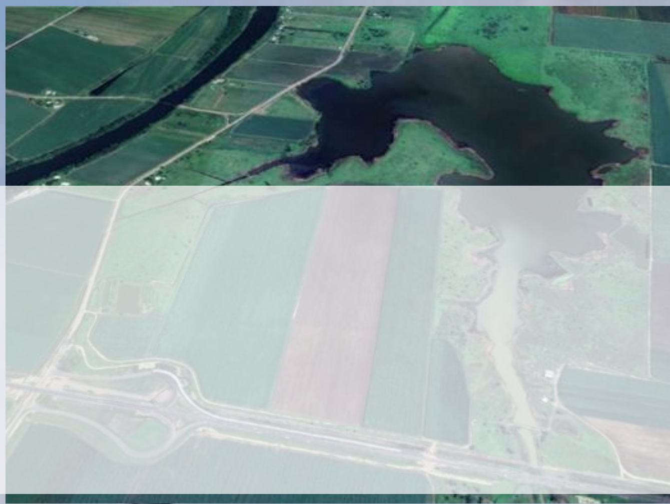
environmental consultancy
'local to global – catchment to coastal'



Horseshoe Lagoon
System Management Plan
Version 1

Prepared by Jim Tait
May 2022

> Contents

> List of abbreviations

BBIFMAC	Burdekin Bowen Integrated Floodplain Management Advisory Committee
BHWSS	Burdekin Haughton Water Supply Scheme
BMP	Best Management Practices
BOD	Biological Oxygen Demand
BSC	Burdekin Shire Council
CAP	Conservation Action Planning
DIWA	Directory of Important Wetlands in Australia
EVNT	Endangered, Vulnerable and Near Threatened
DO	Dissolved Oxygen
ICM	Integrated Catchment Management
JCU	James Cook University
NRM	Natural Resource Management
RMA	Riparian Management Agreement
SMP	System Management Plan
TSS	Total Suspended Solids

> Executive summary

Econcern was contracted by NQ Dry Tropics in late 2021 to develop System Management Plans (SMPs) for five high value wetland systems located on the Lower Burdekin River floodplain approximately 50km south of Townsville, North Queensland. The development of these SMPs forms part of the Restoring the Bowling Green Bay Ramsar Wetlands project, funded by the Australian Government's National Landcare Program. These SMPs aim to improve environmental management outcomes in floodplain tributary and distributary creek systems that comprise the Cape Bowling Green Bay Ramsar wetland catchment. This current round of SMP development follows the initial SMP prepared by Econcern for the Lower Burdekin floodplain's Sheep Station Creek catchment in 2020 (Econcern 2021). This catchment was the first focus because it had the longest history of environmental management investment of any Lower Burdekin wetland system. This history has provided much learning and delivered a range of innovative management outcomes. Many of the management issues identified in the Sheep Station SMP are generic to the broader Lower Burdekin floodplain and, in the interest of document brevity, this initial SMP is referenced substantially in subsequent SMPs, including this document. However, as detailed in this SMP for Horseshoe Lagoon system, there are a range of distinct environmental management challenges associated with the unique landscape, hydrological setting, and development history of any individual wetland system. These factors need to be recognised in any prudent extension of wetland management planning strategies from one system to adjoining areas.

The Horseshoe Lagoon system occurs within a distributary channel of the Haughton River, which connects via overbank flows in large flood events. It comprises five reach settings including drained agricultural floodplain, large (~96ha) freshwater lake, floodplain drainage depression, creek channel, and coastal plain drainage depression/wetland complex. It has a narrow contributing catchment area of 6500ha running from south to north, dominated in its southern two-thirds by irrigated agricultural land, draining north to a grazing-dominated coastal plain before discharging into an estuarine national park. The hydrology of the modern system is highly modified by near perennial irrigation tailwater inflows from the Burdekin Haughton Water Supply Scheme (BHWSS) in its southern catchment. The system sits within the Horseshoe Lagoon Conservation Park and has biodiversity values of national and state significance, including listings as nationally-important wetlands, state significant wetlands, and 'of concern' regional ecosystems. It also has habitat and site records for endangered and vulnerable wildlife, and high bird and fish habitat values.

The main environmental management issues of the Horseshoe Lagoon system are associated with its hydrology being altered by a seasonal inflows that contribute to a range of concerns. These include loss of seasonal character, degraded water quality, cyclical proliferation of floating aquatic weed infestations, aquatic grass weeds dominating bank areas, impacts of current weed control methods, fish passage barriers associated with poor reach conditions (weed infestation, low dissolved oxygen), woody weed infestation of remnant riparian vegetation, and a lack or loss of critical habitats.

This management plan has been developed for natural resource managers and stakeholders associated with the Lower Burdekin floodplain. These include riparian landholders like cane farmers and graziers; BHWSS operator Sunwater; local government (Burdekin Shire Council); Traditional Owners (represented by Gudjuda Reference Group Aboriginal Corporation); and the broader community, including community-based interest and natural resource management (NRM) groups such as Burdekin Bowen Integrated Floodplain Management Advisory Committee (BBIFMAC), Lower Burdekin Landcare, and NQ Dry Tropics.

Over the past two decades these stakeholders have been involved in a range of innovative environmental management initiatives that have improved the condition of floodplain wetland systems in the region. Actions have included the use of weed harvesters and excavators to remove neglected aquatic weed infestations, the development of coast-shared weed control programs instituted through Riparian Management Agreements (RMAs), and multiple riparian revegetation programs. At the time, these initiatives were truly innovative in the sense they had not been done before in the seasonal dry tropics, or – in the case of RMAs – Australia. Management initiatives in the Horseshoe Lagoon system include an aquatic weed control program established via an RMA, road crossing and coastal bund fish passage works, revegetation of distributary lagoons, and establishing a bird viewing hide. This SMP seeks to build on this gained experience and identify further environmental management opportunities that could be pursued with stakeholder support.

This plan was prepared following site field work and consultation with landholders and other management stakeholders between November 2021 and February 2022. Through this field work, a literature review, and targeted stakeholder engagement, it was possible to identify system asset values, threats to these assets, and management strategies and nominated works to address threats. The condition of riparian zone vegetation was also mapped and a management planning map covering the system was prepared. This management plan examines the management needs of the wetland system under 10 issue areas covering:

1. Altered hydrology;
2. Aquatic weeds;
3. Water quality;
4. Fish passage barriers;
5. Lack of riparian vegetation;
6. Woody weeds;
7. Fire regime;
8. Grazing regime;
9. Critical habitat loss;
10. Climate stress.

While each issue is examined separately in terms of management needs and opportunities, the relationship and interaction between issues is also identified where relevant to support integrated management recommendations and solutions. Implementation of this plan's recommendations depends entirely on voluntary adoption by relevant management stakeholders and the availability of sufficient resources to facilitate them.

> Background

Cape Bowling Green Bay Ramsar wetland

Ramsar wetlands are recognised as wetlands of international importance and listed under the Ramsar convention. These are wetlands that are representative, rare or unique, or are important for conserving biological diversity. Australia currently has 65 Ramsar wetlands covering some 8.3 million hectares. Five are in Queensland including the coastal Cape Bowling Green Bay in the Lower Burdekin. As a signatory to the Ramsar convention, the Australian Government has a legal responsibility to ensure for the wise use and conservation of Ramsar wetlands. To this end, NQ Dry Tropics has been funded by the Australian Government's National Landcare Program to restore high value wetland systems in the catchment of the Cape Bowling Green Bay Ramsar wetland. To approach this task strategically, an SMP was initially developed for an individual floodplain distributary stream that drains to the Ramsar site: Sheep Station Creek (Econcern 2021). Examining environmental management arrangements for this one entire creek catchment generated a useful SMP template that has since been applied, with some site-specific adjustment, to adjoining floodplain tributaries and distributaries comprising the Cape Bowling Green Bay catchment. This SMP has been developed for the Horseshoe Lagoon system.

Lower Burdekin floodplain – identifying assets and threats

This wetland SMP uses terminology and methodology aligned with Conservation Action Planning (CAP), more broadly applied by NQ Dry Tropics within its NRM region. In essence, a CAP seeks to identify the 'assets' within a given planning region, identify 'threats' to these assets, and develop strategies which may serve to reduce the threats to assets. Assets fall within a range of non-mutually exclusive categories including:

- Environmental,
- Economic,
- Social, and
- Cultural assets.

In seeking to serve the improved environmental management of the catchment of the coastal Ramsar wetland, this SMP is primarily focused on environmental assets. However, the greater dimension of environmental assets needs to be considered and promoted in presenting the case for their conservation. For example, a healthy wetland system has recognised environmental value. Where this same wetland provides for nature-based recreation such as birdwatching or fishing, it also holds social value. If fish populations supported by the wetland include commercially-targeted species, it also holds economic value. If the site is of significance to Traditional Owners, or the history of non-Indigenous Australians, it also has cultural value.

While some asset values are complementary, they can also sometimes be in competition. For example, the developed irrigation water supply systems of the Lower Burdekin floodplain are very important economic assets that have delivered employment and economic benefit to the regional community. They have, however, often come at a cost to the health of wetland systems impacted by the consequent modification of floodplain hydrological regimes that has accompanied irrigation development. Other examples of value conflict can occur where appreciation of the recreational values of a wetland, for instance, four-wheel driving, may conflict with the conservation of sensitive biodiversity, or where a pasture species favoured as an asset for pastoral production acts as an invasive weed in wetland habitats. Ultimately, it is for society's social, political, and legal systems to determine which values are managed within a regional landscape. This SMP seeks to identify best management practice for identified environmental assets, while recognising that such management aspirations need to operate within a broader economic, social, and cultural context.

System Management Plan – scope and purpose

This SMP has been commissioned by NQ Dry Tropics to provide a blueprint for improved environmental management of the targeted wetland system. In doing so, it aims to support improved management and protection of the environmental assets of the Cape Bowling Green Bay Ramsar wetland on the coastal margin of the targeted system. The SMP's scope includes the ecological assets of the targeted wetland system, and also the biophysical condition, processes and management arrangements within the system's catchment area that may ultimately impact wetland condition.

This SMP aims to provide a 'go to' document for investment in the management of high value Burdekin floodplain wetlands. Recognising the vagaries of environmental management funding and the consequent often reactive nature of program investment, it provides a proactive planning tool that can direct management funding when it becomes available toward already defined priorities. It also acts as a prospectus for those seeking to pursue funding applications or sponsor environmental management. Further, this SMP seeks to document historical wetland management gains, the implementation issues surrounding them, and provide recommendations on how to better address outstanding environmental management challenges facing the contemporary wetland system.

The SMP’s intended audience is the range of natural resource management stakeholders associated with the Lower Burdekin floodplain. These include riparian landholders, most of which are cane farmers; BHWSS operator Sunwater; local government (Burdekin Shire Council); catchment heavy industry (such as Wilmar); Traditional Owners (represented by Gudjuda Reference Group Aboriginal Corporation); and the broader community, including community-based interest and NRM groups such as Burdekin Bowen Integrated Floodplain Management Advisory Committee (BBIFMAC), Lower Burdekin Landcare, and NQ Dry Tropics.

Over the past two decades these stakeholders have been involved in innovative management initiatives that have improved the condition of wetlands that were considered highly degraded in the early 2000s back to relatively healthy, though modified, aquatic ecosystems today (Econcern 2021). Innovative management approaches implemented have included the use of weed harvesters and excavators to remove neglected aquatic weed infestations; the development of a cost-shared aquatic weed control programs instituted through RMAs; fish passage provision around instream infrastructure, and reach-scale riparian revegetation programs. At the time, these initiatives were truly innovative in the sense that they were novel approaches for the seasonal dry tropics, or – in the case of RMAs – were Australian-firsts.

Implementation of this plan’s recommendations depends entirely on their voluntary adoption by landholders and other relevant management stakeholders and the availability of sufficient funding and material resources to facilitate it.

Horseshoe Lagoon system overview

Location and geomorphic setting

The Horseshoe Lagoon system is located approximately 56km south of Townsville and 4.2km to the south, southeast of the township of Giru on the eastern floodplain of the Haughton River in the Lower Burdekin region. Horseshoe Lagoon is a natural lake formed within an overbank flood distributary channel of the Haughton River that has been blocked by alluvial deposition in its lower reaches. It is up to 1.2km wide and 2km long with an approximately 96ha surface area, and sits within a relatively short floodplain drainage system that is a tributary stem of Barramundi Creek. This drainage system is 9km long from the upstream margin of the lake downstream to tidal influence associated with the Barramundi Creek estuarine complex. Along its length, the drainage system emanating from Horseshoe Lagoon is initially a poorly-defined drainage depression that coalesces into a defined stream channel that hosts several waterholes up to 30m wide and 200m long before spilling into drainage depressions on marine coastal plains (Corrick Plains Station). Here it once again lacks a defined channel, but hosts several lakes embellished by constructed earth bunds. Beyond the bunds, the system becomes estuarine and enters the Cape Bowling Green Bay National Park and Ramsar wetland site.

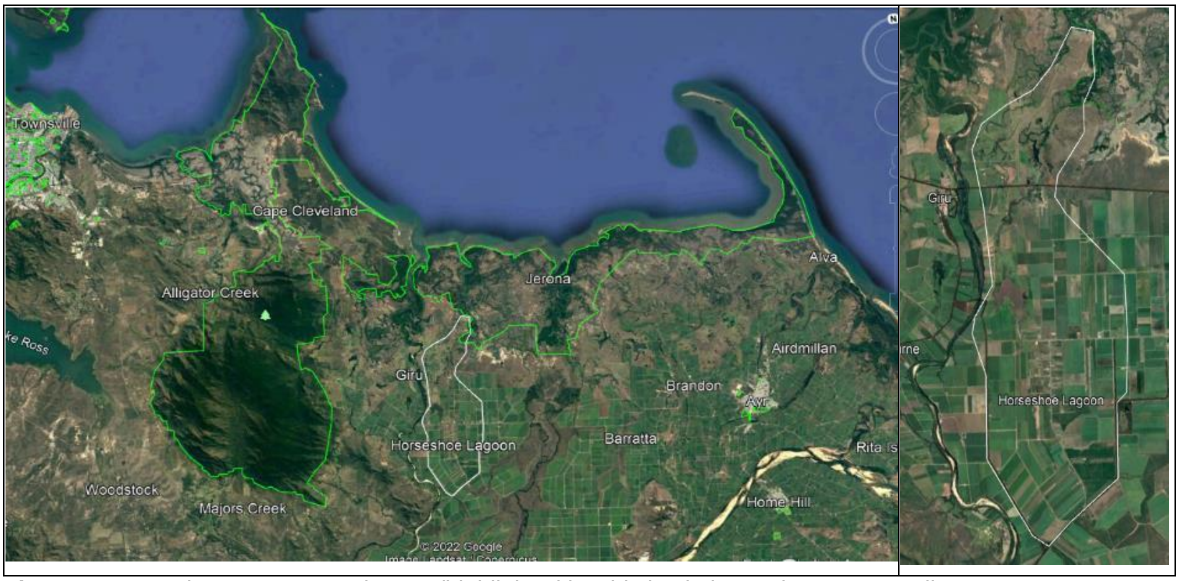


Figure 1. Horseshoe Lagoon catchment (highlighted in white) relative to the Cape Bowling Green Bay Ramsar wetland site (green line), and relative to Giru, the Haughton River and the Bruce Highway (right).

Upstream of the marine plains, several other distributary channels hosting lagoons also break off the left bank of the lower Horseshoe Lagoon drainage system toward the main Haughton River channel. The system has a catchment area of 6500ha which is nested within the Haughton River basin. Although the natural contributing catchment upstream of the lake was historically floodplain that lacked a defined drainage network, there is now some 6km of constructed irrigation tailwater channel draining to the lagoon from its upper catchment boundary. This upper catchment encompasses floodplain that has been levelled and intensively developed for farming irrigation, which is supported by the Burdekin Haughton Water Supply Scheme (BHWSS) and operated by Sunwater.

Hydrology – natural and modified

Like all wetlands in the seasonal dry tropics, the natural hydrology of the system was highly seasonal and related to the timing and magnitude of the annual wet season. The contemporary hydrology of the Horseshoe Lagoon system is dominated by inflows of irrigation tailwater and supply channel overflow from BHWSS in its upper catchment. These aseasonal inflows contribute to near-perennial outflows from the lagoon to the downstream drainage system, and a major reduction in dry season drawdown of lagoon water levels. Aseasonal inflows from the BHWSS enter the lagoon system at the most upstream point of the lake and via two separate drainage channels that enter the system from the east, below the lake. Wet season hydrology is still distinctive from the dry season and includes runoff from contributing floodplain catchment areas, including adjoining farmland and periodic large inflows associated with overbank distributary flood breakouts from the adjoining Haughton River. Contributing catchment runoff rates have been increased by levelling for farm development and associated constructed drainage channels. Much of the catchment area is underlaid by shallow sand-bedded alluvial aquifers that interact with surface features, including the Horseshoe Lagoon and other channel hosted lagoons. Significant areas of these aquifers are now impacted by irrigation-driven groundwater rise.

Land use, tenure and remnant vegetation

Most of the system and its catchment is freehold tenure, though the Horseshoe Lagoon waterbody is a declared conservation park. There are also several blocks of Crown land reserve within the system's lower catchment, and some of the lower creek channel and adjoining dense riparian forest stands occur within Crown watercourse. Crown land corridors also extend into the site from the upstream highway and the bottom coastal end of the system (Corrick Plains) falls within pastoral leasehold land. Several linear leasehold land easements run parallel to the drainage system downstream from the main lake, while the tidal area at the bottom of the system demarcates the beginning of the coastal Cape Bowling Green Bay National Park and Ramsar wetland area. Most of the land use within the catchment is irrigated sugarcane, but there are also significant areas of horticulture (mango plantation); some of which occurs on smaller rural residential holdings. Horseshoe Lagoon's northern margin and downstream northern half of the catchment are dominated by grazing. Given the intensive land use pattern within the system's catchment, there is limited remnant vegetation and most remaining stands of native vegetation are disturbed to some degree. Higher value stands include structurally-complex and diverse riparian forest and adjoining floodplain woodland in the lower reaches of the creek drainage downstream of Horseshoe Lagoon, and remnant riparian forests within distributary channels in the northwest of the catchment. Other areas of remnant vegetation include coastal plain grassland and open woodland in the catchment's northern coastal margin. Aquatic plant communities, including those within coastal swamps, have been widely impacted by freshwater inflows and associated aquatic weed proliferation. Although some areas that are more isolated from freshwater inflows and retain seasonally-variable water levels and salinity still contain good stands of native bulkuru spike rush and representative native aquatic plant communities.

Key assets and values

Horseshoe Lagoon is listed in the national Directory of Important Wetlands in Australia and its value is reflected by inclusion in a declared conservation park. The system is primarily recognised for its high waterbird habitat values. These values support recreational use by bird watchers, and public bird watching infrastructure has been established on the lagoon's perimeter. The Corrick Plains coastal wetland complex, located at the bottom of the system, is a declared nature refuge. It is also a state-significant wetland that has previously been recognised as barramundi nursery habitat; a value historically shared with Horseshoe Lagoon; the latter also having a historical site record for the vulnerable freshwater sawfish. The coastal wetland complex also supports significant waterbird and waderbird populations, including endangered species, and its tributary drainage supports estuarine crocodile populations. The remnant vegetation associated with the lower drainage system and adjoining coastal plain have fauna habitat values encompassing migratory passerines (songbirds), cover-dependent owl species, raptors, and tree hollow-dependent bats. The whole system is a Ramsar site interface catchment providing a range of ecosystem services to the site, such as water quality treatment, primary production, and flows of materials and biota.

Historical and current management

The Horseshoe Lagoon system has been included in a range of past and ongoing environmental management initiatives. Riparian Management Agreements (RMAs) were established between riparian landholders, Burdekin Shire Council (BSC), NQ Dry Tropics and Sunwater to fund sustained aquatic weed control. This has involved a weed harvester and weed-raking excavator, and boat and helicopter-based weed spraying programs. The targeted species has primarily been water hyacinth, but has also included aquatic grass hymenachne. An earlier hymenachne spraying program conducted on the outflow channel from the main lagoon was discontinued after a high-flow event subjected the sprayed area to high erosion risks. Fish passage provision works were conducted on a stream crossing downstream of the main lagoon's outflow channel and on earth bunds separating coastal lakes from tidally-influenced areas. A revegetation program was also successful on the riparian frontages of distributary channel water bodies in the northwest of the system.

Ongoing threats, management challenges

The most significant ongoing threat to the condition of the Horseshoe Lagoon system is altered hydrology due to aseasonal inflows of irrigation tailwater and supply channel overflows from the Sunwater operated BHWSS. Impacts include reduced dry season water level drawdown and channel bank exposure/drying throughout the system; reduction of dry season salinity levels in the receiving coastal lakes, and the associated proliferation of floating aquatic weeds and exotic grasses (hymenachne); loss of native emergent aquatic plants to weed competition and control efforts; and water quality impacts. Water quality impacts associated with BHWSS inflows and weed proliferation and control include sustained turbidity, elevated nutrients, organic loading and depletion of dissolved oxygen. Fish passage barriers are also created throughout the system where weed chokes result in anoxic water. Other identified threats include potential head cutting erosion of the downstream bank of Horseshoe Lagoon during flood outflows, erosion of retaining earth bunds at the tidal interface of the lower coastal lakes on Corrick Plains, irrigation-driven groundwater rise in the mid and upper catchment, and further spread of exotic trees/woody weeds in remnant riparian vegetation.

> Methods – assessment and reporting

Stakeholder consultation

Stakeholder consultation for the preparation of this management plan was undertaken between November 2021 and February 2022 and involved:

- on-site consultation with riparian landholders distributed through the wetland system;
- meetings with representatives from community organisations involved in project work within the targeted wetland system, including Lower Burdekin Landcare, BBIFMAC and NQ Dry Tropics;
- consultative meeting with Sunwater;
- meeting with BSC managers and operational staff involved in overseeing the aquatic weed control program service delivery; and
- informal engagement with researchers from research and development (R&D) providers that have worked across the Lower Burdekin floodplain, primarily at Tropwater, James Cook University (JCU).

For each interviewed landholder, engagement involved non-structured questioning about impressions of the environmental status of the creek; opinion of the adequacy of existing management arrangements; suggestions for additional or improved management approaches, and willingness and/or nominated preferences for conducting various on-ground environmental management works on the landholders' riparian landholdings. The latter are captured as 'nominated works' in Appendix 1 and presented on catchment management plan sheets (Appendix 2).

Literature review

Literature reviewed for preparation of this plan was sourced from 'grey literature' associated with previous NRM management plans, strategies, and consultant reports from the Lower Burdekin, plus formal scientific journal papers covering topics usually directly related to the Lower Burdekin floodplain study area. A range of information was also sourced online from Queensland Government agency sites including Queensland Globe (https://qldglobe.information.qld.gov.au/), Wetland Info (https://wetlandinfo.des.qld.gov.au/wetlands/), and DES regional ecosystem descriptions (https://apps.des.qld.gov.au/regional-ecosystems/).

Field work

Most field work was conducted in conjunction with landholders. Once site access permission was granted by landholders, some sites were subsequently revisited to gain additional information. Information was collected primarily by noted observation and digital images and included details about: riparian vegetation condition, weed infestation status, evidence of fire history, status of revegetation sites, potential fish passage barriers, water infrastructure, habitat values, incidental records of flora or fauna, observations of land degradation, and potential works sites

Management planning mapping

Maps of riparian vegetation condition were produced to inform environmental management planning for the wetland system (Appendix 2). These were generated by using a computer-based geographic information system (ArcGIS) to draw lines (polygons) around features on digital aerial images that depicted different classes of riparian vegetation condition. Eleven classes of riparian condition were defined including overstorey vegetation, grasses, and within channel aquatic classes. These are below and in Appendix 2:

1. Remnant vegetation.
2. Degraded remnant.
3. Revegetated.
4. Exotic trees.
5. Grassland.
6. Exotic grasses.
7. Cumbungi.
8. Open water.
9. Native aquatic plant-covered water.
10. Floating aquatic weed-covered water.
11. Water with emergent aquatic plants.

Mapping system reaches into these riparian condition classes provides a basis for:

- examining the overall and relative ecological condition of the wetland system;
- identifying system-scale drivers of ecological degradation;
- developing generic management recommendations for reaches dominated by condition types;
- defining strategic priorities for restoration and protective management; and
- a timeline baseline to compare with future creek condition states.

In addition to riparian vegetation condition, GPS-reference points collected in the field for reach asset values, management issues and nominated works are also displayed on the management plan maps (Appendix 2).

> Summary system assets, threats, and nominated management strategies/works

System assets, threat management issues and nominated works compiled during the development of this SMP are tabulated in Appendix 1 and presented on management planning maps (Appendix 2). They are described and summarised below.

Assets

These are ecological values associated with the wetland and/or adjoining riparian ecosystem that are significant at scales beyond this site alone. They are underpinned by criteria such as productivity, biological diversity, habitat connectivity, representativeness, and habitat provision that serve fish and wildlife populations and nature conservation objectives at reach, catchment, regional, state, or even national scales.

The main ecological asset values identified for the Horseshoe Lagoon system include:

- A large (96ha) freshwater lake that is a nationally important, a state significant wetland, and a conservation park with good waterbird populations and established recreational use for bird watching.
- Corrick Plains Nature Refuge: a state significant coastal wetland complex with waterbird, waterfowl and waderbird habitat values, including housing endangered and vulnerable species.
- A diverse and structurally-complex coastal creek riparian vegetation corridor that includes channel-hosted waterholes and adjoining floodplain woodland remnants. This area provides habitat for a diversity of fauna including estuarine crocodiles, freshwater turtles, other reptiles, migratory fish and passerines, and other woodland birds, owls, raptors, and bats.
- A series of distributary lagoons, with the better condition waterways retaining natural hydrology and good riparian vegetation and providing high value habitat for terrestrial fauna and fish.
- A diverse range of bird habitats and populations covering numerous group types, from woodland and coastal grassland species, to migratory passerines, owls, raptors, waterbirds, waterfowl, and waders.
- High value remnant floodplain and coastal plain woodland and grassland remnants that include matters of state environmental significance, for example, ‘of concern’ regional ecosystem and habitat for Endangered, Vulnerable and Near Threatened (EVNT) wildlife species.
- High value fish habitats, including key nursery and adult habitat for the migratory and recreationally and commercially important barramundi.

- An interface wetland system between intensive production and protected landscapes (including the Ramsar wetland) that provides a range of ecosystem services to the downstream receiving environment, including water quality processing, primary production and flows of materials and biota.

Threats/management issues

System management issues include aquatic and riparian zone threat management concerns that are characteristic of a wetland reach or specific to it. They also include threat management issues that occur at more than one site within the wetland system, and are well demonstrated by a particular reach example. Some identified threat management issues have impacts that affect the wetland ecosystem at a catchment scale.

