BASIN PLAN 2012, SCHEDULE 12, MATTER 8

NSW 2020 Five-yearly Matter 8 Report

Department of Planning, Industry and Environment
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Foreword

New South Wales and federal agencies are working together to deliver water for the environment. The overall goal is to generate ecological benefits for rivers and their biota.

Under the Murray–Darling *Basin Plan 2012* (the Basin Plan), this goal is known as ‘Matter 8: the achievement of environmental outcomes at an asset scale’. NSW and other member states are required to report progress in their jurisdiction every five years.

This is the first Matter 8 report by the NSW Government. It covers the period from 1 July 2014 to 30 June 2019 and was prepared by two key agencies involved in environmental water delivery and monitoring: the Department of Planning, Industry and Environment (Water group and Energy, Environment and Science group) and the Department of Primary Industries – Fisheries.

The NSW Government would like to acknowledge the cooperation of the other Murray–Darling Basin States and federal agencies in the preparation and delivery of this report.

Executive summary

This report describes the ecological condition of environmental assets in the NSW portion of the Murray–Darling Basin from 2014 to 2019. It sets a baseline against which future environmental outcomes related to the Basin Plan will be assessed. This sound, scientific information can be used to enhance environmental policy and decision-making, leading to healthier rivers in NSW.

The report addresses the influences of climate and hydrology on environmental outcomes, before being divided into chapters on five key themes: Native Vegetation, Waterbirds, Native Fish, Other Species and Ecosystem Function. These themes reflect the condition of priority assets, which in turn can be influenced by the delivery of environmental water.

In NSW, reporting of environmental outcomes at an asset-scale includes:

- discrete asset locations (such as a wetland) as defined by the Basin Plan Schedule 8 and the Basin-wide environmental water strategy (BWS)
- the recorded range (within NSW) of key ecological populations that NSW defines as ecological assets.

For each theme, the ecological condition and outcomes of environmental watering are reported for relevant assets. Included are the methods used for monitoring and evaluation, the results of this scientific work, and recommendations for future monitoring and management.

Some themes also report progress towards environmental outcomes at the scale of water resource plan (WRP) areas and/or using the objectives and environmental watering requirements (EWRs) in the relevant NSW long-term water plans. This adds a layer of complexity, but ultimately provides more rigorous, useful information.

Influences on environmental outcomes

Climate

The driest years on record

NSW experienced severe drought during the reporting period, with four of the five warmest years on record occurring during this time. 2019 was the driest year on record and the last six months of the reporting period had the lowest recorded inflows in NSW history.

Hydrology

Environmental water delivery is crucial

Environmental flow deliveries are crucial to meet the long-term water requirements of rivers and their biota. During the reporting period, these flows helped initiate the inundation regime for the next five years and progress towards environmental outcomes for the 2024 reporting period.

Flows in the Murray–Darling Basin rivers during the reporting period were below the average for the previous 15 years, which included the millennium drought (2001-2010). The 2016–17 winter was the wettest within the reporting period, however, discharges and peak flows were generally lower than the long term average.

There were also varying levels of success in meeting the environmental water requirements in the NSW long-term water plans between planning units, depending on the required types of flows. If the climatic and hydrologic conditions in the next reporting period (2019–24) are similar or drier than those in this reporting period, it is unlikely that the environmental water requirements in most planning units will be met in 2024.

Achievement of environmental objectives

Native vegetation

Responsive to inundation frequency and duration

Native vegetation is central to the health of the NSW Murray–Darling Basin. It provides critical support for biodiversity by providing food, habitat, and improved water quality and availability.

The condition of non-woody vegetation (for example grassland, shrubland, and reeds) was related to water year and time since last inundation. Shorter periods between inundation, and longer periods of inundation, result in more submerged and emergent plants, and fewer terrestrial and exotic species.

The condition of woody vegetation communities ranged from very poor to good. While condition improved after inundation in the following water year, stand condition declined at most locations during the last two, very-dry years of the reporting period. The condition and survival of larger trees suggests that groundwater connectivity is important in maintaining tree survival.

Inundation frequency and duration are vital for maintaining both community condition and population structure of vegetation communities. This means environmental water can be used to meet these ecological needs very effectively. Increasing lateral connectivity with smaller flows also promotes stronger responses of non-woody vegetation to inundation.

Combining water delivery with additional measures, such as exclusion of carp using fish screens, can dramatically increase non-woody vegetation and aquatic species diversity.

Waterbirds

Rely on a network of wetlands

Waterbirds are highly mobile and rely on a network of healthy wetlands to complete their life cycles. Wetlands across the NSW Murray–Darling Basin are recognised as internationally important for waterbirds.

Five of these wetlands received environmental water during the reporting period. Ground and aerial surveys showed that these sites provided important support for a diverse range of waterbird species.

The total number of waterbird species was maintained through the reporting period. However, the total number of individual birds declined. This is consistent with declines in waterbird breeding activity reported since 1983.

Large waterbird breeding events were only recorded in 2016–17, when there was widespread natural flooding and environmental water delivered to key wetlands in the NSW Murray–Darling Basin.

Native fish

Specialist species at risk

Healthy and diverse populations of native fish and crayfish support significant cultural, social, recreational and economic outcomes, but require access to plentiful, high-quality habitats.

Slightly less than half of the total number of environmental watering objectives were met for native fish during the reporting period. While almost two thirds of objectives for the presence of species were met, less than one-tenth were met for distribution and one-fifth for abundance. Almost half of the recruitment/population structure objectives were met, but these were mostly for generalist species without strong ecological links to flow.

A new statistical tool, the native fish Population Health Index (PHI), was developed to help track the condition of native fish populations. An overall PHI was calculated for 28 fish species (23 detected, plus 5 undetected non-vagrant species). It was Excellent for 0 species, Good for 1 species, Moderate for 10 species, Poor for 10 species and Very Poor for 7 species.

Other species

Frog breeding supported by water delivery

There are a wide range of species that benefit from environmental water delivery.

Native fogs were monitored during the reporting period. The number and diversity of flow-dependent frog species were stable in the monitored areas of the NSW Murray–Darling Basin. Monitoring in the Gwydir, Macquarie–Castlereagh, Lachlan, Murrumbidgee and NSW Murray–Lower Darling showed that the delivery of water for the environment supported breeding activity in flow-dependent frog species. Watering also provided habitat and breeding opportunities for the vulnerable southern bell frog in the Murrumbidgee and NSW Murray–Lower Darling.

This report does not contain monitoring results for other species that can benefit from river flows and inundation of floodplain habitats such as turtles, snakes, water rats, bats, insects, platypus and woodland birds. However, it is likely that the influences of climate and hydrology, and some of the outcomes of watering reported in each of the themes, are transferable to these species.

Ecosystem functions

Refugia vital during drought

Connecting the wide range of freshwater ecosystems in the NSW Murray–Darling Basin to each other and their floodplains is a vital component of the lifecycle of many plants and animals, and supports productivity by moving nutrients throughout the NSW Murray–Darling Basin.

NSW has developed several methods to identify, assess and map key refugia for threatened fish and determine the extent and condition of groundwater-dependent ecosystems. NSW has trialled a groundwater health index and continued groundwater level monitoring across the NSW Murray–Darling Basin. We have progressed with identifying groundwater-dependent vegetation and assigning an ecological value across the NSW Murray–Darling Basin. Research into the relationships between productivity, inundation and flow, and the contribution of unregulated tributaries to the productivity within catchments continued throughout the reporting period.

Summary of recommendations

From information to action

Specific recommendations to improve the rate of progress towards achieving environmental outcomes from water delivery are provided in each theme. Here, these are summarised into five overall recommendations. Following the recommendations provided, through targeted monitoring, research and management, will create the greatest possibility of meeting Basin Plan targets and objectives.

1. **Maintain and improve monitoring.**

   This report presents a baseline assessment of environmental outcomes in the NSW portion of the Murray–Darling Basin. NSW will need to maintain a number of monitoring programs to track changes in environmental assets through time. Monitoring programs must be able to detect the type and scale of changes relevant to each species or ecosystem. Extra, targeted sampling may be required to assess outcomes of individual flow events, additional species and/or for species that were not detected, or not detected on an annual basis, in this reporting period. Ongoing annual sampling is essential to report future progress towards Basin Plan objectives.

2. Fund and deliver native fish recovery strategies.

Native fish species recovery strategies provide frameworks for conserving and recovering native fish species diversity and health. Investment is required in management actions that complement state activities to maximise outcomes through coordinated efforts. Those actions require data and guidance from programs, such as the current monitoring report, to be achieved.

3. Accelerate conservation of rare and threatened species.

Several threatened and very rare species require urgent conservation action to reduce the risk of extinction from the NSW portion of the Murray–Darling Basin. Many species have been affected by the drought. The scale of recovery may depend on a variety of programs including restocking, genetic rescue, extra surveys in and around their key habitat areas, actions that help protect these habitats, and management of flows to improve population resilience and dispersal opportunities. It is important that agencies work collaboratively with Indigenous communities, recreational users, landowners and other community groups in delivering these actions.

4. Pursue complementary actions to maximise watering benefits.

Environmental watering creates benefits across entire ecosystems. These benefits are stronger if the outcomes are supported and protected by complementary actions. Such actions include improvements of habitats, management of pests, reduction of cold-water pollution, increased connectivity, including through addressing constraints to flow management and providing fish passage, and use of screens to exclude carp and reduce fish loss to water diversions. These actions are consistent with proposals such as the NSW Fish for the Future program under the Northern Basin toolkit. Complementary actions would likely support environmental outcomes across all themes throughout the NSW Murray–Darling Basin.

5. Enhance understanding of species relationships to flows.

Despite their central importance to the Basin Plan, the cause-effect relationships between flow conditions and population health remain quite poorly understood for most species. Existing conceptual models of ecosystem-flow relationships currently guiding flow delivery and prioritisation are largely derived from expert opinion, rather than being data-driven. A critical part of the adaptive management approach is to assess and improve our understanding of the critical flow needs driving environmental outcomes. The current monitoring program contributes large volumes of data which will allow hypothesis-based testing of existing conceptual models through time. However, to get best benefit from environmental water allocations in the short-term, targeted cause-effect assessments of select high-priority species and sites are also required.

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Abbreviations

AWD	Annual water determination
BF	Baseflow
BK	Bankfull flow
BOM	Bureau of Meteorology
BWS	Basin-wide environmental water strategy
CF	Cease to flow
Dbh	Diameter at breast height
DOC	Dissolved organic carbon
DPI	Department of Primary Industries
Du	Ducks and small grebes
EWR	Environmental water requirement
GDE	Groundwater-dependent ecosystems
GL	Gigalitre
He	Herbivores
HEVAE	High ecological value aquatic ecosystem
HEW	Held environmental water
La	Large waders
LF	Large fresh (pulse)
LTA	Long-term average
LTWP	Long-term water plan
MDB	Murray–Darling Basin
MDBA	Murray–Darling Basin Authority
MER	Monitoring, evaluation and reporting
MIL	Murray Irrigation Limited
NF	Native fish
NSW	New South Wales
OB WL	Overbank Wetland inundation flows
OS	Other species
PCT	Plant community types
PEW	Planned environmental water
PHI	Population health index

Pi	Piscivores
PPWWP	Private Property Wetlands Watering Project
RPA	Reporting period average
SDL	Sustainable diversion limit
SF	Small fresh (pulse)
Sh	Shorebirds
SRA	Sustainable Rivers Audit
SUVA	Specific ultraviolet absorbance
UNSW	University of New South Wales
VF	Very low flow
WB	Waterbirds
WRP	Water resource plan
WRPA	Water resource plan area
WSP	Water sharing plan

Chapter 1 Introduction

Implementation of the Murray–Darling Basin Plan requires member states to submit regular reports against Matters listed in Schedule 12 of the Basin Plan, including Matter 8: ‘the achievement of environmental outcomes at an asset scale’. Basin states must report on Matter 8 progress every five years, commencing in 2020.

This is the first Matter 8 report to be released by the NSW Government and coincides with the submission, assessment and/or accreditation of the 20 NSW water resource plans (WRPs). The monitoring, evaluation and reporting (MER) activities associated with the WRPs had not commenced during the reporting period. NSW has prepared this report with the view that it will be used as the baseline against which ecological outcomes in future Matter 8 reporting can be assessed.

NSW interpretation of Matter 8 requirements

Reporting period

The reporting period is 1 July 2014 to 30 June 2019.

Definition of an environmental asset

Schedule 8 of the Basin Plan provides criteria for identifying an environmental asset, and Appendices 4 and 7 of the Basin-wide Environmental Watering Strategy (BWS) provide listings of important assets for waterbirds and fish respectively. The definitions in Schedule 8 and the BWS appendices largely define environmental assets as discrete ecosystem locations. However, important ecological populations such as Murray cod or River red gum can occur across multiple locations and need to be managed at their natural scale. NSW identifies these populations as assets, therefore the ‘asset scale’ is considered the recorded range of key species and populations.

Reporting of environmental outcomes at an asset-scale may include:

1. discrete asset locations as defined by the Basin Plan Schedule 8 approach and the BWS. The BWS assets and potential MER coverage are described in each theme chapter.
2. the recorded range (within NSW) of key ecological populations that NSW defines as ecological assets. Environmental outcomes will be reported at the asset scale within NSW and the scale of WRP areas (if appropriate).

Definition of environmental outcomes

The Basin Plan defines environmental outcomes (including environmental objectives and targets) in Chapter 5, Chapter 8, Schedule 5 and Schedule 7. The BWS provides expected outcomes for river flows and connectivity, native vegetation, waterbirds and native fish.

Long-term water plans (LTWPs) and water sharing plans (WSPs) contain their own environmental objectives that have been aligned to Basin Plan and BWS environmental outcomes. This alignment has been accredited by the Murray–Darling Basin Authority (MDBA) as a component of WRP implementation. The alignment of the environmental objectives in the BWS, LTWP and WSP is provided in Appendix 1.

NSW collects monitoring data to evaluate progress towards achieving the environmental objectives in the BWS, WSPS and LTWPs. In this report, the environmental outcomes are presented in the same themes used in LTWP objectives (which are aligned with Basin Plan and BWS objectives (Appendix 1).

Definition of achievement

This report defines achievement of environmental outcomes as the condition and extent of assets relevant to the LTWP objectives in the 2014–19 reporting period. The LTWP objectives are listed in the alignment table in Appendix 1.

In addition, the report will seek to identify where changes may be required to policy, management, and/or monitoring and/or where success could be used to inform adaptive management in other areas.

Structure of this report

The report is structured using the LTWP themes: Native Vegetation, Native Fish, Waterbirds, Other Species and Ecosystem Functions.

Each theme will include reporting against the relevant LTWP objectives at the asset's recorded scale, with some outcomes limited to a specific NSW WRP area, or areas (Figure 1-1).

Monitoring for all BWS assets was not possible. The LTWPs and WSPs do not include specific monitoring of the BWS river flows as these are regarded as strategies for achieving environmental outcomes rather than objectives on their own. However, objectives related to longitudinal and lateral connectivity are included.

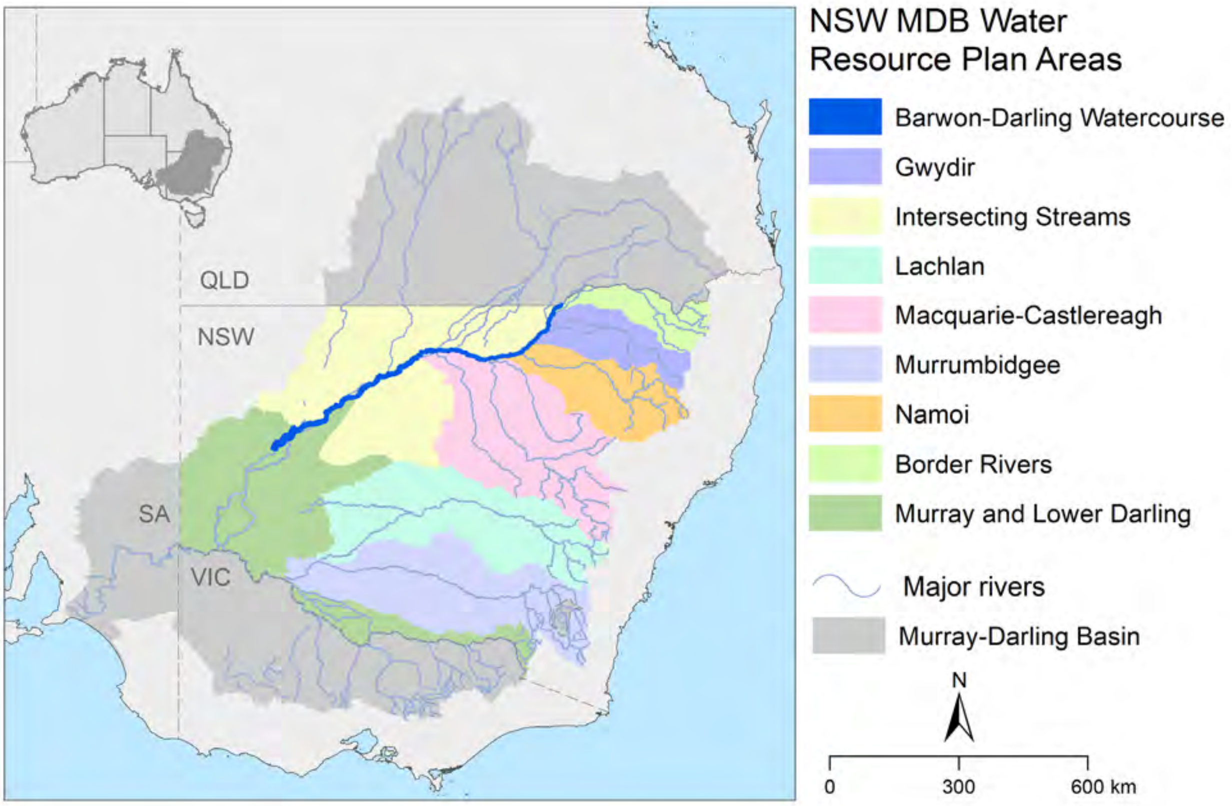


Figure 1-1 Location of the NSW Murray–Darling Basin Water Resource Plan Areas (WRPAs)

Chapter 2 Influences on environmental outcomes

The condition and extent of ecosystems are controlled by a wide range of factors, most of which are beyond the control of water managers. External factors can have a direct impact on the location, timing, frequency, duration, size and effectiveness of environmental watering. These factors most be considered as part of any ecological outcome reporting process.

Climate in the Basin during the reporting period 2014–19

Climatic conditions, especially rainfall and temperature, affect the entire Murray–Darling Basin (MDB) through direct impact on the quantity and quality of water available for all users, which in turn influences water management decisions and the ecological outcomes that can be expected (Table 2-1).

Table 2-1 Management strategies under different resource availability scenarios (Adapted from MDBA 2019)

Resource availability scenario	Management strategies
Very dry	• Allow dry-down consistent with historical wetting-drying cycles • Sustain key in-channel pools, instream habitat and core wetland areas • Provide very low flows to relieve severe unnatural prolonged dry periods and support suitable water quality • Ensure sufficient volumes are allocated to re-start the river following prolonged cease-to-flow events • Limit exceedance of maximum inter-event periods for smaller flows as opposed to maintaining the long-term ideal frequency of events
Dry	• Allow dry-down consistent with historical wetting-drying cycles • Sustain key in channel pools, instream habitat and core wetland areas • Provide freshes and wetland inundating flows to core wetlands, where possible, at ecologically relevant times • Avoid exceeding maximum inter-event periods and provide events which have recently had lower than ideal frequency • Provide low flows to relieve severe unnatural prolonged dry periods and support suitable water quality • Protect tributary inflows
Moderate	• Provide freshes, bankfull and wetland inundating flows, where possible, at ecologically relevant times • Improve condition of key off channel waterholes • Build on natural events to provide wetland and floodplain inundation at ecologically relevant times • Provide flows to systems that are otherwise cut off from natural flows • Prioritise EWRs that are approaching their maximum inter-event period or lower than ideal frequency • Provide low flow connectivity • Consider carrying over water to support water used in drier years

Resource availability scenario	Management strategies
Wet	• Build on natural events to provide wetland and floodplain inundation at ecologically relevant times • Protect naturally occurring floodplain wetland inundating events and high flow connectivity • Provide flows to systems that are otherwise cut off from natural flows • Where possible, provide events that are well below their maximum inter-flow event period to improve resilience during dry periods • Carry over water to support water use in drier years

Both reconstructions of past climates using palaeo techniques such as tree rings, fossils and the cave deposits plus modern instrumental records show that the semi-arid climate of the Murray–Darling Basin is highly variable, with extended dry periods interspersed by generally shorter-term sporadic wetter periods recorded through the mid to late Holocene (Ho et al. 2015, Mills et al. 2013). These wetter periods bring flood events that play a critical role in connecting river networks, replenishing drought refuges and recharging wetlands and groundwater.

