Freshwater wetlands of Moreton Bay *Quandamooka* and catchments: Biodiversity, ecology, threats and management

Abstract

Freshwater wetlands of the Moreton Bay Region and Bay islands are prominent landscape features of high biodiversity performing essential ecological functions and providing ecosystem services. This paper reviews the types, extent, biodiversity and ecology of freshwater wetlands in the region, and documents the main threats to wetland ecosystems. These wetlands are protected and managed under Queensland and federal legislation, international obligations and a range of laws, policies and programs administered by government agencies. Important initiatives include the Queensland Wetlands Program, the Healthy Waterways and Catchments and Resilient Rivers alliance, and Queensland's water management plans. The ongoing challenge for those managing the Moreton Bay Region and Bay islands is to appreciate the importance of freshwater wetlands as essential landscape components and sources of valuable ecosystem services, and to recognise how human activities threaten their biodiversity, integrity and future in spite of rigorous monitoring, dedicated management programs and conservation initiatives. Recommendations to ensure the future of freshwater wetlands in the Moreton Bay region and Bay islands include: (i) sustaining and enhancing wetland biodiversity, functions and ecosystem services in the context of expanding human populations, growing demands for water and infrastructure, and likely threats associated with climate change; (ii) increasing support for research, monitoring, communication and management of freshwater wetlands on the mainland and Bay islands; and (iii) maintaining a well-coordinated holistic approach to integrated land, water and wetland management based on sound multidisciplinary science, societal values and expectations, and partnership arrangements (such as the Healthy Waterways and Catchments and Resilient Rivers Alliance).

Keywords: habitat types, wetland extent, vegetation, fish, invertebrates, monitoring, conservation, climate change

Introduction

Freshwater wetlands in catchments of the Moreton Bay region (from Deception Bay to the Jumpinpin Bar) and offshore (Bay) islands of South East Queensland (SEQ) are prominent landscape features of high biodiversity (Fig. 1). Wetlands deliver essential ecological goods and services such as supplying food and water, trapping and transforming pollutants, regulating climate and flooding, sequestering carbon, providing habitat for biodiversity, and presenting opportunities for

***Figure 1**. Moreton Bay and its catchment area. Our study boundaries were Caloundra in the north, Ipswich in the west and the Gold Coast to the south.*

recreation and tourism (1–3). The Moreton Bay region is a semi-enclosed basin bounded on its eastern side by two large vegetated sand islands (Moreton and North Stradbroke) and a deltaic coast on the western side, where six large rivers (Nerang-Coomera, Logan-Albert, Brisbane, North-South Pine) and multiple smaller rivers and creeks discharge to the Bay from a combined catchment of approximately 22,000 km² (Fig. 1). Part of the region forms the Moreton Bay Ramsar site which was listed

in 1993 as a wetland of international importance (4) due to its large size (approx. 1,206 km²); diverse freshwater, estuarine and intertidal wetlands; significant waterbird and shorebird populations; as well as diverse, rare and endemic flora and fauna (5). Moreton Bay and the Bay islands have important cultural, social, economic and recreational values. The site of Wallum Wallum Creek, on the west coast of North Stradbroke Island, has evidence of

continuous Aboriginal occupation extending back some 20,000 years, with present-day hunting, fishing and the gathering of local food plants continuing the cultural and provisional traditions of the Quandamooka people. The Moreton Bay region offers major opportunities for nature-based tourism and recreation, with more than 12 million visits annually (6).

This paper begins with a summary of the freshwater wetland systems and their pattern of extent within the Moreton Bay catchment and Bay islands, followed by an overview of the ecological functions and biodiversity of selected wetland flora and fauna. Freshwater wetlands on the mainland and Bay islands are threatened by increasing land-use change, water infrastructure and use, pollution, habitat loss/fragmentation, and alien animals and plants. A brief account of threats to wetlands, including the implications of climate change, is followed by an outline of management activities underway to assess wetland condition, mitigate threats, and maintain the ecological

integrity and ecosystem services of freshwater wetlands. The paper ends with recommendations for future wetland research, monitoring, management and conservation**.**

Wetland systems and extent

The Queensland Government's *Strategy for Conservation and Management of Queensland Wetlands* (7) defines wetlands as 'Areas of permanent or periodic/intermittent inundation, whether natural or artificial, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 metres'. This definition has been modified to make it more practical to apply in mapping and legislation (8). At the broadest level Queensland wetlands have been grouped into lacustrine (lake), palustrine (swamp, marsh), riverine, estuarine, marine and subterranean systems; these systems have been classified at a finer habitat level and the Queensland Government has mapped them state wide (9).

