**Managing threats and restoring wetlands within catchments of the Great
Barrier Reef, Australia**

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Abstract

1. In the catchments of the Great Barrier Reef (GBR) in Australia, there are over a million hectares of wetlands, which help to sustain the health and resilience of the reef.
2. Here, we review the status, values, and threats of wetlands in the GBR catchments, as well as the management, protection, and the challenges and opportunities for their restoration and rehabilitation.
3. Currently, wetlands in the GBR catchments have low rates of area loss and are generally well protected. However, they face major management challenges due to the intensive land use of the catchments, especially grazing, agriculture, horticulture, and mining. Major threats to these wetlands include water pollution, invasive species, changes in hydrology, and increasing temperature and salinity from climate change.
4. In recent years wetlands have been considered primarily for their role in improving water quality to ameliorate contaminated terrestrial runoff to the GBR, with little attention given to their intrinsic values and other ecosystem services.
5. Financial opportunities for wetland restoration in addition to government-funded schemes include water pollution offsets, payment for ecosystem services, and nitrogen markets.
6. Wetlands need to be protected, managed, and restored for the ecosystem services they provide to the GBR, but also for their intrinsic value as significant features of coastal landscapes.

Keywords: invasive species; floodplains; mangroves; nitrogen; Queensland; rehabilitation; rivers; sea level rise

1. Introduction

Wetlands are one of the most valuable ecosystems on Earth and are considered priority areas for conservation (Keddy et al., 2009). They are among the most threatened ecosystems on the Planet, as humans have historically exploited them for freshwater provision, sewage and solid waste disposal, aquaculture production, fertile arable land, and urban infrastructure (Junk et al., 2013). Over half of the world's wetlands have been lost (Davidson, 2014) and only 11% of the remaining wetlands have some level of protection (Reis et al., 2017).

The Great Barrier Reef (GBR) is the largest coral reef in the world with outstanding values that have conferred it the status of World Heritage Area. In the catchments of the GBR, there are over one million hectares of wetlands (WetlandInfo, 2017). These wetlands provide valuable ecosystem services, including some that directly serve the reef, such as improving water quality and sustaining coastal fisheries. Wetlands within the GBR catchments also have intrinsic values such as biodiversity and less known ecosystem values such as flooding mitigation and carbon storage (Waterhouse et al., 2017). These values have not been considered to the same degree as for other parts of the broader reef ecosystems, and in-depth knowledge on wetland condition, threats, and functions has been relatively poor (Australian and Queensland Government, 2016; Waterhouse et al., 2017).

In this review, the protection and management, as well as the challenges and opportunities for restoration and rehabilitation of wetlands within the GBR catchments are examined. To achieve this, information on the status, values, and threats to these wetlands were compiled. Additionally, the protection status, current management practices, and potential financial opportunities for wetland restoration were examined. This research will contribute to

improving the conservation of this globally important region, where wetlands are essential for the health and resilience of the GBR.

1.2 Wetland definition, extent, and types

Wetlands in Queensland are defined as: “Areas of permanent or periodic/intermittent inundation with water that is static or flowing, fresh, brackish or salt” (WetlandInfo, 2017).

They must have at least one of the following attributes: (1) Periodically supports plants or animals adapted and dependent on wet conditions for at least part of their life cycle; (2) the substratum is predominantly anaerobic, undrained soils that are saturated, flooded or ponded; and (3) the substratum is saturated, or covered by water at some time (WetlandInfo, 2017).

From vegetation, soil, and long-term inundation mapping, wetland area within the GBR catchments has been estimated as 1,571,420 ha (WetlandInfo, 2017). The GBR catchments have at least 36 river basins divided into five regions: Cape York, Wet Tropics, Burdekin, Mackay-Whitsundays, Fitzroy, and Burnett-Mary region (Fig. 1a). Wetlands in the GBR catchments cover a wide range of climates from equatorial, tropical, subtropical, to arid and semiarid.