The large area of the Murray–Darling Basin also means that climate and hydrology vary. River flows are generally higher and more consistent in the southern Basin. In addition, there has been a recent trend toward lower annual rainfall and higher annual temperatures across the entire Basin (Timbal et al. 2015, MDBA 2020).

The extended hot and dry period continued within this reporting period (2014 to 2019) with a short period of high rainfall in Figure -2).

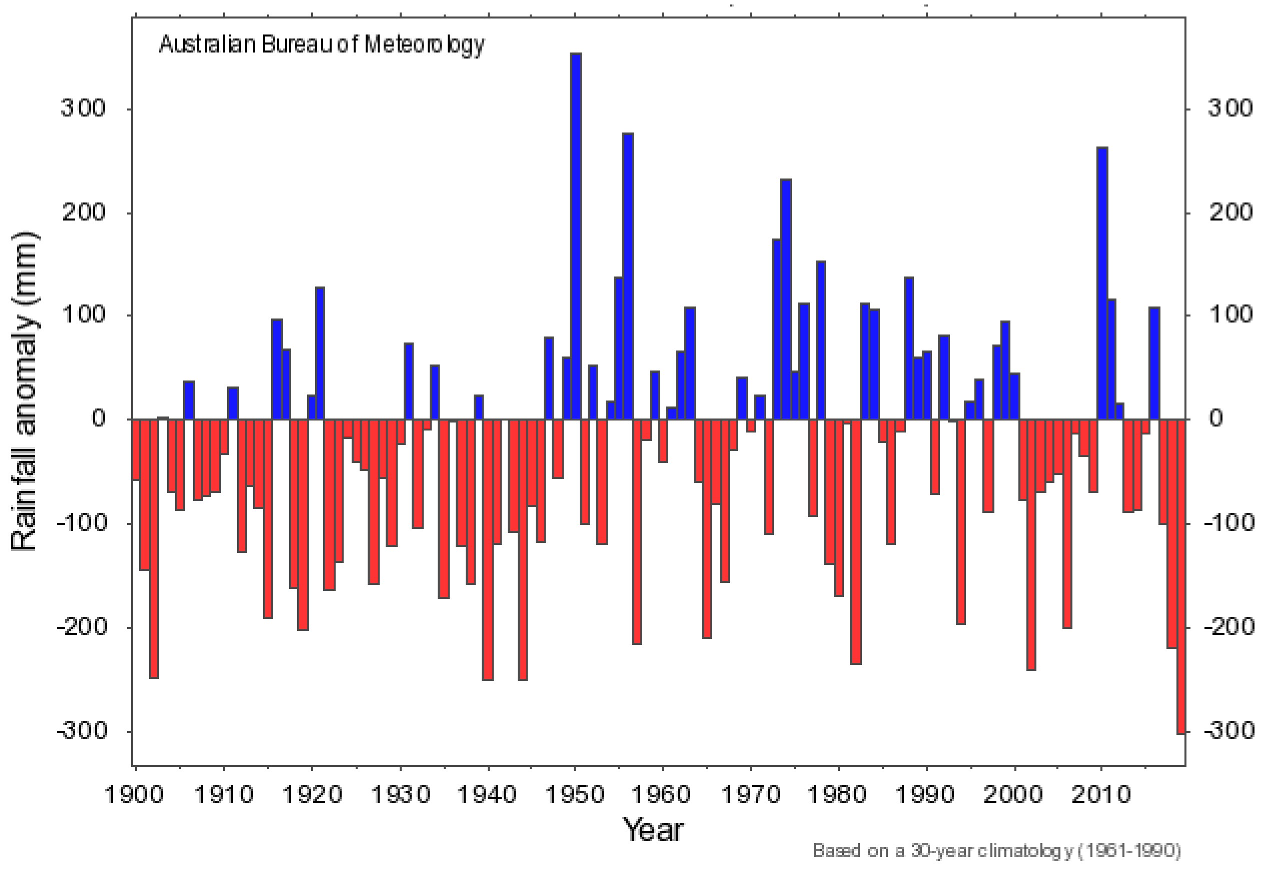


Figure 2-1 Annual rainfall anomaly for NSW/ACT

The NSW MDB was designated as entirely in drought during the 2017–18 water year (ACCC 2019), as the mean annual rainfall for the period 2012–13 to 2018–19 was 411 mm, which is similar to the 417 mm mean rainfall recorded during the Millennium Drought of 2001–10 and below the 30 year average (1961-1990) of 466 mm (BOM 2019). Drought conditions continued beyond the end of the reporting period in June 2019.

An important difference between the recent drought and the preceding Millennium Drought has been a change in the seasonal rainfall patterns. Prior to 2012, dry conditions were most common from May to November, when ambient temperatures and water losses to evapotranspiration tended to be low. Since 2012, seasonal dry periods have tended to occur between September and April (BOM 2019; MDBA 2020) (Figure 2-2).

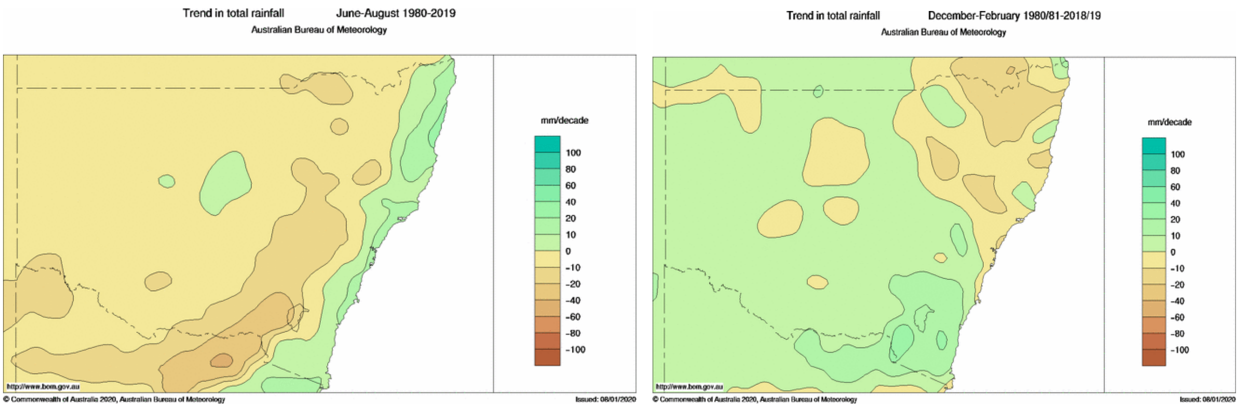


Figure 2-2 Trends in Total rainfall for NSW in Winter (left) and Summer (right) (From BOM 2019)

Between July 2012 and June 2018, the Australian Bureau of Meteorology (BOM) identified severe long-term rainfall deficiencies (rainfall was in the lowest 5% of records) across 16% of the Basin, and serious rainfall deficiencies (lowest 10%) across 28% of the Basin. Severe and serious deficiencies were spread throughout NSW and in the Warrego and Paroo catchments within Queensland (BOM 2019). In May of 2018, wind speeds and evaporation rates were at a record high in the Basin (MDBA 2018). The reporting period also had 5 of the top 10 warmest years on record for Australia having annual national mean temperatures at least 0.95 °C above average (Figure 2-3) (BOM 2020). 2019 was the driest and warmest year on record for NSW and four of the five warmest years on record for NSW are in the reporting period (2019, 2018, 2014, 2017) (BOM 2020).

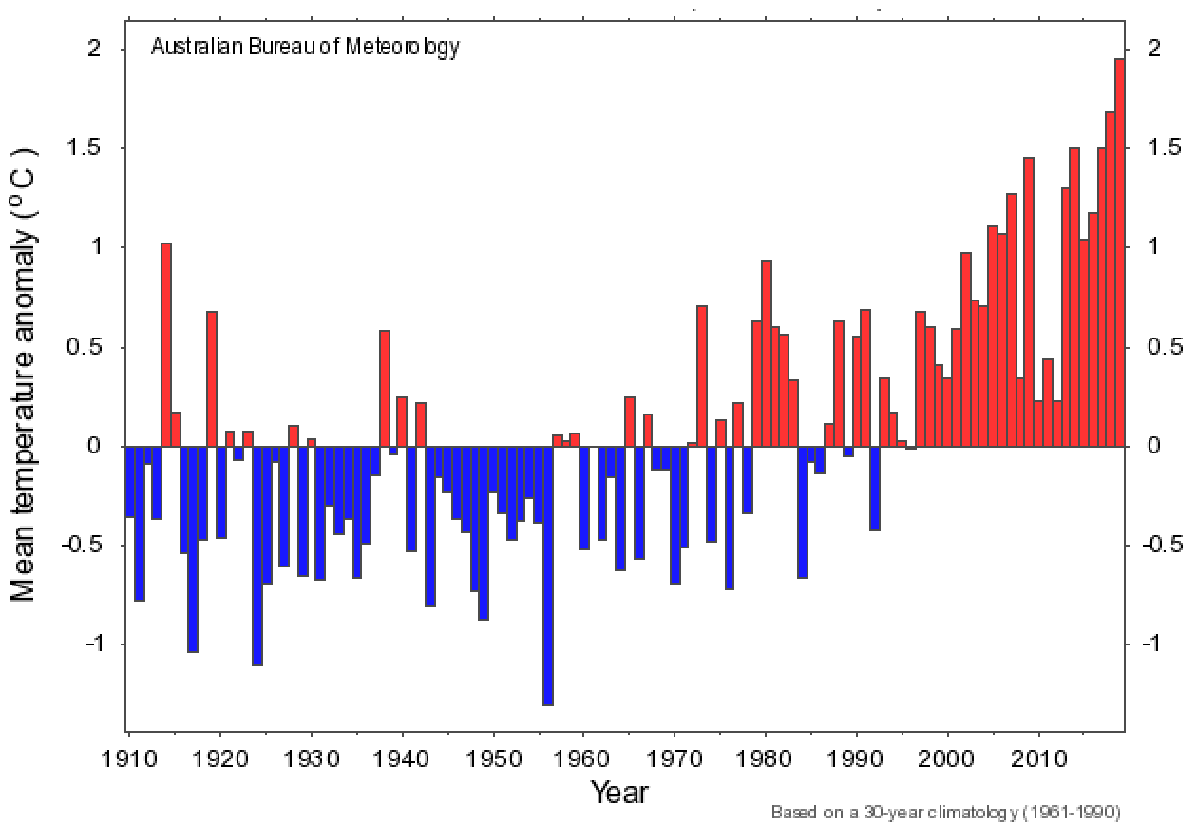


Figure 2-3 Annual Temperature anomaly for NSW/ACT

Other factors

The are many factors besides climate that can influence ecological outcomes, that are beyond the control of the Basin Plan and water managers. For example, changes to land use and/or how it is managed can influence when, where and how much water is used as well at the quality of the water downstream.

Ecological outcomes can be influenced by local factors such as fire, feral animals and other pests and diseases. Global factors such as climate change, pollution and/or habitat loss will also influence local outcomes. For example, research to support an Australian Threatened Species Index found that there has been an average 59% decrease in threatened bird relative abundance in Australia over the last 30 years (ATBSI 2018). The 2018 Living Planet Report states that the global average mammal, fish, bird, amphibian and reptile populations fell by 60% between 1970 and 2014 (WWF 2018).

This report does not attempt to quantify or compare the relative impact of all these factors or the ecological outcomes for specific assets against the application of the Basin Plan. However, these factors must be considered both in terms of their impacts on the extent or condition of environmental assets of future operation, monitoring and evaluation of water management.

Environmental water use

Environmental water in NSW is delivered via a water access licence dedicated for environmental use (held environmental water – HEW – or as planned environmental water –PEW), which may be either discretionary (for example an environmental water allowance to be released at the discretion of the environmental water manager) or non-discretionary provisions that are specified within water sharing plan (WSP) rules. The availability of held environmental water is reliant on General Security, High Security allocations and Supplementary flow events, depending on the water resource plan area. The accrual of environmental water allowances may also be linked to water access licence allocations or other water availability triggers. Like all other water licensees, the volume of water that environmental water users can access, known as an allocation or available water determination (AWD), varies from year to year, based on water availability, the licence category and size of their individual entitlement. This allocation is dependent on a range of factors including dam storage levels, river flows and catchment conditions.

General security licences only receive allocations after higher security reliability has been established, including High Security, Town Water supply and Stock and Domestic licences.

The provisions for discretionary and non-discretionary environmental water vary across WSPs. Some rules are activated under dry conditions while others become active when flows have exceeded a threshold.

When allocations are high, there may be opportunities to provide flows that increase connectivity between valleys, or supplement natural flows to reach wetlands and forests that otherwise would not receive water. During dry years, priority is given to risk mitigation and ecosystem survival, for example preventing fish deaths in isolated pools.

At the start of the 2014–15 water year, storage inflows were the lowest on record in many locations, particularly in the northern Basin (BOM 2016). By the start of the 2015–16 water year, storages had dropped even lower. Very high flows between July and September 2016 reversed this trend and pushed storages back up to 86% capacity by November. Purchased water allocations were close to 100% by the end of 2016. By June 2017, Basin storages had dropped to 78% and continued to decline over the following water year (BOM 2018). Almost 60% of stream gauges recorded lower-than-average flows during the 2017-18 water year. By the start of the 2018–19 water year, total storages were at 48%, with a steady decline down to 30% by June 2019. Some storages in the northern Basin were as low as 1%–3%, well below the thresholds for purchased water to be allocated. Table 2-2 summarises the discretionary environmental water use for each water year in the valleys where there has been ecological monitoring.

Table 2-1 NSW Environment water use (in GL/year) during the water years between 2014–15 and 2018–19

NSW = NSW licenced Environmental Water; CEW = Commonwealth licenced Environmental Water; EWA = Environmental Water Allowance accrued under the Water Sharing Plan for the relevant Water Source; TLM = The Living Murray; RMIF = River Murray Increased Flows; MDWWG = Murray–Darling Wetlands Working Group (OEH 2015; 2016; 2017; 2018; DPIE-EES 2020)

Year	Valley	Total	NSW	CEW	EWA	TLM	RMIF	MDWWG
2014–15	Gwydir	86.5	n/a	56.6	29.9	n/a	n/a	n/a
2014–15	Macquarie	33.8	6.0	10.0	17.7	n/a	n/a	n/a
2014–15	Lachlan	6.5	1.5	5.0	n/a	n/a	n/a	n/a
2014–15	Murrumbidgee	295.8	68.7	152.6	73.1	1.5	n/a	n/a
2014–15	Murray	83.6	30.1	39.6	5.8	8.2	n/a	n/a
2014-15	*Total Northern Basin*	*120.3*	*6.0*	*66.6*	*47.6*	*0.0*	n/a	n/a
2014–15	*Total Southern Basin*	*385.9*	*100.2*	*197.1*	*78.8*	*9.7*	n/a	n/a
2015–16	Gwydir	13.3	0.1	8.4	4.8	n/a	n/a	n/a
2015–16	Macquarie	55.1	4.4	14.2	36.4	n/a	n/a	n/a
2015–16	Lachlan	48.1	12.1	36.0	-	n/a	n/a	n/a
2015–16	Murrumbidgee	227.9	16.0	108.3	103.6	n/a	n/a	n/a
2015–16	Murray	209.1	16.6	131.2	5.8	55.5	n/a	n/a
2015-16	*Total Northern Basin*	*68.3*	*4.5*	*22.6*	*41.1*	*0.0*	*0.0*	*0.0*
2015–16	*Total Southern Basin*	*485.1*	*44.6*	*275.6*	*109.4*	*55.5*	*0.0*	*0.0*

Year	Valley	Total	NSW	CEW	EWA	TLM	RMIF	MDWWG
2016–17	Gwydir	46.8	3.0	22.8	21.0	n/a	n/a	n/a
2016–17	Macquarie	89.2	8.3	54.5	26.4	n/a	n/a	n/a
2016–17	Lachlan	40.8	6.3	29.5	5.1	n/a	n/a	n/a
2016–17	Murrumbidgee	530.4	45.4	241.5	158.6	85.0	n/a	n/a
2016–17	Murray	683.4	32.8	393.6	84.0	122.9	50.0	n/a
2016-17	*Total Northern Basin*	*136.0*	*11.3*	*77.4*	*47.4*	*0.0*	*0.0*	*0.0*
2016–17	*Total Southern Basin*	*1254.6*	*84.4*	*664.6*	*247.7*	*207.9*	*50.0*	*0.0*
2017–18	Gwydir	47.0	15.7	28.3	3.0	n/a	n/a	n/a
2017–18	Macquarie	134.4	19.5	50.7	64.2	n/a	n/a	n/a
2017–18	Lachlan	53.8	3.0	33.5	17.3	n/a	n/a	n/a
2017–18	Murrumbidgee	270.0	16.1	179.2	74.6	n/a	n/a	n/a
2017–18	Murray	333.9	21.7	206.3	5.8	82.9	17.2	n/a
2017-18	*Total Northern Basin*	*181.4*	*35.2*	*79.0*	*67.2*	*0.0*	*0.0*	*0.0*
2017–18	*Total Southern Basin*	*657.7*	*40.8*	*419.1*	*97.7*	*82.9*	*17.2*	*0.0*
2018–19	Gwydir	114.2	-	62.2	52.0	n/a	n/a	n/a
2018–19	Macquarie	127.6	24.4	52.1	51.1	n/a	n/a	n/a
2018–19	Lachlan	36.1	8.7	18.2	9.3	n/a	n/a	n/a
2018–19	Murrumbidgee	195.4	-	61.8	117.5	16.1	n/a	n/a
2018–19	Murray	142.7	10.7	70.7	5.7	n/a	55.2	0.5
2018-19	*Total Northern Basin*	*241.7*	*24.4*	*114.2*	*103.1*	*0.0*	*0.0*	*0.0*
2018–19	*Total Southern Basin*	*374.3*	*19.4*	*150.7*	*132.5*	*16.1*	*55.2*	*0.5*

Basin Plan implementation

Basin Plan implementation has progressed in stages, with amendments taking place between 2014 and 2019. Some of the milestones have influenced environmental watering strategies, in particular:

- The BWS was launched in 2014. Basin states were required to align environmental management objectives with the BWS. Member states began to shape monitoring programs around BWS and Basin Plan requirements. Joint venture monitoring and evaluation programs were established in 2015–16, and mapping and monitoring from these programs began in 2016–17. Early results from the joint venture programs have included coordinated fish tracking and development of woody vegetation condition assessment methods.
- Water recovery proceeded steadily towards the 2750 GL/year sustainable diversion limit (SDL) target, until the Basin Plan was amended in November 2017. A new SDL of 2075 GL/year was adopted, with the shortfall from the previous target to be achieved through sustainable diversion limit adjustment mechanisms (SDLAMs). A total of 36 SDLAM projects were agreed to by member states. As of June 2018, total water recovery was 2117.5 GL/year and has remained at that level. By early 2020, no SDLAM projects have been implemented.
- The Northern Basin Review which recommended that water recovery target for northern Basin catchments be amended from 390 GL to 320 GL on the basis that the Australian,

Queensland and New South Wales governments agree to implement a number of so-called 'toolkit measures' designed to improve water management.