The types and extent of freshwater wetlands in river basins draining into Moreton Bay vary with catchment area, natural environmental characteristics (e.g. climate, geology, topography, soils, surface and groundwater hydrology) and human influences. Table 1 presents summary data on the extent of wetland systems (assessed in 2013) for the large river basins draining into Moreton Bay, and the Bay islands. In the populous Brisbane catchment (area 13,541.7 km²), the dominant wetlands by areal extent in 2013 were riverine and artificial or highly modified wetlands (e.g. dams, ring tanks, irrigation channels), together forming 90% of total wetland area (495.9 km²); palustrine and lacustrine wetlands were numerous (approx. 1,048 in this catchment); however, they made up only 7.3% and 1% of the total wetland area respectively (10). In contrast, freshwater wetlands on the two barrier islands and several small islands in Moreton Bay (total area 547.2 km²) in 2013 were mainly palustrine (e.g. sedge and *Melaleuca* swamps) forming 48.9% of total wetland area; lakes (1.3%) and artificial or highly modified wetlands (1.6%) made up the rest of freshwater wetland area on Bay islands (10). Small streams flowing to the coast add further habitat diversity (e.g. Eagers Creek, Spitfire Creek on Moreton Island; Myora Creek on North Stradbroke Island).

Table 1. Wetland systems and extent (km^2) in the large river catchments draining to Moreton Bay and on Moreton Bay islands (10)

Catchment	Total area	Artificial	Estuarine	Lacustrine	Palustrine	Riverine	Total wetland area
Coomera–Nerang	1303.9	36.3	34.9	0.2	20.5	18	109.8
Logan–Albert	4149.8	26.9	21.8	5.2	34	45.9	133.9
Brisbane	13541.7	206.6	8	4.7	36.2	240.1	495.9
North-South Pine	1484.4	36.4	45.7	0.2	39.7	26.7	148.7
Moreton Bay islands	547.2	2.1	63.6	1.7	64.6	0	132

Biodiversity and ecology of mainland freshwater wetlands

Describing the biodiversity and ecology of mainland freshwater wetlands of the Moreton Bay Region is a challenge given the richness of their flora and fauna and the diversity of wetland types. Ecological features of the Brisbane catchment and species lists for freshwater flora, invertebrates and fish were published in *The Brisbane River: a source-book for the future* (11–13). Although dated, these papers offer comprehensive species lists and a benchmark for analysis of changes in diversity over time. Since then numerous studies (14–20), two books (21, 22) and a Special Issue (23) have documented aspects of the biodiversity and ecology of streams, rivers, lakes and impoundments in Moreton Bay catchments and the Bay islands.

By comparison, there has been far less research on the biodiversity and ecology of palustrine wetlands. This began to change with establishment of the Queensland Government's *Strategy for Conservation and Management of Queensland Wetlands* (7) and the Queensland Wetlands Program (QWP) in 2003. Wetland*info,* developed through the QWP, is the major portal for information on Queensland's wetlands, which are home to 130 species of freshwater fish, around 210 species of waterbird and 3,000 plant species (24). The Aquatic Conservation Assessment (25) of riverine and non-riverine wetlands in 16 catchments of the SEQ mainland and Moreton Bay islands is another useful resource. Descriptions of Broad Vegetation Groups (BVGs – high level groups of plant communities throughout Queensland's bioregions) provide further information on wetland typologies and floristics (26). The following brief account of the functional roles and diversity of wetland flora and fauna focuses on three important components of most riverine and palustrine wetlands — riparian vegetation, hydrophytes (aquatic plants) and fish.