Wetlands are classified into the broad systems of lacustrine riverine, palustrine, estuarine and modified/ artificial by the Queensland Government consistent with Australia’s and Ramsar classifications (Bino, Kingsford, & Brandis, 2016; WetlandInfo, 2017; Fig. 1b-e). Riverine wetlands are contained within a channel (river, creek or waterway); palustrine wetlands include vegetated swamps that are non-riverine or non-channel systems with more than 30% cover of emergent vegetation; lacustrine wetlands are large, open, water-dominated systems (> 8ha); and estuarine wetlands are influenced by tidal inundation. Additionally,

modified/artificial wetlands include human-made structures such as dams, constructed lagoons and irrigation channels, where the original hydrology has been modified extensively. Floodplains are not considered wetlands, but wetlands within floodplains were included if they fulfilled the definition of wetland, and are sometimes referred to as floodplain wetlands. Within the GBR region, riverine wetlands comprise most of the area with 666,600 ha, followed by estuarine wetlands with 433,300 ha, palustrine wetlands with 281,600 ha, and lacustrine wetlands with 22,420 ha (WetlandInfo, 2017). Artificial and highly modified wetlands comprise 167,500 ha (~10% of wetland area).

1. Status and threats to wetlands within the GBR catchments

Changes in the area of wetlands in the GBR catchments is assessed every four years (see Environmental Protection Agency 2005 for detailed methodology). Historically, large wetland losses occurred in the region (Bino et al., 2016), but recently, there has been a low net loss of natural wetland area (< 0.1%, 2005-2013) and an annual gain rate of 1% in artificial wetlands (WetlandInfo, 2017). However, degradation is a major issue (Bino et al., 2016; Waterhouse et al., 2017), with most wetlands considered to be in moderate condition (Australian and Queensland Government, 2016). The most significant impacts on wetlands of the GBR catchments are water pollution, invasive species, altered hydrological connectivity, and climate change.

2.1 Water pollution: nutrients, sediments, and pesticides

In the GBR catchments, 87% of the land (447,354.2 ha) is modified or intensively cultivated, primarily for grazing and dairy, but also for sugarcane production, horticulture, and mining (Geosciences Australia, 1997). These activities cause runoff of sediment,

117 nutrients, pesticides, and other pollutants that flush into wetlands through surface runoff and
118 groundwater drainage (Bainbridge, Brodie, Faithful, Sydes, & Lewis, 2009, Waterhouse et al.
119 2017). Pollution loads to the GBR have increased substantially since pre-European
120 settlement; total suspended solids have risen by 3 to 6-fold to 9,900 ktonnes per year, total
121 nitrogen loads have risen 2 to 6-fold to 55 ktonnes per year, and total phosphorous has risen
122 from 3 to 9-fold to 13 ktonnes per year (Kroon et al., 2012, Waterhouse et al. 2017).

123
124 The effects of water pollutants on wetlands in the GBR catchment are driven by
125 pollutant loads, residence time, wetland area, and climate (Davis, Pearson, Brodie, & Butler,
126 2016; Waterhouse et al., 2017). The GBR region comprises a range of climates, from the
127 tropical wet north (> 3,000 mm per year) to the subtropical and drier south (500 mm per year;
128 Australian Bureau of Meteorology, 2018). Most annual rainfall occurs during the wet season
129 (December – May) when large amounts of pollutants are rapidly mobilised and transported
130 downstream (Davis et al., 2016). During the dry season, low flushing, high nutrient loads, and
131 large amounts of organic matter cause deterioration of water quality in many channel
132 waterholes, floodplain lagoons, and lakes (Davis et al., 2016). Thus, wetlands within the
133 GBR are threatened by extensive pulses of flood water carrying high pollutant loads during
134 the wet season, and by chronic exposure to poorly flushed water during the dry season.