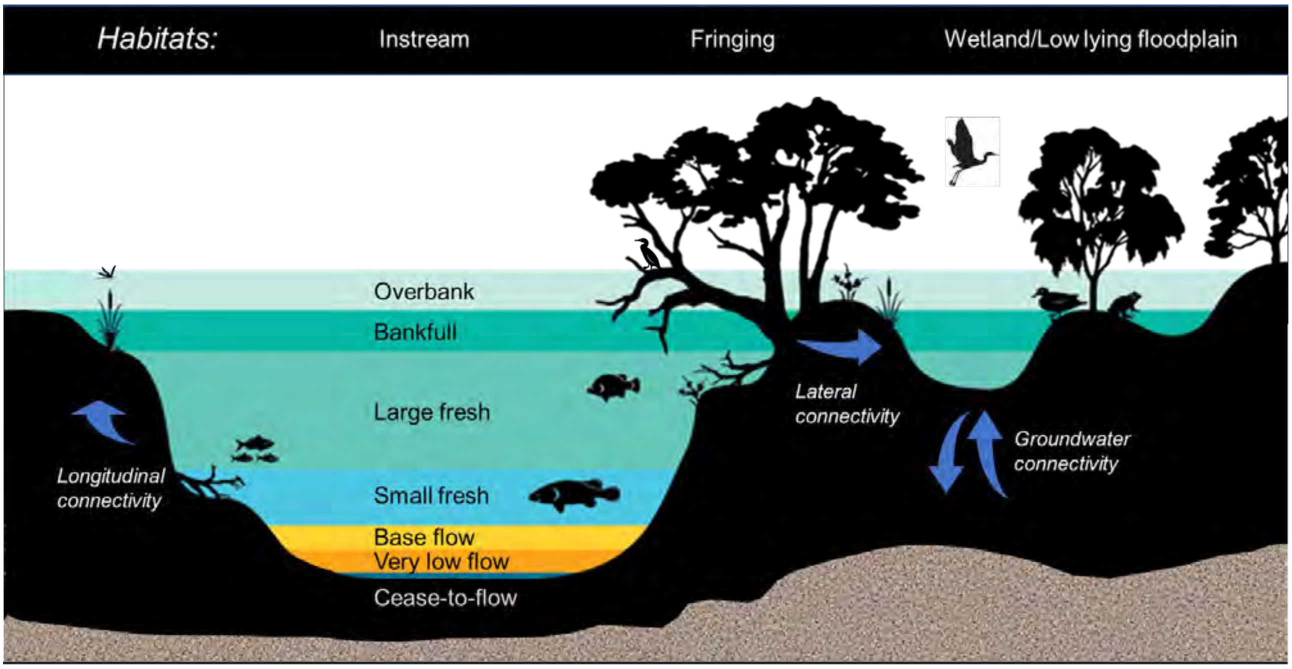
- Interstate and interagency coordination improved, leading to the first coordinated watering event in 2017. Coordination of water delivery in the southern Basin continued to improve through the Southern Connected Basin Environmental Watering Committee (SCBEWC).
- New water delivery infrastructure was added to the River Murray, but operational constraints and third-party issues on the Murray and Murrumbidgee presented challenges. Some watering events could not be achieved due to unresolved third-party issues and capacity constraints. On several occasions, however, environmental water was successfully linked to existing flows and environmental water return flows were re-credited and re-used at downstream locations.

Chapter 3 Hydrology

Floodplain landscapes in the NSW portion of the Murray–Darling Basin are shaped and sustained by river flows that vary in size over time to create patterns, or regimes, of wetting and drying. Flow and flooding regimes drive the ecological productivity and biodiversity of flow-dependent habitats, provide cues for key biological processes such as breeding or migration, support dispersal of plants and animals and shape how a river links with its floodplain. These flow regimes connect instream and fringing habitats longitudinally along rivers, and laterally across wetland and low-lying floodplain habitats which support a range of ecological processes through the variable nature of hydrological connectivity (Figure 3-1).

Ecologically important aspects of the flow regime are characterised by the size of the flow, its timing and duration, and the frequency in which it re-occurs (Poff et al., 1997). These flow regime characteristics describe the hydrological variability in relation to their ecological function and so can be used to assess the environmental water requirements of biota. Within each long-term water plan (LTWP) the environmental water requirements (EWRs) are the flow or inundation regimes that a species, a group or community of species needs to ensure its survival and persistence through time and in the landscape. EWRs are based on the current state of knowledge of a species' biological and ecological needs at different life cycle stages, and the known river flow characteristics measured at a flow gauge location relevant to the species' geographical range.

Lateral connectivity (overbank floodplain and wetland inundation) is the most influential driver of floodplain wetland ecosystems (Bunn and Arthington 2002). Floodplain wetlands in the semi-arid region of the NSW portion of the Murray–Darling Basin are shaped and sustained by variable flow regimes which produce diverse inundation patterns changing the availability of freshwater habitats through time, as such making floodplain wetlands inherently diverse and dynamic (Walker et al., 1995; Ward et al., 2002). These inundation patterns characterise floodplain wetlands and their habitat structure, composition and function (Amoros & Bornette, 2002; Wiens, 2002) (Figure 3-2). Inundation regimes are known to be important for sustaining a mosaic of different vegetation types which in turn support a diversity of fauna sometimes in high abundance, and often at critical life cycle stages (Roberts & Marsden 2011, Kingsford & Auld, 2005). For these reasons, targeted wetland inundation is the primary focus for environmental water managers. Hence why mapped inundation extent and distribution is a useful indicator of environmental watering outcomes in floodplain wetlands where flooding from river flows varies widely in space and over time (Thomas et al. 2015).



Flow category description

Overbank /Wetland inundating flows (OB/WL)
Both overbank and wetland inundating flows provide broad scale lateral connectivity with floodplains and wetlands. They support nutrient, carbon and sediment cycling between the floodplain and channel, and promote large-scale productivity.

Bankfull flow (BK)
Inundates all in-channel habitats and connects many low-lying wetlands. Partial or full longitudinal connectivity. Drown out of most small in-channel barriers (e.g. small weirs).

Large fresh (pulse) (LF)
Inundates benches, snags and vegetation higher in the channel. Supports productivity and transfer of nutrients, carbon and sediment. Provides fast-flowing habitat. May connect wetlands and anabranches with low commence-to-flow thresholds.

Small fresh (pulse) (SF)
Improves longitudinal connectivity. Inundates lower banks, bars, snags and in-channel vegetation. Triggers aquatic animal movement and breeding. Flushes pools. May stimulate productivity/food webs.

Baseflow (BF)
Provides connectivity between pools and riffles and along channels. Provides sufficient depth for fish movement along reaches and contributes to maintaining water quality by providing hydraulic diversity and export of nutrients and salt.

Very low flow (VF)
Minimum flow in a channel that prevents cease-to-flow conditions. Provides connectivity between some pools.

Cease-to-flow (CF)
Partial or total drying of the channel. Stream contracts to a series of disconnected pools. No surface flows.

Figure 3-1 Conceptual diagram of the different flow categories and how they influence habitat

Categories affect connectivity longitudinally along rivers, laterally across wetland and floodplain habitats and vertically with groundwater sources. (Source: Modified from DPIE 2019b)

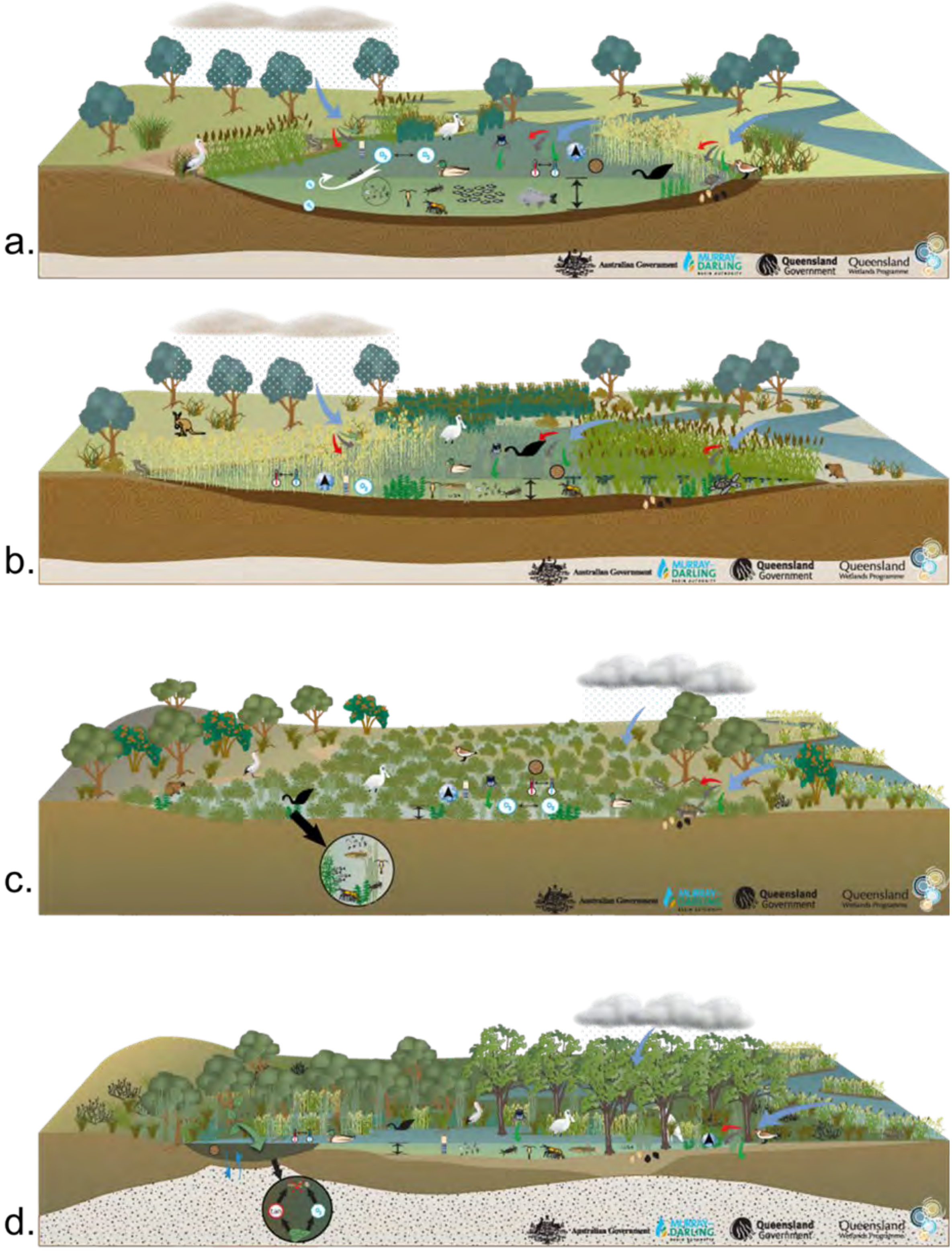


Figure 3-2 Conceptual models of four common types of inland (semi-arid to arid) floodplain wetland habitats

a. floodplain lakes and lagoons; b. grassland-sedgeland-herbland swamps; c. lignum shrubland swamps; and d. river red gum forest and woodlands, which often occur together to form a mosaic of habitats on the floodplains of the Murray–Darling Basin (e.g. Gwydir wetlands, Macquarie Marshes, Lower Lachlan, Lowbidgee floodplain, Millewa forest) and are reflective of spatially variable flooding regimes. Refer to source for more detailed information: [WetlandInfo](), Department of Environment and Science, Queensland.

Findings

1. The 2014–19 reporting period was hydrologically very dry with the average daily flow below the long-term (1976–2019) average, a reflection of one of the most severe droughts on record in NSW, especially in the Central West, Far West and North West regions that were the worst affected to date.
2. The large flow peaks of 2016–17 were relatively small compared to the flow peaks that occurred in the 15 years prior to this reporting period (1999-2014), except in the Lachlan and the Murray where the 2016–17 flow peaks were the largest in 30 years.
3. Environmental water requirement (EWR) success rates for meeting the ecological water needs in the Gwydir and Lachlan Water Resource Plan Areas (WRPAs) during the 2014–19 reporting period were variable across flow types and planning units.
4. Whilst some EWR flow events occurred during the reporting period, the long-term ecological requirements were not met because they did not occur with the required 10-year frequency. To enable the ecological objectives of some EWRs to be achieved by 2024, the frequency of their occurrence would need to be increased in the next five years to meet the stated long-term ecological water requirements. However this may not be possible due to river management operations and water availability.
5. Environmental flow deliveries were crucial to enabling lateral connectivity, inundating critical wetland habitats for their maintenance during the very dry conditions of the reporting period and to provide drought refugia, and providing the required inundation regime for important wetland habitat and keeping the inundation regime on-track for the next five years to meet the long-term ecological water requirement targets by 2024.

What was expected

The 2014–19 reporting period included a range of flow conditions in monitored areas including very dry conditions (Figure 2-1 and Figure 2-2), small managed overbank events and large natural overbank events were augmented with water for the environment. Due to the prevailing hot and dry conditions it was expected that for the reporting period the average daily discharges in the NSW Murray–Darling Basin valleys would be below the long-term (1976–2019) average daily discharges. It was also expected that not all EWRs would have their ecological water requirements successfully met in the reporting period in all locations because of the dry conditions. For some EWRs it was expected that they would not occur because operational river management constraints prevent the management of EWRs with environmental water or the flow volumes of some EWRs are too large to be managed using environmental water. High flows in the 2016–17 water year were expected to produce the occurrence of large freshes, bankfull, overbank and wetland inundating EWRs in relevant planning units.

Environmental water was expected to provide lateral connectivity and wetland inundation flows to relatively small and localised areas to provide important drought refugia and support critical habitats for native vegetation, waterbirds, fish, frogs and endangered ecological communities during dry periods. It was expected that the inundation regime of the five-year reporting period would be suitable for maintaining a proportion of non-woody wetland vegetation and river red gum communities in five large floodplain wetlands (Gwydir wetlands, Macquarie Marshes, Lower Lachlan, Lowbidgee floodplain and Millewa Forest).

Method

Longitudinal connectivity

River flows were measured at selected flow gauges in rivers of the northern and southern basin (Figure 3-3) to calculate the average daily discharge for a long-term period (1976–2019) (LTA) and for the reporting period (July 2014–June 2019) (RPA). The percentage of days below long-term average during the reporting period and during the fifteen years prior to the reporting period (1999–2014) was also calculated.

Assessment of environmental water requirement success

This section is an analysis of the river flows that contribute to achieving specific ecological outcomes as defined by the long-term water plan (LTWP) environmental water requirements (EWR) in the actively managed planning units of the Gwydir and Lachlan WRPAs (Figure 3-3) (see also Appendix 2 for maps of individual planning units). The EWRs described in each LTWP focus on the components of the flow regime that are considered important to achieve the environmental objectives established for the identified environmental assets within each WRPA.

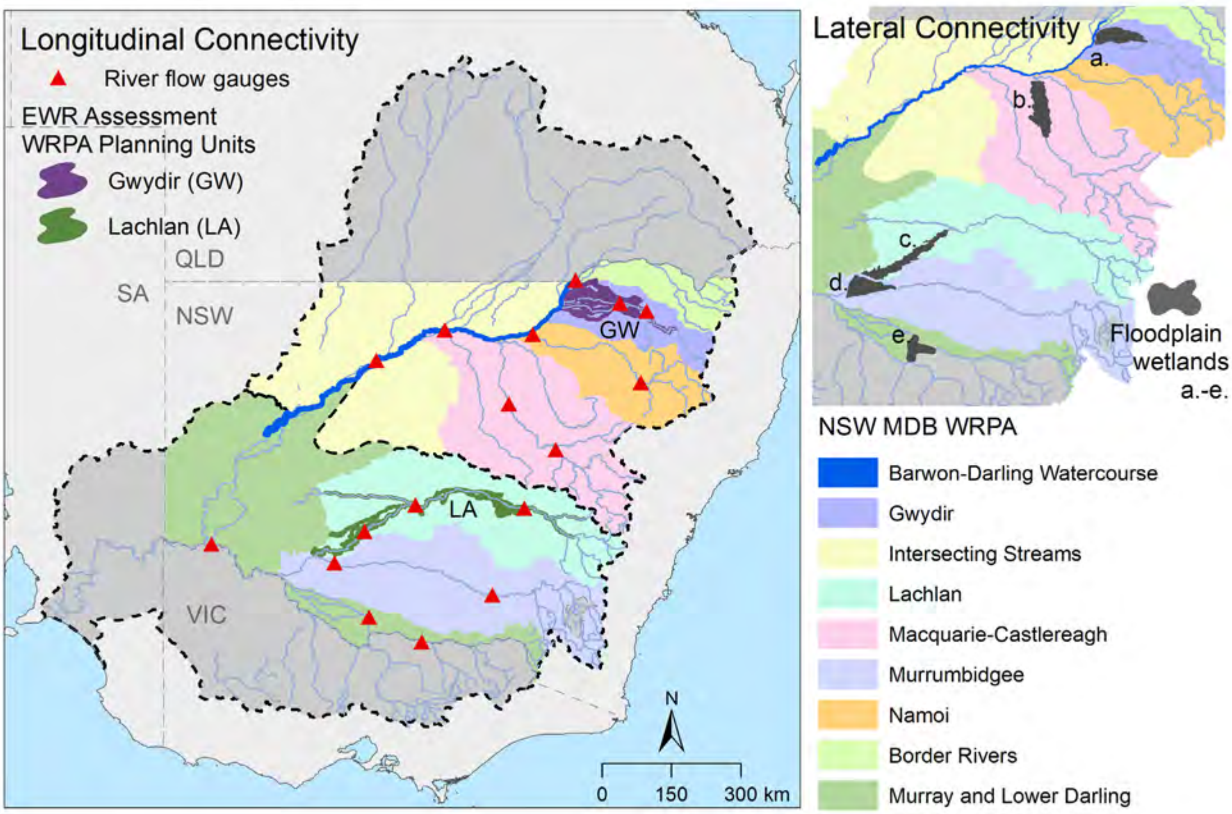


Figure 3-3 Location of selected river flow gauges used to measure average daily discharge and the actively managed planning units in the Gwydir and Lachlan WRPAs for assessment of environmental watering requirements, and the location of floodplain wetlands where lateral connectivity assessment was undertaken

a. Lower Gwydir-Gingham watercourse, b. Macquarie Marshes, c. Lowbidgee floodplain, d. Lower Lachlan (Western Lachlan watercourse) and e. Millewa Forest.

Each EWR has flow characteristics that are measurable within the short-term window of a flow event (or pulse) and within the relatively long-term window of the 10-year flow regime at the specified flow gauges for each WRPA's actively managed planning units as set out within each associated LTWPs (see NSW LTWPs). An EWR flow event is defined as occurring within a water year if the discharge in the water year matches the specified flow event parameters of flow magnitude (or cumulative volume), timing (seasonality) and minimum duration. The long-term ecological water requirement is defined as the frequency (the number of years) the EWR flow event is required to occur within a 10-year window. For example, an EWR frequency of 3-5 years means that the EWR is required to occur 3 to 5 years in a 10-year period.

To determine if the EWRs occurred in each water year of the reporting period, river flows measured at flow gauges relevant to each planning unit were analysed against the specified EWR flow magnitude, seasonality and minimum duration. To determine if the required EWR 10-year frequency was achieved in each water year of the reporting period, river flows were analysed using the 10-year frequency analysis window that ended in the water year of interest (Figure 3-4). For example, if the water year of interest is 2014–15 then the years of the 10-year frequency analysis window are 2005–06 to 2014–15, and if the water year of interest is 2015–16 then the 10-year frequency analysis window is 2006–07 to 2015–16, and so on (Figure 3-4).