Riparian vegetation

A healthy biodiverse riparian (fringing) vegetation corridor is universally recognised as essential to wetland functioning and ecological health (27, 28). Riparian vegetation can promote nitrogen transformation and the processing of nutrient and sediment fluxes from upland catchments to streams (29, 30). Shading by riparian trees and shrubs influences the light environment and water temperatures that in turn govern many biological processes, including primary production, invertebrate and fish recruitment and aquatic biodiversity (31, 32). Riparian and littoral vegetation stands, and root systems contribute physical structure to stream banks and beds, constrain bank erosion and shape channels and wetland aquatic habitat (32, 34). Large woody debris and other vegetation fragments derived from riparian trees and shrubs influence water flows, channel formation and aquatic habitat (35). Submerged logs and leaf packs create structure where invertebrates and fish find refuge from thermal extremes, protection from predators and safe spawning sites (36, 37). In forested headwater catchments, riparian inputs (leaves, flowers, fruits) contribute energy to aquatic food webs through biological processing by microbes and invertebrates, while further downstream the aquatic food web is usually more dependent on production by algae and plants (38, 39). Riparian plants and connected corridors of vegetation along riverbanks provide habitat and movement pathways for birds, mammals, reptiles, frogs and invertebrates (40).

The riparian vegetation associated with wetlands of the Moreton Bay region is diverse and may include small, medium and large trees (over 30 m), woody shrubs, vines, grasses, rushes, sedges, herbs, forbs, ferns, mosses and palms. Community diversity and composition reflect interactions between climate (especially rainfall), topography and soils, moisture availability and duration of inundation (20). Riparian communities in the Moreton Bay region have been assigned to BVG 16a ‘Open forest and woodlands dominated by species of *Eucalyptus* fringing drainage lines’ (26). Surveys of the riparian vegetation of SEQ streams and rivers from the Mary River in the north to the Nerang River south of Brisbane recorded over 191 species of woody trees and shrubs (20). In this study area, the most abundant native species were sandpaper fig (*Ficus coronata*), black bean (*Castanospermum australe*), three-veined laurel (*Cryptocarya triplinervis*), and weeping lilly pilly (*Syzygium floribundum*), with bottlebrush (*Melaleuca viminalis*) and black tea-tree (*M. bracteata*) in areas of lower rainfall. Alien taxa comprised 26.5% of all individuals recorded, with the most abundant alien species being Chinese elm (*Celtis sinensis*), lantana (*Lantana camara*), leucaena (*Leucaena leucocephala*), camphor laurel (*Cinnamomum camphora*), and broad-leaved privet (*Ligustrum*

lucidum).

Hydrophytes (non-riparian)

Hydrophytes are plants that are adapted to and dependent on living in wet conditions for at least part of their life cycle (24). Non-riparian hydrophytes (often called aquatic macrophytes, which include macroalgae) colonise many different types of wetland including ponds, lakes, impoundments, palustrine wetlands, streams and rivers, rapids and waterfalls. They are important features of shallow aquatic ecosystems, where they influence ecological processes (e.g. nutrient cycling and physicochemical properties of the water column such as dissolved oxygen and pH), channel morphology, habitat structure, and the diversity and species composition of invertebrate and fish communities (17, 41). The physical forms (emergent, floating, submerged) and structures of aquatic plants create habitat complexity and provide shelter for invertebrates, fish and waterbirds, as well as spawning substrate for some aquatic species, crimson-spotted rainbow fish (*Melanotaenia duboulay*) for example (22). High rates of primary production support aquatic food webs based on living plants (grazing food webs) and dead organic matter (detrital food webs) (28, 39).

Vegetation complexes in Queensland's wetlands belong to BVG 34 'Wetlands associated with permanent lakes and swamps, as well as ephemeral lakes, claypans and swamps; includes fringing woodlands and shrublands', within which seven sub-groups capture the floristic characteristics of riverine, lacustrine and palustrine wetlands (26). For example, BVG 34c 'Palustrine wetlands … on coastal floodplains dominated by sedges and grasses such as spikerush (*Oryza* spp., *Eleocharis* spp.) or cord rush (*Baloskion* spp. /*Leptocarpus tenax*/*Gahnia sieberiana*)/ sword grass (*Lepironia* spp.) is a common vegetation formation in coastal areas of SEQ (26).