135
136 Excessive nutrients in the GBR region coupled with high temperatures have
137 deteriorated the water quality, caused the excessive growth of algae and aquatic weeds
138 (Pearson, Connolly, & Boyero, 2015; Pearson et al., 2013), and decreased macroinvertebrate
139 and fish diversity (Arthington, Godfrey, Pearson, Karim, & Wallace, 2015; Mantyka-Pringle
140 et al., 2014). Excess nitrogen has contributed to dieback of mangrove forests during periods
141 of low rainfall (Lovelock, Ball, Martin, & Feller, 2009).

Nutrients can be transported in dissolved forms, but also as particles bound to suspended sediment. Increased sediment has caused loss of habitat of the native freshwater moray (*Gymnothorax polyuranodon*), a diadromous fish that lives within interstitial spaces among boulders (Ebner, Fulton, Donaldson, & Schaffer, 2016). Increased turbidity can also decrease the diving duration of freshwater turtles (*Elseya irwini*; Schaffer, Hamann, Rowe, & Burrows, 2016). Some invertebrate species in lowland streams of the GBR have shown resistance to high suspended sediments, at least in the short-term (Connolly & Pearson, 2007). In estuarine wetlands, excessive sedimentation may increase mangrove areas in some locations, but also cause the death of trees in other areas where sediment buries seedlings and roots (Lovelock & Ellison, 2007).

In addition to nutrients and sediments, pesticides are a significant source of stress for wetlands in the GBR region (Lewis et al., 2009). The most regularly reported herbicides are Photosystem II inhibitors (PSII; Smith et al., 2012) including atrazine, ametryn, hexazinone, tebuthiuron, and diuron (Lewis et al., 2009). Herbicides can affect the whole food chain. In benthic microalgae, PSII inhibiting herbicides reduce growth (Magnusson, Heimann, & Negri, 2008) and modify diatom community composition (Wood, Mitrovic, Lim, & Kefford, 2017). In amphibians and fish, atrazine causes osmoregulatory disturbance affecting gill histopathology, gonadal morphology, reproductive fitness, and the dynamics of fish populations (Kroon, Hook, Metcalfe, & Jones, 2015). The long-term ecological effects of exposure to herbicides in the GBR region are currently poorly understood.

2.2 Invasive species

Wetland degradation caused by nutrient runoff and hydrological alteration favours the establishment of invasive non-native macrophytes (Fig. 2a). The most prevalent species include hymenachne (*Hymenachne amplexicaulis*), paragrass (*Urochloa mutica*), salvinia (*Salvinia molesta*), cabomba (*Cabomba caroliniana*), water lettuce (*Pistia stratiotes*), and water hyacinth (*Eichhornia crassipes*; Mackay, James, & Arthington, 2010; Werren, 2001). Invasive macrophytes reduce oxygen levels in the water column through the decrease in water surface aeration, a decrease in algal photosynthesis, and the increase in organic matter decomposition, all of which affect fish and invertebrates (Perna, Cappo, Pusey, Burrows, & Pearson, 2012; Waltham & Fixler, 2017). Although asphyxiation thresholds vary among species and life stages (Butler & Burrows, 2007), hypoxia events during the summer months can cause extensive fish kills (Perna et al., 2012).

Many non-native aquatic and terrestrial vertebrates have spread throughout wetlands of the GBR catchments. Aquatic species include: cane toads (*Bufos marinus*) and several fish species such as Mozambique tilapia (*Oreochromis mossambicus*), gambusia (*Gambusia holbrooki*), guppies (*Poecilia reticulata*), swordtails (*Xiphorhophorus hellerii*), and platys (*Xiphorhophorus maculata*) (Harrison & Congdon, 2002; Pearson et al., 2015). Infestations of tilapia (*O. mossambicus*), and Black mangrove cichlid (*Tilapia mariae*) are prevalent in some wetlands of the GBR (Russell, Thuesen, & Thomson, 2012; Fig. 2d), spreading through irrigation networks (Russell, Ryan, McDougall, Kistle, & Aland, 2003). Tilapia displace native fish species and introduce diseases (Canonico, Arthington, McCrary, & Thieme 2005; Russell et al., 2012). There is little information on the population size and distribution ranges of non-native species, and their ecological effects are mostly unknown (Sheaves et al., 2014).