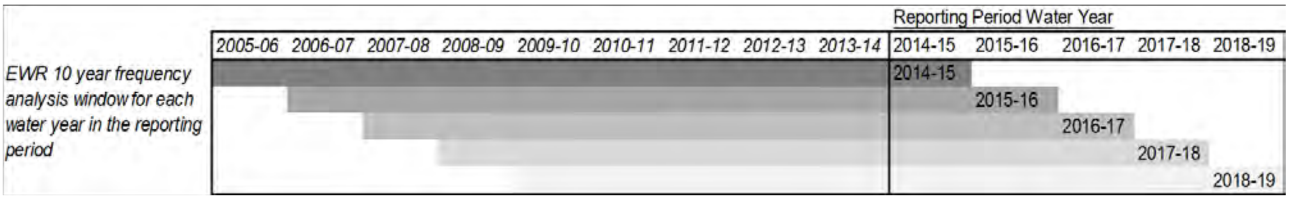


Figure 3-4 Diagram of the EWR 10-year frequency analysis window for each water year in the reporting period (2014–15 to 2018–19).

There is a difference between an EWR flow event occurring in a specific water year and an EWR successfully meeting the ecological water requirements in a specific water year. An EWR is successfully met in a specific water year of the reporting period (for example, 2014–15) if the long-term ecological water requirement, that is the 10-year frequency, is achieved based on the 10-year frequency analysis window (Figure 34). Even though an EWR flow event may have occurred in a specific water year (that is flows reached the required magnitude, seasonality and minimum duration), if the 10-year frequency requirement was not met for the 10-year window of that year, then the EWR was not successfully met. In contrast, an EWR flow event may not have occurred in a water year of the reporting period, but the EWR was successful for that year because the EWR flow event occurred within the 10-year window at the required frequency.

The success rate of each EWR was calculated as the number of reporting period years (July 2014–June 2019) in which the EWR was successfully met. The minimum success rate is reported as zero which means that the EWR 10-year frequency requirement was never met during the five-year reporting period and the maximum success rate is five which means that the EWR long-term frequency requirement was met every year of the five-year reporting period.

Lateral connectivity

For the purposes of this report, lateral connectivity has been assessed at five floodplain wetlands where inundation extent has been monitored from satellite imagery during the five-year reporting period (July 2014–June 2019): Lower Gwydir-Gingham watercourse, Macquarie Marshes, Lower Lachlan (Western Lachlan watercourse), Lowbidgee floodplain and Millewa forest (Figure 33) as part of the Department of Planning, Industry and Environment's, Environment, Energy and Science group environmental water management program. An assessment of inundation extent and the inundation regime that occurred in different vegetation types during the 2014–19 reporting period was undertaken using inundation maps derived from satellite imagery (Landsat and Sentinel-2) (Thomas et. al 2015; Thomas and Heath, 2014a, b, c; Thomas and Heath 2017a, b; Thomas et al.

2020). For each water year, individual inundation maps were combined to create an annual inundation map. Annual inundated area was calculated based on the cumulative area of the floodplain inundated each water year. The percentage area of vegetation types inundated was calculated from the annual inundation maps and existing vegetation maps for each wetland: a. Gwydir wetlands (Bowen et al., 2015), b. Macquarie Marshes (Bowen and Simpson, 2014a), c. Lower Lachlan (OEH, 2018), d. Lowbidgee floodplain (Bowen and Simpson 2014b) and e. Millewa forest (Bowen and Simpson 2011). Inundation frequency for the five-year reporting period was mapped using a spatial overlay analysis of the five annual inundation maps to count the number of times (0-5) a location was inundated. The percentage of vegetation area inundated a number of different times in the five year period (July 2014-June 2019) was also calculated: not inundated (0), inundated once (1), twice (2), three (3), four (4) or five (5) times to determine if inundation requirements were being met across the floodplain wetlands during the reporting period.

Results

Longitudinal connectivity

River flows during the July 2014-June 2019 reporting period were highly variable in major NSW rivers of the northern and southern Murray–Darling Basin valleys (Figure 3-5 and Figure 3-6). Hydrologically, the reporting period was dry, with the average discharge either similar to (3%–11%) or much lower (by 50%–70%) than the long-term (1976–2019) average, but with Lachlan as the exception (Table 3-1). Also, the percentage of days when discharge was below the long-term average during the July 2014–June 2019 reporting period, were comparable (−5%–12%) to the percentage of days that flow was below the long-term average during the preceding 15 years (1999–2014). This 15-year period was dominated by the Millennium Drought, a long period (2001–09) of very low flows in southeast Australia (van Dijk 2013). The rivers of the northern Murray–Darling Basin valleys were hydrologically drier than those in the southern Murray–Darling Basin valleys.

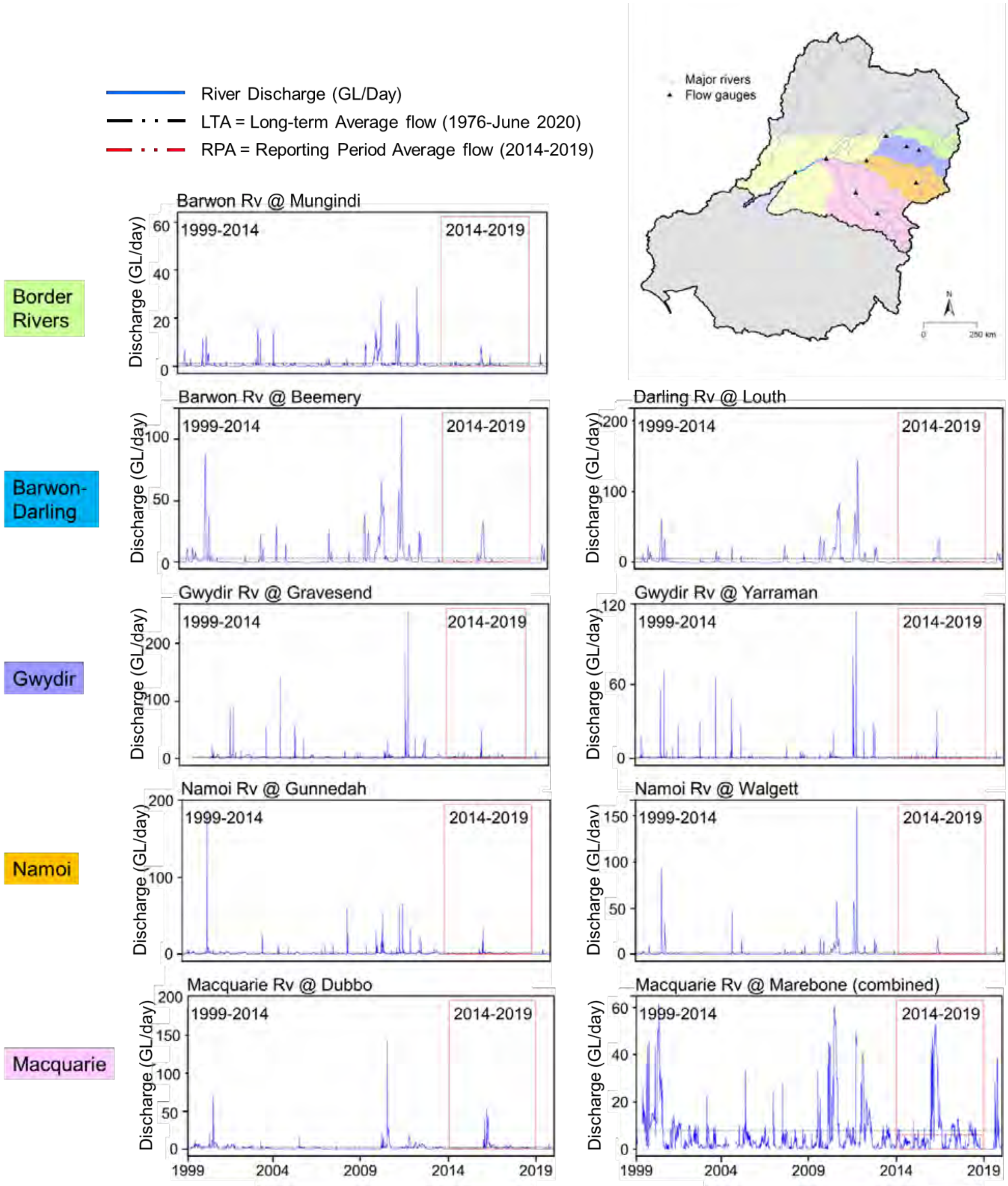


Figure 3-5 Northern WRPA river flows (discharge GL/day) for the reporting period July 2014-June 2019 and the preceding 15 years July 1999-June 2014

This includes the Long-term Average daily discharge (calculated for 1976-2019) and the Reporting Period Average daily discharge (calculated for 2014-2019)

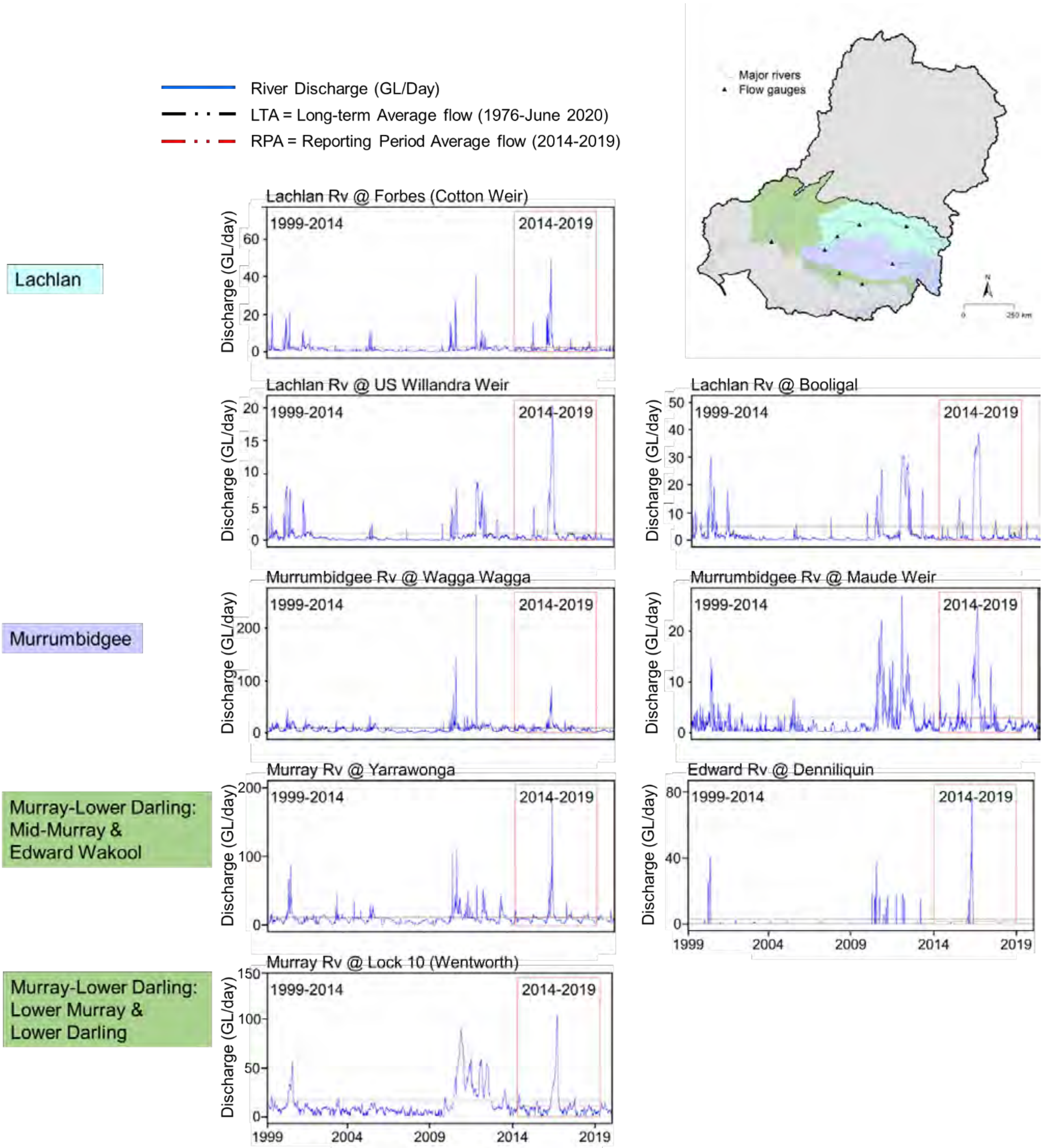


Figure 3-6 Southern WRPA river flows (discharge GL/day) for the reporting period July 2014-June 2019 and the preceding 15 years July 1999-June 2014

This includes the Long-term Average daily discharge (calculated for 1976-2019) and the Reporting Period Average daily discharge (calculated for 2014-2019).

Table 3-1 Summary of flow discharge

This includes the Long-term (July 1976-June 2019) Average Daily Discharge (LTA) ± SD (ML), the Reporting Period (July 2014–June 2019) Average Discharge (RPA) (ML), the percentage difference between the two averages [(RPA-LTA)/LTA], and the percentage of days below the LTA during the reporting period and in the 15 years prior to the reporting period (July 1999-June 2014).

WRPA	Gauge Station	ADD: Long-term (LTA)	ADD: Reporting Period (RPA)	ADD: % Difference	% of Days Below LTA: Reporting Period	% of Days Below LTA: 15 years prior to 2014
Gwydir	Gwydir River @ Gravesend	1,650	991	−40%	82%	79%
Gwydir	Gwydir River @ Yarraman	716	353	−51%	90%	88%
Macquarie	Macquarie River @ Dubbo	2,744	2,008	−27%	83%	78%
Macquarie	Macquarie River @ DS of Marebone (MB) Weir plus MB Break @ DS MB Regulator	772	596	−23%	80%	77%
Barwon–Darling	Barwon River @ Beemery	3,451	1,316	−62%	93%	81%
Barwon-Darling	Darling River @ Louth	5,433	1,374	−75%	94%	82%
Border Rivers	Barwon River @ Mungindi	1,244	361	−71%	95%	89%
Namoi	Namoi River @ Gunnedah	1,494	654	−56%	89%	83%
Namoi	Namoi River @ Walgett	1,518	326	−79%	96%	89%
Lachlan	Lachlan River @ Forbes (Cotton Weir)	2,390	2135	−11%	87%	89%
Lachlan	Lachlan River @ US Willandra Weir	1,035	1,290	25%	86%	88%
Lachlan	Lachlan River @ Booligal	502	392	−22%	85%	89%
Murrumbidgee	Murrumbidgee River @ Wagga Wagga	10,006	8,353	−17%	73%	74%
Murrumbidgee	Murrumbidgee River @ DS Maude Weir	3,064	2,856	−7%	80%	85%
Murray–Lower Darling:	Murray River @ Yarrawonga	12,420	12,104	−3%	75%	79%
Mid-Murray & Edward Wakool	Edward River @ Deniliquin	3,122	1,510	−52%	95%	96%

WRPA	Gauge Station	ADD: Long-term (LTA)	ADD: Reporting Period (RPA)	ADD: % Difference	% of Days Below LTA: Reporting Period	% of Days Below LTA: 15 years prior to 2014
Murray–Lower Darling: Lower Murray & Lower Darling	Murray River @ Lock 10 (Wentworth)	16,432	10,674	−35%	89%	81%

In most rivers, the peak of 2016–17 was by far the largest flow event in the five-year reporting period and occurred as a result of widespread catchment rainfall instigating dam spills and tributary flows. Whilst the 2016–17 flow peak was large compared to other flows during the five-year reporting period, the 2016–17 flow peak was relatively small compared to the flow peaks that occurred in the 15 years prior to this reporting period (1999-2014) (Figure 3-5 and Figure 3-6), with the exception of rivers in the Lachlan and the Murray where the 2016–17 flow peaks were the largest in 30 years (Figure 3-6).

In the northern Murray–Darling Basin rivers, the five-year reporting period average (RPA) discharge was consistently lower than the long-term average (LTA) daily discharge across the major rivers by 23%–27% in the Macquarie, 40%–51% in the Gwydir, 56%–71% in the Namoi, and 62%–75% in the Barwon-Darling (Table 3-1). Daily discharge during the 2014–19 reporting period was below the LTA most of the time with 82%–90% of days below the LTA in the Gwydir, 80%–83% of days below the LTA in the Macquarie, 93%–94% in the Barwon-Darling and 89%–96% in the Namoi. During the reporting period, daily discharge was below the LTA daily discharge for a similar to, or slightly greater time than, the percentage of days below the LTA daily discharge in the preceding 15 years.

In the southern Murray–Darling Basin river valleys, the reporting period average (RPA) discharge was also lower than the long-term average (LTA) discharge across the major rivers at most river gauges: 7%–17% for the Murrumbidgee, 3%–52% for the mid-Murray-Edward, 35% for the Lower Murray & Lower Darling and 11%–22% for the Lachlan at two flow gauges (Table 3-1). The exception to this was on the Lachlan River, upstream of Willandra Weir, where the RPA discharge was 25% larger than the LTA. This was a result of the large flow peak of 2016 (27 September 2016) which was 81% larger than the largest flow peak since 1976 (26 September 1998), inflating the average discharge for the reporting period. As with most other flow gauges the percentage of time flows were below the LTA during the reporting period at the Willandra gauge was the same (1% more) than the preceding 25 years. Overall, the percentage differences between the LTAs and RPAs in the southern rivers were not as great as those in the north, but they were more wide ranging between the upstream and downstream gauges.

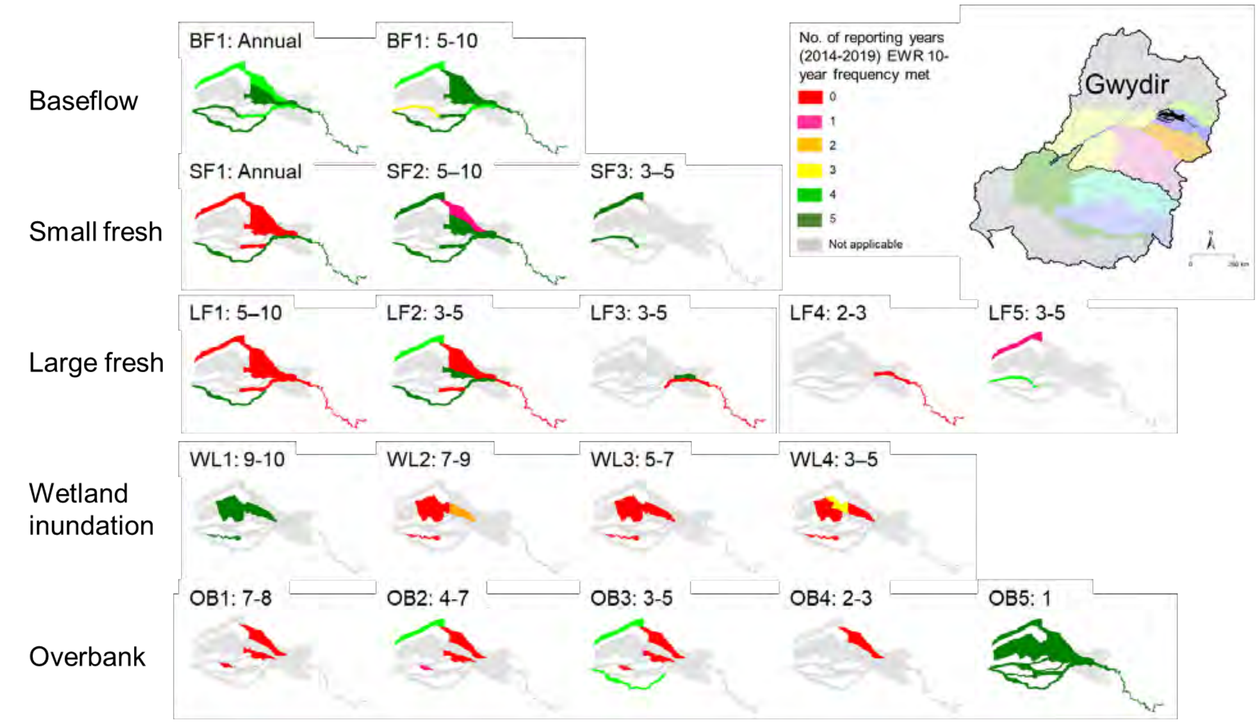
Assessment of environmental water requirement success

Gwydir EWRs

In the Gwydir WRPA, small freshes are critical to longitudinal connectivity and play an important role in maintaining in-channel habitats, flushing pools, stimulating instream productivity and enabling aquatic animal movement. A Small Fresh 2 (SF2) EWR is required to occur 5 to 10 years in 10 years to enhance the spawning of riverine generalist native fish species for example, Carp-gudgeon species complex and riverine specialist native fish species for example, Murray cod, as well as to maintain non-woody native vegetation within channels and to create quality instream habitat (Gwydir LTWP). The success rate of the SF2 EWR was five years in most of the relevant planning units, which means that the long-term ecological water requirements of the EWRs were met every year of the 2014–19 reporting period (Figure 3-7). The exception to this SF2 EWR success rate was in the Carole Creek planning unit, where the long-term ecological water requirements were met in only one of the reporting years (Figure 3-7). For locations of Gwydir WRPA planning units, refer to Appendix 2.

