






Northern Gulf

Inland Waters Regional NRM Assessment

2015



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NRM Planning

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Australian Government

This project is supported by the Northern Gulf Resource Management Group Ltd through funding from the Australian Government.

CONTENTS

Lower Norman River

Gilbert River Mid Basin

Lower Staaten River main channel and floodplain lagoons and Wyabba Creek confluence.

Rifle Creek, upper Mitchell River Basin

FIGURE 1.1 RIVERSCAPES FROM THE FOUR RIVER BASINS COMPRISING THE NGRMG PLANNING AREA.

1.1 INTRODUCTION- NORTHERN GULF FRESHWATER ECOSYSTEM NRM ISSUES

The Northern Gulf planning region is comprised of four river basins, the Mitchell, Staaten, Gilbert and Norman. These four rivers collectively drain an area of over 190,000 km^2 distributed across four biogeographic regions or 'bioregions' (Figure , Table 1.1) and 19 subregions (Sattler and Williams 1999). The four basins are biogeographically differentiated with the Staaten and Norman, lying almost entirely within the Gulf Plains, while the upper half of the Gilbert Basin and upper third of the Mitchell Basin drain the Einasleigh Uplands (Appendix 1). The eastern margin of the Mitchell Basin also extends into the Wet Tropics, while its northern extent includes the Cape York Peninsula Bioregion. These various bioregional settings support a diverse range of freshwater environments which include seasonal lowland rivers, coastal and floodplain wetlands, spring fed rocky gorges and perennial rainforest mountain streams.

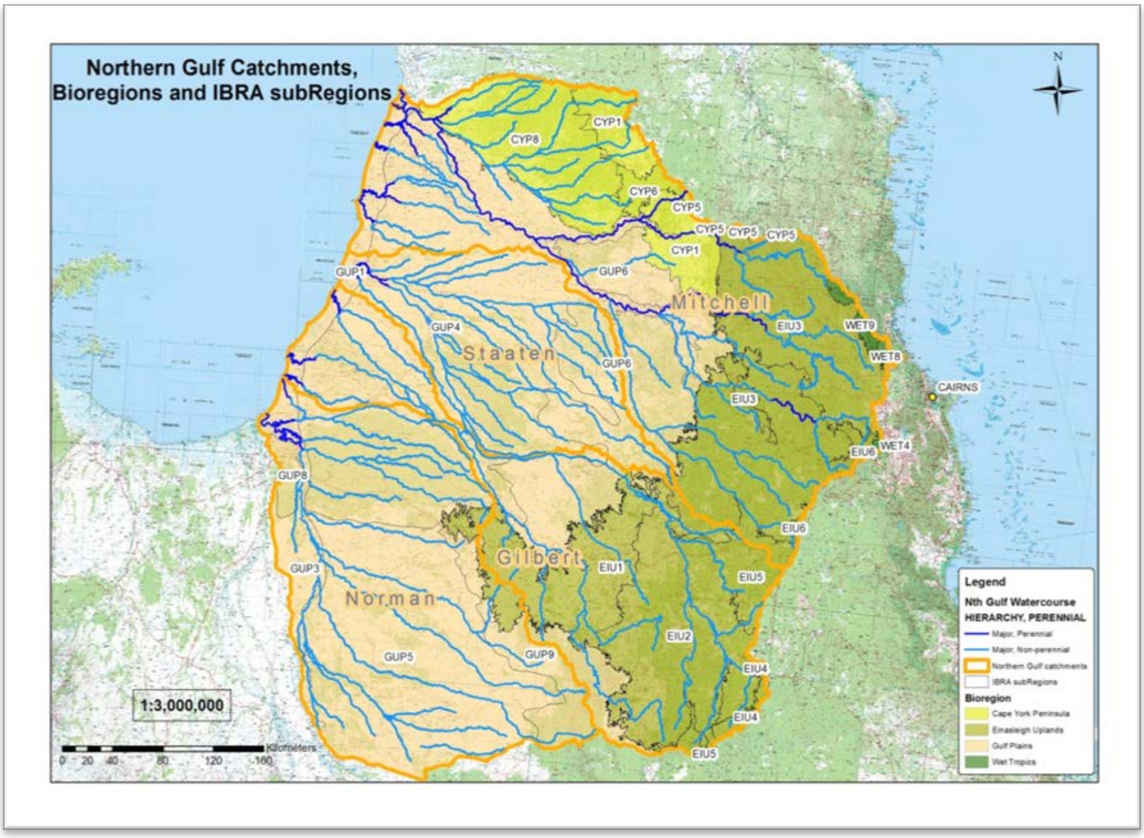


FIGURE 1.2 BIOREGIONAL COMPOSITION NORTHERN GULF RIVER BASINS

TABLE 1.1 RIVER BASIN AREA AND MAJOR SUB-CATCHMENTS

River Basin	Area km^2	Major Sub-catchments
Norman	50,302	Clara, Yappar, Norman and Carron Rivers
Gilbert	46,789	Smithburne, Etheridge, Einasleigh and Gilbert Rivers
Staaten	25,665	Clark, Vanrook creeks, Red and Staaten Rivers
Mitchell	75,426	Lynd, Tate, Walsh, Palmer, Alice and Mitchell Rivers

Rainfall across all river basins is highly seasonal and concentrated in the summer, monsoon-influenced wet season. There is a gradient in mean annual rainfall from the more northern Mitchell River basin which is dominated by a tropical savanna climate with >1200 mm rainfall, to the southern Norman River basin which is dominated by a hot grassland climate and receives <600 mm rainfall in its south (NLWRA 2002). Variability in climate creates variable hydrological conditions and flow regimes between and within Northern Gulf river basins. Within the more watered main stems of the Mitchell and upper Gilbert River basins, a stable summer flow regime occurs while in more western and southern basins, summer flow is predictable but intermittent. Smaller catchment systems have greater intermittency and less predictable summer flows (Kennard *et al* 2010). The limited development of water resources within Northern Gulf river basins and their retention of near natural flow regimes are recognised to underpin the health of their aquatic ecosystems and define them as ecological assets of global significance (Leigh and Sheldon 2008).

Given the concentration or rainfall within the December to March wet season, flooding is common across the extensive river floodplains and low gradient coastal plains of the Northern Gulf region and all basins exhibit flow connectivity via distributary networks during major flood events (Hydrobiology 2005). Overbank flows associated with riverine systems creates extensive areas of vegetated swamps (palustrine wetlands) and also floodplain lagoon and lake (lacustrine) wetland systems. As for rivers, the majority of 'off river' wetlands are highly seasonal, with only a small but ecologically important proportion retaining water through the annual dry season (Burrows 2004a).

In a seasonally dry environment like the Northern Gulf, groundwater plays an important role in the hydrology and ecology of freshwater ecosystems. It influences the flow regimes of streams, the availability of aquatic refugia during the dry season and the composition and structure of riparian vegetation communities (Hydrobiology 2005, Cook *et al* 2011). Groundwater aquifers within the Northern Gulf include shallow alluvial sand beds and beach ridge deposits, Tertiary sediments, fractured rock basements and sandstones within the Carpentaria and the Great Artesian Basin which underlies much of the region (CSIRO 2009).

Rivers draining the Northern Gulf represent an eastern component of a contiguous band of relatively undeveloped tropical river systems that drain the entire northern margin of the Australian continent. These rivers collectively represent the greatest extent of high integrity natural rivers remaining in Australia, and one of the main remaining extents of natural tropical rivers globally (Pusey 2011, Arthington 2012). As such they have globally significant ecological values and nationally important cultural, social and economic values (Pusey and Kennard 2009, Pusey 2011).

The values associated with Northern Gulf freshwaters are described more fully in the description of assets (following section) but include:

- Wetland aggregations listed in the directory of nationally important wetlands in Australia (described below in section 1.2.2.4);
- Australia's largest distributary delta and greatest density of ox-bow lagoons, both in the Mitchel Basin (Blackman *et al* 1999, Cook *et al* 2011);
- The second highest levels nationally of river basin (Mitchell) freshwater fish species richness and endemism (Pusey 2011);
- Population strongholds for internationally threatened aquatic species (e.g. freshwater sawfish *Pristis pristis*);
- Wetland areas of major cultural importance to Aboriginal people (Strang 2005);
- Significant freshwater recreational and traditional fisheries;
- Flow and primary productivity process linkages underpinning multimillion dollar commercial marine fisheries (Burford *et al* 2010, Halliday *et al* 2012); and
- National parks and other areas utilised for nature-based recreation and ecotourism by regional residents, domestic and international tourists.

The naturalness of Northern Gulf freshwater ecosystems is largely attributed to the limited extent of more intensive land use and development within contributing catchment areas (Appendix 1). Only the Mitchell River basin contains a significant area of intensive land use, including a collective total of approximately 50,000 ha of irrigated and non-irrigated cropping and horticulture land on the tablelands of its upper catchment, which includes the Dimbulah

Irrigation Area. While these land uses present an intensive development pattern and associated NRM issues at a local catchment scale, they still constitute less than a quarter of a percent of the overall river basin area.

Mining is another intensive land use that occurs within most Northern Gulf river basins but its overall extent is also very limited relative to the planning area, i.e. less than 0.02%. However, impacts from mining can be intensive at a local scale and within the Northern Gulf they have generated aquatic ecosystem impacts and catchment management legacies that extend beyond mining sites to receiving systems (Bartareau *et al.* 1998, Butler *et al* 2008).

In recent years undeveloped river basins in northern Australia, including those within the Northern Gulf, have become the focus of Government and community aspirations to further develop Australia's water resources and agricultural production potential. The Gilbert River basin in particular has been the focus of specific proposals for tens of thousands of hectares of 'green field' irrigated agriculture development. Two separate irrigation development proposals for the Gilbert River basin could result in river flow reductions of up to 14% of mean annual flow and 20% of median flows (Petheram *et al.* 2013b, IFED 2013). Potential aquatic ecosystem impacts related directly to proposed water resource development that have been identified by initial CSIRO scoping studies (Petheram *et al.* 2013) include:

- Reduced coastal floodplain inundation and wetland connectivity during lower rainfall years;
- Altered flows and catchment contaminant loads affecting river waterhole water quality and ecology;
- Flow and physical barrier constraints on aquatic species distribution, movement, recruitment and population viability; and
- Reduced flow driven productivity declines for Gulf of Carpentaria fisheries.

The most significant operating threats to Northern Gulf aquatic ecosystems are associated with current land use and condition. Rangeland grazing occupies greater than 95% of the area of the Mitchell, Gilbert and Norman River basins and 80% of the Staaten River basin (the residual 20% comprised of National Park). Grazing generates direct (e.g. trampling and browsing of riparian vegetation, disturbance of wetland habitat) and indirect (e.g. increased soil erosion and basin sediment loads) impacts to freshwater ecosystems.

Other threats to freshwater ecosystems across the Northern Gulf include pervasive ecological pressures posed by weeds, feral animals, fire regime management and climate change. Climate change is emerging as a significant threat to freshwater ecosystems globally and nationally. This is due to its influence on climatic and hydrologic regimes which affect the persistence and quality of aquatic habitats (Morrongiello *et al.*2011), and its exacerbation of existing ecological pressures already compromising the resilience of aquatic ecosystems (Kingsford 2011, Williams *et al.*2012). Recent regional scale assessments by CSIRO and BOM of climate change projections for the *Monsoonal North cluster* which covers the Northern Gulf (Moise 2014, Gobius 2015), have found that the region will be exposed to a range of increasing climatic stressors that will impact freshwater ecosystems. These include:

- Higher temperatures and more frequent and hotter hot days;
- Large increases or decreases in rainfall;
- Increased intensity of heavy rainfall events;
- Increased evaporation rates, and reduced soil moisture;
- Fewer but possibly more intense tropical cyclones; and
- Higher sea levels and more frequent sea level extremes.

To implement natural resource management requires action by natural resource managers. In the Northern Gulf, landholders represent the principal natural resource managers. In terms of areal extent, the most important landholders are graziers on pastoral leasehold lands and Traditional Owners on Aboriginal land. In the last decade the emergence of Land and Sea Ranger programs have provided Traditional Owners with an enhanced capacity for achieving NRM aspirations. Government agency managers of public lands such as National Parks, farmers in agricultural areas, local government authorities, private landholders in urban and peri-urban areas and individuals staying on or travelling through the region are also effectively 'natural resource' managers, albeit of more limited resources than the first two groups nominated.

1.2 ASSETS AND STATUS

Inland waters and freshwater ecosystems of the Northern Gulf are associated with four river systems, the Mitchell, Staaten, Gilbert and Norman. A broad and inclusive definition of what constitutes a *River System* includes:

- The contributing catchment area, including the aggregate of stream channels and drainage lines draining the river basin and forming its estuary/mouth;
- Surface and subterranean hydrological linkages including surface water, aquifers and recharge areas;
- Landforms shaped by active river system geomorphic (i.e. fluvial and alluvial) processes including levees and floodplains;
- Flow and groundwater-dependent vegetation communities and regional ecosystems including those associated with channels, alluvial levees and floodplains; and
- Dependent biota including plants and animals.

Although these river system components can be conceptualised individually, all have some level of interdependence via catchment-framed biophysical process linkages. As identified in the Coastal and Marine section of the NRM plan, biophysical and ecological process continuity also extends between freshwater and receiving marine aquatic ecosystems and generates a broad, and at most nominal, boundary between them. This is particularly the case in the highly seasonal climatic regime of the Northern Gulf where estuarine systems and coastal wetland aggregations seasonally host extensive areas of 'freshwater' wetland and water salinity regimes can vary from freshwater to hypersaline (Blackman *et al* 1999).

While recognition of the connectedness between different components of a river system is critical for developing effective NRM strategies, there is also merit in defining individual river system assets as a focus for identifying specific NRM needs. Assets include components of a river system that are associated with ecological, social and/or economic values. Some 'river system' assets are covered by other sections of the NRM plan, including contributing catchment areas included in the Grazing Lands section and tidal estuaries and river mouths included in the Gulf Coast section. Different assets can be differentiated on the basis of value sets, threats, primary stakeholder groups and management needs and opportunities. The significance of different asset types often varies between river basins (see Appendix 1).

For the purposes of examining the NRM needs of the Northern Gulf's inland waters, four non-exclusive asset areas have been identified:

1. Freshwater Environments;
2. Aquatic Biodiversity;
3. Freshwater Fisheries; and
4. Water Resources

1.2.1 Freshwater Environments

Within northern Gulf river basins, a great diversity of freshwater environments can be described at a range of scales. For the purposes of NRM planning, freshwater environments have been grouped under three non-exclusive types of wetland system which have particular vulnerabilities, suites of threats and spatial occurrences in the landscape. These are:

1. Riverine Corridors;
2. Off-River wetlands; and
3. Groundwater Dependent Ecosystems.

1.2.1.1 Riverine Corridors

River environments are perhaps the most well recognised assets of freshwater ecosystems. They provide habitat resources and convey water flows, materials and biota that support both aquatic and terrestrial biodiversity, including within biophysically connected coastal and marine ecosystems. Rivers occupy an important place in both traditional Indigenous culture and mainstream Australian folklore. They provide material and spiritual sustenance for Aboriginal people and are a source of inspiration and a place for recreation for both residents and visitors of the Northern Gulf region. Rivers are also an economic life blood for regional primary industries.

In terms of formal wetland classification and mapping (Appendix 1), riverine systems are defined as *wetland and deepwater habitats contained within a channel* (QEPA 2005). For NRM purposes it is useful to consider riverine habitats in terms of the terrestrial and semi-terrestrial vegetation within the 'riparian zone' that fringes channels and the aquatic and stream bed habitats contained 'in-channel'. Riverine corridor assets considered here are the combination of within channel aquatic and stream bed habitats and the fringing 'riparian zone'.

There are many definitions of what constitutes the 'riparian zone' of a river (Brooks *et al.* 2008). In Queensland, native vegetation regional ecosystems (REs) are mapped and classified by reference to land zones. Alluvial landforms associated with rivers including channels, levees and floodplains, fall within land zone 3 (Sattler and Williams 1999). In the seasonal tropics of the northern Gulf where annual wet season flood flows commonly break out of river channels and inundate broad floodplains, there is an argument for considering the entire alluvial zone as a 'riparian zone' and associated floodplain vegetation communities as riparian vegetation (Brooks *et al* 2008). For Queensland State, wetland mapping riparian vegetation associated with riverine systems (as opposed to other wetland types) is identified as 'fringing community' regional ecosystems associated with channels and watercourses within land zone 3 (QEPA 2005). 'Fringing community' and riverine REs have been mapped and classified across the Northern Gulf (Table 1.2) and include a diverse suite of structural vegetation types ranging from closed canopy gallery rainforests to open woodlands (Hydrobiology 2005, Qld Herbarium 2015).

The riparian zone is an important interface between aquatic and terrestrial ecosystems and contains habitat with high biodiversity and catchment functional values (Fisher *et al.* 2004; Brooks *et al.* 2008). Riparian vegetation is important for providing: bank stability, terrestrial and instream habitat (e.g. via contributions of woody debris) and wildlife food resources, corridors for wildlife movement and mitigation of basin sediment and nutrient load impacts on instream water quality (2004a, Brooks *et al.* 2008; Greiner 2009). Riparian vegetation also regulates instream light levels and water temperature (through shading), and thereby aquatic plant growth and dissolved oxygen levels which increase the refugial value of waterholes during the dry season for a wide range of species (Burrows 2000, 2004a). Riparian zones are commonly more fertile and productive, though ecologically sensitive, parts of the landscape and are therefore often vulnerable to disturbance from livestock, human access and development and other threats such as weeds and feral animals (Dowe 2004; Brooks *et al.* 2008; Greiner & Miller 2008). Due to the high biodiversity and catchment functional values of riparian areas, their management is integral to maintaining instream riverine environments, water quality and biodiversity, particularly fresh water fish diversity (Pusey & Arthington 2003).

TABLE 1.2 LIST AND VEGETATION MANAGEMENT ACT (VMA) AND BIODIVERSITY STATUS OF FRINGING RIVERINE AND RIVERINE WETLAND ASSOCIATED REGIONAL ECOSYSTEMS OCCURRING IN NORTHERN GULF PLANNING AREA BIOREGIONS (QLD HERBARIUM 2015)

Bioregion	RE	VMA Class	Biodiversity Status	Short Description
Gulf Plains	2.3.17	Least concern	Of concern	Coolibah *Eucalyptus microtheca* woodland on channels in fine textured alluvial plains
Gulf Plains	2.3.24	Least concern	Of concern	Paperbark *Melaleuca spp.* woodland-open forest on sands in channels and on levees
Gulf Plains	2.3.25	Least concern	Of concern	River Red Gum *Eucalyptus camaldulensis* woodland on levees and floodplains
Gulf Plains	2.3.26	Least concern	Of concern	River Red Gum *Eucalyptus camaldulensis* and Leichardt Tree *Nauclea orientalis* open forest fringing major tributaries
Cape York Plains	3.3.5	Least concern	No concern at present	Evergreen to semi-deciduous notophyll vine forest on alluvia on major watercourses
Cape York Plains	3.3.10	Least concern	No concern at present	Blue Paperbark *Melaleuca dealbata* tall forest on drainage lines and swamps
Cape York Plains	3.3.11	Of concern	Endangered	Weeping Paperbark *Melaleuca leucadendra* ± Blue Gum *Eucalyptus tereticornis* open forest on alluvium
Wet Tropics	7.3.23	Endangered	Endangered	Simple-complex semi-deciduous notophyll to mesophyll vine forest on lowland alluvium, predominantly riverine levees
Wet Tropics	7.3.25	Of concern	Of concern	Weeping Paperbark *Melaleuca leucadendra* ± vine forest species open forest to closed forest on alluvium fringing streams
Wet Tropics	7.3.26	Of concern	Endangered	River She Oak *Casuarina cunninghamiana* woodland to open forest on alluvium fringing streams
Wet Tropics	7.3.28	Of concern	Endangered	Rivers and streams including riparian herbfield and shrubland on river and stream bed alluvium and rock within stream beds
Wet Tropics	7.3.49	Of concern	Of concern	Notophyll vine forest on rubble terraces of streams
Wet Tropics	7.11.42	Of concern	Endangered	Blue Gum *Eucalyptus tereticornis*, Pandanus sp., Swamp mahogany *Lophostemon suaveolens*, Blue tea tree *Melaleuca dealbata* and Red stringybark *Eucalyptus pellita* woodland to open forest on peaty sands/muds of perched drainage areas.
Einasleigh Uplands	9.3.1	Least concern	Of concern	River Red Gum *Eucalyptus camaldulensis* and/orBlue Gum *E. tereticornis* ± Paperbark *Melaleuca spp.* ±

				River She Oak *Casuarina cunninghamiana* fringing woodland on channels and levees
Einasleigh Uplands	9.3.12	Least concern	Of concern	Waterholes and lagoons in the bed of larger rivers containing aquatic vegetation
Einasleigh Uplands	9.3.13	Least concern	Of concern	Paperbark *Melaleuca spp.*, River Red Gum *Eucalyptus camaldulensis* and River She Oak *Casuarina cunninghamiana* fringing open forest on streams and channels
Einasleigh Uplands	9.3.14	Least concern	Of concern	Silver–leaf Paperbark *Melaleuca argentea* and/or Weeping Paperbark *M. leucadendra*, Northern Black wattle *Acacia auriculiformis* and White apple *Syzygium forte* woodland on major rivers
Einasleigh Uplands	9.3.15	Least concern	Of concern	Blue Gum *Eucalyptus tereticornis* ± River She Oak *Casuarina cunninghamiana* ± Paperbark *Melaleuca spp.* fringing woodland on channels and levees
Einasleigh Uplands	9.3.22	Least concern	Of concern	Cullen's ironbark *Eucalyptus cullenii* ± Red bloodwood *Corymbia erythrophloia* woodland on alluvial flats
Einasleigh Uplands	9.3.27	Least concern	No concern at present	Grassland ± emergent *Eucalyptus spp.* on alluvium within basalt flows

Riverine Condition Assessments in the Northern Gulf

Condition assessments are important for underpinning the strategic management of aquatic habitats. Areas in good condition provide a focus for protective management, while areas in poor condition may represent restoration priorities. Evaluation of site values and consideration of catchment location and dominant threatening processes further inform strategic management by identifying where valuable assets in good condition can be cost effectively protected or alternatively where high site values are threatened by poor condition and warrant investment in restorative management. A number of sub-catchment and basin-scale studies restricted to the Mitchell and Gilbert Rivers have undertaken assessments of river condition within the Northern Gulf region. National assessments of river, catchment and riparian zone condition have also covered Northern Gulf river basins albeit at coarser scales of assessment.

Herbert *et al* (1995) assessed 9 sites in the Palmer sub-catchment as part of the Cape York CYPLUS study and 17 sites in the Walsh sub-catchment were assessed as part of the Barron Basin Water Resource Plan in 1998 (Burrows 2004a). A further 44 sites in the Walsh and upper Mitchell sub-catchments were assessed for a Natural Heritage Trust-funded study of the environmental condition of the upper Mitchell Basin (Ryan 2002). The first basin scale assessment of condition was conducted by the State of the Rivers program which assessed 88 sites across the Mitchell Basin, including 21 sites in the Mitchell sub catchment, 17 in the Lynd, 11 in the Palmer, 19 in the Walsh, 5 in the Alice and 14 in the lower Mitchell plains (Moller *et al* 2002). All of these studies assessed a range of similar attributes examining riverine condition primarily via qualitative scoring and description via reference to assessment pro-formas. Across all studies attributes assessed included: reach disturbance, channel morphology, bank stability, geomorphic change, substrate composition, instream habitat, channel habitat diversity, aquatic habitat diversity, hydraulic change and riparian vegetation condition.

National Assessments of river and catchment condition conducted by the National Land and Water Resources Audit (NLWRA 2002a) only covered the Mitchell basin due to a lack of data coverage for other basins, and outputs are too coarse scale to serve regional planning. These assessments do however place the condition of the Mitchell in a broader state and national context. Catchment condition was assessed as generally

The regional ecosystem database compiled by the Queensland Herbarium (2015), lists the *Vegetation Management Act* (VMA) status of each fringing or riverine RE which is derived from consideration of its pre-clearing and post-clearing extent, and its biodiversity status which is inferred from an assessment of threats known to be affecting its condition within the Bioregion (Table 1.2). The high exposure of fringing riverine and riverine regional ecosystems to existing threats and ecological pressures is illustrated by their relatively threatened VMA and biodiversity status. More than a third (35%) has either an '*of concern*' or '*endangered*' VMA status, while a collective 85% have either an '*of concern*' or '*endangered*' biodiversity status (Table 1.2). The proportion of riverine associated REs recoding a threatened status exceeds all other wetland system associated REs (

Table 1.3), highlighting the vulnerability of riverine corridors to land use and other threats. High total grazing pressure and weed invasion, particularly by rubbervine, are the two most commonly recorded threats impacting the biodiversity status of these riverine associated REs (Qld Herbarium 2015). These threats are discussed further under *Section 7.4*.

The condition of Northern Gulf riparian vegetation communities has also been assessed by a number of dedicated studies, although these have primarily been focused on the Mitchell and Gilbert River basins due to their larger populations and existing or potential development pressures (Ryan 2002, Moller *et al* 2002, Dowe 2004; Brooks et al 2008), see Insert Box - *Riverine Condition Assessments in the Northern Gulf*.

The in-channel riverine habitats of the Mitchell and Gilbert River basins are also the most well described within the literature due to the greater amount of assessment, monitoring and research that has occurred within these basins (Ryan 2002, Moller *et al* 2002, Hydrobiology 2005, DNWR 2008, Lymburner and Burrows 2008, Brooks et al 2008, CSIRO 2009, Ward *et al* 2011, Barber *et al* 2013). Aquatic and channel habitats in other basins have generally only been characterised around sites surveyed for other purposes e.g. fish sampling (Burrows and Perna 2006, Hogan *et al* 2009). Larger scale regional, state and national studies, including the Queensland wetland mapping program (QEPA 2005), national river environmental and flow regime classifications (e.g. Stein 2006, Kennard *et al* 2010), and Gulf, Cape York and northern Australia aquatic ecosystem conservation value assessments (Rollason and Howell 2010, Howell and Kenna 2012, Kennard et al 2010, 2011) also provide contextual information for habitats of less studied basins. More recent studies focussed on the Mitchell and Gilbert basins have contributed information on biophysical condition and process drivers (Lymburner and Burrows 2008, Brooks et al 2008, Barber *et al* 2013), ecosystem metabolism and food web carbon flows (Hunt *et al* 2012, Jardine *et al* 2012, 2013), seasonal dynamics (Pettit *et al* 2012, Ward *et al* 2013) and on threats posed to Aquatic ecosystem values by proposed water resource development (DSITIA 2014, Bayliss *et al* 2014).

moderate or better and riverine condition was largely unmodified, with some sections considered to be moderately modified. In general, these ratings ranked lower than most east coast Cape York catchments, similar to the upper Herbert catchment and better than the Burdekin catchment (Burrows 2004a). A national assessment of river disturbance placed each Northern Gulf river basin in different disturbance classes (Stein *et al* 2002). In order from least (Class 1 undisturbed) to more disturbed classes (Class 8 severely disturbed), Northern Gulf basins were assessed as Staaten (Class 2), Mitchell (Class 4), Norman (Class 5) and Gilbert (Class 6). At a finer scale of differentiation, Stein (2006) assessed river disturbance at the scale of individual stream segments and indicated areas of higher river disturbance to be associated with main stems in the vicinity of Einasleigh in the Gilbert River basin and lower delta and upper catchment main stems within the Mitchell River basin. Areas of assessed river disturbance were associated with water resource development and associated on-stream infrastructure (Walsh sub-catchment), vegetation status, adjoining catchment land use, and assessed grazing pressure and infrastructure development (Stein 2006).

National assessments of the condition and trend of riparian zones within bioregional subregions (NLWRA 2002c), indicated riparian condition was only fair across most of the Gulf Plains subregions but was good in Einasleigh Uplands and Cape York subregions. Riparian condition trend was assessed to be declining across Gulf Plains subregions but was static within Einasleigh Uplands and Cape York subregions within the Northern Gulf. This same assessment identified grazing pressure and weeds as the major threatening processes affecting riparian condition and trend (NLWRA 2002c).

More recently riparian vegetation condition at 172 headwater sites across the Gilbert and Mitchell catchments was assessed using The Tropical Rapid Appraisal of Riparian Condition (TRARC) method (Brooks *et al* 2008). This method provides a quantified score (0-100) with a higher score implying better condition. In contrast to earlier site-based assessments, the TRARC method employed quantitative measurement of 24 indicators organised into sub-indices examining plant cover, regeneration, erosion and weeds. These indices collectively contribute to the overall site score but site assessments can also be made by reference to an individual sub-index or indicator values.

At a basin level the earlier State of the Rivers study found that Mitchell Basin riparian vegetation condition was good to very good at 82% of sites, moderate at 10% of sites and poor to very poor at 8% of sites,

An ecological and geomorphological assessment conducted for the Gulf and Mitchell Basin water resource plan (Hydrobiology 2005) divided all Northern Gulf river basins into reaches based on geomorphic and management criteria that related to the suite of river environments present. There is an enormous diversity of instream or 'within channel' riverine environments across the Northern Gulf. They range from small, clear flowing, perennial, upper catchment rainforest streams to spring-fed gorges in rocky arid uplands, to large, seasonal, turbid, meandering lowland rivers (Hydrobiology 2005).

At any site the natural suite of instream habitats present reflects reach and catchment characteristics and processes, including contributing catchment size, regional geology, landscape geomorphology, climate, and particularly flow hydrology (Pusey *et al* 2011). Perenniality of flows and waterholes, and size and diversity of instream habitats are recognised as key determinants of the aquatic biodiversity that is hosted by tropical Australian rivers (Pusey *et al* 2011). Physical and biotic features that can contribute to instream habitat diversity at a site include substrate type (clay-bedrock), channel depth profile (shallows to deep pools), reach flow condition (riffles, runs, pools or dry stream bed), water clarity, aquatic plants (submerged, floating and emergent), fringing/overhanging riparian vegetation, tree root masses, undercut banks, snags and organic litter piles (Ryan 2002, Moller *et al* 2002).

Instream habitats of the Mitchell basin have been the focus of the greatest amount of monitoring (e.g. for water quality - Butler and Burrows 2005) and research which has examined food web carbon sources and connectivity and ecosystem metabolism (Hunt et al 2012, Jardine et al 2012, 2013). The permanence of riverine waterholes, seasonal changes in water quality and their potential value as refugia for aquatic biodiversity have also been the focus of studies within the Mitchell and Gilbert River basins (Lymburner and Burrows 2008, Hermoso *et al* 2013, McJanet *et al* 2014, Waltham *et al* 2014). Similar studies have also focussed on floodplain waterholes (Petit *et al* 2012, Ward *et al* 2014).

Because riverine corridors lie along the interface between terrestrial and aquatic ecosystems and provide conduits for the transport of water, sediment and other materials from contributing catchments, their condition can be impacted by both land and water resource use. Land use impacts operate via changes to contributing catchment condition (and resultant changes in sediment and other contaminant loads, landscape water balance and run off) and via direct impacts on riparian and instream habitats. More intensive land and water resource use is generally associated with greater impacts to riverine habitats (NLWRA 2002). Historic land use that has left a legacy of altered catchment processes and degradation (e.g. erosion, mining contamination) can also indicating a relatively undisturbed status for riparian vegetation in this essentially uncleared and undeveloped river basin (Moller *et al* 2002). The TRARC assessment of headwater streams produced a similar proportion of sites with better conditioned riparian vegetation. Riparian condition was found to be in the 50-79 range at 90% and 85% of the sites in the Gilbert and Mitchell River catchments respectively (Brooks *et al* 2008).

One of the intended outcomes of condition assessments is an indication of where disturbed sub catchments and reaches occur. The TRARC survey covered too small an area to provide a basin overview but across the assessed Gilbert and Mitchel sub-catchments areas with lower condition, scores were associated with areas of high intensity agriculture and water resource infrastructure in the Walsh and upper Mitchell sub catchments. In the Gilbert Basin higher riparian condition scores were relatively randomly distributed within the Copperfield River and Lagoon Creek sub-catchments but were associated with sites with better regeneration and cover indices (Brooks *et al* 2008). In the State of the Rivers basin overview all sites recording poor to very poor riparian vegetation condition occurred within the Walsh and Lynd sub-catchments while the Palmer was the only other sub-catchment to share sites in moderate condition with these sub-catchments. Results for other riverine condition attributes contrasted with finding for riparian vegetation including the highest percentage of poor and very poor reach condition and bank stability sites recorded within the Alice and lower Mitchell sub-catchments, the highest percentage of poor and very poor channel habitat diversity sites recorded in the Palmer and lower Mitchell sub-catchments and the highest percentage of poor and very poor aquatic habitat diversity sites recorded in the Palmer and Lynd sub-catchments. These results suggest that different pressures may affect the condition of different riverine habitat components independently and/or alternatively riverine habitat components have different vulnerabilities to the same pressures in different reaches or sub-catchments.

Findings from these condition assessments have generally been intuitive in that poorer condition sites are associated with areas of known historical disturbance (e.g. mining in the Palmer and Walsh sub-catchments), areas with more intensive land use patterns (e.g. reaches with agriculture and water resource infrastructure development associated with the MDIA in the Walsh and upper Mitchell) and sub-continue to impact receiving riverine environments long after contemporary land use patterns or practices have changed (Bartareau *et al* 1998).

In the Northern Gulf the dominant land use (i.e. >90% area in most basins; see Appendix 1) is rangeland grazing which represents a less intensive but very extensive land use pattern. Grazing is recognised to pose a host of direct and indirect threats to riverine environments (Burrows 2000, 2004a) and represents the most significant land use threat in terms of the extent of area affected. In the Northern Gulf, rangeland grazing has been implicated in the initiation of accelerated gully erosion that now affects over a 100,000ha of the Gilbert and over 160,000ha of the Mitchell River basin in terms of raw active gully erosion (Brooks and Knight 2008). Resultant elevated catchment sediment loads are implicated in major changes to riverine habitats, including a significant loss of pool habitat (Brooks et al 2008, Shellburg *et al* 2010, see insert box *A Changing Riparian Environment*).

Direct impacts to riverine corridor habitats associated with grazing include pugging of the beds and banks of water bodies, grazing and trampling based removal of riparian vegetation including sapling regeneration and emergent vegetation on stream margins, accelerated bank erosion and scalding of frontage areas, associated water quality impacts (elevated turbidity and nutrient levels) and promotion of woody weed species (Burrows 2000, Burrows 2004, Dowe 2004, Tait 2005). Given the highly seasonal nature of the Northern Gulf's climate, dry season watering of livestock can be particularly destructive depending on access to perennial waterhole that also have high environmental values as dry season refuges for both aquatic and terrestrial fauna (Burrows 2000).

More intensive land uses, including mining and irrigated agriculture, occupy only very small areas within Northern Gulf river basins (Appendix 1) but are associated with riverine habitat condition impacts (see River *Condition Assessments* insert box). Water resource development has the potential to pose significant threats to the condition of tropical riverine habitats via impacts to waterhole levels and perenniality, ecosystem maintaining flow regimes, habitat connectivity and catchment contaminant loads associated with water end uses e.g. agriculture (Hydrobiology 2005, Pusey *et al* 2011). There has been very limited development of water resources within Northern Gulf river basins, however condition impacts are recognised for sub- catchments hosting existing areas of development, e.g. Walsh and upper catchments with land types vulnerable to erosion and degradation from current extensive grazing land use (e.g. erosion-prone reaches of Lynd, Mitchell and Gilbert). Some counter-intuitive findings e.g. low channel and aquatic habitat diversity and poor reach condition scores from sites in sub-catchments lacking a history of intensive land use, e.g. Alice and lower Mitchell, may partially relate to limitations in assessment methodologies where predetermined concepts of what constitutes 'good condition', does not match the natural condition of savanna landscape floodplain rivers (Burrows 2004a, Brooks *et al* 2008). Alternatively or concurrently they may also point to the vulnerability of some Northern Gulf river corridors to pressures associated with less intensive but extensive land uses, i.e. rangeland grazing (Shelberg *et al* 2010).

Another useful output of condition assessments is information concerning the relative significance of different threats to condition in different reaches and sub-catchments. In the State of the Rivers assessment, exotic plants were present at 77% of the sites surveyed, with rubbervine being the predominant species found at 64% of the sites. Rubbervine was considered abundant at 84% of the sites where the species was present (Burrows 2004a). In the more recent TRARC study of headwater sites some differentiation in weed species prevalence was observed between the Gilbert and Mitchell basins. In the Mitchell Basin the most prevalent weeds were Guinea Grass (76% sites), Noogoora burr (36%), Hyptis (32%), and Rubbervine (24%), noting that prevalence does not necessarily equate to ecological significance. In the Gilbert Basin the most prevalent weeds were Rubbervine (38% sites), Hyptis (8%), and Noogoora burr (8%). Other basin distinctions in terms of riparian zone condition impacts were also observed. For the Gilbert River, erosion and productivity decline received a high level of concern and weed problems a very high level of concern, while in the Mitchell, erosion and the loss of productivity and freshwater habitat were considered to be of moderate concern, and weed problems of a high concern (Dowe 2004).

One of the main limitations of site based assessment of riparian zone condition is the attribution of site results to larger scale entities such as reaches or sub-catchments, and the high Mitchell (Burrows 2004a). Proposals for further development of water resources in Northern Gulf river basins, particularly major proposals within the Gilbert basin, have the potential to generate more extensive impacts on riverine habitats (Petheram *et al* 2013).

Threats to the condition of riverine environments that don't have direct land and water resource use drivers include exotic species (feral animals and weeds) and climate change. Feral pig rooting of river banks, wallowing on stream margins and browsing of emergent vegetation represents a major threat to the condition of riverine environments across most northern Gulf river basins, including those within protected areas that are otherwise considered 'near pristine' e.g. Staaten River National Park (Hogan et al 2009). A large range of weed species also impact the floristic condition of riparian vegetation communities in the Northern Gulf (Brooks *et al* 2008). The most significant weeds include those that change vegetation structure and ecosystem function. These include rubbervine which collapses riparian canopies, shades out understory strata and ground cover and prevents regeneration; aquatic weeds such as water hyacinth and para grass which blocks light penetration and results in the loss of submerged aquatic plants and instream water quality decline; and Guinea grass which introduces hot fire fuel loads into fire sensitive riparian communities (Burrows 2004a, Tait 2005). Rubbervine is the most widespread of these weed species across Northern Gulf river basins (Moller *et al* 2002). Water hyacinth infestations are primarily restricted to the distributary stream systems of the lower Mitchell sub-catchment but have extended to the lower Gilbert Smithburne sub-catchment where it represents a priority for control action (Hogan and Vallence 2011). Para grass and guinea grass primarily occurs in ungrazed areas of the upper Mitchell and Walsh sub-catchments in reaches with agricultural development and irrigation tailwater discharges (Moller *et al* 2002, Burrows 2004a, Hydrobiology 2005, Brooks et al 2008).

Climate change is also emerging as a significant threat to riverine environments and all freshwater ecosystems due to its influence on climatic and hydrologic regimes which affect the persistence and quality of aquatic habitats (Morrongiello *et al*.2011). The capacity of more extreme climate events (droughts, floods) to exacerbate existing ecological pressures, e.g. poor catchment condition, represents the other main avenue for climate change impacts on rivers (Kingsford 2011). Associated sea level rise has also been identified as a key threat to lowland river reaches in the near coastal zone of the Northern Gulf (Kennard 2015).

site density and associated fieldwork commitment required to produce accurate outputs at a basin scale. For basin scale assessments of riparian condition there is an identified need to integrate site based assessment methods such as TRARC with remote sensing techniques (Brooks *et al* 2008). Satellite imagery based assessments of Mitchell and Gilbert Basin riparian zones conducted by Brooks *et al* (2008) highlighted the dynamic nature of each river's riparian zone (see '*A changing Riparian Environment*' insert box), and the need to consider the broad full extent of the 'alluvial zone' when assessing 'riparian' condition in these seasonal rivers. This study also identified limitation with the existing site based TRARC method in terms of its ability to be integrated with basin scale remote sensing approaches and recommended a modified TRARC method or alternative site based method for verifying remotely sensed riparian condition data (Brooks *et al* 2008). The TRARC methodology was seen to still have a valuable role for assessing and monitoring riparian zone condition at smaller site, reach and/or local catchment scales, particularly in relation to emerging threats (e.g. new weed infestations), for prioritising management investment and for tracking condition responses to management investments (Brooks *et al* 2008).