Terrestrial non-native vertebrates, such as pigs (*Sus scrofa*) and cattle cause some of the most significant impacts on wetlands of the GBR region (Fig. 2a, c). Pigs and cattle feed on saltmarsh and mangroves, increase nutrient concentrations and sediment resuspension in the water, and modify macrophyte communities (Doupé, Schaffer, Knott, & Dicky, 2009; Pettit et al., 2012). These disturbances cause pH changes and anoxia, affecting the habitat of many animals, including freshwater turtles (*Chelidae*) and fish (Doupé et al., 2009; Waltham & Schaffer, 2018). Pigs can also affect the trophic chain as they feed directly on many native species such as freshwater turtles (Waltham & Schaffer, 2018). In turn, pigs have become a new source of nutrition for crocodiles in the region (Adame et al., 2018).

2.3 Altered hydrological connectivity

One of the overarching factors affecting the biodiversity and ecological health of wetlands is hydrological connectivity (Bunn & Arthington, 2002). In the GBR catchments, barriers such as tidal exclusion bunds, dams, weirs, roads, rail crossing, urban infrastructure, weirs, and aquatic plant blockages have altered hydrological connectivity (Karim et al., 2013). Groundwater extraction for mining and irrigation also threatens the hydrological connectivity of wetlands and could result in saltwater intrusion into freshwater habitats (Narayan, Schleeberger, & Bristow, 2007). Fish recruitment in floodplain lagoons depends on flood dynamics (Godfrey, Arthington, Pearson, & Karim, 2017), and hydrological alterations can disrupt nursery habitats and alter their life cycles (Sheaves, Baker, Nagelkerken, & Connolly, 2015).

Hydrologically altered wetlands can support some of the original fauna. For example, the highly modified wetlands in the Burdekin delta support native fish species (Davis &

Moore, 2015), and small remnant riparian wetlands are important for bird biodiversity (Keir, Pearson, & Congdon, 2015). Similarly, frequent water flushing of some floodplain lagoons in the Wet Tropics has maintained good water quality and relative high fish diversity, despite the variable connectivity with main river channels (Arthington et al., 2015). However, due to the lack of pre-impact baseline data, the long-term viability of fish populations and the full consequences of barriers and altered connectivity are unknown.

The disconnection of wetlands can cause water stagnation and dissolved oxygen depletion. Long periods of drought followed by large floods have been associated with severe “blackwater” events, where water poor in oxygen is flushed downstream causing the death of organisms in riverine and coastal ecosystems (Whitworth, Baldwin, & Kerr, 2012).

2.4 Climate change

As temperatures increase, oxygen concentrations in the water column decrease, causing asphyxiation of aquatic animals which are unable to surface, respire, or escape (Butler & Burrows, 2007). Increased temperature can cause both acute and chronic exposure effects in aquatic biota (Wallace, Waltham, Burrows, & McJannet, 2015) by modifying the metabolic rate of fish, but also growth, resource allocation for reproduction, and population size (Jobling, 1995).

Climate change is varying the timing, frequency, and intensity of precipitation (CSIRO, 2016). A decrease in precipitation could change river flow patterns, which may decrease connectivity, increase salinity, and decrease sediment supply (Bunn & Arthington,

2002; Gilman, Ellison, Duke, & Field, 2008). The increase in frequency and severity of droughts and floods (CSIRO, 2016) will result in more severe and frequent blackwater events (Whitworth et al., 2012).

Tropical storms cause defoliation, abrasion, stem breakage, uprooting and sediment smothering of wetlands (Sanford et al., 1991). Additionally, prolonged inundation as a result of flooding may ‘suffocate’ some wetland species (McKee, 1996). However, tropical storms can also increase growth in mangrove forests, as high rainfall causes alleviation of hypersalinity, and increases nutrient delivery (Lovelock et al., 2011). In 2011, cyclone Yasi damaged 17% of the mangroves in Hinchinbrook Channel, especially those fringing the seaside (Asbridge, Lucas, Accad, & Dowling, 2015). One year after the cyclone, a large proportion of the forest recovered (Asbridge et al., 2015), however, until now, some areas have not improved. The increase in the frequency and intensity of extreme weather events will modify community structure and productivity of mangroves (Lovelock, Cahoon, et al., 2015), favouring species that are tolerant to disturbances and have rapid regeneration (Baldwin, Egnotovich, Ford, & Platt, 2001).

