating water quality and salinity impacts (J Tait (Ecocern) 2013, pers. comm., 25 February).

Vital wetland habitat has been lost for various land uses including urban and industrial development. This habitat loss has exposed potential acid sulphate soils by various drainage construction activities.[4] For a map of acid sulphate soils in the Mackay district please refer to Appendix G.

Sugar mills and their by-products are another source of pollutants for the World Heritage Area. Although mill by-products such as mill mud are a cost effective option of nutrient supply to cane lands, recycling of these products generally occurs close to mills to reduce transportation costs.[48] Heavy metals such as cadmium and zinc have been found at concentrations five and three times higher respectively than background soil concentrations in mud surrounding sugar mills.[49] Long-term application of these products to the same area may result in cadmium accumulation in soils. Long-term accumulation increases the risk for food crops grown in rotation with sugar cane to become contaminated with this toxic metal and eventually violate the Australia New Zealand Food Standard Code.[49,50] It was recommended by Barry et al. 2001[49] that a wide distribution of these recycled materials is necessary for sustainable use of these valuable resources. In 2002/2003, Mackay Sugar changed their pricing structure to encourage spatial distribution of mill mud and spreaders were developed in the Mackay area to improve application efficiency by reducing traditional rates (approximately 200 tonnes/hectare) to approx. 30 tonnes/hectare.[18]

There is a large amount of commercial infrastructure associated with the Hay Point and Dalrymple Bay coal loading facilities and the associated vessels (Table 3.3.1 and Figure 3.3.1).

Table 3.3.1: Details of the Hay Point and Dalrymple Bay Port Facility (Study Site 17)

<table>
<tr><th rowspan="2">Coal Terminal</th><th rowspan="2">Trading Ports</th><th rowspan="2">Cargo</th><th colspan="2">Number of Berths</th><th>Number of vessel visits (per annum)</th><th>Coal export capacity (million tonnes/year)</th></tr>
<tr><th>Current</th><th>Proposed Additional</th><th>Current</th><th>Current</th></tr>
<tr><td>Hay Point</td><td>1</td><td>Coal</td><td>2</td><td>6</td><td rowspan="2">1121</td><td>140</td></tr>
<tr><td>Dalrymple Bay</td><td>1</td><td>Coal</td><td>4</td><td>0</td><td>85</td></tr>
</table>

The Port of Hay Point is the world's largest coal export port and is separated into two separate coal terminals, Dalrymple Bay Coal Terminal and Hay Point Services Coal Terminal (Study Site 17). The port consists of four berths that can load 20,000-220,000 dead weight tonne ships.[51] In the wake of Cyclone Ului, a record 220 ships (Figure 3.3.2), 102 of which were bulk carriers, waited an average of one month to load coal from the Port of Hay Point.[52] This was double the number of ships in queue two months prior to the cyclone.[52] Although it is not a regular occurrence to have such a large number of ships waiting near the port, even half the number of vessels in queue could have serious negative implications on the surrounding marine environment and the World Heritage Area.

Sources of heavy metals and metalloids from port facilities can include leaching of antifoulant paints from ship vessels, leaching of trace levels present in coal particles and corrosion of marine metals.[53] Organotin compounds are potent toxins, a property that has resulted in organotin use in a range of biocides including vessel antifoulants.[54] Tributyltin (TBT) based antifoulant paints were used on vessels in Australia from the early 1970s and were banned on vessels < 25 m in Eastern Australian states in 1989 due to growing evidence of the detrimental impacts on the marine environment.[54] Although TBT was banned in 2008, only 34 of the 168 states within the International Maritime Organization (IMO) ratified to the agreement set by The International Convention on the Control of Harmful Antifouling Systems for Ships. TBT remains a threat to the marine environment and the World Heritage Area.

Copper is also used as an antifoulant and is a main biocide in copper based paints commonly used on small boats, in addition to being an additive to TBT-based paints.[54] TBT quickly kills organisms such as mussels, algae and barnacles, which naturally attach themselves to hard surfaces including ship hulls, however is also leached into the marine environment. TBT and heavy metals that can be found in sediments as paint flakes from ships dissolve into the water and stay solubilised or attach to particulate matter that will settle out. Heavy metals are potentially toxic to marine organisms,[55] while TBT has been considered as the most toxic substance deliberately introduced to the marine environment.[56] TBT is responsible for imposex (females develop male sex organs) in dog-whelks[57,58] and shell deformations in oysters[59]. Both TBT and heavy metals accumulate in organisms and food chains and eventually reach humans through fish consumption.[60,61,62] TBT and heavy metals are persistent pollutants and can remain stored in sediments for many years, re-entering the food chain when the sea bottom is disturbed by passing vessels in shallow areas and ports, or by storms and dredging activities.

Another environmental issue with docked vessels is the release of ballast water. Each day 10,000 marine organisms are transported around the world in ballast water holding tanks of ships before being released into a new environment.[63] Although Australia has stringent protocols on ballast water release, vessels can contain 70,000 tonnes of ballast water, which makes sterilization difficult due to the sheer volume of water. Invasive species (Asian green mussel or Asian bag mussels) can disrupt ecosystems by out-competing indigenous species for food and habitat and by carrying diseases.

Figure 3.3.1: Hay Point and Dalrymple Coal Terminal, the largest coal export port in the world (Study Site 17)

Figure 3.3.2: Bulk carriers waiting to load coal at the Port of Hay Point (photo: The Daily Commercial News, March 10 2010)

Another potential source of pollution in the coastal area of the Plane basin is coal. Coal contains polycyclic aromatic hydrocarbons (PAHs), which can be toxic and carcinogenic to a variety of species. Information is limited on the effects of PAHs on many marine organisms. Coal can enter the environment via a variety of mechanisms such as the natural erosion of coal seams, and during various stages of coal processing such as disposal of colliery waste, wind and water erosion of coal stockpiles, and accidental spillage.[64] Once in the marine environment, coal particulates are dispersed via currents throughout inshore coastal ecosystems.[65] In Australia, coal particulates have been found in sediment traps as far as the continental shelf break.[66] The behaviour and distribution of particulate coal in tropical waters is largely unknown, however exposure of marine organisms to coal dust is likely to increase as loading volumes and shipping increases. It is therefore imperative that more research is done to investigate the potential effects of coal on key tropical organisms.

Intensive mining

There is a large amount of mining infrastructure in the adjacent Bowen basin in Central Queensland. Mining products are transported by rail through the Plane basin to be exported from the Hay Point and Dalrymple Bay Coal Terminals.

Intensive urban residential

Mackay Regional Council is currently proposing commercial and urban expansion south of Bakers Creek.[67] If the mining boom continues, and population continues to expand as predicted (by 2031, the Mackay population is expected to be 187,367),[46] ongoing urban expansion in low-lying coastal floodplain areas in the current way will likely cause further localised impacts on the health of the coastal estuaries. The southern suburbs of Mackay are already within the northern portion of Plane basin and this urban expansion is expected to increase and replace sugar cane land (J. Brodie (TropWater) 2013, pers. comm., 12 March). Implications of urban expansion include:

- Loss of peripheral freshwater wetlands
- Loss of estuaries that back urban expansion projects
- Infilling of low-lying areas
- Loss of catchment detention functions
- Increased run-off rates
- Increased transport of contaminant loads and freshwaters to receiving estuaries.

Run-off from urban areas will continue to impact on water quality entering the World Heritage Area, as retention time of run-off waters within urban catchments is reduced by deepening and modifying existing waterways to support engineered drainage. Due to the increase in impermeable surfaces and intensification of development in the landscape, water quality impacts are likely from urban development. Water sensitive urban design can assist with maintaining or improving water quality outcomes in an urban landscape. Urban development should be avoided in areas identified as important environmental values. Generally these include coastal ecosystems in wetland, riparian and flood prone areas.

Sewage discharge is limited to the Mackay South, Bakers Creek and Sarina Sewage Treatment Plants. During the dry season the Mackay South Sewage Treatment Plant provides cane farmers with quality recycled water for irrigation purposes. The other smaller settlements are currently unsewered and impacts on the World Heritage Area are unknown. Table 3.3.2 outlines the status of wastewater treatment in the main urban centres in the Plane basin.

Table 3.3.2: Status of wastewater treatment in the Plane basin[68]

Urban centre	Wastewater treatment
Mackay South	Upgraded in 2008, the Mackay South wastewater plant services Mackay city, North Mackay, West Mackay, Andergrove, Slade Point, Beaconsfield, Mackay Harbour, Paget and Walkerston. Treated water is discharged into Bakers Creek.
Sarina	Currently being upgraded (commenced in 2013), the Sarina Sewage Treatment Plant services the Sarina Township and can cater for 8,000 people.
Bakers Creek	The plant treats domestic waste and trade waste from Mackay, tertiary treated effluent is discharged into Bakers Creek.[69]

Production – dryland

There was a small reduction in dryland production between 1999 (317 hectares) and 2009 (257 hectares). Impacts from these properties are likely to be minimal.

Production – irrigated

Irrigated sugar cane cropping represents the second largest use by area in the Plane basin (Figure 3.3.3). The extent of irrigated production in the southern part of the Plane basin is limited by water supply, with irrigated croppers using either ring tanks (water storage dams filled from streams) or bore irrigation. Impacts from irrigation could potentially be on par with those experienced in the lower Burdekin floodplain (refer to the Haughton basin assessment) and may have impacts on the adjacent aquatic environments, including poor water quality and high sediment and nutrient loads.

Soil erosion occurs at accelerated rates within cane lands and was first recognised as a major source of river sediment when cane was predominantly burnt and hand-harvested.[4] In the late 1970s, annual soil loss rates between 42-227 tonnes per hectare were measured around Mackay.[70] Due to the implementation of minimal tillage and mechanical green cane harvesting/trash blanketing (GCTB) cultivation methods over the last three decades, soil erosion rates have been reduced to approximately 5-15 tonnes per hectare on well managed cane lands.[71,72,73] Nutrient loss associated with soil erosion has been minimised under GCTB methods, making fertilisers the major sources of nitrogen and phosphate from cane lands.[4]

Figure 3.3.3: Sugar cane (left) is grown as close as possible to drains and channels, soil erosion as a result of lost vegetation (right) (Study Site 9)

Water – marsh/wetland production

Between 1999 and 2009 there was an increase in wetland marsh production. In 1999, Queensland Land Use Mapping Project classification identified the Plane basin having no marsh wetland production (ponded pastures), however in 2009 this had increased to 5479 hectares. This is due to changes in land use categories which provide more accurate representation of ponded pastures which in 1999 were categorised as water storage areas.

Historically, management sought to increase the extent of grazing land in many parts of the catchment. This involved the bunding of coastal salt pan areas to prevent tidal ingress, allowing pasture grasses to become established. These areas, known as ponded pastures, are mapped as 'wetland production' under the Queensland Land Use Mapping Project classification. Ponded pastures reduce the natural production and subsequent inshore coastal waters, leading to likely declines in inshore fish and invertebrate productivity (Figure 3.3.4).

Figure 3.3.4: Bund walls along Notch Point Prawn Farm (Study Site 18)

Water – intensive use and water - storage and treatment

Kinchant Dam (Study Site 15) is built on Sandy Creek and provides irrigation and water for the surrounding towns. Within Plane Creek there is Middle Creek Dam which is a small drinking supply dam[4] and four weirs including Jackson's Weir, Council Dam, Mill Dam and CSR dam. These dams highly regulate the flow of the creek[33] and present significant barriers to fish passage.

PART B: OUTCOMES OF BASIN ASSESSMENT

Chapter 4: Projected condition of Great Barrier Reef catchment values

4.1 Summary of current state of coastal ecosystems

The coastal ecosystems of the Plane basin have been highly modified. The Plane basin has undergone large hydrological modifications as a result of clearing, levelling and drainage of extensive agricultural land areas, and regulated flows emanating from Kinchant Dam. The region is dominated by grazing and the coastal region is dominated by sugar cane cultivation. These agricultural practices are the main source of sediment and nutrient loads in some waterways. Coastal ecosystems that have been most affected are forests, woodlands, and grass and sedgelands (Table 4.1.2). In the coastal zone, estuaries (saltmarsh and saltpan) in many areas have been bunded for ponded pastures, which has resulted in an increase in freshwater wetlands (Table 4.1.1). These changes have compromised the ability of coastal ecosystems to provide ecological functions to the World Heritage Area.

Table 4.1.1: Percentage of remaining coastal ecosystems in the Plane basin. Orange cells indicate areas with 10-30 per cent remaining; yellow 31-50 per cent and green greater than 50 per cent. Note these figures provide no information about ecosystem condition or functionality. White cells denote an absence of this coastal ecosystem from the basin

Plane basin % coastal ecosystems remaining	Rainforests	Forests	Woodlands	Forested floodplain	Grass and sedgelands	Heath and shrublands	Freshwater wetlands	Estuaries
Plane basin	92	38	28	N/A	13	97	86	95
Floodplain	70	20	28	N/A	10	100	86	95
Coastal zone	84	43	36	N/A	68	100	86	95

The current state of coastal ecosystems in the Plane basin is summarised in Table 4.1.2.

Table 4.1.2: Summary of the current state of coastal ecosystems in the Plane basin

	Coastal ecosystem	Current condition
	Rainforests	8 per cent of rainforests in the basin have been lost, status is good.
	Forests	Heavily impacted with 38 per cent remaining which is mostly used for grazing. Only 20 per cent of forests on the floodplain and 43 per cent of forests in the coastal zone remain.
	Woodlands	Reduced in extent by 72 per cent with much of the remainder under grazing regimes.
	Forested floodplain	Not assessed.
	Grass and sedgelands	Extensively modified with only 13 per cent remaining. Remnant grass and sedgelands impacted by water from irrigation and land modification.
	Heath and shrublands	Reduced in extent by 3 per cent. Most remnant heath and shrublands are buffered by other remnant coastal ecosystems or protected areas.
	Freshwater wetlands	Almost a quarter of the Plane basin wetlands have been modified. Remaining wetlands assessed appear to be in a reasonable condition. Increases in coastal zone for freshwater wetlands can be attributed to ponded pastures.
	Estuaries	Mangrove systems mostly intact and in near pristine condition. Much of

		the saltmarsh/saltpans have been modified with bund walls for ponded pastures.

4.2 Outline of key current and likely future pressures and impacts on coastal ecosystems in the Plane basin

Table 4.2.1 provides a brief summary of the current pressures and future outlook for coastal ecosystems in the Plane basin. Pressures include expansion of irrigated production, urban areas, changes to hydrology and expansion of the Hay Point and Dalrymple Bay Port Facility.