A Small Fresh 3 (SF3) EWR is required to occur 3–5 years in 10 years to enable inter-catchment dispersal of flow specialist native fish species and to provide dispersal opportunities between catchments for all native fish species (EF4) (Gwydir LTWP). Every year of the reporting period, the long-term ecological water requirements of this EWR were successfully met in the relevant planning units (Gil Gil Creek and Lower Mehi, which connect to the Barwon River). Having occurred four times during the 5-year reporting period, the hydrological conditions are on track to meet the 2024 ecological targets if the current frequency of occurrence is maintained into the next five years (Figure 3-7).

EWR Long-term ecological water requirements - Number of years EWR is required to occur in 10 years



Number of reporting years (2014-2019) the EWR occurred (values)
Number of reporting years (2014-2019) EWR 10 year frequency was met (colours)

Gwydir Planning Unit	BF1-10	BF2-5-10	SF1-10	SF2-5-10	SF3-3-5	LF1-5-10	LF2-3-5	LF3-3-5	LF4-2-3	LF5-3-5	BK1-8	WL1-9-10	WL2-7-9	WL3-5-7	WL4-3-5	OB1-7-8	OB2-4-7	OB3-3-5	OB4-2-3	OB5-1
Ballin Boora																0	0	0		0
Carole Creek	4	5	3	1		0	0									0	0	0	0	0
Central Gingham												5	3	1	1					0
Central Lower Gwydir											0	5	1	1	0					0
Central Mehi	4	5	4	4		1	0													0
Gil Gil Creek	4	4	2	1	4	0	0			0							1	0		0
Goonal Creek											0									0
Gwydir downstream of Copeton	5	5	5	5		1	0	1	0		0									0
Lower Gingham											0	4	1	1	1					0
Lower Gwydir	5	5	4	4		1	0				1					0	0	0		0
Lower Mehi	5	3			4					2										0
Main Gwydir River	5	5	4	3		0	0	1	0		0									0
Mallowa Creek												4	2	0	0					0
Moomin Creek	4	5	5	3		4	4											1		0
Tarren Creek											0									0
Upper Gingham	5	5	4	2		1	0					5	3	1	1					0
Upper Mehi	4	4	5	5		1	0	0												0
Western Gingham Floodplain											0									0
Western Gwydir Floodplain											0									0

Figure 3-7 Success rate (0-5 colour codes) of the EWR long-term ecological water requirement (10-year frequency) being met for the five-year reporting period within the relevant planning units of the Gwydir WRPA

See Appendix 2 for planning unit locations. The table indicates the number of reporting years in which the EWR occurred (values) in addition to the colour coding of the success rate of the EWR's long-term ecological water requirement being met.

Large freshes in the Gwydir WRPA are important for inundating in-channel habitat, providing fast-flowing habitat and for supporting in-stream productivity. The success rate of large freshes was variable in the Gwydir WRPA. A large Fresh 2 (LF2) EWR is required to occur between October to April, 3–5 years in ten years to enhance the spawning of flow-pulse specialist native fish species for example, Golden perch (NF4), as well as to maintain non-woody native vegetation within channels and to create quality instream habitat. The long-term ecological water requirements of this EWR were successfully met every reporting year in the Lower Gwydir, Upper Mehi and Moomin Creek planning units and in four of the five years in Gil Gil Creek. For all other relevant Gwydir planning units, the long-term ecological water requirements of the EWR were not met in any of the reporting years. While the long-term ecological water requirements were met in many locations, the LF2 EWR did not occur in any year of the reporting within any planning unit, with the exception of Moomin Creek. This means that it will need to occur more frequently in the next 5-year reporting period to ensure that the long-term requirements are met to achieve the 2024 ecological objectives (Figure 3-7).

Large Fresh 5 (LF5) EWR is designed to promote hydrological connectivity between catchments to create opportunities for the dispersal of flow-pulse specialist native fish species (for example, Golden perch, Silver perch). To achieve these objectives, this EWR needs to occur 3–5 years in 10 years to meet the long-term ecological water requirements. These were successfully met in 1 of the 5 years for Gil Gil Creek and in 2 of the 5 years for the Lower Mehi (Figure 3-7).

In the Gwydir WRPA, there are flows that specifically target the inundation of wetlands and low-lying floodplain habitats to provide broad-scale lateral connectivity with floodplain and wetlands and to support nutrient, carbon and sediment exchange between the floodplain and channel, and to promote productivity. The Small Wetland Inundation (WL1) EWR is required to inundate non-woody wetland vegetation communities with high frequency (9–10 years in 10) to ensure the protection of core wetland areas as refugia in the landscape and as waterbird habitat (foraging and breeding), particularly during dry times. In every year of the reporting period, the long-term ecological water requirements of this WL1 EWR were successfully met in the relevant planning units (Upper and Central Gingham and Central Lower Gwydir) (Figure 3-7).

The WL1 EWR also occurred every year of the reporting period using environmental water and so the hydrological conditions are on track to meet its 10-year frequency requirement that maintain and protect core wetland areas for the next water year in the Upper and Central Gingham, and the Central Lower Gwydir planning units. The Small Wetland Inundation (WL2) EWR is required to inundate 7–9 years in 10 years for the maintenance and regeneration of non-woody vegetation in wetlands and floodplains (for example, spike-rush sedgelands, marsh grasslands) for the maintenance of waterbird foraging and breeding habitat (for example, open water lagoons and lakes, river red gum, river coobah, lignum), as well as frog habitat. These types of flows are also critical for supporting large-scale productivity (EF5), driving aquatic food webs on the floodplain and to allow frog dispersal and to provide opportunities for them to breed. The 10-year frequency of of the WL2 EWR were not met in any of the reporting years for the relevant wetland planning units (Central and Lower Gingham, Central Lower Gwydir and Mallowa) with the exception of the Upper Gingham, where the EWR was successfully met in two of the five reporting years. As a result of environmental water actions, the WL2 EWR occurred in some years during the reporting period in all the relevant planning units (one to three times, Figure 3-7). However, to enable the ecological objectives of the EWR to be achieved by 2024, the frequency of occurrence of this EWR in the next five years needs to be increased to meet the stated long-term ecological water requirements.

Larger wetland inundation flow events are required with moderate to high frequency (2–5 years in 10). The Large Wetland Inundation (WL3) aims to enhance the spawning of floodplain specialist native fish species (for example, olive perchlet), to promote lignum and coolibah wetland plant community regeneration as well as to support waterbird foraging and breeding habitat, and is critical for supporting large-scale productivity on the floodplain. The WL3 is required to occur 5–7 years in 10 years to meet the long-term ecological requirements of these objectives but this was not achieved in any of the five years of the reporting period (Figure 3-7).

The Large Wetland Inundation (WL4) EWR is required to occur 3–5 years in ten years to enable the dispersal of all native fish species, to promote the maintenance of lignum and coolibah wetland plant communities including waterbird breeding habitat and to support large-scale floodplain productivity. This was successful in meeting the long-term ecological requirements in three of the five reporting years in the Central Gingham planning unit but unsuccessful in all years for all other relevant planning units.

Both large wetland inundation EWRs (WL3 & WL4) occurred once during the reporting period in some planning units, which served to provide a wide variety of waterbird foraging habitats and to maintain potential breeding habitats at that time (Figure 3-7). However, to meet the 2024 ecological targets, the frequency at which of both EWRs occur will need to increase during the next five years.

As with wetland inundating flows, overbank flows provide broad-scale lateral connectivity with floodplain and wetlands and provide lateral connectivity with floodplain and wetlands, support nutrient, carbon and sediment exchange between the floodplain and channel, and promote floodplain productivity. Small overbank flow events in the Gwydir are required with reasonably high frequently (3-8 years in 10). The Small Overbank 1 (OB1) aims to promote lignum regeneration (NV4e) as a priority and is required to occur 7–8 years in ten years to meet the 10-year frequency requirements of these objectives. This was not achieved in any of the five years of the reporting period in any of the relevant Gwydir planning units (Figure 3-7).

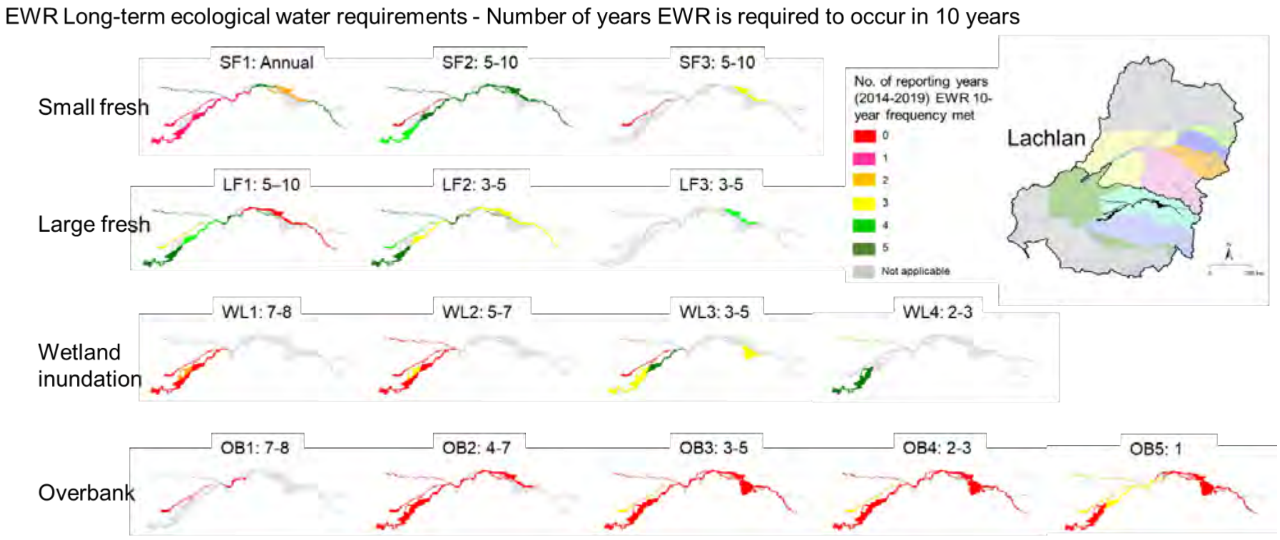
The Small Overbank 2 (OB2) aims to enhance the spawning of floodplain specialist native fish species (for example, olive perchlet), maintain river red gum communities and to promote lignum and coolibah wetland plant community regeneration, as well as to promote productivity on the floodplain. The OB2 EWR is required to occur 4–7 years in 10 years to meet the 10-year frequency requirements of these objective and this was achieved in four of the five years in the Gil Gil Creek planning unit (Figure 3-7).

The Small Overbank 3 EWR (OB3) priority aims are to promote the dispersal and improve the condition of all native fish species, as well as to promote instream and floodplain productivity. To achieve this, the EWR needs to occur 3–5 years in 10 years. During the five-year reporting period the OB3 EWR was successfully achieved in four years for the Gil Gil Creek and Moomin Creek planning units, but in all other planning units it was not achieved in any year (Figure 3-7).

Large overbank flow events do not occur frequently and rely on large flows from widespread catchment rainfall that instigates dam spills and tributary flows. The Large Overbank 5 (OB5) EWR aims to maintain the coolibah woodland communities of the Gwydir as well to maintain waterbird habitat and support waterbird breeding, and to establish between-catchment connectivity. This EWR is required to occur one year in 10 and given that the last OB5 occurred in 2011–12, this EWR was successfully achieved in all of the five reporting years for all relevant planning units. For this EWR to be successfully achieved every year of the next five years it will also need to occur in the next two years (that is 2019–20 or 2020–21).

Lachlan EWRs

In the Lachlan WRPA, small freshes are critical to longitudinal connectivity throughout the entire Lachlan River system and play an important role in maintaining in-channel habitats, flushing pools, stimulating instream productivity and enabling aquatic animal movement. A Small Fresh 1 (SF1) EWR is required to occur annually to ensure there is no loss of native fish species, to maintain in-channel native vegetation, provide drought refugia and instream habitat, and to promote opportunities for dispersal and movement (see Lachlan LTWP). The success rate of the SF1 EWR was variable across planning units. The EWR long-term water requirements were met every year of the reporting period in three Lachlan planning units (Lachlan River–Condobolin to Lake Cargelligo, Upper Lachlan River and Willandra Creek (Figure 3-8). For locations of Lachlan WRPA planning units, refer to Appendix 2.



Number of reporting years (2014-2019) the EWR occurred (values)
Number of reporting years (2014-2019) EWR 10 year frequency was met (colours)

Lachlan Planning Units	BF2-5-10	SF1-10	SF2-5-10	SF3-5-10	LF1-5-10	LF2-3-5	LF3-3-5	BK1-Natura	WL1-7-8	WL2-5-7	WL3-3-5	WL4-2-3	OB1-7-8	OB2-4-7	OB3-3-5	OB4-2-3	OB5-1
Belubula River	5	4	2	4	2	1		2							2	1	1
Booberoi Creek								1							0	0	0
Lachlan River - Condobolin to Lake Cargelligo	5	5	5		1	1		1						1	0	0	0
Lachlan River - Forbes to Condobolin	5	5	5	3	2	1	2	0						1	1	1	0
Lachlan River - Lake Cargelligo to Willandra Weir	5	5	5		2	1		2					2	1	1	1	1
Lower Lachlan Watercourse	5	5	5		2	1		1	2	1	1			1	1	1	1
Merrimajeel Creek									3	1	1	1		1	1	0	0
Merrowie Creek													2	1	1	1	1
Merrowie Creek		5	1	1	3	1			1	1	1						
Mid Lachlan Anabranches	5	5	5		5	5		1						1	1	1	0
Mid Lachlan Anabranches	5	6	5		3	2		1									
Muggabah Creek									3	1	1	1		1	1	0	0
Upper Lachlan River	5	6	5		1	1		1							1	0	0
Upper and Mid Lachlan Floodplains											1				1	1	0
Western Lachlan Watercourse (Cumbung Swamp)	5	5	4		3	3		0	1	1	1	1		1	1	0	0
Willandra Creek	5	5	5		2	1		2		2		1		1	1	1	1

Figure 3-8 Success rate (0-5 colour codes) of the EWR long-term ecological water requirement (10-year frequency) being met for the five-year reporting period within the relevant planning units of the Lachlan WRPA

See Appendix 2 for planning unit locations). The table indicates the number of reporting years in which the EWR occurred (values) in addition to the colour coding of the success rate of the EWR's long-term ecological water requirement being met.

In the other relevant planning units, the EWR was successfully met in two of the reporting years (Lachlan River–Forbes to Condobolin, Mid-Lachlan Anabranches) or successfully met once (Figure 3-8). In one of the relevant planning units, Merrowie Creek, the EWR was unsuccessful in all years. Having occurred every year during the reporting period, the hydrological conditions in each relevant planning unit are on track to meet the 2024 ecological targets if the current frequency of occurrence is maintained into the next five years. A Small Fresh 2 (SF2) EWR is required to occur 5–10 years in 10 years with the main objective being to enhance the spawning of riverine generalist native fish species (for example, Carp-gudgeon species complex, Australian smelt) and riverine specialist native fish species (for example, Murray cod, Macquarie perch) (see Lachlan LTWP). The success rate of the SF2 EWR was five years in most of the relevant planning units, which means that 10-year frequency requirements were met every year of the 2014–19 reporting period (Figure 3-8). The exception to this SF2 EWR success rate was in the Western Lachlan Watercourse (Cumbung Swamp) planning unit, where the requirements were met in four of the reporting years and in Merrowie Creek where it was unsuccessful in all years. The EWR occurred every year during the five-year reporting period in most planning units (Figure 3-8) and so if the current frequency of occurrence is maintained into the next five-year unit, the long-term water requirements are on track to be met by 2024.

Large freshes in the Lachlan WRPA are important for inundating in-channel habitat, providing fast-flowing habitat, supporting productivity as well as potentially connecting low lying wetlands and anabranches. The success rate of large freshes was variable in the Lachlan WRPA. The Large Fresh 1 (LF1) EWR is required to occur 5–10 years in 10 to promote the dispersal of and improve the condition of all native fish species, as well as to maintain in-channel native vegetation, provide habitat, support frog survival and breeding opportunities and to promote instream productivity. This EWR was successfully met in all five reporting years for four of the Lachlan planning units (Lachlan River–Lake Cargelligo to Willandra Weir, Mid-Lachlan Anabranches, Western Lachlan Watercourse (Cumbung Swamp) and Willandra Creek) but was unsuccessful in the other relevant planning units further upstream (Figure 3-8). The EWR was successfully met four times in the Lower Lachlan and three times in Merrowie Creek as a result of environmental water deliveries. The EWR occurred at least once during the reporting period in all planning units but the planning units that received the EWR 3–5 times will be on track to meet the long-term water requirements by 2024 if the pattern of flows is repeated in the next five years.

A Large Fresh 2 (LF2) EWR is required to occur 3–5 years in ten years with the main aim to enhance the spawning of flow pulse specialist native fish species for example, golden perch (NF4), as well as to maintain non-woody native vegetation within channels (NV1), create quality instream habitat, promote productivity and promote nutrient, carbon and sediment transport. The ecological water requirements of this EWR were successfully met at three times in all the relevant planning units. The EWR was met every reporting year in the Lachlan River–Lake Cargelligo to Willandra Weir, Mid-Lachlan Anabranches, Western Lachlan Watercourse (Cumbung Swamp) and the Willandra Creek planning units. In other planning units, it was successfully met in four years for Merrowie Creek and in three years for all the other relevant planning units (Figure 3-8). In the planning units where it occurred only once during the reporting period to meet the long-term environmental water requirements it will need to occur more frequently in the next 5 years to ensure that the long-term requirements are met to achieve the 2024 ecological objectives.

In the Lachlan WRPA, there are flows that specifically target the inundation of wetlands and low-lying floodplain habitats to provide broad-scale lateral connectivity with the river and associated wetlands and floodplains, and to support nutrient, carbon and sediment exchange between the floodplain and channel, support waterbird and frog survival, habitat and to promote large-scale productivity. The Small Wetland Inundation (WL1) EWR is required to inundate wetland habitats with high frequency (7–8 years in 10) to maintain non-woody wetland vegetation communities (for example, common reed, sedgelands, cane grass), to promote spawning of floodplain specialist native fish species (for example, Southern pygmy perch, Murray hardyhead) and to promote productivity, and to ensure the protection of core wetland areas as refugia in the landscape and as waterbird habitat (foraging and breeding), particularly during dry times.