Sea level rise will impact wetlands, especially coastal wetlands (Lovelock & Ellison, 2007). The response of estuarine wetlands to sea level rise will depend on their productivity, sediment supply, the grain size of the sediment, tidal range, and rainfall (Lovelock, Adame, et al., 2015). Intertidal wetlands in the mouths of rivers will rely on sediment supplied during high rainfall events to maintain elevation relative to sea level, while wetlands in islands far offshore will depend on root growth (Lovelock, Adame et al., 2015). According to a model for the Indo-Pacific, mangroves from the GBR catchments, where sediment supply is high,

are at relatively low risk of being submerged by 2100 (Lovelock, Cahoon, et al., 2015). Additionally, sea level rise will cause mangroves to migrate into saltmarsh or adjacent freshwater wetlands (Saintilan & Rogers, 2013; Fig. 2b). Further acceleration of sea level rise may result in the loss of intertidal wetlands of the region (Lovelock, Cahoon, et al., 2015).

Increases in atmospheric CO₂ will also contribute to changes in wetland vegetation. For example, increase in CO₂ will increase mangrove production, with limits set by changes in nutrients and salinity (Reef et al., 2015). It is possible that mangroves of the *Avicennia* genus will become dominant in areas where nutrients and salinity levels are high (Reef et al., 2016).

2. Protection and management of wetlands in the GBR catchments

Wetlands have been overexploited historically and are currently one of the worst protected and managed ecosystems on Earth (Kingsford, Basset, & Jackson, 2016). In Australia, management and policy have been constrained by data on distribution, type and extent of wetlands in most states, but not in Queensland (Bino et al., 2016). In 1999, the Queensland Government endorsed the Strategy for the Conservation and Management of Queensland's wetlands with two main objectives: 1) the sustainable use and management of natural wetlands and integrated catchment practices; and 2) the development of community awareness to encourage community involvement in wetland management (State of Queensland, 2017). In 2003, The Queensland Wetlands Program was established by the Queensland and Australian Government to support projects and programs that enhance the wise use and sustainable management of Queensland's wetlands. The program delivers

detailed mapping and classification of wetlands, planning, management, rehabilitation guidelines, monitoring and assessment, and communication material.

In the GBR catchments, wetlands are protected by laws passed by the Queensland and Commonwealth governments, but also through international obligations, such as Ramsar (Table 2, 3). In the GBR catchments about 17% of wetlands occur in protected areas or reserves (Table 2), and most of the high-value wetlands are protected through planning legislation (Table 3). Similar to other regions in the world, wetland protection in Queensland has not prevented their degradation, which requires catchment management solutions that support hydrological connectivity, adequate water quality and upstream pest control (Bino et al., 2016).

The Wetlands in the Great Barrier Reef Catchments Management Strategy 2016–21 (DEHP, 2016) supports the Reef 2050 Long-Term Sustainability Plan (Commonwealth of Australia, 2015) and the Reef Water Quality Improvement Plan 2017-2022 (State of Queensland, 2018) and outlines the activities required to manage wetlands in the GBR sustainably. As part of current management practices, wetland extent is monitored every four years, and recently, a program to monitor their condition has been established (Australian and Queensland Government, 2016). The focus of wetland management in recent years has been on their role in improving water quality by removing nutrients and sediment that otherwise would reach the GBR. However, recent activities have placed more focus on the intrinsic value of wetlands and their need for improved management (State of Queensland, 2018). Table 4 summarises management strategies for the threats that wetlands face in the GBR.