In contrast to the multi-attribute approaches used for past site-based assessments, more thematic assessments separately examining key threats nominated on the basis of their ecological significance, for example specific weeds (e.g. rubber vine) or bank /gully erosion, may offer a greater capacity for generating basin scale, site verified, remotely sensed riparian condition assessments. Higher resolution remotely sensed data also provides a means (albeit at a cost) for overcoming the limitations encountered applying Landsat TM imagery to Gilbert and Mitchell Basin riparian condition assessments (Brooks *et al* 2008). Technological advances in the cost effective collection and processing of such data including the use of higher resolution satellite imagery, multi-spectral aerial imagery, light detecting and ranging radar (LiDAR) and unmanned aerial vehicles (UAVs) point toward future possibilities for obtaining regional scale assessment of riverine corridor condition suited to guiding management investments (Johansen *et al* 2010, 2013, Jensen *et al* 2011, Dufour *et al* 2013, Capuana 2013).

The range and significance of threats facing Northern Gulf riverine habitats and other freshwater aquatic ecosystems are covered more fully in *Threats to Freshwater Ecosystems* (Section 0). Existing knowledge of the condition of rivers within the northern Gulf based on past assessments is presented in the *River Condition Assessments* insert box. Description of additional values associated with the northern Gulf's riverine corridors is discussed under following asset descriptions.

TABLE 1.3 BIOREGIONAL VEGETATION MANAGEMENT ACT (VMA) AND BIODIVERSITY STATUS OF WETLAND SYSTEM ASSOCIATED REGIONAL ECOSYSTEMS (RES) OCCURRING WITHIN THE NORTHERN GULF PLANNING REGION (QLD HERBARIUM 2015)

	Riverine			Palustrine/ Lacustrine			Floodplain			Estuarine			
	No. REs	% EBS	% OCBS	No. REs	% EBS	% OCBS	No. REs	% EBS	% OCBS	No. REs	% EBS	% OCBS	Total No. REs
GUP	4	0%	100	8	22	41	18	0	50	4	0	0	34
CYP	3	33%	0	10	0	10	14	0	21	2	0	0	29
EIU	7	0%	86	9	0	66	8	0	63	0	0	0	24
WET	6	75%	25	13	62	15	14	69	24	0	0	0	33
Total No. REs	20			40			54			6			120
% Endangered VMA	5%			5%			6%			0			5%
% Of Concern VMA	30%			30%			24%			0			26%
% Endangered Biodiversity Status (EBS)	25%			25%			17%			0			20%
% Of Concern Biodiversity Status (OCBS)	60%			30%			41%			0			38%

A CHANGING RIPARIAN ENVIRONMENT (BROOKS *ET AL*. 2008)

Using remote sensed Landsat TM images from both 1988 and 2005, Brooks *et al*. (2008) examined change in the extent of vegetation community types, in-channel pools, sand deposits, floodplain waterbodies and floodplain bare ground within the alluvial zone of the Mitchell and Gilbert River basins over the intervening period.

They found that there has been a substantial turnover but ultimately a net increase in the area of in-channel vegetation across all sub-catchments within the Mitchell (6950 ha increase) and Gilbert (12040 ha increase) Basins between 1988 and 2005. There had also been substantial net accumulation/deposition of sediment within channels in both river systems including all sub-catchments of the Gilbert (20.6 km^2 increase in sand bar area) and most sub catchments of the Mitchell (17.7 km^2 increase in sand bar area). In the Mitchell this amounted to an average 1.04 km^2 decline in pool area per annum over the 17 year period. Two Mitchell Basin sub-catchments (Walsh and Palmer) with a history of mining disturbance (and possibly historically elevated sediment bed loads) exhibited a net increase in pool area over the assessed period. A net shift in floodplain vegetation cover toward woody vegetation communities with greater canopy density was also observed over the same period in both the Mitchell (2686 km^2 increase) and Gilbert (1090 km^2 increase) Basins.

Brooks *et al*. (2008) cautioned that the study represented a 'first cut' at quantifying riparian zone status within the Northern Gulf region using remote sensing at a basin scale. Further investigations were recommended to confirm the dramatic changes they had measured over such a short time period and to identify whether drivers of change were directional or related to inter-annual climatic variability. Several hypotheses and areas for further investigation were nominated:

- A strong correlation between indicators of land use intensity (predominantly grazing) and sub-catchment in-channel sedimentation points to catchment condition as the potential causal linkages of elevated basin sediment loads;
- Increased in-channel vegetation is most likely attributable to increases in the available substrate within the channel facilitating the establishment of Melaleuca forests;
- The flood regime during and preceding the assessment period may have has been conductive to vegetation colonisation rather than stripping;
- The increase in floodplain vegetation cover may reflect an increase in invasive species (e.g. rubbervine or bellyache bush);
- Rainfall patterns, fire regime (and interactions of grazing with the latter) may be important drivers behind vegetation cover changes on the floodplain; and
- Climate change (including increased CO_2 concentrations) may have made the environment more conductive to in-channel riparian vegetation colonisation.

To examine these hypotheses and better understand the drivers of changes, Brooks *et al*. (2008) nominated a requirement for more frequent time series imagery to compare with inter-annual flood flow behaviour and collection and interpretation of fire regime and land use pressure data. More recent studies have identified grazing initiated alluvial gully erosion as the key source of elevated basin sediment loads in both these river systems (Shellberg *et al* 2010, Shellberg 2011, Shellberg and Brooks 2012). Key messages that emerge from this work include:

1. Northern Gulf Riparian zone condition is highly dynamic and assessments of directional change need to incorporate multi-scalar spatial and temporal variability;
2. Catchment condition may be the dominating driver of riverine corridor condition; and
3. Integration of catchment scale monitoring of riverine corridor condition with property scale Grazing Land Management Planning is a priority for the region Brooks *et al*. (2008).

1.2.1.2 Off-River Wetlands

Off-river wetlands are freshwater wetlands not located within contemporary river channels. They include vegetated swamps (palustrine systems) and lagoons and lakes (lacustrine systems). Off-River wetlands are described independently of riverine corridors (above) because they occur in different spatial settings and have some distinct though not mutually exclusive habitat characteristics, values and management issues. They are predominantly located on river floodplains and low lying coastal plains but can also occur outside these land forms in landscape depressions, areas of impeded drainage and in association with groundwater seepages and springs. The latter are discussed further under groundwater dependent ecosystems. Off-river freshwater wetlands associated with coastal wetland aggregations are described in the Gulf Coast section of the NRM plan, as are estuarine wetland systems.

Although the term ‘off-river’ is used to collectively describe these wetlands it is generally only an accurate description outside of wet season flood periods and does not discount the importance of riverine ecosystem processes for their formation and ecological maintenance. Some ‘off-river’ wetlands are hosted within prior river channels that have been isolated by rivers cutting short cuts across meander bends (AKA ‘billabong’ or ox-bow lagoon formation), or by river channel avulsion and migration. Where such channels have not been infilled they usually still function as distributary stream networks during flood flows. As noted for river corridors (above), during annual wet season flooding when the entire alluvial zone or floodplain may be inundated, most off-river wetlands effectively become ‘in-river’

Off-river wetlands within the Northern Gulf support a range of ecological, social and economic values (Blackman *et al* 1999). Occurring off main river channels, palustrine and lacustrine systems are generally more sheltered environments and support habitats such as submerged and fringing aquatic plant communities that are less commonly associated with riverine systems. These aquatic plant communities provide habitat for aquatic invertebrates and also feeding, roosting, nesting and moulting habitat for waterbirds. The shallow and sunlit conditions and fertile substrates often associated with palustrine and lacustrine systems also drive relatively high primary productivity which provides productive nursery and adult habitat for aquatic reptiles and fish including fishery associated species such as barramundi (Bruinsma and Duncan 2000). Productivity hotspots associated with lakes and swamps is seasonally exploited by animal consumers including up to 22 species of migratory shorebirds which visit the Gulf each year (CLCAC 2014).

More permanent off-river wetlands provide aquatic refugia for fish and other obligate aquatic biota and act as dry season refuges for a range of waterbird species including nationally and internationally significant populations of some species (Blackman *et al*. 1999). Some species of fish e.g. the rare Lake Grunter *Variichthys lacustris* have only been recorded from off-river wetland habitats (Burrows 2008), while many others depend on them at crucial stages of their life cycle (Pusey *et al* 2004). Off-river wetlands also host sites and animal and plant resources of great cultural importance to Traditional land owners including long neck turtles, waterfowl such as magpie geese and water lilies (Monaghan 2001, CLCAC 2014, CLCAC 2014b, CLCAC 2014c). Perennial off-river wetlands also provide important watering points for grazing stock. Off-river wetlands also perform a range of catchment functional roles including: providing detention areas for catchment run off which moderates flow rates and peaks; acting as retention areas for sediment and other contaminant loads which moderates downstream water quality; and function as recharge and/or discharge areas for shallow groundwater aquifers which contributes to basin landscape water balance.

Water supply to off-river wetlands is variable and depends upon landform setting and includes local catchment run in, overbank flows from adjoining river systems during flood events and groundwater aquifer discharges (Hydrobiology 2005). Due to the Northern Gulf’s highly seasonal rainfall, extended dry seasons and the generally shallow nature of most palustrine and lacustrine wetlands, the majority are highly seasonal and only a small subset hosted in deeper distributary channels or supplemented by groundwater are perennial (*Blackman et al*. 1999, Lymburner and Burrows 2008, Ward *et al* 2013). Such perennial off-river waterholes are important dry season refugia for plants and animals, particularly obligate freshwater biota (Burrows 2004, Pettit *et al* 2012, DSITIA 2014). For floodplain hosted off-river wetlands, wet season flooding is critically important for maintaining their condition and biological communities. Such flooding provides hydrological connectivity between floodplain wetlands and rivers, enables fish movement and recruitment between estuarine, river channel and floodplain habitats, scours wetland basins, resets their water quality, provides plants propagules and promotes germination and growth of floodplain vegetation communities (Hydrobiology 2005, Pettit et al 2012, Ward et al 2013). Recent food web studies have also demonstrated the importance of wet season flooding and hydrological connectivity between rivers, their floodplain and floodplain wetlands for enabling the transferal of carbon subsidies from floodplain food sources to river channel, estuarine and adjoining coastal fisheries (Jardine *et al* 2012, Hunt *et al* 2012).

Queensland wetland system mapping (QEPA 2005) has spatially defined and quantified the areal extent of the various wetland system types within Northern Gulf river basins (Table 1.4, Figure 1.1 to Figure 1..4). Wetland mapping also identifies which regional ecosystems (REs) are associated with different wetland types. REs associated with vegetated swamps (palustrine systems) and lagoons and lakes (lacustrine systems) are listed with their *Vegetation Management Act* and Biodiversity status in Table 1.5.

TABLE 1.4 EXTENT OF WETLAND SYSTEMS WITHIN NORTHERN GULF RIVER BASINS

	Area km^2				% Wetlands Area				% Basin Area			
System	**Mitchell**	**Staaten**	**Gilbert**	**Norman**	**Mitchell**	**Staaten**	**Gilbert**	**Norman**	**Mitchell**	**Staaten**	**Gilbert**	**Norman**
Artificial and highly modified	59.1	0.1	17.4	4.0	1.7	0.0	0.6	0.1	0.1	0.0	0.0	0.0
Estuarine	533	188	504	631	15.4	17.3	16.6	17.8	0.7	0.7	1.1	1.3
Lacustrine	42	16	33	12	1.2	1.5	1.1	0.3	0.1	0.1	0.1	0.0
Palustrine	1,563	532	1,051	1,572	45	48.9	34.6	44.4	2.2	2.1	2.3	3.1
Riverine	1,252	351.4	1,430	1,321	36.3	32.3	47.1	37.3	1.7	1.4	3.1	2.6
Total	**3,449**	**1,087**	**3,036**	**3,539**	**100**	**100**	**100**	**100**	**4.8**	**4.3**	**6.5**	**7.0**

A total of 40 regional ecosystems are associated with palustrine and lacustrine wetlands of the Northern Gulf region. These include grasslands and sedgelands, open woodlands, woodlands, eucalypt forest and rainforest vegetation types. Most are hosted within alluvial land zones that include old river channels, lagoons, permanent lakes and shallow seasonal depressions in alluvial plains. Other land zones and land forms including upland rock pavements, volcanic craters, sandstone gullies and gorges and coastal sand dunes and swales also host these wetland types where shallow groundwater aquifers or seepage areas occur.

TABLE 1.5 LIST AND VEGETATION MANAGEMENT ACT (VMA) AND BIODIVERSITY STATUS OF PALUSTRINE AND LACUSTRINE WETLAND ASSOCIATED REGIONAL ECOSYSTEMS OCCURRING IN NORTHERN GULF PLANNING AREA BIOREGIONS (QLD HERBARIUM 2015)

Bioregion	**RE**	**VMA Class**	**Biodiversity Status**	**Short Description**
7.3 Gulf Plains	2.2.2	Least concern	No concern at present	Secondary dunes and swales
7.4 Gulf Plains	2.3.2	Least concern	No concern at present	Freshwater and brackish wetlands in old river channels on low plains adjacent to estuarine zone
7.5 Gulf Plains	2.3.16	Least concern	Of concern	Deepwater lagoons with water lilies and sedges

Bioregion	RE	VMA Class	Biodiversity Status	Short Description
7.6 Gulf Plains	2.3.33	Least concern	Of concern	Coolibah *Eucalyptus microtheca* open woodland and sedges in circular depressions in sand plains, on cracking clays
7.7 Gulf Plains	2.3.34	Least concern	No concern at present	River Red Gum *Eucalyptus camaldulensis* woodland and sedges in circular depressions on podsolic soils
7.8 Gulf Plains	2.3.38	Of concern	Of concern	Sedges in lagoons on plateau surfaces on earths and solodised soils
7.9 Gulf Plains	2.3.39	Endangered	Endangered	Springs on recent alluvium
7.10 Gulf Plains	2.10.8	Of concern	Endangered	Springs associated with quartzose sandstone or lateritised sandstone gullies and gorges
7.11 Cape York Plains	3.3.14	Least concern	No concern at present	Willow bottlebrush *Melaleuca saligna* ± Broad leaf tea tree *Melaleuca viridiflora*, Swamp mahogany *Lophostemon suaveolens* woodland on drainage swamps
7.12 Cape York Plains	3.3.27	Least concern	No concern at present	Melville Island bloodwood *Corymbia nesophila* ±Darwin Stringybark *Eucalyptus tetrodonta* ± Cape York red Gum *Eucalyptus brassiana* woodland on alluvial sediments
7.13 Cape York Plains	3.3.32	Least concern	No concern at present	Broad leaf tea tree *Melaleuca viridiflora* ± Willow bottlebrush *Melaleuca saligna* woodland in sinkholes and drainage depressions
7.14 Cape York Plains	3.3.41	Least concern	No concern at present	Clarkson's paperbark *Melaleuca clarksonii* low open forest in swamps
7.15 Cape York Plains	3.3.49	Least concern	No concern at present	Broad leaf tea tree *Melaleuca viridiflora* low open woodland on low plains
7.16 Cape York Plains	3.3.50	Least concern	No concern at present	Broad leaf tea tree *Melaleuca viridiflora* ± Quinine bush *Petalostigma pubescens* ± Fibre barked tea tree *Melaleuca stenostachya* low open woodland on low plains
7.17 Cape York Plains	3.3.56	Least concern	No concern at present	Wanderrie grass *Eriachne spp.* ± Three awned speargrasses *Aristida spp.* closed tussock grassland alluvial plains
7.18 Cape York Plains	3.3.58	Least concern	No concern at present	Brown beard rice *Oryza rufipogon* ± Spikerush *Eleocharis spp.* closed tussock grassland in seasonally inundated depressions
7.19 Cape York Plains	3.3.65	Least concern	No concern at present	Ephemeral lakes and lagoons on alluvial plains and depressions

Bioregion	RE	VMA Class	Biodiversity Status	Short Description
7.20 Cape York Plains	3.3.66	Of concern	Of concern	Permanent lakes and lagoons, frequently with fringing woodlands or sedgelands
7.21 Wet Tropics	7.3.1	Endangered	Endangered	Mat grass *Hemarthria uncinata* and/or Southern Grass *Ischaemum australe* ± *Sorghum spp.* grassland, and/or ephemeral sedgelands, on seasonally inundated alluvial plains
7.22 Wet Tropics	7.3.4	Of concern	Endangered	Mesophyll vine forest with Fan palm *Licuala ramsayi* on poorly drained alluvial plains and alluvial areas of uplands
7.23 Wet Tropics	7.3.5	Least concern	Endangered	Five veined paperbark *Melaleuca quinquenervia* and/or Cajuput *Melaleuca cajuputi* closed forest to shrubland on poorly drained alluvial plains
7.24 Wet Tropics	7.3.10	Of concern	Endangered	Simple-complex mesophyll to notophyll vine forest on moderately to poorly-drained alluvial plains of moderate fertility
7.25 Wet Tropics	7.3.16	Least concern	Endangered	Poplar Gum *Eucalyptus platyphylla* woodland to open forest on alluvial plains
7.26 Wet Tropics	7.3.29	Of concern	Endangered	Sedgelands and grasslands of permanently and semi-permanently inundated swamps, including areas of open water
7.27 Wet Tropics	7.3.31	Of concern	Endangered	Grey rush *Lepironia articulata* sedgeland to open sedgeland of permanently to semi-permanently inundated peat swamps of alluvial plains
7.28 Wet Tropics	7.8.7	Of concern	Endangered	Blue Gum *Eucalyptus tereticornis* open forest to tall open forest and associated grasslands, predominantly on basalt uplands
7.29 Wet Tropics	7.11.1	Least concern	No concern at present	Simple-complex mesophyll to notophyll vine forest on moderately to poorly drained metamorphics (excluding amphibolites) of moderate fertility of the moist and wet lowlands, foothills and uplands
7.30 Wet Tropics	7.11.19	Of concern	Of concern	Pink bloodwood *Corymbia intermedia* and/or Swamp mahogany *Lophostemon suaveolens* open forest to woodland on uplands on metamorphics
7.31 Wet Tropics	7.12.1	Least concern	No concern at present	Simple-complex mesophyll to notophyll vine forest of moderately to poorly-drained granites and rhyolites of moderate fertility of the moist and wet lowlands, foothills and uplands

Bioregion	RE	VMA Class	Biodiversity Status	Short Description
7.32 Wet Tropics	7.12.29	Least concern	No concern at present	Pink bloodwood *Corymbia intermedia* and/or Swamp mahogany *Lophostemon suaveolens* open forest to woodland ± areas of Black she-oak *Allocasuarina littoralis* and Forest oak *A. torulosa* on uplands on granite and rhyolite
7.33 Wet Tropics	7.12.37	Of concern	Of concern	Rock pavements and seepage areas of wet lowlands, uplands and highlands of the eastern escarpment and central range on granite and rhyolite, with Oak trees *Allocasuarina spp.* shrublands and/or sedgelands
7.34 Einasleigh Uplands	9.3.4	Of concern	Of concern	Permanent or seasonal wetlands frequently fringed by narrow bands of trees and shrubs including Eucalyptus spp. on alluvial plains
7.35 Einasleigh Uplands	9.3.6	Least concern	No concern at present	Poplar Gum *Eucalyptus platyphylla* ± *Eucalyptus spp.* ± Bloodwoods *Corymbia spp.* woodland on alluvial plains
7.36 Einasleigh Uplands	9.3.7	Least concern	No concern at present	Wetlands and seasonally inundated grasslands with a fringing open woodland of mixed Eucalyptus spp. on Tertiary surfaces
7.37 Einasleigh Uplands	9.3.10	Least concern	No concern at present	Black tea-tree *Melaleuca bracteata* low closed forest ± Eucalyptus spp. emergents or vine thicket species on swamps in basalt plains
7.38 Einasleigh Uplands	9.3.11	Least concern	Of concern	Wetlands (sometimes ephemeral) with aquatic species and fringed with *Eucalyptus spp.* communities within basalt plains and flows
7.39 Einasleigh Uplands	9.3.25	Least concern	Of concern	Bluegrass *Dichanthium spp.*, and/or Mitchell grasses *Astrebla spp.* ± Flinders grasses *Iseilema spp.* grassland on alluvial deposits derived from basalt soils
7.40 Einasleigh Uplands	9.3.26	Least concern	Of concern	Mixed grassland to open grassland including Love grasses *Eragrostis spp*, Three awned speargrasses *Aristida spp.*, Bottle-washer grasses *Enneapogon sp.*, Flinders grasses *Iseilema spp.*, Windmill grass *Chloris sp.*, or Bluegrass *Dichanthium sp.* on non-basalt derived alluvial deposits
7.41 Einasleigh Uplands	9.8.7	Least concern	Of concern	Semi-evergreen vine thicket on cones, craters and rocky basalt flows with little soil development
7.42 Einasleigh Uplands	9.10.2	Of concern	Of concern	Springs and their associated vegetation on quartzose sandstone, limestone, metamorphic rock and granite

Amongst Northern Gulf region river basins, the Norman also has the greatest collective total area (3539 km^2) and percentage (7%) of basin area occupied by all wetland types. This includes the greatest area (1572 km^2) and percentage (3.1%) of basin occupied by palustrine (vegetated swamp) wetland systems (Figure 1.1). This is a consequence of its flat low lying topography a feature associated with draining predominantly Gulf Plains subregions. The Gilbert River basin (Figure 1.2) is comprised 6.5% by wetland systems including the greatest area (1321 km^2) and percentage (3.1%) of riverine systems. The Staaten River basin (Figure 1.3), which lies almost entirely within the Gulf Plain bioregion, has the greatest percentage of its total wetland area comprised of palustrine systems (48.9%). The Mitchell basin (Figure 1..4) has the second lowest percentage of basin area (4.8%) occupied by wetland system (after Staaten Basin 4.3%), but due to its large size, has the second highest total wetland area (3449 km^2), including the greatest area of lacustrine (lake) systems (42 km^2) and a near equivalent total area of palustrine systems (1563 km^2) to the Norman Basin. As described for the Norman, the extensive area of palustrine systems within the Mitchell is associated with extensive areas of flat, low lying topography associated with both Gulf Plains and Cape York Plains bioregional subregions. The density and areal extent of palustrine (vegetated swamp) systems within the northern Gulf region which also extends beyond the region north toward Cape York Peninsula and south toward the south east Gulf of Carpentaria is the greatest found in northern Australia (Cook *et al* 2011).

Another geomorphic feature of the Northern Gulf that contributes to the large extent of wetlands within its river basins is the large fluvial megafans (distributary deltas) that form the lower portion of both the Mitchell and Gilbert River basins (Blackman *et al* 1999). The Mitchell River's fluvial megafan is Australia's largest and extensive areas of palustrine and lacustrine wetland are associated with it and the Gilbert's anabranching distributary floodplain stream systems (Figure 1.2, Figure 1..4). These are unique to western Cape York Peninsula and the south east Gulf of Carpentaria are found nowhere else in tropical Australia (Cook *et al* 2011). One of the features associated with these extensive distributary networks is a large area of ox-bow lake (lacustrine) wetland systems of which

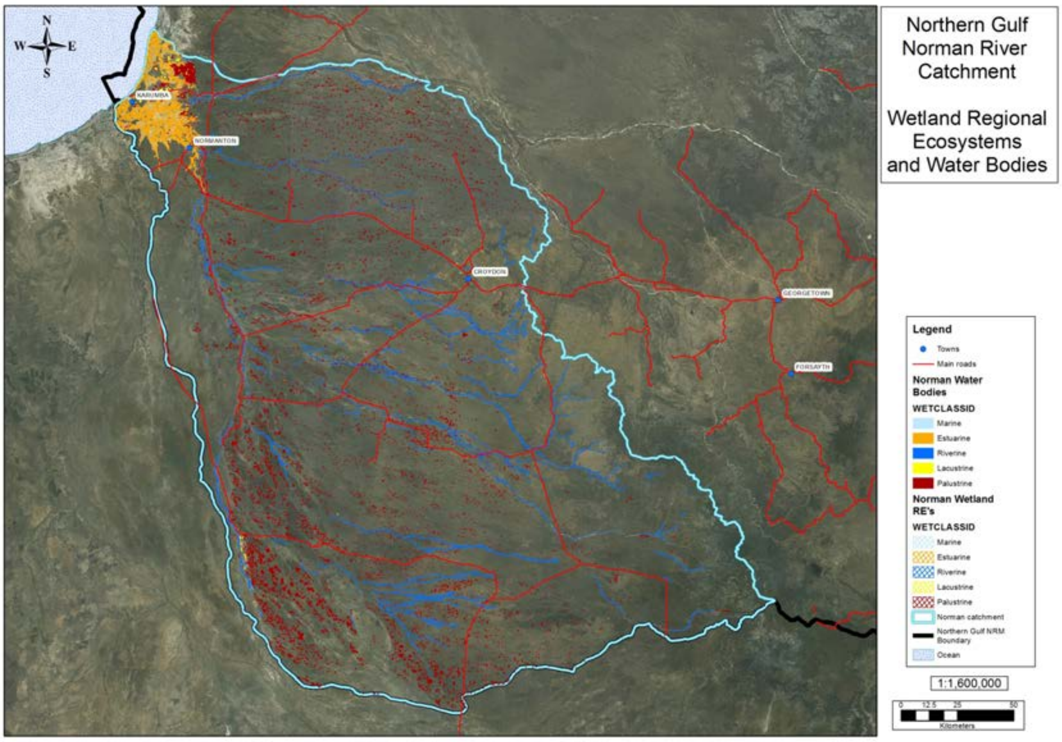


FIGURE 1.1 NORMAN RIVER CATCHMENT WETLAND REGIONAL ECOSYSTEMS AND WATERBODIES

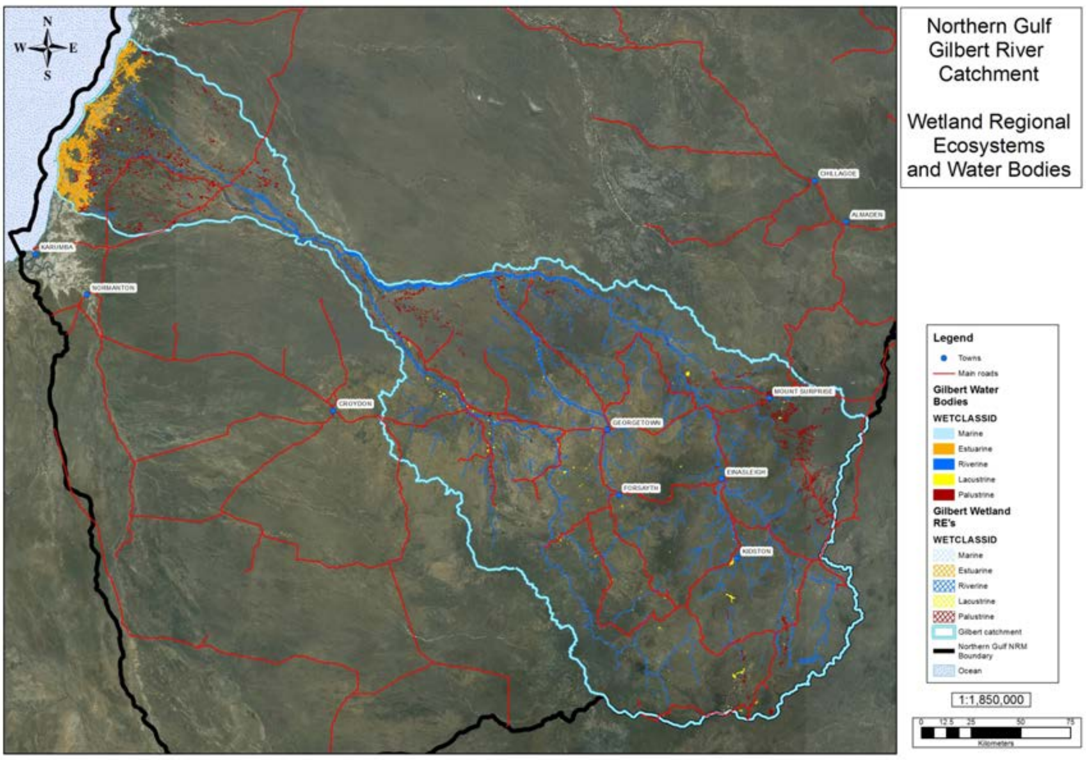


FIGURE 1.2 GILBERT RIVER CATCHMENT WETLAND REGIONAL ECOSYSTEMS AND WATERBODIES

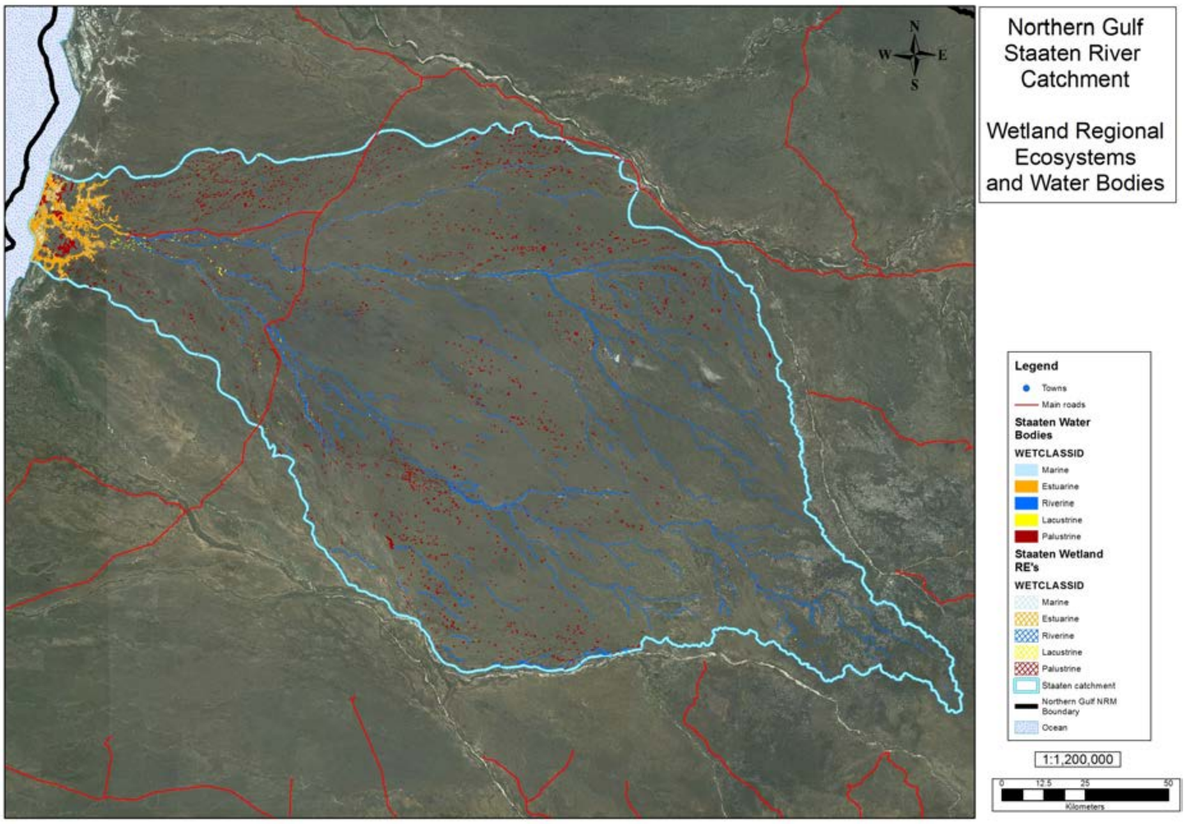


FIGURE 1.3 STAATEN RIVER CATCHMENT WETLAND REGIONAL ECOSYSTEMS AND WATERBODIES

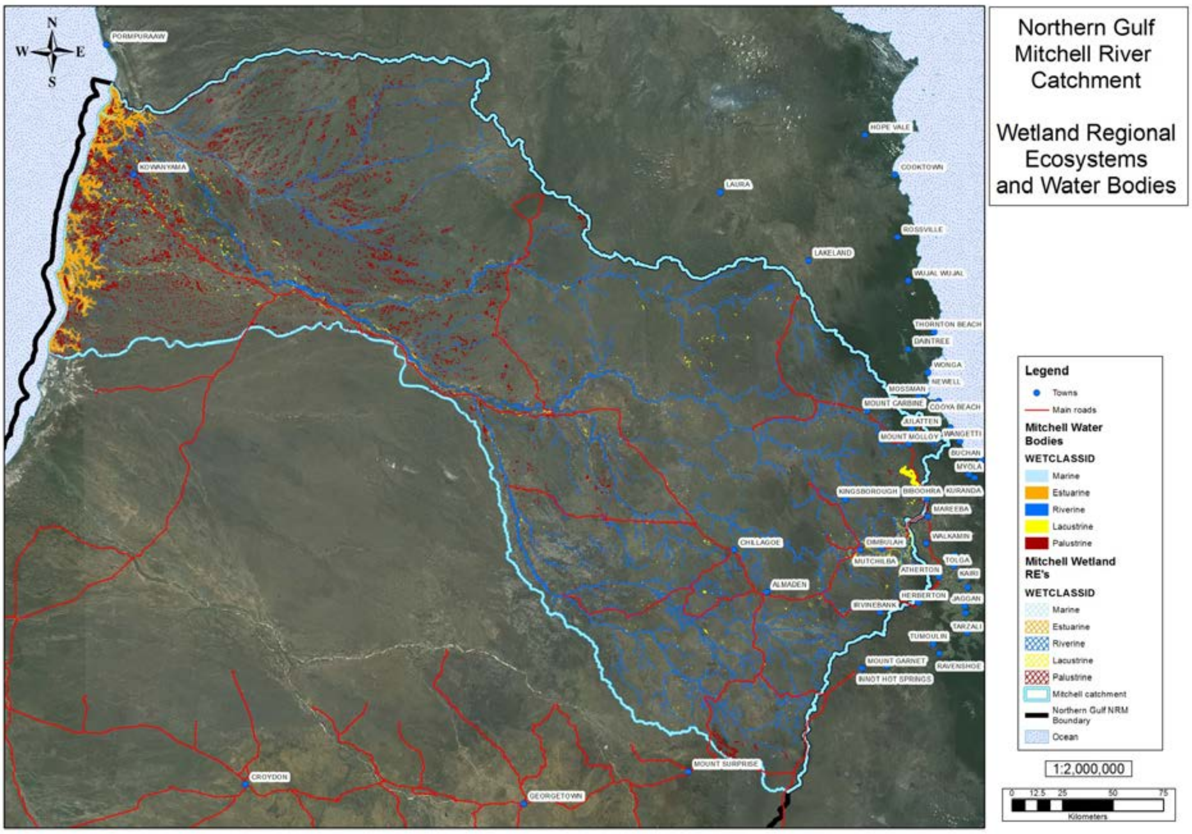


FIGURE 1..4 MITCHELL RIVER CATCHMENT WETLAND REGIONAL ECOSYSTEMS AND WATERBODIES

the Mitchell floodplain shares the greatest density found in northern Australia with the Fitzroy River floodplain in Western Australia (Pusey *et al* 2011).

Wetland aggregations associated with these distributary deltas (Mitchell Fan Aggregation and Smithburne-Gilbert Fan Aggregation) are listed in the *Directory of Important Wetlands in Australia* (Environment Australia 2001). This directory has an associated digital database providing comprehensive descriptions of ecological, hydrological and geomorphological features and values: http://www.environment.gov.au/topics/water/water-our-environment/wetlands/australian-wetlands-database. Other directory-listed freshwater wetland aggregations occurring within the Northern Gulf region that contain extensive lacustrine and palustrine systems include: Macaroni Swamp, the Dorunda Lakes Area Aggregation, the Southeast Karumba Plain Aggregation and the Southern Gulf Aggregation. The latter two occur within the Gulf coastal zone and are described as assets within the Gulf Coasts section of the NRM plan. The significant biodiversity values of these directory-listed wetlands are described more fully in *Section 7.3.2 Freshwater Biodiversity*.

While there has been no comprehensive assessment of the condition of off river wetlands within the Northern Gulf, available information including the regional ecosystem database (Qld Herbarium 2015), basin scale remote sensing studies (Lymburner and Burrows 2008, Ward *et al* 2013) and field data collected from a range of sites (Blackman *et al*. 1999, Tait 2005), indicate that condition is variable and that there is a range of operating threats.

The regional ecosystem (RE) database compiled by the Queensland Herbarium (2015) lists the *Vegetation Management Act* (VMA) and biodiversity status of each lacustrine and palustrine wetland associated REs (Table 1.5). The high exposure of these wetland-associated regional ecosystems to existing threats and ecological pressures is illustrated by their VMA and biodiversity status. More than a third (35%) has either an '*of concern*' or '*endangered*' VMA status, while a collective 55% have either an '*of concern*' or '*endangered*' biodiversity status (Table 1.5). Within the Queensland Herbarium (2015) regional ecosystem database, ecological pressures and threatening processes recorded against lacustrine and palustrine wetland associated REs occurring within the northern Gulf include (in order of decreasing record number):

- Ponded pastures;
- Rubbervine and other terrestrial weeds;
- High total grazing pressure;
- Pig rooting;
- Fragmentation from clearing;
- Stock trampling;
- Excavation for dams;
- Rill, gully and sheet erosion;
- Inappropriate fire regime;
- Other aquatic weeds;
- Catchment hydrological change; and
- Water extraction.

These threats are discussed further under *Section 7.4*. It is important to recognise that the number of records for these threatening processes does not imply spatial or management significance at a regional scale. Many records are associated with REs that have only a small spatial occurrence within the region (e.g. those associated with the Wet Tropics), and often concern threatening processes that may be predominantly affecting the RE in bioregional areas outside of the northern Gulf.

Within the Northern Gulf region different suites of threats affect wetlands in different land use contexts including: (1) the more intensively developed landscapes of the upper Mitchell Basin, (2) the extensive pastoral grazing lands of the broader region and (3) the dynamic coastal zone. It is within the more intensive land use areas of the upper Mitchell basin where issues associated with modified catchment hydrology (including irrigation tailwater inputs), clearing fragmentation, elevated nutrients and other contaminant loads and ungrazed ponded pasture weeds are most prominent (Burrows 2004, Hydrobiology 2005). In the dynamic coastal zone, threats associated with rising sea levels and destructive cyclones and storm surges are relevant, while in the extensive grazing lands, pervasive threats associated with total grazing pressure and stock trampling, pigs and other feral animals, rubbervine and other terrestrial and aquatic weeds are the most significant operating threats impacting the condition of off-river wetlands.

Extensive rangeland grazing is the dominant land use within the Northern Gulf (Appendix 1) and the majority of the mapped off-river wetlands occur on pastoral leases. On pastoral lands off-river wetlands are generally utilised as watering points and pasture resources for grazing stock. The potential and observed impacts of grazing stock on freshwater wetlands in the Northern Gulf have been described by Burrows (2004), Tait (2005) and Pettit *et al* (2012). They included accelerated soil erosion and scalding of frontage areas, pugging of the beds and banks of water bodies, grazing and trampling-based removal of fringing riparian vegetation and aquatic macrophytes, water quality impacts including elevated turbidity, increased nitrogen and phosphorus levels (also in adjoining riparian areas) and associated eutrophication, disruption and loss of benthic algae food sources and distribution and promotion of weed species. Impacts of this nature have the capacity to seriously undermine the productivity and habitat values of off-river wetlands. In the lower Mitchell distributary systems Pettit *et al* (2012) found shallow off-river wetlands were more susceptible to cattle impacts than deeper ones, and that wet season flooding and hydrological connectivity was critical for resetting water quality conditions and promoting aquatic plan community re-establishment.

There is evidence that increases in the Gulf's cattle herd in recent decades and associated changes to fencing configurations and watering point availability has placed additional pressure on freshwater wetland frontages (Tait 2005, Shellberg *et al.* 2010). However, stocking density and grazing management practices on pastoral leases vary across the region with some properties utilising fencing configurations, seasonal spelling and conservative stocking regimes that reduce stock associated impacts on freshwater wetlands (Tait 2005).

Another common wetland disturbance associated with pastoral land use is the bunding and/or excavation of wetlands basins and drainage lines to increase their water holding capacity and functional value as stock watering points (Tait 2005, Qld Herbarium 2015). While wetland habitat values can sometimes be accentuated by artificial increases in site perenniality, such developments can also significantly impact riparian and marginal wetland vegetation communities and affect aquatic habitat connectivity.

Grazing land use has been removed from off-river wetlands in protected areas across significant areas of the Northern Gulf including the Mutton Hole Wetlands Regional Park near Normanton, the Staaten River National Park and the Mitchell-Alice Rivers National Park (DEHP 2015). In terms of wetland habitat resources and water quality, the better condition of wetlands within these ungrazed areas contrasts markedly with commercial pastoral leases (Tait 2005). However, even in areas lacking commercial grazing operations, feral cattle, horses and pigs still provide a significant source of impact to Gulf freshwater wetland habitats (Tait 2005, Pettit et al 2012, CLCAC 2014). Pigs are particularly destructive to freshwater wetlands due to their targeted feeding on wetland aquatic plants such as spike rushes *Eleocharis spp.* and predation of wetland fauna including turtles, mussels, frogs and the eggs of waterbirds and turtles (Doupe *et al.* 2008, Fordham *et al.* 2008).