Vegetation removal

The introduction of the *Vegetation Management Act 1999* and the *Sustainable Planning Act 2009* now regulates vegetation clearing on approximately 95 per cent of Queensland by triggering assessment and applying penalties for non-approved clearing. The *Vegetation Management Act 1999* also provides mapping of areas of conservation significance through regional ecosystems. Regrowth vegetation (especially riparian) provides some protection. However, this legislation does not provide protection to mangroves, grasses, non-woody vegetation or plants within some grassland ecosystems. Marine plants such as mangroves, saltmarsh and saltcouch are provided protection under the *Queensland Fisheries Act 1994*. Other legislation also applies depending on the tenure of the land.

Port development

Due to extreme water restrictions there is no room for expansion of sugar cane croplands (J. Brodie (TropWater) 2013, pers. comm., 12 March). However, coastal changes are expected with the proposed expansion of the Hay Point Terminal as new facilities are planned to be built as part of the Dudgeon Point Coal Terminal Project. The expansion will likely affect the health and resilience of coastal ecosystems in the Plane basin. The Hay Point expansion is currently under assessment, however, if it gains approval and begins construction, the work will likely lead to an increase in the demand for residential developments. Impacts from urban residential areas can include clearing of remnant vegetation areas, clearing of shore bird roosts, increases in hydrocarbons, herbicide and fertiliser applications, introduction of feral animals into adjacent natural areas and increase of plastics, toxicants and pharmaceuticals. The estimated capacity of coal exports after expansion is 180 Mtpa.[74] The expansion will cost an estimated $10-12 billion and will include new coal stockyards, approximately 13 million cubic tonnes of capital dredge material, a new barge facility, a two-piled jetty structure that is five kilometers in length connecting offshore wharves to shore, six new ship berths, a new rail connection from Goonyella system to Dudgeon Point, expansion of the existing Tug Harbour at Half Tide and construction of site infrastructure.[74] Environmental impact assessments are not yet complete; however these port expansions will potentially have broad implications for the surrounding marine environment. Changes to flora and fauna, water quality and hydrology, and marine wildlife need to be monitored. Vessels numbers and hence vessel traffic and shipping impacts will increase, as well as noise and dust pollution. The port is within the World Heritage Area and adjacent to the Marine Park.[75]

Climate Change

The impacts of climate change will vary across the basin, with the highest threats to low-lying coastal areas and the floodplain. Future development planning needs to map and consider the risks of sea-level rise, storm surge and flooding before allowing for development in the coastal zone and floodplain. The interaction of rising sea temperatures and ocean acidification will exacerbate the impacts from catchment run-off on inshore coral reef ecosystems.

Table 4.2.1: Summary of the current pressures and future outlook for coastal ecosystems in the Plane basin

Pressure	Current status (1999-2009)	Description	Future outlook	Description
Urban development	Increase	Urban residential increased by 19 per cent (and by 9 per cent for the coastal zone) between 1999 and 2009.	Increase	Mackay, the major urban centre, is expected to increase in size from approximately 121,397 in 2011 to 187,387 in 2031.
Port development	No Change		Increase	Expansion proposed for Hay Point and Dalrymple Bay Port Facility.
Agriculture	Increase	Agriculture production (dryland and irrigated) has increased by 0.5 per cent (and by 3 per cent for the coastal zone) between 1999 and 2009. The majority of this increase is attributed to irrigated production.	Increase	An increase in irrigated cropping development is likely to continue into the southern part of the basin. In the past, the expansion of cane has been limited by infrastructure constraints.
Irrigation infrastructure	Increase	Water storage and transport has increased in extent by 7 per cent between 1999 and 2009.	Increase	Likely to increase to support an expansion of irrigated production.
Grazing	Decrease	Grazing has declined by 11 per cent between 1999 and 2009.	Likely to decrease	Some areas of grazing are expected to be replaced by irrigated production.
Introduced species	Uncertain	Established throughout the basin.	Uncertain	Ongoing control programs for weed management in place however climate change impacts are uncertain and may encourage proliferation of some weed species. Expansion of irrigation infrastructure may increase extent of aquatic and terrestrial weeds.

Climate Change	Increase	Not assessed.	Increase	Increasing intensity of episodic events, droughts and changes in rainfall patterns all likely to impact on coastal ecosystems.
Vegetation removal	Minimal change	The introduction of the *Vegetation Management Act 1999* provided a regulatory framework for broad-scale land clearing across Queensland. Since its introduction, the rate of vegetation clearance in the basin has significantly declined.	Uncertain	Amendments proposed for the *Vegetation Management Act 1999.*

4.3 Current and likely future impacts on coastal ecosystems and likely resultant impacts on the World Heritage Area

The Plane basin has changed, and any management actions to improve the condition of the adjacent World Heritage Area need to consider this system as a whole. The key current and likely future impacts on coastal ecosystems and likely resultant impacts on the World Heritage Area are summarised in Table 4.3.1.

The future prospects for the Plane basin are largely dependent on the ability to restore coastal ecosystem extent, condition and function within an intensively developed landscape. If well managed, the potential to improve the health and resilience of wetland, estuarine and inshore coastal marine ecosystems (and the industries they support) are enormous. Failure to address these problems will however continue to impact on coastal ecosystems and the species they support.

Actions are being taken to improve the condition of the Plane basin. Natural Resource Management Group Reef Catchments have been working closely with local government and landholders to make improvements. One example of initiatives introduced by Reef Catchments is working with Department of Natural Resources and Mines and the sugar cane industry on monitoring new farm systems that grow sugar cane more efficiently with reduced water quality impacts.[76]

The Reef Water Quality Protection Plan (Reef Plan) is a collaborative program of coordinated projects and partnerships designed to improve the quality of water in the World Heritage Area though improved land management in Great Barrier Reef catchments. Reef Plan is a joint Australian and Queensland Government initiative that specifically focuses on non-point-source pollution. This is where irrigation or rainfall carries pollutants such as sediments, nutrients and pesticides into waterways and the Reef lagoon. Reef Plan sets targets for water quality and land management improvement, and identifies actions to improve the quality of water entering the World Heritage Area. Initially established in 2003, Reef Plan was updated in 2009 and 2013.

Table 4.3.1: Key current impacts and likely future impacts in the Plane basin and likely consequences for the World Heritage Area

Current impacts on Coastal Ecosystems	Trend 1999-2009	Impacts on the World Heritage Area	Future likely impacts on Coastal Ecosystems	Future likely impacts on the World Heritage Area
Broadscale clearing of coastal ecosystems for agriculture, urban or industry	Rates of clearing have declined as a result of the *Vegetation Management Act 1999.*	Loss of ecological process and connectivity, replacement of some ecological processes depending on the nature of the modified system.	Coastal ecosystems unlikely to be returned to their former state, however no further losses expected.	No change likely to occur.
Farm run-off	Improvements as a result of increasing rates of best management practice uptake.	Improvements to water quality expected, although delayed due to lag effects. Changes in land use will not be obvious for a few years.	Dependant on extent of new horticulture and uptake of best management practice.	Water quality expected to improve over time.
Groundwater changes	Groundwater extraction lowering the watertable in particular, Alligator Creek and Sandy Creek.	Potential decline in biological and biogeochemical processes, changes to connectivity.	Over extraction of groundwater may lead to increases in salinity and loss of dry season refugia in waterways.	As for current impacts.
Drainage of the floodplain	Increase due to industrial and urban expansion.	Changes to fish passage and reduction in water residence time causing a reduced capacity for biogeochemical processes to occur. Changed catchment hydrology including peakier flows with an increased contaminant transport capacity due to land clearing, levelling, wetland filling and surface drainage network establishment.	May increase as a result of expected increase in irrigated cropping.	As for current impacts.
Introduced aquatic weeds and declining wetland health	Introduced aquatic weeds are well established in the basin.	Lead to lowered oxygen levels in aquatic ecosystems that render habitats unsuitable for most native fish species. Create blackwater pulses that cause downstream fish barriers. Act as a barrier to fish movement.	Uncertain.	If weeds continue to proliferate a reduction in water quality, fish habitat and connectivity are likely to occur.
Stream/river bank	Increasing as a result of	Increase in suspended sediments	Management actions (e.g.	Likely to improve under

erosion	extreme weather events. Legacy issues from historical clearing.	and turbidity in coastal waters; increase in sediment (sand) build up in waterways.	Reef Plan) underway to restore riparian areas.	uptake of best management practice and restoration projects.
Declining water quality	Improvements in recent years although still a major threat to the World Heritage Area.	Decline in inshore ecosystem health and resilience.	Likely to improve as a result of management actions targeted at improving water quality.	Improvements expected but will take time to take effect.
Barriers to fish migrations	Increase with the construction of dams and weirs.	Reduction/loss of connectivity and fish passage.	Projects planned to improve fish passage through lowering of smaller bund walls or installing fish ladders. New dams proposed may reduce fish passage.	Dependent upon effective works being implemented and connections restored and maintained.
Introduced species	Established throughout the basin (mostly in modified landscapes).	Introduced grasses generate hotter fires that can destroy forest canopies and expose soil which can be eroded, especially when fires occur late in the dry season.	Eradication to date has been ineffective and many grasses are still used for pasture grasses. Strategic basin scale management actions are needed to manage and control.	Likely to lead to increases in erosion and therefore more suspended sediments in the World Heritage Area.
Changed overland hydrology	Most development/modification has occurred on the floodplain and coastal zone.	Changes to connectivity and water retention which has impacted on all ecological processes.	Development continues to occur on the floodplain and coastal zone.	Likely decline in water quality and aquatic biodiversity in the World Heritage Area.
Ponded pasture/wetland production	It became illegal to establish new ponded pastures in the coastal zone in 2001 (policy for development and use of ponded pasture).	Loss of connectivity and declines in fish productivity, blackwater, and the potential release of acid sulphate soils.	Plans to modify ponded pastures to improve ecosystem health.	Improved productivity, ecosystem health and resilience.

Water quality

Water quality remains the greatest current and future risk to the World Heritage Area from the Plane basin. The loss of coastal ecosystems and changes to connectivity has reduced the capacity to provide ecological functions to the World Heritage Area. In addition, the extent of habitat for species with connection to the World Heritage Area has been reduced and, if this continues, will affect natural productivity and may reduce the gross value of production of commercially and recreationally important fish species.

Figure 4.3.1 provides an example of the relationships between pressures, state and impact from increased pollutants being delivered to the World Heritage Area. Note that these sequential impacts are linked primarily to nutrient loading scenarios, and do not define the cumulative impacts from increasing temperature and nutrients, or from other pollutants such as suspended sediment and pesticides. Current work[77,78,79] indicates that the combined impacts of rising temperatures and increasing nutrients, particularly dissolved inorganic nitrogen (DIN), will reduce the resilience of coral reefs to recover from more frequent bleaching events.[80]

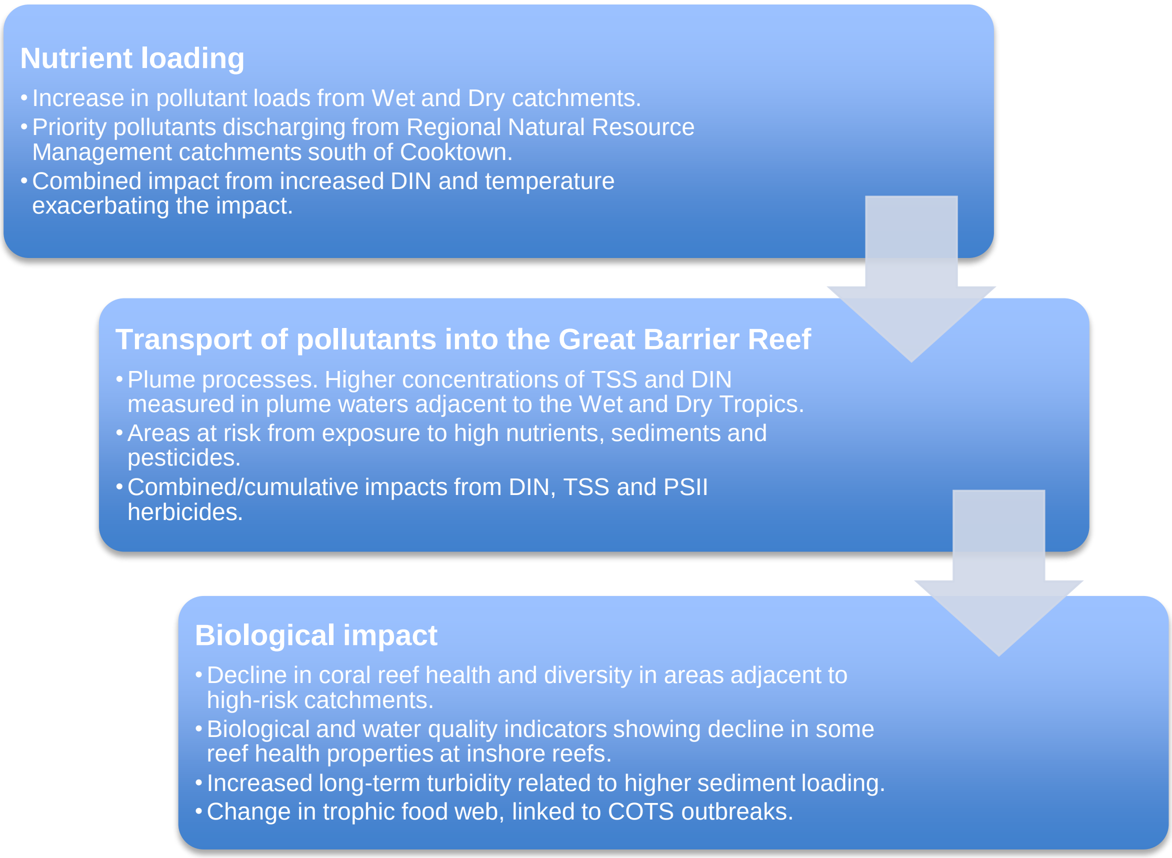

Figure 4.3.1: Pathway from nutrient enrichment to biological impact from total suspended solids (TSS); dissolved inorganic nitrogen (DIN); photosynthesis inhibiting herbicides (PSII); and crown-of-thorns starfish (COTS)

The impacts of increasing sediments and nutrients on coral reefs (Figure 4.3.2) and seagrass (Figure 4.3.3) include shading, reduced resilience and reduced recruitment.