The WL1 EWR was successfully met in two of the five years for the planning units Merrimajeel and Muggabah Creeks but was unsuccessful in the other relevant planning units (Lower Lachlan Watercourse, Merrowie Creek, Western Lachlan Watercourse (Cumbung Swamp) (Figure 3-8). As a result of environmental flows, the EWR occurred in three of the five reporting years for Merrimajeel and Muggabah Creeks and twice in the Lower Lachlan Watercourse, and it also occurred once in 2016–17 for Merrowie Creek and Western Lachlan Watercourse (Cumbung Swamp). For the hydrological conditions to be on track to meet the 10-year frequency requirements that maintain and protect core wetland areas for the next five years, the planning units that were inundated by the WL1 three times this reporting period would need to be inundated every year in the next five years.

The Small Wetland Inundation (WL2) EWR is required to inundate 5–7 years in 10 years primarily to maintain lignum condition and to promote floodplain productivity but it also aims to provide for general maintenance of non-woody wetland vegetation, river reg gum woodland including for waterbird and frog habitat and potential breeding. The 10-year frequency requirements of the WL2 EWR were met in three of the five reporting years for the Merrimajeel and Muggabah Creek planning units but was unsuccessful in all years in the other relevant planning units (Lower Lachlan Watercourse, Merrowie Creek, Western Lachlan Watercourse (Cumbung Swamp), Willandra Creek) (Figure 3-8). The WL2 EWR occurred once during the reporting period in most of the relevant planning units and twice in Willandra Creek. However, to enable the ecological objectives of the EWR to be achieved by 2024 the frequency of occurrence of this EWR in the next five years needs to be increased to meet the stated ecological water requirements.

Large Wetland Inundation flow events (WL3) are required with moderate to high frequency (2–5 years in 10). The WL3 EWR aims to primarily enable the dispersal of all native fish species and maintain lignum shrubland but is also aims to provide opportunities for increased abundance of floodplain specialist native fish species, maintain non-woody wetland and river red gum communities, support waterbird and frog survival, habitat and potential breeding, and is critical for supporting large-scale productivity on the floodplain. The WL3 is required to occur 3-5 years in 10 years to meet the long-term ecological requirements of these objectives and this was successfully achieved five times in the Lower Lachlan Watercourse planning unit, three times in Merrimajeel Creek, Muggabah Creek, Upper and Mid Lachlan Floodplains and the Western Lachlan Watercourse (Cumbung Swamp) but was unsuccessful in all years in Merrowie Creek (Figure 3-8). It occurred once during the reporting period and would need to re-occur one to two times in the next five years for the requirements to be met by 2024.

The Large Wetland Inundation (WL4) EWR is required to occur 2–3 years in ten years with the aim to maintain and improve the condition of river reg gum woodlands, lignum and black box woodlands, support waterbird and frog survival, habitat and potential breeding, and to provide broad-scale lateral connectivity and large-scale productivity on the floodplain. This EWR was successfully met in all five reporting years for three of the four relevant planning units: Merrimajeel Creek, Muggabah Creek and the Western Lachlan Watercourse (Cumbung Swamp) (Figure 3-8). It was also successfully met in three of the five reporting years in Willandra Creek and it occurred once (2016–17) in all the four relevant planning units. Given that it was met during the reporting period the water requirements are likely to be met in the next five years.

As with wetland inundating flows, overbank flows can provide broad-scale lateral connectivity with floodplain and wetlands and provide lateral connectivity with floodplain and wetlands, support nutrient, carbon and sediment exchange between the floodplain and channel, and promote floodplain productivity. Small overbank flow events in the Lachlan are required with reasonably high frequency (3–8 years in 10). The Small Overbank 1 (OB1) aims to maintain and improve lignum condition and promote productivity as a priority and is required to occur 7–8 years in ten years to meet the requirements of these objectives. This EWR is relevant to two planning units (Lachlan River–Lake Cargelligo to Willandra Weir and Merrowie Creek) but it was not met in any of the five reporting years although it did occur twice (Figure 3-8).

The Small Overbank 2 (OB2) aims to enhance the spawning of floodplain specialist native fish species, maintain river red gum communities, improve lignum and black box woodland condition, and to promote productivity on the floodplain, as well as to support waterbird and frog survival, habitat and potential breeding. The OB2 EWR is required to occur 4–7 years in 10 years to meet the requirements of these objective and this was not achieved in year for any of the Lachlan planning units, although it did occur in one of the reporting years (2016–17) in all planning units (Figure 3-8). If water availability is similar to 2014–19 period, it is unlikely this EWR will re-occur with sufficient frequency in the next five years to meet the ten-year ecological watering requirements by 2024.

The Small Overbank 3 (OB3) EWR aims are to primarily promote the dispersal and improve the condition of all native fish species and to promote broad-scale floodplain productivity, as well as to provide wetland and floodplain habitat, opportunities for nutrient exchange and to maintain waterbird habitat. To achieve these objectives, the OB3 EWR needs to occur 3–5 years in 10 years. During the 5-year reporting period, the OB3 EWR was successfully achieved in three years for the Merrowie Creek planning unit but in all other planning units it was not achieved in any year (Figure 3-8). It did occur in one of the reporting years (2016–17) in most Lachlan planning units but will need to occur at least twice in the next five years to meet 10-year ecological watering requirements by 2024 to enable the ecological objectives of the EWR to be achieved in the next reporting period.

Large overbank flow events do not occur frequently and rely on large flows from widespread catchment rainfall that instigates dam spills and tributary flows. Large Overbank 4 (OB4) EWR in the Lachlan needs to occur 2–3 years in ten years to achieve the priority objectives, which are to maintain lignum shrublands and black box woodlands and to increase opportunities for non-colonial and colonial waterbird breeding and maintain waterbird habitat and to promote large-scale productivity across the floodplain. The OB4 EWR was successfully achieved in three of the five reporting years in the Merrowie Creek planning unit but was unsuccessful every year in all other planning units (Figure 3-8). The OB4 EWR did occur in one year of the reporting period for many planning units and so if it re-occurs at least once in the next five years it will be on track to meeting the long-term water requirements by 2024.

The priority aim of the Large Overbank 5 (OB5) EWR is to establish between catchment connectivity as well as to maintain and improve river red gum woodland condition, increase opportunities for non-colonial and colonial waterbird breeding and maintain waterbird habitat and to promote large-scale lateral connectivity and productivity across the floodplain. This EWR is required to occur one year in 10 and was successfully met in three of the five reporting years for four planning units (Lachlan River–Lake Cargelligo to Willandra Weir, Lower Lachlan Watercourse, Merrowie Creek, and Western Lachlan Watercourse (Cumbung Swamp)) (Figure 3-8). Given that this EWR also occurred within the reporting period (in 2016–17) the long-term water requirements of this EWR will be met in the next five years for these planning units to enable the ecological objectives of the EWR to be achieved by 2024.

Lateral connectivity

As a result of managed flow deliveries, tributary flows or dam spills, each floodplain wetland received flows of varying magnitudes from small to large freshes, wetland inundations, and from small to large overbank flows consequently inundating a wide range of floodplain area. Inundation extent for the reporting period was at its largest in 2016–17 within each floodplain wetland as a result of widespread catchment rainfall triggering dam spills and tributary flows (Figure 3-9).

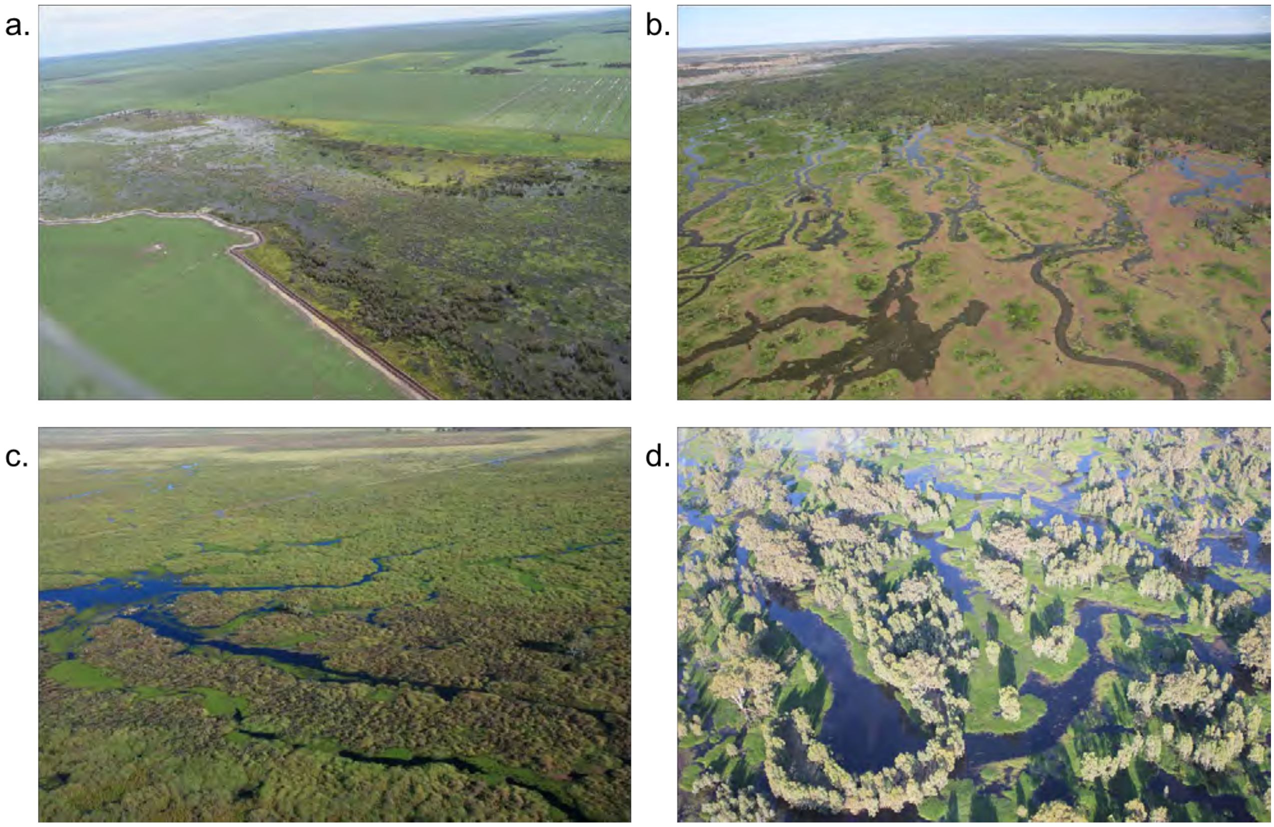


Figure 3-9 Lateral connectivity (inundation) during large flows of 2016 across the floodplain wetlands

a. Gwydir wetlands (Photo: Daryl Albertson), b. Macquarie Marshes (Photo: Rachael Thomas), c. Booligal wetlands of the Lower Lachlan (Photo; Paul Packard) and, d. Lowbidgee floodplain (Photo: Alison Borrell)

In the Lower Gwydir-Gingham the area inundated in 2016–17 was four to five times larger than the area inundated during the four other water years (Figure 3-10(a) and Table 3-2). Most (89%) of the non-woody wetland was inundated, as well as 64% of lignum shrubland and 29% of river red gum woodland (Figure 3-10(a)). This would have supported the provision of a broad range of waterbird foraging habitats and the availability of waterbird breeding habitat, as well as habitat for frogs.

Environmental water actions targeted the inundation of the Lower Gwydir and Gingham wetlands in the other four years using small wetland inundation flow types (Table 3-2 OEH 2015; OEH 2017; OEH 2018; DPIE 2020). Inundation extent in 2014–15 and 2018–19 was similar (~8400 ha, Figure 3-10(a) and Table 3-2), and inundated 60% of non-woody wetland vegetation and 25%–29% of lignum-river cooba plant communities which are both important core wetland habitats in the Gwydir-Gingham wetlands. The inundated extent during the years of 2015–16 and 2017–18 were the smallest of the five years resulting in 36%–42% of non-woody vegetation inundated, as well as 12%–19% of river red gum woodland and 18%–21% of lignum-river cooba plant communities being inundated. Whilst these areas represent relatively small proportional areas of available wetland habitat, they provided important drought refugia and supported the maintenance of critical waterbird, fish and frog habitat.

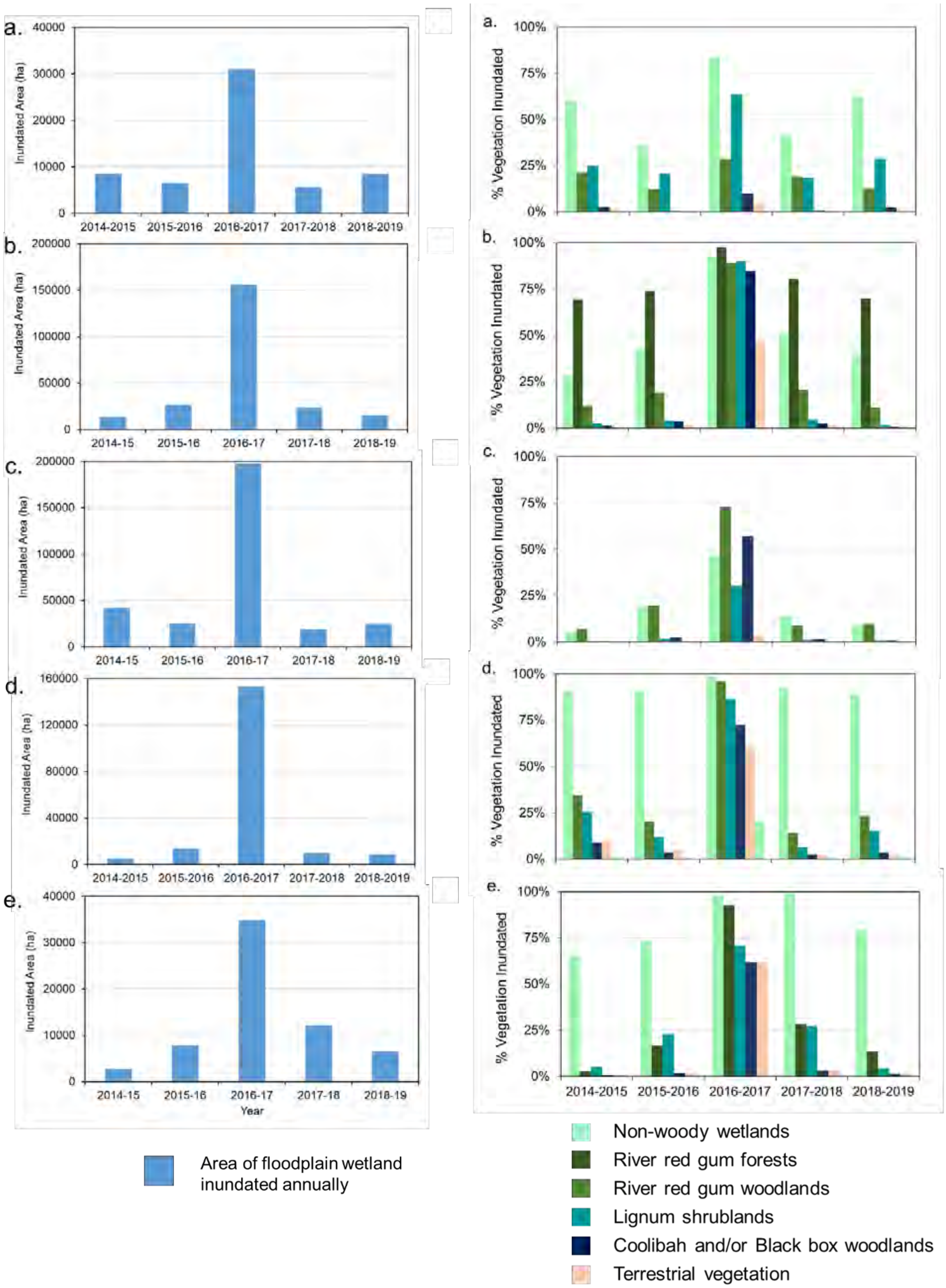


Figure 3-10 Inundated area (ha) (total cumulative area of the floodplain inundated annually) (left) and percentage area of vegetation types inundated (right) for the five floodplain wetlands

a. Lower Gwydir-Gingham wetlands, b. Macquarie Marshes, c. Lowbidgee floodplain, d. Lower Lachlan (Western Lachlan watercourse) and e. Millewa Forest Swamp

Table 3-2 Flow category, annual inundated extent (ha) (% of floodplain boundary, Figure 3-3) and seasonality based on flow and flood peak (2014-15 to 2018-19) in five NSW floodplain wetlands

a. Lower Gwydir-Gingham watercourse, b. Macquarie Marshes, c. Lowbidgee floodplain, d. Lower Lachlan (Western Lachlan watercourse) and e. Millewa Forest

A. Lower Gwydir-Gingham watercourse	2014–15	2015–16	2016–17	2017–18	2018–19
Flow category	Small wetland inundation	Small wetland inundation	Large & small wetland inundation	Small wetland inundation	Small wetland inundation
Inundated extent	8,475 (3%)	6,512 (3%)	30,996 (19%)	5,650 (4%)	8,381 (5%)
Season	Spring–Summer	Winter; Summer	Spring–Summer	Spring–Summer	Spring–Summer

B. Macquarie Marshes	2014–15	2015–16	2016–17	2017–18	2018–19
Flow category	Small fresh & Overbank/ medium wetland flow	Large fresh-Overbank/ small wetland flow	Overbank/ large wetland flow	Overbank/ small wetland flow	Overbank/ small wetland flow
Inundated extent	13,679 (5%)	26,526 (9%)	155,701 (55%)	22,978 (8%)	15,115 (5%)
Season	Spring	Winter–Spring	Winter-Spring	Spring	Late winter–Spring

C. Lower Lachlan (Western Lachlan watercourse)	2014–15	2015–16	2016–17	2017–18	2018–19
Flow category	Small freshes	Small & large freshes, & wetland	Small & large freshes, wetland & overbanks	Small freshes	Small freshes
Inundated extent	3,310 (2%)	9,293 (6%)	95,289 (63%)	7,117 (5%)	4,676 (3%)
Season	Spring & summer	Spring & summer	Spring	Summer	Summer; winter

D. Lowbidgee floodplain [diversions through regulators off Maude and Redbank Weirs]	2014–15	2015–16	2016–17	2017–18	2018–19
Flow category	Small freshes plus *wetland connecting flows	Small & large freshes plus *wetland reconnecting flows	Small & large freshes, small & large overbanks plus *wetland & floodplain reconnecting flows	Small & large freshes plus *wetland connecting flows	*wetland connecting flows
Inundated extent	42,004 ha (13%)	25,348 ha (8%)	197,372 ha (61%)	18,750 ha (6%)	24,689 ha (8%)
Season	Winter–Spring	Spring–Summer	Spring	Late winter–Spring	Spring

E. Millewa Forest Swamp	2014–15	2015–16	2016–17	2017–18	2018–19
Flow category	Small & large freshes & bank full	Large fresh & bank full	Large freshes & small, medium & large overbanks	Large freshes & small overbank	Large freshes & small overbank
Inundated extent	4,204 (7%)	14,507 (21%)	62,406 (93%)	23,722 (32%)	14,124 (18%)
Season	Winter–Spring	Winter–Spring	Winter–Spring	Late winter–Late spring	Spring–Late spring

In the Macquarie Marshes, the area of floodplain inundated in 2016–17 was six to eleven times larger than the area inundated during the four other water years (Figure 3-10(b) and Table 3-2). Almost all (93%) of the non-woody vegetation in wetlands and across the floodplain was inundated, as well as 90% of lignum shrubland, 97% of river red gum forests and 89% of river red gum woodlands, as well as 85% of the black box and coolibah woodlands (Figure 3-10(b)). Vast areas of the floodplain were also inundated with 47% of the terrestrial floodplain landscape inundated. Such a large inundation extent would have supported a broad range of waterbird foraging habitats suitable for a diversity of species in high numbers and the availability of waterbird breeding habitats, especially for colonial nesting birds, as well as habitat for frogs.