Cane toads *Rhinella marina* are another feral animal species common within off-river wetlands of the Northern Gulf that cause significant impacts to native fauna. While exotic fish have not yet successfully colonised the river basins of the Northern Gulf, three exotic species have been recorded in the Walsh sub-catchment of the upper Mitchell basins including guppy *Poecilia reticulata*, Mozambique tilapia *Oreochromis mossambicus and* spotted tilapia *Tilapia mariae*. An established population of the latter discovered in Eureka Creek in the Walsh sub-catchment along with a single individual of Mozambique tilapia were successfully eradicated from the site in 2008 (Burrows 2008, PestSmart 2013).

Aquatic weeds are recognised as one of the most significant threats to the condition of off-river wetlands in tropical Queensland (Burrows 2004, Smith *et al* 2007). Current infestations within the Northern Gulf are limited in extent but include many species known to be associated with severe degradation of aquatic ecosystem in other regions including floating aquatic weeds water hyacinth, salvinia and water lettuce and ponded pasture grasses hymenachne and paragrass (Burrows 2004, Perna and Burrows 2005, Tait 2013).

Water lettuce is common in Lake Mitchell though infestation levels have not yet been reported as problematic. Salvinia has previously been reported from lagoons in the vicinity of Mt Molloy though current infestation status or problems are not known (Burrows 2004). Water hyacinth infestations are primarily restricted to the distributary stream systems of the lower Mitchell sub-catchment but have extended to the lower Gilbert Smithburne sub-catchment where it is nominated as a priority for control action (Hogan and Vallence 2011). In the lower Mitchell sub-catchment water hyacinth infestations seasonally cover the surface of smaller lagoons within delta distributary systems (Pettit *et al* 2012). While Traditional land owners have discounted the severity of these infestations due to them being flushed out by annual wet season flooding (S. Rizvi pers comm.), experience in other tropical Queensland delta systems (e.g. the Burdekin) would suggest freshwater fish diversity and carrying capacity would be being impacted (Perna and Burrows 2005). Pettit et al (2012) found waterholes in the lower Mitchell infested with water hyacinth to have the lowest aquatic plant species richness and diversity. Any opportunity to eradicate infestations of this weed of national significance (WONS), should be pursued particularly considering the potential for them to act as infestation sources for adjoining catchments which are hydrologically linked during wet season flooding.

The main occurrences of ponded pastures as invasive weeds of off-river wetlands currently recognised within the Northern Gulf are within the more intensively developed catchments of the upper Mitchell basin including within the Walsh sub catchment and in Lake Mitchell, both of which are reported to contain Hymenachne and para grass (Burrows 2004). Reported infestations occur in sites that are hydrologically modified (dammed, artificially supplemented) and ungrazed, two factors commonly correlated with severe infestations of these species (Tait 2011). Ponded pasture grasses were promoted by Government primary production agencies throughout pastoral areas of the Northern Gulf through the nineties. Although these grasses are no longer actively promoted and Hymenachne is now recognised as a weed of national significance (WONS), some pastoral properties are reported to maintain pondages as dry season forage reserves. Experience in other seasonally dry pastoral areas of the southern Gulf would suggest the infestation potential of these ponded pasture species in grazed landscapes outside of artificially impounded areas is low as grazing pressure and habitat seasonality limit infestation potential (Tait 2005). However, in perennial off-river wetland areas protected from grazing stock e.g. protected areas, the infestation and ecosystem degradation potential presented by these exotic pasture species is more significant (Tait 2013), and careful management and monitoring of ponded pasture grass use in pastoral enterprises is recommended.

As reported for riverine corridors, the most significant weed infestation in terms of distribution and areal extent currently affecting off-river wetlands are those that infest wetland frontages and fringing riparian vegetation. These include rubber vine, parkinsonia, chinee apple, mimosa, calotrope and prickly acacia (Tait 2005, CLCAC 2014). These weeds can lead to the collapse or replacement of native wetland riparian vegetation communities, the loss of open habitats adjoining wetland basins and associated nesting, feeding, roosting habitat resources for waterbirds and other fauna. Given the extent of these weed infestations, control efforts need to be strategically targeted at higher value wetland assets, infestations that have some prospect of control outcomes and via management methods that can be cost effectively delivered on a broad acre scale (e.g. controlled burning where appropriate).

The threats posed by global warming (Section 7.5), including both climate change and sea level rise, present significant risks for the Northern Gulf's off-river wetlands, the latter primarily for those in lower catchments near coastal zones. Freshwater wetland ecosystems are particularly vulnerable to climate change because the persistence and quality of aquatic habitats depend heavily on climatic and hydrologic regimes (Morrongiello *et al* 2012). In low gradient landscapes such as the coastal Gulf of Carpentaria, sea level rise exacerbated by storm surges associated with greater intensity cyclones is anticipated to generate impacts to coastal floodplains and floodplain obligate biota over vast spatial scales (Pusey and Kennard 2009). Impacts of climate change on freshwater environments will primarily be realised by exacerbation of existing pressures (Section 7.5). The following are identified as particularly relevant to off-river wetlands:

- Saltwater intrusion, inundation and loss of freshwater wetlands and associated riparian vegetation resources from coastal floodplains;
- Hot fire regime impacts on riparian vegetation structure, floristic composition and associated faunal values;
- Reduced extent and number of perennial waterbodies being sustained through dry season with increased grazing and feral animal impacts on residual waterbodies and loss of associated aquatic refugial values;
- Reduced vegetation cover (drought years) in contributing catchment areas and greater rates of soil erosion and mobilisation of sediment loads, resulting in wetland basin infilling, turbidity increases and habitat losses;

- Increased thermal stress and associated water quality impacts associated with stratification, increased decomposition/respiration rates, depressed dissolved oxygen and algal blooms resulting in reduced refugia function for aquatic biota through the dry season;
- Generation of potentially advantageous conditions for opportunistic exotic fish and weed species with broader habitat tolerances resulting in displacement of native biodiversity;
- Disruptive extreme/large flood events resulting in geomorphic (scouring, erosion) and sustained inundation impacts, with some potentially beneficial outcomes for flushing out exotic weeds and enhanced connectivity between wetlands and river channels.

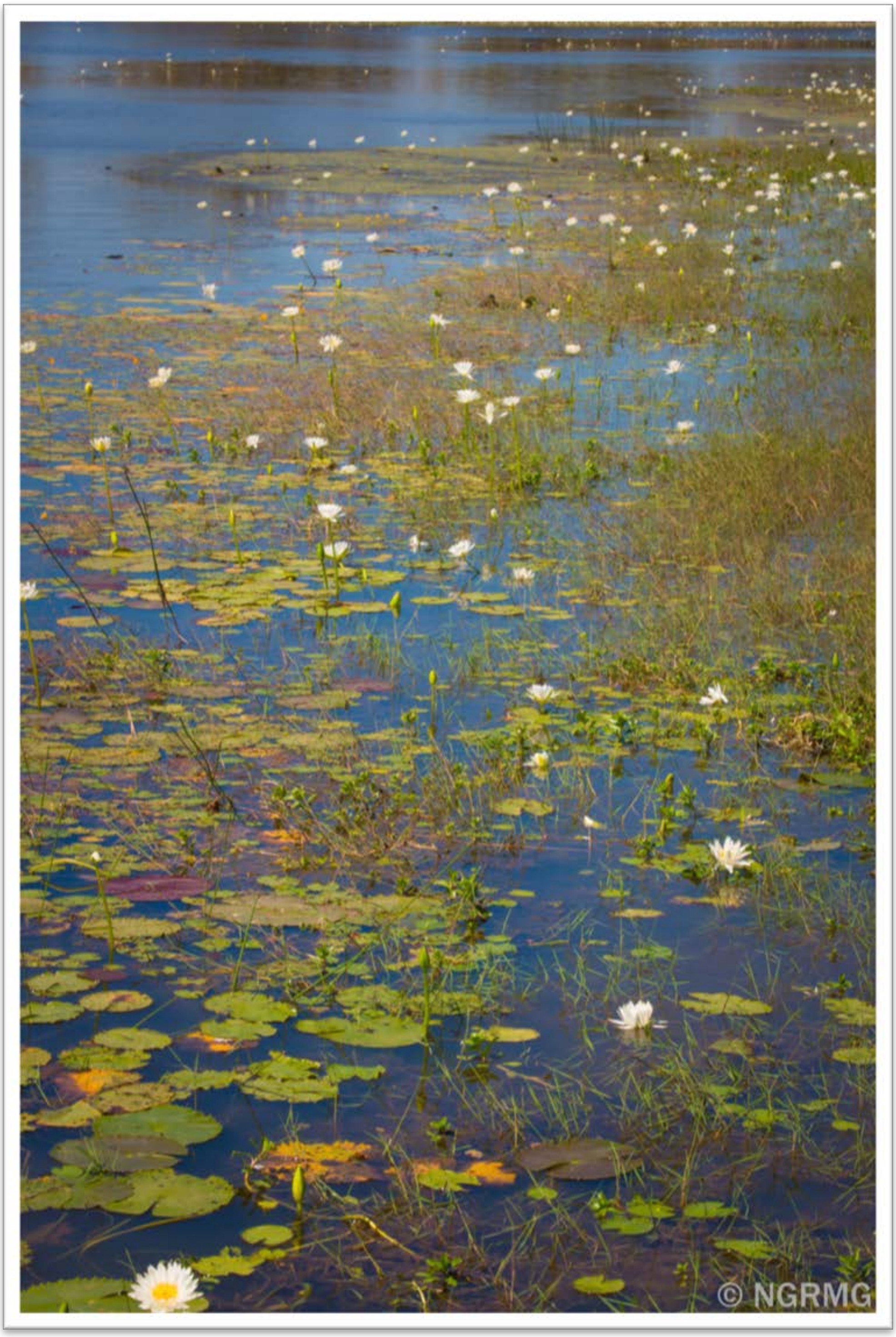


TABLE 1.6 LIST AND VEGETATION MANAGEMENT ACT (VMA) AND BIODIVERSITY STATUS OF FLOODPLAIN AND FREQUENTLY INUNDATED REGIONAL ECOSYSTEMS OCCURRING IN NORTHERN GULF PLANNING AREA BIOREGIONS (QLD HERBARIUM 2015)

Bioregion	RE	VMA Class	Biodiversity Status	Short Description
7.43 Gulf Plains	2.3.1	Least concern	No concern at present	Grassland on low plains adjacent to estuarine zone
7.44 Gulf Plains	2.3.3	Least concern	No concern at present	Mitchell grasses *Astrebla spp.*. grassland on plains of cracking clays
7.45 Gulf Plains	2.3.4	Least concern	No concern at present	Bluegrass *Dichanthium spp* and Brown top *Eulalia aurea* grassland on plains of cracking clays
7.46 Gulf Plains	2.3.6	Least concern	Of concern	Deciduous woodland on plains of cracking clay
7.47 Gulf Plains	2.3.7	Least concern	No concern at present	Gidgee *Acacia cambagei* low woodland on plains on clays
7.48 Gulf Plains	2.3.9	Least concern	Of concern	Coolibah *Eucalyptus microtheca,* Bauhinia *Lysiphyllum cunninghamii* low open woodland and Three awned speargrasses *Aristida spp.* on plains and low rises of texture contrast soils and earths
7.49 Gulf Plains	2.3.10	Least concern	No concern at present	Coolibah *Eucalyptus microtheca*, Eucalyptus chlorophylla low open woodland, and Melaleuca viridiflora woodlands and savannahs, on plains
7.50 Gulf Plains	2.3.11	Least concern	No concern at present	Coolibah *Eucalyptus microtheca*, Gutta-*percha Excoecaria parvifolia* open woodland and Bluegrass *Dichanthium spp.* On grey clay plains
7.51 Gulf Plains	2.3.12	Of concern	Of concern	Gutta-*percha Excoecaria parvifolia* open woodland with sedges in seasonal swamps on grey clay plains
7.52 Gulf Plains	2.3.18	Least concern	Of concern	Whitewood *Atalaya hemiglauca* and Beefwood *Grevillea striata* low woodland on low rises and plains on red loamy soils
7.53 Gulf Plains	2.3.21	Least concern	Of concern	Brown box *Eucalyptus leptophleba* and Bloodwood *Corymbia spp.* woodland on low rises and plains on fine sands and red earths
7.54 Gulf Plains	2.3.22	Least concern	Of concern	Long fruited bloodwood *Corymbia polycarpa* and Paprbark *Melaleuca spp.* woodland on sandy channels and levees
7.55 Gulf Plains	2.3.23	Least concern	Of concern	Brown box *Eucalyptus leptophleba* and Broad-leaved carbeen *Corymbia confertiflora* woodland on sandy alluvial terraces and levees
7.56 Gulf Plains	2.3.28	Least concern	No concern at present	Paperbark *Melaleuca spp.* woodland in depressions and shallow valleys on solodised soils and pale earths

Bioregion	RE	VMA Class	Biodiversity Status	Short Description
7.57 Gulf Plains	2.3 .29	Least concern	Of concern	Paperbark *Melaleuca spp.* Low woodland fringing depressions and broad valleys on solodised soils
7.58 Gulf Plains	2.3 .31	Least concern	Of concern	Paperbark *Melaleuca spp.* low woodland in depressions and valley bottoms on fine-textured yellow earths
7.59 Gulf Plains	2.3 .36	Least concern	No concern at present	Paperbark *Melaleuca spp.* low woodland in bottoms of shallow valleys, on solodised soils
7.60 Gulf Plains	2.5 .3	Least concern	No concern at present	Evergreen scrub on plains on mainly deep sandy soils
7.61 Cape York Plains	3.3 .16	Least concern	No concern at present	Greenleaf box *Eucalyptus chlorophylla* ± Grey bloodwood *Corymbia clarksoniana* woodland on alluvial plains and colluvial fans
7.62 Cape York Plains	3.3 .20	Least concern	No concern at present	Grey bloodwood *Corymbia clarksoniana* woodland to open forest on alluvial outwash plains
7.63 Cape York Plains	3.3 .23	Least concern	No concern at present	Grey bloodwood *Corymbia clarksoniana* or Long fruited bloodwood *Corymbia polycarpa* woodland on stream levees
7.64 Cape York Plains	3.3 .25	Least concern	No concern at present	Brown box *Eucalyptus leptophleba* ± Corymbia tessellaris ± C. clarksoniana woodland on floodplains
7.65 Cape York Plains	3.3 .29	Least concern	Of concern	Long fruited bloodwood *Corymbia polycarpa* ± C. curtipes woodland on Mitchell River levees
7.66 Cape York Plains	3.3 .31	Least concern	No concern at present	Darwin Stringybark *Eucalyptus tetrodonta* ± Grey bloodwood *Corymbia clarksoniana* woodland on floodplains
7.67 Cape York Plains	3.3 .33	Least concern	No concern at present	*Thryptomene oligandra* and Broad leaf tea tree *Melaleuca viridiflora* woodland on sides of depressions
7.68 Cape York Plains	3.3 .36	Least concern	No concern at present	Brown box *Eucalyptus leptophleba* woodland to open woodland on alluvial plains
7.69 Cape York Plains	3.3 .42	Least concern	No concern at present	Broad leaf tea tree *Melaleuca viridiflora* low woodland in drainage areas
7.70 Cape York Plains	3.3 .45	Of concern	Of concern	Greenleaf box *Eucalyptus chlorophylla* ± Broad leaf tea tree *Melaleuca viridiflora* low open woodland on Mitchell River floodplain

Bioregion	RE	VMA Class	Biodiversity Status	Short Description
7.71 Cape York Plains	3.3 .47	Least concern	No concern at present	Lemon scented paperbark *Melaleuca citrolens* ± Small leaf paperbark *M. foliolosa* low open woodland along drainage lines
7.72 Cape York Plains	3.3 .51	Of concern	Of concern	Wattle paperbark *Melaleuca acacioides* ± *Hakea pedunculata* tall shrubland on marine plains
7.73 Cape York Plains	3.3 .52	Least concern	No concern at present	Small leaf paperbark *M. foliolosa* ± Lemon scented paperbark *Melaleuca citrolens* tall shrubland with *Bossiaea armitii* on eroding drainage areas
7.74 Cape York Plains	3.3 .61	Least concern	No concern at present	Panic grass *Panicum spp.*, Fringe rush *Fimbristylis spp.* tussock grassland on coastal alluvial clay plains
7.75 Wet Tropics	7.3 .8	Least concern	Endangered	Broad leaf tea tree *Melaleuca viridiflora* ± *Eucalyptus spp.* ± Swamp mahogany *Lophostemon suaveolens* open forest to open woodland on poorly drained alluvial plains
7.76 Wet Tropics	7.3 .12	Endang ered	Endangered	Mixed eucalypt open forest to woodland, dominated by Blue gum *Eucalyptus tereticornis* and Morton bay ash *Corymbia tessellaris* ± Blue leaf paperbark *Melaleuca dealbata*, (or vine forest with these species as emergents). Lowland alluvial plains
7.77 Wet Tropics	7.3 .14	Of concern	Of concern	Brown box *Eucalyptus leptophleba* ± Grey bloodwood *Corymbia clarksoniana* ± Blue leaf paperbark *Melaleuca dealbata* woodland to open forest on alluvium in low rainfall areas of the west and north
7.78 Wet Tropics	7.3 .20	Of concern	Of concern	Pink bloodwood *Corymbia intermedia* and *Turpentine Syncarpia glomulifera*, or Pink bloodwood C. *intermedia* and Red stringybark *Eucalyptus pellita*, or *S. glomulifera* and Oaks *Allocasuarina spp.*, or Gympie messmate *Eucalyptus cloeziana*, or Cadaga *Corymbia torelliana* open forest (or vine forest with these emergents) on alluvial fans at the base of ranges
7.79 Wet Tropics	7.3 .21	Of concern	Of concern	White Stringybark *Eucalyptus portuensis* ± Pink bloodwood *Corymbia intermedia* open forest to woodland on alluvium on alluvial fans at the base of ranges
7.80 Wet Tropics	7.3 .35	Endang ered	Endangered	Brown salwood *Acacia mangium* and/or Hickory wattle A. celsa and/or A. polystachya closed forest on alluvial plains
7.81 Wet Tropics	7.3 .39	Of concern	Endangered	Blue gum *Eucalyptus tereticornis* ± Poplar gum *E. platyphylla* ± Pink bloodwood *Corymbia intermedia* ± Swamp mahogany *Lophostemon suaveolens* open woodland to open forest, and associated sedgelands and grasslands on broad drainage depressions of uplands

Bioregion		RE	VMA Class	Biodiversity Status	Short Description
7.82	Wet Tropics	7.3.40	Endangered	Endangered	Blue gum *Eucalyptus tereticornis* open forest on well-drained alluvial plains of lowlands
7.83	Wet Tropics	7.3.43	Of concern	Endangered	Blue gum *Eucalyptus tereticornis* open forest to woodland on uplands on well-drained alluvium
7.84	Wet Tropics	7.3.45	Least concern	Of concern	Grey bloodwood *Corymbia clarksoniana* ± C. tessellaris ± E. drepanophylla open forest to open woodland on alluvial plains
7.85	Wet Tropics	7.3.48	Of concern	Endangered	White Stringybark *Eucalyptus portuensis* and Narrow leaf ironbark *E. drepanophylla* ± Pink Bloodwood *Corymbia intermedia* ± Lemon Scented gum *C. citriodora* open woodland to open forest on dry uplands on alluvium
7.86	Wet Tropics	7.11.41	Of concern	Of concern	Broad leaf tea tree *Melaleuca viridiflora*, Single flowered paperbark *M. monantha*, Red wattle *Acacia flavescens*, and Beefwoods *Grevillea spp.* shrubland, with emergent Grey bloodwood *Corymbia clarksoniana*, or open woodland of Narrow leaf ironbark *Eucalyptus drepanophylla* with *M. monantha* or Cypress pine *Callitris intratropica*, on metamorphics
7.87	Wet Tropics	7.11.48	Of concern	Endangered	Broad leaf tea tree *Melaleuca viridiflora* ± Grey bloodwood *Corymbia clarksoniana* ± Eucalyptus platyphylla woodland to open forest on metamorphics
7.88	Wet Tropics	7.12.60	Of concern	Endangered	Broad leaf tea tree *Melaleuca viridiflora* ± Grey bloodwood *Corymbia clarksoniana* ± Eucalyptus platyphylla woodland to open forest on granite and rhyolite
7.89	Einasleigh Uplands	9.3.2	Least concern	No concern at present	Brown box *Eucalyptus leptophleba* and/or Greenleaf box *Eucalyptus chlorophylla* ± Dallacy's gum *Corymbia dallachiana* woodland on river levees and terraces
7.90	Einasleigh Uplands	9.3.3	Least concern	Of concern	Brown box *Eucalyptus leptophleba* ± Cooktown ironwood *Erythrophleum chlorostachys* woodland on alluvial flats
7.91	Einasleigh Uplands	9.3.5	Least concern	Of concern	Reid River box *Eucalyptus brownii* ± *Eucalyptus spp.* ± Bloodwoods *Corymbia spp.* open woodland on alluvial plains
7.92	Einasleigh Uplands	9.3.16	Least concern	Of concern	Blue gum *Eucalyptus tereticornis* and/or Poplar gum *E. platyphylla* and/or Grey bloodwood *Corymbia clarksoniana* woodland on alluvial flats, levees and plains

Bioregion	RE	VMA Class	Biodiversity Status	Short Description
7.93 Einasleigh Uplands	9.3.19	Least concern	Of concern	Eucalyptus coolabah open woodland on alluvial plains
7.94 Einasleigh Uplands	9.3.20	Least concern	No concern at present	Georgetown box *Eucalyptus microneura* ± Bloodwoods *Corymbia spp.* ± Brown box *Eucalyptus leptophleba* woodland on alluvial plains
Einasleigh Uplands	9.3.23	Of concern	Of concern	Boree *Acacia tephrina* open forest on alluvial clay plains
7.95 Einasleigh Uplands	9.3.24	Least concern	No concern at present	Broad leaf tea tree *Melaleuca viridiflora* and/or Lemon scented paperbark *M. citrolens* low woodland ± Bloodwoods *Corymbia spp.* emergents on alluvial deposits

1.2.1.2 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems (GDEs) contain communities of plants and animals that rely on groundwater to survive and represent a geographically small, yet diverse and significant component of Australian biodiversity. Groundwater dependent ecosystems also have significant social, economic and spiritual values (Murray *et al*. 2003). There are three commonly recognised types of groundwater dependent ecosystems; subterranean ecosystems within groundwater aquifers and caves which include specially adapted stygnofauna, ecosystems associated with the surface expression of groundwater including springs, soaks and perennial streams, and ecosystems reliant on groundwater within the root zone (NCGRT n.d.).

Springs and groundwater soaks and associated biological communities are perhaps the most well recognised groundwater dependent ecosystems and there are a number of spring ecosystems in the Northern Gulf region, particularly within the Einasleigh uplands bioregion. However, in a seasonally dry environment like the Northern Gulf, groundwater plays an important role in the hydrology and ecology of most freshwater ecosystems. It can influence the flow regime of streams, the availability of aquatic refugia during the dry season and the composition and structure of riparian vegetation communities (Hydrobiology 2005, Cook *et al* 2011). Considering the linkages between groundwater and surface water, a broad suite of aquatic and even terrestrial ecosystems can be identified as having some 'groundwater dependence'. Groundwater aquifers within the Northern Gulf include shallow alluvial sand beds and beach ridge deposits, Tertiary sediments and fractured rock basements and sandstones within the Carpentaria and the Great Artesian Basin (CSIRO 2009).

The Great Artesian Basin underlies much of the Northern Gulf region and several major springs in the Northern Gulf are fed from this source (Burrows 2004a; Fensham 2006). Springs are particularly important because they feed permanent wetlands that provide refuge for a range of unique aquatic and terrestrial fauna in an otherwise dry landscape, giving them high biodiversity values (Fensham & Price 2004; Fensham 2006). Spring-fed aquatic refugia occur in the upper catchments of all Northern Gulf rivers including the Norman, Gilbert and Staaten (Hydrobiology 2005). Throughout the Great Artesian Basin many discharge springs have become inactive due to a loss of pressure created by excessive extraction of water, predominantly for pastoral uses (Burrows 2004a; Fensham & Price 2004; Fensham 2006). Some of the remaining Great Artesian Basin discharge springs occur in the Northern Gulf region (Fensham & Fairfax 2003; Burrows 2004a) and these may be threatened by future extraction. Two of these springs, Jantala (Blackbraes National Park) and Bulleringa (Bulleringa National Park) are of particularly high conservation value due to their floristic values (Fensham & Price 2004). Springs are particularly vulnerable to disturbance from livestock, feral pigs, ponded pastures, excavation and bore-drain construction

(Fensham & Fairfax 2003; Burrows 2004a) as they offer a permanent water source. Two Mitchell Basin groundwater dependent wetlands that are also associated with cave systems are listed in the *Directory of Important Wetlands in Australia* (Environment Australia 2001); these are the Spring Tower Complex and the Undara Lava Tubes. Both systems are supplied by permanent and seasonal groundwater springs. The former occurs in limestone within the upper Walsh sub-catchment and is an example of subterranean karst wetlands, while the latter occur in subterranean lava tubes associated with the Undara lava flows south east of Mount Surprise (Blackman *et al* 1999).

Stygofauna are tiny creatures that live underground in aquifers; they include crustaceans, worms, gastropods, beetles, mites and fish (NCGRT n.d.). Stygofaunal communities of the Northern Gulf region remain relatively unsurveyed and undocumented (Hogan *et al*. 2009a). Most cannot survive above ground and rely on groundwater for survival. They are therefore, very vulnerable to changes in their environment. Stygofauna including blind amphipods have been recorded within the Spring Tower cave complex (Blackman *et al* 1999). Dewatering of groundwater at an adjoining mining operation is believed to be associated with significant reductions in groundwater levels within this system (Blackman *et al* 1999).

Ecosystems that rely on the surface expression of groundwater include wetlands and rivers that are supplied by groundwater discharge. Some near coastal marine environments within the Gulf of Carpentaria are also supplied by groundwater discharge (Hydrobiology 2005), though the significance of these discharges to ecosystem function and values is unknown (DISITIA 2014b). The most obvious examples of groundwater surface expression include rivers and streams that flow during the dry season (e.g. the Mitchell and upper catchment streams of the Staaten and Gilbert), and waterholes that persist while others of equivalent volume recede and dry. Many of the Northern Gulf's perennial aquatic habitats that function as aquatic refugia during dry seasons are maintained by groundwater (Hydrobiology 2005, Barber *et al* 2013). Across northern Australia, higher levels of aquatic biodiversity including fish species richness are associated with perennial stream flows and aquatic habitats (Pusey *et al* 2011). The second highest river basin fish species richness nationally is recorded for the Mitchell River basin and is partially attributable to its extensive and diverse perennial aquatic habitats. This illustrates the direct dependence of aquatic biodiversity generally on groundwater.

Ecosystems reliant on groundwater within the root zone include woodlands and forests that are reliant on their roots being within reach of groundwater to persist through dry periods (NCGRT n.d.). Within the Northern Gulf, groundwater dependent vegetation communities include regional ecosystems associated with fractured rock aquifer discharge areas, fringing riverine areas, floodplains and beach ridges. On alluvial land forms, the root zones of these vegetation communities access shallow sand lenses that act as seasonal or permanent groundwater aquifers. These aquifers usually depend on a combination of rainfall, overbank flooding, and within channel river flows for recharge (Hydrobiology 2005). In some instances shallow sand aquifers are also supplied by deeper underlying sedimentary or fractured rock aquifers (CSIRO 2009).

Groundwater fed baseflows within the sand beds of the dry Gilbert River channel represent another example of a groundwater dependent ecosystem that also occurs within seasonal rivers of the Northern Gulf (Hydrobiology 2005). The wetted zone of these sand beds is known as the *hyporheic zone* and organisms living within it as the *hyporheos* (Hogan and Bennison 2007). While the hyporheos of the Gilbert River are yet to be documented, these environments and their associated communities are known to be important to a range of ecosystem functions including nutrient cycling and water quality maintenance (DISITIA 2014).

Removal of water from groundwater dependent ecosystems, or a change in the timing, quantity, quality or distribution of groundwater can influence ecosystem status. For example, reducing the availability of groundwater to vegetation would reduce the recruitment or survivability of seedlings and therefore cause changes in the associated fauna assemblages (Murray *et al*. 2003). Over extraction of groundwater from the sand bed aquifers of the Gilbert River has been identified to have the potential to cause a range of impacts, including increased water stress to dependent riparian vegetation communities, changes to the depositional transport and erosion characteristics of the rivers and alteration of water quality (salinity, nutrients, temperature, dissolved oxygen and perenniality of downstream waterbodies [Hydrobiology 2005, Barber *et al* 2013, DISITIA 2014]).

While many GDEs are associated with groundwater discharge areas and their source, aquifers management also needs to consider groundwater recharge areas. Recharge areas for the Great Artesian Basin occur within several of the Northern Gulf's river basins, including the Mitchell which also hosts important recharge areas for sub-artesian groundwater aquifers within the Palmer River sub-catchment (Hydrobiology 2005, CSIRO 2009). Land use impacts including vegetation clearing, soil erosion and sub soil exposure/scalding can impact the functional viability of such recharge areas. Construction of on-stream water infrastructure can also impact downstream groundwater recharge processes by altering the range and duration of instream and/or overbank flows that provide recharge of shallow alluvial aquifers associated with the river channels and floodplains (Tait 2013). In the Mitchell River basin the construction of Lake Mitchell on the more perennial stem of the upper catchment has been identified as source of potential impact on groundwater recharge processes for downstream shallow aquifers (Hydrobiology 2005).

While the Mitchell River has been subject to specific groundwater resource investigations that have identified further resource exploitation potential (CSIRO 2009), elsewhere limited understanding of groundwater resources or demonstrated exploitation constraints highlight the need for prudence and further assessment if further development of the region's groundwater resources is to be pursued. Indications that a significant proportion of some regional rivers' dry season baseflows are fed by aquifers containing ancient groundwater not recharged by contemporary processes, provide an example of sustainability constraints associated with further groundwater development (Hydrobiology 2005). The potential for projected climate change within the Northern Gulf (Moise 2014, Gobius 2015) to impact groundwater recharge characteristics poses another emerging risk to its groundwater dependent ecosystems.

1.2.2 Freshwater Biodiversity

Biodiversity by its simplest definition means 'life in all its forms'. Nationally and internationally, biodiversity associated with freshwater ecosystems is emerging as some of the most threatened, due to high human demands for water and other river resources and due to the impacts of development within river catchments (Dugeon *et al.*2005, Abell et al.2007, Arthington 2012). Globally undeveloped river basins are restricted to a handful of the world's most remote locations (about 0.16% of the earth's surface area) including the high north e.g. Siberia, Canada, Alaska and less populated parts of the tropical zone e.g. Amazonia and northern Australasia (Arthington 2012). The relatively undeveloped river basins draining northern Australia including those within the Northern Gulf collectively represent the greatest extent of high integrity natural rivers remaining in Australia and have globally significant ecological values and nationally important cultural, social and economic values (Pusey *et al.*2009, Pusey 2011). Besides the relative 'intactness' of the Northern Gulf river ecosystems attributable to limited land and water resource development, the rich aquatic biodiversity of the region is also associated with the bioregional diversity of its river basins, particularly the Mitchell which may possibly contain the most ecologically diverse aquatic ecosystems in Australia, reflecting a large river system with wet tropics, dry tropics and monsoonal influences (Close *et al* 2012). The other major contributions to relatively high aquatic biodiversity regionally include the perenniality of freshwaters, including baseflow rivers, stream and groundwater supplemented wetlands and the extent of wetlands associated with wet season flooding and extensive alluvial landforms, e.g. floodplains and deltas. The national and international significance of the Northern Gulf's river systems conveys responsibilities and opportunities for the development of NRM strategies for the region.

Freshwater biodiversity has intrinsic, utility and conservation values, none of which are mutually exclusive and all of which have linkages to economic, social and cultural values. Intrinsic values are associated with the maintenance of life and evolutionary processes *for its own sake*. Utility values are derived from species and ecosystems that are useful to humans in terms of providing sustenance, materials, recreation or other ecosystem products or services some of which provide economic benefits. Examples within the northern Gulf include fish, crustaceans and wetland plants which provide traditional sustenance resources or form the basis of traditional and recreational fisheries; river landscapes which provide sense of place, spiritual meaning and cultural identity, recreational opportunities and the base for ecotourism; watering points and floodplain pasture resources that are utilised by the pastoral industry; primary productivity, nursery habitats and flood flows that support productive commercial fisheries and a host of catchment ecosystem services that maintain natural resource quality and life support e.g. groundwater recharge, run off detention, erosion prevention, carbon sequestration, nutrient cycling, contaminant interception and oxygen production. Some 'direct use' or utilitarian values of biodiversity translate directly into economic values with market place visibility. The extent to which management of dependent industries also serves biodiversity conservation outcomes is a key measure of their ecological sustainability and a focal area for regional NRM.

The 'conservation value' of biodiversity relates to the contribution that a particular complement of individuals, species, ecosystems or sites provides to the task of conserving biodiversity. Fortunately, the inclusion of Northern Gulf river basins in the Northern Australia Water Futures Assessment (NAWFA) area, and the associated Northern Australia Aquatic Ecological Assets Project (Kennard *et al*.2010, 2011), has resulted in the aquatic biodiversity values of the region being the subject of much recent assessment and definition (Hermoso *et al*.2011). High biodiversity conservation values within the region have been defined in relation to all of northern Australia by: application of multiple conservation evaluation criteria considering vital habitat, evolutionary history of biota, diversity, distinctiveness, naturalness and representativeness (FigurE 1.5); by systematic conservation planning approaches targeting inclusion of wetland associated birds, fish, turtles and wetland types (Figure 1.6) and by reference to patterns of freshwater fish and turtle species richness and endemism (Figure 1.7). Examining these outputs, the freshwater biodiversity of the Northern Gulf region is seen to have nationally high values in relation to: diversity, distinctiveness, vital habitat and representativeness (FigurE 1.5); freshwater fish, palustrine and lacustrine wetlands (Figure 1.6); and freshwater fish species richness and both freshwater fish and freshwater turtle endemism (Figure 1.7).

While some components of the Northern Gulf's freshwater biodiversity e.g. fish (Appendix 2), have been relatively well surveyed in recent years under the impetus of prospective water resource development, much of it remains relatively undocumented. Where survey efforts are expended new species are discovered and the range of known species extended (e.g. Hogan *et al* 2009). Systematic surveys for a range of key fauna groups including freshwater turtles, aquatic invertebrates, stygofauna (aquifer dwelling) and hyporheic (river bed sand dwelling) fauna have not yet been conducted within the region.

Threats to aquatic biodiversity in the Northern Gulf are essentially the same as those identified for freshwater habitats. They include pervasive threats such as total grazing pressure, weeds, feral animals, fire regime and catchment condition and directed threats such as land clearing and development, hunting and fishing. Emerging threats include water resource development and associated land use intensification, climate change and sea level rise and the prospect of new exotic species establishing.

While there is a general assumption that the status of aquatic biodiversity within the region is secure on account of limited development, there is only limited monitoring data and coverage by which to test such assumptions. Available data does indicate that some pressures such as the impact of grazing and associated soil erosion are increasing (Shellberg and Brooks 2012). In comparison to many other regions of Australia, the resilience of the Northern Gulf's aquatic ecosystem to potential threats including that associated with climate change is best served by the intactness of its catchment's ecosystems, particularly their hydrological integrity (Kingsford 2011).

The following sections examine a range of freshwater biodiversity assets within the Northern Gulf region including different biota groups (fish and other aquatic vertebrates, invertebrates, waterbirds); areas of wetland ecosystem that are recognised to be of national importance and which provide a focal point for conservative management (DIWA wetland aggregations); wetland ecosystems that are defined by current vegetation management frameworks (wetland associated REs); threatened components of freshwater biodiversity that are afforded statutory protection as a basis for recovery (threatened species and ecological communities); and existing protected areas, the so called '*jewels in the biodiversity conservation crown*'. Examination of each of these assets status within the Northern Gulf region identifies needs and opportunities in relation to regional NRM planning.

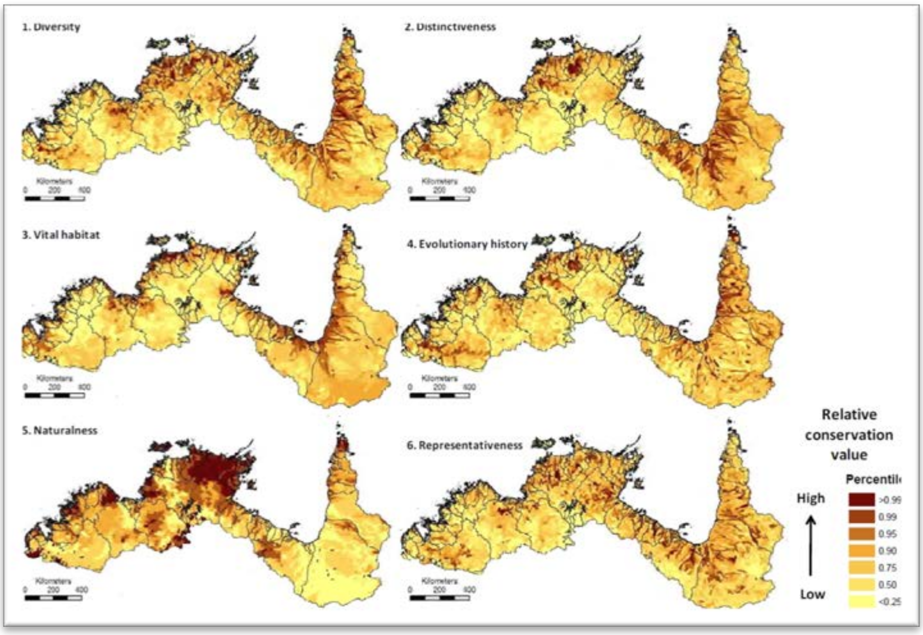


FIGURE 1.5 RELATIVE CONSERVATION VALUE FOR EACH SUB-BASIN ACROSS NORTHERN AUSTRALIA, ACCORDING TO SIX NATIONAL HIGH CONSERVATION VALUE AQUATIC ECOSYSTEM CRITERIA (SOURCE: KENNARD 2010).