The main system management issues for the Horseshoe Lagoon system include:

- Aseasonal inflows from irrigation scheme (BHWSS). This is the most significant ongoing threat to the condition of the main (not distributary) Horseshoe Lagoon system and has generated both altered hydrology and water quality impacts that act as the primary drivers for secondary threats, such as aquatic weed infestation and poor reach condition fish passage barriers.
- Altered hydrology, including a loss or reduction in dry season water level drawdown and channel bank exposure/drying throughout the system, and reduction of dry season salinity levels in coastal lakes.
- Cyclical proliferation of floating aquatic weeds that represent a symptom of the altered hydrology and water quality of the system and – under current control approaches – perpetuate water quality (low dissolved oxygen, high nutrients) and weed infestation risks.
- Loss of critical native emergent aquatic plant habitat to aquatic floating and grass weed competition, and associated weed control spraying impacts on water edge zones.
- Water quality impacts associated with turbid inflows and nutrient loading from the BHWSS, dissolved oxygen degradation associated with organic loading, weed chokes and dead aquatic weed biomass killed by spraying based control, and from the loss of seasonal salinity conditions in coastal wetlands receiving freshwater inflows.
- Fish passage barriers throughout the system associated with road crossings, coastal bunds, and weed chokes; the latter's organic loading resulting in deoxygenated water.
- Domination of lake and distributary frontages and adjoining floodplain areas with exotic grasses, like guinea, hymenachne and para,that limit native vegetation recruitment and present dry season hot fire risks.
- Further spread of exotic trees/woody weeds and rubber vine, and the associated condition decline of remnant riparian vegetation.
- Limited availability of lakeside riparian vegetation and associated critical habitat, for instance, instream snags and bird roost/perch sites.
- Erosion of retaining earth bunds at the tidal interface of coastal lakes on Corrick Plains.
- Potential head cutting erosion of the downstream floodplain of Horseshoe Lagoon during flood outflows.
- Risks of irrigation-driven groundwater rise in the mid and upper catchment.

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Nominated works

This is a non-exhaustive list of wetland system asset threat management strategies or works that were identified over the course of project field work, or subsequently during desktop-based assessment. They are proposals only and implementation would be subject to landholder endorsement, funding resourcing, appropriate agency approvals where required, and further landholder and management stakeholder engagement.

Nominated works for the Horseshoe Lagoon system include:

- Prevent or reduce aseasonal inflows of BHWSS water to the system to reinstate seasonal hydrological character to the lagoon and lower system and mitigate some of the impacts associated with aseasonal inflows. Management options potentially include:
    - Reduce the supply of channel overflow volumes and establish a 'smart gate' to balance storage for scheme tailwater reuse upstream of the Horseshoe Lagoon inflow;
    - Promote off-stream tailwater reuse for drain water currently draining to the system below Horseshoe Lagoon;
    - Install a controlled outlet-height gravity-fed pipe from Horseshoe Lagoon to the Haughton River to reinstate seasonal drawdown of lagoon water levels and outflows.
- Re-establish grazing of lagoon foreshores (ideally in conjunction with seasonal drawdown of water levels) to control exotic aquatic grass margins without spraying, and promote native emergent aquatic plant communities.

- Develop systems and use of machinery/infrastructure/site conditions to increase the use of ‘physical biomass removal’ aquatic weed control methods.
- Revegetate sections of the lake’s full supply level bank margin with shade-casting riparian vegetation.
- Revegetate lagoon outflow channel with shade-casting riparian vegetation in conjunction with rock-armoured contour bunds to create a shaded open channel for fish passage that reduces head-cutting erosion risks.
- Conduct targeted woody weed and rubber vine control to protect and improve the condition of high value riparian habitat remnants in the lower system, including reserve and state land with a vested public interest.
- Install rock armouring to eroded tidal interface bunds using a rock ramp fishway configuration to protect wetland water levels while enhancing fish passage.
- Conduct re-snagging and establish large woody debris roost habitat in the seasonal water level zone of the lagoon margins.
- Conduct a seasonally and catchment-stratified integrated investigation of fish community composition, movement, and dissolved oxygen status.
- Support the implementation of groundwater monitoring and investigations that examine any linkages between groundwater behaviour and floodplain remnant vegetation condition, and between lagoon and system water levels, artificial perenniality, and groundwater accession rates.

> System management plan, key threats to assets and recommended management strategies

Wetland system catchments are perhaps one of the most readily-identified examples of an integrated system. In other words, changes in the condition of one component of the system influences and impacts the status of other components. When considering the management of a wetland system, the Integrated Catchment Management (ICM) approach developed in Queensland in the 1990s (DPI 1993) still offers one of the most useful frameworks for considering how management initiatives across a range of issues serve to deliver benefits for the system as a whole.

Based on consultation with management stakeholders, a literature review, and field investigations, the following 10 threat management issues are identified as important to the ecological health of the Horseshoe Lagoon system. They include:

1. Altered hydrology;
2. Aquatic weeds;
3. Water quality;
4. Fish passage barriers;
5. Lack of riparian vegetation;
6. Woody weeds;
7. Fire regime;
8. Grazing regime;
9. Critical habitat loss, and
10. Climate stress.

While each issue is examined separately in terms of threat management needs and opportunities, the relationship and interaction between issues is also identified where relevant to support integrated management recommendations and solutions. One example of a threat that operates across nearly all other threat management issues is the emerging impact of climate change, which has a demonstrated capacity to exacerbate existing environmental stress.

Altered hydrology

Types and impacts

The natural hydrology and associated ecology of wetlands within the seasonal dry tropics, including those of the Lower Burdekin floodplain, is highly seasonal and related to the timing and magnitude of the annual wet season. The key drivers and stimuli for biophysical processes that determine the ecological character of the Lower Burdekin’s natural floodplain wetlands include elements such as annual inundation in response to wet season rainfall, connection to floodplain distributary channel flows, the subsequent cessation of flow, waterhole isolation, and water level drawdown through the dry season, sometimes to complete drying. These seasonal events provide for germination of aquatic plants; reproduction, movement, and recruitment of fish populations;

nesting, and breeding of waterfowl; flushing of organic matter, scouring, and habitat resetting within drainage channels; seasonal changes in water quality, and processing and assimilation of catchment nutrient loads.

In the contemporary, modified floodplain system, the hydrology of most freshwater wetlands, including most stream networks, is influenced by irrigated farm and/or irrigation scheme development within contributing catchment areas. Irrigation tailwater, including supply channel overflow from Sunwater's owned and operated BHWSS or individual farms, drain to low lying areas that host wetlands. Often, in the case of the BHWSS, this is via large, constructed drains. Within both the Burdekin Delta and floodplain, distributary stream channels are used by both Sunwater and Lower Burdekin Water operations to convey water pumped from main rivers (Haughton, Burdekin) to deliver surface water for irrigators and to recharge shallow groundwater aquifers. Across large areas of the BHWSS, irrigation-driven groundwater rise has also occurred to the extent that some water tables now discharge to surface drainage networks. Elevated groundwater is also suspected of directly impacting the condition of native vegetation, including riparian zones in some areas of the floodplain.

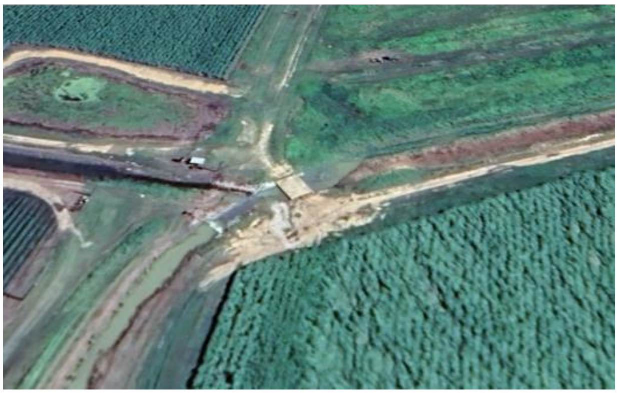

Photo 1. Sunwater drain RH5 conveying catchment runoff from the BHWSS over a small in-channel weir into a drain leading to the upper Horseshoe Lagoon system (right).

Photo 2. Water flowing to Horseshoe Lagoon (above) from the BHWSS due to irrigation tailwater flows, or catchment rainfall run, is a source of both turbidity and nutrient loading.

The collective impact of irrigation tailwater, channel overflow, pumped flows and elevated groundwater discharge is that historically-seasonal floodplain stream systems such as Ironbark, Barratta, Collinson's, Sheep Station, Plantation, Kalamia, and Saltwater creeks, and many smaller unnamed distributary streams, are now perennial or semi-perennial; maintaining connective flows or seepage between wetland water bodies that were historically isolated, or even dried during the dry season. These aseasonal inflows contribute to a reduction in dry season drawdown of lagoon water levels and altered water quality (higher turbidity and nutrient loading). This altered hydrology and water quality has generated major changes to wetland aquatic plant communities, increasing the abundance of fringing exotic aquatic grasses and floating weeds; decreasing the abundance of native water lilies, submerged aquatic plants, sedges, and other emergent aquatic plants; and impacting associated habitat values for wetland fauna, including birds, reptiles and fish. The colonisation of historically drying, but now saturated, distributary channels by impenetrable stands of cumbungi bullrush has also impacted system water quality, fish passage, and hydraulic capacity, in addition to habitat values. A positive habitat impact associated with increased stream perennially has been the development of denser and more diverse riparian vegetation zones along some previously seasonal creek systems. Some stakeholders have expressed concerns that this also represents a flow capacity impact, though comparisons with unshaded, weed-filled channels have not been tested.

Another form of altered hydrology impacting the Burdekin floodplain and coastal wetlands include damming and bunding of stream channels and floodplain drainage depressions. These are usually established to form watering points and/or ponded pasture forage for grazing stock. In near-coastal areas such structures also inadvertently, or intentionally, exclude tidal ingress, the latter sometimes being employed by water managers as a saltwater intrusion prevention groundwater management tool. Where these structures are established in tidally-influenced areas, upstream of the bunds freshwater vegetation replaces the natural salt tolerant plants, and downstream areas risk of becoming hypersaline. In some catchment settings where inflows to impounded areas remain seasonal, the habitat quality of wetlands that establish within them can be good. Where such areas are subject to sustained aseasonal inflows and reduced seasonality, they usually become dominated by exotic aquatic grasses, floating weeds and/or cumbungi. Independent of bunding or damming, sustained aseasonal flows of freshwater into estuarine areas such as the Barratta Creek estuary is changing their salinity regime, water quality and primary productivity as weeds such as hymenachne advance into areas previously characterised as tidal.


June 1959


June 1969


Jan 1976


Jun 1982


May 1991


Apr 1994


Sept 2004


Jan 2022

Figure 2. Time series aerial photographs of Horseshoe Lagoon from 1959 to 2022. They illustrate reduced seasonality, loss of native aquatic plant zonation, and maintenance of full supply water levels after 1994.

Photo 3. Horseshoe Lagoon outflow drain conveying near-perennial outflows to the lower system via an aquatic weed-choked (hymenachne, water hyacinth) channel.

Photo 4. Maintenance of lake water levels at near full supply level has contributed to waterlogging, death of riparian trees, loss of native emergent aquatic plants, exotic aquatic grass domination of margins, and proliferation of floating aquatic weeds.

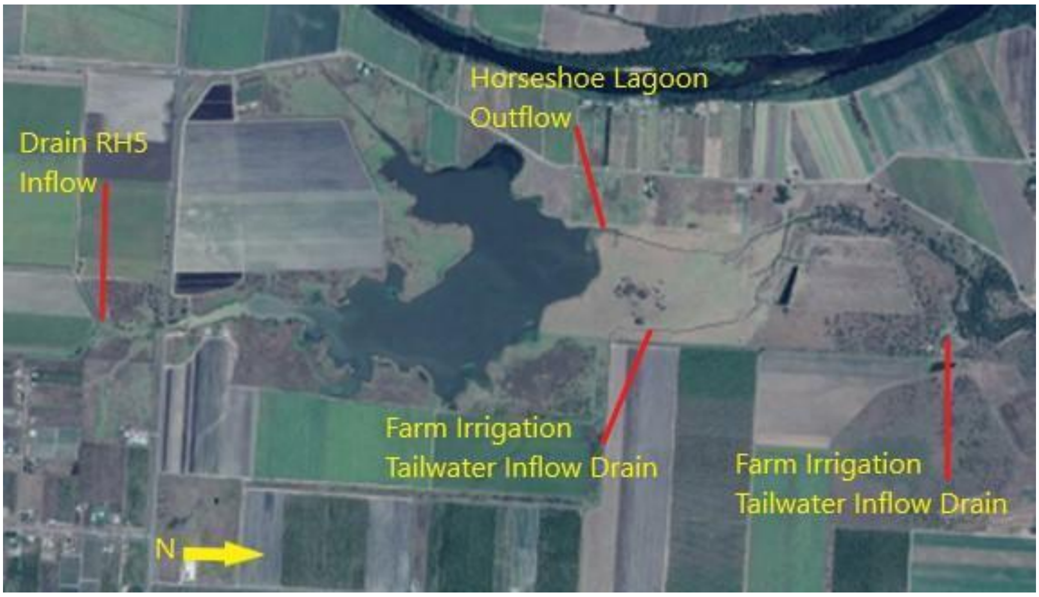

Photo 5. Sources of aseasonal inflows to Horseshoe Lagoon and the lower drainage system.

Photo 6. Earth bunds provide tidal exclusion and increased freshwater pasture pondage on the downstream margins of the Corrick Plains Nature Refuge. These bunds separate tidal mangrove

Photo 7. Where high flows damaged bund walls the aerial extent of post wet season-ponded freshwater wetland could be reduced. Rock armouring of these areas using a rock ramp fishway configuration could both

communities (right), from brackish bulkuru sedge *Eleocharis dulcis* (spikerush) communities (left).

secure the wetland and provide enhanced fish access to nursery areas.

The upper catchment Burdekin Falls Dam represents another basin-scale alteration of hydrology that also impacts floodplain wetlands. This dam acts as a detention area during high rainfall events across the basin, serving to reduce the height and frequency of Lower Burdekin flood peaks that previously would have broken out of the river channel into floodplain distributaries, scouring and resetting habitat conditions for channel-hosted wetlands. Riverbank levees constructed to prevent such outbreaks and protect farmland have also reduced the occurrence of these ecologically important flows. Another impact consequence of the Burdekin Falls Dam capturing flood events is that, while river baseflows historically drained to clear, now water reticulated through irrigation scheme areas remains turbid for most, if not all, the calendar year. This sets in train a host of water quality

associated impacts for a river and floodplain system that naturally had high clarity water outside of the annual wet season.

Photo 8. Corrick Plains Nature Refuge coastal wetlands and pasture pondages illustrating different in situ hydrological settings and aquatic plant outcomes. Note inflow is at bottom of image.

System specifics

Where discussion relates to management issues listed in Appendix 1, or mapped in Appendix 2, the designated management issue (M) number is referenced.

Like most Lower Burdekin floodplain wetlands, the Horseshoe Lagoon system was historically highly seasonal. It was inundated and experienced one or more short flow events during the wet season, and in the dry season, it dried – almost completely in some years – to a series of isolated waterholes and coastal swamps. This seasonal hydrology determined the system's ecological character, which included a diverse range of native aquatic plant communities that were adapted to different water depths and levels of seasonal exposure. This created different plant habitat zones, including dry exposed banks, important to waterbirds and other wetland fauna within and around the boundaries of wetland water bodies (Figure 2).

In the contemporary Horseshoe Lagoon system, the hydrology is highly modified from natural (M1) and dominated by inflows of irrigation tailwater and supply channel overflow from the BHWSS, which was established in the system's upper and eastern catchment in the early 1990s (Photo 1 and 2). These aseasonal inflows contribute to near-perennial outflows from the lagoon to the downstream drainage system (Photo 3 and 5) and a major reduction in dry season drawdown of lagoon water levels (Photo 4). Additional inflows of irrigation tailwater come into the system downstream of Horseshoe Lagoon from farms served by the Haughton main channel in the eastern catchment (M9). Alteration of the system's hydrology extends downstream to the tidal zone, where channel-blocking bunds now impound near perennial inflows and water bodies. These bunds were historically established to exclude tidal inflows and capture freshwater runoff to create seasonal pasture pondages and watering points for cattle (Photo 6).

This altered hydrology has generated major changes in aquatic plants communities throughout the system, particularly an increase in floating aquatic and grass weeds (M4). Exotic 'ponded pasture' grass species hymenachne and para now dominate the water edge and shallow zone that previously supported emergent, submerged and floating native aquatic plants like water lilies. Floating aquatic weeds also periodically infest these zones. Within Horseshoe Lagoon, factors like competition from aquatic grasses and floating weeds, and periodic chemical spraying associated with weed control, all serve to reduce the area, abundance, and diversity of native aquatic plant communities (see *Aquatic weeds* section). Water quality impacts, like higher turbidity and nutrients, and lower dissolved oxygen (DO); fish passage barriers, created by reaches with weed chokes and low DO; along with other reduced habitat values for wetland fauna; are also associated with the hydrology-modifying aseasonal inflows. Downstream of the main Horseshoe Lagoon, there are smaller channel-hosted lagoons in the lower creek system that are adjoined by high value riparian forest habitat which are also impacted by the same suite of aquatic weeds and water quality impacts. These challenges limit their full habitat value potential (M12).

In the coastal lacustrine (lake) wetlands at the bottom of the system within the Corrick Plains Nature Refuge, the impacts of altered hydrology have been particularly pronounced in the past 10 years (see *Aquatic Weeds* and *Fish passage barrier*s section). Historically, this area largely dried and was subject to tidal influence in the late dry season, which promoted important habitat resetting and a brackish salinity regime that supported the growth of adapted plant species such as bulkuru sedge. Bulkuru sedge is an important food and nesting resource for several waterfowl and waterbird species, like brolgas and magpie geese, and creates ideal water quality conditions and nursery habitat for post-larval barramundi. The historical establishment of earth bunds on the downstream margins of this coastal wetland complex to exclude tidal inflows and promote ponded pastures coexisted with these wetland habitat values for decades while hydrological seasonality was maintained. In recent decades, sustained aseasonal inflows and subsequent aquatic weed infestation (M13), has impacted seasonal hydrology and salinity regimes, and significantly reduced these ecological values (Photo 8). Some of the bunds maintaining the extent of these coastal wetlands have been breached and eroded by wet season high flows. Further widening or deepening of these breaches could result in reductions of the wetland area extent.

Photo 8. Drainage easement to the east of the Horseshoe Lagoon main drainage system, which conveys irrigation tailwater from farms supplied by the Haughton main channel to a confluence with the system's lower catchment creek channel. It sits beneath dense stands of aquatic grass weeds.

Photo 9. Tree death within floodplain woodland remnants adjoining the Horseshoe Lagoon system has been attributed by the landholder to rising groundwater.

A further hydrological risk for the system is the hymenachne dominating the main Horseshoe Lagoon's outflow areas (Photo 3). Hymenachne is relatively shallow-rooted and forms a dense thatch rich semi-buoyant mat-like cover of wetted areas. During high flow events this covering can be lifted and rolled back by high flow velocity water exposing underlying areas to erosion. When broad flood outflow events concentrate into exposed channel areas, channel head cutting can result. If these cuts were to migrate all the way to the outflow margin of the lagoon, its water level could be permanently lowered (M8).

Irrigation-driven groundwater rise is recognised for much of the Horseshoe Lagoon system's BHWSS catchment area. The relationship between the modified hydrology of Horseshoe Lagoon and adjoining groundwater aquifer behaviour is not well understood, but suitable geomorphology and soil types occur for connectivity. Understanding groundwater connectivity and accession risks could provide additional impetus for improved management of the system's hydrological status. Within remnant floodplain vegetation adjoining the lagoon system, several tree stands have succumbed to die back (Photo 9) with no obvious evidence to attribute it to insect attack or hot fire impact. Groundwater rise has been nominated as a likely cause by the landholder (M11).

Any management initiatives that seek to improve the hydrological status of the Horseshoe Lagoon system need to be cognisant of established water use practices, including primary production associated with the currently available aseasonal flow volumes. Although not BHWSS customers, licensed water users adjoining the lagoon have water use and pumping infrastructure established within the hydrologically modified lagoon.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Engage BHWSS operator Sunwater and water users, riparian landholders, Queensland Parks and Wildlife Service (QPWS), Department of Agriculture and Fisheries (DAF) and Birdlife Australia to reduce aseasonal flows of scheme tailwater into the Horseshoe Lagoon system and out of the main lagoon waterbody. This would reinstate the seasonal drawdown, associated seasonal water quality conditions and fringing emergent aquatic plant communities. Actions include:
    a. Promote reuse of irrigation tailwater, including for off stream floodplain pasture irrigation, to reduce flow volumes in three tailwater drainage channels (RH5 and drains flowing west from Trembath Road) feeding to the Horseshoe Lagoon system. Do this via zero access cost incentives (see below re: Department of Resources access fees) and/or by facilitating recycle pit infrastructure. The latter could be supported by public funding due to public benefit.
    b. Establish a 'smart gate', or weir, on the main tributary drain (RH5) to Horseshoe Lagoon and improved/modernised (telemetric) flow allocation/scheduling. This would reduce channel overflow and to avoid, or minimise, channel contribution to downstream tailwater flows.
    c. Establish contained balancing storage on the terminus of drain RH5 upstream of Horseshoe Lagoon to capture overallocated/underutilised supply flows and to avoid/minimise downstream flows.
    d. Assess the merits of installing a controlled outlet height gravity fed pipe from Horseshoe Lagoon back to the Haughton River as conjunctive infrastructure to control and minimise downstream tailwater flows and for return of water to Giru weir pool balancing storage (Photo 10).
    e. As part of progressing the above recommendations, engage R&D providers to lead development of a model main lagoon water level and lower system flow regime that balances the needs of consumptive water users with reinstatement of system seasonality and ecosystem health[1].
2. Conduct senior management level negotiations with the Department of Resources to develop and implement a Lower Burdekin floodplain 'Area Management Plan'. This plan would encompass the waiving of overland flow and water course water access/licencing fees where sought volumes can be supplied by excess aseasonal flows emanating from farm irrigation and BHWSS area tailwater.
3. Implement Corrick Plains bund erosion stabilisation/rock armouring via a rock ramp fishway configuration (see *Fish passage barriers* section).
4. Conduct erosion stabilisation and channel flow path works for Horseshoe Lagoon outflow channel (see *Fish passage barriers* section).

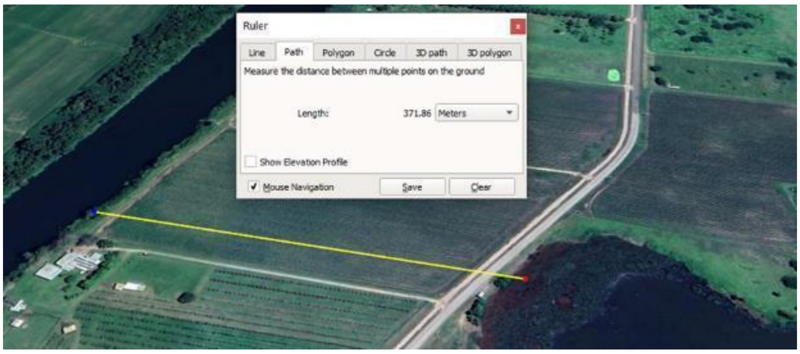

Photo 10. There is 370m between Horseshoe Lagoon and potential surplus flow volume discharge point in Haughton River.

[1] Recognising constraints set by existing Horseshoe Lagoon pump infrastructure/foot valve depth.

Aquatic weeds

Types and impacts

Aquatic weeds are commonly cited as the most significant cause of ecological impact within Lower Burdekin floodplain wetland systems (Waltham *et al* 2020, Tait 2013, Perna *et al* 2012, Veitch *et al* 2007, Tait & Perna 2001). They create blockages to flow and fish passage; outcompete native aquatic vegetation; generate high fire fuel loads in seasonally dry riparian vegetation (in the case of aquatic grasses); cause collapses in instream dissolved oxygen levels via organic loading; and cover open water surfaces, consequently impacting fish and other fauna habitat availability and quality. While these impacts are attributed to weeds, it should be recognised that observed weed infestation levels are often a symptom of other ecological impact drivers that promote weed proliferation. For instance, altered hydrology increasing aquatic habitat availability and reducing water level seasonality, and increased availability of nutrients associated with catchment land use, regulated inflows and irrigation tailwater inflows. Given the ongoing use of the Lower Burdekin floodplain's land and water resources for irrigated agriculture, these drivers of weed proliferation will, to some degree, remain part of most modified ecosystems. Effective weed management needs to be ongoing if management stakeholders want wetland ecological values to be retained or improved. Considering the costs associated with aquatic weed management, there is a strong impetus for control practices to be as effective as possible, and for innovative developments that support continuous improvement in management approaches.

A large range of aquatic weed species are recorded from the Lower Burdekin floodplain, with most of these recorded for the Horseshoe Lagoon system (Table 1). Aquatic weeds include floating, submerged, and fringing emergent growth forms including aquatic grasses. There are also several emerging aquatic weed risk species identified in the *Burdekin Shire Biosecurity Plan* (BSC 2020) that have been more recently recorded in the shire or adjoining regions (Table 2). While exotic species are more commonly recognised as 'weeds', several native aquatic plants (Table 1) have also become weedy in nature under the modified ecosystem conditions of the developed floodplain. Some native species (for example, cumbungi) are now responsible for major ecological and economic impacts. The impacts generated by aquatic weeds vary between species, although some impacts are common to most and often a suite of aquatic weed species are involved in impact-generating infestations (Table 1).

Photo 11. Accumulation of floating rafts of water hyacinth in wind-exposed bays of Horseshoe Lagoon (western banks), taken January 2022.

System specifics

Where discussion relates to management issues listed in Appendix 1 or mapped in Appendix 2 the designated management issue (M) number is referenced.

As identified above, modification of the hydrology and water quality of the Horseshoe Lagoon system following the development of the BHWSS within its southern and eastern catchment has led to the proliferation of aquatic weeds to the detriment of habitat values (M4) and ecological function. While most aquatic weed species recorded within the Lower Burdekin are known within the system, the exotic species of primary concern are floating water hyacinth and fringing aquatic grasses para and hymenachne (Photo 3 and 4). In the time series aerial photographs of Horseshoe Lagoon (Figure 2), floating rafts of water hyacinth filling the bays of the lake become visible in the 1994 image. Aerial images prior to this time exhibit native aquatic plant patterns. Also visible in the 1994 image are broad infestations of native lotus lily a species that occurred naturally in the lagoon (also visible in 1982: Figure 2), but one that is known to proliferate and become 'weedy' under sustained water level conditions (Econcern 2021). Other native species that have been observed to behave as weeds within the modified system include submerged duck weed (*Ceratophyllum*), floating rice grass, and cumbungi. Unlike smaller water bodies where water hyacinth can form complete surface-covering mat-like infestations, factors like the size of the Horseshoe Lagoon waterbody, regular control efforts, and prevailing winds limit the formation of such infestations to within wind-sheltered bays, or against the banks of wind exposed bays (Photo 11). In smaller channel-hosted lagoons and coastal wetlands of the lower system, water hyacinth does form surface-covering mat infestations (Figure 4 and 5). Salvinia, a small floating aquatic weed, along with para grass and hymenachne, is also observed to form surface-covering mat infestations within the smaller waterholes of the lower system's creek channel.

In the mid-2000s the BSC, through its land protection officer, engaged Horseshoe Lagoon riparian landholders in a Riparian Management Agreement (RMA). This included agreeing to share the cost of a boat-based, chemical (glyphosate) spaying-control program for the main weed species of concern, including water hyacinth and hymenachne. Periodically established patches of giant lotus lily have also been controlled under the RMA, as have cumbungi stands developed amongst fringing aquatic grass margins (Figure 3.) Other cost-sharing partners in the RMA include the BSC, Sunwater and NQ Dry Tropics. While the Horseshoe Lagoon waterbody is conservation park, QPWS is yet to participate in the RMA cost sharing.