Surveys of aquatic plants at 44 sites in SEQ streams and rivers from the Mary River to the Nerang River have recorded 74 taxa (42). The most common taxa were the submerged species *Potamogeton crispus*, *Myriophyllum* spp., mosses, and the emergent species *Lomandra* spp., *Carex* spp., *Hydrocotyle* spp. and *Persicaria decipiens*. Alien species comprised 27% of the flora recorded, the most common species being watercress (*Rorippa nasturtium-aquaticum*), mist flower (*Ageratina riparia)* and the sedge *Cyperus eragrostis*. Prominent alien species in lacustrine and palustrine wetlands include floating forms (*Pistia*, *Salvinia, Eichhornia*) and robust emergent species, typically grasses and sedges (e.g. species of *Cyperus*). Invasive alien plants

such as ponded pasture grasses (*Urochloa mutica* and *Hymenachne*) and water hyacinth (*Eichhornia crassipes*) disrupt the hydrology, habitat structure, native fish communities and ecological processes of streams and wetlands (43).

Fish

Fish are important components of most freshwater ecosystems (44, 45). They contribute to biodiversity and ecological functions by their uptake, storage and transport of nutrients, consumption of organisms at lower trophic levels, and regulatory effects on a variety of ecosystem-level properties, such as food-web structure (45, 46). Fish assemblage structure and distribution patterns reflect large-scale predictors such as climate and geology, catchment characteristics, channel structure, riparian processes, habitat complexity and water quality (18, 19, 41). These dependencies and the sensitivity of fish to the common pressures on freshwater ecosystems (water pollution, barriers to movement, altered flow regime, habitat loss/fragmentation and alien species) make them very useful biological indicators of ecological condition (1, 18). Fishing for food or pleasure is an important human activity globally, with many societal benefits, including food security, providing important micronutrients and essential fatty acids, generating wealth, and supporting livelihoods, health and wellbeing (44). However, poorly managed fisheries and recreational activities can affect fish population levels, assemblage composition and ecological functions associated with healthy and resilient aquatic ecosystems (44, 45).

A recent compilation identified 42 native freshwater species (i.e. species that either breed or spend most of their life cycle in freshwater) indigenous to the SEQ wetlands. These fish records come from the large catchments draining to Moreton Bay, small coastal creeks and the Bay islands (Table 2). The region supports Oxleyan pygmy perch (*Nannoperca oxleyana*) listed as ‘Endangered’ under the *Environment Protection and Biodiversity Conservation Act 1999 (Cwlth)*. It also supports species of recreational and commercial importance such as Australian bass (*Percalates novemaculeata*) and sea mullet (*Mugil cephalus*).

Table 2. Number of native, translocated and alien fish species in wetlands of the large catchments draining to Moreton Bay, small coastal creeks and Moreton Bay islands*

Catchment	Total Area	Native species	Translocated species	Alien species

Catchment	Total Area	Native species	Translocated species	Alien species
Coomera–Nerang	1303.9	**29**	**4**	**8**
Logan–Albert	4149.8	**33**	**3**	**7**
Brisbane	13541.7	**37**	**6**	**10**
North-South Pine	1484.4	**29**	**5**	**5**
Moreton Bay islands	547.2	**25**	**0**	**1**

*Compiled by MJ Kennard, Griffith University (June 2018) from references (18, 22, 24, 25)

Six Australian native species have been introduced (i.e. translocated) to the region from other Australian catchments, saratoga (*Scleropages leichardti*), golden perch (*Macquaria ambigua*), barred grunter (*Amniataba percoides*), silver perch (*Bidyanus bidyanus*), Lake's carp gudgeon (*Hypseleotris* sp.) and Australian lungfish (*Neoceratodus forsteri*). A further 14 species in four families (Poeciliidae, Cyprinidae, Cichlidae and Cobitidae) introduced to Australia from other countries have been recorded in SEQ. Most of these alien species have been introduced via the aquarium trade and spread deliberately (e.g. for mosquito control) or accidentally (e.g. escapes from ornamental ponds, dispersal in flood waters) into many water bodies (47). The mosquitofish (*Gambusia holbrooki* – Poeciliidae) is widely distributed in the Moreton Bay region and also occurs on the two large Bay islands (22, 48, 49). Streams and rivers, impoundments and farm dams across the large catchments draining into Moreton Bay support many of these native and alien species, but their occurrence patterns in palustrine wetlands are less well known and warrant more investigation.