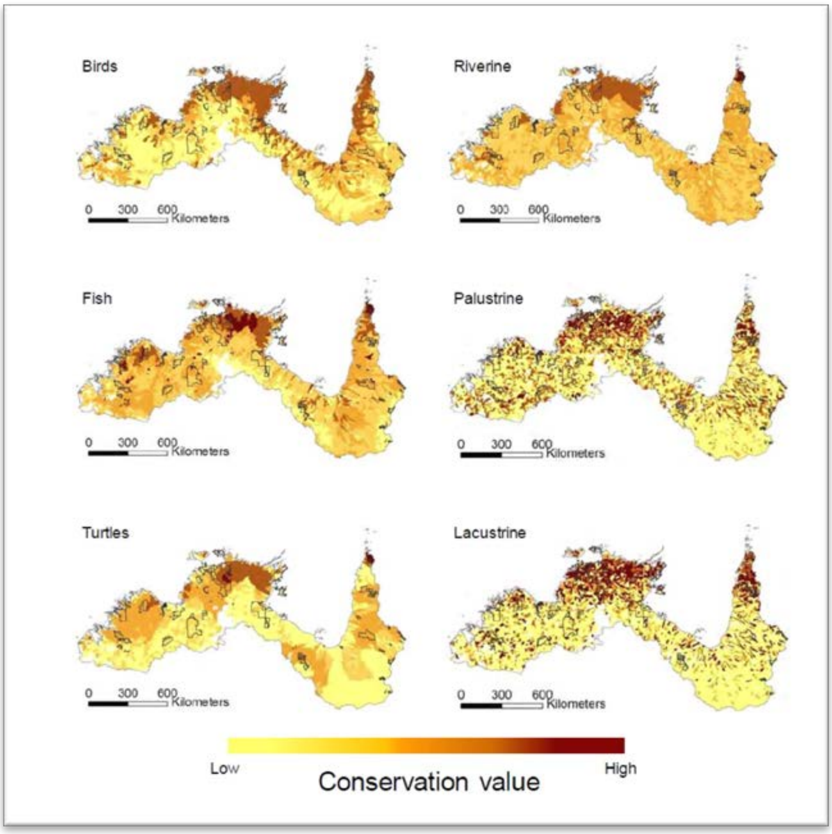
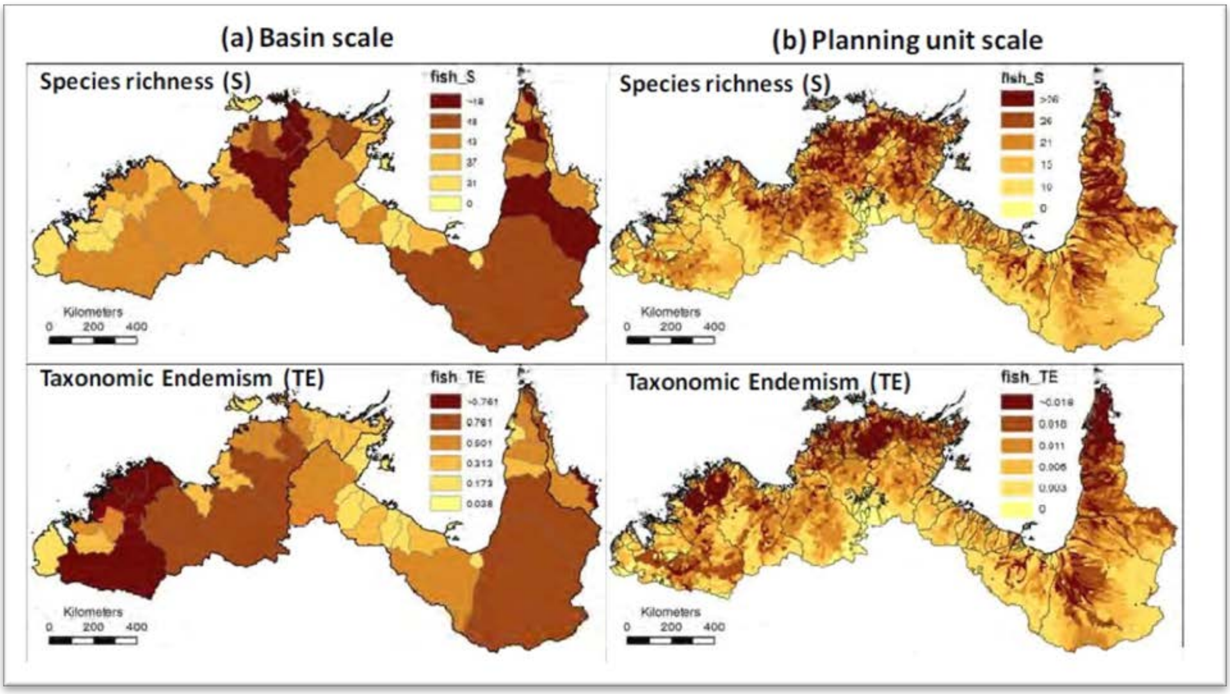


FIGURE 1.6 RELATIVE CONSERVATION VALUE* OF SUB-BASINS IN NORTHERN AUSTRALIA IDENTIFIED USING A SYSTEMATIC CONSERVATION-PLANNING APPROACH AND MARXAN SOFTWARE (SOURCE: KENNARD 2011).

Freshwater Fish Species Richness and Endemism



Freshwater Turtle Species Richness and Endemism

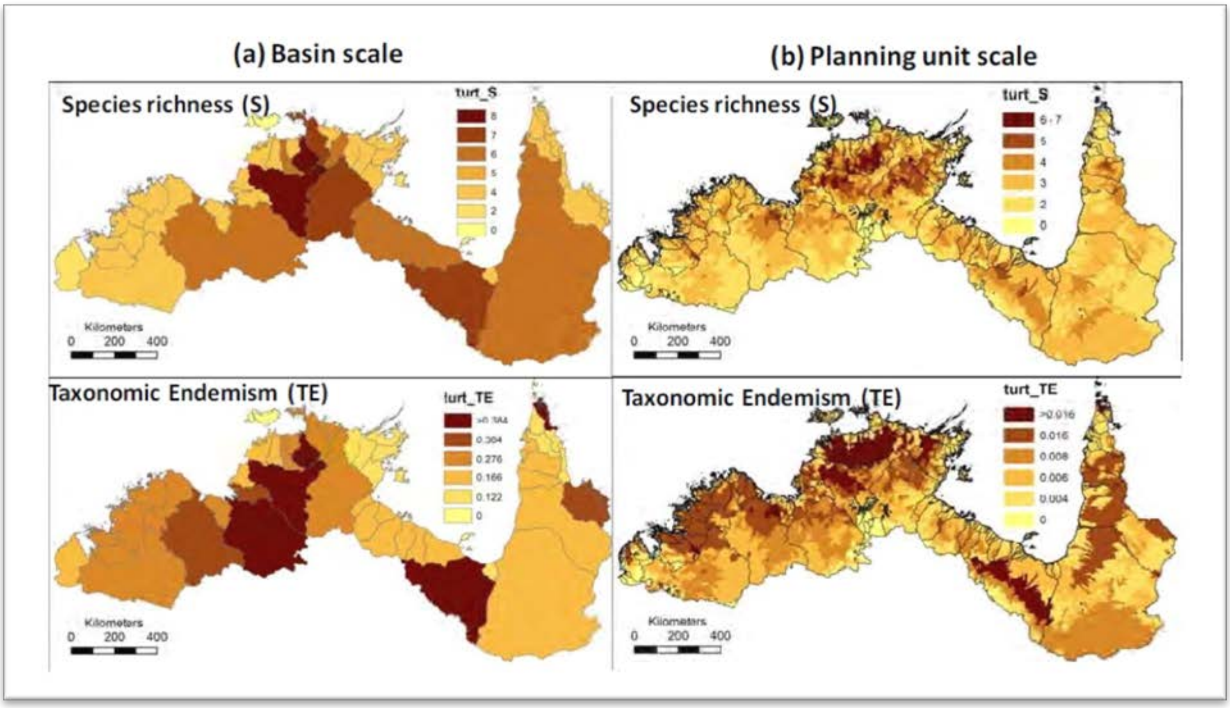


FIGURE 1.7 SPATIAL VARIATION IN FISH (TOP) AND TURTLE (BOTTOM) SPECIES RICHNESS AND ENDEMISM ACROSS NORTHERN AUSTRALIA AT TWO SPATIAL SCALES (SOURCE: KENNARD 2011)

1.2.2.1 FISH AND OTHER AQUATIC VERTEBRATES

Freshwater fish elicit a high level of community interest and within the Northern Gulf they have a range of values spanning ecological, social and economic classes. Several species support traditional and recreational fisheries (discussed in the following section); the latter also forming an important basis for regional tourism. One migratory species, barramundi, is also important to adjoining coastal commercial fisheries. The Northern Gulf contains a large proportion of Australia's total freshwater fish diversity and a number of threatened, rare and restricted species, all of which convey biodiversity conservation values to the region's fish fauna. Other species such as the Gulf Saratoga, a Gondwanan fauna remnant, hold scientific interest for understanding Australia's evolutionary history.

The Northern Gulf region has some of the highest freshwater fish species diversity in Northern Tropical Australia (Figure 1.7). The Mitchell basin shares the second highest basin species richness (~57 species) in Australia with the Wenlock basin in Cape York and the Daly and East Alligator River basins in the Northern Territory (Burrows *et al* 2008, Pusey *et al*. 2011). The high diversity of the Mitchell River basin is partially attributed to the perenniality of its flows and aquatic habitats, which is related to the significant contribution of groundwater discharge to the system (CSIRO 2009, Pusey *et al*. 2011). Relatively high species richness is also observed at smaller sub-basin scales across other Northern Gulf river basins including the Norman and lower Gilbert and Staaten (Figure 1.7). While survey coverage remains incomplete and species counts are confounded by inclusion of migratory marine species, total freshwater fish species richness recorded for Northern Gulf river basins is high by national standards including: Mitchell (57 species), Gilbert (42 species), Norman (48 species) and Staaten (42 species) (Burrows and Perna 2006, Burrows *et al* 2008, Hogan *et al* 2009, Pusey *et al* 2011, Waltham *et al* 2013).

More than a third of the region's freshwater fish, including the enigmatic barramundi *Lates calcarifer,* are migratory species with some life cycle dependence on estuarine habitats (Pusey *et al* 2011). Given the dependence of the fish community on intra-basin movement, maintenance of fish passage including that provided by connective flood flows is critical to sustaining regional fish diversity. Other regional fish species that utilise both marine and freshwater environments include at least three species of freshwater elasmobranchs (sharks and rays). These include the bull shark or river whaler *Carcharhinus leucas*, the freshwater whipray *Himantura dalyensis* and the freshwater Sawfish *Pristis pristis* (Thorburn et al 2003). The latter species is listed as vulnerable under the EPBC Act as it is threatened in coastal waters by commercial gill net and prawn trawl fishery by-catch, and in freshwater by weirs and dams which impede movement to upper catchment habitats, decline in habitat conditions which affect prey abundance, drought, indigenous harvest, habitat modification, and recreational 'trophy' fishing and by-catch (Burrows 2004a, DoE 2014). Given the opportunity, this species can move long distances upstream and has been recorded up to 500 km from the Mitchell river mouth within the Lynd River and to the Mount Surprise reach of the Einasleigh River and to Georgetown on the Etheridge River within the Gilbert Basin (Allen et al., 2002, Waltham *et al* 2013). Other records for the Northern Gulf region include specimens from Norman and Staaten rivers and reports from the Palmer and Walsh rivers (Burrows 2004).

Biodiversity values associated with the Northern Gulf's freshwater fish extend not only to species richness but also to expressed levels of 'endemism' i.e. unique species restricted only to Northern Gulf basins (Figure 1.7). Examples include the lake grunter *Variichthys lacustris* which has only been recorded in Australia from a small number of floodplain lagoon sites in the Mitchell basin and Gilbert's grunter *Pingalla gilbert,* known only from basins of the Northern Gulf and the Flinders River. A number of recorded species also have restricted but disjunct distributions, i.e. they occur within the Northern Gulf and in separated populations in other areas of northern Australia e.g. Cape York and the top end of the NT and/or in Papua New Guinea. Examples of these species include the Lake Grunter (which also occur in PNG), Freshwater Anchovy *Thryssa scratchleyi*, Giant Glassfish *Parambassis gulliveri* and the Gulf Saratoga *Scleropages jardinii*. The latter is a primary freshwater species (evolved solely within freshwater) that is a remnant of Gondwanan fauna and a popular recreational and aquarium species. These disjunct species are believed to be remnants of larger contiguous populations that existed during periods of low sea level when the Gulf of Carpentaria was a freshwater lake and northern Australian and southern PNG river systems were hydrologically connected (Allen *et al* 2002).

Another high conservation value of the region's fish fauna is the relative absence of exotic species. While up to four exotic species have been recorded within the region, including goldfish *Carrasius auratus* in the Norman basin

(Burrows and Perna 2006) and guppy *Poecilia reticulata*, Mozambique tilapia *Oreochromis mossambicus and* spotted tilapia *Tilapia mariae* in the Walsh sub catchment of the upper Mitchell basin, only the guppy has become established, with goldfish disappearing and both tilapia species being successfully eradicated (Burrows 2008, PestSmart 2013).

Understanding of the Northern Gulf's freshwater fish fauna has grown substantially in recent decades as aquatic biota research and survey coverage has increased under the impetus of prospective water resource development (Appendix 2). These surveys have resulted in new species records, including range extensions for species previously only recorded in Papua New Guinea and the discovery of new species including a relatively large and possibly new genus of eel-tailed catfish *c.f. Porochilus* sp. and a new goby *Pseudogobius* sp. (Appendix 2). Despite the recent increase in freshwater fish survey coverage, some key areas including the Lynd sub-catchment of the upper Mitchell and lower sub-catchments including the Alice and Nassau, and adjoining coastal catchments remain relatively unsurveyed as do many other aquatic vertebrate taxa other than fish e.g. turtles and other reptiles.

Recent research has also helped identify key processes and aquatic ecosystem functions that maintain freshwater fish communities. Wet season flooding has been demonstrated to be of particular importance in providing hydrological connectivity between rivers, their floodplain and floodplain wetlands, allowing fish movement and recruitment and enabling the transferal of carbon subsidies from floodplain food sources to river channel, estuarine and adjoining coastal fisheries (Jardine *et al* 2012, Hunt *et al* 2012).

Although fish have been the primary focus of most aquatic survey work conducted to date within the Northern Gulf, its freshwater habitats also support many other aquatic vertebrates including amphibian and reptile species. Survey coverage for frog species is very patchy. Thirty species have been recorded from the Gilbert Basin with most considered generalists with non-specific habitat requirements (Waltham et al 2013). Thirty-five frog species have also been recorded from the upper catchment of the Mitchell within the Australian Wildlife Conservancy sanctuary Brooklyn (AWC 2015). A large number of threatened frog species occur within these rainforest upper catchments (Table 1.8) including many species that have undergone severe range reductions and local extinctions elsewhere due to the introduced chytrid fungus *Batrachochytrium dendrobatidis*. On Brooklyn, these endangered frog species appear secure and are potentially recolonising higher parts of their range (AWC 2015). The frog fauna across the broader Northern Gulf has been assessed to be comprised of generalist species typical of open forest and drier regions of Australia (Burrows 2004). However, the level of endemicity expressed by other faunal groups e.g. fish, and the occurrence of perennial aquatic refugia throughout the region would suggest the prospect of additional unrecorded frog species occurring in the region is high and warrants additional survey effort.

Aquatic reptiles have also been inadequately surveyed in the region. Distributional modelling by Kennard *et al* (2011) suggests up to six species of freshwater turtle occur across the Northern Gulf region (Figure 1.7), but currently published distributional data (Georges and Merrin 2008) and expert opinion suggest only five have thus far been recorded within the region or are expected to occur within the Gilbert basin (Waltham et al 2013). These include Northern long-necked turtle *Chelodina rugosa*, an important traditional food resource, Cann's long-necked turtle *Chelodina canni*, Painted turtle *Emydura subglobosa*, Northern yellow-faced turtle *Emydura tanybaraga* and Saw-shelled turtle *Wollumbinia latisternum*. As suggested for amphibians, the prospect of additional unrecorded turtle species occurring in the region is high and also warrants addition survey effort. Other aquatic reptiles known from the Northern Gulf region include two crocodile species, freshwater crocodile *Crocodylus johnsoni* and estuarine crocodile *Crocodylus porosus,* an aquatic goanna or water monitor Mertens' water monitor *Varanus mertensi* and at least five species of aquatic/semi-aquatic snakes, including the Little file snake *Acrochordus granulatus,* Arafura file snake *Acrochordus arafurae,* water python *Liasis macklot,* Keelback *Tropidonophis mairii and* Macleays Water snake *Pseudoferania polylepis*. A full species list of freshwater species found in the Northern Gulf region is available for download at (Appendix 6).

Given the low human population density and relatively low intensity land use pattern that characterises the Northern Gulf, threats to its rich aquatic vertebrate fauna are not as significant as they are in more developed and biophysically modified regions of Australia and this underpins good opportunities for effective biodiversity conservation. The most significant current threats are not generally associated with direct human impacts but with the same pervasive threats identified to be affecting freshwater environments and habitat quality generally. These include feral animal habitat disturbance and predation, riparian and aquatic weeds, total grazing pressure and associated changes to basin contaminant loads and water quality. Freshwater fish and other aquatic vertebrates are also particularly vulnerable to impacts associated with the introduction of exotic aquatic species, including translocated native species from other regions and the associated prospect of introduced pathogens, as highlighted by the impact of the chytrid fungus on frog populations (Burrows 2004, 2008). Recreational fishing pressure is one example of a direct human impact that can affect aquatic vertebrates, but given generally low recreational fishing pressure within Northern Gulf inland waters this is not considered significant for most species other than threatened taxa such as the freshwater sawfish (DoE 2014). Illegal fishing activities involving the use of methods such as gill nets could present greater concerns for some taxa.

In areas with existing or proposed intensification of land and water resource use, threats to aquatic vertebrate diversity will be higher as realised in more developed tropical river basins (Tait 2013). In-steam water infrastructure, e.g. dams and weirs and other potential fish passage barriers such as road crossings, present significant impact risks to freshwater fish communities that are comprised more than a third by species which depend on intra-basin connectivity and access to estuarine habitats (Pusey *et al* 2011). Water resource development that has the potential to modify wet season flood events in terms of inundation levels, timing or duration also poses major risks to freshwater aquatic ecosystem processes that structure and maintains dependent biodiversity (Jardine *et al* 2012, Hunt *et al* 2012). Refugial waterholes that sustain much of the aquatic biodiversity of the Northern Gulf's seasonal rivers have been assessed to be particularly vulnerable to nutrient, turbidity and water level changes that could be associated with extensive development of intensive agriculture in contributing catchments (Waltham *et al* 2013).

1.2.2.2 Invertebrates

Aquatic invertebrates include fauna groups such as insects, crustaceans, worms and molluscs. Knowledge concerning the freshwater aquatic invertebrates in the Northern Gulf Region is limited as most studies have only identified invertebrates to family level. Some larger 'macrocrustaceans' that form the basis of recreational fisheries are well known to the public e.g. the Giant Freshwater Prawn or 'Cherabin' *Macrobrachium spinipes* and the Red Claw crayfish *Cherax quadricarinatus*. Other equally large freshwater crayfish such as the Red and Blue Spiny Crayfish *Euastacus fleckeri* that occurs in the Mitchell basin in Wet Tropics streams above 700m remain largely unknown to the general public. Ryan *et al* (2002) recorded a total of 11 crustacean species as part of their survey of the upper Mitchell and Walsh rivers including two species of *Caridinia* shrimp, three species of *Macrobrachium* prawns, two *Cherax* crayfish and four freshwater crabs. More detailed surveys of aquatic invertebrates across other Northern Gulf river basins would be sure to reveal additional invertebrate species new to science.

Aquatic invertebrates are critical to the functioning of freshwater ecosystems, playing an important role in food webs as primary and secondary consumers and as important prey items for higher consumers (Waltham *et al* 2013). Maintenance of aquatic invertebrate biodiversity is therefore essential for the sustainability of freshwater ecosystems and dependent biodiversity. Recent assessments of aquatic invertebrates within Northern Gulf river systems suggest that local scale habitat and biophysical variables, rather than inter-basin community distinctions, drive patterns of invertebrate community composition and diversity seen at the site scale (Waltham *et al* 2013). Factors affecting aquatic invertebrate community composition and diversity include water quality, turbidity, nutrient levels, dissolved oxygen and levels of predation. Aquatic invertebrates are commonly used as a biological indicator of aquatic ecosystem health, with sites with higher macroinvertebrate diversity including more environmentally sensitive functional feeding groups or taxa (e.g. filter feeders) considered to be in better ecological health. A large number of sites have been surveyed for macroinvertebrates across the Northern Gulf region. Most sites have a relatively high diversity of macroinvertibrates (Nolen 2001; Hogan *et al.* 2006; Hogan *et al.* 2009a; Hogan *et al.* 2009b; Chambers 2011).

Monitoring of macroinvertebrates in the Gilbert River catchment has found that populations maintain their diversity across years which suggests that the catchment and waterways have remained relatively stable and in good condition (Hogan *et al.* 2006). Some studies across the region have identified a small number of sites with lower diversity of macroinvertebrates (Hogan *et al.* 2006; Gleeson & Searle 2008; Hogan *et al.* 2009a), which in some cases has been attributed to high amounts of algae and livestock damage (Gleeson & Searle 2008; Hogan *et al.* 2009a). Land use and/or water resource development that alters turbidity and nutrient loadings of waterholes or impacts beneficial base flows or wet season flushing flows, has been identified as a source of potentially significant impact to aquatic invertebrate communities in Northern Gulf rivers (Waltham *et al* 2013).

1.2.2.3 WATERBIRDS

Wetlands within the Northern Gulf planning area seasonally host globally significant aggregations of migratory shore birds and nationally significant populations of breeding water birds (Blackman *et al* 1999, Kingsford *et al*. 2013), and provide another example of regional biodiversity assets that carry national and international conservation responsibilities. Most of the significant wetland aggregations hosting these bird populations have been identified via their description and listing in the *Directory of Important Wetlands in Australia* (see following section), though suitable wetland habitats are also more widely distributed across lower basin floodplains and the coastal zone.

The concentration of migratory shorebirds found within wetland aggregations of the coastal Northern Gulf represent the largest in the East Asian - Australasian Flyway and are higher than anywhere else in Queensland (CLCAC 2014). At least half of the state's shore birds pass through or spend extended time in the area from September to April each year and, importantly, high numbers of young birds or non-breeding adults also over-winter here (Garnett 1987, Driscoll 2001). Many of the recorded species are listed under international agreements including: 22 species under JAMBA *Japan – Australia Migratory Bird Agreement* and 31 species listed under CAMBA *China- Australia Migratory Bird Agreement* (Blackman *et al*. 1999). Listing under these agreements protects these species under the Commonwealth's EPBC Act provisions afforded to migratory species (DSEWPC 2012).

Mutton Hole wetlands near Normanton lie within this aggregation and have a range of brackish to freshwater habitats that provide a rich habitat for birds and are a regionally important dry season refuge for many water birds and water fowl species. Species such as the brolga (*Grus rubicundus*), sarus crane (*Grus antigone*), black-winged stilt (*Himantopus himantopus*), pied cormorant (*Phalacrocorax varius*), Australian pelican (*Phelacanus conspicillatus*), magpie goose (*Anseranas semipalmata*), black swan (*Cygnus atratus*), green pygmy goose (*Nettapus pulchellus*), Australasian grebe (*Tachybaptus novaehollandiae*) and hardhead (*Aythya Australia*) breed in these wetlands. Species such as the brolga and sarus crane use Mutton Hole Wetlands as an important dry season and over-wintering refuge (Department of the Environment 2014a).

Other sites within the Gulf Plains e.g. the Smithburne – Gilbert Fan wetland aggregation (Blackman *et al* 1999), supports the main (and perhaps only) breeding populations of the vulnerable Sarus Crane and more than 1% of the global population of twelve species (Brolga, Black-tailed Godwit, Great Knot, Eastern Curlew, Sharp-tailed Sandpiper, Lesser Sand Plover, Grey-tailed Tattler, Little Curlew, Pied Oystercatcher, Broad-billed Sandpiper, Red-necked Stint and Black-winged Stilt) the near threatened Australian Bustard and nine savannah biome restricted species (CLCAC 2014). Surveys conducted by the Carpentaria Land Council Aboriginal Corporation between 2009 and 2013 identified 32 waterbird breeding colonies in the Gulf Plains bioregion (Jaensch & Richardson 2013). At least one colony was recorded in each catchment, except for the Staaten River. Four Northern Gulf catchments (Gilbert, Smithburne, Walker, and Norman) supported four to five bird colonies. Many of the colonies observed were in mangrove habitat (13), freshwater wetlands (19) or in off-channel situations (15) such as floodplains or depression swamps, and only a small number were found in riverine or channel habitats (Van Auken) (Jaensch & Richardson 2013).

The significance of bird populations within south east Gulf wetlands means they meet the Ramsar criteria for wetlands of International importance (Blackman *et al*. 1999), and provides an impetus for Australian Governments both state and Federal to provide for their protection. A National Plan for Shorebird Conservation in Australia, recognised by the Federal Government, identifies wetlands within the Northern Gulf as being of outstanding importance to shorebirds (Watkins 1993). For regional NRM bodies this provides opportunities for securing Government funding support toward targeted bird conservation management initiatives which can also be used to serve broader wetland management outcomes.

The most significant threats to water birds in the Northern Gulf region are those which affect the quantity and quality of suitable wetland habitat. High total grazing pressure and weed impacts to riparian and emergent wetland vegetation that provides waterbird feeding, nesting and roosting resources has been identified as a key management concern (Tait 2005). Feral species such as feral pigs are also implicated in the destruction of wetland habitat resources and predation of eggs from nests. Management actions targeting the protection and sustainable management of DIWA wetlands (following section) and off-river wetland habitats generally (previous section) provide a suitable focus for meeting many of the conservation needs of water birds and migratory shore birds (Tait 2005).

Experience from other regions of Australia. particularly the Murray Darling Basin, also show that processes or developments that reduce flooding of colony sites or floodplain feeding areas, or threaten the health of nesting trees will also impact on the long-term sustainability of waterbird colonies (Kingsford *et al* 2011). Proposals for dams or irrigation schemes that could generate changes to river flow and flooding in lower basin wetlands in the Northern Gulf e.g. within the Gilbert Basin, may therefore pose a serious threat to waterbird colonies and warrant dedicated assessment for potential waterbird impacts.

FIGURE 1.8 A RIVERINE BREEDING COLONY OF EGRETS IN FRESHWATER TREES AND SHRUBS, GULF PLAINS BIOREGION (SOURCE: JAENSCH & RICHARDSON 2013).

1.2.2.4 DIWA Wetland Aggregations

The *Directory of Important Wetlands in Australia* (Environment Australia 2001) lists 851 wetlands that have been assessed to be of national significance and has an associated digital database providing comprehensive descriptions of ecological, hydrological and geomorphological features and values http://www.environment.gov.au/topics/water/water-our-environment/wetlands/australian-wetlands-database . The Northern Gulf planning area contains 8 DIWA wetlands (**Error! Reference source not found.**), including individual sites and large aggregations up to several hundred kilometres in breadth. Wetlands listed in DIWA meet one to six criteria of importance, including:

1. The wetland is a good example of a wetland type occurring within a biogeographic region of Australia
2. The wetland plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex
3. The wetland is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as drought prevail
4. The wetland supports 1% or more of the national population of any native plant or animal taxa
5. The wetland supports native plant or animal taxa or communities which are considered endangered or vulnerable at the national level

6. The wetland is of outstanding historical or cultural significance.

The two most significant DIWA wetland aggregations within the south east Gulf planning area are the Southern Gulf Aggregation and the Southeast Karumba Plain Aggregation, which meet all criteria of importance and collectively extend across the coastal margins of all Northern Gulf river basins. Although these coastal wetland aggregations contain significant freshwater habitats they have been described fully within the coastal and marine section of the plan.

TABLE 1.7 CRITERIA MET BY DIWA WETLANDS WITHIN THE NORTHERN GULF PLANNING AREA

Basin(s)	DIWA wetland	Criteria
Norman - Mitchell	Southeast Karumba Plain Aggregation	1,2,3,4,5,6
Settlement - Norman	Southern Gulf Aggregation	1,2,3,4,5,6
Mitchell-Staaten	Mitchell River Fan Aggregation	1,2,3,4,6
Mitchell	Undara Lava Tubes	1,2,3,5,6
Gilbert	Smithburne – Gilbert Fan Aggregation	1,2,3,4
Staaten	Gulf Plains – Dorunda Lakes Area	1,2,3
Gilbert	Macaroni Swamp	1,2,3
Mitchell	Spring Tower Complex	1,3

DIWA wetlands were identified by one of Queensland's first State-scale assessment of wetland biodiversity assets (Blackman *et al.* 1999). While DIWA listing by itself carries no legal protection, the assessment underpinning their listing is robust and identified values are still current, including many recognised by protection under State (*Qld Nature Conservation Act*) and/or Commonwealth (*EPBC Act*) legislation. As such DIWA wetlands remain a strategic target for investment in NRM programs intended to deliver freshwater biodiversity conservation outcomes.

1.2.2.5 Wetland Associated Regional Ecosystems

In Queensland, management arrangements for remnant native vegetation utilises a bioregional planning framework that maps and assess the status of regional ecosystems (REs) which are 'vegetation communities consistently associated with a particular combination of geology, landform and soil' (Sattler and Williams 1999). The Queensland Herbarium (2015) maintains a regional ecosystem database (REED) that contains information on each RE's *Vegetation Management Act (VMA)* status, biodiversity status, floristic composition, values, threats, appropriate fire regime and other management information. Although statutory protection is only afforded to REs on the basis of their VMA status and only in relation to tree clearing applications, the biodiversity status of an RE (as well as its VMA status) does provide a defacto classification of the level of threat faced by associated ecological communities. As discussed in section 7.3.1.1, Queensland wetland mapping (QEPA 2005) has established which regional ecosystems are associated with different wetland system types. Mapped wetland associated regional ecosystems therefore provide a useful spatial definition of freshwater biodiversity at an ecosystem scale which can be utilised to target NRM strategies intended to deliver freshwater biodiversity conservation and management outcomes.

The status of wetland associated regional ecosystems within the Northern Gulf (Table 1.2, Table 1.5, Table 1.6) provides a broad indication of the condition of freshwater wetland associated biodiversity and a means of identifying threatened and/or specific valued components that can be targeted with tailored management efforts. Unlike other regions of Queensland or Australia, a very limited extent of native vegetation has been cleared from Northern Gulf river basin sub-catchments, with only two (Mitchell and Walsh) exceeding 1% (Accad *et al.* 2013). Examining wetland associated regional ecosystems, only the Mitchell sub-catchment has lost more than 1%. More significant threats currently affecting wetland associated REs are listed in the RE database (Qld Herbarium) and include total grazing pressure, weeds, pig rooting, erosion and inappropriate fire regimes.

1.2.2.6 Threatened Species and Ecological Communities Associated with Aquatic Ecosystems

Species that have historically undergone population reductions and may be 'threatened with extinction' are referred to as 'threatened species'. There are a number of threatened species associated with Northern Gulf freshwater ecosystems that are protected by listing under the Commonwealth *Environment Protection and Biodiversity Conservation Act (EPBC)* 1999 or the *Queensland Nature Conservation Act (NCA) 1992* (Table 1.8). An example of *an endangered ecological community* listed under the *EPBC Act,* 'spring wetland community in the discharge areas of the Great Artesian Basin', also occurs in the Northern Gulf region. The status of listed threatened species under the *EPBC Act* ranges through extinct, extinct in the wild, critically endangered, endangered, vulnerable to conservation-dependent, and under the *NCA* ranges through extinct in the wild, endangered, vulnerable, near-threatened to least concern wildlife.

TABLE 1.8 FRESHWATER WETLAND ASSOCIATED THREATENED TAXA RECORDED FROM THE NORTHERN GULF REGION (SOURCE: *WETLANDINFO* – EHP 2015)

Taxa	Species	Status (EPBC / NCA Acts)
Birds	Australian painted snipe *Rostratula australis*	Endangered/Vulnerable
	Little tern *Sternula albifrons*	NA/Endangered
	Curlew sandpiper *Calidris ferruginea*	Critically endangered/Near threatened
	Eastern curlew *Numenius madagascariensis*	Critically endangered/Near threatened
Reptiles	Estuarine crocodile *Crocodylus porosus*	Marine migratory/Vulnerable
Amphibians	Melville Range treefrog *Litoria andiirrmalin*	Vulnerable/NA
	Australian lacelid *Litoria dayi*	Endangered/Endangered
	Little waterfall frog *Litoria lorica*	Critically Endangered/ Endangered
	Tapping green eyed frog *Litoria serrata*	Near threatened/NA
	Waterfall frog *Litoria nannotis*	Endangered/ Endangered
	Common mistfrog *Litoria rheocola*	Endangered/ Endangered
	Magnificent broodfrog *Pseudophryne covacevichae*	Vulnerable / Vulnerable
	Northern tinkerfrog *Taudactylus rheophilus*	Endangered/ Endangered
Fish	Freshwater sawfish *Pristis pristis*	Vulnerable/NA
Aquatic/Riparian plants	*Fimbristylis micans*	NA /Vulnerable
	Eriocaulon carsonii	Endangered/ Endangered
	Eriocaulon carsonii subsp. orientale	Endangered/ Endangered

Many of the threatened species within the Northern Gulf are also listed on other threatened species lists, e.g. the IUCN Red List of Threatened Species and populations, but these listings carry no specific statutory protections within Australia.

A range of protective provisions are afforded to listed threatened species under both the *EPBC Act* and the *NCA*. Subject to the threatened status of the species, listing under these acts can provide for the preparation of formal conservation advices and/or recovery plans in which certain actions which present threats to the species or result in the taking of threatened species, e.g. clearing of critical habitat may come under Commonwealth or State statutory control. Statutory requirements for the development of recovery and/or threat abatement plans also drive dedicated population survey and species ecological research efforts. In effect, many of the protective provisions that apply to threatened species only become active when triggered by more major development proposals and land use changes that require preparation of Environmental Impact Statements or require tree clearing permits in the case of existing approved land uses such as agriculture and pastoral production. In the absence of historical or dedicated survey effort that confirms the presence of threatened species at a specific locality eliciting specific management interest, most continue to be exposed to the range of pervasive threats that have been responsible for their endangerment e.g. weeds, feral animals, total grazing pressure, fire regime change etc.

From the perspective of regional NRM planning, listed threatened species represent key biodiversity assets that provide a range of opportunities for engaging with the community in the promotion and delivery of sustainable NRM. The presence of threatened species can:

- Act a focal point for eliciting community interest in NRM;
- Provide an impetus for more conservative land and water resource management;

- Engage statutory provisions in support of specific NRM actions;
- Be used to establish ecosystem mascots or ambassadors for NRM program delivery; and
- Attract government, industry and corporate funding for the delivery of on ground activities including survey, research and threat management actions.

Within the Northern Gulf one threatened species that has merit as a candidate ambassador for aquatic ecosystem management activities is the freshwater Sawfish *Pristis pristis* (DoE 2014). This species is listed as vulnerable under the EPBC Act and Critically Endangered on the IUCN Red List of Threatened Species, and populations within the basins of the Gulf of Carpentaria represent a global stronghold for the species (Kyne *et al*. 2013, DoE 2014).

1.2.2.7 PROTECTED AREAS

The Northern Gulf region contains a range of parks, reserves, refuges and other 'protected area' management arrangements that provide varying levels of protection for contained freshwater biodiversity. They include the Wet Tropics World Heritage Area, 16 National Parks, two Conservation Parks, two State Forests, two Forest Reserves, five Resource Reserves, 19 Nature Refuges and a large Private Sanctuary (Appendix 3). These protected areas occur on a range of land tenures including Aboriginal land and other private tenures e.g. Pastoral Leasehold and Freehold. Like most protected areas in Australia, few were dedicated specifically to protect freshwater ecosystems (Hermoso *et al* 2011). One of the limitations of 'terrestrial reserves' in terms of freshwater biodiversity conservation is that their boundaries often don't reflect those of contributing upper catchment areas and 'protected' freshwater systems, therefore remain vulnerable to exogenous disturbances, i.e. impacts generated upstream and external to the reserve. Fortuitously many protected areas in the Northern Gulf are large enough and/or located in upper catchment areas and cover contributing catchment areas, therefore providing a high level of protection for freshwater ecosystems against land use and other anthropogenic impacts. Examples include most Wet Tropics National Parks, Bulleringa National Park, Blackbraes National Park, Undara Volcanic National Park, Okola National Park and Staaten River national Park, the latter covering almost 20% of the entire Staaten basin. Other freshwater protected areas, including some specifically dedicated around freshwater biodiversity assets e.g. Mutton Hole Wetlands regional Park, Mareeba Tropical Savanna and Wetland Reserve Nature Refuge and several nature refuges associated with gorges, springs, creeks and other wetland features (Appendix 3), have varying levels of exposure to catchment based impacts. Regardless of contributing catchment and protected area boundary concordance, all remain exposed to pervasive threats e.g. weeds, feral animals, altered fire regimes and climate change.

Under the protected area classification system developed by the International Union for the Conservation of Nature (IUCN), only National Parks and Conservation Park that fall within IUCN Classes I–IV which include formally binding tenures where biodiversity conservation is nominated as the primary management intent are included in 'protected area' accounting by the Australian National Reserve System (NRMMC 2009, QEHP 2014).

Australia is a signatory to the International Convention on Biological Diversity which has a 2020 target of 17% area representation for member countries in protected areas (NRMMC 2009). Australia currently has 15.45 % and Queensland 7.49% of its area represented in protected areas (CAPAD 2012). However, representation of the Gulf of Carpentaria Drainages Division within protected areas is only 3.8 % the third lowest of all Queensland drainage divisions. Nationally, Northern Gulf aquatic and terrestrial biogeographic regions have been found to be some of the most poorly represented in protected areas (NLWRA 2002c, Tait *et al*. 2003). In a national assessment of the representation of 31 freshwater fish biogeographic province (Unmack 2001) drainage networks in protected areas, Tait *et al*. (2003) found the Southern and Eastern Gulf provinces that comprise the Northern Gulf planning area to be the 4th and 2nd lowest represented nationally. This is also reflected in the level of representation of individual Northern Gulf river basins in national parks (Appendix 1). Other than the Staaten River basin which has 19.2% of its area included in the Staaten River national Park, protection levels for all other basins fall below the 3.8% average for the Gulf Drainage Division i.e. Mitchell Basin (2.6%), Gilbert Basin (2.6%) and Norman Basin (0.2%). Representation of freshwater ecosystems in protected areas is not only low but also skewed toward upper catchment areas (Tait 2003).

Operating under the auspices of the Northern Australia Aquatic Ecological Assets Project, Kennard *et al* (2010, 2011) and Hermoso *et al*. (2011) produced systematic conservation planning based assessments of protection priorities within the Northern Australia Water Futures Assessment (NAWFA) area which included the Northern Gulf. Examining minimum protection standards for a range of freshwater biodiversity assets including freshwater fish, this assessment identified numerous priority areas requiring protection outside the existing protected area network in the Northern Gulf (Figure 1.9). A large number of these areas occur in lower catchment areas including within the poorly protected Norman River basin. Outputs from these assessments provide an indicative aspirational target for further developing the region's protected area network to effectively secure its freshwater biodiversity.

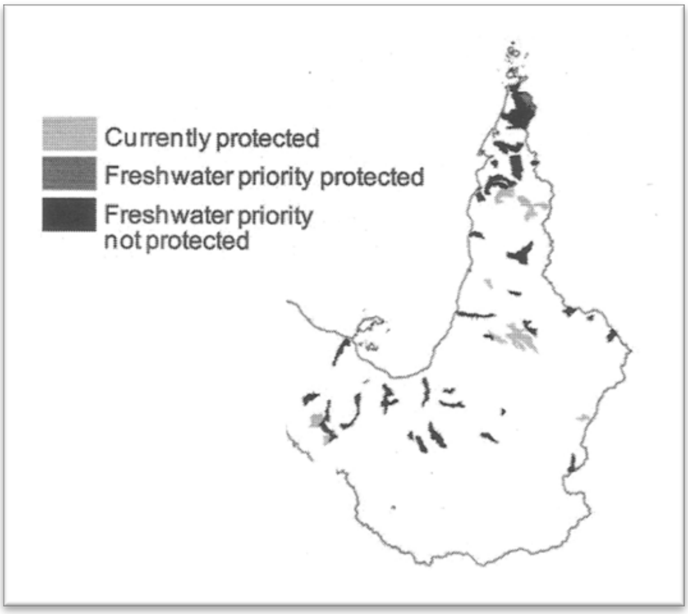


FIGURE 1.9 SPATIAL OVERLAP BETWEEN PRIORITY AREAS FOR FRESHWATER FISH CONSERVATION IN NORTHERN AUSTRALIA AND THE CURRENT RESERVE SYSTEM IN QLD (LIGHT GREY) WITH PRIORITY AREAS OUTSIDE THE EXISTING RESERVE SYSTEM INDICATED IN BLACK (SOURCE HERMOSO *ET AL* 2011).

Protected areas are often considered the premium approach to biodiversity conservation and '*the jewels in the biodiversity conservation crown*'. The securing of relatively intact natural ecosystems via protective management has been demonstrated to be the most effective approach for biodiversity management in terms of both cost and conservation effectiveness and a cheaper option than the ongoing cost incurred managing threats in disturbed ecosystems, or restoring species, habitats and processes in degraded ecosystems (Morton *et al* 2002, NRMMC 2005, Stein 2006, Abell *et al* 2007).

Legal protection of areas provides a statutory mechanism for removing or better managing a range of anthropogenic threats to biodiversity that operate in the broader landscape, including those associated with commercial activities such as total grazing pressure, vegetation clearing, and land and water resource development. However, pervasive threats associated with feral animals, weeds, fire regime and climate change do not recognise land tenure boundaries and require ongoing management to secure biodiversity within 'protected areas'. Collaborative management programs between government conservation agencies and regional community stakeholders targeting pervasive threats affecting protected areas can represent an effective biodiversity conservation investment strategy for NRM plans. Such programs serve to consolidate conservation benefits provided by existing protective management arrangements.