In the other four years, environmental water actions targeted the inundation of a range of different habitats in the Macquarie Marshes using small to medium wetland inundating flows (Table 3-2

OEH 2015; OEH 2017; OEH 2018; DPIE 2020). Inundation extent in 2014–15 and 2018–19 was similarly small (~13,500-15,000 ha, Table 3-2 and Figure 3-10(b)) inundating important core wetland habitats in the Macquarie Marshes: 29% and 40% of non-woody wetland vegetation in respective years and about 70% of river red gum forests in both years. Just over 10% of river red gum woodlands were inundated in 2014–15 and 2018–19 The inundated extent during the years of 2015–16 and 2017–18 were comparable in size and almost twice the size of the 2014–15 and 2018–19 years (~26500ha and ~23000 ha, , Table 2.3 and Figure 3-10(b)) resulting in 43-51% of non-woody vegetation inundated, as well as 74%–80% of river red gum forest.

During the 2015–16 and 2017–18 water years, 19%–21% of river red gum woodland was inundated, which was almost twice the area inundated in 2014–15 and 2018–19. In all years, except 2016–17, only very small proportions of lignum-river cooba plant communities (1%–4%) were inundated. Whilst these represent relatively small proportional areas of available wetland habitat, the inundation from environmental flow deliveries provided important drought refugia and supported the maintenance of important plant communities that provide critical waterbird, fish and frog habitat.

In the Lower Lachlan western watercourse, the 2016–17 inundation extent was between 10–29 times larger than the other four water years (Table 3-2 and Figure 3-10(c)). Almost three quarters of the river red gum woodland area was inundated during 2016–17, as well as over half (57%) of black box woodland area. Only about 50% of all non-woody wetland vegetation and 30% of lignum-river cooba-nitre goosefoot communities were inundated in 2016–17 even though the 2016–17 flow was historically the largest flow in 30 years (Figure 3-10(c)). Nevertheless, this supported the provision of a broad range of waterbird foraging habitats and the availability of waterbird breeding habitat, as well as habitat for flow-dependent frogs. In the other four years, environmental water actions targeted the inundation of a range of different habitats in the Lower Lachlan using small to large freshes and small wetland inundating flows (Table 3-2, OEH, 2015; OEH, 2017; DPIE, 2018; DPIE, 2020). In all other water years, between 5%–19% of non-woody vegetation was inundated and 7%–20% of river red gum woodlands were inundated as well as <1-2% of lignum-river cooba-nitre goosefoot communities and of black box communities (Figure 3-10(c)). Whilst these are relatively small proportional areas of available wetland habitat, they represent thousands of hectares in the landscape inundated from environmental flow deliveries. These areas provided critical drought refuge and supported the maintenance of important plant communities that provide critical waterbird, fish and frog habitat, including for the endangered southern bell frog.

The 2016–17 inundation extent across the Lowbidgee floodplain was 5–11 times larger than the other four water years (Table 3-2 and Figure 3-10(d)). Almost all non-woody vegetation (99%) and river red gum forests (96%) were inundated at some point in time during 2016–17, as well as 86% of river red gum woodlands, 72% of lignum shrublands and 60% of black box woodlands. The inundation of these areas made diverse habitat available and improved over large areas of the floodplains. In the other four years, environmental water actions targeted the inundation of a range of different habitats located in different parts of the Lowbidgee floodplain using wetland reconnecting flows (Table 3-2, OEH, 2015; OEH, 2017; OEH, 2018; DPIE, 2020). In all other water years, 89%–91% of the non-woody wetland habitat, which in the Lowbidgee is dominated by the large open water lakes, was inundated (Figure 3-10(d)). Inundation extent in other plant communities was comparatively small and variable, with 14%–34% of river gum forest habitat inundated, 6%–25% of river gum woodlands inundated and only 3%–9% of lignum shrublands inundated. Whilst these are relatively small proportional areas of available wetland habitat, they represent thousands of hectares in the landscape inundated from environmental flow deliveries. These landscapes provided critical drought refuge and supported the maintenance of important plant communities that provide critical waterbird, fish and frog breeding habitat, including for the endangered southern bell frog.

The inundated extent of Millewa Forest in 2016–17 was between 3 and 13 times larger than the other four water years (Figure 3-10(e) and Table 3-2). Most (98%) of the non-woody wetlands and of the river red gum forests with a sedgeland understorey were inundated during 2016–17 as well as 92% of other river red gum forests (grassy understorey) and woodlands and almost a third of the box woodlands, creating large expanses of diverse and connected aquatic habitat (Figure 3-10(e) and Table 3-2). In the other four years, environmental water actions targeted the inundation of the Millewa Forest using small to large freshes as well as bankfull and overbank flows (Table 3-2 OEH 2015; OEH 2017; OEH 2018; DPIE 2020).

The total inundated area of the Millewa Forest in 2014–15 was the smallest for the five-year period, (1,898 ha) flooding a third of the non-woody habitats, 11% of the river red gum forests with a sedge understorey and only 2% of other river red gum forests and woodlands (Figure 3-10(e)). For the other water years, the proportion of plant community area inundated varied with 73%–99% of non-woody wetlands inundated, 60%–80% of sedge understorey river gum forest habitat inundated and 10%–25% of other river red gum forests and woodland habitats inundated.

Assessment of the inundation regime (2014–19)

Varying extents of inundation over the five-year reporting period created spatially variable flooding patterns across each floodplain wetland landscape (Figure 3-11). Such variability enables different wet and dry wetland habitats to be available and connected hydrologically through time and across the floodplain to support a wide range of different plants and animals at varying stages of their life cycles. The most frequently inundated areas (3 to 5 times, red-purple-blue, Figure 3-11) are equivalent to flooding re-occurring on average every 1–1.66 years and indicative of the core wetlands and refugia. Compared to the total area of each floodplain that was inundated at least once during the five-year reporting period (yellow-blue, Figure 3-11), frequently inundated areas were confined to a relatively small extent: 6% in the Lower Lachlan, 12% in the Macquarie Marshes and 15% in the Lowbidgee floodplain (Figure 3-11). However, in both the Gwydir wetlands and Millewa Swamp Forest the areas of frequent inundation were a larger proportional area of the total area of the floodplain inundated at least once during the reporting period at 23% and 21% respectively. Areas inundated twice in the five years, equivalent to flooding re-occurring every 2.5 years (orange, Figure 3-11) were distributed a little more widely across the landscape but remained a comparatively small proportion of the total area of the inundated floodplain (7%–12%). The largest proportional area of the inundated floodplain was inundated once in the five years (yellow, Figure 3-11), although this proportion varied among floodplain wetlands: 66% in the Gwydir wetlands and Millewa Swamp Forest, 74% in the Lowbidgee and 81%-84% in the Macquarie Marshes and Lachlan respectively.

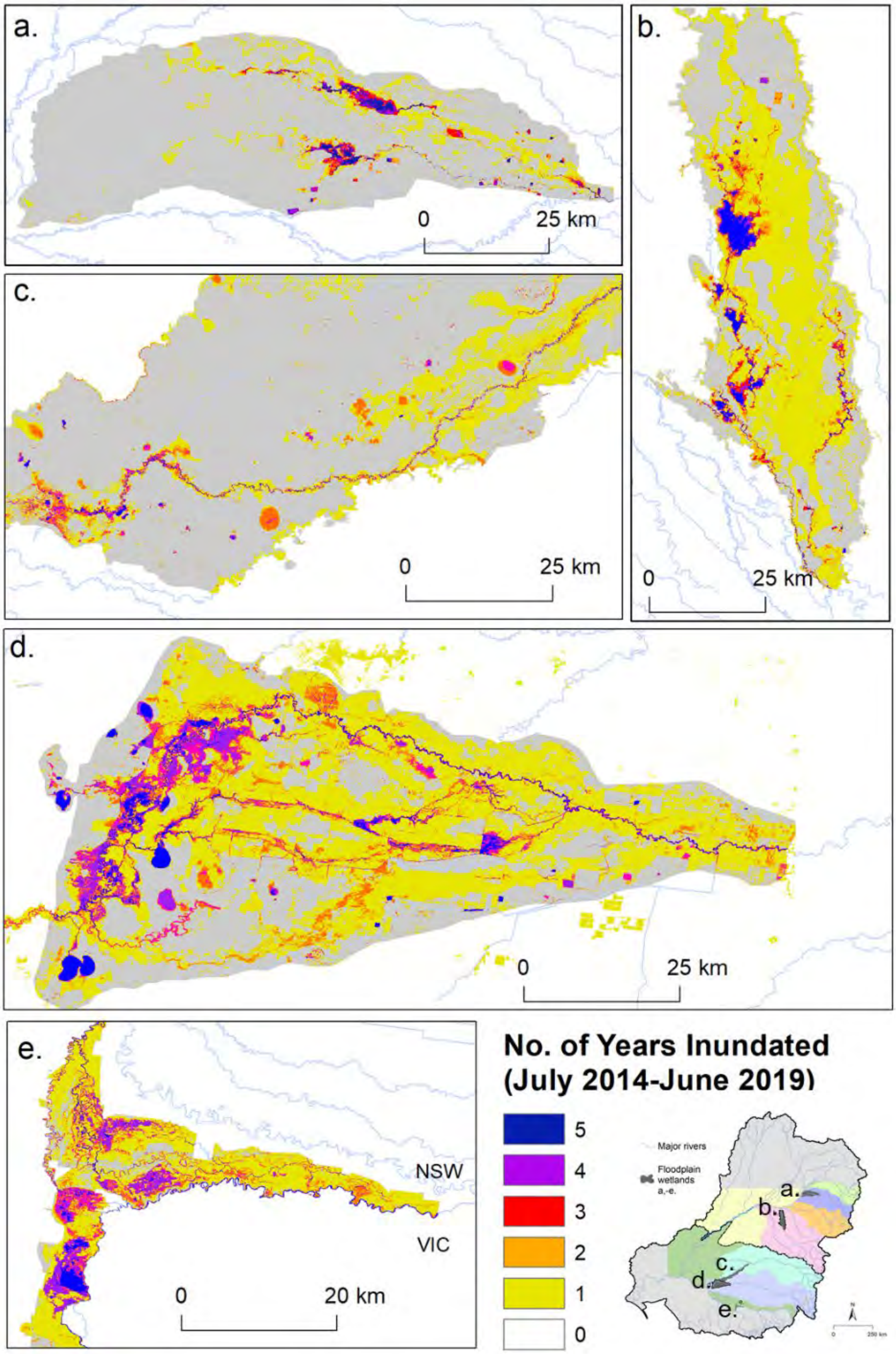


Figure 3-11 Distribution of flood frequency (number of years inundated between July 2014 and June 2019) in the five floodplain wetlands

a. Gwydir-Gingham wetlands, b. Macquarie Marshes, c. Lowbidgee, d. Lower Lachlan, and e. Millewa.

Highly flood-dependent plant species such as water couch, spike-rush, and cumbungi, are common in the Gwydir wetlands and require frequent inundation: eight to ten years in ten years, which equates to a re-occurrence every 1–1.25 years on average and a maximum period of two years between floods (Roberts and Marston 2011). To meet this requirement, inundation would need to occur three to five times in the reporting period. In the Lower Gwydir–Gingham wetlands, about 70% of the non-woody wetland vegetation was inundated three to five years of the five-year reporting period (Figure 3-12). These small frequent wetland inundating events (EWRs WL1 & WL2) were therefore important for maintaining the extent and viability of these species, including Marsh club-rush sedgeland, a critically endangered ecological community occurring in the Gwydir wetlands, 84% of which was inundated every year of the reporting period. But 23% of non-woody wetland vegetation communities, mainly water couch (25%), were inundated only once which equates to two floods in ten years or an average period of five years between floods. Five years between floods is too wide a dry period to maintain the cover of non-woody wetland plant species and so this result indicates that the water requirements were not met for almost a quarter of the known distribution of water couch in the Lower Gwydir–Gingham.

To meet the 2024 target of maintaining and increasing the known extent of the total area of these communities, 100% will need to be inundated every year for the next five years. Seventeen percent of river red gum woodlands were inundated once in the reporting period and almost 50% were not inundated during the five years, which does not meet the inundation requirements of flooding every 2 to 4 years for vigorous growth (Roberts and Marston 2011). Twenty five percent of lignum river cooba were inundated 3–5 years of the five, which is indicative of meeting the water requirements of these plant communities to function as waterbird breeding habitat. However, 32% of lignum-river cooba was not inundated during the reporting period and 31% was inundated only once, which should enable the plants to survive but is unlikely to maintain their vigour or capacity to regenerate (Figure 3-12(a)).

In the Macquarie Marshes, there are expansive areas of the flood-dependent, non-woody wetland plant species that require near annual inundation and a maximum period of two years between floods (Roberts and Marston 2011) including common reed (4,866 ha), sedgelands (6,473 ha) and water couch (5,349 ha) (Bowen and Simpson, 2014a). To meet this requirement, inundation would need to occur three to five times in the reporting period (Roberts and Marston 2011). During the five-year reporting period 42% of non-woody vegetation in the Macquarie Marshes was inundated three to five times (Figure 3-12(b)). Eighty percent of common reed was inundated 3–5 times, as well as 83% of the freshwater lagoons dispersed through the reed beds, which whilst relatively small in area (~390 ha), provide important open water habitat adjacent to tall macrophyte vegetation for waterbird foraging and refuge. About 50% of sedgeland area was distributed evenly across the inundation gradient of 2–5 floods in the reporting period which is likely to meet the water requirements of these plant species into the next five years if the pattern is repeated. However, 41% of sedgelands and two thirds (62%) of water couch and were inundated only once in this reporting period which may support rhizome growth but the time between floods should not exceed seven years (Roberts and Marston, 2011).

Seventy-five percent of the river red gum forest area in the Macquarie Marshes were inundated 3 to 5 times in the reporting period equivalent to a re-occurrence of every 1.66 years. This provided the required hydrological regime not only for the river red gum trees but also importantly for the non-woody aquatic plant species understorey.

River red gum woodlands in the Macquarie Marshes cover almost 20% of the floodplain and for vigorous growth they should be flooded every 2 to 4 years (Roberts and Marston, 2011). During the reporting period, 20% of the river red gum woodlands were inundated two to three times which if repeated during the next five years is likely to meet the ecological water requirements for this proportional area of the river red gum woodland community if it is in good condition. About two-thirds of the river red gum woodland community was inundated once and if this pattern of watering is repeated over the next 5 years the 2024 target that aims to improve their condition may not be met for the majority of the river red gum woodland in the Macquarie Marshes.

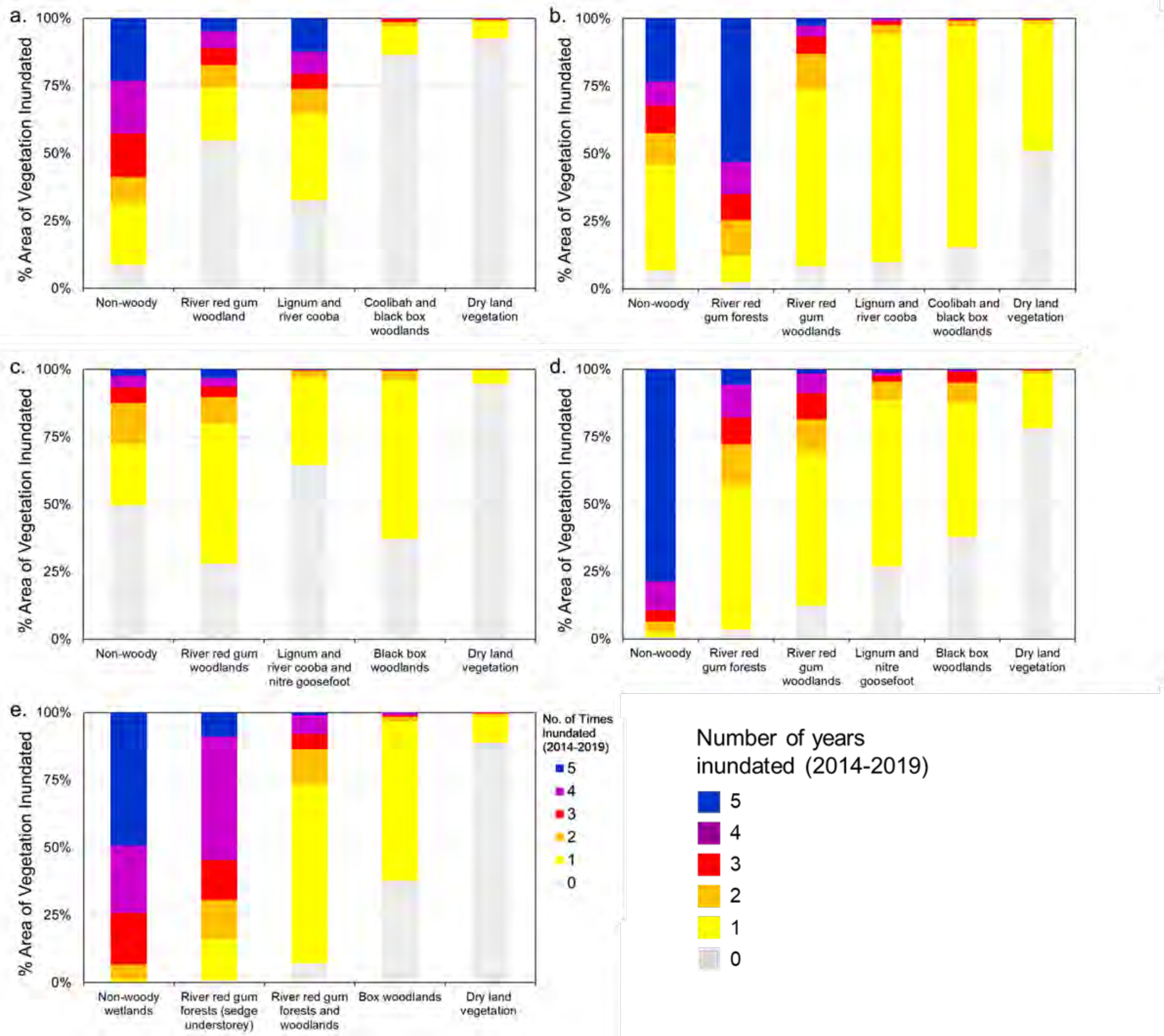


Figure 3-12 Percentage of vegetation area inundated a number of different times in the five year period (July 2014-June 2019)

Not inundated (0), inundated once (1), twice (2), three (3), four (4) or five (5) times for the five floodplain wetlands: a. Gwydir–Gingham wetlands, b. Macquarie Marshes, c. Lowbidgee floodplain, d. Lower Lachlan (western watercourse) and e. Millewa Forest

Most (84%) of the lignum-river cooba area in the Macquarie Marshes were inundated once, whereas only 6% of the area was inundated between 2 and 4 times and <1% inundated five times (Figure 3-12(b). For lignum shrubs to remain large and vigorous with the potential for provisioning waterbird nesting habitat, flooding is required every 1–3 years, which in a five-year period is equivalent to flooding occurring 1.65 to 5 times. This means that the water requirements were not met for most of the known distribution of lignum-river cooba communities in the Macquarie Marshes. To meet the 2024 target of maintaining the known extent of the total area of these communities and of increasing the proportion of lignum communities in intermediate to good condition, at least 50% would need to be inundated twice within the next five years.

In the Lower Lachlan Western Watercourse variable inundation regimes are required for the flood-dependent, non-woody wetland plant species which include mostly cane grass swamps (53%) and common reeds (27%) as well as sedgelands (13%) and cumbungi (7%) (OEH, 2018). Cane grass swamps require flooding every two to three years, although they could tolerate a flood every five to seven, whereas common reeds and cumbungi require near annual inundation with a maximum of two years between floods to maintain vigour. Sedgelands, depending on species, require near-annual flooding to a flood every one to three years with up to 3 to 5 dry years between floods (Roberts and Marston 2011). Therefore, the variable inundation regimes that occurred in the non-woody wetland vegetation of the Lower Lachlan was expected during the reporting period (Figure 3-12(d)).

