Table of Contents

Preface ……….…………………………..…………………………………………………i
Acknowledgements ……………………….……………………………………………….iii

Chapter 1 - Indigenous Knowledge and Culture

Quandamooka Country: The role of science and knowledge in Traditional Owner-led land and sea management………………………………………………………………...3-28
Mibu Fischer, Darren Burns, Joel Bolzenius, Cameron Costello, Darryl Low Choy

A custodial ethic, Indigenous values towards water in Moreton Bay and Catchments………………………………………………………………………….…29-44
Breanna Pinner, Helen Ross, Natalie Jones, Sally Babidge, Sylvie Shaw, Katherine Witt, David Rissik

Chapter 2 - Communities and Values

Values towards Moreton Bay and catchments..……………………………………….47-60
Helen Ross, Natalie Jones, Katherine Witt, Breanna Pinner, Sylvie Shaw, David Rissik, James Udy

Community knowledge about water and engagement in waterway protection in South East Queensland ……………………………...…………………………….. 61-72
Angela J Dean, Kelly S Fielding, Fiona Newton, Helen Ross

Stewardship as a driver for environmental improvement in Moreton Bay …………….. 73-88
Rachael Nasplezes, Joel Bolzenius, Apanie Wood, Ryan Davis, Anne Cleary, Paul Maxwell, David Rissik, Helen Ross

Managing the public health paradox: Benefits and risks associated with waterway use……………………………………………………………………….... 89-104
Anne Roiko, Sonya Kozak, Anne Cleary, Zoe Murray

Education in *Quandamooka* – A long and evolving tradition.……………………….. 105-118
Emily Casey, Timothy Roe, Ian Tibbetts, Dianne Aylward

Chapter 3 - History and Change in Moreton Bay

An environmental history of Moreton Bay hinterlands.…………………………….….. 121-136
Justine Kemp, Jon Olley, Samantha Capon

Historical changes of the lower Brisbane River ………...……………….…….….137-152
Jonathan Richards

Holocene history of Moreton Bay reef habitats……………………….…….….. 153-162
Matthew J. Lybolt, John M. Pandolfi

Trace metal contamination and distribution in sediments of Moreton Bay: An historical review …………………………………………………………………..……..….. 163-178
Guia Morelli, Massimo Gasparon

Chapter 4 – Water Quality, Land-Use and Land-Cover

Moreton Bay and catchment urban expansion and vegetation change……………… 181-186
Mitch Lyons, Stuart Phinn, Chris Roelfsema

Water quality in Moreton Bay and its major estuaries: Change over two decades (2000-2018) ………………………………………………………………………. 187-210
Emily Saeck, James Udy, Paul Maxwell, Alistair Grinham, David Moffatt, Sivakumar Senthikumar, Danielle Udy, Tony Weber

Wetland and benthic cover changes in Moreton Bay ………………………………. 211-226
Eva M. Kovacs, Hannah L. Tibbetts, Simon Baltais, Mitch Lyons, Jennifer Loder, Chris Roelfsema

The impact of marine pollutants and debris in Moreton Bay ………………………. 227-244
Kathy A. Townsend, Christine Baduel, Vicki Hall, Jennifer Loder, Veronica Matthews, Jochen Mueller, Rachael Nasplezes, Qamar Schuyler, Heidi Taylor, Jason van de Merwe, C. Aleander Villa, Liesbeth Weijs

Projected changes to population, climate, sea-level and ecosystems ……………… 245-256
Megan I. Saunders, Elin Charles Edwards, Rebecca Runting, Jozef Syktus, Javier Leon

Chapter 5 - Habitats, Biodiversity and Ecosystem Function

Primary producers in Moreton Bay: Phytoplankton, benthic microalgae and filamentous cyanobacteria ……………………………………………………….. 259-278
Emily Saeck, Alistair Grinham, Jack Coates-Marnane, Tony McAlister, Michele Burford