This RMA has operated for more than 15 years, with up to six spraying interventions per year conducted initially by a private contractor, now BSC operators, in the main Horseshoe Lagoon waterbody. Additional investment in aquatic weed control within the system has come from NQ Dry Tropics, which has supported between one and two helicopter-based spraying interventions annually on the main lagoon if and when surface weed infestations have grown too extensive to be effectively controlled by boat-based operations. NQ Dry Tropics has also supported a helicopter-based spraying intervention for surface-covering water hyacinth infestations in the Corrick Plains coastal wetland complex; a rake-mounted excavator weed biomass removal program adjoining the Queensland Rail (QR) crossing of the lower system, and a drone-based spraying program of water hyacinth mats adjoining the public bird viewing facility on the main Horseshoe Lagoon. Overall, these collective weed management efforts have been successful in maintaining the main lagoon system as an open waterbody with recurring water hyacinth infestations generally now limited to only narrow marginal areas (Figure 3).

Outstanding weed management issues

Despite the success of the RMA-supported aquatic weed control program, some outstanding weed management issues – and opportunities for improving the ecological benefits of weed control efforts – are identified. Some of these issues are shared with other Lower Burdekin wetland systems (Econcern 2021, 2022b) and include the following:

- Persistent and cyclical re-infestations of the main lagoon with floating aquatic weeds (M6), primarily water hyacinth. The reasons for reinfestation need examination in any planning strategy that seeks to improve management outcomes. Likely contributing factors include:
    - sustained high water levels and nutrient availability associated with inflows from irrigation scheme tailwater and catchment land use sources, including via groundwater connectivity;
    - cycling release of nutrients from spayed dead weed biomass that sinks in the water column (M6);
    - limitations in control intervention effectiveness; and
    - retained weed plants and propagules that provide sources of reinfestation.
- Accumulation of bay-blocking floating weed mats in lake margins exposed to the prevailing wind. Even when the overall floating aquatic weed infestation rate of the Horseshoe Lagoon system is low, prevailing winds often accumulate wide, bay-blocking floating rafts of aquatic weeds against bank margins, including near the public bird hide (Photo 11). This impact further reduces the habitat value of shallow margin areas.
- Contribution of spray-controlled dead weed biomass to water quality degradation of lagoon. Namely, dissolved oxygen degradation due to biological oxygen demand of decomposition and nutrient loading released from decomposed weeds.
- Impact of aquatic grass/lagoon margin spraying on native emergent aquatic plant habitats (M4). While the ecological motivation for controlling aquatic weeds is to improve opportunities for native species and habitats to re-establish; under the system's modified hydrological conditions, aquatic grass weeds are the main re-colonisers of sprayed areas, along with minor cumbungi and giant lotus lily. They are then subject to follow-up spraying, resulting in no net habitat gain, other than open water maintenance (Figure 3).
- Lagoon outflow channel blocking infestations of hymenachne (M8) and water hyacinth. The prevailing wind direction accumulates floating water hyacinth mats at the lagoon outflow channel entrance. These become entrained into the channel outflow, and then captured within hymenachne stands. In wetter years, the hymenachne adjoining the outflow channel remains too wet/inundated to allow grazing cattle access to the pasture. The result is a weed-choked channel and potential fish passage barrier (see *Fish passage barriers* and *Grazing regime* sections)

- Inaccessible, channel choke-forming aquatic weed infestations within the lower creek system (M12). The creek system downstream of Horseshoe Lagoon contains valuable aquatic habitats. However, under the modified hydrological condition created by sustained aseasonal inflows, both aquatic floating and grass weeds proliferate and impact open water and fringing habitat availability, water quality, and fish passage.
- Increasing domination of the Corrick Plains coastal wetland complex by floating mats of water hyacinth and other weed species, and by stands of native cumbungi (M13). The latter is increasingly occupying wetland margins previously supporting para grass growth (Figure 4). Weed infestation of the lower system coastal wetlands on Corrick Plains is observed to have increased over the past two decades to the detriment on native aquatic plant communities, bird habitats, water quality, fish passage, and pasture productivity (Figure 4). Equivalent degradation of coastal wetland-receiving tailwater has been documented elsewhere on the Lower Burdekin floodplain, for example, Lower Plantation and Sheep Station creeks (Econcern 2021).

2004 2013 2016

2017 2019 2022

Figure 3. Horseshoe Lagoon bank margin condition and weed infestation status 2004 to 2022 following ~16 years of spray-based control of floating aquatic and grass weeds. Note dead fringing aquatic grasses killed by spraying.

As noted above, the primary driver of observed weed infestation within the system is the altered hydrology associated with tailwater inflows and the nutrient loading associated with these inflows. Reducing, or ceasing, aseasonal inflows and reinstating some level of seasonal hydrology is the optimal approach for addressing the system's weed infestation and many of its other ecological health issues. Whether this is possible, even in the longer term, depends upon water manager commitments to new infrastructure and irrigation scheme operational commitments. Other issues, such as groundwater connectivity, may also ultimately undermine the capacity to manage system hydrology by surface water management interventions alone.

Weed management opportunities

With the objective to improve aquatic weed management outcomes, it is useful to consider opportunities through the lens of two different contexts. One of these considers possible system hydrological management interventions, for example, controlled inflow volumes, or Horseshoe Lagoon water level manipulation (see *Altered Hydrology* recommendations). The other approach involves thinking about actions that result in minimal changes to the system's current hydrological behaviour; in other words, working better with the existing system. Ideally, management actions could focus on the latter, while managers develop the capacity to deliver intervention-based approaches.

Here are some actions that could be taken under each management context:

1. Aquatic weed management opportunities with hydrological management intervention
   - Drawdown main lagoon water level to extend the dry season period; strand floating weed mats (and fringing submerged aquatic plant biomass) on exposed banks; and facilitate grazing-based control of fringing aquatic grasses of lagoon margin (see *Grazing Regime* section). These actions would negate the need for lagoon margin spraying, and would promote native emergent aquatic plants.
   - Install a creek-level sensor that communicates to the 'smart gate' at the main tributary drain (HR5) to help cease outflows from the Horseshoe Lagoon system. This extended dry season period would support the isolation and drawdown of channel-hosted waterholes, while stranding floating weed mats on exposed banks. Also, implement grazing-based control of the lagoon outflow channel (M6) and fringing aquatic grasses of the lower system creek channel margins (M12) (see *Grazing Regime* section).
   - Cease freshwater inflows to Corrick Plains coastal wetlands for the dry season period, ensuring off-stream pasture pondages are inundated before flows cease. This intervention would support the drying out and death of fringing cumbungi stands and floating weed mats. It would also help transition water quality toward a brackish regime in late dry season to support re-establishing native bulkuru spikerush in wetland basins and para grass on basin margins. It would also promote improved water quality and habitat values in subsequent wet season inundation events (M13).

2. Improved aquatic weed management opportunities with existing hydrological regime
   - Implement aquatic weed control methods, like physical harvesting and removal, that avoid nutrient recycling from sunken dead spayed weed biomass (M6). For instance, given the wind-promoted weed mat accumulation on the banks of Horseshoe Lagoon, excavator-mounted rakes or weed-lifting conveyors could be used opportunistically to remove weed mats when ideal conditions occur. This action would assist the nutrient balance and water quality condition of the main waterbody. Ideally, converting harvested weed biomass to a commercial compost or organic soil ameliorant could help offset the costs associated with the use of such machinery. This remains an aspirational goal for aquatic weed management in the broader region, and initial trials have been conducted (Econcern 2021).
   - Improve spraying control intervention effectiveness. This includes facilitating more frequent interventions; enhancing access to monitoring information via regular landholder communication and/or use of a drone flyover; targeting an enlarged operational area of the system, including upper catchment channels and off-stream weed refuges, the latter possibly involving use of drone-based spraying. Also, using different equipment or methods that support increased system access and more effective control, like longer spray booms and higher pressure pumps.
   - Conduct targeted control of weed reinfestation sources, including upper catchment areas and off-stream wetland refuges, to reduce or eradicate site reinfestation potential. A 'line of control' through the wetland system from upper to lower catchment areas could assist control outcomes. A strategic time is immediately following wet season flood flushing flows that have removed most aquatic weed biomass, leaving only small residual infestation to control (Econcern 2021).
   - Establish and promote dense canopy shade-casting riparian vegetation around the full supply water level of the lake margin. This action would exclude bank anchoring points for aquatic grasses and bank margin grass density where bank profiles are steeper. This has habitat benefits to riparian vegetation, shade-tolerant native emergent water plants, and water quality gains, including cooler water, and higher dissolved oxygen and nutrient uptake (see *Lack of riparian vegetation* section).
   - Use grazing and burning regimes that reduce the likelihood of hot fires, helping native vegetation to restore. Implementing controlled grazing in areas where the bank profile allows cattle access in the lagoon margins will reduce the abundance of aquatic grass weeds along the foreshore areas (M2). With or without grazing, introducing controlled burning of marginal areas in the late dry season – when dry thatch conditions allow and where fire breaks/risks, including to remnant riparian vegetation, can be managed – presents another avenue for reducing the abundance of fire-sensitive aquatic pasture grasses from lagoon edges. Fire also promotes a range of water margin native plant species, like native pea *Sesbania,* which is an important waterfowl moulting habitat.
   - Survey the system for the presence of biocontrol organisms for a suite of aquatic weeds, particularly salvinia. Facilitate a targeted introduction of organisms where needed.

Aug 2004

Jun 2013

Sept 2013

Mar 2015

Sept 2016

Nov 2018. *NB:* Dark signatures are cumbungi occupying areas that previously supported para grass.

Figure 4. Changing aquatic plant community at tidal bund interface of coastal wetland Corrick Plains Nature Refuge, 2004 to 2018.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Pursue funding opportunities and establish stakeholder engagement, including consulting with Sunwater, to develop a hydrological regime management capacity for Horseshoe Lagoon system. This would include water use, management arrangements and infrastructure (see *Altered hydrology* section). Following the discussion about management options above, the main opportunities recommended for improved weed management are:
    - I. Implementing a staged dry season drawdown of the main Horseshoe Lagoon water levels, and
    - II. Ceasing aseasonal flows out of Horseshoe Lagoon in the dry season, including into adjoining irrigated farmland catchments to the lower creek and coastal wetland system.
2. Engage funding partners to further develop and trial systems on site, including considering machinery/infrastructure and site conditions, to investigate the viability of increasing the use of physical biomass removal as an aquatic weed control method. Also, further explore the cost offsetting opportunities of soil ameliorant/fertiliser product development. Target wind-accumulated bank edge weed mat areas for trials.
3. Trial and conduct a cost-benefit analysis on a concerted ‘enhanced control intervention’ aquatic weed program. This action includes identifying funding/sponsorship opportunities and engaging with existing BSC weed control service providers, and/or engage other private contractors. Time the trial to follow a wet season flushing event. Employ a catchment-based ‘line of control’ approach, working from the most upstream channel entry to the system, moving downstream, and targeting all adjoining off-stream weed refuge areas with multiple and shortly spaced (~monthly) control interventions. These efforts would employ drone or helicopter-based aerial application to achieve a complete eradication control outcome. As part of the cost-benefit analysis, monitor the timing and source/process of any subsequent reinfestation, and note the follow-up maintenance control required.
4. Engage with site landholders, management agency stakeholders, and service providers to extend weed management initiatives to the lower Horseshoe Lagoon system. Actions include:
    - I. Early in the post-wet season flush, conduct follow up spraying of residual floating aquatic weed infestation sources within creek channel-hosted waterholes and the coastal wetlands of Corrick Plains. Appropriate equipment is needed to access infestations, including a small boat, argo, amphibious vehicle, and drone or helicopter (for spraying).
    - II. Survey the lower system for the presence of biological control agents for salvinia and, if they are not present, facilitate their reintroduction.
5. Engage with landholders adjoining the main lagoon waterbody to identify suitable incentives to facilitate reinstating grazing pressure. Bank profiles provide suitable access of grazing stock to aquatic grass pastures (see *Grazing Regime* section). An associated goal is to develop a method and manual that can be applied to the whole system.
6. Support the BBIFMAC salvinia biocontrol weevil breeding programs (W21). Aid BBIFMAC to record the status of weevil populations within the Horseshoe Lagoon system and, if effective populations are not present, plan reintroduction programs following successful weevil production.
7. Engage with Horseshoe Lagoon foreshore landholders (see also *Critical wildlife habitat* section) to negotiate support for the revegetation of selected lagoon bank areas at the full supply level (FSL) water line with dense canopy-forming, shade-casting riparian tree species, like Leichardt and paperbarks. Also, to provide resources for planting, site maintenance and monitoring, including examining grass control effectiveness, associated native emergent vegetation regeneration, instream water quality conditions (DO, temperature), submerged aquatic plant suppression, and wildlife usage.
8. Trial hot burning of fire sensitive aquatic grass margins in the late dry season as a potential grass control method with broader site prescription. This requires engaging landholders adjoining the main lagoon waterbody (see also *Fire regime* section) and receiving their support. The trial site would be based on fire break opportunities and to avoid risks to existing riparian vegetation. Also, consider the integrated use of spot chemical spraying, and/or applied grazing pressure post fire (as per *Riparian Grazing Guidelines* Tait 2011) and monitor post-vegetation regeneration and habitat merits.
9. Form a local Horseshoe Lagoon Catchment Management Group with responsibility for overseeing the implementation of supported SMP recommendations. This includes direct engagement and development of the aquatic weed management program.

Table 1. Aquatic weeds of Lower Burdekin wetland systems

Common name (* = native)	**Genus species**	**Growth form, habit, and main impacts**	**WONS**	*Queensland Biosecurity Act 2014* **category**	**Priority target weeds of BSC's *Aquatic Weed Management Plan 2020-2025***	**Management methods and notes**
Water hyacinth	*Eichhornia crassipes*	Floating species. Forms rafts that get colonised by other emergent and surface scrambling species, particularly aquatic grasses. Large infestations cover the water surface of lagoons and channels and create anoxic (no dissolved oxygen) reaches and fish passage barriers. Blocks channel flows, increases flood risks and creates mosquito breeding habitat.		3	X	Physical (weed harvester, rake excavator), registered chemicals and biological (weevils). Raft concentration (i.e., culvert gates) and catchment isolation methods are useful. Nutrient removal via harvesting.
Water lettuce	*Pistia stratiotes*	Floating species. Floating plant with similar habit as water hyacinth. Contributes to mixed species floating weed mats.		3	X	Physical (weed harvester), biological (weevil) and registered chemicals. Nutrient removal via harvesting
Salvinia	*Salvinia molesta*	Floating species. Prefers still water. Covers and shades the water surface and contributes organic loading, decreasing dissolved oxygen levels.	X	3	X	Registered chemicals and biological (weevil). Nutrient removal via harvesting.
*Azolla	*Azolla spp*	Floating species. Prefers still waters. Floating plant with similar habit and potential impact to salvinia. Indicative eutrophication.		Not categorised		Physical – water quality management – indicative of high nutrients.
Para grass	*Urochloa mutica*	Emergent aquatic grass. Occurs in dense monocultural stands in moist drainage depressions and riparian vegetation understorey. Extends onto and binds floating weed mats. Shades shallows, excludes native aquatic plants, block channels, suppresses native vegetation recruitment, introduces high fire fuel loads into riparian zones, contributes high organic loading, depletes dissolved oxygen levels.		Not categorised		Physical (rake excavator), registered chemicals and grazing. Implementation of effective grazing systems including the use of water level drawdown is key to the management of this species.
Hymenachne	*Hymenachne amplexicaulis*	Emergent aquatic grass. Occurs on a bank edge zone and grows into water ~2m deep. Extends onto and binds floating weed mats. Similar suite of impacts to para grass but extends into deeper water and not as far up bank onto levees.	X	3	X	Physical (rake excavator), registered chemicals and grazing. Use of haloxyfop down to the water line will protect the natural recruitment of native macrophytes and trees.
Aleman grass	*Echinochloa polystachya*	Emergent aquatic grass. Occurs on a bank edge zone and grows into water ~2m deep. Extends onto and binds floating weed mats. Blocks channels. Outcompetes native aquatic plants on bank edge and shallows zones.		Not categorised		Physical (rake excavator), registered chemicals and grazing. Use of haloxyfop down to the water line will protect the natural recruitment of native macrophytes and trees.
*Rice grass	*Leersia hexandra*	Emergent aquatic grass. Extends onto and binds floating weed mats, forms major infestation in deeper waters of lower catchment bunded drainages.		Not categorised		Physical (rake excavator and/or weed harvester), registered chemicals and grazing. The effectiveness of the weed harvester on this species has not yet been assessed. Good waterfowl habitat.
*'Water green'	*Ipomoea aquatica*	Emergent/floating aquatic vine. Occasionally extends onto and binds floating weed mats.		Not categorised		Physical – not generally a significant problem unless part of the weed mat. Good habitat.

*Cumbungi	*Typha domingensis*)	Emergent bull rush. Occurs in the water edge zone in most of the catchment but forms major infestations in lower catchment bunded drainages. Blocks channels, creates anoxic reaches/fish passage barriers due to high biological oxygen demand (BOD) of accumulated organic material. Decreases native plant diversity and waterbird habitat.		Not categorised		Registered chemicals, water level manipulation and physical (burning, harvesting), i.e., removal of root stock with an excavator. Prevention of tailwater inflows/draining to create seasonal drying has been demonstrated to be very successful.
*Duckweed	Ceratophyllum *demersum*	Submerged aquatic. Forms dense non-rooted submerged beds. Causes depletion in dissolved oxygen values below levels lethal for aquatic organisms/fish during summer night-time respiration and/or turbid wet season inflows.		Not categorised		Physical – weed harvester, shading, water level manipulation, pump foot valve protection. Good habitat.
Cabomba	*Cabomba caroliniana*	Submerged aquatic. Cabomba is an aggressive perennial that can form dense canopies below the water surface. Infestations displace native plants and animals, affect water quality, and impede recreational water users.	X	3	X	Only recorded from Healey's Lagoon. Mechanical control – hand-pull small infestations, taking care to remove the entire plant to prevent re-infestation. Use harvesters on larger areas for temporary control. Herbicide control (Carfentrazone) is currently the only herbicide registered for control of cabomba.
*Giant lotus	*Nelumbo nucifera*	Emergent lily bed. Mainly recorded from more seasonal sub catchment wetland reaches. Emergent plant of bank edge grows in water ~2m. Can block channels, and creates a foundation for accumulation of floating weed mats.		Not categorised		Registered chemicals, water level manipulation and physical (harvesting, cutting). Good habitat.
*Umbrella sedge	*Cyperus exaltatus*	Emergent sedge aggressive secondary coloniser on floating 'platforms' weeds. Occurs throughout the creek system in the water edge zone but forms extensive occurrences in moist margins and depressions of lower catchment-bunded drainages.		Not categorised		Registered chemicals, water level manipulation and physical (harvesting, cutting) – not a major problem. Good habitat.
*Smart weed	*Persicaria decipiens*	Emergent plant that occurs in moist drainage depressions and riparian vegetation zones and extends onto and binds floating weed mats. Forms mono cultural stands usually in response to grazing pressure.		Not categorised		Registered chemicals, physical – not generally a significant problem unless part of weed mat. Good habitat.

Table 2. Emerging aquatic weed risk species of the Horseshoe Lagoon system

Common name	Genus species	Growth form, habit, and main impacts	WONS	*Queensland Biosecurity Act 2014* **category**	Management methods and notes
Arrowhead 	*Limnocharis flava*	An anchored aquatic plant with erect stems that grows in saturated, fertile, and muddy conditions as a perennial plant in areas with sufficient moisture. Can also be annual where moisture is seasonal. Plants grow up to 1m above the waterline. Colonises shallow wetlands and margins of deeper waterways. Blocks channel flows, traps silt, increases flood risks, creates mosquito breeding habitat, reduces access to waterways and displaces native plants and animals. Has been recorded in the Townsville local government area.		2, 3, 4 and 5	No herbicides are registered to specifically control limnocharis and there are no known biological control agents. *Queensland Biosecurity Act 2014* requires that new infestations must: • be reported to Biosecurity Queensland on **13 25 23;** • be identified and removed by approved officers, and • have locations recorded prior to removal. Classed as very high risk in *Burdekin Shire Council Biosecurity Plan* (BSC 2020).
Sagittaria 	*Sagittaria platyphylla*	Emergent aquatic perennial up to 1.5m tall. Grows in irrigation channels, drains, creeks, rivers, lagoons, dams, and wetlands. Establishment favoured by slow moving or static shallow water. Forms floating mats, blocking irrigation ditches, shallow dams, and waterways. Invades and degrades natural wetlands. Competes with native water plants. Has been recorded in the Townsville local government area.	X	3	No herbicides are registered to specifically control sagittaria. Off-label use permits PER80934 allow for the use of glyphosate as a foliar spray. Control is best carried out when water levels are low. Hygiene and containment measures need to be applied to prevent further spread downstream. Mechanical control – place all removed plant material in a sealed plastic bag, leave in sunlight to decompose, then dispose of at council-approved landfill. Alternatively, leave material in the sun to dry, then burn. Classed as very high risk in *Burdekin Shire Council Biosecurity Plan* (BSC 2020).
Water mimosa 	*Neptunia oleracea*	Floating perennial weed that attaches to a bank at the water's edge. Stems to 1.5m long, grow out over water and form spongy, fibrous covering between nodes. Grows on land in damp soil or on water as thick floating mats. Commonly found in and around freshwater pools, swamps, and canals. It is a nitrogen-fixing legume that releases nitrogen into water bodies. This can lead to increased algal blooms and encourage growth of other weeds. Restricts water flow and increases water loss through evapotranspiration. Smothers water surface, shading out native aquatic plants, leads to deoxygenated water and impacts fish populations and creates mosquito habitat. Has been recorded at Saltwater Creek in the Burdekin local government area. Has been subject to sale and distribution through Asian communities and gardeners.		2, 3, 4 & 5	No herbicides are registered for control and there are no known biological control agents. Mechanical control – remove all plant matter from infested waterbody and pull plants out of surrounding banks, making sure to remove the attached root system. Dispose of plant parts in an appropriate waste facility or rubbish bin. Water mimosa is a restricted invasive plant under the *Queensland Biosecurity Act 2014.* • All sightings must be reported to **Biosecurity Queensland** within 24 hours of the sighting. • It must not be given away, sold, or released into the environment without a permit. Classed as very high risk in *Burdekin Shire Council Biosecurity Plan* (BSC 2020).

Water quality

What are the issues and state of knowledge?

Water quality in seasonal Lower Burdekin floodplain wetlands is naturally variable through the year. Under natural predevelopment conditions, water quality in distributary stream systems and their hosted wetlands transitioned from turbid floodplain-inundating flows in the wet season, settling, and clearing into the non-flow period of the early dry season, and then interacting with groundwater that maintained perennial lagoons during the water level drawdown period of the late dry season (Perna *et al* 2012). Seasonal 're-setting' of water quality would then follow with wet season rainfall leading to local catchment run-in, then flow initiation, and – in larger events – Burdekin or Haughton River overbank flushes down distributary systems (Davis *et al* 2017). In seasonal drying wetlands, water quality generally progressed through to the clearing phase, and then into a critical period with higher temperature and turbidity and lower dissolved oxygen prior to drying.

In the contemporary, modified floodplain system, wetland water quality is largely driven by the condition of sourced Burdekin or Haughton River water supplying irrigators via regulated creek flows; aseasonal inflows of farm irrigation tailwater or Burdekin Haughton Water Supply Scheme (BHWSS) channel overflow; the condition of creek reaches or lagoons, particularly their weed infestation status, and by the quality and contaminant load of surface and groundwater inflows from their catchment.

Some of the processes and key drivers of water quality associated with predevelopment hydrological conditions no longer occur as frequently, in the natural seasonal period, or at all. For example, flow cessation, dry season water level drawdown, groundwater domination of inflows, Burdekin/Haughton River overbank flood flow flushing and scouring (Perna *et al* 2012). However, even under the contemporary modified regime, wetland water quality still undergoes major seasonal variation with the early summer wet season, including pre-flushing flow or flood inundation, being identified as the period of greatest water quality stress for hydrologically modified systems (Burrows *et al* 2006, Veitch, *et al* 2007).

Very few sites within the Lower Burdekin floodplain have been a focus for regular water quality monitoring programs. Therefore, our state of knowledge is mainly informed by studies examining water quality issues more generally across the floodplain and within selected drainages, and for some specific fish habitat and weed management investigations (Davis *et al* 2013, 2014, 2017, Veitch *et al* 2007, Veitch and Burrows 2006, Burrows *et al* 2006, Loong *et al* 2005, Perna 2005, Pearson *et al* 2003, Hunter *et al* 1998, Hunter *et al* 1996, Keating *et al* 1995). Fortunately, there have been some specific investigations of the Horseshoe Lagoon system (Burrows and Perna 2005, Dowe 2005, Loong *et al* 2005).

Data collected in the Lower Burdekin and broader Great Barrier Reef (GBR) catchment is available at:
https://www.reefplan.qld.gov.au/tracking-progress/paddock-to-reef/modelling-and-monitoring

https://qgsp.maps.arcgis.com/apps/MapSeries/index.html?appid=9d1aad1e2b444ec6a1890e4032284147

There are water quality issues that are known to cause aquatic ecosystem impacts in the Lower Burdekin floodplain, including the Horseshoe Lagoon system and downstream receiving environments, such as the Cape Bowling Green Bay Ramsar wetland and the GBR World Heritage Area. These issues include:

- low dissolved oxygen (DO);
- high turbidity/total suspended solids (TSS);
- elevated nutrient levels;
- agri-chemical residues, and
- salinity.

The drivers/likely causes, potential impacts, and data and management notes for these issues are summarised in Table 3. Specific considerations for this SMP are discussed below.

System specifics

Where discussion relates to management issues listed in Appendix 1 or mapped in Appendix 2, the designated management issue (M) number is referenced.

As discussed in the *Altered hydrology* section, the contemporary water quality conditions of the Horseshoe Lagoon system are highly influenced by inflows of tailwater from the BHWSS that introduce both suspended solids and nutrients (Photo 1 and 2). Historically, the naturally highly seasonal wetland system would have no source of suspended solids and nutrient loading outside of the wet season, and no local catchment run-in or breakout flows from the adjoining Haughton River Channel. Suspended sediments would settle or be attenuated by submerged aquatic plants. Growth of aquatic plants and the stranding of plant biomass on exposed banks associated with seasonal drawdown would have also served the system in the uptake and processing of available nutrients. Historical aerial images (Figure 2) indicate that the main Horseshoe Lagoon generally had a clear tannin stain water quality outside of the wet season period where turbidity would have been elevated by run-in (Figure 2, Jan 1976 image). Being a relatively shallow open waterbody, when water levels decreased through the dry season, there would be some opportunity for wave action to resuspend bottom sediments and increase turbidity in shallow basins (Figure 2, Jun 1969 image), although deeper basins remained clear. In the contemporary system, turbidity levels can vary widely through the calendar year (Figure 5). In contrast to natural variability, it is often during the dry season irrigation period when tailwater inflow volumes are high that the system can be the most turbid (M5), and the period of the wet season when irrigation demand and tailwater inflow volumes low that the system can be clear.