Biodiversity and ecology of mainland coastal wallum and Bay island wetlands

The freshwater wetlands of the Bay islands have long attracted scientific interest (23, 50–52). Wetland hydrology on the sand islands is influenced by rainfall recharge, evaporation, sub-surface infiltration, groundwater flows and, for some creeks and lakes, the surface expression of groundwater (51). Many wetlands can be classed as groundwater-dependent ecosystems and require permanent or intermittent access to

groundwater to meet all or some of the water requirements of plant and animal communities. This access maintains ecological processes and services (53). Groundwater-dependent ecosystems have been mapped throughout the Moreton Bay region (54, 55).

Variations in hydrology, physical form and water quality distinguish several prominent wetland types of the Bay islands. Perennial streams are typically shallow (<1 m deep) coastal streams that experience enduring flow (e.g. the creek flowing from Blue Lake to Eighteen Mile Swamp, North Stradbroke Island). Chain-of-pond streams form a series of pools of varying depth and with intermittent connectivity, depending on the level of flow. Palustrine wetlands (including peat swamps) form large swathes along the coastal lowlands of dune islands. Eighteen Mile Swamp (Fig. 2a) on North Stradbroke Island is considered to be one of the largest coastal peat swamps in Australia (52). Dune lakes are of two common types. Perched lakes (e.g. Brown Lake, North Stradbroke Island) are separated from the regional groundwater table by semi-permeable indurated layers. Water table window lakes (e.g. Blue Lake, North Stradbroke Island) form between dunes in depressions that extend below the upper surface of the regional groundwater-table (Fig. 2b). Blue Lake's depth and shoreline have remained essentially unchanged over the last century despite climatic variability such as extended droughts (50, 54, 55). This lake forms an important freshwater refuge sustained by groundwater inflow from the island's large unconfined sand aquifers.

(a) A palustrine wetland, Eighteen Mile Swamp, North Stradbroke Island;

(b) A watertable window, Blue Lake, North Stradbroke Island.

Figure 2. Photographs courtesy of Jonathan Marshall, Queensland Government

Wetlands of the sand islands and similar coastal landforms on the mainland are typically located in heathlands referred to as ‘wallum’, a term derived from the Indigenous word for *Banksia aemula*, a small tree characteristic of these areas. Fringing vegetation associated with wallum wetlands is typically BVG 22a ‘Open forests and woodlands dominated by swamp paperbark (*Melaleuca quinquenervia*) in seasonally inundated lowland coastal areas and swamps’ (26). Lakes and palustrine wetlands often have dense fringes of sedges and rushes such as *Lepironia articulata* and species of *Eleocharis, Baumea, Schoenus, Juncus* and *Gahnia* (Fig. 2). The deeper areas of lakes are generally vegetation free, although the clear waters of Blue Lake on North Stradbroke Island allow sedges to grow at depths over 10 m (50).

The marginal (littoral) vegetation of dune lakes provides habitat for a variety of aquatic

invertebrates as well as food, shelter and spawning sites for higher order organisms — fish, frogs and turtles. Two new species of Odonata (dragonflies and damselflies) *Orthetrum boumiera* and *Austrolestes minjeribba* (56) were first discovered at Brown Lake, and a primitive aquatic worm (*Rhizodrilus arthingtonae*) lives in the sandy shallows. Brown Lake lacked fish in the 1970s (50) allowing planktonic midges (*Chaoborus* spp.) and an aquatic bug (*Anisops*, Hemiptera) to assume the role of apex predators in the lake's food web. The recent introduction (date and mechanism unknown) of *G. holbrooki* (the predatory alien mosquitofish) may alter phytoplankton and zooplankton communities and the structure of the food web in this iconic perched dune lake.