The seagrasses of Moreton Bay *Quandamooka*: Diversity, ecology and resilience… 279-298
Paul Maxwell, Rod M. Connolly, Chris Roelfsema, Dana Burfeind, James Udy, Kate O'Brien, Megan I. Saunders, Richard Barnes, Andrew D. Olds, Chris Henderson, Ben L. Gilby

Mangroves and saltmarshes of Moreton Bay …………………………………….. 299-318
Catherine E. Lovelock, Arnon Accad, Ralph M. Dowling, Norm Duke, Shing Yip Lee, Mike Ronan

Freshwater wetlands of Moreton Bay, *Quandamooka* and catchments**:** Biodiversity, ecology, threats and management …………………………………….. 319-334
Angela H. Arthington, Stephen J. Mackay, Mike Ronan, Cassandra S. James, Mark J. Kennard

Zooplankton of Moreton Bay ………………………………………………….. 335-360
Sarah Pausina, Jack Greenwood, Kylie Pitt, David Rissik, Wayne Rochester,

Jennifer Skerratt, Julian Uribe-Palomino, Anthony J. Richardson

Coral and micro-benthic assemblages from reef habitats in Moreton Bay 361-378
John M. Pandolfi, Matt Lybolt, Brigitte Sommer, Roshni Narayan, Paola G. Rachello-Dolmen

Fishes of Moreton Bay: Ecology, human impacts, and conservation 379-400
Andrew D. Olds, Ben L. Gilby, Rod M. Connolly, Ian R. Tibbetts, Christopher J. Henderson, Tim Stevens, Sarah K. Thackwray, Thomas A. Schlacher

Marine turtles in Moreton Bay 401-414
Colin J. Limpus, Owen I. Coffee

Ecology of the marine mammals of Moreton Bay 415-430
Janet M. Lanyon, Michael J. Noad, Justin Meager

Migratory shorebirds of Moreton Bay 431-444
Richard Fuller, David A. Milton, Peter C. Rothlisberg, Robert S. Clemens, Jon Coleman, Kristy Murray, Kiran L. Dhanjal-Adams, David Edwards, Paul G. Finn, Greg Skilleter, Madeleine Stigner, Bradley K. Woodworth

Chapter 6 - Citizen Science

How does citizen science contribute to sustaining the Bay? A discussion of approaches and applications 447-458
Jennifer Loder, Chris Roelfsema, Carley Kilpatrick, Victoria Martin

Building an understanding of Moreton Bay Marine Park's reefs through citizen science 459-474
Chris Roelfsema, Jennifer Loder, Kyra Hay, Diana Kleine, Monique Grol, Eva Kovacs

Citizen science photographic identification of marine megafauna populations in the Moreton Bay Marine Park...475-490
Christine L. Dudgeon, Carley Kilpatrick, Asia Armstrong, Amelia Armstrong, Mike B. Bennett, Deborah Bowden, Anthony J. Richardson, Kathy A. Townsend, Elizabeth Hawkins

Chapter 7 – Industry and Planning

Tourism in the Moreton Bay Region 493-504
Lisa Ruhanen, Mark Orams, Michelle Whitford

Aquaculture in Moreton Bay 505-520
Elizabeth West, Carol Conacher, John Dexter, Peter Lee, Michael Heidenreich, Brian Paterson

Fishers and fisheries of Moreton Bay 521-536
Ruth Thurstan, Kerrie Fraser, David Brewer, Sarah Buckley, Zena Dinesen, Tim Skewes, Tony Courtney, Barry Pollock

Marine transport infrastructure development in Moreton Bay: Dredging, monitoring and future directions 537-546
Adam Cohen, Daniel Spooner, Samuel M. Williams

Charting a course by the stars; a review of progress towards a comprehensive management plan for Moreton Bay 20 years on 547-560
Andrew Davidson, Darryl Low Choy