Table 3. Lower Burdekin floodplain water quality issues

Issue	Drivers/likely causes	Potential impacts	Data and management notes
Low dissolved oxygen	• Aquatic weed infested waterway reaches are promoted by near-perennial regulated flows/sustained water levels and high nutrient availability. • Biological Oxygen Demand (BOD) associated with bacterial decomposition of organic material produced or trapped by aquatic weeds, including grass margins inundated by higher wet season water levels. • Night-time or turbid inflow-promoted respiration of submerged aquatic plants and attached periphyton. • Prevention of instream photosynthesis/oxygen production by turbidity/weed shading. • Prevention of aeration of the water surface due to weed covering. • High BOD of organic loads in catchment run in during wet season. • Deoxygenated groundwater inflows. • Lack of river overbank flooding flushes in the wet season. • Lack of riparian shading/higher water temperatures.	• Fish kills. • Anoxic stream reaches that function as fish passage barriers. • Deoxygenated 'blackwater' flows to downstream receiving environments, including upper reaches of estuaries. • Reductions in instream productivity, biodiversity (including aquatic macroinvertebrates) and fishery resources. • Increased solubility and mobilisation of nutrients in sediments.	Issue well documented by site specific and regional catchment studies (Perna 2003, 2004, 2005, Loong *et al* 2005, 2006, Burrows *et al* 2006, Veitch and Tait 2007). <u>Management objectives</u> • Reduced aquatic weed and submerged plant biomass. • Greater riparian shading. • Reduced instream nutrient availability. • Reduced BOD/organic loading in catchment run in. • Targeted monitoring to increase understanding of specific issues, including: ○ impact of aseasonal flow cessation on DO levels through system, ○ role of BOD load in catchment run in on DO status, ○ DO levels through exotic grass-dominated drainage channels under different flow conditions, ○ status DO in lower system creek channel waterholes and Corrick Plains coastal wetlands, and impact of aseasonal inflows and aquatic weed infestation.
Turbidity	• Mean annual total suspended solid (TSS) loads underpinning turbidity have increased, on average, six-fold in GBR catchment rivers since European settlement. • Burdekin Falls Dam (BFD) receives turbid wet season flood flows and has minimal colloidal settlement. • Irrigation supplies pumped from Burdekin River flows supplied from persistently turbid BFD. • Catchment soil erosion and sediment loads carried in local catchment surface runoff influences turbidity levels during wet season.	• Multiple times the natural run-in loading of receiving water bodies with attached nutrients. • Reduced instream primary productivity. • Reduced submerged water plant diversity and density. • Reduced success of visual predator fish and impacts to sensitive aquatic invertebrates (for example, filter feeders).	Issue well documented at a regional scale with few catchment studies (Perna 2003, 2004, Davis *et al* 2014, 2017). <u>Management objectives</u> • Few management options exist for turbidity imported with BFD water in BHWSS tailwater inflows. Options lie with on-farm BMP and protecting drainage channels from erosion. • For local contributing catchment area there is opportunity to reduce sediment loads in runoff through management of soil erosion risks and catchment groundcover in grazed areas. Also via the design of farm drain systems that incorporate detention basins and vegetation that attenuates suspended sediment loads.
Nutrient loading	• Nutrient load attached to colloids in irrigation supplies pumped from turbid Burdekin River. • Catchment land and water use practices that result in off-farm/property losses (including via groundwater flows) of nutrients, for example, on farm fertiliser use, irrigation tailwater, and post-harvest runoff of high BOD sugar. • Organic nutrients released from decomposing aquatic weed and submerged plant biomass, for example, following weed spraying and during elevated wet season flows.	• Eutrophication (nutrient pollution) of waterway. • Promotion of aquatic weed/submerged plant growth and associated impacts. • Algal blooms, dissolved oxygen crashes, and fish kills. • Export of elevated nutrient loads to downstream-receiving environments,	Limited site data available. Sunwater monitors tailwater drainage systems, but data is not publicly available. Previous site monitoring has recorded concentration exceedances above ecosystem health guidelines (Perna 2003, 2004, Loong *et al* 2005, Davis *et al* 2013. 2014, 2017). <u>Management objectives</u> • Improve on-farm/property practices, for example, fertiliser application rates and practices and irrigation scheduling and volumes.

Issue	Drivers/likely causes	Potential impacts	Data and management notes
	• Wet season local catchment run-in of sediment and attached and dissolved nutrient loads. • Mobilisation of nutrient loads accumulated in bottom sediments (particularly when water becomes anoxic).	for example, Ramsar wetland and GBR lagoon.	• Remove and/or control aquatic weed and submerged plant biomass. • Promote riparian vegetation buffers and emergent aquatic plant stream margins with nitrate stripping/uptake functions. • Design farm drainage systems to provide nutrient interception and processing capacity, including riparian and aquatic vegetation, detention basins, and controlled rates of runoff/discharge.
Agri-chemical residues	• On-farm use and practices that lead to off-farm losses including inadequate chemical storage, application methods; timing (especially in relation to rain and irrigation events) and conditions; wash down, and irrigation practices. • Off-farm movement via irrigation tailwater, groundwater accession and rainfall runoff. • On-stream use for aquatic weed control.	• Direct lethal effects on periphyton and phytoplankton. • Long-term, low-dose pesticide exposure can produce effects in freshwater organisms after several generations affecting growth, metamorphosis, locomotor activity, antipredator behaviours, immune capacity, infections, and gonadal condition. • Sublethal effects on endocrine systems of fish and endocrine disruption in amphibians. • Export of pesticide residue loads to downstream receiving environments. For example, Ramsar wetlands and GBR lagoon present impact risks to mangroves, seagrass, algal endosymbionts in corals and benthic microalgae.	Issue documented regionally, including in adjoining drainages, regional groundwater and at Burdekin farm drainages. Previous monitoring of the floodplain creek system has recorded concentration exceedances above ecosystem health guidelines for both low and event flows. Research indicates mixed pesticide residues produce impacts equivalent to higher concentration (Davis *et al* 2013, 2017, Hunter *et al* 1998, Hunter *et al* 1996, Keating *et al* 1995). <u>Management objectives</u> • Improved on-farm/property practices, such as pesticide application rates and use timing in relation to rain and irrigation events, and irrigation methods and applied volumes. • Increased use of tailwater recycling pits and treatment wetlands. • Real time monitoring and reporting at paddock/sub catchment scale to tie results to practices. • Design farm drainage systems to provide contaminant load interception and processing capacity including riparian and aquatic vegetation, detention basins and controlled rates of runoff/discharge.
Salinity	• Rising saline groundwater contaminating adjoining aquifers and/or discharging to surface water features. • Marine saltwater intrusion into coastal freshwater wetlands or aquifers promoted by high(er) sea levels or drawn-down freshwater aquifers.	• Physiological stress or death of freshwater biota or exposed terrestrial vegetation.	Emerging management issue for Burdekin Haughton Water Supply Scheme (BHWSS) and near coastal areas. <u>Management objectives</u> • Reduce accession of surface water to groundwater (possibly including by lowering of surface water levels in artificially maintained wetlands). • Manage groundwater rise including dewatering bores and conjunctive use/discharge. • Bunding saltwater intrusion pathways and maintenance of hydraulic head for coastal freshwater aquifers. • Accommodate landward migration of coastal wetland mosaic.

Jan 2022 | Sep 2019 | Aug 2017 | Apr 2016

Figure 5. Seasonally variable turbidity conditions observed within Horseshoe Lagoon.

Limnological investigations of the main Horseshoe Lagoon waterbody (Loong *et al* 2005) have found measurements of most water quality criteria meet requirements for ecosystem health, except for nutrients (Table 4). Dissolved oxygen (DO) levels were found to be below critical thresholds for aquatic biota at one site where sampling was conducted beneath a floating water hyacinth mat. No water quality monitoring data is available for the lower system, though tailwater drainage channel discharge (M9) to the lower system (Photo 5), aerial image interpretation, and site investigations (Photo 12, 13, and 15) indicate that it shares the same water quality risks as the main lagoon waterbody. These risks include dissolved oxygen degradation below surface aquatic weed infestations, variable turbidity in relation to tailwater inflow volumes, and eutrophic (nutrient polluted) conditions. However, in comparison to the main Horseshoe Lagoon waterbody, waterholes within the lower system are much smaller and therefore more prone to total surface-covering by aquatic weed infestation. They are also not as open to wind-based mixing of the water column (Loong et al 2005), and therefore more likely to experience critically low DO conditions. Distributary lagoons isolated from tailwater inflows have not been site visited, but aerial photo interpretation (Photo 14) suggests that they retain better water quality more representative of natural conditions. Data collection at these distributary lagoons would provide an informative comparison.

Table 4. Laboratory water quality results for Horseshoe Lagoon (Loong *et al* 2005). Nutrient values exceeding ANZEC Guidelines for ecosystem health are highlighted in yellow.

Vertical position	WQ Zone	Sample	Total Nitrogen (µg N/L)	Total Filterable Nitrogen (µg N/L)	Ammonia (µg N/L)	Nitrate + Nitrite (µg N/L)	Total Phosphorus (µg P/L)	Total Filterable Phosphorus (µg P/L)	Filterable Reactive Phosphorus (µg P/L)	pH	Conductivity (µS/cm)	TDS (mg/L)
top	C	G001	1039		2	8	110		27			
top	C	G002	1271		45	10	141		21			
top	A	W001	1116	749	3	2	126	45	12	8.22	306	154
bottom	A	W002	1377	780	3	3	168	48	16	8.20	306	162
top	B	W003								8.00	308	163
bottom	B	W004								8.00	307	163
top	C	W005								7.53	307	166

Photo 12. Channel-hosted waterholes lower Horseshoe Lagoon creek system June 2013.

Photo 13. Channel-hosted waterholes lower Horseshoe Lagoon creek system Aug 2017.

Photo 14. Clearwater distributary lagoons isolated from aseasonal tailwater inflows.

Photo 15. Algal growth indicative of high nutrient availability at Corrick Plains coastal wetlands.

Proposed hydrological management options (see *Altered hydrology* section) include reduction, or cessation, of tailwater inflows and improved management of aquatic weed infestations. However, the complete cessation of tailwater inflows to the main Horseshoe Lagoon waterbody is probably less tenable given water use patterns. If pursued, reinstating seasonal hydrology to the main lagoon could require a controlled outlet level flow bypass to the Haughton River. In this instance, suspended solid (turbidity) and nutrient loading of the Horseshoe Lagoon waterbody would still occur. A Sunwater management modernisation scenario that effectively reduces BHWSS surface water inputs to the system and groundwater connectivity could provide a pathway for nutrient loading. This highlights the conjunctive water quality management need to address both the aseasonal inflow volumes to the wetland system, and the contaminant loads in the source tailwater contributing to the aseasonal inflows.

Recommendations

1. Implement recommendations in the Altered *hydrology* section as a path towards reducing water quality risks.
2. Implement recommendations in the *Aquatic weeds* section as a path towards reducing water quality risks.
3. Reduce off-farm export of nutrients and suspended solids to the tailwater drainage system by highlighting the underlying driver of aquatic weed infestations – elevated nutrient availability – to Horseshoe Lagoon catchment primary producers. Seek to showcase existing practitioners and/or engage ‘adopters’ in trialling methods or practices, including on-farm fertiliser use Best Management Practices (BMP); irrigation tailwater recycling; farm runoff detention; and establishing riparian vegetation within farm drainage lines, or constructed wetland/detention basins.
4. Redesign tailwater drainage reach in the Horseshoe Lagoon catchment to demonstrate the use of constructed wetlands in the drainage network. Also, to show appropriate in-basin aquatic vegetation management for suspended sediment attenuations and nitrate stripping/nutrient processing.

Fish passage barriers

Fish movement needs

The Lower Burdekin floodplain's native freshwater fish community (Table 5) needs to take a range of movements to fulfill life history cycles, and to distribute to suitable floodplain distributary creek and wetland habitats (Veitch *et al* 2007, Carter and Tait 2010).

The main classes of lifecycle movement are:

- Resident – can complete life history at resident site.
- Potamodromous – needs to move within catchment to different freshwater habitats, for example, from pools to running riffles, gravel beds, or off-stream floodplain swamps.
- Amphidromous – young recruit from marine environments, but adults breed in lower freshwater.
- Anadromous – lives in marine environments and moves to freshwater to breed.
- Catadromous – breeds in marine/estuarine environments and recruits to freshwater.

Even resident species capable of breeding and recruiting juveniles without needing to move to different areas or habitats will still naturally undertake intra-catchment movements to distribute their population and colonise new areas. Potamodromous species are compelled to undertake intra-catchment movements within the wetland system to access required breeding and/or nursery habitats, for example, floodplain wetlands or flowing riffle reaches. Diadromous species are all those that need to move between fresh and marine environments to reproduce and include several of the life cycle types (listed above). Most diadromous species in tropical Queensland, including the iconic barramundi, are catadromous; meaning they spawn as adults in marine waters and, as juveniles, recruit back to freshwater habitats. In evolutionary time, all species – regardless of their life history cycle – need to be able to move within their range to maintain healthy gene flow between populations.

System specifics

Natural connectivity patterns

In seasonally dry climates, the timing of fish movement activity is very much influenced by the framework provided by the wet season conditions under which fish evolved, like attraction to flows. Historically, the distributary drainages of the Burdekin floodplain, such as the Horseshoe Lagoon system, only flowed seasonally during the wet season, often only for short periods, and transitioned to a chain of isolated waterholes in the dry season. Fish passage connectivity was only provided when catchment runoff, floodplain inundation and/or Haughton River channel flood outbreaks generated flow events.

Photo 16. The outflow of Horseshoe Lagoon extends across what was historically a floodplain drainage depression (M7). An excavated channel now provides a conduit for aseasonal outflows that keep the floodplain wetted for extended periods. These conditions support extensive aquatic pasture growth, primarily hymenachne adjoining the channel and para grass on the broader floodplain.

Photo 17. A small open section (cattle crossing) of the Horseshoe Lagoon outflow channel illustrating the dense growth of hymenachne adjoining it. Where grass grows over the channel, it can create anoxic (low dissolved oxygen) water quality conditions which create a fish passage barrier. In drier years when cattle can access the channel for grazing, an open channel is created ahead of wet season flows.

These connective flows provided opportunities for resident species to recolonise seasonal habitats, and give other life history types opportunities to access habitats required for successful breeding. In the case of catadromous species like barramundi, this involved movement of adults to estuary mouths to breed and the return movement of juveniles from coastal nursery swamps, such as Corrick Plains, to the main upstream lagoon. Under pre-development conditions, catadromous fish could enter Horseshoe Lagoon from the top of the system via Haughton River flood breakout flows, as well as via the lower estuarine connected stream reach.

The currency of fish survey data for the Horseshoe Lagoon system is dated (Perna 2003, Burrows and Perna 2005) to provide a current understanding of the status of fish passage connectivity within the system (Table 5). Contemporary assessments of system conditions would suggest that previous survey results remain relevant, and that a deterioration in connectivity status is the most likely trend since these surveys were conducted (Figure 6).

These past surveys recorded few (~4) migratory species within Horseshoe Lagoon, including long-finned eel, tarpon, barramundi and gudgeons. Because the gudgeon was not identified to species level, it is not clear whether it was a resident or migratory species (Table 5). Resident gudgeon species are usually very abundant, so the record of only a single individual (Burrows and Perna 2005) suggests the record may have been a migratory species in low abundance. Tarpon, another normally abundant migratory species, was only recorded on one occasion. Barramundi were recorded on both occasions, but only in very low numbers and their presence was attributed to stocking, rather than natural recruitment, by the report authors. Long-finned eel was relatively abundant on both occasions, but the high capacity of this species for moving across passage barriers means its presence does not provide a useful measure of connectivity available to less vagile species. The fish survey results from nearly 20 years ago indicate a poorly-connected system with a range of migratory species not represented, while those present are in low abundance.

This contrasts with local anecdotal knowledge (including the author's) of the system. Up until at least the mid-1980s, Horseshoe Lagoon was renowned for its barramundi populations, predominantly young age class fish, that were targeted for catch release fishing by members of the Lower Burdekin and Townsville Sportfishing Clubs. The site also has a 1980s record of the endangered freshwater sawfish (*Pristis pristis)* (DES 2022), apparently captured during a drying event. This historical information points toward the lagoon once having good fish passage connectivity, albeit only for short durations under its natural seasonal hydrological character.

Following the fish survey work of the mid 2000s, a farm road crossing of the lower Horseshoe Lagoon stream channel was identified as an operating fish passage barrier (Photo 18). NQ Dry Tropics subsequently invested to rectify this barrier. Site conditions were subsequently modified by high flows and the landholder, and its current effectiveness and status remains unclear.

Types of barriers

In addition to the road crossing barrier, other fish passage barrier threats to asset values are identified for the Horseshoe Lagoon system. These are listed as management issues (M) in Appendix 1, and are mapped in Appendix 2. They include instream structures and poor reach conditions, including:

- a farm road crossing at the transition point between the excavated outflow channel and formed stream channel (Photo 18), which presents an instream physical structure barrier;
- (M7) hymenachne and water hyacinth-dominated excavated outflow channel through the floodplain drainage depression from Horseshoe Lagoon to the lower creek system, which presents a water quality and physical fish passage barrier (Photo 3, 5, 16 and 17; see Figure 8 in *Grazing regime* section);
- (M12) poor reach conditions in the lower system creek channels, including aquatic grass and water hyacinth weed mat chokes, present a likely water quality fish passage barrier (Photo 13 and Figure 6, upstream of the QR line);
- (M13) poor reach conditions across Corrick Plains coastal wetlands (QR crossing to coastal bunds), including surface-covering weed mats and dense cumbungi stands, which present a water quality and fish passage barrier (Figure 6);
- (M14) bund overflow paths between freshwater wetlands and downstream tidal reaches (Photo 6, 7 and 19) present a likely physical barrier for small species/individuals under low/recessionary flow conditions. There could also be a water quality barrier, given the weed infestation status of the coastal swamps.

Other than the two relatively minor instream physical barriers identified (road crossing, coastal bunds), the most significant fish passage issue is the modified hydrological status of the system. These conditions drive the weed infestation and associated water quality constraints that create multiple fish passage challenges (see *Altered hydrology, Aquatic weeds* and *Water quality* sections).

As per the management recommendations for *Aquatic weeds* and *Water quality*, the most significant improvement for fish passage would be achieved via management actions to address the system's hydrological regime, allowing for seasonal channel and wetland drying. Failing that, the challenge for management is to provide – at least for a seasonally-critical period – a conduit of connected channel flow from Horseshoe Lagoon to the estuary that is sufficiently weed free, and has water of a dissolved oxygen status suitable to pass fish. Under its current condition status, this is only likely to occur during large flood events (for instance, ~1 in 20 year ARI) that see flood breakout flows from the Haughton River through the system to the estuary, and provide flushing, freshening, and dilute the biological oxygen demand (BOD). It is unknown if high flow events in the past decade, including recent events, have provided this capacity. Monitoring of water quality and fish movement during such events and surveying of the currently-established fish community would provide valuable information to progress management deliberations.

One of the most significant concerns identified for fish passage, and other ecological functions/habitat values within the system, is the apparently degrading status of the coastal wetlands on the Corrick Plains Nature Refuge (Figure 6). The long-term trend of this system appears to be following other Lower Burdekin coastal wetland systems that have a longer history of hydrological modification due to aseasonal flows. For example, the lowermost reaches of Plantation and Sheep Station creeks on the Burdekin Delta (Econcern 2021). Both systems have weed-infested tidal interface swamps that have presented intractable fish passage barriers for nearly three decades. The condition status of the Corrick Plains appears to be following the same trajectory, including a shift from native bulkuru sedge-dominated open water channels indicative of seasonal hydrological conditions in 2003, through to weed mat-choked cumbungi-fringed and anoxic water bodies in 2018. Drone imagery of this site collected in December 2021 showed the condition unchanged from 2018. It is not known whether recent high flow events have reset the system. Despite its currently-degraded state, it is still assessed to be recoverable given strategic investments in water and weed management.

Photo 18. Farm Road crossing of the stream channel downstream of Horseshoe Lagoon. This instream structure has been the site of past NQ Dry Tropics fish passage investment, though site conditions were subsequently modified by high flows and the landholder, and its current effectiveness and status remains unresolved.

Photo 19. Bunds separating tidal reaches (left) from freshwater swamps nursery habitat (right). While fish passage is available over these bunds during high flows, steep gradients exist during low recessionary flows. Low gradient rock ramps at these bund sites would improve fish passage.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Pursue recommendations in the Altered *hydrology* section to reduce the impact of fish barriers.
2. Pursue recommendations in the *Aquatic weeds* section as a path towards reducing fish barriers.
3. Engage with Fisheries R&D providers to obtain current fish community and fish passage information for the Horseshoe Lagoon system, including:
    a. an initial survey of fish species and abundances at sites stratified through the system including (a) Horseshoe Lagoon (b) creek channel-hosted waterholes (c) Corrick Plains bunded coastal wetlands;
    b. a high flow event survey of fish movement (using fyke nets) and dissolved oxygen conditions at least at sites (a) and (c);
    c. a recessionary flow event survey of fish movement (using fyke nets) and dissolved oxygen conditions at sites (a) and (c), and at the previously identified road crossing barrier.
4. Engage landholder in the conceptual design and revegetation of the Horseshoe Lagoon outflow channel with shade-casting riparian vegetation in conjunction with rock-armoured contour bunds. These break the gradient of the flow channel to create an open, shaded channel that facilitates fish passage, yet is protected and mitigates against head cut erosion risks (W7).

5. Engage landholder in the conceptual design and rock armouring of eroded tidal interface bunds using a rock ramp fishway configuration to protect wetland water levels while enhancing fish passage (W10).
6. Rock ramp fishway repairs are required at existing culverts/fishway.

Table 5. Life cycle movement requirements of fish recorded from Lower Burdekin floodplain freshwater wetland systems (Species recorded at Horseshoe Lagoon by Perna 2003 or Burrows and Perna 2005, * = exotic)

Name	Genus and species	Life cycle movement	Horseshoe Lagoon Record
Tarpon	*Megalops cyprinoides*	Catadromous	2003
Long-finned eel	*Anguilla reinhardtii*	Catadromous	2003, 2005
Bony bream	*Nematalosa erebi*	Resident	2005
Salmon catfish	*Arius graeffei*	Anadromous/Potamodromous	
Rendahl's tandan	*Porochilus rendahli*	Potamodromous	2003
Black Catfish	*Neosilurus ater*	Potamodromous	2003, 2005
Hyrtl's tandan	*Neosilurus hyrtlii*	Potamodromous	2003
Snub-nosed gar	*Arrhamphus sclerolepis*	Resident	
Long-tom	*Strongylura kreffti*	Resident	
Fly-speckled hardyhead	*Craterocephalus stercusmuscarum*	Resident	2003, 2005
Eastern rainbow fish	*Melaanotaenia splendida*	Resident	2003, 2005
Barramundi	*Lates calcarifer*	Catadromous	2005
Jungle perch	*Kuhlia rupestris*	Catadromous	
Agassiz's glassfish	*Ambassis agassizii*	Resident	
Sailfin glass perch	*Ambassis agrammus*	Resident	2003, 2005
Spangled perch	*Leiopotherapon unicolour*	Potamodromous	2003
Striped grunter	*Amniataba perchoides*	Resident	
Mouth almighty	*Glossamia aprion*	Resident	2003, 2005
Mangrove jack	*Lutjanus argentimaculatus*	Catadromous	
Archer fish	*Toxotes chatareus*	Resident	
Scat	*Scatophagus argus*	Catadromous	
Bully mullet	*Mugil cephalus*	Catadromous	
Giant herring	*Elops hawaiensis*	Catadromous	
Milkfish	*Chanos chanos*	Catadromous	
Silver biddy	*Gerres filamentosus*	Catadromous	
Empire gudgeon	*Hypseleotris compressa*	Catadromous	2003, 2005
Midgley's Carp Gudgeon	*Hypseleotris bucephala* (Formerly *H. midgleyi*)	Resident	2003, 2005
Purple-spotted gudgeon	*Mogurnda adspersa*	Potamodromous	
Snakehead gudgeon	*Giurus margaretacea*	Catadromous	
Sleepy cod	*Oxyeleotris lineolatus*	Resident	2005
Big-headed gudgeon	*Philypnodon grandiceps*	Potamodromous	
Flathead goby	*Glossogobius giurus*	Amphidromous	
Speckled goby	*Redigobius bikolanus*	Amphidromous	
*Mosquito fish	*Gambusia holbrooki*	Resident	
*Three-spot gourami	*Trichogaster trichopterus*	Resident	
*Tilapia	*Oreochromis mossambicus*	Resident	

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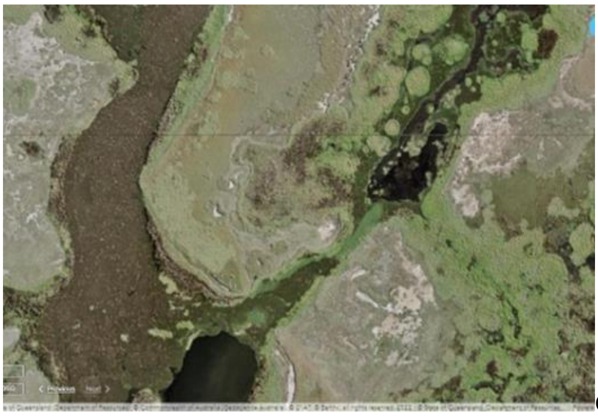
Stream channel upstream of QR crossing, 2003.

Stream channel upstream of QR crossing, 2018.

Corrick Plains wetlands between bunds and QR line, 2003.

Corrick Plains wetlands between bunds and QR line, 2018.

Corrick Plains wetlands between bunds and QR line, 2003.



Corrick Plains wetlands between bunds and QR line, 2018.

Corrick Plains wetlands main tidal bundwall, 2003.

Corrick Plains wetlands main tidal bundwall, 2018

Figure 6. Corrick Plains coastal wetland open water/weed infestation status comparison: 2003 versus 2018.

Lack of riparian vegetation

What is it and why is it important?

The riparian zone is the interface between land and a watercourse or wetland. Riparian zone vegetation is an important component of the landscape because it supports a range of biophysical functions and values. These functions include:

- bank erosion protection;
- maintenance of channel stability and form;
- nutrient uptake;
- interception of sediment loads;
- providing leaf litter food sources and structural habitat, including root undercuts/snags for aquatic ecosystems;
- shading and cooling the water's edge and preventing dense submerged aquatic plant growth, thereby increasing the water's dissolved oxygen carrying capacity;
- excluding sun-loving aquatic and levee grasses, thereby helping to maintain open water habitat and channels, reduce wildfire fuel loads and risk, and decrease pest rodent harbourage habitat.
- Providing wildlife corridors and refuge habitats including for predators of adjoining cane land pests; and
- flood protection by reducing catchment runoff rates and slowing the velocity of channel breakout flows.

In intensively developed landscapes like the Lower Burdekin, the riparian zone assumes additional importance because it is often the most significant area of remnant natural habitat. Given its location at the interface between terrestrial and aquatic ecosystems, the riparian zone is important to both. The quality of instream aquatic habitats is often determined, to some degree, by the condition of the riparian zone (Figure 7). Due to these high ecological and catchment functional values, areas lacking riparian vegetation can present threats to the function and value of the aquatic ecosystem. Therefore, rehabilitation of the riparian zone is a priority focus for nature conservation and catchment management project investment.