Abundances of a range of other reef associated organisms have also been shown to change along water quality gradients.[80]

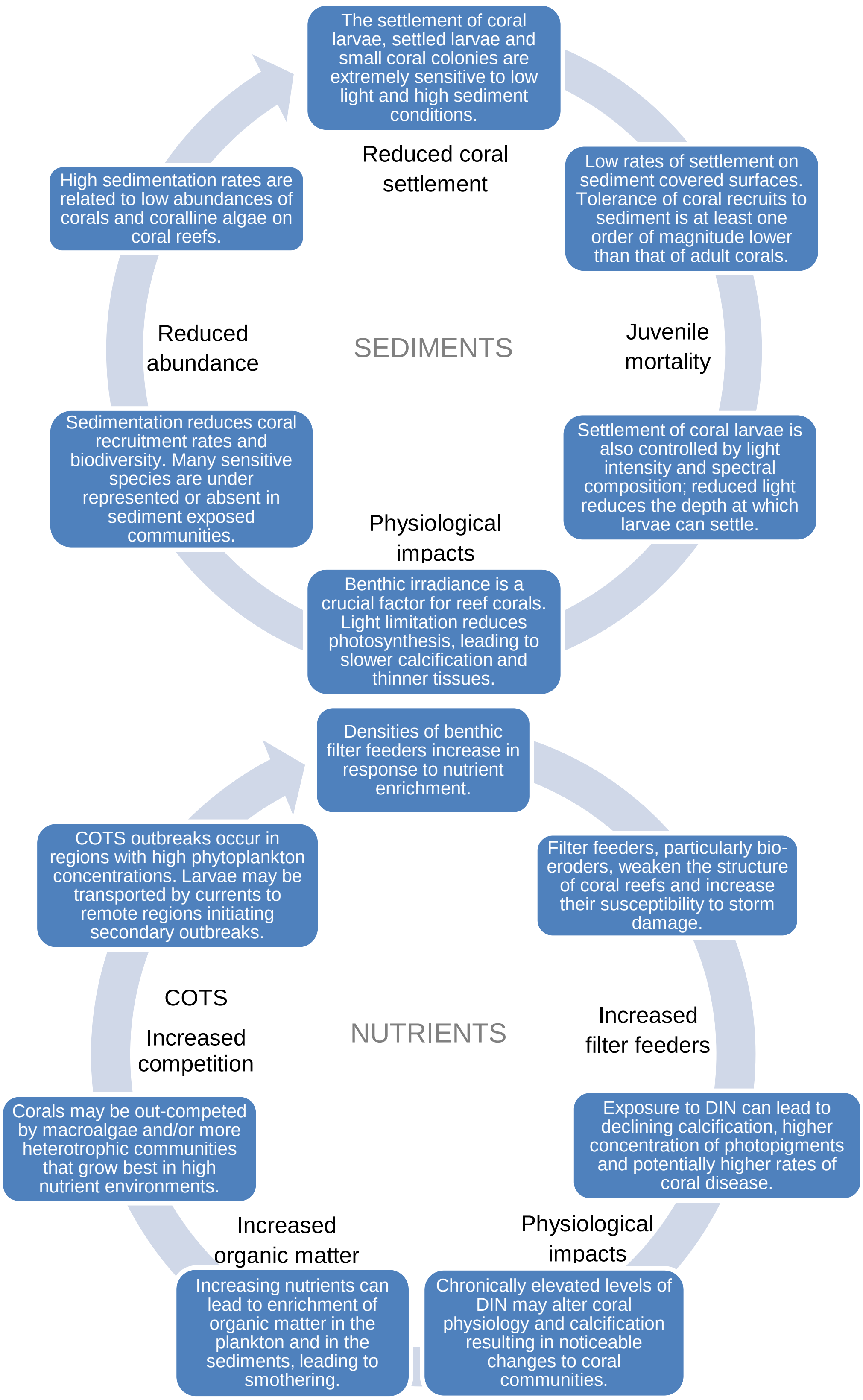

Figure 4.3.2: Potential and known impacts of increasing nutrients and sediments on coral reefs[80]

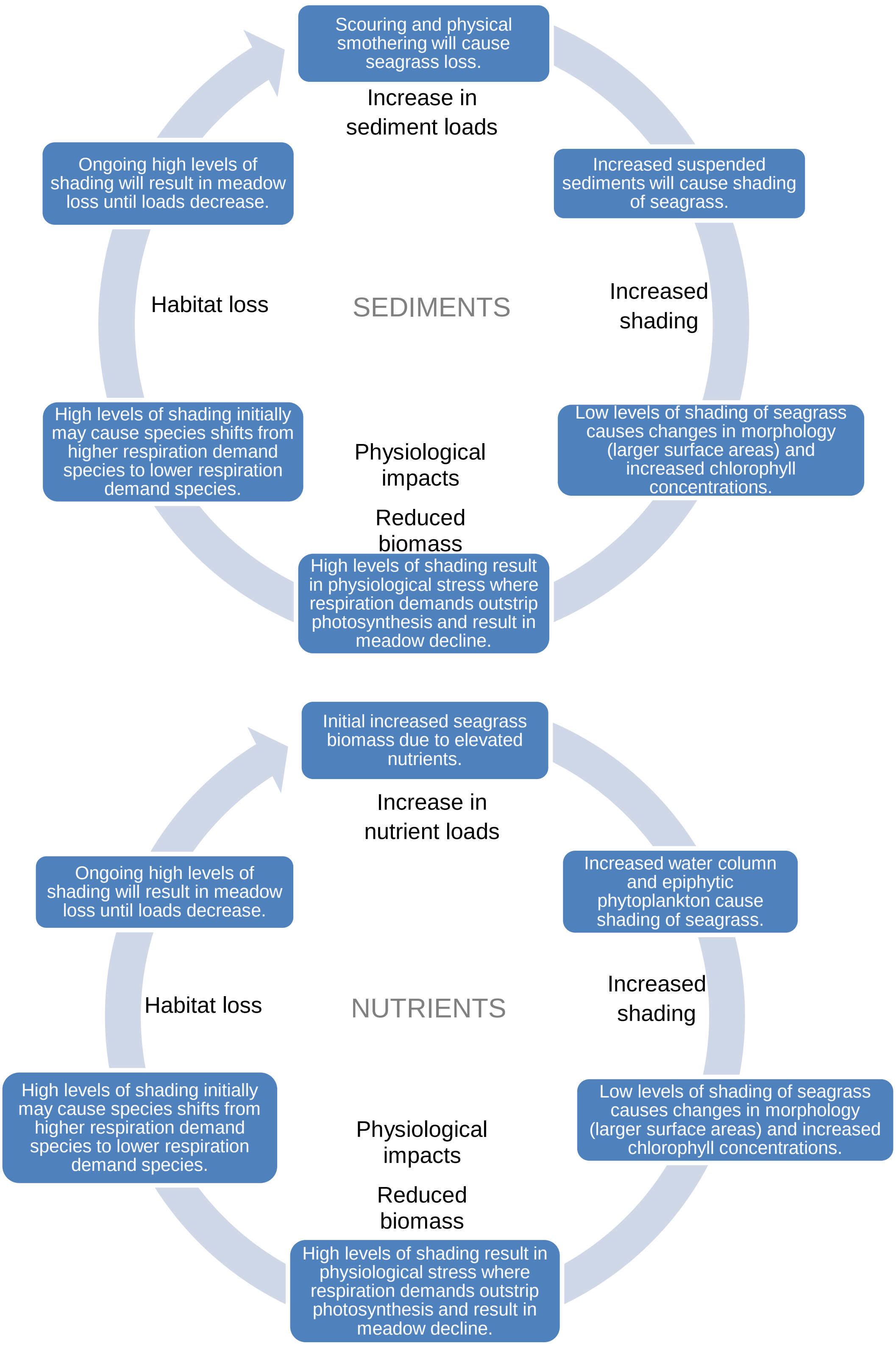

Figure 4.3.3: Potential and known impacts of increasing nutrients and sediments on seagrass beds[80]

Reef Rescue initiatives have been implemented in the Plane River catchment that include grazing grants to promote better soil health, control gully and stream bank erosion, improve water quality through riparian fencing and spreading of waters to exclude stock from creeks and rivers. Water quality improvement grants are also attainable for growers that use effective chemical application rates, reduce off-farm run-off, and apply fertiliser in a precise manner to promote better soil health.

4.4 Priorities for conservation and restoration

Coastal ecosystems located in the floodplain and coastal zone are those that have experienced the greatest losses and those most at risk in the future. Future conservation measures should include protection of these ecosystems from further loss and impacts and restoration efforts should also focus on these areas. These areas are also at greatest risk from flooding, storm and climate change impacts. New high value infrastructure, such as residential and industrial development, should be avoided in these areas. Current infrastructure in these areas needs to be constructed and managed to current best practice for minimising impacts on the area's hydrological processes.

As with much of the catchment, many of the issues affecting the health and resilience of the Great Barrier Reef adjacent to this basin stem from legacy issues such as broadscale vegetation clearing. Current legislation prevents recurrence of many of these legacy issues however management actions to recognise and rectify these problems are rare. Riverbank erosion is still occurring due to upstream channelisation, clearing, loss of riparian vegetation and weed species all of which reduce habitat for species with connections to the Reef.

This Report demonstrates that the coastal ecosystem services provided by the Plane basin cannot be further degraded if it is to support the outstanding universal value and integrity of the World Heritage Area. The coastal ecosystems in the floodplain are currently at greatest risk and require effective protection and restoration measures to ensure the long-term health of the Reef.

Coastal zone

Coastal ecosystems in the coastal zone generally have the closest connections to the World Heritage Area and generally have a higher capacity to provide physical, biological and biogeochemical processes for the World Heritage Area. Some coastal ecosystems in the coastal zone also fall within the World Heritage Area. The coastal zone is also the area at greatest risk from the impacts of climate change. Actions that could be taken to reduce pressure on the coastal zone in the Plane basin include:

- Limit further loss of remaining coastal ecosystems.
- Limit further intensive development in the coastal zone, particularly in intact areas. This will not only reduce environmental impacts, but may also reduce the risk of economic impacts resulting from future climate change, as scenarios predict that the coastal zone will be at greatest risk from sea-level rise and storm surge.
- Consistent with Queensland planning provisions, future urban developments that cannot be sited outside of the coastal zone be constructed to current best practice, employing principles such as water sensitive urban design, gross pollutant traps and tertiary sewage treatment.

- Manage modified coastal ecosystems to provide ecological functions and values that support the health of the World Heritage Area through the continued improvement in land management practices (grazing, dryland and irrigated production).
- Restoration of coastal ecosystems within drainage networks.
- A sub-basin scale landscape strategic study of land use and coastal ecosystems to enable a balance between sustainable agriculture and functional coastal ecosystems.
- Protect and restore native vegetation cover, linkages and buffers where they remain including alluvial plain remnants, all remaining buffers around estuarine systems (especially small remnants in the north of the basin adjoining Mackay and larger ones in the southern section of the basin).

Floodplain

Floodplains support particularly rich coastal ecosystems, especially in terms of diversity and abundance. These areas are important for the physical, biological and biogeochemical processes they provide for the long-term health and resilience of the World Heritage Area. Actions that can be taken to reduce pressure on the floodplain include:

- Limit further loss and increased protection of remaining coastal ecosystems.
- Improve connectivity between remnant coastal ecosystems within the floodplain.
- Improvements to agricultural practices to current best practice standards within the floodplain.
- Strategic vegetation management – planting of climate change adapted species, plants designed to address the modified landscape (deep rooted trees planted on floodplain to assist in managing rising groundwater and salinity, well managed grazing in riparian areas to reduce introduced pasture grasses.
- All future urban developments that cannot be sited outside of the floodplain be constructed to current best practice, employing principles such as water sensitive urban design, gross pollutant traps and tertiary sewage treatment.
- Limit further intensive development in the floodplain. This will not only reduce environmental impacts, but may also reduce the risk of economic impacts resulting from future climate change, as scenarios predict that the floodplain will be at increased risk from flooding.
- Restoration of ecosystem function by commitment to 'water sensitive' drainage design incorporating detention or retention functions or structures in natural and constructed drainage network (for example, construction of detention or retention functional areas, preferable doubling as wetland habitat, in all new development on the periphery of Mackay city).

Riparian areas

Riparian vegetation provides important physical, biological and biogeochemical processes essential for the long-term health and resilience of the World Heritage Areas. Riparian vegetation slows water velocity and provides connectivity across the basin. Actions that can be taken to reduce pressure on the riparian zones include:

- Improve agricultural practices in areas where riparian vegetation is minimal or non-existent to restore their function.

- Appropriate restoration of riparian corridors and increase widths appropriate with stream order (i.e. the higher the stream order the wider the buffer) and with vegetation adapted for future climate scenarios this will provide better connections, in-stream habitat, reduce erosion, improve water quality and reconnect the basin.
- Introduce low levels of well managed grazing in riparian areas where introduced grasses dominate. Controlling of exotic grasses, in particular, hymenachne as it chokes waterways and removes oxygen which reduces water quality. Non-native grasses pose a fire risk to well established riparian forests.
- Protect riparian zones from future development, including urban and agricultural development.
- Any further development adjacent to waterways should ensure that it does not contribute further to point and non-point source pollutants entering waterways.
- Restore and manage remnant and riparian vegetation to minimise bank erosion and filter nutrients and sediments.
- Reinstate riparian vegetation within drainage networks.

Wetlands

Wetlands provide habitat for many species with connections to the World Heritage Area and are often referred to as the 'kidneys of the Reef'. Wetlands provide important physical, biological and biogeochemical processes that support the long-term health and resilience of the World Heritage Area. Potential management actions for wetlands include:

- Improve connectivity, where appropriate, to wetlands to allow greater connections between wetlands and to the World Heritage Area.
- Control and management of introduced species such as aquatic weed species that compromise wetland health.
- Restore and manage wetlands to maximise nutrient recycling, sediment deposition and nursery areas for fish species.
- Reinstate wetland function within drainage networks.
- Buffering of wetlands in intensively developed agricultural floodplains (potentially including resumption of agricultural land).

Hydrological Connectivity

The hydrological processes within catchments set the backbone of all ecosystem functions and water quality outcomes. These catchment ecosystems and water quality outcomes in turn are in direct connection with the health of the marine environment to which they drain, and have therefore been of increasing concern for the long-term health of the Great Barrier Reef.[81] Actions that could be taken include:

- Limit construction of dams and weirs in this basin where they might impact on coastal ecosystems or the Marine Park.
- Seek to protect or reinstate in-stream habitats to provide improved flow regulation and fish habitat structure.
- Improved overland flow detention to trap entrained sediment to allow for sediment and nutrient cycling while maintain connectivity in the landscape for World Heritage Area species that utilise the catchment for part of their lifecycle.