Chapter 8 – Moreton Bay Marine Park

Managing for the multiple uses and values of Moreton Bay and its catchments...... 563-578
Helen Ross, David Rissik, Natalie Jones, Katherine Witt, Breanna Pinner, Sylvie Shaw

Performance of marine reserves for fish and associated ecological functions in the Moreton Bay Marine Park 579-592
Ben L. Gilby, Andrew D. Olds, David Rissik, Christopher J. Henderson, Rod M. Connolly, Tim Stevens, Thomas A. Schlacher

Changes in fish and crab abundance in response to the Moreton Bay Marine Park rezoning..593-614
Mick Haywood, Richard Pillans, Russ Babcock, Emma Lawrence, Ross Darnell, Charis Burridge, Darren Dennis, Anthea Donovan, Sue Cheers, Robert Pendrey, Quinton Dell

Non-extractive human use and vessel characteristics in Moreton Bay Marine Park following rezoning 615-638
Rob Kenyon, Russ Babcock, Quinton Dell, Emma Lawrence, Christian Moeseneder, Mark Tonks

Appendices

Maps of Moreton Bay and catchment

A. Southern Moreton Bay and Islands 641

B. Northern Moreton Bay, Moreton and Bribie Islands 643

C. Brisbane River catchment 645

D. Greater Moreton Bay catchment rivers 647

E. Electronic appendix 639

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

Angela H. Arthington[1], Steve J. Mackay[1], Mike Ronan[2], Cassandra S. James[3], Mark J. Kennard[1]

Author affiliations: 1. Australian Rivers Institute, Griffith University, Nathan Qld, 4111, Australia; 2. Wetland Team, Department of Environment and Science, Conservation and Sustainability Services, Queensland Government, Brisbane Qld, 4000, Australia; 3. Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER), College of Science and Engineering, James Cook University, Douglas Qld, 4814, Australia.

Corresponding author: a.arthington@griffith.edu.au

ORCID
Angela Arthington: https://orcid.org/0000-0001-5967-7954
Steve Mackay: https://orcid.org/0000-0002-2956-9626
Mike Ronan: https://orcid.org/0000-0002-0199-2174
Cassandra James: https://orcid.org/0000-0003-4886-787X
Mark Kennard: https://orcid.org/0000-0003-4383-4999

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 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).