Off-reserve NRM strategies are also needed to secure the '*gold that holds the conservation crown together*' (i.e. areas outside of protected areas). Non-statutory and voluntary conservation agreements with private landholders can play an important role in securing biodiversity in off-reserve areas but seldom provides the longer term security afforded by formal designation of legally protected areas. Regional planning initiatives that can identify further opportunities to protect high value freshwater biodiversity assets by statutory and non-statutory means and also improve the comprehensiveness, adequacy and representativeness of freshwater biodiversity in the Northern Gulf's protected area network and will serve its effective conservation. The enhanced resilience that protected areas afford aquatic ecosystems against a range of pervasive threats is also the main adaptive strategy recommended for addressing emerging climate change pressures (Kingsford 2011, Williams *et al.* 2012).

1.2.3 Freshwater Fishery Resources

The freshwater ecosystems of the Northern Gulf directly and indirectly support a range of fishery resources including: fish, crustaceans and other taxa targeted by fishers within freshwaters; nursery habitats that provide recruitment for both freshwater and coastal fisheries; water flows, primary productivity and nutrient exports that drive fisheries recruitment and production not only within freshwater ecosystems but also adjoining estuarine and coastal systems (Hogan and Bennison 2007, Burford *et al* 2010, Halliday *et al* 2012, Bayliss *et al* 2014, DISITIA 20914).

Northern Gulf freshwater recreational and traditional fisheries are comprised of several primary and a number of secondary fish species and at least two primary crustaceans species, and in the case of traditional fisheries a range of other taxa including mussels, turtles, snakes and crocodiles (TablE 1.9) (Strang 2005, Hogan and Bennison 2007, Jackson *et al.* 2011).

In contrast to the commercial and recreational fisheries of the coastal Northern Gulf which have been the subject of a number of studies (e.g. Zeller and Snape 2006, Greiner *et al* 2009, 2013), the fisheries and supporting ecosystem resources of the Northern Gulf's inland waters have not been specifically assessed or documented. Greater documentation of the Northern Gulf's inland fisheries and the ecosystem resources that underpin them is a prerequisite to an improved capacity for their management and sustainable development. Definition of nursery habitat for barramundi, an important species across all fishery sectors, provides one example of a key information gap associated with regional fishery resources. Although the species is recognised to use coastal, floodplain and instream wetlands as nursery habitats (Pusey et al 2004), the relative significance of each has not been assessed within Northern Gulf basins. Hogan and Vallance (2011), recommended that a tagging study be conducted to assess the relative contribution of these habitats to barramundi recruitment levels, information that would serve assessment of risks to the fishery posed by water resource development, sea level rise and climate change (DISITIA 2014, Close *et al* 2012).

Both Northern Gulf residents and visitors engage in freshwater recreational fisheries. Given the low resident population density it is likely that a major component of the recreational fishing pressure exerted at publically accessible areas is by visiting tourist fishers. Recreational anglers make up the vast majority of tourist visitors to the Gulf of Carpentaria (Greiner *et al.* 2009), although most target coastal fisheries and it is not known how many choose to fish in freshwaters. Tourist access to freshwater fishing resources in the Northern Gulf is restricted by land tenure and road access. Unless visitors make private arrangements with pastoralists or Traditional land owners, legally accessible freshwater fishing sites are generally restricted to public land tenures e.g. national parks and state land/council reserves and where gazetted road corridors intersect or come in close proximity to rivers. As larger river water courses are State land, rivers accessed by gazetted roads also provide further access opportunities, particularly where navigable by small water craft. The mid-reaches of the Mitchell Basin is a popular recreational fishing area that is accessed in this way. Road corridor crossings of most other rivers including the lower Staaten, lower Gilbert, Einasleigh, Etheredge and Norman Rivers are also used as access points albeit informally and sometimes without legal permission. Access to freshwater fishing sites is also available on Aboriginal land at Kowanyama and Pormpuraau subject to a limited season, local council permits and 4WD road access only (CYSF 2014). Unpermitted access of recreational fishers to riverine lands and associated site impacts is an issue of concern for both Indigenous and Pastoral landholders (CLCAC 2014).

NRM issues that can potentially arise in relation to unregulated recreational fisher access include: clearing and disturbance of river bank environments, littering, interference with stock and associated fencing and gates, spread of weeds (both terrestrial and aquatic), unmanaged fires, exceeding site carrying and/or sustainable fishing pressure capacity, and undertaking of illegal fishing activities e.g. use of gill nets and traps, exceeding bag limits etc. Other environmental threats associated with recreational fishing, regardless of access legitimacy include: impacts to non-target species taken as by-catch including turtles and threatened species such as the freshwater sawfish, and the use of exotic or translocated fish as live bait.

Although most recreational freshwater fishing in the Northern Gulf targets wild fisheries, there has been some artificial stocking and translocation of native fish to further develop recreational fisheries. Historically, both sooty grunter and sleepy cod were stocked into the upper Mitchell and Walsh Rivers to augment naturally occurring populations (Burrows 2004). Both the Glenmore Weir on the Norman River near Normanton and Lake Belmore near Croydon (both within the Norman Basin) have also been stocked with barramundi, sooty grunter and striped sleepy cod to create (Lake Belmore) and enhance recreational fisheries, and these water bodies continue to be stocked with barramundi. Stocking is supported by both recreational and commercial fishing sectors and fingerling production is currently undertaken by a facility in Karumba operated by the Carpentaria Shire Council with support from James Cook University. The creation of stocked fisheries has been a success in terms of providing enhanced recreational fishing opportunities and an additional drawcard for fishing tourists.

TABLE 1.9 FRESHWATER FISH AND OTHER BIOTA TARGETED AS PRIMARY OR SECONDARY SPECIES BY RECREATIONAL AND TRADITIONAL FISHERS.

Fish	Notes
Barramundi *Lates calcarifer*	Primary species all fisheries incl. coastal commercial fishery
Sooty grunter *Hephaestus fuliginosus*	Primary species rec and traditional fishery
Gulf grunter *Scortum ogilbyi*	Primary species traditional fisheries secondary rec
Spangled perch *Leiopotherapon unicolor*	Small secondary species rec and traditional
Sleepy cod *Oxyeleotris lineolata*	Primary species rec and traditional
Striped sleepy cod *Oxyeleotris selheimi*	Primary species rec and traditional
Archerfish *Toxotes chatareus*	Secondary species rec and traditional
Tarpon *Megalops cyprinoides*	Predominantly catch and release rec fishery
Gulf Saratoga *Scleropages jardinii*	Predominantly catch and release rec fishery favoured as a primary species in some traditional fisheries
Giant glassfish *Parambassis gulliveri*	Small secondary species favoured in some traditional fisheries
Carpentaria catfish *Arius paucus*	Primary species traditional fisheries secondary rec
Salmon catfish *Arius leptaspis*	Primary species traditional fisheries secondary rec
Berney's catfish *Arius berneyi*	Secondary species traditional fisheries
Forktailed catfish *Arius graeffei*	Secondary species traditional fisheries
Black catfish AKA Butter Jew *Neosilurus ater*	Primary species rec and traditional
Long tom *Strongylura krefftii*	Secondary species rec and traditional
Crustaceans	
Cherabin *Macrobrachium spinipes*	Primary species rec and traditional fishery
Red Claw crayfish *Cherax quadricarinatus*	Primary species rec and traditional fishery
Molluscs	
Freshwater mussels *Velesunio spp.*	Primary species favoured in some traditional fisheries
Reptiles	
Northern long-necked turtle *Chelodina rugosa*	Primary species favoured in traditional fisheries some other species e.g. C. *canni* and genera also targeted e.g. *Emydura spp, Wollumbinia sp*
Arafura file snake *Acrochordus arafurae*	Primary species favoured in some traditional fisheries
Freshwater crocodile *Crocodylus johnsoni*	Secondary species favoured in some traditional fisheries
Estuarine crocodile *Crocodylus porosus*	Secondary species favoured in some traditional fisheries
Water monitor *Varanus mertensi*	Secondary species favoured in some traditional fisheries

However, there are risks associated with the stocking and translocation of native fish including creation of novel or excessive predation pressure for vulnerable species, introduction of disease and compromising genetic viability of indigenous populations (Burrows 2004b, Russel 2007). Given a lack of translocation protocols in earlier decades, some of the earlier fish stockings in the upper Mitchell basin were derived from mixed non-indigenous stock from other regions (Burrows 2004b). There has been no subsequent assessment of the genetic impacts of these earlier translocations. Current fish stocking within the Northern Gulf is regulated and utilises indigenous brood stock, though ecological risks could still occur if fish are stocked at unnatural densities and/or outside of their historical range (Burrows 2004b). Private stocking of farm dams and the desire to stock impoundments in upper catchment areas created as part of proposed water infrastructure development, represent areas for ongoing assessment and management of fish stocking risks.

Generally the high integrity of Northern Gulf aquatic ecosystems and fish populations undermines the legitimacy of fish stocking in open waters as an ecologically sustainable practice. Where fish populations have been demonstratively diminished or sustained impacts to natural population recruitment processes exist i.e. fish passage barriers, the need for fish stocking may be justified. For any waterbody, the need to stock and the level of required stocking needs to be informed by fish population monitoring. Although such monitoring was conducted in associated with Northern Gulf fish stocking in earlier years, resourcing constraints have meant that government agencies have been unable to continue to perform such activities (Pers. comm.). Recreational fishing representatives and both stocking and conservation advocates have nominated such activities as a priority for improved management of stocking programs and re-instatement of such monitoring is recommended as a freshwater fishery management action target for the region.

While there is overlap between traditional and recreational fisheries in terms of some methods used and species taken, there are also significant distinctions in that traditional fisheries: have much higher participation rates; target a much broader range of taxa including species less desired by the broader community and species legally protected from take by non-indigenous fishers (TablE 1.9); utilise a broader suite of methods including a much greater dependence on hand collecting, spears, and nets; are more subsistence based with lower rates of release; are not directly subject to *Fisheries Act* regulations (when conducted for traditional purposes), and usually have additional educational, social and cultural motivations for participation including fulfilment of community responsibilities and obligations and strengthening of cultural identity (Coleman *et al*. 2003, Jackson *et al*. 2011). Beyond provisioning and recreation, one of the key values attributed to fishing by Indigenous people in northern Australia is its role as an educational activity that teaches young people about their country, responsibilities under customary law, as well as the social act of cooking and consuming fish with family (Jackson *et al*. 2011).

Results from a northern Australia Indigenous fisher survey indicated participation rates in Indigenous fisheries in north Queensland were greater than 93% and less than 2% of catch was returned (Coleman *et al*. 2003). In northern Australia including the Northern Gulf, customary fishing, hunting and harvesting activities contribute significantly to Indigenous household income and diet (Jackson *et al* 2011). In surveys in Cape York it was found customary production was very significant in meeting people's nutritional needs including up to 80% of protein which came from wild resources (Altman *et al*. 2009).

The above discussion of freshwater fishery resources in the Northern Gulf has identified that generally, resources are in good condition attributable to the region's low population density and associated low fishing pressure and the limited development and modification of the region's river ecosystems. The sphere of NRM issues associated with the region's freshwater fishery resources not only include those associated with sustaining the natural resource base that underpins the fishery, but also potential impacts of fishers on those natural resources and others, and opportunities to further develop freshwater fisheries as a path toward ecologically sustainable regional economic development.

Most current threats to the northern Gulf's freshwater fishery resources are associated with the potential for further degradation of the freshwater environments and habitats that underpin fishery resources, particularly floodplain and coastal wetland areas that act as productivity powerhouses and nursery habitats for many targeted species. These have largely been discussed in preceding sections and are summarised in *Section 7.4*. As identified above, instream barriers are a particularly significant threat for the Northern Gulf's freshwater fish fauna given the proportion of species that depend on intra-basin movements. Currently major fish passage barriers are limited to a small number of structures occurring in the lower and upper Norman basin (Glenmore Weir, Lake Belmore), upper

Einasleigh (Kidston Dam) and upper Mitchell basin including the Walsh (four weirs – Collins, Bruce, Leafgold and Solanum) and upper Mitchell sub-catchments (Lake Mitchell). One of these structures (Glenmore Weir on the lower Norman) is fitted with a fishway structure which is currently undergoing a design upgrade (A. Berghuis pers. Comm) in conjunction with a planned increase in weir height. While structures located in upper basin areas generate less impact on migratory estuarine associated species, they still interfere with movement and population recruitment for freshwater species that depend on inter-reach movements. Large aggregations of such species have been observed below the Lake Mitchell spillway during flow events (Hydrobiology 2005). Assessment of the relative significance of fish passage barriers presented by existing water infrastructure within the region is a worthy management action target. Smaller potential fish passage barriers such as road crossings have not been well documented within the region and given their capacity to restrict fish access to upper catchment habitat and their common abundance (Carter *et al.*2007), are also suggested as a focus for inland water management action targets.

As marine breeding barramundi are one of the main target species for freshwater fishers in the region, freshwater fishery management considerations also need to extend to the status of the species in estuarine and marine areas where concerns exist regarding the sustainability of the commercial barramundi fishery (see Coastal Gulf section). Although such concerns may prove to be unfounded, any reduction in the breeding population and recruitment capacity of barramundi in marine and estuarine areas could translate to reduced recruitment to freshwater populations.

River basin water resource and associated agricultural development and climate change are two emerging though as yet largely unrealised threats that potentially pose some of the most significant concerns for the future sustainability of the region's freshwater fishery resources. Reductions in fisheries production attributed to river regulation modifying and reducing freshwater flows has been well documented across developed region of Australia and Internationally (Gillson 2011). In the Northern Gulf, potential impact concerns for freshwater fish habitat and fisheries associated with proposed water resource development include: reduced floodplain inundation and wetland connectivity particularly in lower rainfall years, reduction in dry season water quality due to altered flows and contaminant loads and flow and physical barrier constraints on fish species distribution, movement, recruitment and population viability (Petheram *et al.* 2013, Bayliss et al 2014, DISITIA 2014).

The primary risk to freshwater fishery resources posed by climate change will operate by exacerbation of existing pressures (Kingsford 2011, Morrongiello *et al.*2012). In the northern Gulf this includes the capacity for more extreme dry and wet seasons to exacerbate total grazing pressure impacts, increasing soil erosion, water quality decline in refugial waterholes and physical habitat impacts. Failed wet seasons may also generate reduced productivity and connectivity impacts on fishery recruitment. Elevated temperatures and altered flow regimes will also impact dry season water quality and may provide conditions that facilitate further infestation of wetland habitats by riparian and aquatic weeds and are conducive to exotic fish establishment. In an assessment of risks to freshwater ecosystems across northern Australia, the Northern Gulf was also identified as one of three regions at greater relative risk from sea level rise (Close *et al* 2012). This could have implications for barramundi nursery wetland habitats that occur in near coastal areas, although the capacity of these habitat types to move landward in response to sea level rise has not been assessed.

1.2.4 WATER RESOURCES

In Queensland water resource management is delivered by a statutory planning process under the *Water Act 2000* that stipulates the preparation of Water Resource Plans (WRPs) and associated Resource Operations Plans (ROPs) for river basin bound planning areas. The lifespan of a WRP is determined by the responsible minister with regard to the sufficiency of existing plan water entitlements meeting needs, the identification of any additional uses for plan area water resources and/or the failure of the plan to meet existing or other identified ecological outcomes. WRPs and ROPs govern the allocation of water for consumptive use and the environment and set operational rules for the maintenance of flow-dependent environmental assets. Three WRPs cover the Northern Gulf: the *Water Resource (Barron) Plan 2002, Water Resource (Gulf) Plan 2007* and the *Water Resource (Mitchell) Plan 2007*, each of which also have associated Resource Operations Plans, *Barron Resource Operations Plan 2005, Gulf Resource Operations Plan 2010 and Mitchell Resource Operations Plan 2009*. These WRPs and ROPs, including recent amendments: *Draft Barron Resource Operations Plan November 2014, Gulf Resource Operations Plan Amendment July 2014* (DNRM 2014), *Water Resource (Gulf) Amendment Plan 2014*, *Water Resource (Barron) Amendment Plan 2014* and the associated *Barron Draft Amended Plans Overview Report, Gulf Draft Amended Plans Overview Report* (DNRM 2014), provide detailed information and references to supporting technical documents (Hydrobiology 2005, Baylis et al 2014, DISITIA 2014) on the water resources of the Northern Gulf and associated management issues.

The Water Resource Planning process involves significant consultation with community and industry stakeholders including via a *Local Water Consultation Group* that includes NGRMG representation. In comparison to the Government-led statutory planning process and formal stakeholder engagement that is pursued for water resource planning, regional community-based NRM planning represents a less direct conduit for affecting water resource management outcomes, but still can play an important role. To maximise regional community NRM planning outcomes in regard to water resources it is likely to be most affective by 'dovetailing' with the WRP process and seeking to compliment it by addressing issues that support its effective implementation and/or alternatively fall outside of its capacity to serve sustainable water resource management. Opportunities to fulfil this role are the focus of regional water resource management issues discussed in this section.

Based on an understanding of the *Water Act 2000* and broader water resource management arrangements practiced in Queensland, the following are proposed as means by which regional community-based NRM can effectively contribute to water resource management outcomes:

- **Education/Information dissemination** – the capacity of regional stakeholders to contribute effectively to sustainable water resource planning depends to some degree on their level of understanding regarding the water needs of the environment, the ecological costs and trade-offs associated with water resource development and consequently what constitutes realistic water development aspirations. Community NRM organisations can play an important role in facilitating increased awareness including via the independent dissemination of technical information to regional stakeholders with interests in water resource management outcomes.
- **Representational advocacy** – Many regional stakeholders with interests in water resource management outcomes lack effective organisational vehicles or may have other limited means (educational, material, technical) to engage with formal water resource planning processes. Indigenous community perspectives of water resource 'values' are one example of stakeholder interests underrepresented in formal water resource planning processes (Jackson *et al* 2011). In a region with a relatively low population dominated by primary production industries, biodiversity conservation can also lack the effective representation it enjoys in larger cosmopolitan centres even where proportionally equivalent community support exists for it. Community NRM organisations can play an important role in providing forums and other processes to canvass and provide input from the full suite of regional stakeholder interests to the water resource planning process.
- **Development and promotion of adoption of BMP** – The management reach of WRPs and associated ROPs seldom extend beyond operational rules governing the timing and volumetric allocation of water. However, the potential for downstream impacts of water resource use is also related to end user water use methods and practices. Regional NRM body engagement with irrigators and other water users can

play a pivotal role in the development, trialling, adoption and monitoring of Best Management Practices (BMP) in regard to a host of water resource issues e.g. irrigation methods, water use efficiency, tailwater management and farm development in new irrigation areas.

- **Water quality management –** Other than the mitigation of water quality stress via flow commitments, the management of water quality impacts, including those associated with the discharge of irrigation tail water, is generally outside of the scope of the water planning process (DNRM 2014). While point source pollution is managed under the provisions of the *EPA Act 1994,* diffuse point pollution sources are generally unregulated unless captured under specifically developed Healthy Waters Management Plans (HWMPs) established under the *Environmental Protection (Water) Policy 2009*. Water quality management including via community-based monitoring, promotion of on-farm BMP and more formal development of HWMPs or non-statutory Water Quality Improvement Plans (WQIPs) in conjunction with relevant agencies, represents a core area for regional NRM body engagement in water resource management.
- **Independent oversight and assessment of effective implementation of WRPs and ROPs** - An output of the water resource planning process is a range of commitments to the maintenance of flow dependent ecological assets and operational provisions by which ecological outcomes specified in WRPs will be met by ROPs. Assessment of the achievement of ecological outcomes is dependent upon sufficient monitoring being conducted by responsible agencies. In practice this may not occur. For example across Queensland over the 2011-2012 reporting period, nine of the twenty-two river basins (41%) subject to statutory Water Resource Plans (WRP) in Queensland had no ecological monitoring conducted and ten lacked sufficient information to assess achievement of WRP ecological outcomes (QDNRM 2012). Representing the interests of community stakeholders, regional NRM bodies can play a role in the independent overview of the fulfilment of ecological monitoring commitments by responsible agencies, reviewing the success or otherwise of ecological outcome commitments and in reporting findings to the community and community responses back to agencies and the WRP process. There is also some opportunity for regional NRM bodies to broker funding for targeted investigations that examine issues in relation to ecological outcomes under WRPs and ROPs.
- **Further definition of flow dependent assets and their management needs –** The definition of flow dependent ecological assets and their management requirements that supports WRPs is seldom complete. Changing climatic or catchment conditions, improved scientific understanding and new information including monitoring data can lead to the identification of new flow dependent ecological values and/or redefine the management needs of established ones. Regional NRM bodies can play an important role in supporting the further definition of flow dependent values and their management needs by canvassing community input on the status of these assets, by engaging the community in targeted monitoring programs and by sponsoring and facilitating the engagement of science providers in targeted investigations of flow based aspects of the region's aquatic ecosystems.

Preceding sections covering freshwater environments, freshwater biodiversity and fishery resources are in effect describing values and assets associated with the Northern Gulf's water resources. Regional land use descriptions (provided elsewhere in the regional plan) covering irrigated agriculture also represent descriptions of values albeit consumptive ones, associated with the development of regional water resources. The following section retains an emphasis on natural aquatic ecosystems while examining two primary aspects of the status of the regions water resources i.e. (1) issues associated with water quantity and flow regimes, and (2) issues associated with water quality.

1.2.4.1 WATER QUANTITY/FLOW REGIMES

The water resources of the Northern Gulf are comprised of the surface and groundwater resources of the Mitchell, Staaten, Gilbert and Norman River basins (Table 1.10). An additional 46,200 ML of water is also supplied to the Mareeba Dimbulah Irrigation Area in the Walsh Sub-catchment of the upper Mitchell basin via an inter-basin transfer from the Tinaroo Dam in the adjoining Barron River basin (Close *et al* 2012).

Mean annual discharge from the four river basins of the Northern Gulf totals some 36,523 Gigalitres. Less than one percent of mean annual discharge is currently diverted from Northern Gulf River basins for consumptive use (Close *et al* 2012).

TABLE 1.10 MEAN ANNUAL DISCHARGE NORTHERN GULF RIVER BASINS (SOURCE HYDROBIOLOGY 2005, CLOSE *ET AL* 2012)

River Basin	Mean Annual Discharge Ml/Annum
Mitchell	22 951 000
Staaten	6 851 000
Gilbert	4 375 000
Norman	2 346 000
Total Northern Gulf	36 523 000

Regional groundwater resources linked to freshwater environments were discussed previously under *Section 7.3.1 Freshwater Environments* and *Section 7.3.1.3 Groundwater Dependent Ecosystems*. Four main types of groundwater aquifers occur within the region:

- Fractured rock basements
- Sandstones within the Carpentaria basin of the Great Artesian Basin (GAB)
- Tertiary sediments, and
- Quaternary alluvium and beach ridge deposits (Hydrobiology 2005, CSIRO 2009).

Other than the Carpentaria Basin of the GAB and the tertiary sedimentary aquifers which include the Karumba basin and its component Bulimba Formation and Wyaaba beds, most of these groundwater resources offer limited exploitable water resources across the region other than for stock and occasionally domestic supplies (CSIRO 2009). The Gilbert River bed sand aquifers with an estimated total saturated volume of 17–20 GL are an exception in that they are exploited for irrigation use. Potential concerns for the ecological sustainability of exploitation from these bed sand aquifers are associated with there being no indication of other aquifer connectivity or recharge to this system, which appears to depend primarily on annual wet season surface flows for recharge (Petheram *et al* 2013b). Within the Mitchell River basin, both the Carpentaria Basin of the GAB and the Bulimba Formation within the Karumba basin are considered to have relatively substantial and as yet relatively unexploited groundwater resources (CSIRO 2009).

Given the very low level of existing water resource development within the region, existing impacts to river basin flow regimes are relatively negligible although some local sub-catchment scale issues can be identified (Table 1.11).

The most significant potential flow regime impacts within the region concern proposed water resource developments. In recent years opportunities for largescale development of irrigated agriculture have been sought in the Gilbert River basin. These opportunities have been progressed by:

- The Queensland's government's granting of additional water licences (14,220 ML) in the basin via the unallocated water tender process;
- The release of CSIRO's Flinders and Gilbert Agricultural Resource Assessment (FGARA) that identified potential to support between 20,000 and 30,000ha of irrigated agriculture in the Gilbert basin by taking up to 670 GL of unallocated water via two large instream storages (Petheram *et al* 2013);
- The release of the Commonwealth Government's Agricultural Competitiveness Green Paper that identified infrastructure projects of interest for the promotion of agricultural development including within the Gilbert Basin; and
- A private proposal for an Etheridge Integrated Agricultural Project which is listed as a coordinated project with the Department of State Development, Infrastructure and development (DSDIP) and is currently undergoing an environmental impact statement (EIS) process (DNRM 2014).

CSIRO's FGARA report highlighted a number of potential risks associated with large scale irrigation development including:

- Reduction in river connectivity and flushing flows supporting waterhole ecology;
- Reduced frequency of coastal floodplain inundation;
- Reduced fisheries production in the Gulf of Carpentaria; and
- Species distribution and lifecycle requirements including migration.

TABLE 1.11 CURRENT WATER RESOURCE EXPLOITATION AND FLOW REGIME ISSUES IDENTIFIED WITHIN THE NORTHERN GULF.

Basin	Diversion Volumes	Water Resource Infrastructure	Groundwater Resource Use	Flow Regime Management Issues
Mitchell	9,029 ML	Collins Weir Bruce Weir, Leafgold Weir Solanum Weir Lake Mitchell	• Kowanyama town water supply. • Grazing industry bores Wyaaba Beds and Bulimba Formation. • Grazing industry bores from Great Artesian Basin	• Unnatural flows Walsh sub catchment due to MDIA discharges (Russell *et al* 2003). • Reduced baseflow contributions and bed sand aquifer recharge below Lake Mitchell (Hydrobiology 2005).
Staaten	Not available	Nil	• Grazing industry bores from Great Artesian Basin	None identified. Integrity of basin's hydrological regime is a key component of its biodiversity value.
Gilbert	6,014 ML	Kidston Dam (Copperfield River)	• Hyporheic flows in river sand bed aquifers. • 400+ bores from Great Artesian Basin, fracture rocks, tertiary sediments, Quaternary alluvium	• Increased bed sand depth to water table within river bed aquifers presents reduced base flow and water quality impact risks to downstream waterholes and dependent riparian vegetation (DISITIA 2014). • Water quality degradation in refugial dry season waterholes already approaching levels stressful to biota (Waltham et al 2013). • Substantial proportion of groundwater resources comprised of old water not recharged by contemporary processes therefore use of systems potentially unsustainable (Hydrobiology 2005).
Norman	1,067 ML	Glenmore Weir (Norman River) Lake Belmore (Belmore Creek)	• River alluvium aquifers used for stock purposes • Grazing industry bores from Great Artesian Basin	• Substantial proportion of groundwater resources comprised of old water not recharged by contemporary processes therefore use of systems potentially unsustainable (Hydrobiology 2005). • Seawater contamination observed in exploited coastal alluvium aquifers (Hydrobiology 2005).

These risks were subsequently investigated by DSITIA (2014) who undertook an environmental assessment of the Gilbert Basin and by CSIRO (Bayliss *et al* 2014) who undertook a targeted assessment of risks to Gulf of Carpentaria fisheries, and other basin aquatic ecological values.

The results of these assessments identified significant risks associated with the water resource development scenarios of the FGARA report even when mitigation strategies were applied, including:

- 15 fishery species potentially at high risk and 8 species at medium risk;
- Potential 3-13% reduction in White banana prawn catch in adjoining coastal fishery zones;
- Potential 3-12% reduction in Barramundi catch in Gilbert River;
- Impacts to wet season flood cue aspects of banana prawn and barramundi reproductive biology and recruitment processes;
- Significant impacts on up to 15 ecological assets within the basin including:
    - Migratory fish guild;
    - Freshwater turtles;
    - Floodplain vegetation;
    - Wetlands;
    - Fluvial geomorphology and river forming processes; and
    - Floodplain energy subsidy.

Due to these identified risks, subsequent assessments were conducted examining reduced water development scenarios for the Gilbert including a smaller total volume of additional development (489 GL) and additional mitigation initiatives including switching from instream storages to off-stream water harvesting and protecting a minimum, cumulative 140,000 ML January–March annual wet season flow (Table 1.12). These proposed mitigative strategies are now included in the proposed amendment to the Gulf WRP, which does not rule out instream water infrastructure (such as dams proposed by FGARA) but limits downstream flow impacts to that associated with a 489 GL off-stream water harvesting scenario (DNRM 2014).

Even with a reduced water resource development scenario and proposed mitigation strategies, residual risks remain associated with proposed water resource development in the Gulf of Carpentaria. Considering smaller water resource development volumes in both the Gilbert and Flinders basin (which adjoins the Northern Gulf region), predicted reduction in the coastal banana prawn catch is still 10% while predicted reduction in the Barramundi catch in the Gilbert basin is 4-5% (DNRM 2014).

To minimise the realisation of residual risks to Gulf fisheries and other Gilbert basin aquatic ecological values, performance indicators and environmental flow objectives have been set in the proposed amendments to the Gulf WRP. These include a low flow performance indicator to limit the proportion of zero flow periods and maintain longitudinal connectivity opportunities for migratory fish and to protect the persistence of refugial waterholes, and a wet season flow performance indicator to ensure that a large wet season flow is maintained between January and March each year (DNRM 2014). Outcomes to be achieved by the amended Gulf WRP have also be defined across economic, social and ecological classes, including several that relate specifically to ecological features of the Gilbert river basin i.e. 3. (1)f (i)-(iii), (i) and (j) (Appendix 4). Achievement of ecological outcomes can only be assessed by appropriate monitoring.

TABLE 1.12 GILBERT BASIN FLOW CLASSES, POTENTIAL WATER RESOURCE DEVELOPMENT IMPACTS TO ECOLOGICAL VALUES AND PROPOSED MITIGATION STRATEGIES (FROM DNRM 2014)

Flow class	Threats from water resource development	Related ecosystem components	Mitigation strategies proposed - Gilbert
No flow/low flow	Capture of low flows by storages and increase in the duration and number of no flow spells	Waterholes as refugia Stable flow spawning fish (Eastern rainbowfish)	Inflow-outflow rules proposed for both Dagworth and Green Hills Dams.For the water harvesting

	Pumping of waterholes and bedsands during spells without flow	Gilbert River bed sand aquifer	development scenario, mitigation is not required.
Low/medium flow	Capture of low and medium flows by storages Loss of seasonal migratory opportunities and cues Loss of ephemeral nature of system	Migratory fish (Hyrtl's tandan, Narrow-fronted catfish, Spangled perch and Largetooth sawfish)	As above
High flow (1 in 2 year flow events)	Capture of high flows by instream storages and water harvesting Loss of seasonal migratory opportunities and cues Reduced connectivity of system	Freshwater turtles (Northern snake-necked turtle, Cann's long-necked turtle), Fluvial geomorphology and river forming processes (including sediment load and nutrient export) Barramundi and Banana prawns	Jan – Mar first wet season flow (provide for fisheries migration) Adopted a new plan outcome 'maintenance Water harvesting developments without instream storages have been recommended
Overbank flow (1 in 10 year flow events)	Capture of overbank flows by instream storages and water harvesting Loss of connectivity to floodplain	Floodplain energy subsidy to riverine food webs, Floodplain wetlands, Floodplain vegetation	The impacts to overbank flows were not able to be mitigated under the Greenhills and Dagworth Dam scenario, but are able to be mitigated under water harvesting development scenarios

Unlike water use that has specified environmental management rules and monitoring requirements described in the Gulf ROP, natural ecosystem monitoring is more generally specified, i.e. "*The chief executive must collect and keep publicly available information on ecological assets that are linked to the ecological outcomes of the Water Resource (Gulf) Plan 2007*" (DNRM 2014). As identified in the introduction to water resource management (above), ensuring that sufficient monitoring is conducted to assess the achievement of outcomes specified in a WRP is an important role that regional NRM bodies can participate in on behalf of regional NRM stakeholders. This can include reviewing the success or otherwise of ecological outcome commitments specified in WRPs (Appendix 4), and reporting findings to the community and community responses back to agencies managing the WRP process. Brokering funding for targeted investigations that examine issues in relation to ecological outcomes under WRPs and ROPs represents another means of engagement for regional NRM bodies in regional water resource management outcomes.

Beyond water resource development, the other major emerging threat for water resources and flow regimes in the Northern Gulf is climate change and associated sea level rise.

While significant increases in precipitation levels are projected for all northern Gulf river basins under future climate change scenarios (Gobius 2015), these changes are predicted to be accompanied by increased seasonal variability that could see reduced precipitation in the driest quarters and also the occurrence of more extended dry seasons and failed wet seasons in some years (Moise 2014). Subject to the nature of annual rainfall patterns, predicted changes in groundwater recharge rates due to climate change across northern Australia range from

+39% to -5% (Close *et al* 2012). The Mitchell basin has been identified as being particularly vulnerable to climate change impacts on flow regimes due to it being fed by shallow, local unconfined aquifers. Under increased dry season climate change scenarios, some areas are likely to experience considerable increases in the duration of low or zero flows, which may have major ecological impacts as will any changes to flood frequency (Close *et al* 2012). The implementation of additional water entitlements in Queensland river basins including those within the Northern Gulf was identified by Close *et al* (2012) to exacerbate climate change impact risks.

Relative to other stressors, sea level rise is rated as a low risk to the maintenance of Northern Gulf river basin flow regimes, water quality or aquatic biodiversity, though significant rises of 0.43- 0.59m are predicted under different emissions scenarios by 2090 (Gobius 2015). However, within the near coastal zone such rises are likely to generate significant local impacts on shallow coastal alluvial aquifers already vulnerable to saltwater intrusion (Hydrobiology 2005).

1.2.4.2 Water Quality

Good water quality is essential for the maintenance of aquatic ecosystem health and underpins biodiversity assets including those generating economic and social values, i.e. fisheries, recreation and ecotourism. Good water quality also supports consumptive values of water resources for stock, domestic, urban, agricultural and mining industry supplies.

There is insufficient monitoring coverage or credible data to provide a quantitative description of water quality status in relation to established water quality guidelines across the entire Northern Gulf region (Butler and Burrows 2005, SoE 2011). However, some sub-catchments (e.g. Walsh, Upper Mitchell) have been sufficiently monitored to describe their water quality status in relation to a number of water quality criteria over monitored periods (Ryan *et al*. 2001, Butler and Burrows 2006a & b, Butler *et al* 2008). Water quality issues and relevant ecosystem condition and land use drivers can also be identified for other regional river basins on the basis of studies of representative systems both within and outside the region (Butler and Burrows 2006a). These include studies of the Gilbert and Flinders basin conducted under the impetus of potential water resource development (Waltham *et al* 2013, 2014), and water quality improvement plans for other seasonal dry tropical albeit east coast Queensland river basins including the Burdekin and Normanby (Dight 2009, Howley *et al* 2013).

Identified water quality issues within the Northern Gulf region fall into three land use contexts:

1. *Extensive land use grazing catchments* – In terms of extent of affected area (i.e. >90% of area of basins – see Appendix 1) and downstream impacts, the range of water quality issues associated with rangeland grazing lands are likely the most significant but are currently the most poorly documented within the region. Contaminants of concern are diffuse source sediments and nutrients, both primarily associated with stream bank disturbance and accelerated soil erosion caused by domestic stock often in combination with feral animals, particularly pigs.
2. *More intensive land use, i.e. irrigated agriculture and settlement catchments* – Water quality impacts associated with more intensive land uses tend to be more chronic and involve a broader range of contaminants including sediments, nutrients, pesticides and salinity and include issues associated with generated reach conditions such as eutrophication, hydrological modification (aseasonal flows, groundwater rise) and aquatic weed infestation leading to organic loading and dissolved oxygen collapses. Both diffuse source contaminants from farm lands and point source pollution associated with irrigation tailwater drains and urban sewage treatment plants contribute to water quality impacts. The significance of these types of water quality issues within the region is important within developed sub-catchments but less significant at a regional scale due to the still limited extent of more intensive land uses. Proposals for major agricultural development within the region could see these types of water quality impacts increase in significance including additional issues linked to major water resource development.
3. *Localised intensive mining land use sites* – Water quality impacts associated with past or current mining development and infrastructure including mine sites, waste retention facilities and processing facilities potentially involve some of the most toxic contaminants including heavy metals, mineral processing residues and acid drainage. Fortunately most of these sites are highly localised although their significance is heighted by their potential toxicity to aquatic biota and human health, their long term persistence within the environment and the capacity for bioaccumulation impacts within food chains distant from affected areas.

1.2.4.3 Extensive land use grazing catchments

Within the extensive rangeland grazing areas of the Northern Gulf, different forms of grazing land use-associated water quality impacts occur under a range of different flow conditions. Impacts to ambient conditions during no flows or base flows can occur via residual poor water quality, e.g. elevated turbidity retained from impacted flood flows and via direct disturbance caused by animals entering waterholes, disturbing bottom sediments and contributing waste (Burrows 2004, Pettit *et al* 2012). Storm run-off flows at the end of the dry season prior to the initiation of flushing and diluting wet season flows can also generate high water quality stresses to refugial waterholes via high sediment and associated nutrient load run in from catchments with low levels of vegetation cover due to grazing and/or eroded riparian/alluvial zones (Butler and Burrows 2006b). During peak wet season flood flows in-situ freshwater quality stress due to sediment and nutrient contaminants from catchment run in is lessened by dilution and flushing, but it is during these periods that the greatest loads of these contaminants are transported to downstream receiving estuarine and marine coastal systems where impacts to sensitive habitats, including sea grass and reef ecosystems, can be significant (Butler and Burrows 2006b, Dight 2009, Howley *et al* 2013).

Monitoring data for the potential water quality impacts associated with extensive rangeland grazing land use in the Northern Gulf is limited and challenging to collect, considering some of the most significant events or severe impacts are associated with storm and peak flow events which are difficult to capture unless subject to dedicated monitoring programs (Butler and Burrows 2006b). However the existence of such water quality issues can be inferred from recognition of the catchment drivers such as the extensive areas of alluvial gully erosion occurring in the Mitchell and Gilbert basins (Shellberg and Brooks 2012). In the Normanby Basin in Eastern Cape York, within a relatively equivalent climatic regime the disproportional contribution of these gully erosion sources to elevated turbidity plumes has been captured by flow event monitoring (Howley *et al* 2013). Such processes and potential impacts will also be occurring within Northern Gulf basins similarly impacted by accelerated alluvial gully erosion. Specifically targeting these sources of water quality and physical environment impact (see Section 7.3.1.1), is a more focused approach than broader grazing land management approaches used in other tropical Queensland water quality improvement plans which have primarily considered pasture condition and ground cover e.g. in the Burdekin basin (Dight 2009), although such condition indicators remain critically important for other sustainability issues.

Understanding of water quality stress during baseflow and no flow periods in grazing rangeland parts of the region has been substantially progressed by the Waltham *et al* (2013) investigation of waterhole ecology in the Gilbert and Flinders basin; the latter an appropriate analogue for the Northern Gulf's Norman Basin (Hydrobiology). Salient findings that emerged from this study included:

- Studied waterholes could be classed into three distinctive types (attribution to Staaten and Norman basins not by study authors);
    - Type 1 – Persistently turbid, highly ephemeral flow (only a few Gilbert catchment waterholes, but most likely many Norman and some Staaten waterholes).
    - Type 2 – Seasonally clear, seasonally intermittent flow (includes the majority of non-perennial Gilbert catchment waterholes, and potentially upper Staaten waterholes).
    - Type 3 – Persistently clear, perennial flow (comprises three tributary streams in the Gilbert catchment; Elizabeth, Bundock and Junction Creeks, possibly uppermost Staaten catchment waterholes).
- Water quality in refugial waterholes naturally approaches or surpasses physiological limits for the maintenance of some aquatic biota e.g. fish, due to high temperatures and low dissolved oxygen;
- In systems without groundwater/baseflow supplementation, disconnected refugial waterholes need to have a sufficient volume and quality water for biota to survive the dry season – reduced wet season water quality and or extraction presents threats to the viability of such refugia;
- Some waterholes can only retain water through the dry season if there has been sufficient sustained flow or local rainfall during the preceding wet season to replenish sub surface reserves associated with the river;
- Inputs of turbid water affect different waterhole types differently, e.g. type 1 – limited impact to productivity, type 2 - significant impairing of productivity and potentially resulting in significant dissolved oxygen sag, and type 3 - no significant impact if sufficient baseflow present to clear waterhole;

- Type 1-2 waterholes most likely to stratify as water circulation in type 3 limits it but it still does occur;
- Most waterholes were nutrient limited and quite alkaline, therefore any inputs of ammonia (associated with fertiliser, and more toxic with higher pH) would be likely to generate toxic effects to biota; and
- During the 2012-2013 study period which coincided with a drought year and failed wet season, there was no time at which water could have been extracted from the studied river systems without risk of adverse impacts on the size, permanency and ecological condition of waterholes (Waltham *et al* 2013).