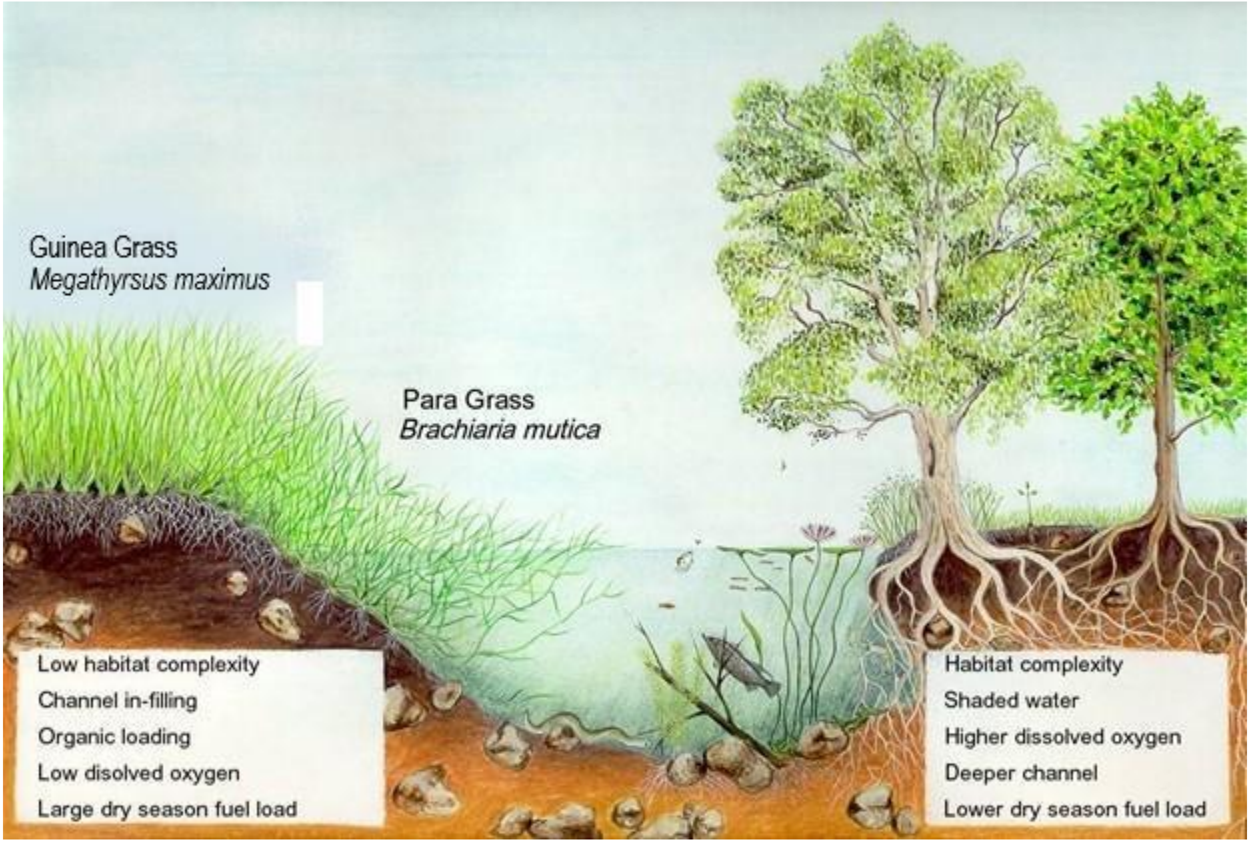


Figure 7. Contrasting ecosystem function and features of an exotic pasture dominated (left) versus native vegetation-dominated (right) riparian zone (Illustration by Lois Genis).

Status of Burdekin floodplain riparian zones

In developed landscapes of the Lower Burdekin, the condition of the riparian zone has often been impacted by a range of land and water resource use pressures, some historical and some current. These include past and ongoing clearing of vegetation; altered stream flows; increased water levels or soil moisture; elevated nutrients; woody weeds, grass, and vine weed invasion; uncontrolled fire; stock grazing and trampling pressure; bank erosion; channelisation; land filling, and rubbish dumping. Depending upon the condition of the riparian zone, different rehabilitation strategies may be appropriate (Table 6 and 7). Where riparian vegetation has been lost completely or partially, revegetation is often a desired rehabilitation strategy. Both intensive and/or extensive revegetation methods may be applied for riparian zone rehabilitation, and these have been described in extensive detail along with the identification of riparian zone rehabilitation objectives, operational planning, and suitable species selection in the Sheep Station Creek SMP (Econcern 2021).

Table 6. Riparian zone rehabilitation approaches for different existing condition contexts

Existing condition context	**Potential rehabilitation strategy**	**Notes**
1. Areas of remnant vegetation	Protect from clearing, monitor and control weeds, implement fire management suited to vegetation type. **Extensive revegetation**.	Total fire exclusion is appropriate for fire sensitive and/or closed canopy riparian forests.
2. Areas of degraded remnant vegetation	If in ungrazed landscape, control/spay out exotic pasture grasses with grass selective herbicides. If in grazed landscape, manage stock grazing and trampling pressure to keep exotic understory pastures subdominant, allow natural seedling recruitment, and avoid accumulation of large fire fuel loads. Monitor and protect natural regeneration, conduct ‘in-fill’ planting revegetation (plus stock protection, weed control and watering maintenance) if required for denuded sections. Implement fire management suited to vegetation type. **Extensive revegetation with ‘fill in’ intensive revegetation.**	Often includes some areas devoid of remnant native vegetation that may require more intensive rehabilitation approaches, for example, as per 3.
3. Areas with no remnant native vegetation, for example, reaches dominated by exotic grasses	In grazed landscapes stock exclusion fencing is required to support intensive revegetation efforts. Control/spay out weeds, prepare a site for revegetation (holes, mulch, irrigation/watering), plant and maintain (stock protection, weed control, watering) and protect from fire at least until vegetation is established at ~24 months. **Intensive revegetation.**	Initial site preparation may include use of controlled burn to open site access. Direct seeding with fire-stimulated germination species (wattles) prior to burn, or ash bed germinating species (eucalypts, melaleucas) post-burn can add additional recruitment where seasonal/soil moisture conditions suit. Potential erosion risks of high rainfall or flows should be considered if site spray out or burning is planned.
4. Areas of remnant/degraded remnant vegetation with a high exotic pasture grass fire fuel load and associated hot fire risk	If the site is large enough/suitable, implement controlled grazing (or other means of grass weed control) and fire management suited to vegetation type. Control woody weeds, monitor and protect natural regeneration. **Extensive revegetation with ‘fill in’ intensive revegetation.**	If the site includes areas devoid of remnant native vegetation consider fencing configurations that create protected grazing exclusion areas to allow more intensive rehabilitation approaches, as per 3. For small sites unsuited to grazing, for example, narrow riparian corridors, fire exclusion and alternate grass weed control are preferable.
5. Areas of remnant/degraded remnant vegetation with sustained high grazing pressure	If possible, implement grazing spelling and monitor/protect natural regeneration. Alternatively, establish grazing exclusion fencing around areas of degraded remnant vegetation and rehabilitate as per 2, or fence off areas lacking native vegetation and rehabilitate as per 3. **Extensive revegetation with ‘fill in’ intensive revegetation.**	Extended spelling that allows accumulation of a fire fuel load and controlled burning suited to the vegetation type can promote recruitment of fire-germinated species whose abundance has been reduced under a sustained grazing regime.

System specifics

Where discussion relates to management issues listed in Appendix 1 or mapped in Appendix 2, the designated management issue (M) number is referenced.

Photo 20. Isolated stands of riparian trees occur on lake margins. The riparian zone is primarily characterised by grass weed margins that are managed by chemical spraying (see killed grass). Dense riparian shading could provide some level of alternative grass control.

Photo 21. The contemporary riparian zone of the main Horseshoe Lagoon waterbody has low habitat and ecological values and is dominated by exotic pastures and aquatic weeds.

Under natural, highly seasonal, predevelopment conditions the foreshore-littoral zone of Horseshoe Lagoon was characterised by fire-mediated patches of floodplain and riparian trees, rather than a contiguous riparian vegetation margin (Figure 2). Only isolated patches of riparian overstory vegetation occurred along the high waterline of the lagoon. The most extensive treed vegetation occurred on the adjoining floodplain, some of which was historically cleared for pasture improvement and subsequently for agricultural development (Figure 2). Although isolated stands of riparian vegetation remain on the bank of the main lagoon (Photo 20), lake margins are mainly dominated by exotic pasture, both grazed and ungrazed, with low habitat and ecological value (Photo 21).

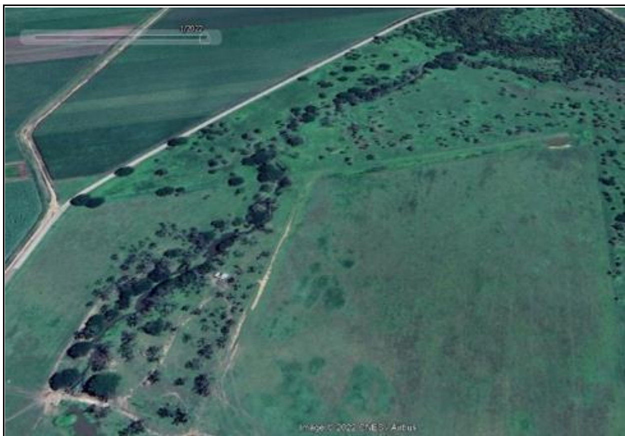


Photo 22. The initial stream channel corridor downstream from Horseshoe Lagoon is dominated by exotic rain trees and has an open structure. Grazing contributes to the maintenance of its understory condition. Its modified hydrology would support revegetation to a denser shade generating riparian vegetation community type. NB large canopy trees are exotic rain trees.

Photo 23. Floodplain vegetation adjoining and near the main Horseshoe Lagoon provides many of the habitat values normally associated with riparian vegetation.

Although the lagoon has a history of being completely grazed in earlier years (Figure 2), most of the southern shoreline has been ungrazed in recent years. These ungrazed pasture areas retard native vegetation recruitment, and present hot and wildfire risks to remnant vegetation and adjoining cane land, respectively. Grass weed domination of ground cover, stock trampling or browsing (where stock access) and hot fires (M2) have all contributed to suppressing riparian vegetation recruitment along the now-perennial lagoon's full supply level waterline (M3). Targeting weed grass margins as part of the RMA-supported aquatic weed control program (Figure 3, Photo 20) also impacts the development of native riparian vegetation, although bare bank areas provide habitat value for waterfowl (Econcern 2021).

Given the well-watered bank margin of the hydrologically-modified contemporary lagoon and its tributary channel, dense shade canopy-generating riparian vegetation could be readily established along the high waterline margin. Although it not representative of predevelopment conditions, the benefits of such a riparian zone could be realised in terms of: reduced need for spray-based control of marginal grass weeds; improved recruitment opportunities for shade-tolerant emergent aquatic plant species; habitat provision for bank tree-roosting waterbirds; cooled water from shaded water margins; increasing dissolved oxygen levels and nutrient uptake by excluding submerged aquatic plants; and providing snags and leaf litter to the aquatic ecosystem. Revegetating shade-casting riparian vegetation also has hymenachne management benefits on the Horseshoe Lagoon outlet channel (see *Fish passage barriers* section).

Photo 24. Well-developed riparian vegetation communities occur along the creek channel of the lower Horseshoe Lagoon system (see adjoining photo), but have condition impacts associated with woody weeds, rubber vine and grass-dominated wet margins.

Photo 25. Despite having some weed condition issues (see *Woody weeds* section) the riparian vegetation corridor of the lower Horseshoe Lagoon system is well developed, dense, diverse, structurally complex and contains high wildlife habitat and refuge values. NB: large canopy trees are exotic rain trees.

The best developed existing riparian vegetation habitat occurs within the lower Horseshoe Lagoon system (Photo 24 and 25). The riparian vegetation corridor of this reach is well developed, dense, diverse, structurally complex and contains high wildlife habitat and refuge values. Most of this area is grazed, which reduces hot fire risks, although sustained wetness within the creek channel limits the capacity of stock to graze out hymenachne-dominated edges. The primary management need for this existing riparian vegetation is woody weed management, including rubber vine management (see *Woody weeds* section), where grazing does not occur, including some floodplain vegetation remnants upstream of the highway (see *Fire regime* and *Grazing regime* sections).

The distributary channel network that extends to the west from the lower Horseshoe Lagoon system before re-joining the Barramundi Creek estuary (M15) is an area that once had well developed riparian vegetation, but much of it has been lost to past clearing and fire regime impacts. This area hosts several lagoons and riparian vegetation communities of varying condition (Photo 26, 27 and 28). Included are some high value remnant areas contained within parts of the system that are used for grazing purposes. In ungrazed areas, including parts of the system historically cleared for farmland development, the ground cover is dominated by exotic pasture grasses, like guinea and para. These exotic grasses suppress native vegetation establishment and pose a hot fire risk to remnant native vegetation. The poor condition of riparian vegetation limits its fauna habitat values and contributes to the poor condition of the channel-hosted waterbodies. These areas were the focus for past NQ Dry Tropics investment in revegetation and wetland management. Some of the revegetation is establishing well, although exotic pasture grass competition and associated hot fire risks remain a threat to its security. Further promotion of native revegetation and regeneration within this distributor lagoon system would add to the biodiversity value of the broader system.

Photo 26. Most downstream distributary lagoons associated with the lower Horseshoe Lagoon system on the Corrick Plains property. Grazing land use has limited the impacts associated with an ungrazed exotic pasture understory. Riparian vegetation condition adjoining the lagoons is good and has high habitat values. Also note open water status of lagoon water bodies supported by grazing-based control of grass margins.

Photo 27. Distributary lagoons associated with the lower Horseshoe Lagoon system upstream of Corrick Plains (above) and downstream of Poopoonbah Road. These lagoons have been the site of past revegetation efforts, which are still being established. This is a cane farming property and management of exotic pasture understory and associated hot fire risks remains a challenge for re-establishing riparian vegetation. Integration of controlled grazing in such landscapes could assist with grass weed management, but presents its own challenges adjoining cane farming land use.

Photo 28. Distributary lagoons associated with the lower Horseshoe Lagoon system upstream of Poopoonbah Road (above) and downstream of Gardini Road. This smaller land holding is ungrazed and exotic pastures (guinea, para grass) dominate groundcover, retard native vegetation regeneration, and present associated hot fire risks to remnant or revegetated riparian vegetation. Integration of controlled grazing in such landscapes could provide a broad acre tool for establishing revegetation sites and promoting regeneration of native vegetation via grass competition and fire risk reduction.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Seek funding resources and engage lagoon frontage (including tributary channels) landholders to trial intensive revegetation methods to establish dense canopy-forming riparian vegetation along the Full Supply Level (FSL) waterline of selected bank margins and channel reaches (W2). This management trial would replace grass weed chemical spraying and promote enhanced habitat values, and has the potential to be more broadly adopted around the lagoon waterline.
2. Engage lagoon outflow landholder in integrated revegetation and channel stabilisation works for fish passage provisions (W7; see *Fish passage barriers* section).
3. Engage with landholders to undertake integrated riparian revegetation in lower system distributary lagoons. Consideration should be given to the applying both intensive and extensive revegetation approaches, with the potential inclusion of grazing and fire management in the latter.
4. Engage management stakeholders to discuss investment in woody weed, fire, and grazing regime management to improve the condition of riparian and floodplain remnant vegetation (W3, W8; see *Woody weeds, Fire regime* and *Grazing regime* sections).

Table 7. Mapped riparian vegetation condition class – ecological value, management issues and identified revegetation needs and opportunities

Exotic grasses
● Has low ecological value, presents hot fire risks to remnant native trees and adjoining cane farms and harbours rodent crop pests. ● Can provide suitable cover and bank stability for excavator-maintained channel reaches. ● Growth of aquatic grass species (para, aleman, hymenachne) onto water bodies blocks water flow and creates floating aquatic weed mats. This reduces water dissolved oxygen and creates biological oxygen demand (BOD) when grass decomposes in water, particularly when inundated by elevated flows/water levels, creating anoxic 'blackwater'. ● Fire risks can be reduced by fuel load reduction with controlled grazing where site conditions allow. ● Where no remnant native trees are present, revegetation is dependent on more intensive methods, for instance, seedling planting. ● Establishing a shade-generating overstorey tree canopy that controls grass density and reduces bank-side anchor points for aquatic grass species provides a catchment-scale revegetation target.
Remnant vegetation
● Has high ecological value, including providing habitat for fauna uncommon in developed landscapes. ● Mapped units can include significant areas of exotic grass and degraded remnant classes. ● Condition can trend positively or negatively depending on operating pressures, for example, weeds, grazing regime, fire regime, physical disturbance, and hydrological change. ● Controlled grazing of exotic grass understorey can reduce fire fuel loads and associated hot fire risks and, with spelling, promote natural regeneration. ● Exclusion of fire, or a controlled burning regime, can promote increased canopy development and suppression of understorey fuel loads and promote natural regeneration. ● Provides baseline comparison sites, target species lists and seed sources for regeneration of equivalent reach areas. ● Provides nucleus areas for strategic regeneration of adjoining riparian areas. ● 'Fill in' planting can be used to increase mid and overstorey canopy development, though promoting natural regeneration is more appropriate where integrity is high. ● Priority management focus for remnant vegetation is protection and represents a more cost-effective investment than revegetation.
Degraded remnant
● Ecological value is variable depending on landscape context, but can provide important habitat resources, including feeding and nesting sites within a modified landscape. ● Mapped units usually include significant areas of exotic grass and may include exotic trees/woody weeds. ● Condition can trend positively or negatively depending on operating pressures including weeds, grazing regime, fire regime, physical disturbance, and hydrological change. ● Controlled grazing of exotic grass understorey can reduce fire fuel loads and associated hot fire risks and, with spelling, promote natural regeneration. ● Exclusion of fire or a controlled burning regime can promote increased canopy development and suppression of understorey fuel loads and promote natural regeneration. ● Remnant trees provide the opportunity to use more extensive revegetation approaches, for instance, the promotion of natural regeneration via seedling recruitment and growth ● 'Fill in' planting/intensive revegetation can be used to target denuded areas along with promoting natural regeneration within remnant stands. ● An integrated mix of intensive and extensive revegetation approaches is an appropriate management focus and provides a catchment scale revegetation target.
Revegetated
● Observed ecological value is generally high, particularly where the area includes mature remnant stands or individual trees of the original vegetation community. ● Primary management focus is protection and maintenance, particularly in relation to reinfestation by grass weeds and associated hot/uncontrolled burn risks. ● Some sites warrant 'fill in' intensive revegetation to address areas denuded by uncontrolled burns and/or die-off of short-lived pioneer species. ● Good opportunity to increase habitat values by dedicated understorey/ground cover planting and introducing physical habitat features, like logs and artificial nest hollows.
Exotic trees
● Ecological value is limited in monoculture plantings (orchards) but can be higher when mixed with remnant native species. Can provide some nesting and feeding habitat resources and a range of useful functional values, for example, stabilising stream banks, and shading out aquatic grass weeds, and duckweed around pump intakes. ● Where mixed with native tree species, selected control and clearing and 'in fill' revegetation can be used to regenerate sites toward native vegetation dominance.
Grassland
● 'Catch all' class for grassland areas that are not the 'exotic grasses' class associated with the immediate riparian zone (above). When this includes native grasslands, it can have high habitat values for grassland-dependent species, particularly granivorous birds. ● Riparian areas that represent cleared areas are an appropriate for intensive revegetation, particularly adjoining lagoons subject to aquatic grass weed infestation.

Woody weeds

Types and impacts

Woody weeds threatening the condition of Lower Burdekin wetland systems include exotic trees and vines that infest riparian zones and catchment areas to the detriment of native habitat values, catchment processes and production values. The key species recorded in the Lower Burdekin are listed in Table 8 (below). Although some woody weeds are utilised as shelter or food habitat resources by native fauna, their occurrence within native vegetation communities results in the competitive exclusion of native plants. Native fauna have evolved and developed direct or indirectly dependent relationships with these native flora. For example, while canopy-dwelling birds may inhabit an exotic tree canopy, it will generally not support the same populations of native insect food sources that a native tree canopy will. The greatest scope for impact occurs where weeds have the invasive capability to dominate a regional ecosystem setting to the exclusion of native biodiversity, and/or change native vegetation structure and/or function. For example, severe infestations of rubber vine can create 'vine towers' that completely smother and collapse host trees, destroying the vegetation structure (e.g., closed canopies) required by dependent species and opening the vegetation community to further weed infestation, such as sun-loving grasses.

Photo 29. Exotic rain tree (foreground left) and golden shower tree (background right) adjoining the upper reaches of the creek channel that drains the Horseshoe Lagoon overflow.

Photo 30. Exotic rain tree sapling growing into the margin of a native paperbark-dominated riparian vegetation community. This species forms large towering shade canopies that exclude understory.

Where vegetation structure gets completely altered by woody weed infestation, secondary impacts may also be generated. For example, a rubber vine tower causing canopy collapse opens-up fire-sensitive riparian vegetation to secondary weedy grass infestation, which leads to its exposure to fire impacts. Dense canopy-forming woody weed species, such as chinee apple, can form closed-canopy infestations that shade out understorey grass in formerly open woodland areas. This reduces pastoral productivity and exposes understorey areas to increased soil erosion in the event of heavy rainfall or floodplain overland flows.

Not all species are declared weeds under the *Queensland Biosecurity Act 2014*. Control methods vary from various forms of chemical spraying, including basal cut and foliage spraying; the use of bio controls like rubber vine rust fungus (*Maravalia cryptostegiae*); and the use of fire. Heavy machinery is also often used for clearing more dense infestations where access for other forms of control is limited, or control by other methods is cost exorbitant. Where heavy machinery is employed, the risks to remnant vegetation stands mixed within woody weed infestations need to be managed to avoid impact to remnant habitat values.

In recent decades there has been substantial investment by NQ Dry Tropics in the control of woody weed infestations at Lower Burdekin wetland sites, including two nationally significant wetlands: Serpentine Lagoon and Woodhouse Lagoon. Other sites include Churches Lagoon (on Sheep Station Creek) and Collinson's Lagoon, adjoining the Bruce Highway. An observed reduction in rubber vine infestation levels has also been noted over the past two decades at some sites, including Barratta Creek, where rust fungus successfully established during a series of wetter years.

Levels of woody weed infestation vary between systems but, overall, the extent of infestation across the greater floodplain remains significant. Investment in further control needs to be informed by strategic priorities to make effective use of limited resources. Intervening in low level infestations, including at upper catchment sites before they spread downstream and/or become more extensive, represents prudent investment. Public investment in the resources required to tackle large extensive infestations can only be justified where there are high value wetland assets at stake and/or a production dividend that promotes landholder engagement and co-investment.

System specifics

Woody weed infestation issues within the Horseshoe Lagoon system appear primarily located in the stream channel riparian corridor of the lower system, downstream from the main lagoon. The main species of concern are rubber vine and exotic trees, including rain tree, golden shower tree, yellow oleander, tamarind, and chinee apple (Table 8). Chinee apple also occur scattered through woodland areas of the adjoining floodplain and coastal plain. Rubber vine has the greatest infestation density and is observed to be impacting habitat values. In some reaches it dominates riparian vegetation canopies and is changing riparian vegetation structure and impacting production values in the way it excludes understory grass growth.

Photo 31. Rubber vine tower dominating the mid-story and canopy of a Moreton Bay Ash, livistona palm riparian vegetation community.

Photo 32. Dead and poorly condition eucalypts with fire scars in upper reach riparian zone, indicative of impact of rubber vine and past fires.

Most of the exotic trees of concern (except for chinee apple) are undeclared weed species, although a general biosecurity obligation exists for control of all. Current infestation levels of the exotic trees are relatively low in terms of production impacts that would motivate landholder investment in control. However, aerial photo interpretation (Photo 22, 25, 29 and 30) of the distribution and spread of some of the more obvious canopy species, like rain tree, suggests that they are continuing to distribute downstream from an apparent source site adjoining Horseshoe Lagoon, with their canopy dominance increasing to the exclusion of native species.

This pattern of infestation and expanding distribution downstream appears to be replicated by other exotic tree species, with the lowermost riparian vegetation corridor having less exotic canopy dominance. While it was not systematically surveyed, the dominance of rubber vine in aerial images appears to be most significant in the upper reaches of the creek channel. Currently, infestation levels of woody weeds do not appear to be significant from a primary production perspective. Rather, they are generating impacts from an environmental perspective, including outcompeting native canopy species, and degrading the floristics of an otherwise valuable riparian vegetation corridor that has significant habitat values. The observed distribution of the weed tree canopies would suggest that the full infestation potential of the site has not yet been reached, and control would be strategic and prudent to help protect environmental values (M10).

Examining land tenure covering the creek riparian corridor and adjoining floodplain/coastal plain (see *Critical Wildlife habitat* section), substantial sections of the lower wetland system – including much of the riparian vegetation – occur on state land tenures, including reserves, Crown watercourse, road reserves and leased state land. This land tenure context presents a range of management opportunities and challenges. State land can present public interest and access opportunities, and public investment in environmental management outcomes can be justified for public good. Leasehold arrangements can still provide environmental and public good outcomes.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Engage with landholders of the creek drainage riparian vegetation corridor system downstream of Horseshoe Lagoon to develop a targeted woody weed/exotic tree/rubber vine control program (W8).

   Developing an engagement plan should include the following steps:

    a. Consultation with local government and state government agencies with responsibilities for Crowns reserves and state land, for instance, BSC and DES. In doing this, identify weed management resourcing by the council/state government and consider public interest and investment options.

    b. Conduct a detailed transect survey of the targeted management reach to define weed infestation levels, existing biocontrol presence (for instance rubber vine rust fungus), and detailed habitat values for strategic prioritisation of weed control.

    c. Weed management of Horseshoe Lagoon system as part of a landscape-scale biodiversity conservation strategy for the Horseshoe Lagoon system (see *Critical wildlife habitat* section).