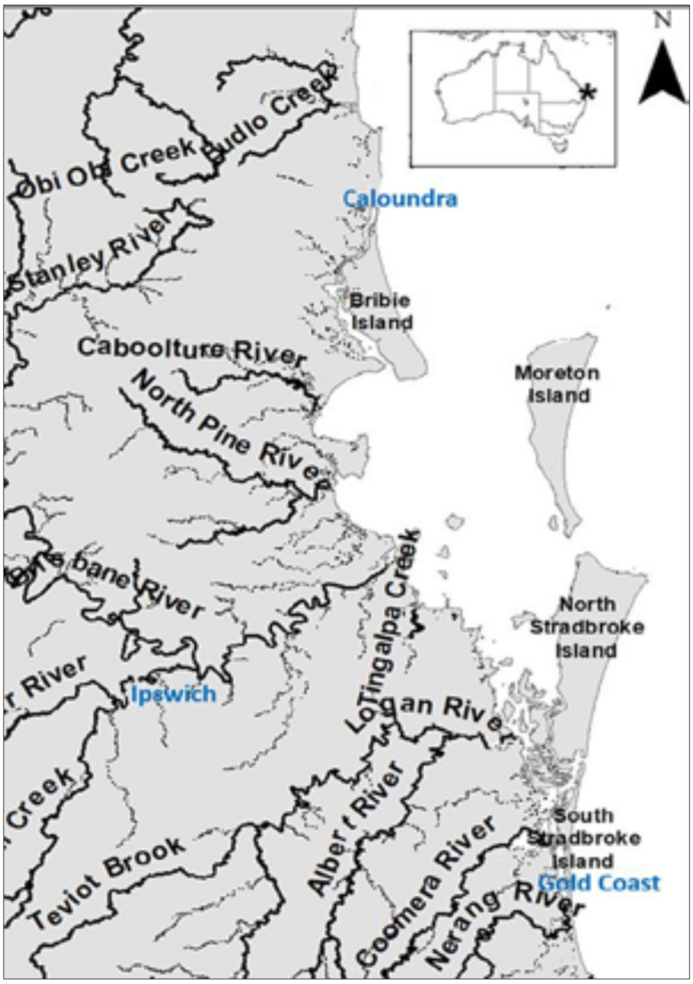

Figure 1. Moreton Bay and its catchment area. Our study boundaries were Caloundra in the north, Ipswich in the west and the Gold Coast to the south.

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	1,303.9	36.3	34.9	0.2	20.5	18.0	109.8
Logan–Albert	4,149.8	26.9	21.8	5.2	34.0	45.9	133.9
Brisbane	13,541.7	206.6	8.0	4.7	36.2	240.1	495.9
North-South Pine	1,484.4	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	132.0

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
Coomera–Nerang	1,303.9	**29**	**4**	**8**
Logan–Albert	4,149.8	**33**	**3**	**7**
Brisbane	13,541.7	**37**	**6**	**10**
North-South Pine	1,484.4	**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 past 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) (b)

Figure 2. (a) A palustrine wetland, Eighteen Mile Swamp, North Stradbroke Island; (b) A watertable window, Blue Lake, North Stradbroke Island. (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 combined 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:

(i) 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;

(ii) Increase support for research, monitoring, communication and management of freshwater wetlands on the mainland and Bay islands;

(iii) 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).

References

1. Bunn SE, Abal EG, Smith MJ, Choy SC, Fellows CS, Harch BD., Kennard MJ, Sheldon F. 2010. Integration of science and monitoring of river ecosystem health to guide investments in catchment protection and rehabilitation. Freshwater Biology 55(1):223-240
2. Greenway M. 2016. Stormwater wetlands for the enhancement of environmental ecosystem services: Case studies for two retrofit wetlands in Brisbane, Australia. Journal of Cleaner Production 163(1):S91-S100
3. Reis V, Hermoso V, Hamilton SK, Ward D, Fluet-Chouinard E, Lehner B, Linke S. 2017. A global assessment of inland wetland conservation status. Bioscience 67 (6):523–533
4. Ramsar Convention Secretariat 1971. A Guide to the Convention on Wetlands. 1971, 4th Edition 2006. Ramsar, Iran
5. Environmental Protection Agency1999a. The Moreton Bay Information Sheet on Ramsar Wetlands (RIS). Accessed 2018.5.31, Available from: http://www.environment.gov.au/water/topics/wetlands/database/pubs/41-ris.pdf
6. Queensland Parks and Wildlife Service 2012. Queensland Parks and Wildlife Service Community Executive Summary. Queensland Parks and Wildlife Service, Department of National Parks, Recreation, Sport and Racing, Brisbane. 20p.
7. Environment Protection Agency 1999b. Queensland Government Strategy for Conservation and Management of Queensland Wetlands. Accessed 2018.5.31, Available from: https://wetlandinfo.ehp.qld.gov.au/wetlands/what-are-wetlands/definitions-classification/classification-systems-background/typology.html
8. Department of Environment and Resource Management 2011. Queensland Wetland Definition and Delineation Guideline, Queensland Government, Brisbane 44p.