- Improve landscape connectivity through the use of finer scale coastal ecosystem mapping to identify required connections and actions that provide values and services to support the World Heritage Area.
- Encourage strategic improvements to land management practices, in particular restoring aquatic connectivity, broadscale grazing and pasture management, and the revegetation of critical coastal ecosystems.
- Accurately assess and modify dams, weirs and ponded pastures to promote hydrological connectivity.
- Appropriate modification of fish barriers to improve fish populations through increased access and opportunity for species migration.

Other Areas

Areas outside of the coastal zone and floodplain still provide some physical, biological and biogeochemical processes to the World Heritage Area. Potential management actions for these areas include:

- Appropriate restoration of riparian corridors to a standard that provides effective ecological functions.
- Encourage best practice management of agricultural activities, particularly in areas where riparian buffers are minimal or non-existent.
- Plan and manage new land use to have no net impact on the World Heritage Area.

4.5 Potential management actions

This report has been developed as a baseline for the Plane basin. In order to ensure that the basin is best represented, consideration of additional finer scale data, local knowledge and information will further enhance this assessment.

Ensuring the long-term health and resilience of the World Heritage Area requires greater protection of, and restoration of important ecological processes and functions provided by the Plane basin coastal ecosystems. Actions that would increase protection and restore processes and function include:

1. The inclusion of rehabilitation plans into the life of a mining project and audited by management agencies to ensure compliance.
2. Greater protection, restoration and management of remnant and riparian vegetation to reduce bank erosion and to filter nutrients and sediments.
3. Greater protection, restoration and management of wetlands and their floodplains that recycle and trap nutrients and sediments and provide important nursery areas for fish species.
4. Restore connectivity of streams, rivers and waterways to promote hydrological connectivity and improve fish passage.
5. Manage modified coastal ecosystems to provide ecological functions and values that support the health of the World Heritage Area through the continued improvement in land management practices (grazing, dryland and irrigated production).
6. Encourage strategic vegetation management, including planting of climate change adapted species and plants designed to address the modified landscape (e.g. deep

rooted trees planted on floodplain to assist in managing rising groundwater and salinity).

7. Plan and manage new land use to have no net impact on the World Heritage Area.

4.6 Knowledge gaps

In assessing this basin, a number of knowledge gaps were identified, including:

- A current lack of information regarding the inshore and offshore coastal areas within the Plane basin. Much of the past and current research has been conducted within streams related to cane cultivation processes. Information on the link between these land use changes and their impacts on downstream and marine ecosystems is lacking.
- There is currently no ground water monitoring south of Carmila.
- Implications of agricultural chemicals on the marine environment.
- Reef Plan focuses on sediments, nutrients and pesticides, but further water quality research is required that relates to pollutants that are not covered by Reef Plan, such as microplastics, pharmaceuticals etc., and their effects on the World Heritage Area.
- Effectiveness of current marine monitoring sites. Current sites in this basin are limited to locations that provide ease of access and do not necessarily reflect monitoring at specific river mouths. Integrated monitoring of in-stream and river mouth water quality and ecosystem health would provide more pertinent information on the ability of remaining coastal ecosystems to provide services to maintain the health and resilience of the World Heritage Area.
- Limited information on the effects of coal dust on marine organisms.
- No monitoring of litter and microplastics or pharmaceutical components occurs within the Plane basin. Plastic debris has been monitored along shorelines within and North of Mackay, especially on the Whitsunday islands and may expand southwards into the Plane basin.
- The impacts of climate change and groundwater extraction on coastal ecosystems (and their interactions).
- The impacts of land use changes on groundwater water quality and groundwater dependent ecosystems.
- The impacts of groundwater extraction on ground water movement and consequences for ‘downstream ecosystems’.

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Appendix A – Field Assessment Template

Date	Basin Name	Latitude (-18.861499)	Camera No	Photo No
Time	**Way Point**	**Longitude (145.865234)**	**Photo no.**	
Team Members				
Experts				
Site Name				
Site Description				
Site Condition (circle): Excellent Good Average Poor Very poor Unknown				
Coastal Ecosystems: Coral Reef Open Water Lagoon Floor Seagrass Coastline Estuaries Freshwater Wetlands Mangroves Saltmarshes Heath and Shrublands Grass and sedgelands Forested Floodplain Woodlands Forests Rainforests				
Condition: intact fragmented cleared other				
Landuse: **Conservation and natural environments** (inc wetlands), **Forestry:** dryland or irrigated plantation, **Grazing:** dryland, irrigates or natural vegetation **Intensive:** commercial, mining, animal production, urban residential **Production:** dryland or dryland sugar, Production forestry, **Water:** marsh wetland production or intensive use, water storage and treatment, uncertain				
Direct Impacts (threats):				
Direct Impacts (threats):				
Indirect Impacts / Threats:				
MNES or threatened species				
Other Information				

Appendix B – Key terminology used in this report

Basins:	An extent or an area of land where surface water channels to a hydrological network and discharges at a single point i.e. river, stream, creek. Defined by Queensland Government and may include many sub-basins.
Coastal zone:	Area of coast as defined by the *Coastal Protection and Management Act 1995* (Queensland)
Coastal Ecosystem:	Marine, estuarine, freshwater and terrestrial ecosystems that connect the land and sea and have the potential to influence the health and resilience of the Great Barrier Reef. For this study, this includes the Great Barrier Reef catchment and 10% of the Reef waters seawards of the coastline.
Ecosystem:	A dynamic complex of plant, animal and micro-organism communities and the non-living environment interacting as a functional unit. Source: Millenium Ecosystem Assessment 2005.[82]
Ecosystem function:	The interactions between organisms and the physical environment, such as nutrient cycling, soil development and water budgeting.
Inshore marine areas:	Include (but not limited to) those areas extending up to 20 km offshore from the coast and which correspond to enclosed coastal and open coastal water bodies as described in the *Water Quality Guidelines for the Great Barrier Reef Marine Park (2010)*.[83]
Great Barrier Reef catchment (catchment):	The 35 river basins in Queensland which drain into the Great Barrier Reef (Table 1).
Natural Resource Management (NRM) regions:	A group of basins managed by non-government organisations (NRM bodies) within Queensland (Table 1).
Natural Resource Management (NRM) bodies:	Non-government organisations focused on environmental and sustainable agriculture programs and activities.
Non Remnant:	Vegetation that does not meet the criteria of remnant vegetation as defined under the Vegetation Management Act 1999.
Pre-clear:	Queensland Government reconstruction of regional ecosystems to represent vegetation pre-European settlement.
Post-clear:	Queensland Government mapping of the state of regional ecosystems that occurred in 1999 and 2009.
Remnant vegetation:	Vegetation that meets all of following criteria: • 50 per cent of the predominant canopy cover that would exist if the vegetation community were undisturbed. • 70 per cent of the height of the predominant canopy that would exist if the vegetation community were undisturbed. • Composed of the same floristic species that would exist if the vegetation community were undisturbed.
Regional ecosystem:	Regional ecosystems (REs) are vegetation communities that are consistently associated with a particular combination of geology, land form and soil in a bioregion. The Queensland Herbarium has mapped the remnant extent of regional ecosystems for much of the State using a combination of satellite imagery, aerial photography and on-ground studies. Each regional ecosystem has been assigned a conservation status which is based on its current remnant extent (how much of it remains) in a bioregion. Some areas of Cape York have not been mapped.
Sub-basin	Smaller catchment area situated within a basin.
Vulnerability:	The degree to which a system or species is susceptible to, or unable to cope with, adverse effects of pressures. Vulnerability is a function of the character, magnitude, and rate of variation or change to which a system or species is exposed, its sensitivity, and its adaptive capacity.

Appendix C – Values and their elements that underpin matters of national environmental significance

Values and their elements that underpin matters of environmental significance	Matters of national environmental significance						
	World Heritage Properties	National heritage places	Wetlands of international importance	Listed threatened species and ecological communities	Listed migratory species	Commonwealth marine areas	Great Barrier Reef Marine Park
Biodiversity - Habitats							
Islands	✓	✓				✓	✓
Beaches and coastlines	✓	✓				✓	✓
Mangroves	✓	✓				✓	✓
Seagrass meadows	✓	✓				✓	✓
Coral reefs (<30m)	✓	✓				✓	✓
Mesophotic (deep water) corals	✓	✓				✓	✓
Lagoon floor	✓	✓				✓	✓
Shoals	✓	✓				✓	✓
Halimeda banks	✓	✓				✓	✓
Continental slope	✓	✓				✓	✓
Open waters	✓	✓				✓	✓
Saltmarshes	✓	✓	✓			✓	✓
Freshwater wetlands*	✓	✓	✓			✓	✓
Forest floodplain*	✓	✓				✓	✓
Heath and shrublands*	✓	✓				✓	✓
Grass and sedgelands*	✓	✓	✓			✓	✓
Woodlands*	✓	✓				✓	✓
Forests*	✓	✓				✓	✓
Rainforests*	✓	✓		✓		✓	✓
Biodiversity - Species							
Dune & saltmarsh plants*	✓	✓					
Mangroves	✓	✓				✓	✓
Seagrasses	✓	✓				✓	✓
Macroalgae	✓	✓				✓	✓
Benthic microalgae	✓	✓				✓	✓
Corals	✓	✓				✓	✓
Seahorses and allies	✓	✓				✓	✓
Other invertebrates	✓	✓				✓	✓
Plankton and microbes	✓	✓				✓	✓
Bony fish	✓	✓				✓	✓
Sharks and rays	✓	✓		✓	✓	✓	✓
Sea snakes	✓	✓				✓	✓
Marine turtles	✓	✓		✓	✓	✓	✓
Estuarine crocodile	✓	✓			✓	✓	✓

Values and their elements that underpin matters of environmental significance	**Matters of national environmental significance**						
	World Heritage Properties	**National heritage places**	**Wetlands of international importance**	**Listed threatened species and ecological communities**	**Listed migratory species**	**Commonwealth marine areas**	**Great Barrier Reef Marine Park**
Seabirds	✓	✓		✓	✓	✓	✓
Shorebirds	✓	✓		✓	✓	✓	✓
Whales	✓	✓		✓	✓	✓	✓
Dolphins	✓	✓			✓	✓	✓
Dugongs	✓	✓				✓	✓
Ecosystem Processes – Physical processes							
Ocean currents	✓	✓				✓	✓
Cyclones & wind	✓	✓				✓	✓
Freshwater inflow	✓	✓				✓	✓
Sedimentation	✓	✓	✓			✓	✓
Sediment re-suspension	✓	✓				✓	✓
Sea level	✓	✓				✓	✓
Sea temperature	✓	✓				✓	✓
Light	✓	✓				✓	✓
Aquatic connectivity	✓	✓	✓				
Ecosystem Processes – Geomorphological processes							
To be determined (SEWPaC advice)							
Ecosystem Processes – Chemical processes							
Nutrient cycling	✓	✓	✓			✓	✓
Pesticide accumulation	✓	✓	✓			✓	✓
Ocean acidity	✓	✓				✓	✓
Ocean salinity	✓	✓				✓	✓
Ecosystem Processes – Ecological processes							
Microbial processes	✓	✓				✓	✓
Particle feeding	✓	✓				✓	✓
Primary production	✓	✓	✓			✓	✓
Herbivory	✓	✓				✓	✓
Predation	✓	✓				✓	✓
Symbiosis	✓	✓				✓	✓
Bioturbation	✓	✓				✓	✓
Reef building	✓	✓				✓	✓
Competition	✓	✓				✓	✓
Ecological connectivity	✓	✓	✓			✓	✓
Recruitment	✓	✓	✓			✓	✓
Heritage – Outstanding Universal Value							
Superlative natural phenomena, exceptional natural beauty and aesthetic importance (Criterion VII)	✓	✓					
Geological processes and geomorphic	✓	✓					

Values and their elements that underpin matters of environmental significance	Matters of national environmental significance						
	World Heritage Properties	National heritage places	Wetlands of international importance	Listed threatened species and ecological communities	Listed migratory species	Commonwealth marine areas	Great Barrier Reef Marine Park
features (Criterion VII)							
Ecological and biological processes (Criterion IX) See Ecosystem Processes	✓	✓					
Natural habitats for conservation of biodiversity (Criterion X) See Biodiversity - Habitats	✓	✓					
Integrity	✓	✓					
Heritage – Natural							
See Biodiversity and Ecosystem Processes above							
Heritage – Indigenous							
Cultural practices, observances and customs						✓	✓
Sacred sites, sites of significance, places for cultural tradition						✓	✓
Stories, song lines and marine totems	✓	✓				✓	✓
Indigenous structures, tools and archaeology	✓	✓				✓	✓
Places of historic significance - Indigenous						✓	✓
Places of aesthetic value - Indigenous						✓	✓
Heritage – Non-Indigenous							
Places of historic significance – historic shipwrecks						✓	✓
Places of historic significance - World War II features and sites						✓	✓
Places of historic significance - lighthouses						✓	✓
Places of historic significance – other						✓	✓
Places of scientific significance (research stations, expedition sites)						✓	✓
Places of aesthetic value See OUV - Criterion VII	✓	✓				✓	✓
Places of social significance – iconic sites						✓	✓
Community benefits derived from the Great Barrier Reef Region							
Income	✓	✓				✓	✓
Employment	✓	✓				✓	✓
Understanding and appreciation	✓	✓				✓	✓
Enjoyment						✓	✓
Access to Reef resources						✓	✓
Personal attachment						✓	✓
Social relationships						✓	✓
Health benefits						✓	✓

Appendix D – Threatened species of the Plane basin

Birds

- Black-throated Finch (southern)
  - *Poephila cincta cincta*
- Painted Snipe
  - *Rostratula benghalensis* (sensu lato)
- Red Goshawk
  - *Erythrotriorchis radiatus*
- Squatter Pigeon (southern)
  - *Geophaps scripta scripta*
- White-bellied Storm-Petrel (Tasman Sea), White-bellied Storm-Petrel (Australasian)
  - *Fregetta grallaria grallaria*

Frogs

- Eungella Day Frog
  - *Taudactylus eungellensis*

Mammals

- Greater Large-eared Horseshoe Bat
  - *Rhinolophus philippinensis* (large form)
- Humpback Whale
  - *Megaptera novaeangliae*
- Koala
  - *Phascolarctos cinereus* (combined populations of QLD, NSW and the ACT)
- Northern Quoll
  - *Dasyurus hallucatus*
- Water Mouse, False Water Rat, Yirrkoo
  - *Xeromys myoides*

Other

- Cycad
  - *Cycas megacarpa*
  - *Cycas ophiolitica*

Plants

- Black Ironbox
  - *Eucalyptus raveretiana*
- Siah's Backbone, Sia's Backbone, Isaac Wood
  - *Streblus pendulinus*
- Heath
  - *Leucopogon cuspidatus*
  - *Neisosperma kilneri*
  - *Omphalea celata*