The latter point highlights the link between water quality and changes in flow regimes, e.g. drought, and how proposed intensification of land and water use within basins currently dominated by rangeland grazing will introduce new risks to water quality in these systems.

Aquatic weed infestation represents another issue that can occur in extensive land use areas and generate water quality impacts, although more significant infestations are often associated with modified hydrological conditions and nutrient loading as has been reported for para grass in the Walsh River sub catchment and other east coast basins (Butler et al 2008, Tait 2013). In the lower Mitchell water hyacinth infestations in distributary lagoons have been associated with low dissolved oxygen and biodiversity (Pettit *et al* 2012). Experience in other regions would suggest such impacts could be exacerbated by changes in flow regimes that could be associated with water resource development (Tait 2013).

1.2.4.4 More intensive land use catchments

The main area of intensive land use within the Northern Gulf Region occurs in the upper Mitchell basin, particularly within the Walsh and upper Mitchell sub-catchments. A water quality monitoring program conducted by Ryan *et al* (2001) identified a range of issues across these sub-catchments (see insert box), and although this data is now more than a decade old, many of these issues remain relevant.

Upper Mitchell Basin Water Quality (Ryan *et al*. 2001)

'A monthly water quality sampling program was conducted at 25 sites across both Walsh and upper Mitchell sub-catchments and collecting information on 19 parameters. Sampling occurred in most months from November 1996 to June 1999. Water quality varied temporally and spatially and was greatly influenced by the intensity and type of land use activity. Results indicated that:

- conductivity was generally low except at sites of groundwater discharge such as at Font Hills, Dingo Creek, and the lower Walsh River;
- levels of dissolved oxygen below that required for aquatic ecosystem health were observed at sites in the upper Mitchell River and lower Walsh River during periods of low river flow, but also occurred at streams impacted by high nutrient enrichment;
- high total nitrogen concentrations were associated with nutrient enriched sites while high ammonium-N concentrations were frequently associated with low flow and low dissolved oxygen content;
- phosphorus concentrations, suspended solids and turbidity were generally low, however peaks were noted during initial flow events of the wet season;
- tannin and lignin concentrations were highest during moderate flow events in the upper Mitchell River following the flushing of organic material into streams;
- stream temperatures below 17° C were consistently recorded from June to August and were thought to have contributed to several fish kills observed in the upper catchment; and
- anthropogenic influences at sites in Two Mile Creek and Cattle Creek, including sewage treatment runoff and flood irrigation runoff, resulted in unseasonal (mid-year) extremes in most water quality parameters including low dissolved oxygen, ammonia, total nitrogen, phosphorus, suspended solids, turbidity and tannin and lignin'.

The Walsh River has a more diverse mix of more intensive land use than other parts of the region, including cattle grazing, numerous abandoned mines, townships such as Irvinebank, Watsonville, Dimbulah and Mutchilba and the Mareeba Dimbulah Irrigation Area (MDIA) which grows a variety of different crops. There is a lack of baseline information on water quality in this system, which makes it difficult to assess its overall environmental health (Ryan *et al*. 2001; Butler & Burrows 2006).

However, limited monitoring and analysis indicates that the most significant pollution sources into the Walsh are largely generated by flood irrigation (see insert box) runoff from the Cattle Creek catchment which has impacted dissolved oxygen, total nitrogen and chloride concentrations (Ryan *et al*. 2001).

Irrigated areas in the Arriga Plain near Dimbulah also coincided with very low dissolved oxygen levels. Irrigation runoff and land clearing contribute large concentrations of sediment and nutrients to the natural drainage system at the very top of the catchment at Dingo Creek, and to the lower catchment on lower Cattle Creek. The elevated ammonia levels observed in Cattle Creek can most likely be attributed to irrigation tail water runoff from farms that had recently been treated with an ammonia-based fertiliser such as urea, ammonium nitrate or aqua ammonia. High ammonia concentrations suggest that much of the runoff in Cattle Creek was being carried there via surface drains, i.e. from readily identifiable point sources that are much easier to manage than diffuse sources. (Butler *et al*. 2008). This impacts on water quality downstream from Cattle Creek, at least as far as Algoma (1.8 km downstream from the confluence with the Walsh River). Nitrogenous compounds and turbidity were noticeably elevated at Algoma compared to 2.8 km upstream at Bontaba (Ryan *et al*. 2001).

In most cases nutrient enrichment (termed eutrophication) adversely affects aquatic ecosystems by stimulating excessive growth of aquatic plants which degrade aquatic habitats and cause acute water quality problems such as dissolved oxygen crashes, algal blooms or unhealthy pH levels. However, Cattle Creek is narrow and well-shaded by riparian vegetation, so there are only a few places where there is sufficient light available for aquatic plants to grow vigorously. In Two-Mile Creek however, there appears to be high levels of eutrophication and weed infestation (Butler *et al*. 2008). Cattle Creek offers a diverse range of natural aquatic habitats along its course. If some of the more severe water quality problems could be addressed, this creek would have the potential to become a regionally significant biodiversity refuge. However current dissolved oxygen levels in Cattle Creek were barely sufficient to support fish life (Butler *et al*. 2008).

The results of the water and sediment surveys also showed some evidence of slightly elevated metal accumulations in the bottom of dams and weirpools in the Walsh River sub-catchment (Butler *et al*. 2007). These impoundments tend to trap sediments and some of the contaminants they contain. However despite this, surveys have found both Collins Weir (Watsonville) and Bruce Weir (Dimbulah) to be in quite good ecological condition with high macro-invertebrate diversity. This indicates that metal accumulations are not causing serious or chronic problems in these locations (Butler *et al*. 2008).

In contrast, water quality in higher rainfall, wet tropical areas of the upper Mitchell sub-catchment which have a sustained baseflow appears to be relatively good, i.e. catchments that feed the McLeod River, Bushy Creek and Rifle Creek, and there were signs of increased development pressures in some tributaries such as Rifle Creek (Mt Molloy), Bushy Creek (Julatten), the Mitchell River at Mount Carbine as well as Two-Mile Creek (west Mareeba). Elevated turbidity was noted after moderate rainfall events at sites at Karma Waters (downstream from Hodgkinson River confluence), as well as at Mount Carbine, Bushy Creek and Rifle Creek, which are indicative of pressures from land management practices and of disturbed upstream systems (Ryan *et al*. 2001).

The elevated total nitrogen and total phosphorus concentrations at Adil Road implicated the Mareeba Sewage Treatment Plant discharges as the major source of pollution into the Mitchell catchment (Ryan *et al*. 2001; Butler *et al*. 2008). The nutrient concentrations that have been reported in these creeks are two to ten times higher than acceptable levels, and historical data indicate that this has been the case for more than a decade. Some of the ammonia concentrations are actually high enough to be acutely toxic to aquatic animals and could cause fish kills under high pH conditions (Ryan *et al*. 2001).

While Ryan et al (2001) assessed water quality overall to be relatively good throughout the majority of the upper Mitchell basin, more management effort was required at hot spots, such as Cattle Creek and Two-Mile Creek and other potentially impacted streams, such as Rifle Creek. Rifle Creek has increasing pressures on its water quality via a number of diffuse pollution sources, including irrigation practices, fish farms, and recreational pressures. Furthermore, the septic sewage treatment tank at Rifle Creek camp ground may have inadequate capacity to cope with use pressure during the peak tourism period which coincides with the lowest stream flows of the dry season, creating another pollution point source into the wider catchment (Ryan *et al*. 2001; Butler *et al*. 2008).

An important point to acknowledge in the assessment of water quality issues associated with more intensive land use catchment of the region, is the poor currency of the monitoring data and the lack of current monitoring information by which to assess the current status of these systems or their response to proposed management measures (Butler *et al*. 2008). A key area for regional plan management action targets is engaging stakeholders within these agricultural catchments in targeted water quality monitoring programs that are established in conjunction with management actions designed to deliver water quality improvements. This is the case not only for existing agricultural sub-catchments, but also proposed ones within the Gilbert Basin.

1.2.4.5 Localised intensive mining land use sites

The Northern Gulf region contains literally thousands of small to medium sized, current and historical mining sites. Many of the historical sites were not adequately rehabilitated and continue to be a source of pollution into water catchments to this day. Runoff from these sites can contain elevated concentrations of salts, acids, heavy metals and other toxicants (Younger & Wolkersdorfer n.d.).

The upper Walsh catchment was one of the most historically important mining provinces in Queensland at the turn of the 20th century, resulting in over 3,069 abandoned mines in the upper Mitchell/Walsh catchment areas (Bartareau *et al*. 1998). The Croydon Shire was also a major epicentre of gold mining activity in the late 1880's, when it was the fourth largest town in the colony of Queensland (Glenville 2002). One of the most historically significant alluvial gold mines in the Georgetown region was at Kidston, near Einasleigh where 588.3kg (18 976 oz) of gold were produced between 1907 and 1910 (Bain *et al*. 1979). Many of these abandoned mines are still contaminating the waterways of these catchments from old workings, mullock heaps and tailings dams (Butler *et al*. 2008).

A review of literature identified sites of particular concern (Table 1.13). Most of the problem areas are located within the Walsh catchment, where a wide variety of metals, including antimony, arsenic, copper, selenium, silver, tin and zinc, were historically mined. Bartareau *et al*. (1998) study of 10 mines identified that all were discharging arsenic, copper, cadmium, lead and zinc.

Mining can affect water quality in three principal ways:

- By liberation of sediment, exposed by excavation processes,
- By mobilising pre-existing waters of poor quality (most commonly naturally saline waters) so that they artificially enter the freshwater environment, and
- By promoting the weathering of previously stable minerals, which release eco-toxic metals and other solutes, usually also contributing some degree to salinisation of the waters with which they come into contact (Harding 2005; Younger & Wolkersdorfer n.d.).

These impacts can further affect aquatic ecosystems in the following ways:

- Persistence in the various environments (water, suspended solids and sediment);
- Toxicity to specific aquatic organisms;
- Bioaccumulation by these organisms;
- Bioamplification along the trophic web, and
- Indirect effects on the biota (Harding 2005; Younger & Wolkersdorfer n.d.).

Given the large number of past mining sites contaminating streams throughout the Northern Gulf region, a systematic risk assessment based upon the compilation of available information and targeted data collecting is required to prioritise any proposed remediation efforts. Nearly all of the potentially affected waterways have only seasonal surface flows after heavy rains, with limited aquatic habitat available for most of the year. This limits the spatial and temporal extent of potential ecological impacts but may also increase the vulnerability of the few permanent waterholes contained within these systems, potentially undermining their effectiveness as drought refugia and/or dry season water sources. Another important consideration in assessing the risk posed by these sites is the potential for extreme wet season events to exacerbate the liberation of contaminants, including by the regional scale inundation and breaching of multiple mining waste retention facilities as occurred during the 2009 wet season floods (CLCAC 2014). Engaging relevant government agencies and industry bodies in undertaking further assessment of these risks to water quality within the region is recommended as a management action target for inclusion in the regional NRM plan.

As identified in the introduction to water resource assets (above), water management of regional water quality issues is a key area for inclusion in regional NRM planning. Such planning needs to consider not only current threats but also emerging ones, and management actions need to encompass both actions that seek to reduce the potential for water quality impacts and monitoring activity to assess management effectiveness and further refine management needs. Existing threats to water quality have been identified in the preceding discussion. Emerging threats include land and water use intensification, including proposed irrigation development (Gilbert Basin) and urban expansion (e.g. Southedge proposal, upper Mitchell basin), climate change stress delivered via more extreme high flows and droughts, and the possibility of range expansion for existing or new aquatic weed species.

TABLE 1.13 ABANDONED MINING SITES IN THE NORTHERN GULF THAT ARE OF PARTICULAR CONCERN FOR CONTAMINATION OF WATERWAYS.

Author & Location	Comments
(Cummings 2008) Maytown and Sandy Creek – Palmer River	The number of small (both current and historical) alluvial gold mining operations in the area continue to be problematic, particularly due to their direct disturbance of the channels and riparian areas of the lease areas. A preliminary analysis of Landsat data by Brooks and Knight (pers. comm.) suggest 3–4 km of channel per annum were mined for alluvial gold in the period 1987–2005. Because mining occurs in-channel, it represents a potentially significant sediment source to the Palmer River, as well as a major local disturbance to the in-stream habitat. It is possible that the rate of alluvial mining by small miners in the Palmer will increase in coming years as the price of gold increases. Furthermore, in addition to the disturbance of in-stream habitat, it has also been estimated that >4000 ML of water is stored in small mine dams at any one time (Brooks and Knight, pers. comm. 2007).
(Butler *et al.* 2007) Irvinebank, Wolfram Camp and Collins Weir – Walsh River	An assessment of metals accumulation in sediments at 40 sites in the mineralised tributaries of the upper Walsh catchment found high levels of metals at most sites, with priority sites nominated for further ecological assessment including Irvinebank, Wolfram Camp and Collins Weir in the upper Walsh River.
(Butler *et al.* 2007) Emu Creek, parts of Gibbs Creek and sites located within Horse, Mishap and Sandy Creeks – Walsh River	This group of small adjacent tributaries is located on the southern side of the Walsh River where elevated levels of arsenic have been detected. The levels of arsenic (and to a lesser extent mercury) at one site downstream of Collins Weir on the Walsh River were also significant. Arsenic can occur in many different forms, some of which are relatively benign, so the existing concentration levels at these sites are not indicative of a definite problem. Nevertheless, the possibility that arsenic levels are high enough to adversely affect some components of the ecosystem at these sites cannot be discounted without carrying out more detailed investigations (Butler *et al;* 2007).
(Butler *et al.* 2008) Bullaburrah Creek/ Stannary Weir on Eureka Creek – Walsh River	Significant silver (Ag) anomalies (concentrations 5 to 14 times higher than the dataset's median) were found at sites located in Bullaburrah Creek, the downstream reaches of Emu Creek and in Stannary Weir on Eureka Creek. Outside of the Gibbs Creek sub-catchment, the most significant other positive anomalies were recorded for molybdenum (Mo) at the three Bullaburrah Creek sites. Tests detected a localised reduction in macro-invertebrate diversity in the river at the mouth of Bullaburrah Creek, and there are no obvious water quality anomalies other than the elevated molybdenum levels that could potentially explain this finding.
(Butler *et al.* 2008) Jamie Creek – Walsh River	Jamie Creek is the site of Baal Gammon mine, which is still active today. In the past, highly contaminated sediment water originating from the Baal Gammon site has been found in close proximity to the township of Watsonville and the Walsh River. The site has been subject to extensive bunding and rehabilitation to prevent further contamination into the wider catchment and should be continued to be monitored closely.
(Butler *et al.* 2008) Poison Water on Oaky Creek	Poison Water on Oaky Creek reported metal concentrations (for zinc, aluminium and copper) at levels known to be highly toxic to aquatic life. At this site the only living organisms observed were water striders (insects which live on the water surface). Water samples collected from this site contained concentrations of zinc and aluminium that were several orders of magnitude higher than guideline values for the protection of aquatic ecosystems (ANZECC and ARMCANZ 2000).

(Butler *et al*. 2008) Oaky Creek in the Gibbs Creek drainage system	The highest Risk Index value encountered during this study was a value of 85 obtained for zinc (Zn) on Oaky Creek in the Gibbs Creek drainage system. This site also yielded the highest deviation score by far; a value of 127.4 (i.e. the concentration was almost 130 times higher than the median). However, there were only a few other incidences of zinc enrichment and these were confined to the Gibbs Creek area. The Gibbs Creek sites were also responsible for the majority of the anomalies observed for other metals in this study. Overall the seven sites reported significant anomalies for antimony (5 cases, including an extreme value of 61.8), tin, tungsten and arsenic (4 cases each), zinc, copper, lead (3 cases each), nickel, barium, beryllium, cobalt, selenium and thallium (one case each). Some of these may be attributable to the distinctive and complex natural mineralogy of the area, but regardless of the reason there is little doubt that metals pose a potential threat to aquatic life in this sub-catchment area (Butler et al, 2008).

In developing appropriate management action targets to address water quality issues, it will be important to consider the different land use context scenarios in which they are generated. Development of grazing land management strategies, particularly gully erosion mitigation and means of reducing stock pressure on river corridor alluvial frontages, riparian vegetation and associated floodplain wetlands represents the appropriate water quality management approach for the extensive rangeland grazing areas.

1.4 SUMMARY OF THREATS AND STRATEGIC MANAGEMENT RESPONSES

Threats to the condition and/or sustainability of Northern Gulf freshwater ecosystems have been identified throughout preceding descriptions of assets and their status. This section seeks to summarise common threats identified across asset areas and to identify priority management needs and responses that provide an appropriate focus for strategic regional NRM planning.

1.4.1 Catchment Land Use, Development and Management

The condition of freshwater ecosystems is intimately linked via a range of biophysical processes to the status of contributing catchment areas (NLWRA 2002a). Biophysical process linkages between freshwater ecosystems and their contributing catchment areas include landscape water balance and associated patterns of run off, rates of soil erosion and mobilisation and levels of primary production, carbon export and nutrient cycling (GBRMPA 2012). Catchment land use and associated patterns of land and water resource development represents one of the primary sources of modification to these biophysical processes (NLWRA 2002b). Consequently land use can represent a major threat to freshwater ecosystems if it results in catchment biophysical processes being modified beyond the natural range of seasonal and inter-annual variability to some new condition state.

More intensive forms of catchment development and/or land use patterns have the greatest capacity to modify and impact receiving aquatic ecosystems, as has been observed in the more developed eastern and southern regions of Queensland (Dennison *et al* 1999, Qld SoE 2011). Many of the potential impacts associated with catchment land use can be mitigated to some extent by adoption of good catchment management practices and/or pursuit of sensitive development patterns. For receiving freshwater environments, key catchment management needs are associated with the maintenance of natural hydrological regimes and sediment and nutrient loads. Patterns of development that minimise impacts to downstream freshwater ecosystems include those that retain high levels of native vegetation cover within a variegated landscape, and protect areas that are vulnerable to degradation and/or represent functionally important components of the natural landscape such as riparian zones, overland flow paths and wetlands. Fortunately land use types and patterns across the Northern Gulf region are some of the less intensive in Queensland. However, management of impacts associated with existing and any proposed intensification of land use within the Northern Gulf represents a key focus for the sustainable management of its freshwater ecosystem assets.

1.4.1.1 Total Grazing Pressure

Threat to Freshwater Ecosystem Assets	**Catchment Land Use - Total Grazing Pressure**
Regional Extent	Broad/Extensive
Intensity Land Use/Impacts	Extensive low intensity land use, generally low impact with seasonal and localised intensive impacts
Affected Assets	• Freshwater Environments • Aquatic Biodiversity • Water Resources
NRM Management Needs/Appropriate Responses	• Mapping and definition value/threat • Catchment/land management planning • Land use exclusion/buffers • Demonstration sites/trials • BMP development/adoption • Protected areas • Rehabilitation • Integrative management approaches • Survey and monitoring • Material/financial incentives

Issues surrounding grazing production sustainability are covered within other sections of the regional NRM plan. The focus here is identifying freshwater ecosystem assets threatened by total grazing pressure and strategic NRM responses.

Extent of Threat & Affected Assets

Rangeland grazing represents the most extensive land use within the Northern Gulf, occupying greater than 90% of total land area (Appendix 1). Most grazing occurs on unimproved native pastures and only a very small area of the region <1% has been cleared to support improved pasture production. While rangeland grazing within the Northern Gulf represents a less intensive land use in terms of direct physical modification of the landscape, high total grazing pressure is well recognised as a driver of habitat disturbance and land degradation and has generated a host of direct and in-direct impacts to the condition of Northern Gulf catchments and receiving aquatic ecosystems (DPI 1993, Burrows 2000, 2004, Tait 2005). Both domestic livestock and feral animals contribute to total grazing pressure and cause degradation to riparian areas by trampling stream banks, damaging vegetation, reducing ground cover and increasing the potential for erosion. Erosion initiated by high total grazing pressure and other stock impacts along riparian zones increases the transfer of sediment into waterways, causing increased turbidity that can have detrimental effects on water quality and aquatic organisms (Burrows 2000; McCullough & Musso 2004; Bartley *et al*. 2010). Resulting elevations in basin sediment loads are also implicated in impacts to receiving coastal and marine aquatic ecosystems (see Gulf Coasts section).

The recruitment of trees that provide shade and help to regulate water temperature is also inhibited through trampling by livestock (Burrows 2000). Vegetation along riparian zones can be particularly important for a wide range of species that cannot survive in adjacent woodlands (Burrows 2000). A number of studies have found overgrazing and the subsequent modification of riparian vegetation communities to be detrimental to bird species assemblages and abundance (Reid & Fleming 1992; Burrows 2000).

Livestock can generate excessive nutrient (manure and urine, soil attached phosphorus and via bed sediment disturbance) availability within water bodies that support outbreaks of nuisance plants or algae and reduce water quality (Burrows 2000; McCullough & Musso 2004). The degradation of water quality can impact freshwater fish and other aquatic species (Burrows 2000; Pusey & Arthington 2003). The lack of flowing water throughout much of the year, in the seasonal tropics of northern Australia, makes some water quality problems associated with cattle more significant (Burrows 2000). The contraction of rivers into separated water holes concentrates stock impact as cattle congregate around the smaller water bodies (Burrows 2000). In lower Mitchell basin lagoons, cattle disturbance of bottom sediments and aquatic macrophytes has been observed to accentuate degradation of water quality and habitat conditions as the dry season progresses (Pettit *et al* 2012). Further, the effects of livestock and feral animals on riparian zones are exacerbated during extended hot dry years, when water resources decline (Robertson 1998; Greiner & Miller 2008).

In the review of inland water asset status high total grazing pressure was identified as a major source of threat to all Northern Gulf freshwater environments including riverine corridors, off-river wetlands and surface components of groundwater dependent ecosystems (*Section 7.3.1*). Examining individual wetlands-associated regional ecosystems, high total grazing pressure is the most commonly cited pressure generating an *endangered* or *of concern* biodiversity status for riverine, palustrine, lacustrine and floodplain regional ecosystems (Qld Herbarium 2015). High total grazing pressure also threatens biodiversity assets, including DIWA wetland aggregations and protected areas as well as freshwater fishery and water resources via increased soil erosion, water quality decline and promotion of weed infestation.

It is generally accepted that the size of the cattle herd within the south east Gulf region has increased substantially over the last half century and that management measures pursued in recent decades to more evenly distribute grazing pressure on properties e.g. land type fencing and watering point provision have also facilitated an overall increase in total herd size and grazing pressure (Tait 2005, Shellberg *et al*. 2010).

Management Needs and Strategic NRM Responses

Given the extent of grazing land use within the Northern Gulf region, affecting change in grazing practices is challenging but also an avenue for significant gains in regional NRM outcomes affecting freshwater ecosystems and other natural resource assets.

There are at least two broad non-exclusive NRM strategies that can be pursued to reduce the threat posed by high total grazing pressure on freshwater ecosystem assets:

1. Reductions in overall herd size and total (including feral animal) grazing pressure; and
2. Reduction of total grazing pressure on identified high value/grazing-sensitive assets.

Some grazier stakeholders on coastal zone properties have nominated reductions in herd size as an economically viable strategy that can reduce pressure on pasture and land resources while facilitating increased weight gains for individual beasts and overall enhanced enterprise profitability. Conduction and promotion of case studies that document the economic merits of such management strategies for different land types could provide an incentive for broader adoption of reduced stocking rates on pastoral properties with vulnerable aquatic ecosystem assets. The provision of material or financial incentives for targeted asset protection could also have a role to play in the uptake of herd size reduction based management strategies.

While a reduction in total grazing pressure regionally would have much merit from a NRM perspective it would require major investment to achieve regional adoption and may not enjoy broad industry support. Management approaches specifically targeting higher value freshwater ecosystem assets and/or areas of particular sensitivity/vulnerability to total grazing pressure provide a more strategic approach for regional NRM planning. Higher value freshwater ecosystem assets and/or areas of particular vulnerability to total grazing pressure can be defined both generically and more specifically by reference to regional prioritisation exercises. River corridors, associated riparian zones and off-river wetlands and springs represent generic assets. General areas of sensitivity/vulnerability to high total grazing pressure included steeper stream banks and contributing catchment areas, flood flow paths and areas with erosion prone soils including old alluvial terraces and floodplains, particularly those with dispersive subsoils (Shellberg and Brooks 2012).

Within a Grazing Land Management Planning (GLMP) context, such assets or areas vulnerable to degradation can be afforded protection via fencing configurations and seasonally varied and/or conservative stocking regimes including spelling (Tait 2005). In the past, regional NRM bodies have provided material and financial incentives for stock excluding riparian fencing on Gulf River systems (see Management of Riparian Zones insert box). Developing and extending a GLMP incentive program to support fencing of other high value wetland assets would also serve their protection. Ideally such a program would be progressed in conjunction with other management measures that integratively addressed other pervasive threats including fire regime, weeds and feral animals.

A broad GLMP program will deliver river basin condition benefits, including enhanced protection of generic freshwater ecosystem assets. However, targeting programs specifically at pastoral properties assessed to contain regionally important assets or to be major sources of elevated sediment loads associated with alluvial gully erosion, would represent a more strategic investment in freshwater ecosystem and biodiversity protection.

This underpins the importance of NRM bodies conducting GIS based mapping and data collation to develop freshwater (and other) ecosystem asset and land degradation risk layers. These can provide the basis for regional prioritisation and targeting of NRM programs that seek to deliver aquatic (& terrestrial) ecosystem protection and biodiversity conservation benefits, in addition to production sustainability ones. The following examples are a non-exhaustive list of valuable assets or land vulnerability layers that could be used to guide GLMP program investments to serve freshwater ecosystem management and protection:

- Highly vulnerable/degraded (actively eroding) alluvial land types (Shellberg and Brooks 2012);
- Aquatic Conservation Assessments produced using AquaBAMM by DEHP (Rollason and Howell 2010, Howell and Kenna 2012);
- Northern Australia Water Future Assessment ecological assets layers (Kennard et al 2010, 2011);
- Priority areas for the conservation of freshwater biodiversity (Hermoso *et al* 2011);
- Priority aquatic refugia within the Mitchell and Gilbert River Basins (Lymburner and Burrows 2008,, Hermoso *et al* 2013, McJanet *et al* 2014, Waltham *et al* 2014);
- Directory of Important Wetlands In Australia http://www.environment.gov.au/topics/water/water-our-environment/wetlands/australian-wetlands-database/directory-important
- Groundwater Dependent Ecosystems including springs (QEPA 2005, Fensham and Price 2003);
- ‘Endangered’ or ‘of concern’ wetland associated regional ecosystems (Qld Herbarium 2015);
- Known or predicted occurrences of threatened riparian or aquatic wildlife species and/or their habitats (Qld Wildnet, SPRAT, VMA essential habitat version 3.1)

Participatory learning/monitoring programs that engage pastoral landholders in actively monitoring the condition of assets vulnerable to total grazing pressure could also provide a useful tool for building their capacity to better manage freshwater ecosystems. A simple wetland assessment and monitoring pro-forma (SWAMP) utilising digital camera-based photo point monitoring of wetland systems (Tait 2005) provides one example of a monitoring system that could serve such management needs.

MANAGEMENT OF RIPARIAN ZONES

To reduce the impacts of livestock on riparian areas, lower stocking rates, fencing or provision of additional watering points and supplements away from watercourses may be used (Burrows 2000; Fisher *et al.* 2004; Martin *et al.* 2006). Fencing riparian zones enables spelling and better control of cattle which reduces the risk of erosion, sediment and nutrient input into waterways (Greiner 2009). Studies have found that sediment yields can be reduced by up to 50% after one year of cattle exclusion (Bartley *et al.* 2010). One of the constraints to fencing riparian areas and installing additional watering points is costs, which often make this management option not appealing to land managers (Agouridis *et al.* 2005). Further, permanently removing a portion of the pastures from production could further reduce productivity (Agouridis *et al.* 2005). To overcome some of the financial constraints, land managers can implement grazing of the riparian areas for short time periods when the stream is least sensitive to the effects of grazing (Agouridis *et al.* 2005). Fencing riparian zones can also have long term financial benefits by reducing mustering costs and the time it takes land managers to check rivers for stock and remove bogged cattle (Burrows 2000).

Determining appropriate widths for riparian buffer zones requires consideration of the size of the watercourse, the maximum height of water flows, the slope and soil type of banks, the vegetation community and the productivity impact on the landowner (Greiner 2009). A general buffer zone recommendation is 50m along each side of a minor water course and 100 to 200m on each side of major creeks or rivers (McCullough & Musso 2004).

1.4.1.2 MINING

Threat to Freshwater Ecosystem Assets	**Catchment Land Use - Mining**
Regional Extent	Limited/Localised – sub catchment
Intensity Land Use/Impacts	Intensive land use. Localised intensive impacts – capacity to be propagated to downstream systems and/or to bio accumulate
Affected Assets	• Freshwater Environments • Aquatic Biodiversity • Fisheries • Water Resources
NRM Management Needs/Appropriate Responses	• Mapping and definition value/threat • Development constraints/planning controls • Catchment /land management planning • Land use exclusion/buffers • Inventory and prioritisation • Protected areas • Rehabilitation • Research and development • Survey and monitoring

Extent of Threat & Affected Assets

Mining is an intensive land use that has the capacity to significantly modify the physical landscape and biophysical processes that underpin ecosystem condition. The Northern Gulf region contains literally thousands of small to medium sized, current and historical mining sites, although collectively these still represent a very small proportion of the region. As identified in the discussion on water quality, many of the historical sites were not adequately rehabilitated and continue to be a source of pollution into water catchments to this day. Runoff from these sites can contain elevated concentrations of salts, acids, heavy metals and other toxicants (Younger & Wolkersdorfer n.d.). Freshwater ecosystem assets threatened by mining impacts include freshwater environments (particularly river corridors), freshwater biodiversity and water resources. Besides contaminant risks to water quality, mining can also generate hydrological and geomorphological impacts to sites and catchments. Most impacts are localised although some more extensively mined areas have been disturbed at sub-catchment scales.

As previously identified, most of the problem areas of particular concern for the contamination of waterways are located within the Walsh catchment, where a wide variety of metals, including antimony, arsenic, copper, selenium, silver, tin and zinc were mined. The Palmer River sub-catchment is another area with significant historical and recent mining activity that has left an impact legacy.

Where they occur, heavy metals are pollutants of considerable concern because they are not readily eliminated from aquatic ecosystems. Instead, they are either accumulated in sediments or biota, or transported to other ecosystems (e.g., from the land to streams by stormwater runoff). Thus, metals such as arsenic, cadmium, chromium, copper and mercury frequently accumulate in aquatic plants and in river and lake sediments, and some of these elements can be remobilised and incorporated into food webs. Some metals such as mercury (Hg) can bioaccumulate within food webs (Goodyear & McNeill 1999), and affect the physiology, growth and reproduction of organisms at multiple trophic levels (Kelly 1988; Harding 2005). Bioaccumulation not only presents risks to aquatic organisms but also to human consumers particularly those who have a subsistence dependence on and/or consume significant quantities of aquatic organisms for food.

Significant concerns are held amongst the Kowanyama community in particular, regarding the potential threat posed by mine related pollution in the Palmer River. However monitoring to date has demonstrated that mercury trophic magnification factors within food webs were low, relative to other regions of the world, and few fish approached or exceeded consumption guidelines. This suggests that the health of humans and wildlife consuming fish such as barramundi from these rivers is unlikely to be compromised by exposure to this toxic element (Jardine *et al.* 2012).

Management Needs and Strategic NRM Responses

Given the impact potential of mining as an intensive land use it is generally incompatible with the protection and maintenance of catchments with high conservation value aquatic biodiversity assets. This highlights the merits of protected area arrangements that quarantine this form of intensive development from catchments containing such values. Regional NRM planning can play an important role in identifying regionally important freshwater ecosystems assets that need to be protected from such forms of intensive development and in working with regional community stakeholders, local and state governments to identify which appropriate state and local government planning mechanism can be employed on behalf of regional communities to limit impacts risk posed by mining development.

Primary responsibility for the management of aquatic ecosystem impacts associated with existing and past mining operations, including rehabilitation needs, lies with development proponents and regulating government agencies. However in the case of many historical sites, environmental management obligations were lax or not effectively enforced. Community NRM bodies such as NGRMG can play an effective role in this context by contributing to monitoring and assessment activities that help define current levels of risk, by acting as a broker in providing community stakeholders with access to relevant and independent information concerning risks posed by sites, and by providing regional community overview that encourages government and industry to fulfil management and rehabilitation responsibilities. Given the large number of mining sites within some sub-catchments of the Northern Gulf region, a regional risk assessment and management response prioritisation exercise is required to strategically address the threats posed by this land use, and an activity that could be readily supported by regional NRM body support and community engagement.

As experienced during the 2009 wet season extreme flood event, where mine waste facilities were inundated by high flows and contaminants liberated to the environments, greater climatic extremes associated with climate change need to be factored in any assessment of the relative risks posed by mining sites and infrastructure to freshwater ecosystems.

1.4.1.3 AGRICULTURE

Threat to Freshwater Ecosystem Assets	Catchment Land Use - Agriculture
Regional Extent	Limited/Localised – sub catchment
Intensity Land Use/Impacts	Intensive land use. Localised intensive impacts – capacity to be propagated to downstream systems
Affected Assets	• Freshwater Environments • Aquatic Biodiversity • Water Resources
NRM Management Needs/Appropriate Responses	• Mapping and definition value/threat • Development constraints/planning controls • Catchment/land management planning • Land use exclusion/buffers • Demonstration sites/ trials • BMP development/adoption • Protected areas • Rehabilitation • Research and development • Survey and monitoring

Extent of Threat & Affected Assets

There is currently very limited agricultural development within the Northern Gulf region, occurring primarily within the Mitchell and Gilbert basins and occupying less than a 1% of the region (Appendix 1). The most significant area of existing development is associated with the Mareeba Dimbulah Irrigation Area in the Walsh Sub catchment of the upper Mitchell basin. If realised, proposals to further develop the Gilbert River basin's water resources will see significant expansion of irrigated agriculture land use in the region (Petheram *et al* 2013).

Agriculture is an intensive land use that requires the clearing of native vegetation and results in major biophysical changes to catchment landforms and processes. Irrigated agricultural development is also usually accompanied by water resource and associated infrastructure development, which generates concomitant impacts. Receiving aquatic ecosystems downstream of intensive agricultural development can be impacted via changes in catchment hydrology including run off rates and flow patterns, altered and elevated sediment and nutrient loads and other contaminants including pesticide residues. Water quality impacts associated with existing agricultural development in the region were discussed under water resources.

Where catchments are intensively developed to agriculture, the loss or degradation of important landscape elements such as riparian forests and wetland basins exacerbates impact potential due to the removal of functioning buffers between the intensively modified contributing catchment and the receiving aquatic ecosystem. Disturbances created within aquatic ecosystems due to their juxtaposition with intensive agriculture also facilitate a host of secondary impacts such as weed invasion and algal blooms. This suite of impacts may be persistent and difficult to rectify, leaving an enduring environmental legacy (Pusey & Kennard 2009). The ecosystems impact challenges associated with riverbasins that have been intensively developed to agriculture have been well documented in other more developed regions of Queensland such as the GBR catchment (GBRMPA 2012).

As observed in other regions of Queensland, intensive agricultural development can threaten all forms of freshwater ecosystem assets including freshwater environments, biodiversity, fisheries and water resources. Impacts can also be propagated to adjoining coastal and marine areas (GBRMPA 2012). Given the currently limited agricultural development in the Northern Gulf region it does not yet present a basin scale threat to aquatic ecosystems assets although freshwater ecosystem impacts associated with agricultural development are well recognised for sub-catchments with more extensive agricultural land use (Ryan 2002).

Management Needs and Strategic NRM Responses

Although limited in overall regional extent, the NRM needs of these agriculture-dominated sub-catchments is an important focus for freshwater ecosystem management in the region. The need to address the management needs of aquatic ecosystems in agriculture-dominated catchments in the regional NRM plan is also underpinned by the prospect of major increases in agricultural land use in the region (Petheram *et al* 2013).

In developing effective NRM responses to the challenges posed to freshwater ecosystems by agricultural development, the NGRMG needs to address management and planning needs surrounding existing agricultural areas as well as prospective development areas. Ideally lessons learned regarding aquatic ecosystems impacts associated with current agricultural development in the region and elsewhere in North Queensland should be used to inform development planning and management in prospective development areas.

Within the existing agricultural areas of the upper Mitchell there is a need to further promote the adoption of Best Management Practices (BMP) in regard to on farm water, nutrient and pesticide use. Engagement of primary producers in BMP trials and monitoring of receiving ecosystem condition provides a means for direct participatory learning. Education of the regional community regarding the need for BMP adoption and communication of trial outcome is also essential for promoting broader BMP adoption.

Given the impacted status of some receiving aquatic ecosystems in agriculture-dominated sub-catchments, there is also some need for system rehabilitation. Opportunities are associated with re-instating system hydrology via better water use and drainage management, improving buffer functions between agricultural land use, receiving aquatic systems via riparian revegetation and remnant vegetation rehabilitation, and via construction of wetland detention basins.

While improving on-farm practices and retrofitting catchment functions is an appropriate NRM investment area for existing agriculture areas, prospective development areas present the opportunity for pro-active catchment management and protection initiatives and these provide an important focus for freshwater ecosystem asset management in developing agricultural areas.

Such initiatives need to consider a hierarchy of planning and management opportunities, starting with the layout of development within contributing catchment areas and the need to exclude highly valuable or sensitive areas from development and to maintain natural catchment buffers including wetland basins and riparian vegetation. Extending to individual farm layouts, development planning needs to consider land form and capability and the inclusion of run off retention basin features. On-farm cultivation and irrigation methods and practices represent the next level of management intervention that provides opportunities for downstream ecosystems protection. Given the 'green field' status of prospective agricultural development within the region, there is every opportunity for development to be progressed and informed by the best current knowledge concerning ecologically sustainable development approaches. Wherever possible and appropriate, such knowledge should be drawn from existing agricultural areas within the region or from other relevant regions elsewhere in tropical Queensland. Facilitating such initiatives is an important focal area for inclusion in the NGRMG regional NRM plan.

1.4.1.4 Soil Erosion

Threat to Freshwater Ecosystem Assets	**Catchment Management Issue – Soil Erosion**
Regional Extent	Sub catchment - Broad
Intensity Land Use/Impacts	Regional extensive to localised intensive impacts – capacity to propagate impacts to downstream ecosystems including coastal and marine
Affected Assets	• Freshwater Environments • Aquatic Biodiversity • Fisheries • Water Resources
NRM Management Needs/Appropriate Responses	• Mapping and definition value/threat • Development constraints/planning controls • Catchment/land management planning • Land use exclusion/buffers

	• Demonstration sites/ trials • BMP development/adoption • Strategic control programs • Rehabilitation • Integrative management approaches • Research and development • Survey and monitoring • Material/financial incentives

Extent of Threat & Affected Assets

There has been long-standing recognition that soil erosion is a significant catchment management issue within Gulf river basins (DPI 1993). More recent assessments have served to quantify the extent of the issue at basin scales, the importance of gullies and sub-soil profiles as sediment load sources and the initiation and exacerbation of the problem in conjunction with increases in regional cattle herds and total grazing pressure (Tait 2005, Brooks *et al.* 2008, Shelberg *et al.* 2010, Shelberg and Brooks 2012).

While soil erosion is in itself a significant land degradation issue that can directly impact asset condition (i.e. wetland and riparian frontage habitats), it is its contribution to increased sediment loads conveyed by river flows that underpin its significance as a threat to downstream aquatic ecosystems, including receiving coastal and marine systems (see Gulf Coasts section). Increased sediment loads have the capacity to drive a range of geomorphic changes in receiving riverine environments, and in the Mitchell and Gilbert basins have been implicated in major reductions in the availability of pool habitat (Brooks *et al* 2008). Given the demonstrated capacity of turbidity to affect biota, primary productivity and nutrient dynamics, soil erosion and resulting elevated basin sediment loads present a range of direct and indirect threats to all freshwater ecosystem assets including aquatic habitats, biodiversity, freshwater fisheries and water resources.

There are at least three main forms of soil erosion that contribute sediment loads within river basins bank, hill slope and gully (NLWRA 2002). The relative contribution of these different sources depends upon catchment geology and associated soil types, climate and land use. In the Northern Gulf region, gully erosion particularly of alluvial land forms has been identified as the main source of sediment loads to river basins and ultimately the Gulf of Carpentaria (Shellberg and Brooks 2012). Gully erosion is widespread in alluvial areas, including both riparian zones and floodplains. Alluvial gullies are concentrated, direct and major sources of sediment to river systems. The erosion of floodplain soils via alluvial gully erosion presents major local and cumulative threats to:

- The local pastoral industry through the loss of productive riparian land;
- Existing human infrastructure (e.g., roads, fences, dams, buildings, water points);
- Future potential agricultural development;
- Downstream aquatic ecosystems influenced by high suspended sediment concentrations, associated nutrients, and habitat changes from sedimentation (i.e. pool and lagoon infilling);
- Indigenous cultural use of water bodies for subsistence, commercial, and ceremonial purposes (i.e., fisheries production); and
- The long-term sustainability of the landscape and provision of ecosystem services. (Shellberg & Brooks 2012).