Wetland restoration

On-ground activities have involved small to medium scale projects, for example, monitoring, managing and removing weeds and other invasive species, and removing bunds and other barriers for improving hydrological connectivity (WetlandInfo, 2014a, b, Table 4). Although some projects have been relatively successful, there is still a need to increase their scale to have a meaningful impact at the landscape level. Future restoration projects need clear objectives and goals, and it is important to acknowledge that wetland restoration can provide some, but not all, of the expected ecosystem services that wetlands are capable of delivering (Adame, Hermoso, Perhans, Lovelock, & Herrera-Silveira., 2015).

Wetland restoration activities in Australia can come at a substantial cost to the private landholder or community organisation who owns the land. Landowners are incurring private restoration costs to deliver ecosystem services that in many cases also include public goods. Regulating services in particular (e.g. pollution assimilation) are non-excludable, i.e. it is not feasible to exclude individuals from receiving the ecosystem service once it has been made available. Here, the role of governments becomes important in designing an effective system consisting of a mixture of both regulatory and economic instruments to create economic incentives to undertake wetland restoration.

Application of economic incentives for wetland restoration is increasing, and include offsets for nutrient and sediment pollution, payment for ecosystem services, and nitrogen and carbon markets (Waltham et al., 2017). Offset frameworks could provide economic support for wetland restoration. For example, nutrient discharges or dredging at one point could be offset by wetland restoration to improve water quality in the catchment (Bell, 2016).

However, offsets for wetland restoration need to be based on demonstrable outcomes (i.e. wetland rehabilitation) and not on activities (removing non-native macrophytes; Bell, 2016). Additionally, damage in one wetland to restore another should only be used as the last resource, and wetland protection should always be prioritised over restoration (Maron, Gordon, Mackey, Possingham, & Watson, 2015).

A complementary recommended approach to offsetting pollution and incentivising wetland restoration are payments for ecosystem services or PES (State of Queensland, 2016). PES is based on the concept that the ‘consumer’ of ecosystem services, or those who benefit from their supply, should pay the ecosystem service ‘supplier’ to cover the costs of production. Restoration activities with the aim of supplying a particular ecosystem service, such as improvements in water quality, could deliver additional environmental benefits such as biodiversity protection, fisheries production, coastal protection, climate regulation, and support a range of cultural, recreational and educational values (Adame et al., 2015).

Finally, nitrogen markets, or more generally water quality trading, have also been proposed as a possible economic mechanism for reducing nitrogen pollution in waterways and potentially incentivising wetland restoration (Smart et al., 2016). A tradable market approach encourages innovation and flexibility in complying with the regulations. Water quality trading is an emerging economic tool that is being considered by regulators around the world, notably New Zealand, countries fringing on the Baltic Sea, the United States of America, and could potentially be used in Australia to incentivize wetland restoration and rehabilitation (Greenhalgh & Selman, 2012; Waltham et al., 2017). However, for a nitrogen market to be effective, it needs to have clearly-defined goals, a monitoring strategy, adequate

market drivers, and stakeholder engagement (Greenhalgh & Selman, 2012). A poorly designed nitrogen market can result in thin trading, thereby reducing environmental gains.

In conclusion, wetlands in the GBR catchments face significant management challenges to overcome legacy deterioration caused by intense and diverse land uses in the catchments. In recent years wetlands have been managed primarily for the improvement of water quality to the GBR, but their contribution still needs to be integrated into management models and strategies (Wallace, Stewart, Hawdon, & Keen, 2008). Future efforts need to be directed to the management and restoration of wetlands for their intrinsic values and broader contributions to healthy ecosystems in the GBR and its catchments.

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Figure legends

Fig. 1 Catchment area of the Great Barrier Reef (grey) in Queensland, northeast of Australia, and main bioregions (Cape York, Wet Tropics, Burdekin, Mackay-Whitsundays, Fitzroy, Burnett-Mary), and representative wetlands of the region: a) estuarine wetlands, mangroves at Cardwell, b) riverine wetlands in the Murray River, c) palustrine wetlands- *Melaleuca* sp forests and marsh at Girramay National Park, and d) lacustrine wetlands at Mungalla Station, Herbert River. Photos by M.F. Adame.