The endangered Oxleyan pygmy perch (*Nannoperca oxleyana*) and ornate rainbowfish (*Rhadinocentrus ornatus*) are coastal wallum wetland habitat specialists restricted to wetlands of the sand islands and mainland coastal wallum (57). Their populations are often geographically isolated from one another leading to high levels of genetic divergence (58–59). Frogs associated with wallum wetlands include the wallum froglet (*Crinia tinnula*), Cooloola sedgefrog (*Litoria cooloolensis*), wallum rocketfrog (*Litoria freycineti*) and wallum sedgefrog (*Litoria olongburensis*). These 'acid frogs' are adapted to the unusual water quality of dune lakes and wetlands, particularly the acidity (low pH) of their waters (60).

Threats to mainland freshwater wetlands

Wetlands are one of the world's most threatened ecosystems, as humans have historically exploited them for freshwater, sewage and solid waste disposal, aquaculture production, fertile arable land and recreation/tourism (61, 62), or claimed them for urban and heavy industry infrastructure (63). Over half the world's freshwater wetlands have been lost (62) and only 11% of the remaining wetlands have some level of conservation protection (3). Wetlands of the major catchments draining to Moreton Bay are embedded in a matrix of protected areas; patterns of land-use; urban, civic and industrial developments; transport corridors; and open spaces (1, 21) that also have different levels of protection under legislation. The human footprint is increasing with Brisbane's population (>2.4 million in 2018) expected to rise by 820,000 residents over the next two decades (64). Rivers and palustrine wetlands have been degraded (and reduced in extent) through widespread catchment disturbance, deforestation including

riparian loss and fragmentation, catchment and bank erosion, water pollution, river corridor engineering, dams and water diversions, wetland drainage, groundwater depletion, aquatic habitat loss and fragmentation, establishment of alien species, and fishing (20, 34, 49, 65–67). Climate change is likely to exacerbate these threats and intensify impacts on wetland ecosystems (68).

Threats to mainland coastal wallum and Bay island wetlands

Wetlands of the mainland coastal wallum and Bay islands are highly susceptible to many threats — tourism and recreation, urban developments, sand and mineral mining, forestry and land clearing, groundwater extraction, water pollution, fire, weeds, grazing, and alien animals and plants (23, 69). Developments along the coastal mainland have resulted in extensive loss of paperbark (*Melaleuca*) swamp forests. Local changes to hydrology and water quality impacts associated with groundwater extraction may threaten wetland vegetation, rare invertebrates, endangered freshwater fishes, and acid frogs (51, 52, 57). Tourism and water-based recreation can add nutrients to freshwater wetlands of low nutrient status and cause algal blooms and disrupt aquatic food chains (69). The alien mosquitofish preys on fish eggs and may compete with two habitat specialists, the endangered Oxleyan pygmy perch (*N. oxleyana*) and ornate rainbowfish (*R. ornatus*), for food and habitat (48). Sand mining can adversely affect wetlands but is expected to cease on North Stradbroke Island in 2019.

Freshwater wetland management in the Moreton Bay Region

Wetlands are protected and managed under Queensland and federal legislation, international obligations and a range of laws, policies and programs administered by government agencies. Ramsar-listed wetlands are among the matters of national environmental significance protected under the *Environment Protection and Biodiversity Conservation Act 1999 (Cwlth)*. The quality of Queensland waters is protected under the Environmental Protection (Water) Policy 2009. Environmental values and water quality objectives have been determined for all areas of the Moreton Bay region.

The conservation values of Queensland’s freshwater wetlands have been formalised through Aquatic Conservation Assessments applying the Aquatic Biodiversity

Assessment Mapping Method 'AquaBAMM' (70) to palustrine, lacustrine and riverine wetlands of 16 SEQ catchments (25). Overall, approximately 53% of river reaches scored 'Very high' or 'High' for the overall AquaScore. These reaches tended to be in the higher elevation areas of catchments and on Bay islands where wetlands are relatively less disturbed than in many lowland areas of the region.