Despite this, alluvial gully erosion across the North has been poorly documented, and historically hill slope erosion has received more attention (Bartley *et al.* 2010; Shellberg & Brooks 2012). The erodibility of floodplain soils plays a major role in where alluvial gullies will become established. Older, elevated, near-river, floodplain soils in the tropics are often highly weathered silty loams, compared to clay soils that dominate floodplain areas more distant from the active channel and sandy soils that tend to occur within it. These sodic, silty soils are dispersive and predisposed to erosion, especially when disturbed.

Once initiated, alluvial gullies continue to grow over time and consume local riparian zones. This type of sediment infilling can completely bisect local lagoons in floodplains and reduce their habitat volume and connectivity with main river channels. If left unchecked, this type of erosion and sedimentation can completely infill ancient lagoons at accelerated rates, eliminating habitat for fish such as barramundi or other native species and reducing future water supplies for stock and humans.

The soils of the Mitchell catchment are particularly susceptible to gully erosion and naturally prone to structural breakdown, and gullied areas have increased between 1.25 to 10 times their historic 1949 area (Brooks *et al.* 2009). Remote sensing based mapping within the 31,000 km^2 Mitchell River fluvial megafan has identified that active gullying into alluvium occupies ~ 0·4% (129 km^2) of the lower Mitchell catchment (Brooks *et al.* 2009). Analysis of this imagery indicates that eroded areas can cover up to 1% of the total catchment area and locally >10% of the floodplain area (Shellberg & Brooks 2012). This is estimated to be contributing up to 90% of the total sediment yield in this catchment (Olley & Wasson 2003). Alarmingly, specific sediment yields of 1250 t/ha have been recorded from individual gullies in the Mitchell, yields that are comparable with the globally highest recorded rates from the Chinese Loess plateau (Brooks *et al.* 2007).

Retrospective analysis of trends in gully area growth suggests that the current phase of extensive gullying was initiated between 1880 and 1950 in the Mitchell catchment. Initiation points of alluvial gullies include the banks of rivers, lagoons, creeks and other water bodies, which may then be exacerbated by high flow channel scour, rainfall runoff, flood drawdown; bank seepage points and slumps, animal tracks and poorly constructed roads. Sub-surface soil dispersion and large slope imbalances mean that even large features like alluvial ridges or floodplains sloping away from the river can be breached or overcome by gully erosion. These gullies can subsequently develop into very large gully complexes and creek drainage systems (Shellberg 2011).

Suspended sediment concentrations (SSCs) transported out of alluvial gullies in the Mitchell catchment typically are > 10,000 mg/L but can exceed 100,000 mg/L from the largest gullies during peak runoff. The combination of highly unstable soils, rapid scarp retreat, intense tropical rainfall and runoff, and high sediment concentrations can lead to local sediment yields which are high by both Australian and world standards.

Future projections of gully growth in the Mitchell catchment suggest that some alluvial gullies will continue to create chronic erosion for hundreds if not thousands of years, growing 10 to 50 times their initial 1949 size, unless mitigated by land management intervention (Shellberg & Brooks 2012). The long-term evolution and geology of the Mitchell megafan has created the template for gully erosion potential, while shorter term land management changes has promoted the acceleration of erosion rates, thereby increasing gully density along previously productive riparian areas (Brooks *et al.* 2009).

Gullies of up to 5m deep or more form continuous scarps along both riparian margins for tens of kilometres along some reaches of the Mitchell River (Brooks *et al.* 2007). Preliminary assessments of gully activity on the Mitchell River shows rates of headwall retreat up to 10m/yr, generating specific sediment yields of 1250 t/ha (Brooks *et al.* 2006).

This acceleration of gully erosion from historical rates can be largely attributed to the introduction of hard-hoofed cattle in the 1880's and steady increases in herd sizes since then (Shellberg *et al* 2010). Intense cattle grazing concentrated in the riparian zones during the dry season increases the potential for gully erosion to occur when the wet season arrives, especially along steep banks, floodplain hollows and channels. Cattle have reduced native grass cover in these riparian areas and increased physical disturbance of soils, while establishing cattle tracks over steep banks used to access water where run off concentrates. This is compounded by episodic drought, the invasion of exotic weed and grass species, fire regime modifications, and more recently road construction (Shellberg & Brooks 2012).

Projected climate change (Moise 2014), has the potential to further exacerbate these processes, as erosion from potentially more intense tropical rainfall on exposed soils and overland runoff from surrounding catchment areas will further accelerate alluvial gully erosion and scarp retreat. Projected more frequent and extended droughts will also lead to greater pressure on riparian and alluvial areas from grazing animals. Current practices of grazing down grass cover to minimal levels near waterways in the late dry season, forming dense water access cattle pads cut into steep banks and early wet season fire burning of remnant vegetation, all result in exposed and disturbed erodible soils at the beginning of the tropical monsoon rain season (Shellberg & Brooks 2012).

Vegetation on riparian banks and adjacent floodplains are a key defence in preventing alluvial gully erosion into dispersible sodic soils. Native deep-rooted perennial grass performs best at protecting and binding surface soils to prevent erosion initiation, compared to tree, shrub or exotic weed species. However, animal tracks (pads) and roads that concentrate water can also overwhelm the effectiveness of grass cover in resisting soil and gully erosion. Increased vegetation cover on gully channels and networks can be promoted by removing chronic disturbances inhibiting natural recovery (e.g. grazing and clearing), or by direct planting of vegetation within or around gully networks (Shellberg 2011; Shellberg & Brooks 2012).

Management Needs and Strategic NRM Responses

Soil erosion is a threat of regional significance to a host of natural resource assets, including freshwater ecosystems. There are a number of reasons which may be cited for the limited management intervention that has occurred thus far in the region. These include the daunting scale and the apparent cost-effective intractability of the problem. Associated with this is the perception that the area of productive land being lost is relatively small in relation to overall pastoral land holdings and that management costs are prohibitive in relation to economic risks associated with land losses. More recent quantification of the areal extent of the issue within the region would challenge such perceptions but this knowledge needs to be effectively communicated for perceptions to change. Pastoral agronomist assessments of productive land losses and better quantification of the downstream ecosystem impacts associated with extensive gully erosion, may also help drive increased appreciation of the significance of the issue and greater ownership of the need to deliver management solutions. This would be dependent on effective information communication and dissemination programs.

Another issue facing effective management of gully erosion is the general question of what is 'doable' in terms of cost effective rehabilitation. A range of rehabilitation methods have now been developed or proposed to address gully erosion (Shellberg and Brooks 2012). To progress further development and adoption of such management methods, they need to trialled on a large scale across a range of land form and land use/management settings. Financial and material incentives can often provide an impetus for landholder engagement in such trials. Given public interest in the impacts associated with soil erosion, justification for government investment in program funding needs to be communicated to funding bodies. Where incentives are used to facilitate landholder engagement in trials, opportunities should be sought to select readily accessible, high profile sites and landholders willing to be engaged in field days and other communication programs.

Experience gained from basin scale soil erosion assessments indicates that some source areas can contribute a disproportionate contribution to basin loads (Howley *et al* 2013). Conducting equivalent source tracing assessments within Northern Gulf river basins would provide a means to strategically target key sediment load areas and reduce the scale of intervention areas. Ultimately the initiation of gully erosion processes within the Northern Gulf is closely related to land use impacts, primarily total grazing pressure. Halting the advance and initiation of gully erosion needs to be incorporated as a major focal point in the development of Grazing Land Management Plans (GLMPs). GLMPs also provide an appropriate vehicle for identifying how integrative management methods addressing grazing pressure, weed management and fire regime can be developed to address not only soil erosion but other condition impacts of floodplain and riparian areas collectively. Recognising that not only grazing land use, but also agriculture and infrastructure such as roads, also contribute to alluvial gully soil erosion issues is also a salient consideration for NRM planning needs, including that associated with prospective agricultural development areas.

STABILISING GULLY SLOPES AT MT MULGRAVE STATION (SHELLBERG 2011)

The Mt Mulgrave station homestead is located on the banks of the Mitchell River. The station house, quarters, sheds, corrals and air strip are literally surrounded by alluvial gullying due to the highly dispersive soils and land use related disturbances. Erosion threats to infrastructure have prompted various actions to stabilize gully scarps.

Where gully scarp retreat threatened to undermine the air strip and hanger, a section of gully scarp was re-graded with a bulldozer, back filled with some sand and gravel, and revegetated with grass. A small berm was constructed above the surrounding soil surface along the scarp front so as to reduce overland flow from pouring off the old scarp face. Since the scarp was located inside the airstrip fenceline, the re-established grass thrived due to reduced stock pressures, rotational grazing and periodic spelling. This combination of measures was successful at reducing scarp retreat over the last decade. Similar success in gully front stablisation has been achieved along the river frontage just downstream of the station house. In comparison, the remaining untreated scarp front outside the airstrip fence continued to erode at an average rate of 0.13 m/yr over 50 years, with maximum rates up to 1.4 m/yr.

a

b

a) oblique aerial view of a gully head scarp at Mount Mulgrave next to the air strip fence line (in black). Note the dark green vegetated patch within the air strip (middle right) which represents a section of the gully front that was re-graded, backfilled with gravel, re-vegetated with grass, and only lightly grazed in rotation. b) Ground view in October 2008 of the re-graded section of gully scarp.

Old tyres are not an effective measure to reduce gully erosion and can add toxic material to soils and waterways from the photo-chemical breakdown of the tires over time.

1.4.1.5 FIRE REGIME

Threat to Freshwater Ecosystem Asset	Catchment Management Issue –Fire Regime
Regional Extent	Broad/Extensive
Intensity Land Use/Impacts	Localised intensive to regional extensive impacts
Affected Assets	• Freshwater Environments • Aquatic Biodiversity • Water Resources
NRM Management Needs/Appropriate Responses	• Mapping and definition value/threat • Catchment/land management planning • Demonstration sites/ trials • BMP development/adoption • Strategic control programs • Environmental education/ interpretation • Integrative management approaches • Research and development • Survey and monitoring

Extent of Threat & Affected Assets

General issues concerning sustainable fire regime management are covered within other sections of the regional NRM plan. The specific focus here is on identifying freshwater ecosystem assets threatened by inappropriate burning and strategic NRM responses applicable to the coastal zone.

Inappropriate fire regimes, particularly hot, late dry season burns, are recognised to pose threats to a range of freshwater ecosystems assets including riverine corridors, biodiversity and water resources. Many wetland-associated regional ecosystems are fire sensitive, including fringing riparian and wetland communities including springs (CLCAC 2013, Qld Herbarium 2015). Inappropriate burns can also generate secondary impacts via increased exposure of contributing catchment areas to soil erosion at the beginning of the wet season, destabilisation of stream bank areas, opening overstorey canopies promoting weed invasion and higher instream temperatures and by increasing grazing pressure on residual fire refugia.

In agricultural areas where grazing land uses have been removed, the proliferation of exotic pasture grasses that create high fuel loads in riparian areas present another fire regime management challenge for riparian and wetland systems (Tait 2011).

Management Needs and Strategic NRM Responses

Fortunately appropriate fire management guidelines have been developed for the Gulf savannahs to help land managers plan hazard reduction burns and for undertaking planed burns for improved production and conservation outcomes (CLCAC 2013b). In some areas Indigenous Land and Sea Ranger programs have initiated controlled burning based management of Indigenous Protected Areas and other accessible traditional country areas (CLCAC 2014). Further adoption of these guidelines and implementation of appropriate burning practices across the Northern Gulf region would significantly reduce the threat posed to fire sensitive freshwater ecosystem assets by uncontrolled fire. Impasses to further adoption of controlled burning include conflict with pastoral production objectives e.g. burning can reduce the availability of late dry season pasture reserves. Conflict can also arise between burning practices pursued for weed (e.g. rubber vine) control and conservation of fire sensitive biodiversity values.

Initiatives that could serve improved fire regime management in the Northern Gulf have been identified in consultation with regional stakeholders (see Gulf Coastal section), and include:

- Further promotion and distribution of the fire management guidelines that have been developed for the south east Gulf coastal savannahs (CLCAC 2013b);
- Supporting Land and Sea Ranger Program capacity to continue and expand controlled burning programs on protected areas and accessible traditional lands and to act as service providers for other land managers wanting to implement controlled burns;
- Including fire regime management objectives in management agreements with pastoralist recipients of material or financial incentives for weed, total grazing pressure and biodiversity management.

To encourage greater adoption of appropriate fire regime management there is also a need to better communicate the costs associated with inappropriate burning of riparian and wetland areas, including under the spectre of projected climate change. Promoting enhanced resilience is one of the primary approaches nominated for enhancing the adaptive capacity of ecosystems to the projected impacts of climate change. These include major changes in the discharge characteristics of river basins and extended drought periods (Gobius 2015). Under this scenario resilient riparian and wetland areas will provide increasing important ecosystems services in maintaining water quality, bank stability and refugia. In this context the imperative to enhance the resilience of fire sensitive riparian and wetland communities and fire regime management within contributing catchment areas gains increased importance.

1.4.2 Water Resource Development

1.4.2.1 Surface Water

Threat to Freshwater Ecosystem Asset	**Water Resource Development – Surface Water**
Regional Extent	Currently limited localised – sub catchment
Intensity Land Use/Impacts	Localised intensive to extensive sub-catchment impacts capacity to propagate impacts to downstream ecosystems including coastal and marine
Affected Assets	• Freshwater Environments • Aquatic Biodiversity • Fisheries • Water Resources
NRM Management Needs/Appropriate Responses	• Mapping and definition value/threat • Development constraints/planning controls • Catchment/land management planning • BMP development/adoption • Inventory and prioritisation • Protected areas • Research and development • Survey and monitoring

Extent of Threat & Affected Assets

Existing levels of surface water resource development in the Northern Gulf (detailed in the description of water resource assets) are very low by national standards and currently present only relatively localised impact risks to freshwater ecosystems (see Table 1.11). Existing impacts are primarily associated with water infrastructure (discussed below under instream barriers), minor flow modifications including flow supplementation e.g. within the Walsh River basin (Ryan 2002) and exploitation of bed sand aquifers in the Gilbert River basin (DISITIA 2014). The most significant threats posed to Northern Gulf freshwater ecosystems by surface water resource development are associated with proposed rather than existing development (Baylis *et al* 2014, DISITIA 2014). Freshwater ecosystem assets that can be impacted by surface water development include freshwater environments, biodiversity, fisheries and water resource conditions including water quality as demonstrated in other regions of Queensland. e.g. Murray Darling Basin where surface water resources have been over developed e.g. ~56% of mean annual flow extracted from the Condamine–Balonne River system (SoE 2011).

Surface water resource development poses threats to aquatic ecosystems due to strong linkages between stream flow and aquatic ecology. Four principles (below) linking stream flow to ecology (Bunn and Arthington 2002), provide a basis for understanding how alteration of flow regimes due to water resource development may impact aquatic ecosystems:

1. Flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic community composition;
2. Aquatic species have evolved life history strategies primarily in direct response to the natural flow regimes;
3. Maintenance of natural patterns of longitudinal and lateral aquatic habitat connectivity is essential to the viability of populations of many riverine species;
4. Invasion and success of exotic and introduced species in rivers is facilitated by the alteration of flow regimes.

Essentially water flow (mediated by catchment biophysical features) is the main structural architect and connective medium of a river ecosystem. Flows erode, transport and deposit materials, organic and mineral, particulate and soluble. Flows shape river channels, floodplains and estuaries, scour deep holes, remove accumulated organic matter and move bed load sediment. The frequency and duration of channel and overbank flows provide the opportunity and conduit for biota movement, recharge alluvial aquifers, determine channel and floodplain waterhole levels and perenniality, refresh instream water quality and drive estuary salinity regimes and productivity. Given the range of ecosystem functional attributes linked to flow regime, the capacity for water resource development driven alteration of flow regime to generate ecosystem impacts is apparent.

Recent water resource development proposals for the Gilbert basin would have resulted in reductions of up to 14 % of mean annual and 20% of median flows (Petheram *et al*. 2013). Even with mitigative strategies in place, development of this magnitude was assessed to present a range of risks to not only freshwater ecosystem assets but also to adjoining coastal and marine systems. Significant impacts were identified for up to 15 ecological assets within the basin including:

- Migratory fish guild;
- Freshwater turtles;
- Floodplain vegetation;
- Wetlands;
- Fluvial geomorphology and river forming processes; and
- Floodplain energy subsidy.

Broader risks, including the adjoining marine systems included:

- 15 fishery species potentially at high risk and 8 species at medium risk;
- Potential 3-13% reduction in White banana prawn catch in adjoining coastal fishery zones;
- Potential 3-12% reduction in Barramundi catch in Gilbert River;
- Impacts to wet season flood cue aspects of banana prawn and barramundi reproductive biology and recruitment processes (Baylis *et al* 2014, DISITIA 2014).

Projected impacts of climate change on climatic variability and the hydro cycle, including the increased possibility of both extended droughts and more intense rainfall events (Moise 2014, Gobius 2015), present the likelihood that some climate change impacts will be realised via altered river flow regimes. Assessments of potential impacts associated with altered flow regimes need to be cognisant of the likelihood of cumulative effects of climate change exacerbating those associated with water resource development. Current assessments of freshwater ecosystems impact risks associated with climate change and water resource development proposed within the Northern Gulf rate the latter as the most significant (Close *et al* 2012).

Management Needs and Strategic NRM Responses

As identified in the discussion of water resource assets In Queensland, water resource management is delivered by a statutory planning process under the *Water Act 2000* that stipulates the preparation of Water Resource Plans (WRPs) and associated Resource Operations Plans (ROPs) for river basin-bound planning areas. While this statutory planning process governs water resource management outcomes there are still important opportunities for community-based NRM planning to effectively contribute to water resource management outcomes via directly participating in the Water Resource Planning process and via community engagement and project activities that support WRP implementation and review. These were described in full in the discussion of water resource assets (Section 7.3.4) and include:

- Education/Information dissemination
- Representational advocacy
- Development and promotion of adoption of Best Management Practice
- Water quality management monitoring
- Independent oversight and assessment of effective implementation of Water Resource Plans (WRPs) and Regional Operation Plans (ROPs)
- Further definition of flow dependent assets and their management needs.

1.4.2.2 Groundwater Extraction

Threat to Freshwater Ecosystem Assets	**Water Resource Development – Groundwater**
Regional Extent	Limited/Localised
Intensity Land Use/Impacts	Localised intensive to extensive sub-catchment impacts capacity to propagate impacts to hydrologically linked ecosystems
Affected Assets	• Freshwater Environments • Aquatic Biodiversity • Fisheries • Water Resources
NRM Management Needs/Appropriate Responses	• Mapping and definition value/threat • Development constraints/planning controls • Catchment/land management planning • BMP development/adoption • Protected areas • Integrative management approaches • Research and development • Survey and monitoring • Material/financial incentives

Extent of Threat & Affected Assets

Although the use of bores to extract groundwater for livestock is a common practice throughout the Northern Gulf, development of groundwater resources has generally been limited. Consequently there is little if any documentation of impacts to freshwater ecosystem assets associated with groundwater resource development. Hydrobiology (2005) and CSIRO (2009) report several examples of shallow coastal aquifers where water quality had declined in association with use, possibly due to saltwater intrusion, but did not identify any dependent ecosystem impacts. Ground water extraction has also been identified as a threat to ecologically important springs and other groundwater dependent ecosystems that are fed from the Great Artesian Basin (Fensham & Fairfax 2003) though this is unlikely to apply to many springs within the Northern Gulf region (other than possibly in the south west) as the GAB is little exploited within the region and is supplied by regionally proximal recharge areas (CSIRO 2009). Similar to surface water resources, the greatest threat to freshwater ecosystem assets posed by groundwater resource development is associated with potential development rather than existing. CSIRO (2009) identified a range of groundwater resources within the Mitchell basin that could be developed and exploited. If it were to proceed, such development would need to be carefully managed to minimise risks to dependent freshwater ecosystems assets.

Maintenance of groundwater discharge and surface water connectivity is key to sustaining the dry season ecology of aquatic ecosystems in the Northern Gulf region (Hydrobiology 2005). Groundwater extraction can impact natural groundwater levels, water quality and aquifer discharge rates, reducing riverine baseflows and the duration and persistence of dry season refugial waterholes (Pusey & Kennard 2009). Reduction in groundwater levels and/or discharge may also directly impact on dependent riparian vegetation communities that rely on this water source during the dry season, particularly in drought years (Pusey & Kennard 2009).

Management Needs and Strategic NRM Responses

Current levels of understanding regarding groundwater resources and their exploitation levels within the Northern Gulf region are limited in terms of supporting dependent ecosystem management initiatives. Greater inventory of groundwater dependent ecosystems, including linked surface water flow regime and assessment of the exploitation status of supplying aquifers, is a prerequisite to better identifying ecosystem management needs and developing appropriate NRM responses. As per threats posed by surface water resource development, regional NRM planning outcomes are likely to be best served by aligning with and supporting statutory water resource planning and management arrangements.

1.4.3 Exotic Species

Invasive species are a ubiquitous threat to aquatic ecosystems globally (Arthington *et al* 2010). Freshwater ecosystems are particularly vulnerable to the impacts of invasive species due to the extensive level of intentional and unintentional releases of organisms that occur within them (Sala *et al*.2000). Fortunately only a few exotic aquatic organisms have established populations within Northern Gulf river basins. The low level of exotic aquatic species within the region is indicative of its river system's integrity and represents one of its biodiversity conservation values. The most significant invasive species currently affecting freshwater ecosystems of the Northern Gulf are weeds of riparian areas and terrestrial feral animals.

1.4.3.1 Weeds

Threat to Freshwater Ecosystem Assets	**Exotic Species - Weeds**
Regional Extent	Broad/Extensive
Intensity Land Use/Impacts	Localised intensive to extensive sub-catchment impacts capacity to propagate impacts to downstream ecosystems
Affected Assets	• Freshwater Environments • Aquatic Biodiversity • Fisheries • Water Resources
NRM Management Needs/Appropriate Responses	• Demonstration sites/trials • Inventory and prioritisation • Strategic control programs • Environmental education/interpretation • Rehabilitation • Integrative management approaches • Research and development • Survey and monitoring • Material/financial incentives

Extent of Threat & Affected Assets

As identified in the discussion of freshwater environment conditions, riparian zone weeds are widespread throughout the Northern Gulf region and pose one of the most significant threats to riparian vegetation (Sattler and Williams 1999, NLWRA 2002). A survey of 20 riparian sites in the Gilbert River catchment found that most sites were infested with weeds (Hogan *et al.* 2006). Some areas in the Staaten and Norman River catchments still remain relatively weed-free and management efforts should be made for these areas to maintain this weed-free status (Burrows & Perna 2006; Hogan *et al.* 2009a). Rubbervine (*Cryptostegia grandiflora*) is the most widespread and damaging weed currently found in the region and significant infestations are present in most areas. As this species can grow as either a free-standing multi-stemmed three metre bush or as a vine up to 15 metres high it can actively dominate the canopy of riparian areas forming 'vine towers' that exclude, collapse and kill large trees (Burrows 2004a). Other weeds of concern to riparian habitat include giant rats tail grass (*Sporobolus* spp.), calotrope (*Calotropis procera*), castor oil bush (*Ricinus communis*), chinee apple (***Ziziphus mauritiana)***, noogoora burr (***Xanthium spp.)***, parkinsonia (***Parkinsonia*** aculeate), prickly acacia (***Vachellia nilotica)***, sicklepod (*Senna obtusifolia*) and bellyache bush (***Jatropha gossypiifolia)***. Exotic grasses, including pasture species such as Guinea grass *Megathyrsus maximus,* also pose serious threats to riparian zones in higher rainfall areas of the Northern Gulf region, particularly in agricultural areas where grazing pressure has been removed from the landscape (Tait 2011).

Aquatic weeds also have the potential to cause severe impacts to freshwater ecosystems of the Northern Gulf region. Introduced aquatic plants compete with native plant species and reduce the quality of the habitat for native fauna by forming dense infestations which prevent animal access to habitat resources and reduce dissolved oxygen, sometimes causing fish deaths (Pusey & Kennard 2009; Hogan & Vallance 2011). Currently, exotic aquatic weed infestations within the Northern Gulf region are primarily limited to the Mitchell River basin (Burrows 2004). Recorded species include olive hymenachne (*Hymenachne amplexicaulis*), para grass (*Brachiaria mutica*), water lettuce (*Pistia stratiotes*), salvinia (*Salvinia molesta*), and water hyacinth (*Eichhornia crassipes*) all of which are recognised as being capable of contributing to aquatic ecosystem collapsing infestations (Perna and Burrows 2005, Tait 2013).Fanwort (*Cabomba caroliniana*) also poses a threat to the Northern Gulf Region. Olive hymenachne and para grass were introduced by the cattle industry as ponded pastures (Ryan *et al.* 2001; Challen & Long 2004). Further information for weeds is available in the 'Flora' section of the NRM plan.

Queensland ponded pastured policy (Challen & Long 2004)

The Queensland Government considers that the development of Ponded Pastures should occur only in areas that are not tidal areas, adjacent to natural wetlands or of high conservation or fish habitat value. The development of Ponded Pastures in other areas should occur only where proponents can demonstrate that there will be minimal and acceptable environmental impacts.

Management Needs and Strategic NRM Responses

Given the extent of weed infestation within the region's river basins, management and control responses need to be strategically targeted to be effective. The following provide the basis for developing strategic responses for the management of weeds affecting the region's freshwater ecosystems:

- *Prioritisation of control sites and controlled species.* Not all weed species or infested sites are capable of being managed with available resources. Sites chosen for control need to be prioritised on the basis of the value of threatened assets, the extent and level of current infestations, location within catchments and likelihood of control success. Weed species targeted for control also need to be prioritised on an equivalent basis i.e. the threat they pose to high value assets, status of current infestation levels and prospect for control.

- *Weeds of National Significance (WONS).*_Weeds that have been declared WONS attract additional government support for control programs. Targeting WONS species as a priority provides a means of obtaining greater resourcing to build weed control program and team capacity. Nominating new species to be listed as WONS may provide a means to bring additional resources to the control of emerging problem species.

- *Catchment and quarantine based management strategies.* Weeds, particularly aquatic ones, are spread by flow events within river basins. Effective control programs need to consider the risks presented by upstream re-infestation source areas and target these as a priority for control. Where weed infestations are new or limited to a small areal extent, quarantine-based control programs that establish lines of control and seek to limit the spread of infestations to new catchment areas provide a basis for effective control. Wet season flood flows that flush weed infestations from catchment units may also present new control lines opportunities if management efforts are vigilant and timely.

- *Infestation mapping.* Strategic prioritisation of control efforts including catchment and quarantined based control efforts requires good information on the extent and distribution of infestations. Cost effective use of high resolution remote sensing or emerging technologies such as unmanned aerial vehicles (UAV) present new opportunities for obtaining near real time infestation mapping to guide strategic control efforts.

- *Broad acre tools and integrated control approaches.* Intensive control methods requiring mechanical interventions or high levels of chemical use are unlikely to deliver regional scale weed control outcomes. Development of broad acre management tools including the integrative use of grazing (or other biocontrol) and fire regimes, or chemicals and fire regime and natural recruitment provide examples of opportunities to expand control outcomes to a landscape scale.

- *Research and development.* Innovation in weed control capacity including new opportunities for infestation mapping requires investment in research and development. Regular engagement should be conducted with R&D providers concerning the suite of weed management challenges facing the region to assess if emerging technologies or research arenas offers any prospects of enhanced weed management capacity.

- *Management trials.* Following on from the preceding, innovation in weed control requires trialling of new management approaches. Often such innovation may come from regional community members. Providing opportunities including resourcing to support innovative management trials provides a means to progress and develop new weed control methods.

- *Education and awareness.* Some weed species and the ecological impacts associated with many weed species are not recognised by the broader community. Education and awareness are critical for building the case for implementing regional control programs for ecological weeds and for helping to prevent their spread and establishment.

- *Material and financial incentives.* As identified in the preceding, the significance of ecological weed impacts is not always recognised or appreciated by the broader community and as such support from landholders for control may not be forthcoming, particularly if weed impacts do not also present concomitant risks to production values. In this context the provision of material or financial incentives can often provide an essential impetus for fostering control efforts. Such incentives can be targeted strategically on the basis of prioritisation rationales discussed above.

1.4.3.2 PEST FISH

Threat to Freshwater Ecosystem Assets	**Exotic Species – Pest Fish**
Regional Extent	Localised – sub-catchment (extensive potential)
Intensity Land Use/Impact	Localised intensive to extensive sub-catchment impacts
Affected Assets	• Freshwater Environments • Aquatic Biodiversity • Fisheries • Water Resources
NRM Management Needs/Appropriate Responses	• Mapping and definition value/threat • Catchment/land management planning • Strategic control programs • Environmental education/interpretation • Research and development • Survey and monitoring

Extent of Threat & Affected Assets

Rivers in the Northern Gulf region are largely free from exotic fish species, with only five species being recorded historically. These include the guppy (*Poecilia reticulate*), goldfish (*Carrassius auratus*), eastern gambusia (*Gambusia holbrooki*), Mozambique tilapia (*Oreochromis mossambicus*) and spotted tilapia (*Tilapia mariae*). The guppy is the only species that has become established in the region (Ryan 2002). The Queensland Museum holds only one record of an individual goldfish from the Norman River in 1914, however it is likely that this was a one-off or a mislabelled location as the species has not been recorded since (Burrows & Perna 2006). Similarly eastern gambusia have only been reported from a tributary of the upper Walsh River in one study (DNRW 2008), and it is possible that this was also a species misidentification. An infestation of tilapia (predominantly spotted tilapia) was found in Eureka Creek, a tributary of the Walsh River, during a routine Department of Primary Industry and Fisheries (DPIF) survey in January 2008 (Pearce *et al*. 2009; Russell *et al*. 2012) these populations have since been eradicated (Pearce *et al*. 2009).

The adjoining Wet Tropics region, especially the Barron River Catchment, has high numbers of exotic fish species. The short distance between the Barron River and the upper Mitchell and Walsh Rivers; the large number of people movements and the inter-basin transfer of water between the Barron Catchment and the Mitchell and Walsh River systems via the Mareeba-Dimbulah Irrigation (MDI) system (Ryan *et al*. 2002), means that there is a high risk of spreading exotic and translocated native fishes into Northern Gulf rivers (Burrows 2009).

The establishment and spread of tilapia and gambusia are of considerable concern in the Northern Gulf region. Invasions could cause the displacement of native fish and amphibian species through competition for food or predation (Bradshaw *et al*. 2007). Studies have demonstrated that gambusia predate upon early life stages of a number of native Australian frog species (Komak & Crossland 2000). Tilapia are tolerant of anoxic water conditions (Canonico *et al*. 2005) which allow them to survive depressed dissolved oxygen levles, therefore, giving tilapia an ecological advantage over native fish species. Tilapia are established in the Barron River and Tinaroo Dam and there is a high risk of the movement of the species to the Mitchell River through a number of translocation paths (BMTMG 2001). The potential impacts associated with the spread of tilapia throughout the Northern Gulf region could include ecological alteration of Gulf of Carpentaria river systems with flow on-impacts on both the commercial and recreational fisheries sectors of the region, specifically prawn and barramundi (Ryan *et al*. 2001; Greiner & Gregg 2008; Pearce *et al*. 2009). Further, the spread of tilapia into Gulf of Carpentaria waterways would facilitate their spread further west into the Northern Territory and Western Australia (Pearce *et al*. 2009).

Management Needs and Strategic NRM Responses

Maintenance of the tilapia-free status of Northern Gulf waterways to date owes its success to four main management interventions. These are:

- Community education and awareness;
- Waterway survey and monitoring;
- Inter-basin water transfer screening; and
- Effective and timely control response on detection of infestation.

NRM planning intended to address the ongoing threat of exotic fish infestation of Northern Gulf waterways needs to support, build upon and reinforce existing program success. Opportunities exist to improve commitments across all four of these program areas including via greater community engagement in more regular monitoring and surveying activities and improved screening and exclusion technology on inter basin water transfers. Research and development innovation, including environmental DNA (eDNA) technology also provides the prospect for enhanced surveying and remote detection of alien species. While current management efforts focus on known exotic species risks such as tilapia and gambusia, community education and awareness concerning the risks posed by exotic aquatic species generally provides one of the most important safeguards toward prevention of the next exotic introduction to Northern Gulf waterways. Such education programs also need to address the risks posed by translocated native species, particularly those favoured by recreational fishers which have the same impact capacity as exotic species if introduced into sites beyond their natural range.

ERADICATION OF TILAPIA FROM EUREKA CREEK

Tilapia are an extremely successful pest species. This is due to their ability to adapt to a wide variety of environmental conditions, their phenotypic plasticity, high fecundity and their aggressive territorial behaviour (Canonico *et al*. 2005; Greiner & Gregg 2008; Russell *et al*. 2012). These characteristics not only enable tilapia to outcompete native fish species but also make the species difficult to eradicate, unless in a small confined area (Russell *et al*. 2012).

An infestation of tilapia was found in Eureka Creek, a tributary of the Walsh River, during a routine DPIF survey in January 2008 (Pearce *et al*. 2009; Russell *et al*. 2012; Burrows n.d.) The tilapia were confined to a three kilometre stretch of Eureka Creek and therefore the DPIF were able to eradicate the population using rotenone in October 2008 (Pearce *et al*. 2009; Burrows n.d.). During the eradication a total of 34 spotted tilapia and one Mozambique tilapia were culled. This eradication appears to be successful as monitoring has found no tilapia in Eureka creek since the eradication (Pearce *et al*. 2009).

The origin of many of the infestations of tilapia in Australia can be traced back to escapees that were illegally stocked into farm dams or ornamental ponds (Russell *et al*. 2012). Intentional translocations by members of the public will also continue to be a significant factor in the spread of tilapia throughout waterways in Australia (Russell *et al*. 2012), and is the likely reason tilapia made it into Eureka Creek. Tilapia are mouth brooders, which means the adults protect the eggs and larvae in their mouths. The larvae can survive in the mouth even after the fish has been killed and it is therefore illegal to keep alive or dead tilapia. Under Queensland Law, catching and then using a tilapia in any way (such as keeping parts of a pest fish for consumption) is illegal and penalties of up to $200,000 may apply. Any live caught tilapia should be humanely euthanised and placed into a bin or buried (Department of Agriculture 2012). Any sightings or live captures of tilapia should be reported using the Queensland Government's 'Exotic pest fish reporting form' available online from the Department of Primary Industries and Fisheries at http://www.daff.qld.gov.au/fisheries/pest-fish/report-a-pest-fish-sighting.

THE THREAT OF TRANSLOCATED NATIVE FISH (BURROWS 2004B).

Translocation of native fish between waterways in the Northern Gulf may pose as serious a threat to biodiversity as introduction of exotic species. In the Mitchell catchment a number of native fish species have been translocated including sooty grunter (*Hephaestus fuliginosus*) and sleepy cod (*Oxyeleotris lineolatus*). Some of the translocations were aimed at introducing species into areas where they were previously not found, or to augment the existing natural populations. Translocating native fish between waterways can be as equally damaging as exotic fish species introductions. Introducing native fish may introduce novel predation pressures, cause changes to species abundance and composition and in extreme cases cause local extinctions of some native species including amphibians impacted via predation of tadpoles, and disrupt the structure of aquatic invertebrate assemblages. Translocation of fishes may also cause degraded water quality, spread pathogens and parasites and alter the genetic composition of local fish populations.

1.4.3.3 FERAL ANIMALS

Threat to Freshwater Ecosystem Assets	**Exotic Species – feral Animals**
Regional Extent	Broad/Extensive
Intensity Land Use/Impact	Localised intensive to extensive sub-catchment impacts
Affected Assets	• Freshwater Environments • Aquatic Biodiversity • Fisheries • Water Resources
NRM Management Needs/Appropriate Responses	• Mapping and definition value/threat • Catchment/land management planning • Demonstration sites/trials • Inventory and prioritisation • Strategic control programs • Integrative management approaches • Research and development • Survey and monitoring • Material/financial incentives

Extent of Threat & Affected Assets

Natural resource impacts and management issues associated with feral animals are described fully in the 'Fauna and Pest Animals' section of the NRM plan. Here the focus is on feral animals that pose threats specifically to freshwater ecosystems assets. In the Northern Gulf region, key species in terms of threats to freshwater ecosystems are feral pigs (*Sus scrofa*) and cane toads (*Rhinella murina*). Both species are widespread and common throughout the region and are very common around permanent and semi-permanent waterholes. Other species of concern include feral horses and cattle which add to total grazing pressure affecting catchment and wetland associated regional ecosystem condition including within protected areas from which domestic stock are excluded.

Feral pigs are particularly damaging to riparian areas and other aquatic habitats such as springs and artificial wetlands. Feral pig damage is concentrated along drainage lines, riparian areas and wetlands as the species congregate and feed in these areas (Hone 1988; Mitchell 1993; Hone 1995). Pig digging in soft soils reduces regeneration of plants and disturbs the soil biology, which may cause significant changes to the composition of native vegetation communities (McGaw & Mitchell 1998). Pigs feed within the mud of spring wetlands and have the capacity to upturn and kill large areas of vegetation within a single feeding episode. Small wetlands and springs are particularly vulnerable and this can lead to eradication of the entire vegetated area in some cases (Fensham & Fairfax 2003). Pigs also may impact on freshwater ecosystems by predation on bird and turtle eggs and some aquatic species including turtles and mussels, species important to traditional fisheries. Pigs can also exacerbate soil erosion and foul water quality. Feral pigs have been implicated in the decline of the snake-necked turtle (Tisdell 1982). A survey of aquatic fauna in Karumba found very low abundances of fresh water turtles. The authors partially attributed this to the high abundance of feral pigs that were likely predating upon turtles and their eggs and disturbing nesting sites (Hogan & Vallance 2011).

Within the Mitchell catchment feral pigs are most common in upstream areas (near Bushy Creek and Rifle Creek) and the upper Walsh River in the Herberton Ranges (Ryan *et al.* 2001). The species is more dispersed in drier areas but do congregate around waterholes, particularly swamps, off-river lagoons and spring (Burrows 2004a).

The cane toad is a serious threat to biodiversity in aquatic ecosystems as they are poisonous to native animals that consume them. The species may impact freshwater crocodiles, goannas and water monitors, large fish, aquatic snakes and water rats which feed on cane toads (Burrows 2004a). Cane toads also compete with native frogs and can become dominant in many aquatic habitats (Burrows 2004a). Further information on feral animal impacts is available in the 'Fauna and Pest Animals' section of the NRM plan.

Management Needs and Strategic NRM Responses

Management options for pigs include baiting, trapping, shooting and exclusion fencing. The exclusion of pigs from wetlands is particularly difficult because this management option requires the use of heavy-duty fencing and constant maintenance (Fensham & Fairfax 2003).

There have been fewer management options developed for established cane toad populations. The species is now widespread across the region although some habitats, i.e. dry rocky uplands and undisturbed rainforest, are less suited to the species and may provide isolated infestation refugia. Given the lack of effective management options, efforts to rehabilitate aquatic species impacted by cane toads (e.g. behavioural adaption of populations) may present a more prospective management approach than toad control.

Given the level of freshwater ecosystem impacts generated by feral pigs, their control and management is a priority action for the protection of freshwater ecosystems within the Northern Gulf. As described for weed issues, the extensiveness of feral pig infestation within the region requires that management investments be strategic to have prospects of delivering asset protection outcomes. The following are nominated as appropriate focal areas for regional NRM planning responses:

- Prioritising targeted control efforts at high value assets and/or controllable/isolated infestation (e.g. protected areas, DIWA wetlands other high biodiversity values);
- Building regional pig control capacity via a dedicated program of forums, information dissemination, material and financial support (including for dedicated Land and Sea Ranger programs) and pig control consortiums (next);
- Building pig control 'consortiums'/partnerships across regional stakeholder groups;
- Providing material and financial support for pig control including provision of trap infrastructure, support for baiting and aerial shooting programs, Land and Sea Ranger (and/or other control service provider) operating funds.