9. Department of Environment and Science. Queensland wetland classification method, WetlandInfo. Accessed 2018.5.31. Available from: https://wetlandinfo.des.qld.gov.au/wetlands/what-are-wetlands/definitions-classification/classification-systems-background/typology.html
10. Department of Environment and Science. Moreton Bay Ramsar internationally important wetland — facts and maps. WetlandInfo. (last updated 2013.8.21, date accessed 2018.5.31. Available from: https://wetlandinfo.des.qld.gov.au/wetlands/facts-maps/ramsar-wetland-moreton-bay/
11. Arthington AH, Griffiths M, Hailstone THS. 1990. Freshwater flora and invertebrate fauna of the Brisbane River; pp. 103-130. In: P Davie, E Stock, D Low Choy (Eds) The Brisbane River: a source-book for the future. Australian Littoral Society, Brisbane 427p.
12. Davie P, Stock E, Low Choy D (Eds) 1990. The Brisbane River: a source-book for the future. Brisbane: Australian Littoral Society, Brisbane 427p.
13. McKay R, Johnson I. 1990. Freshwater and estuarine fishes of the Brisbane River. pp. 153-166. In: P Davie, E Stock, D Low Choy (Eds) The Brisbane River: a source-book for the future. Australian Littoral Society, Brisbane 427p.
14. Kerby BM, Bunn SE, Hughes JM. 1995. Factors influencing invertebrate drift in rainforest streams in south-east Queensland. Marine and Freshwater Research 46:1101-1108
15. Hughes JM, Bunn SE, Cleary C, Hurwood DA. 1998. Dispersal and recruitment of *Tasiagma ciliata* (Trichoptera: Tasimiidae) in rainforest streams, south-east Queensland. Freshwater Biology 39:117-127
16. Mosisch TD, Bunn SE, Davies PM. 2001. The relative importance of riparian shading and nutrients on algal production in subtropical streams. Freshwater Biology 46:1269-78
17. Mackay S.J, Arthington AH, Kennard MJ, Pusey BJ. 2003. Spatial variation in the distribution and abundance of submersed aquatic macrophytes in an Australian subtropical river. Aquatic Botany 77:169-186
18. Kennard MJ, Pusey BJ, Arthington AH, Harch BD, Mackay S. 2006. Development and application of a predictive model of freshwater fish assemblage composition to evaluate river health in eastern Australia. Hydrobiologia 572:33-57
19. Stewart-Koster B, Kennard MJ, Harch BD, Sheldon F, Arthington AH., Pusey BJ. 2007. Partitioning the variation in stream fish assemblages within a spatio-temporal hierarchy. Marine and Freshwater Research 58:675–686
20. James C, Mackay SJ, Arthington AH, Capon SJ. 2016. Does flow structure riparian vegetation in subtropical south-east Queensland? Ecology and Evolution 6 (16):5950-5963
21. Tibbetts IR, Hall NJ, Dennison WC (Eds).1998. Moreton Bay and Catchment. School of Marine Science, The University of Queensland, Brisbane 645p.
22. Pusey BJ, Kennard MJ, Arthington AH. 2004. Freshwater fishes of north-eastern Australia. CSIRO Publishing, Collingwood, Victoria 684p.
23. Arthington AH, Page T, Rose CW, Sathyamurthy R Eds. 2011. A Place of Sandhills: Ecology, Hydrogeomorphology and Management of Queensland's Dune Islands. Proceedings of the Royal Society of Queensland 117: 1
24. Department of Environment and Science. Plants, animals, soils, water and more. WetlandInfo 2013. Accessed 2018.5.31. Available from: https://wetlandinfo.des.qld.gov.au/wetlands/ecology/components/
25. Department of Environment and Heritage Protection 2015. An Aquatic Conservation Assessment for the riverine and non-riverine wetlands of Southeast Queensland catchments. Accessed 2018.5.31. Available from: http://wetlandinfo.ehp.qld.gov.au/resources/static/pdf/assessment-monitoring/aquabamm/seq/aca_seq_v1_1_full_20151104.pdf
26. Neldner VJ, Niehus RE, Wilson BA, McDonald WJF, Ford AJ, Accad A. 2017. The Vegetation of Queensland. Descriptions of Broad Vegetation Groups. Version 3.0. Queensland Herbarium, Department of Science, Information Technology and Innovation, Brisbane 251p.
27. Hubble TCT, Docker BB, Rutherfurd ID. 2010. The role of riparian trees in maintaining riverbank stability: A review of Australian experience and practice. Ecological Engineering 36:292–304
28. Naiman RJ, Decamps H, McClain ME, Likens GE. 2005. Riparia - ecology, conservation, and management of streamside communities. Academic Press, London 448p.
29. Dosskey MG, Vidon P, Gurwick NP, Allan CJ, Duval TP, Lowrance R. 2010. The role of riparian vegetation in protecting and improving chemical water quality in streams. Journal of the