The Environmental Health Monitoring Program regularly monitors the ecological health of streams and rivers in SEQ based on 15 indicators of water quality, biodiversity (invertebrates, fish) and ecological functions (1, 71). However, the ecological health of palustrine wetlands is not assessed under this program. The formation of Healthy Waterways and Catchments in 2016 combines two not-for-profit organisations — Healthy Waterways and SEQ Catchments. These entities and the Resilient Rivers Initiative herald a new era of coordination and partnership in land and waterway management in the region.

Water management is a high priority in the Moreton Bay Region with its history of prolonged drought, devastating floods and a population demanding high quality water. Queensland's catchment Water Plans are legislated under the *Water Act 2000* with the aim of ensuring that the health, biodiversity and productivity of the environment is maintained or enhanced for the benefit of future generations. Water Plans have been developed for the Moreton Basin, Logan and Gold Coast areas using novel frameworks for assessing catchment-scale risk (72). The Water Plan (Moreton) 2007 established important ecological outcomes relevant to wetlands, for example, to provide freshwater flows necessary to maintain the long-term pattern of inflows to, and ecological functions of, wetlands and minimise changes to brackish water habitats (73).

Emerging issues — a synthesis for moving forward

The Queensland Government shares responsibility for managing wetlands with the Commonwealth and local governments, landholders and the wider community. Protecting and restoring the ecological health of SEQ wetlands is the focus of several initiatives, including the Queensland Wetlands Program, the Healthy Waterways and Catchments and Resilient Rivers Alliance, and Queensland's water management plans. Nevertheless, freshwater wetlands have been lost and the extent of artificial and highly modified wetlands has increased between 2001 and 2013. For example, the

Logan–Albert catchment (Fig. 1) lost 1.4 km^2 of riverine wetland and gained 14.5k m^2 of artificial and highly modified wetland during this period (10). On the Bay islands, palustrine wetlands decreased in extent by 0.2 km^2, while artificial and highly modified wetlands increased by 1.8 km^2. The biodiversity and ecosystem service losses and risks associated with increasing artificial and highly modified wetland extent are well known in impounded and regulated waterways (20, 66, 67, 72). However, until recently, freshwater palustrine and floodplain wetlands have received far less attention. Assessing progress with wetland management in Queensland, Choy (74) called for greater investment in fundamental science to inform management and conservation.

Climate change projections for the Moreton Bay Region predict warming in all seasons, greater intensity of extreme rainfall events, harsher bush fires and storms and rising sea levels (75). Freshwater ecosystems are vulnerable to changes in water temperature and altered hydrology and are likely to be impacted by altered environmental regimes associated with shifting climates (31, 68). Regime changes are likely to affect wetland character, values and ecosystem services, and may lead to further wetland loss or reduced resilience to many other stressors. Rising sea levels could change the extent and character of low-lying wetlands with implications for the species they contain and the cultural values they provide (75).

Conclusion

The ongoing challenge for the Moreton Bay Region and Bay islands is to sustain and enhance wetland extent, diversity and ecosystem services in the context of expanding human populations; growing demands for water, infrastructure and food; and the likely threats imposed by climate change in a region that already suffers from variable weather patterns, drought and flooding. Climatic shifts interacting with common stressors are likely to profoundly influence the future of the region’s freshwater wetlands. Ecological surprises, losses and gains, and societal adjustments can be expected in the uncharted landscapes and wetlands of changing climate futures. Important recommendations for the future of freshwater wetlands in the Moreton Bay region and Bay islands include:

1. Sustain and enhance wetland biodiversity, functions and ecosystem services in the context of expanding human populations, growing demands for water and infrastructure, and likely threats associated with climate change;
2. Increase support for research, monitoring, communication and management of freshwater

wetlands on the mainland and Bay islands;

3. Maintain a well-coordinated holistic approach to integrated land, water and wetland management based on sound multidisciplinary science, societal values and expectations, and partnership arrangements (such as the Healthy Waterways and Catchments and Resilient Rivers Alliance).