Reptiles

- Flatback Turtle
  - *Natator depressus*
- Green Turtle

Chelonia mydas
Hawksbill Turtle
Eretmochelys imbricata
Leatherback Turtle, Leathery Turtle, Lute Turtle
Dermochelys coriacea
Loggerhead Turtle
Caretta caretta
Olive Ridley Turtle, Pacific Ridley Turtle
Lepidochelys olivacea
Ornamental Snake
Denisonia maculata

Appendix E – Migratory species of the Plane basin

Birds

- Bar-tailed Godwit
  - *Limosa lapponica*
- Black-naped Tern
  - *Sterna sumatrana*
- Bridled Tern
  - *Sterna anaethetus*
- Brown Booby
  - *Sula leucogaster*
- Caspian Tern
  - *Sterna caspia*
- Common Noddy
  - *Anous stolidus*
- Common Sandpiper
  - *Actitis hypoleucos*
- Crested Tern
  - *Sterna bergii*
- Eastern Curlew
  - *Numenius madagascariensis*
- Greater Sand Plover, Large Sand Plover
  - *Charadrius leschenaultii*
- Grey-tailed Tattler
  - *Heteroscelus brevipes*
- Lesser Crested Tern
  - *Sterna bengalensis*
- Lesser Frigatebird, Least Frigatebird
  - *Fregata ariel*
- Lesser Sand Plover, Mongolian Plover
  - *Charadrius mongolus*
- Masked Booby
  - *Sula dactylatra*
- Osprey
  - *Pandion haliaetus*
- Pacific Golden Plover
  - *Pluvialis fulva*
- Roseate Tern
  - *Sterna dougallii*
- Ruddy Turnstone
  - *Arenaria interpres*
- Sanderling
  - *Calidris alba*
- Sharp-tailed Sandpiper
  - *Calidris acuminata*

Silver Gull
Larus novaehollandiae
Wandering Tattler
Heteroscelus incanus
Whimbrel
Numenius phaeopus
White-bellied Sea-Eagle
Haliaeetus leucogaster

Mammals

Dugong
Dugong dugon
Humpback Whale
Megaptera novaeangliae

Reptiles

Flatback Turtle
Natator depressus
Green Turtle
Chelonia mydas
Hawksbill Turtle
Eretmochelys imbricata
Leatherback Turtle, Leathery Turtle, Lute Turtle
Dermochelys coriacea
Loggerhead Turtle
Caretta caretta
Olive Ridley Turtle, Pacific Ridley Turtle
Lepidochelys olivacea
Salt-water Crocodile, Estuarine Crocodile
Crocodylus porosus

Appendix F – Ecological processes

Ecological processes of natural coastal ecosystems linked to the health and resilience of the Great Barrier Reef. Islands have been excluded as they vary considerably between island types.

Process	Ecological Service	Coral Reefs	Lagoon floor	Open water	Seagrass	Coastline	Estuaries	Freshwater wetlands	Forest floodplain	Heath and shrublands	Grass and sedgelands	Woodlands	Forests	Rainforests
	Physical processes- transport and mobilisation													
Recharge/discharge	Detains water						MH	H	✓					
	Flood mitigation						M	✓	H		L			
	Connects ecosystems						✓	H	H					
	Regulates water flow (groundwater, overland flows)	H	L		✓	✓	MH	H	✓		L	MH	MH	H
Sedimentation/ erosion	Traps sediment	M	MH	ML	M		H	H			L	MH	MH	MH
	Stabilises sediment from erosion		✓		M	H	✓	✓	✓	✓	L	MH	MH	M
	Assimilates sediment					✓	✓	H				MH	MH	H
	Is a source of sediment							M				MH	MH	
Deposition and mobilisation processes	Particulate deposition & transport (sed/nutr/chem. etc.)							H						
	Material deposition & transport (debris, DOM, rock etc.)							H						
	Transports material for coastal processes							H						
	Biogeochemical Processes – energy and nutrient dynamics													
Production	Primary production	✓	✓	H	H	✓	H	H				M	M	H
	Secondary production				H	✓	H	✓						
Nutrient cycling (N, P)	Detains water, regulates flow of nutrients							H						
	Source of (N,P)				M	L	H					M	M	H
	Cycles and uptakes nutrients	L	H	H	M	L	H	MH		✓	✓			
	Regulates nutrient supply to the reef				M	L	H	M	H			M	M	H
Carbon cycling	Carbon source				M	L	H	H						H

	Sequesters carbon	✓	H	L	M	L	H	H	✓					
	Cycles carbon	L	H	H	M	L	H					H	H	H
Decomposition	Source of Dissolved Organic Matter						H	H						H
Oxidation-reduction	Biochar source											H	H	
	Oxygenates water		H	H		L	✓							
	Oxygenates sediments		✓		M	L	✓							
Regulation processes	pH regulation				M			H						
	PASS management						H	H						
	Salinity regulation													
	Hardness regulation							H						
	Regulates temperature					✓	✓	✓	✓					ML
Chemicals/heavy metal modification	Biogeochemically modifies chemicals/heavy metals	L			M		✓	H						
	Flocculates heavy metals						✓	H						
Biological processes (processes that maintain animal/plant populations)														
Survival/reproduction	Habitat/refugia for aquatic species with reef connections	H	M	L	✓	H	H	H		✓				
	Habitat for terrestrial species with connections to the reef	H						H						
	Food source		✓		H	✓	✓	✓		H				
	Habitat for ecologically important animals	H	✓		H	L	H			✓	✓			
Dispersal/ migration/ regeneration	Replenishment of ecosystems – colonisation (source/sink)	H			H	M	H	H						
	Pathway for migratory fish							H						
Pollination														
Recruitment	Habitat contributes significantly to recruitment	H			H	H	H	H		H				

Capacity of natural coastal ecosystems to provide ecological functions for the Great Barrier Reef[84]

H – high capacity for this system to provide this service, M – medium capacity for this system to provide this service, L – low capacity for this system to provide this service, N – no capacity for this system to provide this service, X – not applicable, ✓– service is provided but capacity unknown. Boxes with no data indicate a lack of information available. Note that the capacity shown for modified systems assumes periods of low hydrological flow.

Ecological processes of modified systems linked to the health and resilience of the Great Barrier Reef. Islands have been excluded as they vary considerably between island types.

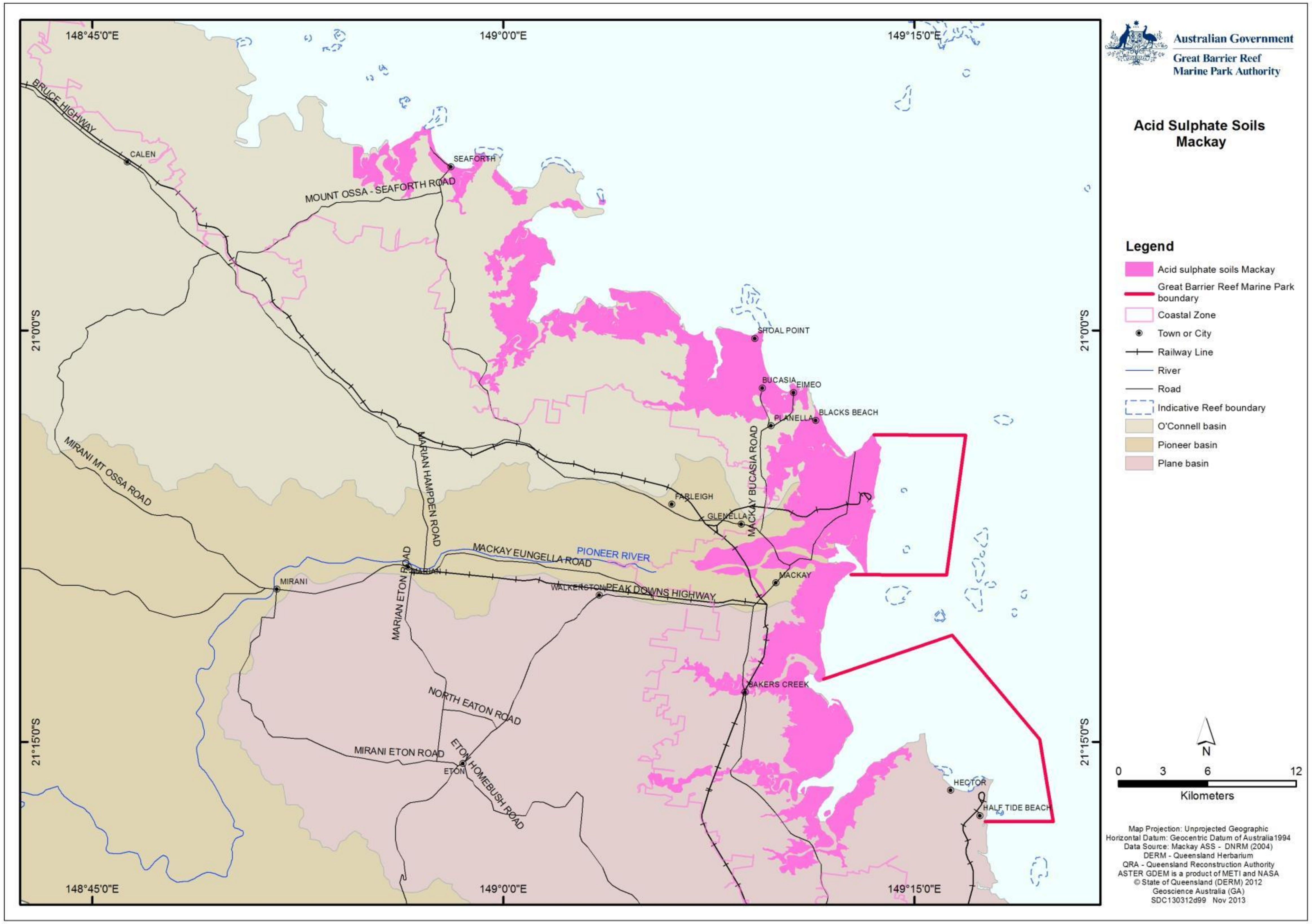
Process	Ecological Service	Groundwater Ecosystems	Irrigated agriculture	Non-irrigated agriculture	Dams & Weirs	Urban	Mining – operational open cut	Forestry Plantation	Extensive agriculture	Ponded pastures
	Physical processes- transport & mobilisation									
Recharge/Discharge	Detains water	✓[1]	M			L	M		H	
	Flood mitigation	✓	N			L	X		X	
	Connects ecosystems	H	L			L	N		L	
	Regulates water flow (groundwater, overland flows)	H	M			L	L		M	
Sedimentation/ erosion	Traps sediment	N	M[4]			L	M		H	
	Stabilises sediment from erosion	✓	M[4]			H	N		H	
	Assimilates sediment		M			L	N		H	
	Is a source of sediment		L			L[11]	M		L	
Deposition & mobilisation processes	Particulate deposition & transport (sed/nutr/chem. etc.)	✓[2]	L			L	L		H	
	Material deposition & transport (debris, DOM, rock etc.)		L			L	L		L	
	Transports material for coastal processes		N			M	L			
	Biogeochemical Processes – energy & nutrient dynamics									
Production	Primary production	N							M	
	Secondary production	✓[3]							H	
Nutrient cycling (N, P)	Detains water, regulates flow of nutrients	✓							M[13]	
	Source of (N,P)	✓							M	
	Cycles and uptakes nutrients	✓							H	
	Regulates nutrient supply to the reef	✓							H	
Carbon cycling	Carbon source	✓							M	
	Sequesters carbon	✓							MH	
	Cycles carbon	✓							H	
Decomposition	Source of Dissolved Organic Matter	✓							L[14]	

Oxidation-reduction	Biochar source								X	
	Oxygenates water	N							L	
	Oxygenates sediments	N							✓$_{15}$	
Regulation processes	pH regulation	✓							✓$_{15}$	
	PASS management								L	
	Salinity regulation								✓$_{15}$	
	Hardness regulation								✓$_{15}$	
	Regulates temperature								L$_{16}$	
Chemicals/heavy metal modification	Biogeochemically modifies chemicals/heavy metals	✓							X$_{17}$	
	Flocculates heavy metals	✓							L	
	Biological processes (processes that maintain animal/plant populations)									
Survival/reproduction	Habitat/refugia for aquatic species with reef connections	N	L$_{5}$	L$_{5}$	L$_{8}$	L$_{12}$	N	N	L	M$_{18}$
	Habitat for terrestrial species with connections to the reef	N	L	L	H$_{9}$	L	N	N	L	L$_{19}$
	Food source	N	N	N	M	L	N	L	M	L
	Habitat for ecologically important animals		N	N	L$_{10}$	N	N	N	M	L$_{19}$
Dispersal/ migration/ regeneration	Replenishment of ecosystems – colonisation (source/sink)	N	N	N	L	N	N	N	M	L$_{20}$
	Pathway for migratory fish	-	N$_{6}$	N$_{6}$	L$_{8}$	N	N	N	✓$_{15}$	L$_{21}$
Pollination		-	L$_{7}$	L$_{7}$	N		N			
Recruitment	Habitat contributes significantly to recruitment		N	N	L	N	N	N	M	N

Capacity of natural coastal ecosystems to provide ecological functions for the Great Barrier Reef[84]

H – high capacity for this system to provide this service, M – medium capacity for this system to provide this service, L – low capacity for this system to provide this service, N – no capacity for this system to provide this service, X – not applicable, ✓– service is provided but capacity unknown. Boxes with no data indicate a lack of information available. Note that the capacity shown for modified systems assumes periods of low hydrological flow. End-notes 1 – capacity depends on hydraulic characteristics of the aquifer (porosity, permeability); 2 - particulate transport occurs sometimes in subterranean systems; 3 - secondary production is variable; 4 - dependent upon crop cycle; 5 - habitat for crocodiles and turtles; 6 - especially in channels, but is dependent on water quality; 7 - depends upon crop; 8 - only where fish passage mechanisms exist; 9 - especially water & shorebirds; 10 - particularly aquatic species (though may lack connectivity); 11 - refers to new developments; 12 - impoundments, ornamental lakes and stormwater channels; 13 - hoof compaction of soil increases run-off; 14 - particulate organic carbon is high, dissolved is low; 15 - unchanged from natural ecosystem capacity; 16 - relates more to extent of vegetation clearance of riparian zone; 17 - contaminant; 18 – in the dry season amongst Hymenachne; 19 - particularly for birds; 20 - sink biologically as species move into areas but reduced water quality can affect badly; 21 - subject to water quality and grazing regime.