Table 8. Woody weeds of management concern on the Lower Burdekin floodplain

Common name	Species	Growth habit	Comments/nature of impacts	Biosecurity status/control methods
Chinee apple	*Ziziphus mauritiana*	Large shrub or small spreading tree up to 8m tall and 10m in canopy diameter.	Forms dense impenetrable ground cover and native midstory excluding infestations.	Chinee apple | Business Queensland
Parkinsonia	*Parkinsonia aculeata*	Small, hairless tree up to 10m tall.	Forms dense impenetrable ground cover and native midstory excluding, infestations.	Parkinsonia | Business Queensland
Prickly acacia	*Vachellia nilotica*	Thorny shrub or small tree up to 5–10m tall.	Forms thickets in open grassland/woodland, reduces ground covers.	Prickly acacia | Business Queensland
Yellow oleander	*Cascabela thevetia*	A large tree that can grow up to 10m high.	Outcompetes native canopy species. Poisonous to stock and humans.	Captain Cook tree or yellow oleander (daf.qld.gov.au)
Golden shower tree	*Cassia fistula*	A spreading tree that is semi-deciduous usually grows less than 10m tall, but has the capability of reaching up to 20m in height.	A weed of riparian vegetation, open woodlands, wetland margins, roadsides, coastal environs and offshore islands.	golden shower tree | Weed Identification – Brisbane City Council
Castor oil plant	*Ricinus communis*	A tall branching, annual or perennial shrub that grows to 3m.	Invades floodplains, riverbanks, may form thickets. Seeds, and to a lesser extent, the leaves are toxic to livestock and humans.	Castor oil plant | Business Queensland
Neem	*Azadirachta indica*	Fast-growing evergreen generally 15-20m tall, with crown diameter up to 20m.	Outcompetes native canopy species.	Neem tree | Business Queensland
Devils' fig	*Solanum torvum*	An upright shrub or small tree usually growing 0.8-3m tall	A weed of closed forests, forest margins, waterways (i.e., riparian areas), plantation crops, roadsides, pastures, disturbed sites and waste areas.	Devil's fig | Weed Identification – Brisbane City Council
Leucaena	*Leucaena leucocephala*	Shrub up to 6m tall.	Forms thickets in riparian zones and alluvial plains, stalls native regeneration and excludes ground covers.	Leucaena | Business Queensland
Java plum	*Syzygium cumini*	Tropical evergreen tree that can reach heights of up to 30m.	Outcompetes native canopy species.	Environmental weed
Tamarind	*Tamarindus indica*	Moderate to large evergreen tree, up to 24m in height, and 7m in girth.	Outcompetes native canopy species.	Environmental weed
Rain tree	*Samanea saman*	Large to massive, evergreen, spreading, umbrella-shaped and symmetrical trees that grow to 60m tall with a crown up to 80m broad.	Spread into native forests, and outcompetes native canopy species, particularly along stream margins and in disturbed areas.	Rain tree (daf.qld.gov.au)
Rubber vine	*Cryptostegia grandiflora*	Climbing vine up to 30m tall in trees, untidy shrub up to 1–2m tall.	Forms dense impenetrable ground cover excluding, canopy dominating /collapsing infestations.	Rubber vine | Business Queensland
Lantana	*Lantana camara*	Heavily branched shrub growing in clumps, thickets or vines.	Forms dense impenetrable ground cover excluding infestation that can extend to the midstory.	Lantana | Business Queensland
Elephant ear vine	*Argyreia nervosa*	Perennial woody vine climbing up to 10m high.	Forms canopy dominating /collapsing infestations.	Elephant ear vine | Business Queensland

Siam weed	*Chromolaena odorata*	Dense, tangling bush up to 2-3m tall, scrambles up trees to 20m.	Forms canopy dominating /collapsing infestations.	Siam weed | Business Queensland

Fire regime

Need

Inappropriate burning has long been recognised as a primary cause of deteriorating riparian vegetation condition in the Lower Burdekin region (BBIFMAC 1999). Fire impacts both sapling recruitment and mature trees. Field work undertaken for the preparation of SMPs identified that burning, particularly in the late dry season, continues to impact riparian vegetation condition across the Lower Burdekin floodplain.

Most native vegetation within the region has some adaptation to fire, which is a natural feature of ecosystems within the seasonal dry tropics. However, most native vegetation has evolved within a certain set of 'fire regime' parameters (see insert box below). If the experienced fire regime is more intense or frequent than its adapted capacity, it will result in mortality of trees and saplings and corresponding declines in vegetation structure, species diversity and associated habitat values.

For native vegetation, fire is a destructive force, but also a regenerative one. Many types of riparian trees, particularly wattles (*Acacia spp*.) and others, like casuarina and grevillea, have seeds whose germination is promoted by fire. Other riparian species, like melaleuca and eucalyptus, have seed that is released from capsules by fire and readily germinates in an ash bed soil layer and/or groundcover openings created by burning. A range of weed species, including rubber vine and para grass, are fire sensitive and controlled burning can provide a riparian restoration tool, along with a fire risk mitigation role.

Fire regime – describes the pattern of burning experienced by a site, or suited to a particular vegetation community, and is commonly characterised in terms of:

- frequency (interval period between fires);
- seasonality (time of year);
- intensity (determined by burn conditions, including time of day, wind, soil moisture, fuel load), and
- extent (amount of habitat type or site burnt per event or year).

Without management attention to the fire regime experienced by a wetland's riparian zone, valuable remnant habitat areas will continue to decline in condition, and ecological gains made by management or revegetation of a riparian zone can be lost.

Photo 33. Dead paperbark (*Melaleuca dealbata)* trees with prominent fire scar. Living trees at the same inundation level suggest death due to hot fire resulting from an ungrazed para grass fuel load.

Photo 34. Valuable floodplain vegetation remnant upstream of the Bruce Highway with dense ungrazed guinea and para grass understorey. A late dry season hot fire in this setting kills native vegetation and degrades remnant habitat values. Controlled grazing with, or without, controlled burning could protect and promote vegetation condition and habitat values.

Causes/constraints

There are several factors contributing to the often-destructive fire regime experienced by riparian zones within the Lower Burdekin region (Tait 2011). These factors may also be understood as barriers to implementing an appropriate fire regime. They include:

Large fuel loads – Amongst many Lower Burdekin wetland riparian zones, habitat remnants are ungrazed. This factor, combined with invasive exotic grasses, like guinea grass/green panic, para grass, and elephant grass, commonly result in large annual fire fuel loads within habitat remnants. These exotic grasses produce a greater standing biomass than native grass species, and have a long growing season due to seasonally-extended soil moisture promoted by regulated stream flows and irrigation tailwater.

Annual fire exposure – The Lower Burdekin remains one of the few sugar-growing regions in Australia where burning is employed pre-harvest to remove cane trash. Most remnant habitat areas on the floodplain occur near cane fields. Consequently, most are exposed to one or more close proximity annual burning events in surrounding cane fields. This presents a high likelihood of remnant habitat areas also experiencing an annual fire frequency, particularly where cultural practices have long favoured 'cleaning' up pest harbourages and fire fuel loads in remnant habitat areas during or after cane field burning.

Risks to cane crops promote late dry burning – Most cane farmers are unwilling to consider utilising fire as part of surrounding landscape management until cane crops have been harvested to avoid the risk of wildfire impacts to cane fields. At a regional level, cane harvesting is not completed until late in the dry season when conditions tend to promote 'hot' fires. This means that any intentional burning of habitat remnants after cane has been harvested is often damaging to vegetation structure, composition and ecological values, and there are fewer opportunities to conduct beneficial 'cool' or less intense 'controlled burns'.

Landscape setting

Appropriate fire regime guidelines suited to the native vegetation types that occur on the Burdekin floodplain have been defined by state government agencies (see Econcern 2021). However, these guidelines assume that fire management is occurring in extensive natural landscapes. The Lower Burdekin floodplain is dominated by irrigated agriculture. Remnant natural habitat tends to occur as isolated 'islands' and non-continuous, narrow riparian corridors surrounded by a 'sea' of developed landscape. In this context, natural landscape fire management approaches that depend on patchy burning of the surrounding landscape mosaic cannot be utilised; particularly when most of the surrounding landscape is developed crop land. Limiting the extent of a vegetation type or remnant patch that is burnt in any one event or year is also challenging where it only occurs in small patches surrounded by a landscape that is burnt annually.

Implementing an appropriate (including no) fire regime

The appropriate fire regime for floodplain vegetation remnants will vary with vegetation type and landscape setting. Importantly, sometimes the most appropriate fire regime for many riparian habitat remnants is total fire exclusion. This applies particularly where the remnants include fire sensitive vegetation; and/or are composed of narrow riparian corridors with limited fuel loads; and are not separated sufficiently from adjoining cane farms to avoid being an uncontrolled fire risk.

Regionally applicable guidelines for the implementation of appropriate controlled burning practices and fire regimes for Lower Burdekin wetland vegetation remnants within different farming landscape contexts were developed for the Sheep Station Creek SMP (Econcern 2021). Burdekin land managers interested in the use of fire as an ecological management tool are referred to that document for more detailed information.

System specifics

Where discussed opportunities relate to a value or management issues listed in Appendix 1 or mapped in Appendix 2, the designated (V or M) number is referenced.

The extent of contemporary fire damage to riparian vegetation communities observed within the Horseshoe Lagoon system, evidenced by recent fire scars, was very low relative to other Lower Burdekin wetlands where SMPs have been prepared (Econcern 2021, 2022). The main fire regime management issues identified were risks associated with existing fuel load conditions, and opportunities associated with the potential use of a fire management regime, combined with grazing, to improve weed, habitat, and biodiversity status.

Much of the southern frontage, including adjoining floodplain areas and tributary drainage systems of the main Horseshoe Lagoon system, are ungrazed and dominated by dense stands of exotic pasture species, including guinea and para grass. Scattered remnant vegetation stands on lagoon margins or across the floodplain are exposed to late dry season hot fire risks that could degrade vegetation condition and habitat values (M2). Grazing to reduce grass fuel loads with or without implemented controlled burns would better secure remnant vegetation values (Tait 2011). Not only could controlled burning secure existing habitat, it could also promote increased biodiversity and habitat values by reducing the abundance of fire-sensitive exotic aquatic grasses, like para and hymenachne, and promote fire adapted native vegetation's germination, including wattles, paperbarks, eucalypts, groundcovers (M3). Although impact risks would need to be assessed, and grazing managed to provide an appropriate fuel load, fire could play a useful role as part of an integrated control program for fire-sensitive rubber vine within the riparian vegetation corridor of the lower system (M10).

The distributary channel network that extends to the west from the lower Horseshoe Lagoon drainage system (Photo 27 and 28) also hosts a range of riparian vegetation communities where groundcover is dominated by exotic pasture grasses, like guinea and para. These prevalence of these grasses expose remnant native vegetation to late dry season hot fire risks. Integrated fire and grazing regime management of these areas (as discussed in the *Lack of riparian vegetation* section) could provide a useful habitat management approach (M15).

Landholders concerned about wildfire risk, with interests in implementing appropriate fire regimes and fuel load management, should also be cognisant of altering landscape conditions and risk scenarios that could arise in association with emerging climate stress.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Conduct a fire regime/controlled burning communication and extension program targeting riparian and lagoon frontage landholders; local fire wardens, and RFS members via shed meetings, other appropriate forums, field days and via published material.
2. When engaging with lagoon frontage landholders, lower system riparian corridor landholders, or distributary lagoon landholders about native vegetation/habitat management, discuss the options of fire regime management by fuel load reduction grazing – with or without conducting supported controlled burns – including incentive-supported programs.

Grazing regime

Why is it a useful tool?

For most Australian landscapes, the conventional wisdom about nature conservation-based management is that the impact of grazing animals should be kept out of disturbance-sensitive riparian and wetland areas. In contemporary riparian and wetland habitats of the Lower Burdekin floodplain, this convention is turned on its head because one of the greatest sources of wetland and riparian habitat threat is invasive exotic pasture species that can become dominant in the absence of grazing. These pasture species include a suite of aquatic grasses, such as para, hymenachne, aleman, and other species that occupy better-drained levee soils, like guinea grass.

Collectively, these grasses generate a range of impacts within wetlands and the riparian zone (Figure 7) of floodplain wetland systems, including:

- Out-competing native vegetation, including groundcovers and sapling recruitment;
- Creating large dry season fire fuel loads that support 'hot' fires;
- Smothering open water and shading out native submerged and emergent edge aquatic plants;
- Degrading water dissolved oxygen levels by organic loading, reduced instream photosynthesis and less water surface – air interaction;
- Impacting fish and waterbird nesting, feeding and egg laying habitats (including dry season-exposed banks used by waterfowl), and
- Socio-economic impacts (including creating mosquito breeding habitat, crop weeds, water channel blockages).

Photo 35. This Horseshoe Lagoon shoreline image was captured during water quality investigations in 2004 (Loong *et al* 2005) and shows the condition outcome under a sustained grazing regime. Visible in the image are areas of bare ground, native water margin plants (*Cyperus spp* and *Persiicaria spp*) and cropped short pasture grass species. All these features offer greater habitat value to waterbirds than an ungrazed exotic pasture-dominated shoreline.

It is within the context of the impacts caused by exotic pasture grasses that grazing, and the lesser disturbance of grazing animals, can be beneficial to the condition and value of riparian and wetland habitats. Ultimately, application of grazing as a habitat management tool requires an appreciation of its impact risks concerning native flora and fauna, bank compaction, and soil erosion (Photo 37); seeking to minimise these impacts while maximising the benefits of reducing exotic pasture dominance. Guidelines for the use of controlled grazing as a riparian and wetland habitat management tool have been developed for the Lower Burdekin region based on a research project involving a range of monitored management trials conducted over a decade ago (Tait 2011). Findings from those guidelines provide a basis for this management plan's recommendations, yet interested readers should refer to that document and the SMP developed for Sheep Station Creek (Econcern 2021) for a more comprehensive treatment of the issue.

Controlled grazing is not a suitable management approach for all sites and is not needed where other methods can be preferentially, or more effectively, applied to control grass weeds, for example, establishing riparian vegetation canopy shading. However, controlled grazing is a useful management tool because it can be used at a landscape scale and fills an important role where other methods may have limitations, such as chemical and mechanical control, or tree canopy shading established by revegetation. Importantly, all these methods are not mutually exclusive, and the best riparian zone rehabilitation outcome may be achieved by an integrated or sequential application of more than one approach.

In terms of site suitability constraints, the main reasons why controlled grazing may not be suitable at some sites include:

- steep banks/erosion prone soils;
- incompatible adjoining land uses;
- species vulnerable to grazing disturbance and/or presence of good condition or grazing-sensitive habitats, and
- site too small, or shape/configuration has high fencing costs, lacks high water stock refuge, or presents ineffective fencing security.

In contrast to controlled grazing, uncontrolled grazing and associated stock trampling, bank erosion and pugging of wetland and riparian areas, can also present a threat to wetland system ecological values. These threats are relevant concerns where wetland systems fall predominantly within grazing as opposed to agricultural land use areas.

Photo 36. Aerial image captured in May 1991 illustrates bank margin comparisons between ungrazed (central section with green para grass margins) versus grazed (remainder of system including tributary channels). NB: native aquatic plant bands and open channels in grazed areas.

Photo 37. Lower system riparian corridor with cattle pad-generated erosion on dispersive sodic soil levees. The beneficial outcomes of applying cattle grazing pressure as a riparian and wetland habitat management tool need to be balanced with management efforts that limit potential impacts (Tait 2011).

System specifics

Where discussed opportunities relate to a value or management issues listed in Appendix 1 or mapped in Appendix 2, the designated (V or M) number is referenced.

Some environmental benefits from the application of controlled grazing include:

- reduced fire fuel loads and hot fire risks;
- promoting a suitable environment for 'cool' burns;
- supporting native vegetation regeneration by reducing hot fire risks and promoting the beneficial disturbance of dense exotic pasture cover;
- reduced groundcover dominance of exotic pasture, like para grass;
- site clearing to allow for more intensive forms of revegetation;
- opening of wet season flow paths (Figure 8);
- creating bare bank habitats favoured by roosting waterfowl, and
- promoting native wetland plant cover within seasonal wetland basins (Tait 2011).

As discussed in Tait (2011), the effectiveness of grazing regimes in reducing the dominance of exotic aquatic grasses can be improved where hydrology manipulations and controlled burning can also be applied. If dry season water level drawdown could be reinstated to the main lagoon (see *Altered hydrology* section), there would be additional opportunities to use grazing to reduce the dominance of exotic pasture and to promote native aquatic plants on exposed lagoon bank margins. Controlled water level drawdown would also ensure that an open outflow channel (Figure 8) could be established by cattle grazing access to a dry exposed channel prior to the wet season when connective flows through an open channel would provide for fish passage.

For many cane farming riparian landholders, there is little interest in accommodating grazing animals near cane fields due to perceived potential conflicts. However, where landholders have grazing management experience, or a family interest in grazing animals such as horses, there can be support for accommodating grazing-based management of wetland frontage areas. In other Lower Burdekin areas, like Sheep Station Creek (Econcern 2021), farmers have also been prepared to let trusted graziers/horse owners utilise grazing opportunities/forage resources on their farms where responsibility for stock and fencing infrastructure is delineated and accepted. The main sites that offer opportunities for grazing-based management of grass weeds and associated fire risks, while improving riparian and aquatic vegetation condition, have been discussed in preceding *Lack of riparian vegetation* and *Fire regime* sections. These include:

- Areas of remnant floodplain vegetation adjoining Horseshoe Lagoon and its tributary drain (M2);
- The littoral zone and waterline margin of the main Horseshoe Lagoon (M3, M4);
- Exotic pasture-dominated floodplain and frontage areas adjoining Horseshoe Lagoon;

- Lower system distributary lagoons and adjoining land parcels (M15), and
- The Horseshoe Lagoon outflow channel (M7, M8).

Aug 2004 – Channels occluded by grass grow over.

Jun 2013 – Channel partially cleared by excavator.

Apr 2016 – Wet period, channels occluded by grass.

Aug 2017 – Dry period, channels opened by grazing.

Jul 2019 – Open channels following effective grazing.

Jan 2022 – Wet period, channels occluded by grass.

Figure 8. Illustration of the changed outflow channel condition delivered by varying levels of cattle grazing access (and excavator clearing, 2013 image) afforded by seasonal wetness and/or the duration of aseasonal outflows.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Develop an infrastructure incentives package to facilitate controlled grazing as a riparian and wetland management and extensive revegetation tool (see *Aquatic weeds, Lack of riparian vegetation* and *Fire regime* sections).

2. When engaging with lagoon frontage landholders, lower system riparian corridor landholders, or distributary lagoon landholders, discuss the option of using grazing regime management as a tool for fire fuel load reduction, or for reducing exotic pasture dominance and enhancing native vegetation recruitment/regeneration opportunities. Grazing regime management approaches be incorporated in management deliberations, planning, and incentive-supported programs.

Critical wildlife habitat

Under the *Queensland Nature Conservation Act 1992* critical habitat is defined as:

> (1) habitat that is essential for the conservation of a viable population of protected wildlife or community of native wildlife, whether special management considerations and protection are required, and
>
> (2) may include an area of land that is considered essential for the conservation of protected wildlife, even though the area is not presently occupied by the wildlife.

Beyond this statutory definition applied to threatened wildlife species listed under state or federal legislation, the concept of critical habitat can be considered more generally as habitat types or features that are essential to the maintenance of specific wildlife species or groups within a particular landscape or area.

Conserving and improving the wildlife biodiversity within the Lower Burdekin floodplain is supported by most stakeholders. Understanding what constitutes critical habitat is important for effective wildlife conservation. Since European settlement in the Lower Burdekin, there has been a reduction in the diversity and population sizes of a range of wildlife species previously occurring in the region, which has coincided with the development of pastoral and agricultural land uses. For example, few younger generation residents know koalas were once common in Bluegum forests on the levees of the Burdekin River.

During the author's own lived experience in the region from the 1960s to present, there are several wildlife species that are anecdotally reported to have become rare, or even extinct from floodplain areas. These include northern quolls, otherwise known as 'native cats', which occurred in the Mount Kelly area until at least the early 1970s. Spectacled hare wallabies, known as 'pademelons' by Burdekin locals, were common in coastal floodplain areas until the 1980s, and are now only recorded in rangeland areas on the margin of agricultural production areas. Further, large, diverse (multi species) finch populations are now reduced in species diversity and population size, and frill neck lizards – once commonly-encountered in habitat remnants – are now a notable record. While the loss of wildlife species can be attributed to a general reduction in available habitat area, habitat fragmentation and feral predators, the loss of critical habitat is often a key cause, even where areas of remnant habitat remain.

Photo 38. The Horseshoe Lagoon system includes two protected areas: the Corrick Plains Nature Refuge (above) and the Horseshoe Lagoon Conservation Park. Many of the habitat values for which these protected areas were declared are being threatened by system drivers operating from outside the protected areas; for instance, aseasonal inflows of irrigation scheme tailwater.

Photo 39. Native bulkuru spikerush and salt couch vegetation, and magpie geese within the Corrick Plains Nature Refuge. Elsewhere within the Corrick Plains Nature Refuge these communities are being lost to exotic pasture dominance and aquatic weed infestation, promoted by sustained aseasonal inflows of irrigation scheme tailwater.

The intention of identifying critical wildlife habitat, and threats to it, is to inform landscape management decisions that support wildlife conservation. A non-exhaustive list of critical habitat features known to be significant on the floodplain, along with their associated values and management implications, are in Table 9.

Some of the main implications of management issues surrounding critical habitat include:

- **Fire regime –** The impact of burning regimes and exotic grass fuel loads on vegetation condition has been widely covered elsewhere in this report. It is important to recognise that uncontrolled burns, particularly hot fires, also impact a range of critical habitat features, including tree hollows, woody debris and shed tree bark.
- **Cultural practices –** Some of the practices that lead to a loss of critical habitat are not from required production activities, but rather long-held cultural values, including an attraction to parkland clearing, 'cleaning up the farm', and removing problem trees. Greater educational extension to landholders on the value of critical habitat features and the wildlife they support could assist in changing some of these practices.
- **Habitat rehabilitation beyond overstorey trees –** In recent decades the concept of habitat rehabilitation has generally become synonymous with tree planting, particularly overstorey trees.

Greater recognition of the importance of critical habitats should lead to including a broader range of activities under habitat rehabilitation, including revegetation of mid-storey and groundcovers, and establishing physical habitats such as logs, woody debris, and nesting hollows/boxes.

- **Recognising regional landscape ecology –** A landholder's perspective on the importance of habitat features or their management needs is often constrained to their own property boundaries. Awareness of the broader landscape ecology, including recognising the regional importance of site-specific features, can inform better management. For instance, contributions of tree stands to functional wildlife corridors, and/or choosing to maintain certain habitat features on a property due to their regional uniqueness and importance.

System specifics

Where discussion relates to values, management issues or nominated works listed in Appendix 1 or mapped in Appendix 2, the designated (V, M or W) number is referenced.

The examination of the various components of the Horseshoe Lagoon system conducted for this SMP reveal that it has high biodiversity values, many of which are assessed to be of state significance (see Appendix 1). State endangered, vulnerable and near threatened species and essential habitat records for the system (DES 2022) including:

- critically endangered eastern curlew (*Numenius madagascariensis);*
- vulnerable estuarine crocodile (*Crocodylus porosus)*, and
- within the historical range of the freshwater sawfish (*Pristis pristis)* and the estuary of the lagoon is with the range of the globally endangered sawfish, *Anoxypristis cuspidata*, and *Pristis zijsron*

Despite high biodiversity values being attributed by state-based evaluation, assessments conducted for the preparation of this SMP indicate a significant loss of biodiversity and habitat values has occurred over the past 30 years. This trend is likely to continue with habitat values further declining unless investment is made to protect and restore critical habitat and ecosystem processes. Despite the main Horseshoe Lagoon waterbody being listed in the Directory of Nationally Important Wetlands in Australia and included in the protected area estate of Queensland as a declared Conservation Park – a tenure only one step removed from National Park – it has experienced the greatest levels of modification in the system, particularly to its hydrology and habitat reduction, most notably bankside habitats. This finding does not seek to downplay the concerted and successful aquatic weed management efforts of the RMA partners. Without these efforts the contemporary lagoon system would now be even more degraded by insurmountable infestations of floating aquatic weeds and grasses, and compounded habitat loss and water quality degradation.

Photo 40. Land tenures surrounding the Horseshoe Lagoon Conservation Park (green), include freehold (blue) and state land (clear). Extension of conservation park boundaries to include lagoon foreshore areas would significantly increase its biodiversity value and protective management capacity.

Photo 41. A significant limitation of the protective capacity of the Horseshoe Lagoon Conservation Park (left) is that it does not include any lagoon foreshore or bank areas; a critical habitat component of the wetland.

Supported by this SMP's findings, the agencies responsible for conserving the values of this conservation park need to become more actively engaged with site and system management actions and partners to ensure the system's biodiversity is protected from further decline, and ideally restored. Delivering more robust nature conservation outcomes for the system as a whole also requires that nature conservation management agencies and stakeholders look beyond the boundaries of existing protected areas – the Horseshoe Lagoon Conservation Park and Corrick Plains Nature Refuge – and think 'outside the box' in terms of existing management arrangements. This needs to include:

- considering the ecosystem as a whole, regardless of tenure boundaries including linkages to adjoining habitat areas (Figure 9);
- taking an active management interest in processes external to the protected areas that ultimately define their ecological character and value, for instance, aseasonal inflows of irrigation scheme tailwater;
- examining biodiversity management investment opportunities provided by the land tenure context of the broader landscape (Figure 9), and
- analysing the cost-benefits of further investment in extending nature conservation tenures or management arrangements within the system.

One of the key limitations of the existing Horseshoe Lagoon Conservation Park (Photo 40 and 41) is the protected area tenure boundary only covers the waterbody, and not any of the lagoon frontages or bank margins. These are critically important habitat components for the waterbird communities for which Horseshoe Lagoon was protected. Negotiations with adjoining landholders with a view to establish collaborative management arrangements, or acquisition of additional foreshore areas into the protected area, could significantly serve the biodiversity conservation capacity of the site and enable managers to adopt bank margin and foreshore habitat management initiatives.

Examining the biodiversity management investment opportunities provided by the land tenure context of the broader landscape surrounding the Horseshoe Lagoon system (Figure 9), it is important to note that there are potential public access and interests associated with state land areas. These state land areas also translate into significant opportunities for conservation management planning, including protected area management arrangements; ecological condition investment, like seasonal hydrology, weed control, fire regime; and targeted restoration, like the revegetation of the corridor linkage to Haughton River; to deliver a regionally-significant biodiversity conservation outcome around the central asset of the Horseshoe Lagoon system.

Photo 42. Magpie geese occupy bare ground bank habitat, a critical habitat for waterfowl that has been lost from areas that are permanently waterlogged and dominated by dense aquatic grass weeds.

Photo 43. Horseshoe Lagoon in 1991, prior to significant hydrological alteration and under a sustained grazing regime, illustrating bare exposed banks and bands of fringing native aquatic plants.

Beyond the aspirational regional conservation planning opportunities articulated above, there are a range of other critical habitat management opportunities that can inform Horseshoe Lagoon system management investment priorities. As identified in management recommendations for the *Aquatic Weeds* section, management opportunities will be determined by the extent that key drivers of system modification and degradation are addressed. Reinstating seasonal hydrological variation to the system would provide the greatest critical habitat dividend. There are also good opportunities to support critical habitat values within the currently modified system.

Many of these needs have been nominated in preceding SMP sections, and include:

- Reinstating main lagoon critical edge habitats, including bare ground and emergent native aquatic plants. This action could be achieved either in conjunction with water level manipulation, or by targeted grazing, burning, spraying, and other vegetation management initiatives.
- Establishing riparian overstory vegetation along sections of the main lagoon Full Supply Level (FSL) waterline to provide roosting sites for tree-utilising water birds along the lagoon margin. Also, to assist in controlling aquatic grass weeds and promote native emergent aquatic plants, and to shade shallow water margins and to ultimately input snags and leaf litter into the aquatic ecosystem.