Fig. 2 a) Wetlands invaded by non-native grass *Hymenachne amplexicaulis* and affected by loss of riparian vegetation and cattle grazing, b) dying of *Melaleuca* forests in Halifax Bay Wetlands National Park as mangroves encroach (green vegetation in the background) probably due to salinization, c) feral pigs congregate in permanent water holes, d) Mozambique tilapia (*Oreochromis mossambicus*), a significant non-native invasive species in wetlands of tropical Australia. Photos by (a,b) M. F. Adame, (c) B. Ross, and (d) S. Westley.

Table 1. The extent of the most common types of wetlands within the Great Barrier Reef catchment (WetlandInfo, 2017). The total does not add to 100% due to small percentages of other types of wetlands.

Wetland Type		Area (ha)	%
Riverine		666,600	42.4
Estuarine	Mangroves	246,200	15.7
	Salt flats and saltmarsh	187,100	11.9
Palustrine	Arid and semi-arid non floodplain tree swamp	17,910	1.1
	Arid and semi-arid floodplain tree swamp	21,130	1.3
	Coastal and sub-coastal non-floodplain tree swamp- <i>Melaleuca</i> and <i>Eucalyptus</i> spp.	32,580	0.6
	Coastal and sub-coastal floodplain tree swamp <i>Melaleuca</i> and <i>Eucalyptus</i> spp.	61,030	3.9
	Coastal and sub-coastal non-floodplain grass/sedge and herb swamp	19,370	1.2
	Coastal and sub-coastal non-floodplain wet heath swamp	17,090	1.1
	Coastal and sub-coastal floodplain grass, sedge, herb swamp	87,880	5.6
	Coastal and sub-coastal saline swamp	11,660	0.7
Lacustrine		22,420	1.4
Artificial and highly modified		162,620	10.3

647 Table 2. Protection status of wetlands within the Great Barrier Reef catchments. Some
 648 wetlands have multiple protection status so areas can overlap (WetlandInfo, 2017).

Protection status	Area (ha)	% total
World Heritage	91,301	5.8
Ramsar	35,348	2.2
National Park	113,386	8.5
Conservation Park	10,504	0.7
Forest Reserve	250	0.02
Resource Reserve	2,437	0.2
State Forest	19,100	1.2
Timber Reserve	42	0.003

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651 Table 3. Programs, policy and legislation relevant to the protection and management of
 652 wetlands within the Great Barrier Reef catchments (WetlandInfo 2017; Queensland
 653 Government, 2018)

International conventions and agreements	
United Nations Convention on Biological Diversity	Legally binding global treaty for the development of conservation and sustainable use of biological diversity, including wetlands, and equitable sharing of benefits.
Ramsar Convention	Australia as a signatory is required to describe and maintain the ecological condition of the wetland. In the GBR, there are two Ramsar wetlands: Shoalwater/Corio Bay, and Bowling Green Bay
World Heritage	The GBR is considered a World Heritage site as an outstanding example of the world's natural and cultural heritage. Wetlands included in the GBR are overseen by the World Heritage Committee, on behalf of United Nations Educational, Scientific and Cultural Organisation (UNESCO).
The East Asian-Australasian Flyway Partnership	Voluntary partnership to facilitate collaborative efforts to protect migratory birds, the wetlands they depend on, and livelihoods
Bonn convention (The Convention on the Conservation of Migratory Species of Wild Animals)	Aims to protect animal species which undergo migration across international boundaries, such as many wetland-dependent birds.
JAMBA/CAMBA/RoKAMBA	Bilateral agreements with Japan, China, and Republic of Korea, respectively, to protect migratory birds and the wetlands they depend on
National Legislation and Policy	
Environmental Protection and Biodiversity Conservation Act 1999	Legal framework to protect and manage important flora, fauna and ecological communities, including wetlands.
Australia's Biodiversity Conservation Strategy 2010-2030	Framework to conserve national biodiversity.
The Australian Government's Threatened Species Strategy	Plan to prioritise effort and work in partnerships to reverse species in decline.
Australian Pest Animal Strategy 2017-2027	Guidance on best practice for vertebrate invasive non-native animal management.