American Water Resources Association 462:261-277.
30. Hunter H, Fellows C, Rassam D, DeHayr R, Pagendam D, Conway C, Bloesch P, Beard N. 2006. Managing riparian lands to improve water quality: optimising nitrate removal via denitrification. Cooperative Research Centre for Coastal, Estuarie and Waterway Management, Brisbane 23p.
31. Bunn SE, Mosisch T, Davies PM. 2002. Temperature and light. In: S. Lovett, P Price (Eds) Riparian Land Management Technical Guidelines, Volume One. Part A: Principles of Sound Management. Land and Water Resources Research and Development Corporation (LWRRDC), Canberra 198p.
32. Olden JD, Naiman RJ. 2010. Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity. Freshwater Biology 55:86–107
33. Brooks A, Andrew P, Howell T, Abbe TB, Arthington AH. 2006. Confronting hysteresis: wood based river rehabilitation in highly altered riverine landscapes of southeastern Australia. Geomorphology 79:399-422
34. Laceby, JP, Saxton NE, Smolders K, Kemp J, Faggotter SJ, Ellison T, Ward D, Stewart M, Burford MA. 2017. The effect of riparian restoration on channel complexity and soil nutrients. Marine and Freshwater Research 68:2041–2051
35. Gurnell A. 2014. Plants as river system engineers. Earth Surface Processes and Landforms 39:4–25
36. Pusey BJ, Arthington AH. 2003. Importance of the riparian zone to the conservation and management of freshwater fish: a review. Marine and Freshwater Research 54:1-16
37. Howell TD, Arthington AH, Pusey BP, Brooks AP, Creese B, Chaseling J. 2012. Responses of fish to experimental introduction of Structural Woody Habitat in riffles and pools of the Hunter River, New South Wales, Australia. Restoration Ecology 20(1):43-55
38. Bunn SE. 1998. Riparian influences on ecosystem function in the Brisbane River. pp. 131–142. In: IR Tibbetts, NJ Hall, WC Dennison (Eds) Moreton Bay and catchment. School of Marine Science, The University of Queensland, Brisbane 645p.
39. Hadwen W, Fellows C, Westhorpe P, Douglas N, Rees GM, Mitrovic S, Taylor BS, Baldwin D, Silvester E, Croome R. 2010. Longitudinal trends in river functioning: Patterns of nutrient and carbon processing in three Australian rivers. River Research and Applications 26:1129-1152
40. Maisonneuve C, Rioux S. 2001. Importance of riparian habitats for small mammal and herpetofaunal communities in agricultural landscapes of southern Quebec. Agriculture, Ecosystems and Environment 83:165–175
41. Kennard MJ, Olden JD, Arthington AH, Pusey BJ, Poff NL. 2007. Multiscale effects of flow regime and habitat and their interaction on fish assemblage structure in eastern Australia. Canadian Journal of Fisheries and Aquatic Sciences.64:1346-1359
42. Arthington AH, Mackay SJ, James CS, Rolls RJ, Sternberg D, Barnes A, Capon SJ. 2012. Ecological-limits-of-hydrologic-alteration: a test of the ELOHA framework in south-east Queensland. Waterlines 75, National Water Commission, Canberra 331pp.
43. Perna CN, Cappo M, Pusey BJ, Burrows DW, Pearson RG. 2012. Removal of aquatic weeds greatly enhances fish community richness and diversity: an example from the Burdekin River Floodplain, tropical Australia. River Research and Applications 28:1093-1104
44. Cooke SJ, Allison EH, Beard TD, Arlinghaus R, Arthington AH, Bartley DM, Cowx IG, Fuentevilla C, Leonard NJ, Lorenzen K, Lynch AJ, Nguyen VM, Youn SJ, Taylor WW, Welcomme RL. 2016. On the sustainability of inland fisheries: Finding a future for the forgotten. Ambio 45(7):753-764
45. Helfman G, Collette BB, Facey DE and Bowen BW. 2009. The diversity of fishes: biology, evolution, and ecology. 2nd Edition. Wiley-Blackwell, Chichester 720p.
46. Winemiller KO, Humphries P, Pusey BJ. 2016. Protecting apex predators. pp. 361–398. In: GP Closs, M. Krkose, JD Olden (Eds) Conservation of Freshwater Fishes, Cambridge, Cambridge University Press 581p.
47. García-Díaz P, Kerezsy A, Unmack PJ, Lintermans M, Beatty SJ, Butler GL, Freeman R, Hammer MP, Hardie S, Kennard MJ, Morgan DL, Pusey BJ, Raadik TA, Thiem JD, Whiterod N, Cassey P, Duncan RP. 2018. Transport pathways shape the biogeography of alien freshwater fishes. Diversity and Distributions 24(10). 10.1111/ddi.12777
48. Arthington AH, Marshall CJ. 1999. Diet of the exotic mosquitofish, *Gambusia holbrooki*, in an Australian lake and potential for competition with indigenous fish species. Asian Fisheries