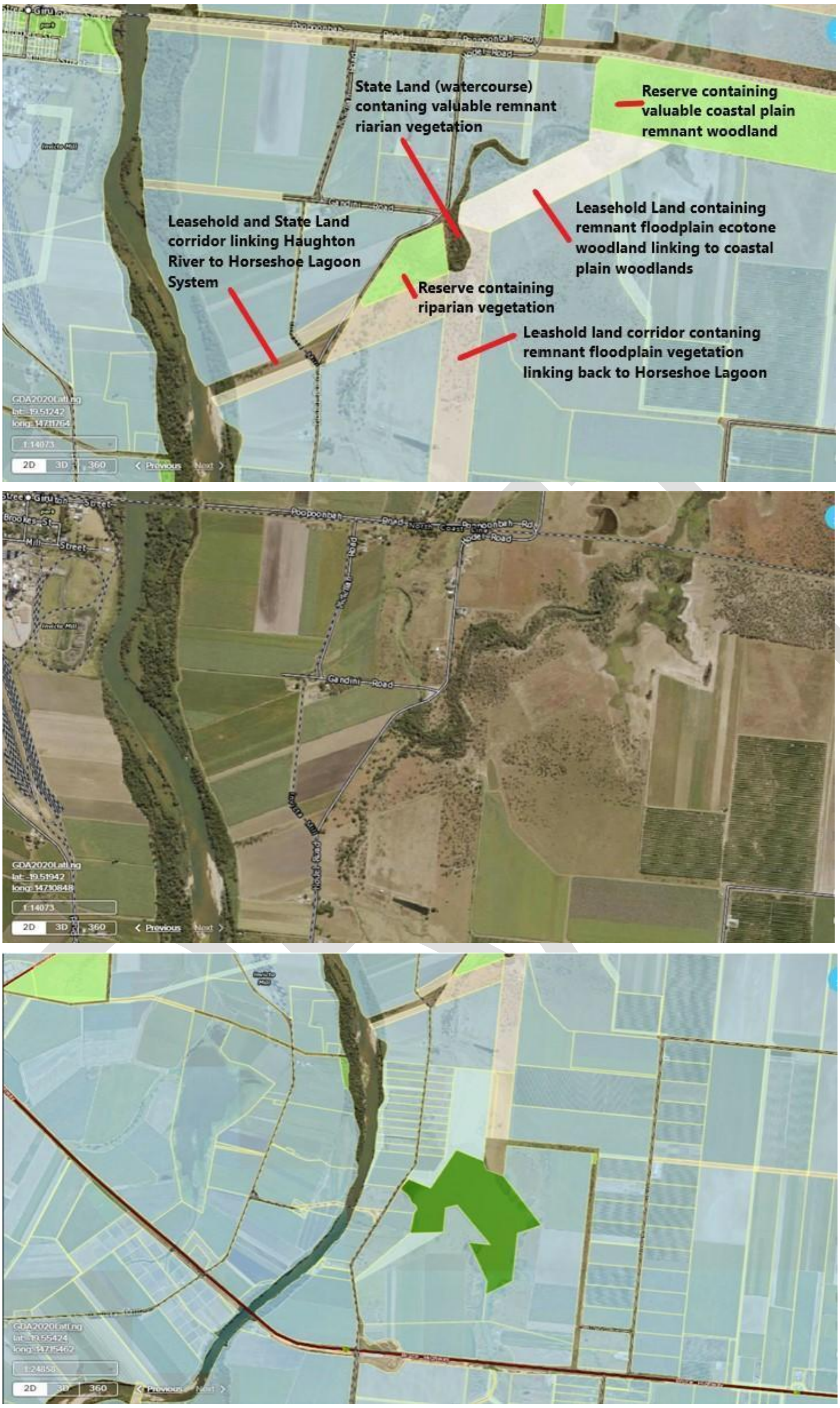


Figure 9. Land tenure context for potential nature conservation planning opportunities for the lower Horseshoe Lagoon system (top) in relation to remnant vegetation (centre) and the existing conservation park (bottom). Green = reserve, clear = state land, brown/white = leasehold land.

- Placing large woody debris and snags into the historical seasonal water level zone/wetted bank margin of the main lagoon system. This would provide critical roosting and sunning habitat for waterbirds and turtles and instream structural habitat for fish, which is currently limited.
- Connecting wet season flow paths to provide fish passage connectivity from the main lagoon system to estuarine reaches. This could be provided by either reinstating seasonal water level drawdown and channel/coastal lagoon drying to create open channel/wetland basins ahead of the wet season, and/or by additional investment in the control of aquatic floating and grass weed chokes and floating mats. These actions would help to establish a shaded, open outflow channel conduit between the main lagoon and the receiving creek system.
- Enhance terrestrial wildlife corridor connectivity between and beyond remnant vegetation areas of the Horseshoe Lagoon system. This includes via targeted revegetation and regeneration of corridor linkages to the adjoining Haughton River riparian corridor, to the lower distributary lagoon systems of Corrick Plains, to the coastal plain woodlands east of Corrick Plains, and between the floodplain vegetation remnants adjoining the main Horseshoe Lagoon system.

Recommendations

1. Engage with nature conservation agencies (DES, QPWS) and state land managers (Department of Resources, BSC) to establish a 'Biodiversity Conservation Management' working group to:
    a. Provide support and co-investment opportunities for developing and implementing a regionally-significant biodiversity conservation outcome (for example, coordinated conservation area, protected area network) around the central asset of the Horseshoe Lagoon system.
    b. Seek endorsement for prioritising investment in the condition management and restoration of state land and reserve areas (V13, 14), with high value remnant riparian and floodplain vegetation offering public interest and access benefits. Explore formal protective management arrangements.
    c. Draw DES/QPWS more directly into the management needs of the Horseshoe Lagoon Conservation Park, including via formal management arrangements with landholders and/or acquisition of lagoon frontage critical habitat areas.
2. Gain the support of nature conservation and local stakeholders to:
    a. develop the management capacity for the system's hydrological regime as the most viable way to deliver critical habitat dividends to the system (see *Altered hydrology* and *Aquatic weeds* sections);
    b. integrate fire and grazing regime management to deliver critical habitat dividends to the water edge and frontage areas of the main Horseshoe Lagoon system (see *Fire regime* and *Grazing regime* sections); and
    c. establish riparian overstory vegetation along trial sections of the Full Supply Level (FSL) bank margin of Horseshoe Lagoon to provide critical habitat values to the modified system (see *Lack of riparian vegetation* section).
3. Gain the support of fisheries management agencies and local stakeholders for the implementation of recommendations in the *Fish Passage Barriers* section to facilitate the re-establishment of critical connected flow path habitats.
4. Engage with QPWS and lagoon frontage landholders and obtain funding resources to conduct re-snagging and establish large woody debris roost habitat in a trial section of the historical seasonal water level zone of the lagoon margins. Monitor subsequent use by wetland fauna to assess merits of pursuing this more broadly around the lake margins.
5. Engage with state land managers (Department of Resources, BSC) and adjoining landholders to seek support for implementing a corridor linkage revegetation project to re-establish habitat connectivity between the Haughton River riparian corridor and the Horseshoe Lagoon system (V12).

Table 9. Examples of 'critical habitat' within the Lower Burdekin floodplain and implications for management

Critical habitat	Why important	Benefited wildlife	Management implications
Tree hollows	Provide nesting and nursery sites that are protected from the elements and predators.	Arboreal mammals (gliders, possums), microbats, hollow nesting birds.	Fire management to avoid uncontrolled burning loss of old trees. Avoidance of old tree clearing. Establishing artificial nest boxes can benefit dependent species.
Fringing 'riparian' communities	Have greater structural complexity, diversity, and associated feeding (fruit, nectar) and nesting resources than surrounding woodlands (or agricultural landscapes).	Migratory passerines, (songbirds), honey eaters, parrots, raptors, roosting waterbirds	Rehabilitation of riparian forests in agricultural landscapes will support populations of dependent species reduced during development habitat losses.
Riparian – Ecotone margins	Greater diversity of habitat and food resources available, as includes both that of the riparian and the adjoining woodland vegetation.	Arboreal mammals (gliders, possums), nectivorous birds, raptors.	Clearing to margin of riparian zones often results in loss of ecotone woodland component in retained vegetation (An ecotone is the boundary between different vegetation assemblages or ecosystem types). Natural recruitment is possible where there are remnant trees. Best opportunities are in broader development set-back corridors.
Mid/understorey trees	Provides a broader range of food resources (wattle gum, broad leaf tea tree nectar, associated insects) than what is provided by overstorey canopy trees alone.	Arboreal mammals (gliders, possums), nectivorous birds, insectivorous bats.	Need to challenge commonly desired parkland clearing aesthetic of 'cleaning up' 'useless scrub' trees, often mid-storey vegetation (like broad leaf tea tree). Need to include in targeted revegetation species.
Bare lagoon banks	Naturally occurring via dry season drawdown of lagoon water levels, provides predator safe roosting and resting areas for waterfowl.	Flock-forming waterfowl, like grass (or plumed) whistling ducks	Lagoon drawdown now more limited or no longer occurs due to modified hydrology. Could trial use of intense grazing, burning, or spraying to create.
Remnant vegetation corridors/landscape linkages	Provides opportunities for disturbance-sensitive wildlife to move between remnant habitat areas in developed landscapes to access food resources, find mates and distribute young to new areas.	Arboreal mammals (gliders, possums), macropods, dasyurids (quolls), reptiles.	The value of small vegetation remnants, even individual trees, can be important in providing this critical habitat and needs to be communicated to avoid incremental loss. Regional wildlife corridors transect most systems (see Appendix 1 values).
Exposed sand beds	Provide nesting sites for aquatic reptiles.	Turtles and freshwater crocodiles.	Now a limited resource due to lack of water level drawdown. Control of grass weeds could be used to create.
Closed 'rainforest'	Provides roosting sites protected from exposure to elements and predators and offers food resources for frugivorous (fruit-eating) fauna.	Owls, flying foxes, pigeons, frogs.	Fire sensitive. Existing closed forest reaches/sites warrant protection. Capacity to create with riparian revegetation should be supported at suited sites.
Low ground-covering bushes	Provides shelter from predators and refuge/resting areas for small mammals in open woodland habitats.	Small macropods, like spectacled hare wallabies, rufous bettongs, dasyurids (quolls), ground-nesting birds.	Impacted by pasture improvement, slashing, intensive grazing, and culture of 'parkland clearing', 'cleaning up scrub' as desired aesthetic. Fauna survey of sites retaining this critical habitat could demonstrate its value. Also, a useful revegetation target.
Logs/woody debris (including terrestrial and water edge)	Provides safe refuges for numerous species of small-to-medium-sized vertebrates. Provides sun basking and roosting sites for wetland fauna.	Roosting waterbirds, reptiles (turtles, snakes, lizards), dasyurids (quolls), and invertebrates.	Lost to frequent burning and 'cleaning up' of habitat remnants. Comparison fauna surveys of sites could demonstrate its value. Inclusion in rehabilitation objectives is valuable.
Rank grasses	Provides grass seed food sources for granivorous birds.	Finches, pigeons.	Critical habitat supported by grazing spelling/timing.
Shed tree bark	Important refugial habitat for arboreal reptiles (like geckos) and numerous invertebrates, insects, spiders, etc.	Geckos, microbats, invertebrates.	Lost to frequent/hot burning. Target for fire regime management.
Flow-connected coastal drainage depressions	Provides a migratory pathway for diadromous fish to move between estuarine and freshwater habitats of the catchment.	Diadromous fish, like barramundi, mangrove jack, mullet, milkfish.	Impacted by aseasonal flows and cumbungi/weed choke/anoxic reach establishment. Key system-scale rehabilitation target for most catchments.

Climate stress

Types and impacts

The most recent and 6th Intergovernmental Panel on Climate Change report provides compelling evidence that the greater than 1°C global heating the planet has experienced since 1890 is unequivocally the result of human activity and is proceeding at a rate that is unprecedented over millennia (IPCC 2022). In Australia, CSIRO modelling has been used to examine the future impact of global heating on regional climate patterns. These outputs can be interpreted at a local government boundary scale Future Climate Dashboard | LongPaddock | Queensland Government

Based on the globe's current greenhouse gas emissions trajectory, predicted impacts of most relevance to wetland system management include:

- Temperatures in Australia will increase by between 2.8 and 5.1°C by 2090 compared to 1986-2005; heatwaves will become more intense, more frequent and of longer duration; and the number of days of severe fire danger are likely to increase in southern and eastern Australia.
- Rainfall amounts are expected to decrease over southern Australia, accompanied by more frequent and more severe droughts. While rainfall trends for northern Australia are more uncertain, greater variability and more frequent, intense extreme rainfall events are projected.
- Fewer, but more severe, tropical cyclones are projected.
- Global sea levels are expected to increase by 45cm to 82cm by 2090, though these levels may be higher if a tipping point is reached which commits one or more land-based ice sheets to irreversible melting.
- Extreme high sea-level events will occur more frequently, increasing the risks of saltwater intrusion, flooding, and erosion in coastal areas.
- In line with global trends, sea waters around Australia are becoming more acidic (>30% since pre-industrial), as the oceans absorb much of the CO_2 released by human activities.

(NCCARF 2019) Climate change and sea-level rise in the Australian region | CoastAdapt

These projected changes – many of which have been increasingly realised over the last decade – have severe consequences for nature and human society, including agricultural production systems. For wetland system management, the following issues are nominated for consideration in the Lower Burdekin region:

Temperature and water quality

Risk – Higher water temperatures, increased rates instream bacterial decomposition of organic matter resulting in lower dissolved oxygen (DO) levels; more widespread and frequent summer fish kills; and water quality fish passage barriers.

SMP focus – Greater extent riparian vegetation shading of waterway margins; reduced weed infestation/organic loads into waterway; and role for supplemented/pumped flows to increase DO during critical periods.

Catchment water quality

Risk – Higher intensity rainfall (coming off the back of extended/more extreme dry seasons); higher rates of runoff (in drought stressed catchments); increased soil erosion and contaminant load carrying capacity; and loads exported more directly to receiving stream and wetland systems.

SMP focus – Improvement in contributing catchment condition, particularly vegetation condition; soil erosion pressure points; and increased focus of designed drainage modulus controls (litres/hectares/seconds) in constructed farm drainage networks, including re-establishing/improving runoff detention function (for example, constructed basins, vegetated drainage lines).

Flood resilience

Risk – Higher intensity rainfall; higher rates of runoff; greater flood peaks; greater frequency of channel breakout flows, and associated erosion, across agricultural floodplains; and potential for erosion and undermining/undercutting of stream banks.

SMP focus – Improving condition (contiguousness and width) of riparian vegetation corridors to shade-out channel-blocking weed growth; secure stream channel stability and baffle the velocity of channel breakout flows; retain and re-establish floodplain overstorey vegetation to baffle overland flow velocities; manage floating aquatic weed and aquatic grass abundance to prevent channel-blocking/infrastructure-destroying debris dams; retain natural wetland flow detention areas; and re-establish runoff flow detention within contributing catchment areas.

Fire regime

Risk – Extended dry seasons; higher air temperatures; lower soil moisture conditions; reduced cool burn season; more extreme, hotter fire outcomes, with greater consequent death of mature trees and impacts to fire-sensitive vegetation; degradation of vegetation structure; and loss of habitat values.

SMP focus – Reducing fire fuel loads in understorey of valuable riparian and wetland /floodplain habitat remnants by promoting canopy closure and/or controlled grazing; promoting cultural change away from farm ‘clean up’ burning; promoting controlled, cool burning regimes for remnant habitat landholders; incorporating fire breaks in property/farm layouts; and engaging fire wardens in ecological fire management principles.

Fauna refugia

Risk – Drier climate; failed wet seasons; higher air temperatures; reduced soil moisture; poor plant fruiting/flowering, which places fauna species, like bats, birds, and tree dwelling mammals, under behavioural, physiological and/or nutritional stress, including lack of shelter, overheating, and lack of food.

SMP focus – Retention, protection (from fire, weeds, clearing, stock pressure) and rehabilitation of dense, structurally complex, floristically diverse, or highly productive habitat remnants. This includes riparian and floodplain forests adjoining streams, lagoons or wetland basins, and habitat nodes, including fire refuges within variegated/developed landscapes.

Invasive species

Risk – Terrestrial ecosystems include native vegetation stressed in terms of growth vigour and/or attained structure by a climate trending towards a bio-climatic envelope outside its adaptive range, namely, too hot, dry, or wet. Other associated stressors, like larger cyclonic, flood, and extreme fire disturbance, present openings for opportunistic weeds or novel insect pests to gain a dominant niche. In aquatic ecosystems, the risk encompasses aquatic habitat quality being degraded outside of optimal conditions for native aquatic species. This includes the water being too hot, having low dissolved oxygen, and/or turbidity, which present advantageous conditions for opportunistic and generalist feral fish species, other novel aquatic pest species, or pathogens to gain a dominant niche. Higher temperatures, failed wets (no flushing flow), and elevated water nutrient status (no flushing dilution) support a longer and more vigorous growing season for aquatic weeds.

SMP focus – Management investment in the condition of terrestrial and aquatic ecosystems to increase system resilience by reducing pest and weed species abundance and maintaining active vigilance regarding identification and proactive control of ‘sleeper’, or new pest species, within the system.

Revegetation species providence

Risk – Seed or seedlings produced from local providence native plant stock may become stressed during their growth, in terms of their vigour, by climate trending toward a bio-climatic envelope outside its adaptive range, namely, too hot, dry, or wet. Stress can also be caused by disturbances like larger cyclonic, flood, drought, and extreme fire events occurring at a frequency, or for a duration, greater than the species has evolutionarily developed adaptive capacity.

SMP focus – Encourage vigilant observation by landholders and NRM practitioners working within the region of the vigour and potential die back of species comprising local vegetation communities across age classes. This includes areas that have undergone revegetation. Trial and compare the growth success of locally-occurring species from seed stock providences from outside (north, inland) the local latitudinal and longitudinal range.

Landward migration of coastal wetland mosaic

Risk – Sea level rise will increase the landward reach of tidal incursion within coastal wetlands. If protective barriers are created or increased to prevent this occurring, existing brackish environments below barriers will become marine, and important brackish habitats will be lost from the coastal wetland mosaic, potentially in conjunction with a reduction in fish passage connectivity. The ultimate transgression of such barriers could also create highly disturbed environments where freshwater vegetation dies in response to rapid salinity changes.

SMP focus – Identify opportunities, including incentives, to encourage the unimpeded incursion of tidal influence into the lower end of coastal wetland systems. This could include by supporting new bund development within upper reaches of coastal wetland basins in exchange for controlled breaching of existing lower reach bunds. This would allow for the staggered incursion of sea level rise into existing lower freshwater reaches of coastal wetlands, creating a brackish habitat, and facilitating an overall landward migration of the costal wetland habitat mosaic.

Mitigation as well as adaptation

While the management issues identified above include various proposals to increase wetland system resilience to adapt to emerging climate stress, it is also important to consider the roles that wetland systems can play in mitigating climate change. Principal amongst these is carbon sequestration and storage. Woody wetland vegetation, including that associated with riparian zones and/or floodplains, and organic material in wetland soils represent stores of carbon. Adding to the biomass of either through planting or regeneration of woody vegetation, or the deposition and long-term burial of organic material in wetland soils, represents carbon sequestration. Conversely, wetland environments that promote organic decomposition and associated methane production contribute greenhouse gas (GHG) emissions to the atmosphere. Reducing GHG emissions, preserving existing stores of carbon and sequestering additional carbon help to mitigate global warming. This knowledge needs to inform all natural resource management actions in a world facing a climate crisis.

Horseshoe Lagoon system specifics

Considering the landscape, land use and condition context of the Horseshoe Lagoon system, seven of the eight issues described above are particularly relevant for system management planning that builds climate stress resilience. These issues include:

- temperature and water quality;
- catchment water quality;
- flood resilience;
- fire regime;
- fauna refugia;
- invasive species;
- landward migration of coastal wetland mosaic; and
- mitigation versus adaptation.

Summarising the identified SMP focal points discussed for these issues above, a Horseshoe Lagoon system that is managed to have resilience in the face of climate stress would have the following features:

- Ability to withstand large, floodplain-inundating breakout flows from the Haughton River, including concurrent high-volume outflows from the main lagoon to the lower creek system, and secondary breakouts flows from the lower system's creek channel to the eastern distributary system, without significant damage to channel integrity or erosion of adjoining floodplain areas. Dense, broad, flow-baffling, bands of riparian vegetation along the Haughton River, Horseshoe Lagoon bank margins, and the lower system creek and distributary channel margins would provide a way to secure channel bank integrity against erosive forces and see breakout flow velocities reduced. Pressure points for potential channel head cutting between the main lagoon and the downstream-receiving creek system would be rock armoured. Any available floodplain land would have corridors of remnant and revegetated floodplain vegetation established across overland flow paths to help baffle overland flow velocities.
- Contiguous, shaded riparian vegetation corridors to maintain cooler water temperatures and exclude aquatic grasses from the main lagoon's Full Supply Level (FSL) bank margins, and along the entire length of the lagoon's outflow channel, lower wetland system's creek channel, and adjoining distributary lagoon system bank margins.
- A seasonal hydrological regime that allows for dry season water level drawdown, and creek channel and coastal wetland drying that ensures for an open channel and wetland basin condition prior to the annual wet season. During this time, water flows and fish passage are not impeded, and the water quality is not degraded by aquatic floating and grass weed chokes and associated organic loading and biological oxygen demand (BOD).
- Specific design features within the BHWSS-constructed drainage network in its contributing catchment area to effectively cope with extreme rainfall events, in a way that controls rates of runoff. This avoids erosion to channels and adjoining farmland and limits the transport of mobilised contaminant loads directly to receiving wetland systems. Such designs would incorporate bank stabilising and high flow baffling riparian vegetation; in-channel vegetation; and constructed broad detention basins that capture and process contaminant loads in first flush events and lower the overall slope and discharge rate of the drainage network.
- Proactive controlled burning and fire regime management. Fire fuel loads in or adjoining areas of remnant vegetation would be actively managed by slashing, grazing and/or controlled burning. Proactive management to reduce hot wildfire risks associated with extended dry season and elevated temperatures would include promoting riparian vegetation canopy cover and closure along the main Haughton River to reduce grass understorey; controlled grazing and/or cool burning of fire fuel loads in lagoon frontage areas, riparian zones and vacant land adjoining production areas dominated by an exotic pasture (guinea, para grass) understory; and maintaining functional fire breaks between extensive areas of unmanaged fire-prone remnant vegetation and vulnerable assets.
- Regional wildlife habitat corridors that link to adjoining remnant habitat areas and contain recognised wildlife refuge habitats. These have been consolidated through targeted regenerative activities, like revegetation, weed, fire control, and are actively protected from threats. Examples could include riparian vegetation areas that incorporate denser refugial habitat nodes where channel benches and adjoining ecotonal woodlands occur. Also, better condition wetland or floodplain vegetation stands that are poorly represented in the post development landscape,
- Controlled populations of weeds and feral invasive species through sustained management commitments. Also, vigilance to identify and eradicate infestation source areas, novel, or sleeper species, and to maintain the resilience of native terrestrial and aquatic ecosystems. For example, with feral fish, competitive advantage for native species occurs where there is good water quality, high connectivity, natural hydrology, good habitat availability, and native predator abundance.

- Planned retreat of production areas and infrastructure from tidally-influenced areas to allow for the landward migration of the coastal wetland mosaic. In the case of the Horseshoe Lagoon system's existing tidally influenced areas, like Corrick Plains, this could possibly entail removing or relocating existing tidal bunds inland, and the protected/promoted succession of marine vegetation, like samphire flats and mangroves, into newly created brackish zones.

A Horseshoe Lagoon system managed to help mitigate global warming would:

- Regenerate or revegetate all land not being used for pastoral or agricultural purposes. The aim is to support natural maximum standing woody biomass structure for the regional ecosystem type concerned, which could be a greater biomass in the case of intentional agroforestry land use.
- Have a management regime for hydrological and associated vegetation, like aquatic weeds, that promotes long-term burial of organic material in depositional environments. This regime also reduces methane emissions associated with the decomposition of organic material in depositional environments.

Recommendations

1. Engage all management stakeholders in:
    a. understanding of projected climate conditions over forthcoming decades and their likely expression on Lower Burdekin floodplain landscapes, including within wetland and production systems;
    b. identifying local site, and individual, along with regional and collaborative, responses and management initiatives that can serve to increase the resilience of natural resource assets of the floodplain to projected climate stress; and
    c. identifying local site and individual, along with regional and collaborative, responses and management initiatives that can serve to increase the global warming mitigative role of floodplain natural resource management, particularly regarding carbon sequestration and minimising GHG emissions.

> Innovative management

Why we need innovation

Environmental management is an imperfect science that is best progressed by an adaptive approach. Through this adjustive approach, different methods can be trialled and successes pursued, while mistakes are used as opportunities for learning, and can be avoided in future efforts. There has been major improvement in the ecological condition of Lower Burdekin wetland systems due to management investments made over the past two decades. However, as identified through this plan, there are still outstanding environmental management issues confronting most wetland systems, and some condition trends remain negative. To achieve further improvements in the environmental condition of wetland systems, there needs to be an ongoing commitment to improving management capacity and outcomes, while recognising the resource constraints for the tasks at hand. Crucially, to take the next step and deliver a new level of improved wetland system management outcomes requires things to be done differently. In some instances, this might involve doing existing approaches better. In other cases, it may call for investigating and applying innovative approaches – essentially drawing on new advanced and original methods.

Much of the environmental management gains achieved for Lower Burdekin wetlands over the past two decades can be attributed to innovation. The use of weed harvesters and excavators to remove neglected aquatic weed infestations; developing a cost-shared weed control program instituted through RMAs; and large reach-scale riparian revegetation outcomes, are all initiatives that Burdekin wetland management stakeholders should be proud of. At the time, these initiatives were truly innovative as it was the first time they had been applied in the seasonal dry tropics – or in the case of RMAs – in Australia.

During the development of the initial SMP for Sheep Station Creek, 15 other innovative management methods, tools, and approaches were proposed. These are listed below, but are described in full in the Sheep Station Creek SMP (Econcern 2021). Five additional innovative management approaches (point 16 to 20 below) were also proposed during the development of the Woodhouse Lagoon and Ironbark Creek – Healey's Lagoon SMPs (Econcern 2022a, 2022b). Another (point 21) was trialled and developed by NQ Dry Tropics Wetland Manager Scott Fry in recent years. The innovative management methods are:

1. Excavated channel weed control via riparian shade tree planting.
2. Alternate channel weed control methods utilising small in-channel machinery.
3. Pumped environmental 'freshening' flow during wet season critical water quality period.
4. Weed control via effective biomass removal and economically viable soil ameliorant product development.
5. Use of mobile herd to deliver controlled grazing outcomes through the catchment.
6. Alternate distributary channel fish passage bypass route.
7. Establishing riparian forest and native water lily shading to reduce submerged plant growth.
8. Catchment line of control for floating aquatic weeds.
9. Establishing farm drainage line revegetation/detention function.
10. Use of monitoring drones.
11. Conducting cool burns in cane land habitat remnants.
12. Direct seeding vegetation regeneration methods for exotic grass-infested riparian zones.
13. Instream physical habitat interventions.
14. Fenceless grazing systems.
15. Alternatives to chemical weed control.
16. Waiving of overland flow/water course access/licencing fees for aseasonal flows originating from farm irrigation and/or BHWSS tailwater flows.
17. Intervention and re-use of farm/scheme area irrigation tailwater for off-stream pasture production.
18. Establishing a suitable water quality fish passage preferential flow path through an aquatic grass weed-dominated drainage depression via riparian shading.
19. Alienation of irrigation supply flows from naturally seasonal wetlands.
20. Forming dedicated catchment management groups to support enhanced aquatic weed and other environmental management of floodplain wetland systems.
21. Use of drones for aquatic weed spraying.

System specifics

Given the overlap in land and water use and condition context of the Horseshoe Lagoon system with other wetland systems that have SMPs, many of the previously identified innovative management approaches are applicable. Fourteen of the listed 21 points (4, 5, 7, 8, 9, 10, 11, 13, 15, 16, 17, 18, 19 and 20) are incorporated in some form in management recommendations in this SMP, and the complete set are assessed to have some relevance.

Point 10 *Use of monitoring drones* was employed during the development of this SMP to collect low altitude high resolution aerial imagery for identifying the current weed infestation status of coastal wetlands on Corrick Plains, and the bank margin condition of Horseshoe Lagoon.

Two management focuses nominated in this SMP may be considered innovative proposals for the Lower Burdekin region, although both are likely to have been used already elsewhere. These include:

(1) the proposal to reinstate a seasonal hydrological regime to the Horseshoe Lagoon system (see *Altered hydrology* section), and

(2) the proposal for using state-lands, as the initial priority areas for restoration and conservation as these would have less restrictions in the way of wetland rehabilitation and then moving into the adjacent private land.