Appendix G – Location of acid sulphate soils in the Mackay district[85]



Appendix H – Water quality report for the Plane basin

Summary
The Plane Creek basin has undergone large hydrological modifications as a result of the construction of dams and weirs, which have restricted fish community movement and resulted in increased entrapments. The coastal region of the Plane Creek basin is dominated by sugarcane cultivation, which has been linked as the main source or sediment and nutrient loads in some waterways. Sandy and Bakers creeks are highly polluted waterways within this basin as a result of tailwater from irrigated croplands being drained into these creeks. Sandy Creek was rated as having the worst water quality out of 18 monitored waterways throughout Queensland. Turbidity levels and nutrient levels in Sandy Creek are frequently above guideline levels. With regards to freshwater conditions, Bakers and Plane creeks were rated as the worst out of 9 waterways, while Sandy Creek was rated the worst for wetland conditions compared to 8 other waterways. Riparian vegetation and wetland area has decreased within the Plane Creek basin. Only 8% of riparian vegetation in Plane Creek was rated in good condition, while only 6% of Carmila Creek riparian vegetation was rated in good condition. The most commonly detected pesticides in the region are ametryn, atrazine, hexazinone and diuron. For example, extremely high values of atrazine and diuron (both 14 μg/L) have been measured in Bakers Creek after high rainfall. High atrazine (170 ng L^{-1}), diuron (5.8 – 70 ng L^{-1}) and hexazinone (20 ng L^{-1}) levels have been found at Sarina Inlet, however none were above water quality trigger values estimated for the Marine Park by the Great Barrier Reef Marine Park Authority. Overall, coral reef ecosystem health has declined as a result of reduced water quality in this region; coral reefs have been in decline since 2007 and seagrasses are showing low resilience to disturbances.

1. Introduction
The Plane basin is situated within the Mackay Whitsunday region and contains 14 large streams that flow directly into the Great Barrier Reef lagoon between Mackay and Clairview.[1] These streams include Bakers Creek, Sandy Creek, Alligator Creek, Plane Creek, Rocky Dam Creek, Marion Creek, Basin Creek, West Hill Creek, Spider Creek, Carmila Creek and Flaggy Rock Creek. The main wet season occurs between December and April. The annual rainfall ranges north to south along the catchment, with higher rainfall in the upper catchment (max. 3000 mm) compared to the middle and lower (1200-2500 mm) regions.[1]

The coastal region of the basin is dominated by sugarcane cultivation, with some beef grazing and plantation forestry.[1] The area of sugarcane cultivation in the Plane Creek Catchment covers 20% and the region has the third highest rate of fertiliser application of all GBR catchments.[2]

Point sources of pollution within the Plane basin include the town of Sarina (5,730 population), which is situated on the banks of Plane Creek and contains a sewage treatment plant, alcohol distillery and sugar mill. Bakers Creek (770 population) contains an abattoir, a recycled water treatment plant and metal works. Aquaculture facilities can be found throughout the basin such as the prawn farm at Notch Point. Industrial sources of potential pollution include Hay Point and Dalrymple Bay coal loading facilities and the associated vessels. Additionally, small settlements are found scattered along the coast. Inefficient management of the above mentioned facilities could have serious detrimental impacts on the various creeks and coastal habitats within the region.

2. Hydrology and drainage

Plane, Sandy and Bakers creeks have undergone large hydrological modifications. The natural flow of Sandy and Bakers creeks has been largely impacted from modifications in Pioneer River to the north. Pioneer River contains two major water storages (Kinchant Dam and Teemburra Dam) and three weirs (Mirani, Marian and Dumbleton). The water stored in these dams and weirs is predominantly used for irrigation of sugarcane and drinking water supply to a lesser extent.[1] Water is diverted from Mirani Weir into Kinchant Dam (storage volume 62,800 ML) where it is retained.[1] Kinchant Dam (situated in the Sandy Creek catchment) releases water for irrigation, after which tailwater eventually enters into the lower course of Sandy and Bakers creeks, creating an artificial flow.

Within the 35 km length of Plane Creek there is one dam (Middle Creek Dam) and four weirs (Jackson's Weir, Council Dam, Mill Dam and CSR Dam), which highly regulate the flow of the creek.[3] Middle Creek Dam is a small drinking supply dam (1,365 ML).[1]

The Mackay coastal plain aquifer provides a major water resource for sugarcane irrigation, the sugar milling industry, stockpile, urban water supply and rural and residential water supplies.[4] Due to over-pumping of groundwater, salt water intrusion has been an issue in the Mackay coastal plains aquifer since the 1970s and the problem worsened significantly during the period of drought between 1992 and 1996.[4] A study conducted by Murphy and Sorensen (2001) monitored 18 sites around Bakers and Sandy creeks for specific water quality and water level measurements. Monitoring was conducted bi-monthly over an 18 month period in conjunction with a limited groundwater age dating program.[4] The results showed that saltwater intrusion has significantly increased since 1994 in areas that were previously thought to not be impacted. The solution to the saltwater intrusion problem was to build Temper Dam, Kinchant Dam and weirs along waterways, which is referred to as the Eton Irrigation Scheme. These dams resulted in a switch from groundwater use to dam water use (J. Brodie (TropWater) 2013, pers. comm.).

3. Basin water quality

a) Water quality

1) Status of monitoring in basin and rivers

Far more water quality research has been conducted in the northern section of this basin in comparison to the southern areas. The Mackay Whitsunday Healthy Waterways Baseline Monitoring Program is coordinated between local, regional and state Natural Resource Management groups and is divided into 3 individual catchment groups that make up the region. Each catchment group is responsible for the on-ground implementation of the project and monitoring within their region. The Sarina catchment is the most relevant of the 3 groups because it includes the majority of the Plane Creek basin, with the exception of Bakers and Sandy creeks, which are in the Pioneer Catchment area.

Data from the lower and estuarine reaches of rivers and streams within the Mackay Whitsunday region was collected by the Environmental Protection Agency (EPA) for many years and has been summarized and assessed at various stages by the Department of

Environment and Resources Management (DERM). The DERM have collected samples from both gauged and un-gauged stations in rivers and freshwater sections of the Mackay Whitsunday region for over 30 years.[1] Parameters measured have included major ions (chloride, sulphate, carbonate, sodium, potassium, magnesium and calcium), pH and turbidity, and nutrient analyses.[1] A comprehensive set of data was collected from Bakers Creek over a 25 year period, however due to the reliability of early data, a trend analysis is only possible for 1994.[1] Trend analyses for ammonia and chlorophyll *a* were conducted at one site in Bakers Creek that showed no statistically significant differences in long-term trends from 1994-1999 for any parameter; however there were highly significant seasonal fluctuations.[5] Data on physical parameters and suspended solids were collected from 2000-2001 at Bakers Creek by the Pioneer Valley Waterboard, which is publically available.[1] Data is still collected by SunWater (carried out by Reef Catchments) in Sandy and Bakers creeks as part of the water resource operations of The Eton Irrigation Area and can be accessed with permission.

2) Water quality data

A list of high profile water quality issues in the Mackay Whitsunday region was created that is discussed in a report written by Brodie et al. (2003).[1] These issues included:

- A number of fish kills in various waterways including Alligator Creek.
- Blue-green algae (cyanobacteria) blooms in Kinchant Dam.
- Reviews suggesting a high rate of chemical use (particularly herbicides) in the region.
- Water quality assessments in which Sandy Creek and Plane Creek were suggested to have the poorest water quality of 18 catchments analysed.
- International scientific journal publications linking declining coral reef health in the Whitsundays to river pollutant discharge.
- Sewage treatment effluent discharge exceeding Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (ANZECC & ARMCANZ 2000) guidelines for total nitrogen (N), total phosphorus (P), ammonia and dissolved phosphorus.

Water quality within Sandy Creek was assessed as part of larger project that monitored catchments containing sugarcane from 1995-2000.[6] Over the five year monitoring period, Sandy Creek was found to have turbidity levels above drinking water guidelines (1 NTU) and generally below the aquatic ecology guideline (50 NTU). Dissolved oxygen levels were highly variable, with values frequently falling below guidelines for both drinking water (6.5 mg/L) and aquatic ecology (6 mg/L). The data record showed that conductivity and pH measurements were below or within the recommended guidelines. High nutrient levels were measured at this site, with nitrate, total nitrogen and total phosphorus frequently exceeding the aquatic ecology guidelines over the five-year reporting period. Sandy Creek was rated as the worst of 18 monitored cane growing catchment sites within Queensland.[7] Sugarcane farming has been linked as the main activity contributing to sediment and nutrient loads in this catchment.[8] According to Rayment (2002) and Bramley and Roth (2002), sugarcane lands generally make disproportionate contributions to in-stream loadings of labile forms of carbon, total suspended solids and nutrients on a unit area basis. In many catchment areas sugarcane production is restricted; meaning the industry's contribution to water quality issues is limited.[9,10] However, the Sandy Creek catchment is dominated by sugarcane production, suggesting that the sugarcane industry needs to be involved in mitigation initiatives.[8] Due to the high levels of contamination found in Sandy Creek, this waterway is a major focus of the Paddock to Reef Monitoring initiative.

Estuaries around Australia were categorized by geomorphologic classification and their condition was assessed with respect to human influence as part of the National Land and Water Resources Audit.[7] The status statements for estuaries within the Plane basin are summarized in Table 1.

Table 1: Estuary status from the Ozestuaries database

Stream	Estuary Status
Bakers	Modified
Sandy	Largely unmodified
Plane	No entry

The Mackay Whitsunday Water Quality Improvement Plan (WQIP) aims to provide water quality that is suitable for human uses and aquatic ecosystem protection.[11] The ecological health of waterways, estuaries and the Great Barrier Reef within the Mackay Whitsunday region are priority areas within the plan. Ecosystem health objectives and targets were developed for both riverine and estuarine ecosystems as well as indices of relative ecological condition for freshwater management areas and estuaries using ecosystem health indicators. Specific water quality values were rated A-E (A = excellent, E = poor) and the conditions from 2008 are presented in Table 2 and Table 3. Bakers and Plane creeks were rated the worst out of the 9 waterways with regards to their freshwater conditions, with poor ratings for four out of six water quality parameters. Sandy Creek was rated the third worst for freshwater conditions. With regards to estuarine conditions, Sandy Creek was rated the worst followed by Plane and Bakers creeks. Water quality was rated as poor in Rocky Dam Creek and Flaggy Rock Creek, while mangroves and saltmarshes were in poor condition in Carmila Creek as well as Sandy and Alligator creeks. The WQIP is mainly pollution based and contrasts with Ozestuaries, which looks at whether the estuary has been "modified" in terms of its geomorphology.

Table 2: Ratings of the current freshwater conditions of various water quality parameters within waterways of the Plane Creek basin. (A = excellent, E = poor) Source: [11]

Waterway	Fish Community	Water Quality	Flow	Barriers to Migration	In stream Habitat	Riparian Vegetation
Bakers Creek	E	E	E	D	D	E
Sandy Creek	E	E	D	D	D	E
Alligator Creek	E	E	B	C	C	B
Plane Creek	D	D	E	E	E	E
Rocky Dam Creek	D	D	C	C	C	B

Marion Creek	C	C	B	C	C	C
West Hill Creek	C	B	A	B	C	D
Carmila Creek	C	C	C	B	D	B
Flaggy Rock Creek	B	C	A	D	C	C

Table 3: Ratings of the current estuarine conditions of various water quality parameters within waterways of the Plane Basin. (A = excellent, E = poor) Source:[11]

Waterway	Fish Community	Water Quality	Flow	Estuary Modification	Mangroves and Saltmarsh
Bakers Creek	B	D	D	B	D
Sandy Creek	D	E	D	B	E
Alligator Creek	D	E	B	B	E
Plane Creek	D	C	D	C	D
Rocky Dam Creek	B	E	C	B	C
Marion Creek	D	D	C	B	B
West Hill Creek	C	D	A	B	B
Carmila Creek	C	B	C	B	E
Flaggy Rock Creek	C	E	B	B	A

Table 4: Current condition report of ambient and event freshwater values for Rocky Dam Creek. Abbreviations: CC = current condition; LOD = is limit of detection which is currently 0.01 µg/L for all herbicides; G = grazing and forestry; C = crop land, I = intensive uses; U = urban. Source:[11]

	Ambient Freshwater Quality Values				Event Freshwater Quality Values				
Key Pollutant	Objective 2050	Current Condition 2007	Target 2014	Action	Objective 2050	Current Condition 2007	Target 2014	Action	Pollutant Source
Dissolved Inorganic Nitrogen µg/L	CC	10	CC	L	300	613	422	H	C, I, U
Particulate Nitrogen µg/L	CC	142	CC	L	340	346	295	M	C, I, U, G
Filterable Reactive Phosphorus µg/L	CC	6	CC	L	30	48	33	M	C, I, U
Particulate	20	22	20	M	70	84	72	M	C, I, U, G

Phosphorus µg/L									
Total Suspended Solids mg/L	CC	4	CC	L	CC	120	CC	L	C, I, U, G
Ametryn µg/L	CC	0.02	CC	L	0.04	0.06	0.04	M	C, I, U
Atrazine µg/L	CC	< LOD	CC	L	0.27	0.37	0.27	M	C, I, U
Diuron µg/L	CC	0.07	CC	L	0.75	1.56	0.75	M	C, I, U
Hexazinone µg/L	CC	0.13	CC	L	0.55	0.74	0.55	M	C, I, U
Tebuthiuron µg/L	CC	< LOD	CC	L	CC	<LOD	CC	L	G
Dissolved Oxygen % saturation	CC	65-77	CC	L					
pH	CC	7.6-7.9	CC	L					
Electrical Conductivity µS/cm	CC	697	CC	L					

The Mackay Whitsunday Healthy Waterways Baseline Monitoring took place at 13 sites throughout the Mackay Whitsunday region in areas where the dominant land uses consisted of bushland, grazing, and intensive cropping (Bakers Creek and Sandy Creek) as well as mixed grazing/intensive cropping (Plane Creek and Carmila Creek), and intensive cropping/grazing (Rocky Dam Creek). Indicators sampled included water temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), total suspended solids (TSS), nitrogen species, phosphorus species and herbicides.[12]

According to Galea et al. (2008), dissolved oxygen (DO) values showed high variability between individual sites and land uses.[12] Within the Whitsunday region Bakers Creek is one of the most intensively cropped (61% cane) catchments. During monitoring Bakers Creek exhibited the lowest minimum (1.2% saturation), lowest median (19.25% saturation) and lowest maximum (52.7% saturation) dissolved oxygen values, indicating that Bakers Creek would not be able to support higher order aquatic taxa such as fish populations and would exhibit a very poor species diversity. Neither Bakers Creek nor Sandy Creek reached the minimum central Queensland water quality guideline value of 80% saturation.