Science 12(1):1-8
49. Kennard MJ, Arthington AH, Pusey BJ, Harch BD. 2005. Are alien fish a reliable indicator of river health? Freshwater Biology 50:174-193
50. Bensink AHA, Burton H. 1975. North Stradbroke Island - a place for freshwater invertebrates. Proceedings of the Royal Society of Queensland 86:29-45
51. Marshall JC, Negus P, Steward AL, McGregor G. 2011. Distributions of the freshwater fish and aquatic macroinvertebrates of North Stradbroke Island are differentially influenced by landscape history, marine connectivity and habitat preference. Proceedings of the Royal Society of Queensland 117:239-260.
52. Specht A, Stubbs BJ. 2011. Long-term monitoring of a coastal sandy freshwater wetland: Eighteen Mile Swamp, North Stradbroke Island, Queensland. Proceedings of the Royal Society of Queensland 117:201-223
53. Richardson E, Irvine E, Froend R, Book P, Barber S, Bonneville B. 2011. Australian groundwater dependent ecosystems toolbox part 1: assessment framework. National Water Commission, Canberra
54. Barr C, Tibby J, Marshall J, McGregor GB, Moss PT, Halverson GPJ. 2013. Combining monitoring, models and palaeolimnology to assess ecosystem response to environmental change at monthly to millennial timescales: the stability of Blue Lake, North Stradbroke Island, Australia. Freshwater Biology 58:1614–1630
55. Department of Environment and Heritage Protection 2015. Groundwater dependent ecosystems in South East Queensland. Queensland Wetlands Program, Queensland Government, Brisbane. 471p.
56. Arthington AH, Watson JAL. 1982. Dragonflies (Odonata) of coastal sand dune fresh waters of south-eastern Queensland and north-eastern New South Wales. Australian Journal of Marine and Freshwater Research 33:77-88
57. Knight JT, Arthington AH. 2008. Distribution and habitat associations of the endangered Oxleyan pygmy perch, *Nannoperca oxleyana* Whitley, in eastern Australia. Aquatic Conservation: Marine Freshwater Ecosystems 18:1240–1254.
58. Hughes J, Ponniah M, Hurwood D, Chenoweth S, Arthington A. 1999. Strong genetic structuring in a habitat specialist, the Oxleyan Pygmy Perch *Nannoperca oxleyana*. Heredity 83:5-14
59. Page TJ, Sharma S, Hughes JM. 2004. Deep phylogenetic structure has conservation implications for ornate rainbowfish (Melanotaeniidae: *Rhadinocentrus ornatus*) in Queensland, eastern Australia. Marine and Freshwater Research 55:165-172
60. Anstis M. 2018. Tadpoles and frogs of Australia. 2nd Edition. New Holland Publishers, Australia 829p.
61. Dudgeon D, Arthington AH, Gessner MO, Kawabata ZI, Knowler DJ, Leveque C, Naiman RJ, Prieur-Richard A-H, Soto D, Stiassny MLJ, Sullivan CA. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews 81:163-182
62. Davidson NC. 2014. How much wetland has the world lost? Long-term and recent trends in global wetland area. Marine and Freshwater Research 65:934-941.
63. Waltham N, Sheaves M. 2015. Expanding coastal urban and industrial seascape in the Great Barrier Reef World Heritage Area: Critical need for coordinated planning and policy. Marine Policy 57:78-84
64. Brisbane City Council 2016. Brisbane Long Term Infrastructure Plan 2012-2031. Accessed 2018.5.31. Available from: https://www.brisbane.qld.gov.au/sites/default/files/Brisbane_Long_Term_Infrastructure_Plan-full.pdf
65. Loneragan N, Bunn SE. 1998. River flows and estuarine ecosystems: implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland. Australian Journal of Ecology 24:431-440
66. Mackay SJ, James C, Arthington AH. 2014. Classification and comparison of natural and altered flow regimes to support an Australian trial of the Ecological Limits of Hydrologic Alteration (ELOHA) framework. Ecohydrology 7:1485-1507
67. Rolls RJ, Arthington AH. 2014. How do low magnitudes of hydrologic alteration impact riverine fish populations and assemblage characteristics? Ecological Indicators 39:179-188