As noted in preceding SMPs, the Lower Burdekin floodplain is awash with aseasonal flows of irrigation supply and tailwater, and altered hydrology is the primary driver of ecological impacts in receiving aquatic environments downstream of irrigation scheme and regulated flow systems. Despite the importance of the issue, there have been only a few examples to date of water managers successfully alienating aseasonal inflows to naturally seasonal wetland systems. The efforts of Lower Burdekin Water in lower Sheep Station Creek's coastal drainage depressions and past efforts of the (then) South Burdekin Water Board at Alma and Lyah Creeks near Inkerman, represent the only known precedents (Econcern 2021). Alienation of irrigation supply flows from the Reed Beds wetland was recommended in the Ironbark Creek – Healey's Lagoon SMP (point 19 in the list of innovative approaches above).

In the case of the Horseshoe Lagoon system, it is irrigation scheme (BHWSS) tailwater, rather than irrigation supply water, that needs to be alienated from the receiving wetland system. In theory, this should be more achievable in the sense that cessation of flows does not impact paying water customers, although – in the case of the Horseshoe Lagoon system – the capacity of licenced water users to extract licenced volumes is positively impacted by inflows of scheme tailwater. These issues, amongst others, would determine what mix of strategies might be employed in returning a seasonal hydrological character to the Horseshoe Lagoon system, including (see *Altered hydrology* section):

- reduction and retention of BHWSS tailwater volumes within the scheme area;
- off-stream re-use of scheme tailwater extracted from tailwater drainage channels; and
- built infrastructure that bypasses tailwater inflows to Horseshoe Lagoon to the Haughton River via a variable height outlet.

Given the importance of modified hydrology as the key driver of ecological degradation within the naturally seasonal wetlands of the Lower Burdekin floodplain, the highest priority is the developing innovative management methods that can restore seasonal hydrological character to wetland systems. In the case of the Horseshoe Lagoon system, this priority is underpinned by a wetland that is of national and state importance and forms part of the Queensland protected area estate, despite undergoing significant degradation in ecological condition in the past 30 years.

Recommendations

1. As per recommendation in the Ironbark Creek – Healey's Lagoon SMP (Econcern 2022b): Establish a consultative SMP stakeholder group to conduct formal meetings with Sunwater to explore BHWSS management arrangements and infrastructure to alienate regulated flows and/or scheme tailwater inflows from seasonal wetland systems. Also, to develop funded project proposals for the sites nominated in the SMPs, including the Horseshoe Lagoon system.
2. As per recommendation in the *Critical habitat* section: NQ Dry Tropics biodiversity asset managers engage with government environmental agencies (DES, QPWS) and state land managers (Department of Resources, BSC) to establish a biodiversity conservation management working group. This group would respond to, and further develop, the proposals and recommendations outlined in the SMPs for enhanced protective management of biodiversity assets on reserves and other state tenure land.

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> Appendix 1 – Reach values, management issues and nominated works descriptions

Reach values (V)
Short description – V1: Large perennial lake 'Horseshoe Lagoon'
V1 – Full description Horseshoe Lagoon is a large freshwater lake. Natural lacustrine habitats of this size are uncommon within the region. Historically, the lake was a highly seasonal waterbody, but it is now maintained at high water levels due to sustained inflows of irrigation tailwater from the BHWSS in its upper catchment. Horseshoe Lagoon is primarily recognised for its high waterbird habitat values. These values support recreational use by bird watchers, and public bird watching infrastructure has been established on the lagoon's perimeter. The site also supports a range of other wetland fauna including reptiles, fish, and amphibians. Historically, the site was recognised as a high value nursery habitat for barramundi, but this value has been impacted in recent decades by the formation of downstream fish passage barriers associated with aquatic weed infestations. The high conservation values of the lake are recognised by its inclusion within the protected area estate as the Horseshoe Lagoon Conservation Park. The site is assessed to have very high value in state riverine Aquatic Conservation Assessments and high value in state non-riverine Aquatic Conservation Assessments. The state biodiversity significance of Horseshoe Lagoon includes its recognition as an ecologically-significant wetland, mapped occurrences of 'of concern' regional ecosystems, and medium habitat value assessments for endangered, vulnerable or near threatened (EVNT) species. Other matters of state environmental significance at the site include regulated vegetation 100m from the designated wetland, mapped essential habitat, and assessed wildlife habitat suitable for endangered or vulnerable and least concern species. This site also forms part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).
Short description – V2: Lakeside riparian remnants
V2 (a – e) – Full description The ecological values of bankside riparian vegetation include the provision of terrestrial and instream habitat and food resources, regulation of shallow margin water temperature, and shade-based exclusion of aquatic grass weeds. Historically, Horseshoe Lagoon was a seasonal wetland with variable water levels that did not have a well-defined riparian zone; although patches of floodplain vegetation, including riparian species, did occur around its high-water level margin. With the hydrology of the system modified toward perenniality and sustained water levels, there is now a much greater opportunity for a marginal riparian vegetation zone to establish and there are already examples of where this has occurred on the lagoon's margin. These naturally-recruited tree stands and remnant floodplain vegetation patches adjoining the water's edge provide existing habitat values and a source of seedling recruits for further expansion and development of bankside riparian vegetation. Existing lakeside riparian vegetation represent matters of state environmental significance, occurring within an ecologically significant wetland, and are regulated vegetation on account of being 100m from a defined wetland, or 'of concern' regional ecosystem, included within mapped essential habitat, or being recognised as wildlife habitat for endangered or vulnerable and least concern species.

All occur within sites that form part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).

Short description – V3: Remnant floodplain woodland

V3 – Full description

Remnant floodplain vegetation adjoining Horseshoe Lagoon contributes to greater overall site biodiversity, including the range of bird and other fauna species that can be supported there. While the floodplain margins surrounding Horseshoe lagoon were historically vegetated by predominantly open grassland and woodland communities, much has been cleared during past pasture improvement development, which has also retarded natural seedling recruitment processes. Remnant stands of floodplain vegetation therefore represent areas of higher ecological value with more diverse habitat resources. Existing remnant floodplain vegetation includes matters of state environmental significance where it occurs within or up to 100m from the defined wetland, contains ‘of concern’ regional ecosystems, is included within mapped essential habitat, or is recognised as wildlife habitat for endangered or vulnerable and least concern species. Most stands also occur within the boundary of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).

Short description – V4: Contiguous riparian vegetation corridor

V4 – Full description

This riparian vegetation corridor initiates just downstream of Horseshoe Lagoon, where the broad drainage depression conveying lagoon outflow forms into a defined stream channel and extends downstream to the QR crossing at the upstream margin of historical tidal influence. Although some reaches are impacted by woody weeds and rubber vine, its overall diversity and structural complexity is high. It broadens in lower reaches to form a dense closed-canopy structure dominated by paperbarks and livistona palms with a range of broadleaf rainforest-associated species also present. This riparian vegetation provides good feeding and nesting habitat resources for frugivorous, insectivorous, and nectivorous birds and bats, and refugia for disturbance-dependent wildlife including owls and mammals. The density of the canopy in some reaches also serves to exclude sun-loving exotic grass understorey, limiting hot fire risks. This riparian vegetation corridor includes matters of state environmental significance including endangered and of concern regional ecosystems, regulated vegetation including GBR riverine regrowth, mapped essential habitat, and habitat suited to endangered or vulnerable wildlife species. The site is assessed to have high value in state riverine Aquatic Conservation Assessments and has state biodiversity significance, including an ecologically significant wetland, ‘of concern’ regional ecosystems, medium habitat value for endangered, vulnerable or near threatened (EVNT) wildlife species, very high condition, ecosystem diversity, and ecosystem value. This site also forms part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).

Short description – V5: Diverse and structurally complex riparian forest, riverine wetland, and ecotone woodland habitat complex

V5 – Full description

This high value habitat complex occurs within a sub-reach of the riparian vegetation corridor downstream of Horseshoe Lagoon where a range of habitat types, including complex riparian forest, channel hosted waterholes and adjoining floodplain ecotone woodland, are juxtaposed in close proximity. This meeting of habitat types presents a more diverse range of available habitat resources capable of supporting greater site biodiversity, and therefore represents an area of higher ecological and nature conservation value. The site is assessed to have high value in state riverine Aquatic Conservation Assessments and has state biodiversity significance, including an ecologically significant wetland, ‘of concern’ regional ecosystems, medium habitat value for endangered, vulnerable or near threatened (EVNT) wildlife species, and very high condition, ecosystem diversity, and ecosystem value. This site also forms part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).

Short description – V6: Channel-hosted deepwater lagoon with riparian forest

V6 – Full description

This site represents the largest channel-hosted lagoon within the main lower Horseshoe Lagoon system. Its values include good condition, diverse and structurally-complex fringing riparian vegetation; a range of instream structural habitat, including abundant snags and aquatic vegetation; and its capacity to support good populations of wetland fauna, including fish, reptiles (including two crocodile and several turtle species), and a diverse range of wetland, woodland, and raptor bird species. The site is assessed to have high value in state riverine Aquatic Conservation Assessments and has state biodiversity significance, including an ecologically significant wetland, ‘of concern’ regional ecosystems, medium habitat value for endangered, vulnerable or near threatened (EVNT) wildlife species, very high condition, ecosystem diversity, and ecosystem value. This site also forms part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).

Short description – V7: Seasonal back levee wetland

V7 – Full description

This small seasonal wetland retains its natural hydrology and has not become dominated by exotic grass cover due to the seasonal effectiveness of control provided by grazing cattle able to access any established exotic pasture species. Consequently, when inundated during the wet season, it provides open water habitats and opportunities for the growth of native aquatic plants that have been excluded from the larger wetland complex due to modified hydrology and exotic grass infestation. These habitat types are utilised by a host of wetland fauna ranging from invertebrates, to frogs and water birds. This representation of a habitat type reduced due to system modification, and its use by local species adapted to seasonal habitats, underpins its value. The site has state biodiversity significance forming part of ecologically significant wetland, which hosts ‘of concern’ regional ecosystems, provides medium habitat for endangered, vulnerable or near threatened (EVNT) wildlife species, and has very high values for condition, ecosystem diversity, and ecosystem value. This site also forms part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).

Short description – V8: Corrick Plains: Large state significant coastal wetland complex

V8 – Full description

This large coastal wetland complex has very high bird habitat values for waterfowl, waterbirds, and migratory waderbirds. It also provides fishery nursery habitat particularly for commercially and recreationally-important barramundi. It is known to host large individuals of saltwater crocodiles. Its high values are recognised by inclusion in the protected area estate as the Corrick Plains Nature Refuge. Matters of state environmental significance associated with the site include being part of a strategic environmental

area (designated precinct), an ecologically significant wetland, containing regulated vegetation up to 100m from the mapped wetland boundary, and providing wildlife habitat for special least concern species. State non-riverine wetland Aquatic Conservation Assessments define the area as being of high conservation significance. It is a state significant wetland, and has state biodiversity significance for ‘of concern’ regional ecosystems, provision of medium habitat for endangered, vulnerable or near threatened (EVNT) wildlife species, and very high values for condition, ecosystem diversity, ecosystem value, and as a wildlife refugia. This site forms part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).
Short description – V9: Large seasonal coastal wetland basin
V9 (a & b) – Full description These two wetland basins form a subset of the coastal wetland complex within the Corrick Plains Nature Refuge. However, unlike the broader wetland complex that has been impacted by aseasonal inflows of tailwater from irrigation areas in the upper catchment, and subsequent aquatic weed infestation, these two wetland basins have limited or no exposure to such inflows. Consequently, they retain a more natural seasonal hydrology and an associated variable salinity regime, which limits their infestation by exotic aquatic grasses or floating aquatic weeds. This results in more natural, higher value habitat conditions, including open water habitat following wet season inundation; better water quality conditions, including clearer water and higher dissolved oxygen; and the growth of native aquatic plant communities, including bulkuru sedge. This creates seasonal wetland habitats with high feeding and nesting values for water birds and improved function as fishery nursery habitat. As per the larger habitat complex, matters of state environmental significance associated with the site include being part of a strategic environmental area (designated precinct), an ecologically significant wetland, containing regulated vegetation up to 100m from the mapped wetland boundary, and providing wildlife habitat for special least concern species. State non-riverine wetland Aquatic Conservation Assessments define the area as being of high conservation significance. It is a state significant wetland and has state biodiversity significance for ‘of concern’ regional ecosystems, provision of medium habitat for endangered, vulnerable or near threatened (EVNT) wildlife species, and very high values for condition, ecosystem diversity, ecosystem value, and as a wildlife refugia. This site forms part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).
Short description – V10: Seasonal distributary lagoons
V10 – Full description These lagoons are hosted within seasonal distributaries that have been formed from a combination of prior channels and contemporary flood outbreaks of the lower Horseshoe Lagoon system. They occur in a range of condition states: some are infested and smothered by ungrazed exotic aquatic grasses, while others retain open water habitats and fringing riparian vegetation; some of which has resulted from past revegetation programs. One of their key values is the retention of natural seasonal hydrology that has been lost from the broader wetland system due to aseasonal tailwater inflows. Some may receive small local irrigation tailwater inflows from adjoining cane land. Although their condition is only fair at best, they still provide suitable habitat for a range of wetland fauna including fish, amphibians, reptiles, and birds. Their potential for further rehabilitation also represents a yet unrealised value. Matters of state environmental significance associated with these sites include an ecologically significant wetland, containing regulated vegetation i.e., GBR riverine regrowth, defined watercourse, and vegetation up to 100m from the mapped wetland

boundary, and providing wildlife habitat for special least concern species. State non-riverine wetland Aquatic Conservation Assessments define the area as being of high conservation significance and riverine wetland Aquatic Conservation Assessments as very high value. One of the lagoons is a state significant wetland, and the broader site also has state biodiversity significance for being part of a bioregional terrestrial corridor and having very high ecosystem value. This site forms part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).
Short description – V11: Seasonal distributary lagoon riparian forest habitat complex
V11 – Full description These seasonal distributary lagoons occur on the most downstream extent of the distributary channel system, formed by a combination of prior channels and contemporary flood outbreaks of the lower Horseshoe Lagoon system. In contrast to the more upstream aggregation of distributary channel lagoons, this complex of lagoons has retained much of its riparian vegetation. It has also been maintained as a grazing property, which has prevented exotic aquatic grass species dominating wetland habitats. The open wetland habitats and their juxtaposition with good condition riparian vegetation provides diverse and productive locations that support a diversity of wetland fauna, particularly birds, reptiles and fish, including providing a suitable nursery habitat for the commercially and recreationally-important barramundi. Matters of state environmental significance associated with these sites include recognition as an ecologically significant wetland, containing regulated vegetation including that up to 100m from mapped wetland boundaries and GBR riverine regrowth, and providing wildlife habitat for special least concern species. State non-riverine wetland Aquatic Conservation Assessments define the area as being of high conservation significance and riverine wetland Aquatic Conservation Assessments as very high value. The site has state biodiversity significance as a state significant wetland, representation of 'of concern' regional ecosystems, inclusion within a bioregional terrestrial corridor, and for having very high condition, ecosystem diversity, wildlife refugia and ecosystem value and for providing medium habitat for EVNT taxa. This site forms part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).
Short description – V12: State land corridor linkage between Haughton River and Horseshoe Lagoon system
V12 – Full description This patch of remnant vegetation occurs on a state land corridor that links back to leasehold and reserve land associated with the lower Horseshoe Lagoon wetland system. Revegetation of this corridor could serve to provide a regionally-significant wildlife habitat corridor linkage between the Haughton River Riparian Corridor and the remnant riparian vegetation habitats of the lower Horseshoe Lagoon system.
Short description – V13: High value riparian vegetation habitat occurring on state land – reserve and watercourse
V13 – Full description This complex of remnant riparian vegetation and adjoining ecotonal woodland occurs on state land, both reserve (western margin) and watercourse (eastern component). These tenures allow for greater public access and associated greater public interest, which could justify public investment in biodiversity condition and conservation outcomes.
Short description – V14: Remnant floodplain/ecotonal vegetation within state land corridor that links between the creek system and the coastal plain

V14 – Full description This remnant floodplain vegetation includes ecotonal woodland adjoining the riparian zone and occurs in a state land corridor. It also includes seasonal wetlands and extends to other state reserve land containing remnant coastal plain woodland. Collectively the land tenure context and remnant vegetation assemblages present significant opportunities for nature conservation planning outcomes.
Short description – V15: State reserve land containing high value coastal plain woodland remnant vegetation juxtaposed with high value coastal wetlands
This broad corridor of state reserve land contains remnant coastal plain woodland that adjoins the coastal wetlands of the lower Horseshoe Lagoon system. These coastal plain woodlands on alluvial soils are poorly represented in the adjoining national park and their protective management is important to the conservation of biodiversity values associated with the Horseshoe Lagoon system and broader region.
Management issues (M)
Short description – M1: Aseasonal inflows of irrigation tailwater and channel overflow from the Burdekin Haughton Water Supply Scheme (BHWSS)
M1 – Like all wetlands in the seasonal dry tropics, the natural hydrology and associated ecology of the Horseshoe Lagoon system was highly seasonal and related to the timing and magnitude of the annual wet season. In the contemporary modified Horseshoe Lagoon system, the hydrology in its upper catchment is dominated by inflows of irrigation tailwater and supply channel overflow from the Burdekin Haughton Water Supply Scheme (BHWSS). These aseasonal inflows contribute to near perennial outflows from the lagoon to the downstream drainage system and a major reduction in dry season drawdown of lagoon water levels. This altered hydrology has generated major changes in aquatic plant communities (increased aquatic weeds, decreased native communities), water quality (higher turbidity and nutrients), fish passage connectivity (barriers created by weed chokes), and associated habitat values for wetland fauna. Licensed water users adjoining the lagoon have water use and pumping infrastructure that has been established in the hydrologically-modified lagoon.
Short description – M2: Ungrazed exotic grass understorey presents hot fire risks to remnant vegetation
M2 – This regenerated area of floodplain woodland vegetation, including eucalypt and paperbark (melaleuca) species, has an understorey dominated by ungrazed exotic pasture grass weeds (guinea, para) that expose it to dry season hot fire risks from surrounding areas. In the absence of active management, its condition and habitat value could degrade.
Short description – M3: Natural structure, clearing, fire and suppression of seedling recruitment has limited riparian vegetation development
M3 – Under its naturally seasonal condition the foreshore-littoral zone of Horseshoe Lagoon was characterised by fire-mediated patches of floodplain and riparian trees, rather than a contiguous riparian vegetation margin. Some of this vegetation was historically cleared for pasture improvement. Lake margins are now dominated by exotic pastures, both grazed and ungrazed. Ungrazed areas present hot and wildfire risks to remnant vegetation and adjoining cane land respectively. Grass weeds that dominate ground cover;

stock trampling or browsing, and hot fires all contribute to suppressing riparian vegetation recruitment along the now-perennial lagoon’s supply near full waterline.
Short description – M4: Lack of seasonal water level drawdown and aquatic grass and floating weeds has reduced native aquatic plant cover
M4 – The modified hydrological status of the lagoon, resulting from inflows from the BHWSS, creates conditions suited for exotic ‘ponded pasture’ grass species hymenachne and para to dominate the water edge and shallow zone. These grasses now dominate areas that previously supported emergent, submerged and floating bed native aquatic plants, like water lilies. Floating aquatic weeds also periodically infest these zones. Both the competition from aquatic grasses and floating weeds and the periodic chemical spraying associated with their control, all serve to reduce the area, abundance and diversity of native aquatic plant communities within Horseshoe Lagoon.
Short description – M5: Sustained aseasonal inflows from irrigation scheme area impacts turbidity and nutrient levels within lagoon
M5 – Under its natural predevelopment condition, Horseshoe Lagoon’s water quality was set by annual wet season inflows; after which the water cleared, and nutrients were processed by seasonal aquatic plant communities during seasonal water level drawdown. Under the modified condition driven by BHWSS inflows, lagoon water quality conditions are often turbid. Tailwater inflow volumes also constitute a large source of additional nutrient loading to the system.
Short description – M6: Altered hydrology and nutrient levels promote aquatic weed infestation cycles further exacerbated by control methods
M6 – BHWSS inflows and the associated loss of dry season drawdown of lagoon water levels creates conditions, including elevated nutrients, that promote the extensive growth of aquatic weeds within Horseshoe Lagoon, including floating species (water hyacinth, water lettuce, salvinia) and fringing aquatic grasses (hymenachne, para). RMAs, including funding commitments established with riparian landholders and other partners (BSC, Sunwater), support a BSC-operated weed spraying program that successfully manages the level of aquatic weed infestation experienced by the lagoon; although efforts need to be ongoing for management gains to be sustained. One of the consequences of controlling aquatic weeds by chemical spraying is that weed biomass sinks within the lagoon, impacting water quality and maintaining high organic nutrient loading.
Short description – M7: Outflows from lagoon promote hymenachne infestation of unshaded outflow channel, which forms a fish passage barrier
M7 – Outflows from Horseshoe Lagoon driven by BHWSS inflows and associated high water levels create near-perennial wetness in the now-channelised drainage depression outflow area. This was historically a seasonal wetland that dried in the dry season, leaving bare open channels. The perennial wetness has promoted the extensive growth of dense exotic aquatic grasses, primarily hymenachne and para, within the channel and on the adjoining floodplain. In wetter years, grazing stock does not access pasture grass stands within the channel and they form dense patches covering the water’s surface. During wet season high flow events

much of this biomass is inundated and bacterial decomposition consumes available oxygen, creating anoxic (deoxygenated) water conditions that present a water quality passage barrier. Also, the conditions potentially present a physical barrier to migratory fish species, including barramundi that attempt to recruit upstream from estuarine nursery areas.
Short description – M8 (a, b): High flow outflows roll hymenachne cover back and generate head-cutting erosion in lagoon outlet channel(s)
M8 – Hymenachne is relatively shallow-rooted and forms a dense thatch-rich semi-buoyant mat-like cover of Horseshoe Lagoon’s outflow areas. During high flow events, this covering can be lifted and rolled back by high flow velocity water exposing underlying areas to erosion. When flood event outflows concentrate into exposed channel areas, channel head cutting can result. If these channel head cuts were to migrate all the way to the outflow margin of the lagoon, its water level could be permanently lowered.
Short description – M9: Additional irrigation tailwater enters system downstream of lagoon, contributing to water quality and hydrology impacts
M9 – In addition to the main inflow of BHWSS water located at the upstream head of the lagoon system, two additional tailwater drains draining the irrigation scheme area enter the system downstream of the main lagoon waterbody, contributing to hydrological and water quality impacts in the lower system.
Short description – M10: Range of woody weed species, including rubber vine and exotic trees, present threats to riparian vegetation condition
M10 – The riparian vegetation of the lower system is relatively diverse, structurally complex, and has a range of associated nature conservation values. One of the apparent risks to its condition is a host of woody (chinee apple, yellow oleander, cassia) and vine (rubber vine) weed species that are established within it. In the absence of dedicated management, the abundance and impact of these weeds is likely to increase.
Short description – M11: Dieback and condition decline in remnant vegetation appears to be driven by groundwater rise
M11 – Irrigation-driven groundwater rise is recognised for much of the system’s catchment area. Within this stand of remnant vegetation, several tree stands have succumbed to dieback with no obvious evidence to attribute it to insect attack or hot fire impact. Groundwater rise has been nominated as the likely cause by the landholder.
Short description – M12: Aseasonal flows and elevated nutrients drive aquatic weed infestation throughout lower creek system
M12 – Chanel-hosted lagoons and pools within the lower system have a range of wetland fauna habitat values, including for fish, reptiles, and birds. As recognised for the main lagoon, altered hydrology and elevated nutrient loading associated with irrigation scheme tailwater inflows to the upper system is promoting the infestation of these water holes by a range of aquatic weeds, which impacts the full realisation of their potential habitat value.

Short description – M13: Aseasonal inflows, and tidal bunds alter salinity regime, aquatic weeds and plant abundance, and habitat values
M13 – The coastal lacustrine (lake) wetland systems of the Corrick Plains area were historically subject to tidal influence in the late dry season, which promoted important habitat resetting and a salinity regime that supported the growth of adapted plant species such as bulkuru sedge. Bulkuru sedge is an important food and nesting resource for several waterfowl and waterbird species, like brolgas, magpie geese, and creates ideal water quality conditions and nursery habitat for post-larval barramundi. The historical establishment of earth bunds on the downstream margins of this coastal wetland complex to exclude tidal inflows and promote ponded pastures; along with sustained aseasonal inflows at the top of the system, and subsequent aquatic weed infestation; has impacted its hydrological and salinity regime, and the associated ecological values of this system.
Short description – M14: Further failure of breached and eroded bund walls will result in reduced extent of coastal wetland
M14 – The aerial extent of the coastal lacustrine (lake) wetlands at the bottom of the Horseshoe Lagoon system was historically increased by earth bunds constructed to exclude tidal inflows and pond freshwater for pastoral production. These wetlands have adapted to this modified hydrological setting over many decades. During high flow discharges over these bunds, some have been breached and eroded. Further widening of these breaches could result in reductions of the aerial extent of the contemporary wetland system.
Short description – M15 (a,b): Riparian vegetation condition of distributary channels impacted by past clearing, fire impacts, and seedling suppression
M15 – The distributary channel network that extends to the west from the lower Horseshoe Lagoon drainage system, before re-joining the Barramundi Creek estuary, hosts several lagoons and riparian vegetation communities of varying condition. These include some high value remnant areas contained within parts of the system used for grazing purposes. In ungrazed parts of the system, including some historically cleared for farmland development, the groundcover is dominated by exotic pasture grasses (guinea, para). These grasses suppress natural native tree seedling establishment and subject any remnant native vegetation to hot fire impacts. The poor condition of riparian vegetation limits fauna habitat values and contributes to the poor condition of the channel-hosted water bodies.
Nominated Works (W) The below section contains short descriptions only. For more information regarding these nominated works, refer to the mapping and recommendations throughout the SMP.
Short description – W1: Reduce inflow volume and re-use of BHWSS tailwater inflows
W1 – Full description
Short description – W2: Promote riparian vegetation regeneration and active revegetation around lagoon full supply margin
W2 – Full description

Short description – W3: Promote grazing and burning regimes to regenerate floodplain vegetation
W3 – Full description
Short description – W4: Assess feasibility, costs and groundwater management benefits of gravity-fed flow outlet to Haughton River to reinstate lagoon water level seasonality
W4 – Full description
Short description – W5: Manage BHWSS inflows to reinstate lagoon water level seasonality and reduce aseasonal outflows
W5 – Full description
Short description – W6: Rock armour lagoon outflow channel sections to protect against head-cutting erosion
W6 – Full description
Short description – W7: Create open water fish passageway by establishing shade-casting riparian vegetation on eastern margin of drain in conjunction with rock-bunded pool sections to decrease channel flow gradient
W7 – Full description
Short description – W8: Resource woody weed and rubber vine control program along length of high value riparian corridor
W8 – Full description
Short description – W9: Resource strategically-timed (post wet season flush) integrated boat and aerial-based spraying of floating aquatic weeds within lower creek system and coastal wetland to reduce reinfestation potential
W9 – Full description
Short description – W10: Rock armour breached bund walls using rock ramp fishway configuration to secure wetland and facilitate improved fish passage
W10 – Full description
Short description – W11: Support integration of controlled grazing into remnant habitat management practices to maintain open water habitat and reduce hot fire risks
W11 – Full description

> Appendix 2 – Management plan map sheets separate attachments