The baseline monitoring also showed pH levels from all land use categories were within the Central Queensland water quality range (6.5-8.0) on 50% of occasions, with the majority falling within the guideline range on 80% of occasions.[12] Bakers Creek was also found to be slightly acidic, which was attributed to dissolving organic matter, presence of nutrients and carbon, seasonal variation, and melaleuca trees that dominate the riparian zone may have also enhanced the acidic influence in the creek. Electrical conductivity was highly variable between individual sites and land uses. Bushland sites exhibited the lowest median values, while intensive cropping sites exhibited the highest median values. TSS concentrations were consistently low (collective median = 4.8 mg/L), although the maximum TSS concentrations were higher than guidelines values. Maximum concentrations were related to either periods of high rainfall or excessively dry periods.

Nutrient concentrations were highest in intensively cropped sites particularly after periods of high rainfall.[12] Sandy Creek and Bakers Creek (intensively cropped) exhibited the highest median and maximum concentrations for most nitrogen and phosphorus species. For example, the maximum total nitrogen (TN) concentrations at Sandy (709 µg N/L) and especially Bakers (1996 µg N/L) creeks were above the central Queensland water quality guideline (500 µg N/L). It was suggested these high TN values could be proportional to the amount of sugarcane within the catchment the stream lays within (Sandy Creek = 51% sugarcane, Bakers Creek = 61% sugarcane).

A week prior to baseline sampling that took place on December 13th, 2006, a substantial amount (70mm) of rain fell.[12] An extremely high TN concentration (6091 µg N/L) was measured at Bakers Creek, which was approximately three times higher than the median. The creek was flowing moderately since the heavy rain fell the week prior to sampling. One month after the high TN value was measured an extremely low dissolved oxygen level (1.2% saturation) was recorded, which was attributed to an algal bloom resulting from the extremely high TN concentrations. The high TN concentrations are likely a result of the long-term application of N-based fertilisers in intensively cropped catchments. Bakers Creek exhibited a median value (665 µg N/L) of nitrate that was approximately 6-fold greater than the next highest value measured at Sandy Creek (125.5 µg N/L) and also an extremely high maximum concentration (3013 µg N/L). The intensive cropping median value (305 µg N/L) was still below the central Queensland water quality guideline. Consistently high total phosphorus (TP) levels were measured at intensively cropped sites. Sandy Creek ranged between 45-439 µg P/L and Bakers Creek ranged from 54-910 µg P/L. The median values at Sandy and Bakers creeks were 119 µg P/L and 138 µg P/L, respectively which is more than double the guideline value of 50 µg P/L. These results indicate that P-based fertilisers are widely used throughout the Mackay Whitsunday region and that the P source available for transportation to the waterway from intensively cropped areas can be reduced with better nutrient management practices. However, there will likely be a lag time from when management practices are implemented to a marked improvement of water quality.

The median filterable reactive phosphorus (FRP) for intensively cropped sites was 47 µg P/L, which is above the central Queensland water quality guideline (20 µg P/L). FRP is the most readily available form of phosphorus used by aquatic plants and makes up a large portion of the P signature, indicating that land management is necessary for the reduction of P to neighboring waterways. High levels of phosphorus can have devastating impacts on aquatic life forms as eutrophication can cause toxic algal blooms, resulting in lowered dissolved oxygen concentrations.[7]

Areas of intensive cropping land use within the Mackay Whitsunday region exhibited the highest median (142.5 µg N/L) of particulate nitrogen (PN) compared to grazing, grazing/intensive cropping, intensive cropping/grazing and bushland.[12] Bakers Creek exhibited the highest median value (245 µg N/L) of PN, with Sandy Creek displaying lower but still high median concentrations (110 µg N/L). Herbicide concentrations were also highest in intensively cropped sites and highest values were often measured after heavy rainfall. The most commonly detected chemicals were ametryn, atrazine, hexazinone and diuron and Bakers Creek water contained extremely high values of atrazine and diuron (both 14 µg/L) after rainfall.

b) Ecological effects of water quality and hydrological changes in basin

Fish communities inhabiting the rivers and creeks of the Plane basin are being negatively impacted by water quality and hydrological changes. Constructed ponded pastures for cattle grazing have caused disturbances to coastal wetland vegetation in addition to hydrology and salinity regimes.[13] The location of pondage banks on or adjacent to barramundi nurseries will likely result in the restriction of barramundi movement and increase the risk of entrapment under specific flow regimes.[14] An additional stress to fish is increased coastal erosion from sugarcane production on floodplains situated along the coast, which is especially high during periods of high rainfall (DPI 1993).[15] Erosion can result in the siltation of waterways and estuaries, altering water flow and environmental characteristics for fish communities and habitats.[13]

Wetlands are ecologically important ecosystems as they perform a number of functions such as nutrient removal and transformation, sediment/toxicant retention, shoreline stabilization, flood flow alteration, groundwater recharge, groundwater discharge, production export, wildlife diversity and abundance etc.[16] Both riparian vegetation and wetlands have been reduced in the Mackay Whitsunday region and the efficiency of these systems to perform the above mentioned functions has thus declined.[1] Surveys of vegetation have been carried out in a number of catchments in the area surrounding the Sarina basin including Carmila Creek[17], Rocky Dam Creek[18] and Plane Creek.[3] From the 18 sites surveyed on Carmila Creek, riparian vegetation was classified as Good - 6%, moderate - 83% and poor - 11%. From the 19 surveyed sites at Rocky Dam Creek vegetation was classified as Good - 47%, moderate - 37 %, poor - 16%. Indicators of riparian vegetation as well as weeds and exotics on Plane Creek were rated as Good - 8%, moderate - 39%, fair - 45% and poor - 8%.

4. Coastal water quality

a) Water quality

1) Status of monitoring in coastal areas

Various regions of the Plane basin are monitored by the Reef Rescue Marine Monitoring Program. Herbicide concentrations[19] and seagrass cover[20] have been measured from the Sarina Inlet.

2) Water quality data

Discharge from waterways into coastal waters is highly variable between and within years and is dominated by large flood events associated with tropical cyclones and monsoonal rainfall.[21,22] Predominant south-east wind regimes create an overall northward movement of water near the coast.[1] Within the Mackay Whitsunday region large tides (approximately 5 m) promote strong mixing of water within the Great Barrier Reef lagoon and thus turbid conditions within shallow waters, especially between Mackay and Shoalwater (within the Plane River basin). Inner shelf reef development is very limited south east of Mackay due to turbid conditions that negatively impact reef formation.[23]

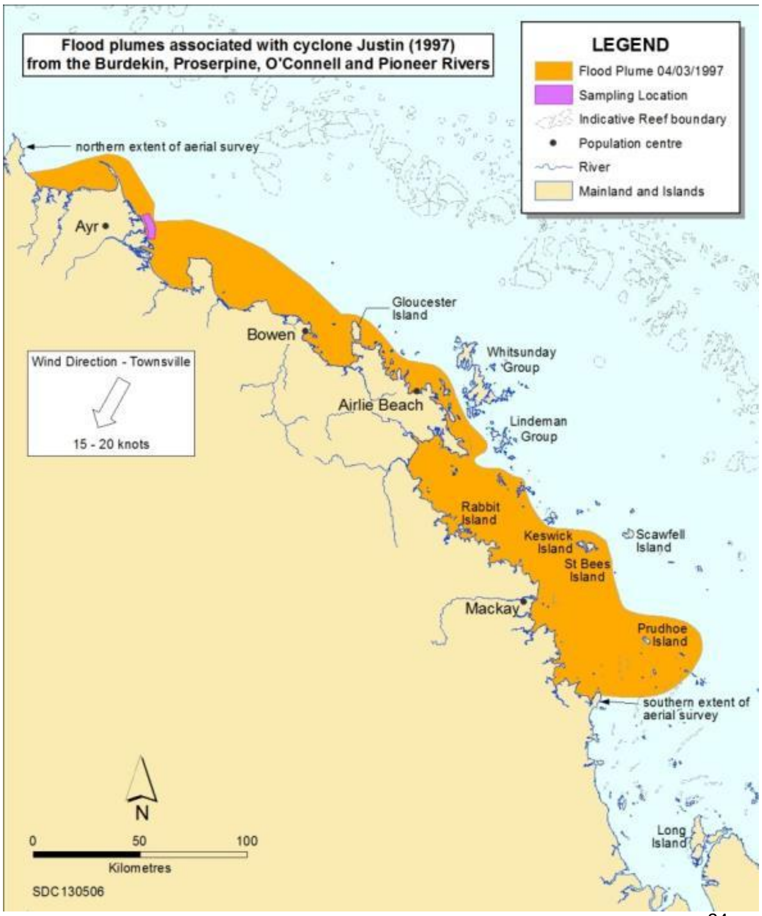


Figure 1: Flood plumes from Mackay rivers during cyclone Justin, 1997[24]

During Cyclone Justin (1997) flood plumes were monitored from the Wet Tropics and Burdekin regions. Due to north- easterly winds during the first part of the cyclone, the plume from the Burdekin River moved in a south-east direction and covered a number of inshore Whitsunday reefs.[24] The plume associated with Cyclone Justin and the Mackay Whitsunday region rivers was mapped (Fig. 1). Winds from the north pushed the flood plumes offshore (south-east) to the inner shelf reefs around the Smith Group, Keswick and St Bees Islands, Northumberland Group and Prudhoe Island, however no sampling was undertaken in plume waters from the Mackay Whitsunday rivers at this point in time.[1]

During the 2010 wet season coastal and inshore areas were monitored within the Mackay Whitsunday region. Although all of the sampling sites monitored were north of Mackay, MODIS AQUA images of Mackay Whitsunday river plumes were taken and maps were created that showed the extent of total suspended solids (TSS), chlorophyll a and the probability that the values of these parameters would exceed water quality guidelines. The maps depict areas within the Plane basin and are provided in Figures 2a-d.[25]

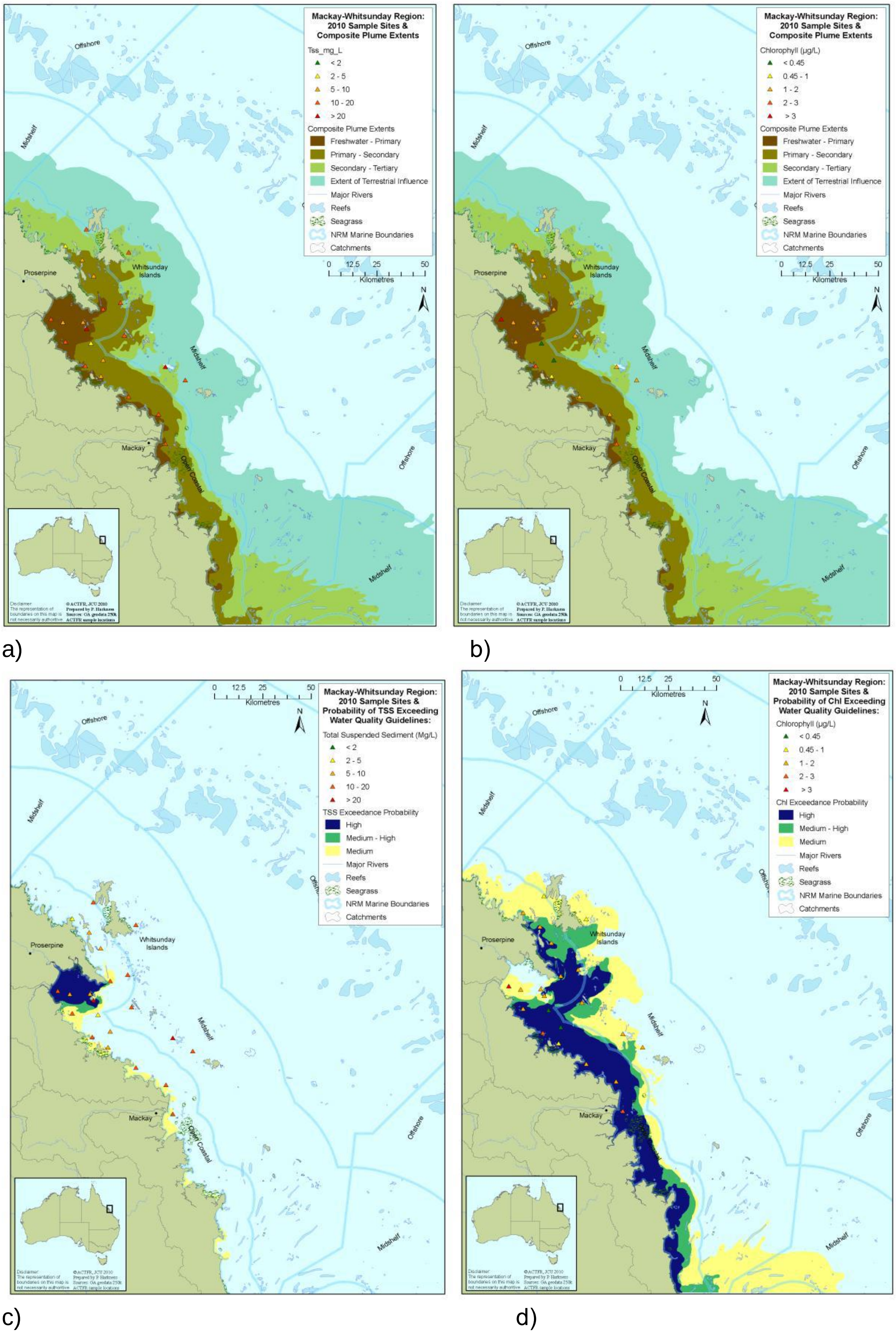


Figure 2: Spatial extent of a) total suspended solids (TSS), b) chlorophyll *a* and the probability of c) TSS and d) chlorophyll a exceeding water quality guideline values within the Mackay Whitsunday region flood plume associated with the 2009/2010 wet season[25]

It should be noted that during extreme weather conditions such as cyclones, water quality in the Mackay Whitsunday region is influenced by flood plumes originating from the Fitzroy River, which is 350 km southeast of the Mackay Whitsunday area.[26]

The spatial distribution of various water quality variables were predicted and mapped across 6 regions and 3 cross-shelf (coastal, inner shelf and outer shelf) positions in the Great Barrier Reef using measurements from 1985-2006.[27] The values predicted for the Mackay Whitsunday region are provided in Table 4. All variables generally decreased with increased distance from the coast with the exception of Secchi depth, which increased at more offshore sites. Compared to the other 5 analysed regions (Cape York, Burdekin, Wet Tropics, Fitzroy, Burnett Mary), the Mackay Whitsundays coastal area contained the second lowest Secchi depth and chlorophyll *a* values. All other variables were generally in the middle of high-low variable rankings between regions.