1.4.4 Instream Barriers

Threat to Freshwater Ecosystem Assets	Instream Barriers
Regional Extent	Limited/Localised (major barriers) – sub-catchment (few systems, smaller barriers undocumented)
Intensity Land Use/Impact	Localised to extensive sub-catchment impacts
Affected Assets	• Aquatic Biodiversity • Fisheries
NRM Management Needs/Appropriate Responses	• Mapping and definition value/threat • Catchment/land management planning • Demonstration sites/trials • Inventory and prioritisation • Rehabilitation • Research and development • Survey and monitoring

Extent of Threat & Affected Assets

Aquatic habitat connectivity is a threat to both freshwater fishery and biodiversity assets. Unlike many other more developed regions of Australia where river barrages and tide gates present connectivity impacts within the coastal zone, most of the connectivity threats in Northern Gulf region occur on inland river reaches (Marsden and Stewart 2005, Tait 2005). Water infrastructure creating instream passage barriers to fish movement were identified in the discussion of water resources (see Table 1.11). Only the Glenmore Weir on the Norman River occurs in lower river reaches where the full complement of regional catadromous (marine breeding) species could be potentially affected, although this structure is fitted with a fishway.

The principle threat posed by passage barriers is reduced access to suitable upstream habitat and consequent reduction in population size of migration-dependent species. The main catadromous species in the Northern Gulf identified to be at risk from passage barriers include two key fishery species, barramundi *Lates calcarifer* and Giant river prawn AKA Cherabin *Macrobrachium spinepes,* and the protected and vulnerable freshwater sawfish *Pristis pristis*. However, many more freshwater fish species recorded from Northern Gulf waters have estuarine or marine life stage dependencies and consequently barriers also present threats to their populations (Allen *et al*. 2002, Hydrobiology 2005, Hogan and Valance 2005, Burrows and Perna 2006). At more inland barrier sites, the suite of affected catadromous species would be small or non-existent, however many potadromous (within freshwater migrating) species are potentially affected. Large aggregations of fish observed below passage barriers such as Lake Mitchell (Hydrobiology 2005), are indicative that these more inland barriers do represent a threat to freshwater fish movement and recruitment needs.

Management Needs and Strategic NRM Responses

While the impacts of passage barriers and potential mitigation options are well understood for some species such as barramundi, for larger bodied species such as sawfish and other taxa such as freshwater crustaceans, understanding and mitigation option are less well developed. For sawfish this limitation can partially be attributed to a lack of effective survey methods and/or effort for freshwater populations including above potential passage barriers. For cherabin the lack of understanding stems from a failure to recognise them as a catadromous species or one that may be threatened by passage barriers. Anecdotal reports from regional stakeholders suggest that cherabin populations in the upper reaches of river systems affected by passage barriers have reduced in the period since the construction of barriers (see Gulf Coastal section).

Some of the main passage barriers identified within Northern Gulf river basins including Glenmore Weir on the Norman have been rectified to some extent by incorporation of fishways (Marsden and Stewart 2005). However, concerns remain regarding the effectiveness of these fishways (particularly for large bodied species such as sawfish), barriers that have not been rectified by fishways and the potential for creation of additional barriers in conjunction with proposed water resource development. Another issue that has not been identified is the potential impact of smaller passage barriers associated with road crossings and culverts. The extent of impact associated with these smaller passage barriers has not been assessed or documented within the Northern Gulf but experience in other regions would suggest their collective impact could be significant (Carter *et al*. 2007).

Strategic areas for further investment in the management of the threat posed by instream barriers to Northern Gulf freshwater fishery and biodiversity assets include:

- GIS based inventory of all passage barriers within Northern Gulf river basins and development of a regionally prioritised works program for rectification, similar to programs conducted in other north Queensland NRM regions i.e. NQ Dry Tropics (Carter *et al*. 2007);
- Barrier independent monitoring of fish (and catadromous crustacean) passage rates in reaches above and below barrier structures;
- Development and implementation of survey methods for freshwater sawfish populations including within suitable habitats stratified across systems affected or not affected by potential passage barriers;
- Further assessment of the fishway passage capacity, and behaviour and design requirements of large bodied fish species particularly freshwater elasmobranchs including the vulnerable freshwater sawfish *Pristis pristis*.

1.4.5 OUTDOOR RECREATION AND FISHERY SUSTAINABILITY

Threat to Freshwater Ecosystem Assets	**Outdoor Recreation and Fishery Sustainability**
Regional Extent	Limited/Localised – sub-catchment
Intensity Land Use/Impact	Relatively low intensity land use with capacity for localised intensive to sub-catchment extensive low impacts
Affected Assets	• Freshwater Environments • Aquatic Biodiversity • Fisheries

NRM Management Needs/Appropriate Responses	• Mapping and definition value/threat • Catchment/land management planning • Land use exclusion/buffers • Demonstration sites/trials • Environmental education/interpretation • Protected areas • Rehabilitation • Integrative management approaches • Survey and monitoring

Extent of Threat & Affected Assets

The tourism industry within the Northern Gulf planning area is discussed elsewhere within the regional NRM plan. Utilisation of freshwater ecosystems areas within the Northern Gulf for outdoor recreation and fishing is restricted to a limited number of publically accessible sites associated with public land, areas (legally or illegally) accessible from road corridors and private land catering to the tourism industry. While nature based tourism is a valued industry within the Northern Gulf and provides important employment and economic opportunities for regional residents, a number of natural resource impacts or threats are attributed to it. Most of these impacts were identified in the discussion of freshwater fishery assets (Section 7.3.3). The significance of the industry as a source of potential threat to freshwater ecosystems assets relates to the fact that riverine and wetland areas, particularly those providing recreational fishing opportunities, are one of the major drawcards for tourists to the region and the focus of camping and fishing activities (Greiner *et al.* 2009).

Recreational fishing can cause a number of adverse impacts on freshwater ecosystems and fish communities, the most obvious being the direct impact of overharvesting target species. Queensland Government fishing regulations aim to protect fish species targeted by recreational fishing by enforcing bag and size limits, closed seasons (on some locations and fish species) and also non-take species (DEEDI 2012). Indirect impacts such as boating and human usage can also impact water quality, particularly from petroleum products and microbial contamination (Burrows 2004b), although such impacts would only be likely in association with very high levels of visitation. Recreational fisher camping and vehicle access to water courses is also recognised to cause impacts to riparian habitats in some Gulf drainages (CLCAC 2014). Further, boats and associated equipment can transfer introduced pests and weeds throughout waterways (Burrows 2004b). Recreational bycatch of endangered or threatened species such as the freshwater sawfish *Pristis pristis* has been show to result in high mortality rates, as some fishermen keep the saw-like rostrum as illegal trophies (Peverell 2005; Pusey & Kennard 2009). Fish stocking activities conducted to support freshwater fisheries at a number of sites within the Northern Gulf also have the potential to generate ecological impacts if poorly managed.

Many of the anglers that do fish in freshwater ecosystems prefer fishing in dams or impoundments rather than in rivers (Greiner & Gregg 2008). Impacts on freshwater ecosystems and fish communities are therefore, likely to be localised to dams, permanent waterbodies and preferred fishing locations (Pusey & Kennard 2009). In the Carpentaria Shire, tourists spend much of their time fishing from the local river and estuaries and anecdotal evidence suggests that recreational fishing is causing some fish stocks to decline (Greiner *et al.* 2004).

Key NRM issues and threats associated with management of outdoor recreation and freshwater fisheries include:

- Poor documentation of existing freshwater fishery and outdoor recreation use patterns;
- Uncontrolled and/or illegal access to culturally or environmentally sensitive areas (e.g. river banks, culturally important waterholes) and associated disturbance of areas by 4WD vehicle traffic, camp site establishment, spreading of weeds or illegal hunting/fishing;
- Concentrated camping pressure at accessible sites and associated sites disturbance, waste disposal and littering issues;
- Limited monitoring of fishery target species status;

- High levels of seasonally or spatially concentrated and potentially unsustainable recreational fishing effort; and
- Poor understanding of fisheries regulations including protected species (e.g. freshwater sawfish) and associated take of under sized fish, excessive bags and protected species.

Management Needs and Strategic NRM Responses

NRM strategies that could be employed to reduce potential impacts associated with outdoor recreation and fisheries on freshwater ecosystem assets include:

- Greater documentation of freshwater fishery and outdoor recreation resources and land uses, access arrangements and activities as a basis for improved management;
- Increased monitoring of freshwater fishery species status, including post stocking;
- Recreational site and species specific management plans;
- Greater surveillance and enforcement of local government camping bylaws and recreational fishing regulations;
- Facilitating increased controlled access to additional freshwater sites within the Northern Gulf as a means to distribute visitor pressure away from sites where impact issues associated with carrying capacity are emerging;
- Establishing demonstration management reaches to trial integrative management arrangements for River Recreation and Conservation Corridors (RRCC) trial sites;
- Engaging or establishing ranger programs for the regulation of tourist camping and access arrangements;
- Providing greater access to freshwater ecosystem and fishery regulation educational and interpretive material including via the establishment of Gulf savannah knowledge interpretive centre(s) or via camp site/boat ramp signage and interpretive materials; and
- Identifying means to expand the nature based foundations of the Gulf's tourism industry away from extractive activities such as recreational fishing toward other assets of the region e.g. bird watching, cultural tourism, nature appreciation, as a means to further promote sustainable development.

1.4.6 Global Warming and Climate Change

1.4.6.1 Climate Change

Threat to Freshwater Ecosystem Assets	**Global Warming – Climate Change**
Regional Extent	Broad/Extensive/Global
Intensity Land Use/Impact	Regional extensive low to medium impact to localised – sub-catchment - scale intensive impacts
Affected Assets	• Freshwater Environments • Aquatic Biodiversity • Fisheries • Water Resources
NRM Management Needs/Appropriate Responses	• Mapping and definition value/threat • Development constraints/planning controls • Catchment/land management planning • Environmental education/ interpretation • Protected areas • Integrative management approaches • Research and development • Survey and monitoring

Extent of Threat & Affected Assets

There is now overwhelming scientific consensus concerning the causes of global warming and associated climate change and of its significance as a threat to the earth's life supporting ecosystems. In their Fifth Assessment Report the Intergovernmental Panel on Climate Change (IPCC) concluded that greenhouse gas emissions have increased markedly as a result of human activities and this will cause changes in all components of the climate including atmospheric, hydrologic and oceanographic systems (IPCC 2013). As a major driver of natural resource condition and an emerging source of potentially severe impact to natural ecosystems assets, climate change needs to be considered in the planning activities of NRM regions including the Northern Gulf.

To help meet NRM planning needs, CSIRO with the Australian Bureau of Meteorology prepared tailored climate change projections for eight clusters of Australian NRM regions, including the *Monsoonal North* cluster which covers the Northern Gulf (Moise 2014). These projections have been reported in full elsewhere in the NRM plan. In summary projections for the *Monsoonal North* Cluster (from Moise 2014) include:

- Higher temperatures;
- More frequent and hotter hot days;
- Rainfall changes may undergo large increases or decreases;
- Increased intensity of heavy rainfall events; changes to drought less clear;
- Mostly small changes to solar radiation and humidity;
- Increased evaporation rates, and reduced soil moisture: changes to runoff less clear;
- Some increase in summer and spring wind speed; fewer but possibly more intense tropical cyclones; and
- Higher sea levels and more frequent sea level extremes.

These projections have subsequently been used by Gobius (2015) to generate a regional spatial analysis of potential impacts across a range natural resources attributes including:

- Rainfall;
- Basin hydrology and flows;
- Sea level;
- River basin risks and vulnerabilities;
- Native animal distributions;
- Major vegetation groups;

- Woody thickening; and
- Weed distribution.

The results of this analysis which was conducted for a range of future greenhouse gas emissions scenarios indicated the potential for significant regional scale impacts across all assets areas, including projected changes in basin discharge rates of greater than a 100%, loss of numerous faunal species from the region and movement of bioclimatic envelopes beyond the adaptive range of extant vegetation communities (Gobius 2015).

The influence of projected climate change on climatic and hydrologic regimes which affect the persistence and quality of aquatic habitats is responsible for it being recognised as one of the most significant emerging threats to freshwater ecosystems (Morrongiello *et al.*2011). The capacity of more extreme climate events (droughts, floods) to exacerbate existing ecological pressures e.g. poor catchment condition, represents the other main avenue for climate change impacts on rivers (Kingsford 2011). Associated sea level rise has also been identified as a key threat to lowland river reaches in the near coastal zone of the northern Gulf (Close *et al* 2012). Ultimately climate change has the capacity to generate minor to significant impacts to freshwater ecosystem assets across the entire region, including freshwater environments; biodiversity, fisheries and water resources. Detailed analysis of these impact risks are presented in the following *Section 7.5 Climate Change Risk Assessment for Inland Waters* and are not reiterated here.

Management Needs and Strategic NRM Responses

Effective responses to the threats posed by climate change need to include both greenhouse gas emissions abatement and impact adaptation. Ultimately the effectiveness of the latter in the longer term is tied to the implementation of global emission control, and even in the shorter term will probably only be effective at the lower end of the emission scenarios promoted by the IPCC (Krockenberger *et al.*2004).

Emissions Abatement

Given the low population density of the Northern Gulf region, the contribution it makes to national greenhouse gas emissions or conversely can make to abatement is limited in terms of total mass but may be significant in terms of potential per capita improvement potential. This is associated with the generally high carbon intensity of energy generation and transportation in more isolated rural regions (AGO 2003). Identifying opportunities for more sustainable energy generation and less carbon intensive transport infrastructure is a challenge for all more remote regions in Australia including the Northern Gulf.

The other means by which the region can limit or reduce greenhouse gas emissions is via land use choices and management. Clearing of vegetation, livestock production and energy intensive broad acre agriculture are all well recognised significant contributors to greenhouse gas emissions (AGO 2003). Wetlands, soil carbon and woody vegetation are well recognised carbon sinks (DSEWPC 2012). Opportunities for innovation in land and energy use to reduce the region's greenhouse gas emissions are identified elsewhere in the NRM plan.

Impact Adaptation

Building resilience of freshwater ecosystems to the impacts of climate change is the primary strategy proposed for impact adaptation (Kingsford 2011). In contrast to more developed regions of Australia where ecosystem resilience needs to be enhanced by more interventionist approaches such as targeted rehabilitation, flow regime management initiatives and possibly even engineering approaches, the strength of the Northern Gulf river basins is their relative intactness, particularly their hydrological integrity (Kingsford 2011). Climate change impacts to freshwater ecosystems will be primarily realised by the synergistic impact of multiple concurrent stressors, particularly via more extreme climate events (droughts, floods) that exacerbate existing ecological pressures, e.g. poor catchment condition. In this context the main path to enhancing the resilience of freshwater ecosystems lies in protecting their existing integrity and addressing existing ecosystems stressors, including pervasive threats posed by extensive grazing land use, weeds, feral animals, fire regime management and soil erosion and more localised threats posed by intensive land and water resource development. The enhanced resilience that protected areas afford aquatic ecosystems against a range of pervasive threats is also an effective adaptive strategy recommended for addressing emerging climate change pressures (Kingsford 2011, Williams *et al.* 2012). The following are identified as NRM approaches that will help improve the resilience of Northern Gulf freshwater ecosystems to the projected impacts of climate change:

- Adoption of conservative grazing regimes that reduce total grazing pressure regionally;
- Implementation of prudent water resource development plans that retain effective protective buffers for the maintenance of aquatic ecosystem processes;
- Targeted programs to improve catchment condition with a particular emphasis on soil erosion and the protection of functional landscape elements such as riparian zones and wetlands;
- Implementation of pervasive threat management programs regionally, addressing riparian weeds, fire regime and feral animals;
- The identification and protection of aquatic and biodiversity refugia within all river basins;
- Increased representative inclusions of freshwater ecosystems across the region in an effective protected area network; and
- Proactive management of mining sites and infrastructure that may present contamination risks during extreme weather events.

Sea Level Rise

Threat to Freshwater Ecosystem Asset	**Global Warming – Sea Level Rise**
Regional Extent	Localised – sub-catchment
Intensity Land Use/Impact	Localised intensive to extensive sub-catchment impact
Affected Assets	• Freshwater Environments • Aquatic Biodiversity • Fisheries • Water Resources
NRM Management Needs/Appropriate Responses	• Mapping and definition value/threat • Development constraints/planning controls • Catchment/land management planning • Land use exclusion/buffers • Environmental education/ interpretation • Protected areas • Research and development • Survey and monitoring

Extent of Threat & Affected Assets

Continued increase in sea levels in the Northern Gulf region associated with global warming has been projected with *high confidence* (Moise 2014). In the near future (2030), the projected range of sea level rise in the Northern Gulf coastline is 6 to 16 cm above 1986-2005 levels, while for the far future (2090), it is in the range 28 to 63 cm, dependent upon the greenhouse gas emission pathway that is followed. Impacts to freshwater ecosystems are likely to be intensive but generally localised to the tidal interface zone although salinisation of freshwater aquifers and storm surge events may have the capacity to periodically create sub-catchment-scale impacts. In an assessment of risks to freshwater ecosystems across northern Australia, the Northern Gulf was identified as one of three regions at greater relative risk from sea level rise (Close *et al* 2012). All freshwater ecosystem assets are likely to be impacted included freshwater environments, biodiversity, fishery and water resources. Detailed analysis of these impact risks are presented in the following *Section 7.5 Climate Change Risk Assessment for Inland Waters* and are not reiterated here.

Management Needs and Strategic NRM Responses

As per climate change threats and global warming generally, the principal and priority management response that needs to be pursued is greenhouse gas emissions abatement (detailed in the preceding section). While adaptive management and impact mitigation is the second most important focus for addressing the threat of sea level rise, opportunities for these types of strategies in regard to freshwater ecosystem assets in the vastness of the Northern Gulf region may be limited. Interventionist approaches and possibilities e.g. bund wall construction, may have a potential role to play in the protection of very high values assets. Possible examples are identified in the Gulf Coasts section of the NRM plan.

Currently the most useful NRM investment in regard to the management of sea level rise impacts would be a detailed risk analysis that examines implications of projected sea level rise for coastal freshwater wetland mosaics. Attribution of asset values (including redundancy/replacement) to the components of the coastal wetland matrix most likely to be impacted by sea level rise would serve to further identify the need and opportunity for future interventionist protective management approaches.

Key				
Probability (**P**)	UC- Uncertain	P- Possible	L- Likely	Almost Certain- A.C
Consequences (**C**)	UK- Unknown	L- Low	Mod- Moderate	M- Major
Risk rating (**R**)	L- Low	Mod- Moderate	H- High	Cr-Critical

Climate Hazard	Freshwater Environments	Aquatic Biodiversity	Freshwater Fishery Resources	Water Resources
Increased incidence of destructive wild fires	• Fire incursions into and degradation of fire sensitive wetland riparian communities **P-C-R – L-Mod-H** • Increased grazing /stock pressure on unburnt riparian/wetland fire refugia **P-C-R – P-Mod-Mod** • Degradation of structural, floristic and functional integrity of riverine corridor riparian vegetation with resultant impacts to bank stability **P-C-R – P-Mod-Mod**	• Loss of fire sensitive plant (& associated fauna) species from regional ecosystems associated with alluvial land zone 3. **P-C-R – L-Mod-H** • Impacts to the condition and functionality of dry season aquatic refugia including enhanced prospect of critical water quality impacts in late dry season/wet season initiation period (via reduced shading, elevated temperature, reduced DO, elevated turbidity, eutrophication) with concomitant impacts to biodiversity **P-C-R – L-Mod-H**	• Reduced viability of aestivation habitat utilised by freshwater long-neck turtles **P-C-R – P-Mod-Mod** • Reduced carrying capacity and nursery function for impacted floodplain and main channel habitats utilised by fishery associated species **P-C-R – P-L-L**	• Reduced ground cover at onset of wet season and reduced trapping capacity of burnt riparian and wetland vegetation resulting in increased capacity for soil erosion and mobilization of elevated basin sediment loads with concomitant impacts to receiving ecosystem water quality and geomorphic condition **P-C-R – L-Mod-H** • Increased rates of run off from burnt catchments resulting in reduced recharge of groundwater aquifers **P-C-R – P-Mod-Mod**

Climate Hazard	Freshwater Environments	Aquatic Biodiversity	Freshwater Fishery Resources	Water Resources
Increased intensity and/or magnitude of high rainfall events (incl. flood and cyclones)	• Destructive disturbance of riverine corridor riparian vegetation via sustained inundation, bank erosion, scalding and gullying of drainage line frontage areas **P-C-R –** AC-M-Cr • Modified physical environment and geomorphic impact to riverine corridor banks, channels, pools and bed via enhanced erosion/scour/sediment deposition **P-C-R –** AC-M-Cr • More sustained inundation of floodplains resulting in reduced cover (during recovery period) and impacts to resilience and carrying capacity of associated vegetation communities. **P-C-R –** AC-Mod-Mod • Potentially beneficial scouring/flushing of exotic aquatic weed infestations from floodplain/delta wetlands providing enhanced control opportunities **P-C-R –** L-Mod-Mod	• Potential for enhanced dispersal of basin weed and exotic fish species to new lower/adjoining catchment sites **P-C-R –** L-Mod-Mod • Potential for enhanced establishment of riparian weed species within disturbed riverine corridors **P-C-R –** L-Mod-Mod • Changed connectivity/inundation patterns altering waterhole community composition **P-C-R –** L-L-L • Subject to event timing, potential positive or negative impacts to riparian and wetland vegetation utilised by waterbirds as nesting resources **P-C-R –** P-Mod-Mod • Subject to event frequency, periodic or sustained loss of macrophyte habitats from channel and floodplain areas subject to high flow scouring **P-C-R –** L-Mod-Mod	• Subject to event timing, potentially beneficial impacts to fisheries recruitment via nursery habitat inundation, increased contribution of floodplain carbon/productivity subsidies and provision of basin habitat connectivity. **P-C-R –** AC-Mod-H	• Greater capacity for basin soil erosion, and export of elevated suspended and bed sediment loads to receiving ecosystems including floodplain lagoons, main channel waterholes and coastal systems. **P-C-R –** AC-Mod-H • Greater prospect of mining associated contaminant loads in retention facilities (i.e. tailings dams), being released via overflow events to receiving aquatic ecosystems **P-C-R –** L-Mod-Mod-H • Potentially enhanced recharge of shallow alluvial aquifers within floodplains and adjoining riverine corridors **P-C-R –** L-UK-L • Potentially enhanced rates of refilling of water supply storages to full supply levels ensuring for environmental allocations **P-C-R –** P-L-L

Northern gulf Resource Management Group

Climate Hazard	Freshwater Environments	Aquatic Biodiversity	Freshwater Fishery Resources	Water Resources
Increased storm surge and rising sea levels	• Saltwater intrusion into previously fresh reaches of coastal drainage networks **P-C-R –** AC-Mod-H • Breaching of coastal inter-swale swamps by tides/storm surge and alteration from fresh to brackish/saline with loss of associated fringing vegetation communities **P-C-R –** AC-Mod-H • Upstream retreat and replacement of freshwater riparian vegetation by marine communities **P-C-R –** AC-Mod-H • Changes to the structural and floristic integrity of wetland riparian vegetation due to storm surge/cyclone disturbance regime **P-C-R –** L-Mod-H	• Sea level rise driven inundation, contraction and loss of wetland habitats and biodiversity associated with the freshwater – brackish – marine interface zone **P-C-R –** AC-Mod-H • Salinisation of coastal freshwater wetlands and marginal vegetation utilised by breeding aggregations of waterbirds **P-C-R –** L-Mod-H • Inundation and contraction marine plain wetland habitats utilised by migratory wader birds **P-C-R –** L-Mod-H	• Inundation, salinisation and contraction of sedge swamp *Eleocharis spp* barramundi nursery habitats **P-C-R –** AC-Mod-H	• Intrusion of marine water into shallow coastal groundwater aquifers with concomitant impacts to dependent vegetation and aquatic ecosystems. **P-C-R –** AC-Mod-H • Increased bank erosion and elevated sediment loads in lower reaches/coastal drainage systems associated with destructive disturbance and salinisation driven loss of stabilizing riparian vegetation and local catchment cover **P-C-R –** P-L-Mod

Climate Hazard	Freshwater Environments	Aquatic Biodiversity	Freshwater Fishery Resources	Water Resources
Longer dry seasons	• Changes in river/stream flow regimes toward greater duration of low and no flows **P-C-R – AC-M-Cr** • Contraction of more mesic (moist) riparian vegetation communities associated with river corridors, wetlands and springs **P-C-R – AC-Mod-H** • Reduced baseflow inputs and reduced volumes/shallower refugial waterholes resulting in greater late dry season degradation of water quality (higher temperatures, lower DO, higher salinity, eutrophication) **P-C-R – L-Mod-H** • Reduction in extent of functional fire refugia and greater intrusion and impact of late dry season fires into fire sensitive riparian vegetation communities **P-C-R – L-Mod-H** • Increased pressure of grazing stock and feral animals on frontage and fringing habitats and water quality associated with perennial/refugial waterholes **P-C-R – AC-M-Cr** • Later onset of wet seasons of shorter duration delaying wetland inundation, habitat resetting and biota recruitment processes and driving temporal and spatial shifts in primary productivity and food web dynamics **P-C-R – L-Mod-H**	• Reduced number, extent and functional viability of dry season aquatic refugia and associated loss of biodiversity. **P-C-R – AC-Mod-H** • Reduction in faunal feeding and nesting resources associated with riparian vegetation of riverine corridors and wetlands and associated impacts to dependent terrestrial biodiversity. **P-C-R – L-Mod-H** • Reduced flows and other identified factors contributing to poor water quality in refugial pools could promote exotic fish species with broader tolerances **P-C-R– P-Mod-Mod**	• Late initiation of connective flows (required for adults to join breeding aggregations), delayed nursery habitat inundation and reduced flow based productivity pulses could lead to late and reduced recruitment of fishery species. **P-C-R – AC-Mod-H** • Reduced extent of perennial floodplain lagoon and main channel water hole habitat reduces adult and juvenile populations of fishery species. **P-C-R – L-Mod-H**	• Reduced river/stream baseflows to flush wet season run in and/or irrigation/STP tailwater contaminant loads through drainage system **P-C-R – L-Mod-H** • Less ground cover on scalded and drought affected catchments resulting in higher rates of soil erosion and elevated basin loads and exports of suspended and bed load sediment **P-C-R – L-Mod-H** • Greater proportion of run off from scalded and drought affected catchments resulting in less infiltration and aquifer recharge **P-C-R – L-Mod-H** • Reduced discharge volume from shallow unconfined aquifers (e.g. associated with Mitchell River) **P-C-R – L-Mod-H** • Greater water resource demands for human/agricultural uses with impact to residual available for environmental allocations **P-C-R – L-Mod-H**

Climate Hazard	Freshwater Environments	Aquatic Biodiversity	Freshwater Fishery Resources	Water Resources
Continued warming of temperature, including more hot days	• Changes to instream biogeochemical processes including rates of decomposition, respiration and trophic metabolism with consequent changes to dissolved oxygen (generation of anoxic conditions), elevated nutrient levels and metal solubility **P-C-R –** AC-M-Cr • Greater likelihood of waterhole stratification and generation of anoxic sub surface layers **P-C-R -** LModH • Greater evaporation rates leading to reduced extent of perennial aquatic habitat refugia being maintained through dry season **P-C-R -** LModH	• Exceedance of thermal thresholds for aquatic species particularly within dry season refugial waterholes and consequent loss of aquatic biodiversity from systems **P-C-R –** ACModH • Exceedance of thermal thresholds for plant species within fringing riparian vegetation communities and consequent loss of plant species and dependent biodiversity associated with riparian communities **P-C-R –** ACModH • Greater incidence of disease breakouts in refugial waterholes associated with thermal stress and enhanced growing condition for pathogens **P-C-R–** P-Mod-Mod • Greater establishment opportunities for invasive exotic fish and aquatic/riparian weed species that have broader low dissolved oxygen/thermal tolerances **P-C-R–** P-Mod-Mod	• Reduced dissolved oxygen in shallow coastal and floodplain nursery wetlands (and upper estuarine nursery habitats) decreasing freshwater fishery species carrying capacity and recruitment levels **P-C-R -** LModH • Impacts of low dissolved oxygen driven fish kills on adult and juvenile populations of fishery species within vulnerable habitat types (floodplain lagoons, refugial channel waterholes) **P-C-R –** L-Mod-Mod	• Greater opportunities for water quality impacts associated with: reduced dissolved oxygen carrying capacity; enhanced mobilization of nutrients from sediments, increased solubility of metals and generation of favorable conditions for blue-green algae outbreaks **P-C-R –** AC-M-Cr

Climate Hazard	Freshwater Environments	Aquatic Biodiversity	Freshwater Fishery Resources	Water Resources
Increasing atmospheric CO_2 concentration and acidification of rain and surface waters	• Lower pH waters in catchments with limited buffering capacity affecting the shell forming capacity and abundances of diatoms and molluscs with flow on impacts associated with a loss of their ecological functions including as grazers and phytoplankton filterers **P-C-R -** LModH • Higher carbon : nitrogen and phosphorous ratios in phytoplankton decreasing their nutritive value and driving trophic shifts in food webs **P-C-R –** L-Mod-Mod • Woody vegetation growth promoted relative to grassy vegetation promoting woodland thickening on floodplains with flow on effects to flow hydrology and food chain carbon sources **P-C-R -** PModMod	• Greater growth rates in woody weed species impacting riparian and floodplain vegetation communities **P-C-R -** PLMod	• Increased mortality of fish larvae and juveniles may result from acidification effects on sensory systems and behavior, leading to decline in recruitment to adult populations. **P-C-R -** PModH • Reduced aerobic capacity in some fish due to acidification could exacerbate other climate change impacts (e.g. reduced dissolved DO). **P-C-R -** PModH	• Lower rainfall pH altering solute composition and increasing mobilization of soluble metals in catchment run off with greater capacity for toxic impacts in receiving waters downstream of contaminant sources **P-C-R –** L-Mod-Mod • Higher algal/ phytoplankton production in the surface waters of stratified water bodies leading to eutrophication and/or blue green algae impacts to water quality **P-C-R -** LModH

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APPENDIX 1. RIVER BASIN NRM PLANNING CONTEXT

[WHERE IS CONTENT?]

APPENDIX 2. NORTHERN GULF REGIONFRESHWATER FISH SURVEYS

Citation	Location	Methods	Key findings
(Barlow 1987)	Kidston Dam, Copperfield River	A total of 3 sites surveyed	• 7 native species recorded
(Herbert *et al.* 1995)	Palmer River	A total of 9 sites surveyed	• Added six fish species to the list of species known to occur (total = 30)
(Hogan & Vallance 1997)	Upper Walsh River (proposed Nullinga dam site)	Desktop survey & briefly sampled fish in the inundation area of the proposed dam site	• No pest fish present • 20 native species recorded
(Vallance *et al.* 2000)	Gilbert River, Copperfield River & Einasleigh River	A total of 11 sites surveyed	• 21 native species recorded • Anecdotal evidence of 5 -10 unrecorded species present
(Ryan *et al.* 2001)	Upper Mitchell River system and Walsh River	A total of 25 sites, each surveyed 4 times along 200m sections divided into 4 50m sections. Some additional sites surveyed	• A total of 36 species (from 19 families) collected in the Mitchell River • A total of 33 species (from 18 families) collected in the Walsh River • Fish communities considered diverse • Occurrence of the Northern Sawfish (*Pristis microdon*) in the lower Mitchell River
(Vallance & Hogan 2001)	Julatten/Mt Molloy area associated with the upper Mitchell River stock route & Mareeba wetlands	A total of 5 sites surveyed	• Fish abundance and diversity was good, apart from one site which had low oxygen levels.
(Jebreen *et al.* 2002)	Mitchell River	A total of 7 monitoring sites surveyed in 2000 and 2001	• High catch rates of rainbowfish, bony bream and banded grunter • Lower catch rates in 2001 reflect lower flow rates
(Burrows & Perna 2006)	Norman River catchment & Saxby River	A total of 14 sites surveyed	• 26 species recorded in the Norman River • 16 species recorded in the Saxby River • A further 11 species have been observed or caught by the landowners • 2 undescribed species captured - catfish (c.f. *Porochilus* sp.) & goby (*Pseudogobius* sp.) • 7 range extensions
(Hagedoom & Smallwood 2007)	Mitchell River	Monitoring the same 7 sites as Jebreen *et al.* (2002) for an additional 6 years	• 45 species recorded • Diversity remains stable
(Hogan *et al.* 2006)	Gilbert River catchment	A total of 18 sites surveyed	• 38 species recorded • 26 species found in stream lagoons, three of which were not found in the main river channel

Citation	Location	Methods	Key findings
(Gleeson & Searle 2008)	Mutton Hole Wetlands – Norman & Staaten catchment	A total of 3 sites surveyed	• 15 species recorded • Goose Lagoon – Highest fish diversity • Black Swan Lagoon – Highest fish abundance • 3 range extensions
(Hogan *et al.* 2009a)	Staaten River catchment	A total of 21 sites surveyed	• 42 species recorded • 3 possibly undescribed species captured • 7 range extensions • 27 species found in seasonal water bodies and 39 in permanent water bodies • Problems with pigs • Low number of weeds
(Hogan *et al.* 2009b)	Mutton Hole Wetlands – Norman & Staaten catchment	A total of 21 sites surveyed	• Undescribed catfish (c.f. *Porochilus* sp.) captured • Possible undescribed goby (*Pseudogobius* sp.)captured • Increased fish diversity than dry season survey • 2 range extensions • Absence of freshwater turtles
(Hogan & Vallance 2011)	Delta Downs Station on the floodplain between the Gilbert and Norman Rivers	A total of 9 sites, 3 sites in 2006 & 6 sites in 2011	• 34 species recorded • Undescribed catfish (c.f. *Porochilus sp.*)captured • No exotic fish present • Fish abundance and diversity was good
(Hogan & Vallance 2012)	Yappar-Norman River catchment	A total of 5 sites surveyed	• 28 species recorded • 2 undescribed species captured - catfish (c.f. *Porochilus* sp.) & goby (*Pseudogobius* sp.) • High fish diversity
Waltham *et al.* 2013	Gilbert River catchment	A total of ten site seasonally sampled 2012-2013	• 22 species recorded

APPENDIX 3. NORTHERN GULF PROTECTED AREAS AND RESERVES

World Heritage Areas
Wet Tropics of Queensland

National Parks
Blackbraes National Park
Bulleringa National Park
Chillagoe-Mungana Caves National Park
Daintree National Park
Errk Oykangand National Park (Cape York Peninsula Aboriginal Land)
Olkola National Park (Cape York Peninsula Aboriginal Land)
Forty Mile Scrub National Park
Hann Tableland National Park
Kuranda National Park
Macalister Range National Park
Mount Lewis National Park
Mount Spurgeon National Park
Mount Windsor National Park
Mowbray National Park
Staaten River National Park
Undara Volcanic National Park

Conservation Parks
Mutton Hole Wetlands regional Park
Olkola (Kurrumbila) Regional Park

Private Wildlife Sanctuary
Brooklyn Sanctuary

State Forests
Herberton Range State Forest
Kuranda State Forest

Forest Reserves
Baldy Mountain Forest Reserve
Kuranda West Forest Reserve

Resource Reserves
Blackbraes Regional Park
Kennedy Road Gravel Regional Park
Moonstone Hill Regional Park
Mount Rosey Regional Park
Palmer Goldfield Regional Park

Nature Refuges
Brooklyn Nature Refuge
Cobbold Gorge Nature Refuge
Dingo Springs Nature Refuge
Eagles View Nature Refuge
Edward Said Nature Refuge
Gilberton Nature Refuge
Goanna Spring Nature Refuge
Harkness Nature Refuge
Mareeba Tropical Savanna and Wetland Reserve Nature Refuge
Nara Springs Nature Refuge
North Head Nature Refuge
Pademelon Haven Nature Refuge
Rutland Plains Nature Refuge
Stuarts Spring Nature Refuge
Tallaroo Springs Nature Refuge

Thylogale Nature Refuge
Torwood Nature Refuge
Werrington Nature Refuge
Wyndham Sandy Creek Nature Refuge

Fish Habitat Areas
Nassau River
Staaten-Gilbert

APPENDIX 4. ECONOMIC, SOCIAL AND ECOLOGICAL OUTCOMES OF THE AMENDED (2014)

GULF WATER RESOURCE PLAN 2007

1. Economic outcomes

Each of the following is an economic outcome for water in the plan area—

(a) provision for the continued use of all water entitlements and other authorisations to take or interfere with water;

(b) protection of the probability of being able to take water under a water allocation, including—

(i) water for the supply of urban water for Mount Isa City; and

(ii) water to support growth in the mining industry in north-west Queensland;

(c) availability of water to support growth in industries dependent on water in the plan area;

(d) provision for the taking of water in Lake Mary Kathleen;

(e) availability of water in the following areas to support growth in irrigated agriculture—

(i) the Gilbert River catchment area;

(ii) the Flinders River catchment area;

(iii) the Nicholson River catchment area;

(iv) the Lower Leichhardt River subcatchment area;

(f) availability of water in the following areas to help Indigenous communities in those areas achieve their economic aspirations—

(i) Cape York Peninsula Region area;

(ii) Flinders River catchment area;

(iii) Gilbert River catchment area;

(iv) the Morning Inlet catchment area;

(v) Settlement Creek catchment area;

(vi) Staaten River catchment area;

(vii) the Gregory River subcatchment area;

(g) encouragement of continual improvement in the efficient use of water;

(h) support of tourism in the plan area, including, for example, by protecting flows that support the natural aesthetics of watercourses and their surroundings;

(i) support of commercial fishing in the Gulf of Carpentaria, including, for example, by protecting flood flows that may deliver nutrients and water to estuarine and marine environments to stimulate growth and movement of native aquatic animals, including fish, prawns and crabs.

2. Social outcomes

Each of the following is a social outcome for water in the plan area—

(a) availability of water for the following purposes—

(i) to support population growth in towns and communities dependant on water in the plan area;

(ii) to help of Indigenous communities in the following areas to achieve their social aspirations—

(A) Cape York Peninsula Region area;

(B) Flinders River catchment area;

(C) Gilbert River catchment area;

(D) the Morning Inlet catchment area;

(E) Settlement Creek catchment area;

(F) Staaten River catchment area;

(G) the Gregory River subcatchment area;

(b) support of water-related cultural values of Aboriginal and Torres Strait Islander communities in the plan area;

(c) promotion of a cooperative approach between the State and relevant Northern Territory government agencies to water resource management, including through the sharing of information;

(d) maintenance of flows that support water-related aesthetic, cultural and recreational values in the plan area.

3. Ecological outcomes

(1) Each of the following is an ecological outcome for water in the plan area—

(a) maintenance of the natural variability of flows that support the habitats of native plants and animals and migratory birds in watercourses, floodplains, wetlands, lakes and springs;

(b) provision for the continued capability of a part of a river system to be connected to another part, including by maintaining flood flows that—

(i) allow for the movement of native aquatic animals between riverine, floodplain, wetland, estuarine and marine environments; and

(ii) deliver nutrients and organic matter throughout the plan area to support natural processes such as breeding, growth and migration in riverine, floodplain, wetland, estuarine and marine environments; and

(iii) deliver water and sediment throughout the plan area to support river-forming processes;

(c) minimisation of changes to natural variability in water levels to support natural ecological processes, including the maintenance of refugia associated with waterholes and lakes;

(d) maintenance of the permanence of water in naturally perennially flowing watercourses and in river bed sands that provide water to support native plants and animals, particularly during dry seasons;

(e) the promotion of improved understanding of the matters affecting flow-related health of ecosystems in the plan area.

(f) maintenance of water in the bed sands of the Gilbert River between AMTD 317km and AMTD 263km—

(i) to provide aquatic habitat for native aquatic plants and animals, particularly during dry seasons; and

(ii) to support riparian vegetation; and

(iii) to contribute to the flow of water in the Gilbert River;

(g) maintenance of the permanence of water flows in the Gregory River and Lawn Hill Creek to provide aquatic habitat for native aquatic plants and animals, particularly during dry seasons;

(h) maintenance of flood flows to the estuarine and marine environments of the Gulf of Carpentaria to stimulate breeding, growth and migration of native aquatic animals;

(i) maintenance of the natural variability of flood flows that inundate, and deliver nutrients, organic matter and sediment to, the wetlands of the areas known as the Southern Gulf Aggregation and the Southeast Karumba Plain Aggregation;

(j) maintenance of flows in the Gilbert River to provide brackish estuarine habitat suitable for juvenile banana prawn development.

(2) Each of the following is an additional ecological outcome for groundwater in the plan area—

(a) maintenance of groundwater contributions to the flow of water in watercourses, lakes and springs;

(b) the support of ecosystems dependent on groundwater, including, for example, riparian vegetation, wetlands and waterholes;

(c) allocation and management of groundwater in a way that is compatible with the outcomes of the *Water Resource (Great Artesian Basin) Plan 2006* to the greatest practicable extent.

Northern gulf Resource Management Group