Australian Weeds Strategy 2017-2027	Guidance on best practice for invasive non-native plant management.
State Legislation and Policy	
Planning Act 2016	The legal framework for land use planning, development assessment and dispute resolution. Deals with matters relating to wetlands
Nature Conservation (Wildlife) Regulation 2006	Provides for the protection of native wildlife, including those of wetlands.
Vegetation Management Act 1999	Regulates the clearing of native vegetation.
Water Act 2000	Legislation for the sustainable planning and management of water resources.
Environmental Protection Act 1994	A key element of the environmental legal system, which protects wetlands while allowing development.
Nature Conservation Act 1992	Conservation of nature allowing for the involvement of indigenous people. It regulates clearing, growing, harvesting and trading of plants.
Marine Act 1994/ Fisheries Act 1994	Protects important estuarine wetlands.
Coastal Protection Management Act 1995	Provides protection and management of coastal wetlands.
Biosecurity Act 2014	Framework and powers for improved management of invasive non-native plants and animals.
Environmental Offsets Act 2014	Framework for which certain impacts on wetlands can be compensated for elsewhere
Environmental Protection (Water) Policy 2009	Establishes environmental values and water quality objectives for wetlands.
Local Programs	
Council Planning Schemes	Wetland management and restoration commitments of local councils
Natural Resource Management Groups	Non-regulatory programs for regional management and rehabilitation of wetlands

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656 Table 4. Management of threats in wetlands of the Great Barrier Reef catchments.

Threat	Type	Management
Water pollution ^{1,2}	Nutrients	Buffer zones: conservation and revegetation of wetlands. Storm and drainage management. Point source licensing and enforcement. Best management fertiliser application methods: subsurface application, appropriate rates for plant growth and soil levels, and avoiding application during or before rain. Treatment systems. Fire management plans. Education.
	Sediments	Streambank remediation. Gully remediation. Land cover management. Stock management: controlled grazing, fencing wetlands, adequate stocking regimes. Cropping management: cover crops, trash blanketing, filter strips, minimising or reducing tillage. Fire management plans. Education.
	Pesticides	Buffer zones. Government regulation. Incentivise organic farming. Point source licencing and enforcement. Best management application: rates and timing. Spill prevention and control/response plans. Education.
Invasive species ³	Macrophytes	Removal: manual, herbicide application, controlled fire. Preventing dispersal. Monitoring and reporting of sighting. Movement restrictions, importation and quarantine practices (state and national). Education.

	Fish	Aquaculture best management practices. Monitoring and reporting of sighting. Monitoring of invasive species. Manual eradication as euthanasia or poisoning in ponds and small dams. Education.
	Cattle/horses	Fencing wetlands. Buffer zone between grazing areas and wetlands. Education.
	Pigs	Eradication program: aerial shooting, trapping, poisoning. Fencing wetlands. Education.
Altered hydrological regime ^{1,2}		Bund/levee removal. Drain regulation. Environmental flow release. Government regulation: water extraction licences, legislation and policies regarding reclamation and drainage activities. Water resource plans. Fish passages.
Climate change ^{1,2}	Increase in temperature	Increase connectivity of waterholes. Decrease pig and cattle disturbances that increase turbidity and increase water temperature. Increase riparian vegetation
	Rainfall variation	Increase wetland connectivity.
	Intense tropical storms	Protect/revegetate coastal wetlands. Increase floodplain connectivity.
	Sea level rise	Buffers zones to allow terrestrial migration of estuarine wetlands. Monitor changes in salinity.

657 ¹ Wetlandinfo 2017; ² Waterhouse et al. 2017; ³ Department of Agriculture and Fisheries, 2018.