Table 4: Mean annual values of water quality variables predicted in 3 cross-shelf regions of the Mackay Whitsunday region

Variable	Coastal	Inner Shelf	Outer Shelf	Across all zones
Secchi depth (m)	4.4 ± 0.8	8.7 ± 0.7	17.0 ± 0.9	13.2 ± 0.8
Chl a (µg L^{-1})	0.6 ± 0.06	0.5 ± 0.05	0.5 ± 0.05	0.5 ± 0.05
SS (mg L^{-1})	3.1 ± 0.3	1.8 ± 0.2	0.8 ± 0.1	1.4 ± 0.2
PN (µmol L^{-1})	1.7 ± 0.1	1.6 ± 0.1	1.2 ± 0.1	1.4 ± 0.1
PP (µmol L^{-1})	0.11 ± 0.01	0.07 ± 0.01	0.06 ± 0.01	0.07 ± 0.01
TDN (µmol L^{-1})	5.8 ± 0.3	5.7 ± 0.3	5.1 ± 0.3	5.4 ± 0.3
TDP (µmol L^{-1})	0.36 ± 0.04	0.33 ± 0.04	0.20 ± 0.03	0.26 ± 0.03
TN (µmol L^{-1})	7.3 ± 0.4	7.4 ± 0.4	7.4 ± 0.5	7.4 ± 0.5
TP (µmol L^{-1})	0.48 ± 0.06	0.42 ± 0.05	0.37 ± 0.06	0.40 ± 0.06

The current best estimates of modelled loads leaving the Plane basin are provided in Table 5. Pre-development loads were substantially lower than current values for all parameters measured. DOP levels have increased the least (15 t/yr) over time, while PSII herbicides (846 kg/yr) and total nitrogen (571 t/yr) have increased the most. After the implementation of the Reef Rescue program in 2008, an improvement in load values was observed for TSS, DIN, PN, TN, PSII herbicides, PP and TP. For example, modelled particulate nitrogen (PN) export values from the Plane Creek basin (Table 5) showed that the total export in 2008/2009 (120 t/yr) had increased compared to pre-development loads (99 t/yr). However, after the implementation of the Reef Rescue program (2009/2010) values decreased to 115 t/yr, which is a 23.2% improvement. Improvements for DON, DIP and DOP loads have not yet been measured.

Table 5: Best estimates of modelled total pre-development values, current values and anthropogenic changes in water quality parameters for Plane basin. Reef Rescue values represent the values after the commencement of the Reef Rescue Program and Reef Rescue change represents the improvement (%) after implementation. Source:[28]

	Pre-development	Current (2008/2009)	Current (2009/2010)	Anthropogenic Increase	Reef Rescue (2009/2010)	Reef Rescue change (%)	Total change (%)
TSS (kt/yr)	34	92	87	58	87	8.3	8.4
DIN (t/yr)	88	309	290	221	290	8.6	8.6
DON	109	438	438	330	438	0	0

(kt/yr)							
PN (t/yr)	99	120	115	20	115	23.2	23.4
TN (t/yr)	296	867	843	571	843	4.2	4.2
PSII (kg/yr)	0	846	725	846	725	14.3	14.3
DIP (t/yr)	18	77	77	59	77	0	0
DOP (t/yr)	5	20	20	15	20	0	0
PP (t/yr)	30	48	46	18	46	11.6	11.9
TP (t/yr)	53	145	143	92	143	2.3	2.3

Routine monitoring conducted as part of the Marine Monitoring Program (MMP) measured herbicide concentrations at 14 different sites using passive sampler techniques.[19] Within the Whitsunday region monitored areas included the Sarina Inlet, which is situated in the Plane basin, as well as Pioneer Bay, Daydream Island and the outer Whitsundays. The highest concentration of atrazine was observed at Sarina Inlet (170 ng L^{-1}), with the second highest observation at Cape Cleveland (20 ng L^{-1}). Highest average and maximum concentrations detected of diuron were measured in the Mackay Whitsunday region (5.8 ngL^{-1} – 70 ng L^{-1}), with the highest values measured at Sarina Inlet. The Mackay Whitsunday sites also had the highest average and maximum concentrations of hexazinone, which ranged in average concentration from 3.6 ng L^{-1} in the outer Whitsunday site to 20 ng L^{-1} at the near-shore Sarina Inlet site. Simazine was not detected in the Mackay Whitsunday region. No monitored herbicide concentrations measured above Water Quality Guideline Trigger values estimated for the Marine Park by GBRMPA.[29] The detection frequency of hexazinone was approximately 58%, diuron was 100%, atrazine 60% and desethyl-atrazine and Tebuthiuron was 30%. These photosystem II herbicides have the potential to cause photosynthetic inhibition of diatoms, seagrass and coral symbionts.[19]

b) Ecological effects of water quality and hydrological changes in coastal areas

The majority of environmental monitoring of coastal ecosystems such as benthic communities (e.g. coral reefs and seagrasses) has been conducted north of the Plane basin in Mackay and the Whitsunday area.[2] However, there are a few Dugong Protection Areas (DPA) within the Plane basin such as Llewellyn Bay, Ince Bay and the Clairview region. Llewellyn and Ince Bays are potentially influenced by Plane Creek, which enters the sea at Sarina Inlet just north of Llewellyn Bay. The Styx and Fitzroy rivers located to the south of Clairview (both outside of the Plane Creek basin) influence all DPAs in the Plane basin region. Another important local waterway is Carmila Creek, which drains into the Clairview DPA. A risk assessment of impacts influencing DPAs was created and is summarized for the Plane Creek area in Table 6. The risk analysis of Plane Creek DPAs (Llewellyn and Ince Bay) shows that Plane Creek is an area requiring special management focus. Measures to reduce pollutant loads are critical to maintaining and preserving water quality health in the Great Barrier Reef.[2]

Table 6: Risk assessment of impacts by catchment activities on water and habitat quality in Dugong Protection Areas (DPAs) in the Great Barrier Reef World Heritage Area. Table modified from Schaffelke 2001[2]

DPA	Adjacent Catchments	Significant Local Watercourse	Development Close to DPA	Fertiliser use	Pesticide use	Sediment export	Summary risk rating
Llewellyn Bay	Plane Creek	N/A	Hay Point Port	High/mod	High	High	High
Ince Bay	Plane Creek	N/A	Hay Point Port	High/mod	High	High	High
Clairview	Styx River	Carmila Creek		Low	Low	High	Moderate

Seagrass in the Plane Creek basin is monitored in the Sarina Inlet. Coastal and estuarine seagrass abundance has varied over time in the Mackay Whitsunday region; however reef sites have been declining since 2007. It has also been found that estuarine meadows exhibit a low ability to recover from disturbances as no seed was recorded in 2009 after large declines were measured the previous year. The estuarine intertidal seagrasses Z*. capricorni*, *H. ovalis* and *H. uninervis* in Sarina Inlet have been highly variable.[30]

5. Additional Pollutants

An environmental problem within the Mackay Whitsunday region is the drainage of wetlands. Vital wetland habitat has been lost due to acid drainage waters created by various drainage construction activities.[1]

An additional source of pollutants is sugar mills and their by-products. Although mill by-products are a cost effective option of nutrient supply to canelands, recycling of these products generally occurs close to mills to reduce transportation costs.[31] Heavy metals such as cadmium (Cd) and zinc have been found at concentrations 5 and 3 times higher, respectively, than background soil concentrations in mud surrounding sugar mills.[32] Long-term application of these products to the same area could result in Cd accumulation in soils. Long-term accumulation would increase the risk of food crops grown in rotation with sugarcane to become contaminated with this toxic metal and eventually violate the Australia New Zealand Food Standard Code.[32,33] It was recommended by Barry et al. (2001) that a wide distribution of these recycled materials is necessary for sustainable use of these valuable resources.[32] In 2002/2003, Mackay Sugar changed their pricing structure to encourage spatial distribution of mill mud and spreaders were developed in the Mackay area to improve application efficiency by reducing traditional rates (approx. 200 tonnes/ha) to approx. 30 tonnes/ha.[7]

The Port of Hay Point is the world's largest coal export port and is separated into two separate coal terminals, Dalrymple Bay Coal Terminal and Hay Point Services Coal Terminal. The port consists of 4 berths that can load 20,000-220,000 dead weight tonne ships.[34] In wake of Cyclone Ului a record 220 ships (Figure 3), 102 of which were bulk carriers, waited an average of a month to load coal from the Port of Hay Point.[35] This was double the number of ships in queue than two months prior to the cyclone.[35] Although it is not a regular occurrence to have such a large amount of ships waiting near the port, even half the amount of vessels in queue could have serious negative implications on the surrounding marine environment. Leaching of antifoulants (discussed in detail in the Don

River basin chapter) from vessels is an ongoing concern and area of research. Another environmental issue with docked vessels is the release of ballast water. Each day 10,000 marine organisms are transported around the world in ballast water holding tanks of ships before being released into a new environment.[36] Although Australia has stringent protocols on ballast water release, vessels can contain 70,000 tonnes of ballast water, which makes sterilization difficult due to the sheer volume of water. Invasive species can disrupt ecosystems by out-competing indigenous species for food and habitat and by carrying diseases. Problems have developed from toxic dinoflagellate algae that accumulate in mussels, oysters and scallops that cause paralytic poisoning in humans upon consumption.[36]

Figure 3: Bulk carriers waiting to load coal at the Port of Hay Point[35]

6. Management

a) In basin for basin

Soil erosion occurs at accelerated rates within canelands and was first recognized as a major source of river sediment when cane was predominantly burnt and hand-harvested.[1] In the late 1970s annual soil loss rates between 42-227 tonnes per ha were measured around Mackay.[37] Due to the implementation of minimal tillage and mechanical green cane harvesting/trash blanketing (GCTB) cultivation methods over the last three decades, soil erosion rates have been reduced to approximately 5-15 tonnes per ha on well managed canelands.[9,38,39] Nutrient loss associated with soil erosion has also been minimized under GCTB methods, making fertilisers the major sources of N and P from canelands.[1]

The Mackay Whitsunday Water Quality Improvement Plan (WQIP) has developed management interventions for the rehabilitation of priority habitats and the reduction of pollutant loads from diffuse and point sources. The implementation of WQIP will take place until 2014 and involves management intervention, monitoring and modelling, planning and legislation.[11]

The Mackay Whitsunday Baseline Monitoring Program monitors water quality from freshwater rivers, streams and creeks within the region through a cooperative program between federal, state and local governments.[12]

Rolfe et al. (2005) conducted a project with the aims of determining how a competitive market-like process could be used to improve water quality within the Sandy Creek catchment.[8] A range of potential management activities were suggested at the farm level to reduce or mitigate the net export of nutrients and sediments into local waterways in the Sandy Creek Catchment.[8] These included the introduction of tailwater recycling systems, conversion to minimum tillage farming systems, a reduction in the application of inorganic fertilisers, the adoption of precision farming technologies including subsurface fertiliser application technologies, key legume rotations, the use of vegetated headlands, contour banks, land retirements on steep slopes and along creek banks, and the introduction of grassed filter strips along riparian zones. Three were then chosen on the basis of their capacity to improve water quality, their applicability to a broad range of cane farms, their compatibility with existing cane farming technologies and their relative acceptability to cane produces and cane advisory agencies. The chosen management actions were: the introduction of grassed filter strips to riparian zones, a 50% reduction to existing industry recommended (BSES) fertiliser application rates and conversion to minimum tillage farming systems. The results of the project indicated the cost-effectiveness of different types of available management actions. On a per hectare basis, it was found to be cheaper to convert farmers to minimum tillage options than to reduce fertiliser usage or establish grass filter strips. The project also showed that there is a wide range in opportunity costs between cane growers for different management actions, meaning that: it could be costly for some landholders to change management practices, it would be more cost-effective to focus only on those landholders with lower opportunity costs and, it would be ineffective to use a fixed rate approval (as in developed grants) to achieve management changes.

b) In basin for Great Barrier Reef

A Natural Resource Management Plan was produced by the Mackay Whitsunday Natural Resource Management (MWNRM) Group (now “Reef Catchments”) with aims of protection and restoration of natural and cultural assets. This plan outlines goals for the protection and management of waterways throughout the region with the goals of conserving biodiversity and developing the sustainable use of natural resources.[12]

7. Potential future impacts:

Due to extreme water restrictions there is no room for expansion of sugarcane croplands (J. Brodie (TropWater) 2013, pers. comm.). However, coastal changes are expected with the proposed expansion of the Hay Point Terminal as new facilities are planned to be built as part of the Dudgeon Point Coal Terminal Project. The estimated capacity of coal exports after expansion is 180 Mtpa.[40] The expansion will cost an estimated $10-12 billion and will include new coal stockyards, a new barge facility, a 2 piled jetty structure that is 5km in length connecting offshore wharves to shore, 6 new ship berths, a new rail connection from Goonyella system to Dudgeon Point, expansion of the existing Tug Harbour at Half Tide and construction of site infrastructure.[40] Environmental impact assessments are not yet complete; however these port expansions will potentially have broad implications for the surrounding marine environment. Changes to flora and fauna, water quality and hydrology, and marine wildlife need to be monitored. Vessels numbers and hence vessel traffic and shipping impacts will increase, as well as noise and dust pollution. The port is within the Great Barrier Reef World Heritage Area (GBRWHA), and the port limits overlap with the Great Barrier Reef Marine Park (Marine Park).[41]

Additionally, the southern suburbs of Mackay are already within the northern portion of Plane basin and this urban expansion is expected to increase and replace sugar cropland (J. Brodie (TropWater) 2013, pers. comm.). Implications of urban expansion are increased waste discharge, however a decrease in the use of agricultural chemicals.

There is also a possibility of increased coastal aquaculture, which could alter coastal foreshore, estuarine, mangrove, salt marsh and marine and other aquatic environments.[42] Environmental impacts associated with aquaculture are water pollution, pest species, strain placed on wild fish populations for feeding and brooding, as well as the culling of natural predators.[42]

8. Knowledge Gaps

There is currently a lack of information regarding the inshore and offshore coastal areas within the Plane basin. Much of the past and current research has been conducted within streams related to cane cultivation processes. Information on the link between these land use changes and their impacts on downstream and marine ecosystems is lacking.

To the best of our knowledge no monitoring of litter and microplastics or pharmaceutical components occurs within the Plane basin. Plastic debris has been monitored along shorelines within and north of Mackay, especially on the Whitsunday Islands and will hopefully expand southwards into the Plane basin.

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