68. Mantyka-Pringle CS, Martin TG, Moffatt DB, Linke S, Rhodes RJ. 2014. Understanding and predicting the combined effects of climate change and land-use change on freshwater macroinvertebrates and fish. Journal of Applied Ecology 51(3):572-581
69. Hadwen WL, Arthington AH. 2011. Visitor impacts and climatic variability will shape the future ecology of Fraser Island's perched dune lakes. Proceedings of the Royal Society of Queensland 117:485-493
70. Clayton PD, Fielder DF, Howell S, Hill CJ. 2006. Aquatic biodiversity assessment and mapping method (AquaBAMM): a conservation values assessment tool for wetlands with trial application in the Burnett River catchment. Environmental Protection Agency, Brisbane
71. Department of Environment and Science. EHMP (Ecosystem Health Monitoring Program). WetlandInfo 2006, updated 2013. Accessed 2018.5.31. Available from: https://wetlandinfo.des.qld.gov.au/wetlands/resources/tools/assessment-search-tool/12/
72. McGregor GB, Marshall JC, Lobegeiger JS, Holloway D, Menke N, Coysh J. 2018. A risk-based ecohydrological approach to assessing environmental flow regimes. Environmental Management 61:358-374
73. Queensland Government 2007. Water Plan (Moreton) 2007. Accessed 2018.5.31. Available from: https://www.legislation.qld.gov.au/view/pdf/inforce/current/sl-2007-0031
74. Choy SC. 2015. Twenty two years of inland aquatic science (1993-2015) and its applications in Queensland: Achievements, learnings and way forward. Proceedings of the Royal Society of Queensland 120:23-29.75
75. Saunders ML, Runting RK, Charles-Edwards E, Syktus J, Leon J. 2019. Moreton Bay and catchment: Projected changes to population, climate, sea level and ecosystems. This volume