Overall, 28% of the non-woody vegetation area was inundated 2–5 times, 23% of non-woody vegetation was inundated once, and half of the non-woody area was not flooded during the five-year reporting period (Figure 3-12(c)). A quarter of the cane grass area was inundated 2–5 times but 60% of it did not get inundated in any year, which may be sufficient to meet the ecological objectives of this plant species. However only 18% of common reed was inundated in 3–5 times (equivalent to a flood every 1–1.66 years), and about the same percentage area was inundated twice, while the largest proportion (39%) was inundated once and a quarter of the common reed area was not inundated in any year during the reporting period. To meet the 2024 target of maintaining or increasing the current extent and maintaining the viability of non-woody vegetation communities occurring in wetlands and on floodplains in the Lachlan this will be difficult for common reed if the inundation regime is over the next five years is similar to 2014–19.

River red gum woodlands require inundation every 2 to 4 years to maintain vigour and for this reporting period half of the river red gum area was inundated once and 10% of river red gum woodland was inundated twice, whilst another 10% was inundated more frequently at 3–5 times. Almost a third of the river red gum woodland area was not inundated during the reporting period even though the 2016–17 flow was historically the largest flow in 30 years. If this inundation pattern is repeated over the next 5 years, the 2024 target that aims to improve river red gum woodland condition may not be met for most of the river red gum woodland in the Lower Lachlan.

In the Lowbidgee floodplain lignum and nitre-goosefoot are important shrubland habitat that together cover 25% of the floodplain (79,914 ha, Lowbidgee Vegetation Map 2008-2011-2013, Bowen and Simpson 2014) and 11% of this area was inundated 2 to 5 times in the reporting period (Figure 3-12(c)). The majority (66%) of this shrubland habitat is lignum, which is an important waterbird and refuge habitat covering about 16% of the Lowbidgee floodplain (52,842 ha) distributed mostly through the Gayini (Nimmie–Caira) and Fiddlers–Uara regions, forming an important connectivity floodway across the floodplain. Large shrubs with a vigorous canopy require flooding every 1–3 years (Roberts and Marston, 2011), which is equivalent to occurring 1.65 to 5 times in 5 years. During this five-year period, 16% of lignum area was inundated 2 to 5 times, whereas almost 70% of the lignum area was inundated once and 16% was not inundated in any year. For lignum shrubs to remain large and vigorous with the potential for provisioning waterbird nesting habitat, flooding is required every one to three years, which in a 5-year period is equivalent to flooding occurring 1.65 to 5 times. To meet the 2024 target of maintaining the known extent of the total area of these communities and of increasing the proportion of lignum communities in intermediate to good condition, at least 50% would need to be inundated twice within the next five years.

Lignum occurs as an important understorey component of river red gum forests across relatively large areas in the Redbank regions including Yanga National Park (36,349 ha, 11% of the Lowbidgee and 70% of all river red gum forests). Almost all of the river red gum forests with a lignum understorey were inundated at least once during the five-year period with 30% of the area inundated 2–5 times and two-thirds inundated once. About 20% of the river red gum forests have a sedge understorey of spikerush Eleocharis spp. (10,680 ha) and 73% of this was inundated 2–5 times in the reporting period with 30% inundated four times whilst 23% was inundated once (Figure 3-12(c).

About 20% of the river red gum forests have a sedge understorey of spikerush Eleocharis spp. (10,680 ha) and 73% of this was inundated 2–5 times in the five-year period, with 30% inundated four times whilst 23% was inundated once. This means that the areas inundated only once in this five-year period need to be flooded within a 3 to 5-year period to maintain vigour and for rhizome growth to be supported but the time between floods should not exceed seven years (Roberts and Marston, 2011). About 80% of non-woody wetlands that are dominated by the large semi-permanent lakes but also include small lagoon habitats (2685 ha, 1% of the Lowbidgee) and relatively small areas of shallow sedgeland habitat (286 ha, <1% of the Lowbidgee) were inundated every year in the five-year reporting period, providing important fish and waterbird habitat (Figure 3-12(c)).

The majority (80%, 29,955 ha) of Millewa Forest is covered by river red gum forests that have an herbaceous and grassy understorey (Millewa Vegetation Map 2010, Bowen and Simpson 2011) that varies compositionally with topography and flooding patterns. Twenty five percent of the river red gum forest with a grassy herbaceous understorey was inundated 2 to 4 times out of the five years, while two-thirds of the river red gum forest with a grassy herbaceous understorey was inundated once during the five-year period (Figure 3-12e). Given the compositional diversity of the understorey and the known water requirements of river red gum forests, it is likely that the 2024 target that aims to maintain or increase the extent of native woodland communities on floodplains will be met if the inundation regime patterns is at least repeated over the next five years.

Small proportions of Millewa Forest are covered by river red gum forests with a predominately sedge understorey (6%) and 84% of this was inundated 2–5 times during the five-year period (Figure 3-12(e)). Sixteen percent was inundated only once during the reporting period, which may support rhizome growth but the time between floods should not exceed seven years (Roberts and Marston, 2011). Non-woody plant communities cover a small proportion of Millewa Forest but provide important aquatic habitat when inundated and include a reedbed complex composed of rushes, sedges and common reed (*Phragmites australis)* (3%), semi-permanent lake and lagoon habitats (1%) and a shallow marsh habitat (<1%) Forest. Such highly water-dependant, amphibious plant species require frequent inundation: eight to ten years in ten years which equates to a re-occurrence every 1–1.25 years on average and a maximum period of two years between floods (Roberts and Marston 2011). Half (49%) of the non-woody wetland habitat was inundated every year during the five-year period, whereas 44% were inundated 3 to 4 times in the five-year period and 7% was inundated once or twice (Figure 3-12(e)). To meet the 2024 target of maintaining the extent and viability of non-woody vegetation communities occurring in the Millewa Forest, a similar inundation regime would need to reoccur in the next five years.

Summary

The 2014–19 reporting period was hydrologically dry, with average flows below the long-term average and with low flows occurring most of the time. The flow peak of 2016–17 dominated the hydrological regime of the five-year reporting period in most rivers. Most of the flow peaks in other years were due to environmental water actions. Whilst the 2016–17 flow peak was large compared to other flows during the five-year reporting period, it was relatively small compared to the flow peaks that occurred in the 15 years prior to this reporting period (1999–2014). An exception to this were rivers in the Lachlan and the Murray where the 2016–17 flow peaks were the largest in 30 years. On average, the northern valley rivers were drier than the southern valley rivers.

Environmental water requirement success rates for meeting the long-term EWRs in the Gwydir and Lachlan WRPAs during the 2014–19 reporting period were variable across flow types and planning units. For example, the SF2 EWR long-term ecological watering requirements were successfully met 4 to 5 years of the reporting period but in only 4 of the 9 planning units, whereas in the Lachlan the success rate was 3 to 5 years in all planning units. For the planning units where the SF2 EWR occurred at least 3 times in the five reporting years as a result of environmental water actions, the hydrological conditions are on track to help meet the 2024 ecological targets if the current frequency of occurrence is maintained into the next five years.

The long-term environmental water requirements of the LF2 EWR (occurring 3–5 years in 10 years) were met in 4 to 5 years of the 2014–19 reporting years in some of the Gwydir planning units (4 out of 9) and were met in 3 to 5 years of the 2014–19 reporting years in all relevant Lachlan planning units. Whilst the year frequency requirements were met in some of the planning units, the EWR did not occur in any of the reporting years for the Gwydir planning units (except for one) and only once for most of the Lachlan planning units. This means that it will need to occur more frequently in the next 5 years to ensure that the long-term requirements are met to achieve the 2024 ecological objectives.

Wetland inundating flows and small overbanks are critically important for lateral connectivity and were often achieved with environmental water delivery. In the Gwydir, the requirements of the Small Wetland Inundation (WL1) EWR were successfully met. It also occurred 4 to 5 years of the five-year reporting period due to environmental water use in most years and so the hydrological conditions are on track to meet the 10-year frequency of the EWR to maintain and protect core wetland areas if the current frequency of occurrence is maintained into the next five years. Medium sized flow events (for example, WL3) need to occur with reasonably high frequency (4 to 7 years in 10). In the Gwydir, the WL3 success rate was zero in all planning units and occurred once only in the reporting period, whereas in the Lachlan the success rate of the WL3 EWR was 5 years in almost all planning units. In the Lachlan it occurred once during this reporting period and so it would need to re-occur one to two times in the next five years for the long-term water requirements to be met by 2024.

Large overbank flow events do not occur frequently and rely on large flows from widespread catchment rainfall that instigates dam spills and tributary flows. The OB5 EWR is required to occur one year in 10 and was successfully met in all years in the Gwydir by flows that occurred in the five years prior to the reporting period. However, in the Lachlan the flows to meet the OB5 EWR did occur within the reporting period (in 2016–17) and the long-term water requirements of this EWR will be met in 2024, regardless of what flows occur.

Lateral connectivity between rivers, wetlands and low-lying floodplain habitats is critical to maintain and protect ecological processes and a variety of functional habitats. Different plant communities across large floodplain wetland have varying ecological water requirements and the inundation regimes that occur can be tracked using satellite derived inundation maps. Environmental flow deliveries successfully inundated small areas in critical core wetland habitat such as common reed, sedgelands, cumbungi and water couch in all water years before and after the large flooding of 2016–17. Areas inundated were localised and represented relatively small proportional areas of available wetland habitat. However, they provided important drought refugia and supported the maintenance of critical waterbird, fish and frog habitat, including the critically endangered ecological community of marsh club-rush sedgeland occurring in the Gwydir wetlands during very dry years. Only a portion of the total area of non-woody wetland vegetation area in each floodplain wetland was inundated during the 5-year reporting period at a frequency that puts the inundation regime on track to meeting the long-term water requirements in 2024, and only if the inundation regime is similar over the next five years.

Environmental flow deliveries successfully inundated large proportions of river red gum forests with sufficient frequency (2 to 5 years of the 5 years), providing the required hydrological regime not only for the river red gum trees but also for the non-woody wetland understorey. However, in all floodplain wetlands large areas of river red gum woodlands were not inundated, or inundation only occurred once during the 5-year period, which does not meet the inundation requirements of flooding of every 2 to 4 years for vigorous growth. Larger flows that can inundate larger areas will be needed more frequently to meet the long-term ecological watering requirements by 2024.

Lignum shrublands are an important waterbird and refuge habitat and occur in all the floodplain wetlands except Millewa Forest. For lignum shrubs to remain large and vigorous with the potential for provisioning waterbird nesting habitat flooding is required every one to three years, which in a five-year period is equivalent to flooding occurring 1.65 to 5 times. During this reporting period, 34% or less of lignum area was inundated 2 to 5 times. However, most of the lignum areas were inundated once or not inundated in any year and while this low inundation frequency should enable the plants to survive, it is unlikely to maintain their vigour or capacity to regenerate.

The reporting period 2014–19 was mostly dry and similar to the preceding five years and so it was to be expected that the long-term ecological water requirements would not be met for many of the EWR flows during this reporting period. Environmental flow deliveries were crucial to enabling EWRs to occur during the five-year period; they contributed to meeting the 10-year long-term water requirements and will also contribute to keeping the inundation regime on-track for the next five years to meet the long-term ecological requirements in 2024.

Chapter 4 Achievement of environmental objectives

Native vegetation

Native vegetation is crucial for the health of the NSW environment. It supports the biodiversity that is central to Australia's cultural identity as well as agricultural productivity. Native vegetation:

- controls erosion by protecting soils and river banks,
- reduces land degradation and salinity,
- improves water quality and availability,
- provides habitat for a wealth of unique biodiversity including threatened species,
- provides spiritual, aesthetic and cultural values for example, scarred and carved trees,
- stores a significant amount of carbon, mitigating the effects of climate change.

A key environmental objective of the Basin Plan is to support vegetation in the Murray–Darling Basin by 2024, by maintaining and/or increasing the extent and improving the condition of flood-dependent species. Table 4-1 outlines LTWP and WSP objectives relevant to native vegetation.

The stability of the system (its resilience) is represented by its capacity to fluctuate between wet and dry phases while constantly reinstating the structure and function typical in each phase (that is, good or 'optimal' condition). Optimal condition is defined as the state in which water availability meets life history needs of indicator species. If the watering regime changes from an acceptable range, then the wetland plant community may still exhibit wet and dry phases but will cease to function at an optimum level. All indicators, metrics and LTWP objectives relate to the following WSP objectives:

- **Regulated and Unregulated WSP:** Protect and contribute to the enhancement of the recorded distribution or extent, and population structure, of target ecological populations,
- **Regulated WSP:** Support environmental watering to protect and contribute to the enhancement of the ecological condition in streams, riparian zones, dependent wetlands and floodplains within the water source (Table 4-1).

Table 4-1 Vegetation metrics and related LTWP and WSP objectives

Indicator	Metrics	LTWP objectives 2024
Non-woody vegetation	Extent	**NV1:** Maintain the extent and viability of non-woody vegetation communities occurring within channels **NV2a:** Maintain or increase the extent and improve the condition of non-woody vegetation communities within semi-permanent, intermittent, temporal and ephemeral wetland and floodplain areas (Murray-lower Darling, Murrumbidgee, Macquarie and Namoi WRPs only) **NV2b:** Maintain or increase the extent and improve the condition of ephemeral understorey vegetation within forests, woodland and open floodplain areas (all WRPs except Barwon–Darling and Border Rivers)

Indicator	Metrics	LTWP objectives 2024
River red gum forest/woodland	Extent and condition	**NV3:** Maintain the extent and improve the condition of river red gum communities closely fringing river channels **NV4a,b:** Maintain or increase the extent and maintain or improve the condition of river red gum forest and woodland
Black box woodland	Extent and condition	**NV4c:** Maintain or increase the extent and maintain or improve the condition of black box woodlands on floodplains
Coolibah woodland	Extent and condition	**NV4d,f:** Maintain or increase the extent and maintain or improve the condition of coolibah woodlands and coolibah wetland woodlands on floodplains
Lignum shrublands	Extent and condition	**NV4e:** Maintain or increase the extent and maintain or improve the condition of lignum shrublands

Details of the relationship between BWS, LTWP and WSP objectives for native vegetation are shown in Appendix 2. In the BWS, water-dependent vegetation has been classified into three 'structural groups' or 'vegetation types': forests and woodlands, shrublands and non-woody vegetation. Each of these vegetation types have specific watering requirements (Figure 4-1). These 'vegetation types' have been adopted for reporting vegetation response.

Figure 4-1 An example of structural groups of water-dependent vegetation (source: MDBA 2014)

For the purposes of this report, both woody and non-woody vegetation responses to watering are based on long-term survey plots and remote sensing of the Macquarie Marshes and Gwydir Wetlands in the northern Murray–Darling Basin. Additional information has been included for woody vegetation in Narran Lakes. We also present a case study from the Murray Private Properties Wetland Watering program and Sunshower Lagoon in the Murrumbidgee.

Non-woody vegetation

Findings

Macquarie Marshes (objective NV2)

- Between 2014–19, non-woody wetland condition in the Macquarie Marshes was related to water year and time since last inundation.
- The number of native and exotic non-woody species present in the extant vegetation peaked during 2016–17, which as the wettest period during the evaluation period.
- Non-woody vegetation condition changed across the Macquarie Marshes during the reporting period. Non-woody wetlands exhibited a wet-phase response to increased watering during the reporting period indicating they remained in a 'wetland state'.
- As the time since last inundation increased, cover of amphibious species decreased while terrestrial species cover increased.
- Increasing inundation duration suppressed the number of exotic species in non-woody wetlands.
- Wet phase vegetation condition declined after 2016–17 as evidenced by decreasing amphibious species cover coupled with increasing bare ground cover. Terrestrial species cover also appeared to decline after 2016–17, perhaps responding to prevailing drought conditions. Native and exotic species richness (number of species) peaked during 2016–17.
- Increasing inundation duration had a positive effect on amphibious species cover and a marginally suppressive effect on exotic species richness.
- Declines in amphibious species cover and exotic species richness were observed as time since last inundation increased.
- Community assemblages of sites in 2017–18 were different based on pre-flood inundation regime. We inferred that river red gum forests and woodlands retained wet-phase wetland response capacity during the reporting period.

What was expected

For both the Macquarie Marshes and Gwydir wetlands (see section below) we expected wetland vegetation to respond to wetter periods or overbank events with an increase in amphibious species richness and cover. Conversely, during dry periods, vegetation response may be characterised by an increase in the number of exotic species (for example, Catford et al. 2014), terrestrial species (Nicol et al. 2003) and bare ground.

Vegetation response to watering regime may be variable. Species numbers and abundance may increase during a dry phase as more terrestrial niches become available (for example, Stokes et al. 2010). Species numbers and abundance may increase in a wet phase (Alexander et al. 2008) as wetland specialists and ephemerals increase representation, or species numbers may decline as competitively dominant aquatic perennials take over.

Methods

We analysed community data from long-term monitoring of field vegetation plots (20 m x 20 m quadrats). A field survey was undertaken annually each autumn throughout the reporting period in the Macquarie Marshes and Gwydir Wetlands. The response of vegetation condition metrics (native and exotic species richness and cover of amphibious and terrestrial species and bare ground) to several predictors (water year, time since last inundation, inundation duration) was modelled using generalised additive mixed models (GAMMs). We used model-based analysis of multivariate abundance data to analyse changes in community assemblage structure across the reporting period.

Results

Macquarie Marshes

From 2014–19, we recorded a total of 140 plant species in non-woody wetland areas in the Macquarie Marshes, 40 of which were exotic. These non-woody vegetation sites predominantly comprised water couch and sedgeland plant communities.

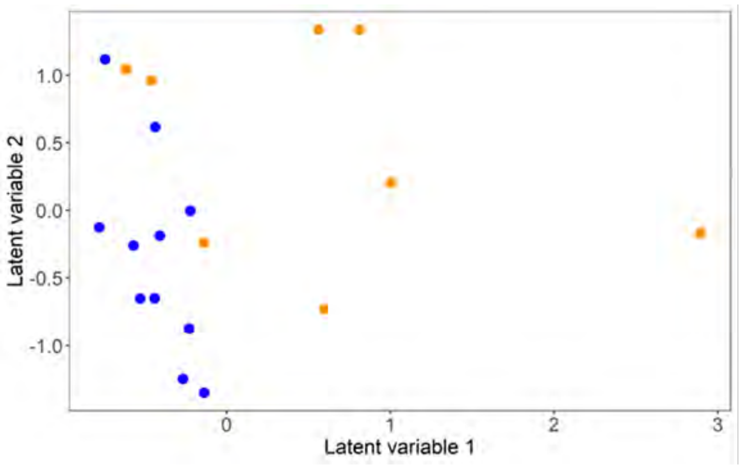
Water year was a significant predictor of change in all vegetation condition metrics within the Marshes. Cover (%) of amphibious species declined, particularly after 2016–17, as drought intensified, while native species richness peaked during 2016–17 under wetter conditions. Bare ground cover increased after 2016–17 while the number of exotic species decreased after 2016–17. Terrestrial species cover showed a linear decline across the reporting period.

Time since last inundation was also related to changes for several vegetation condition metrics. Cover of terrestrial species increased while cover of amphibious species declined as time since last inundation increased. Inundation duration only correlated with changes in exotic species richness: as inundation duration increased, exotic species richness linearly decreased.

The composition of species assemblages in 2017–18 (that is after the 2016–17 flood pulse) varied in relation to antecedent hydrological conditions. In particular, assemblages differed between wetter pre-flood sites (< 3 years since inundation in the 2015–16 water year) and drier pre-flood sites (> 3 years since inundation in the 2015–16 water year). Multivariate analysis of species abundance identified four amphibious species that associated with wetter pre-flood sites and six terrestrial species associated with drier pre-flood sites (Figures 4-2, Figure 4-3).

Terrestrial species cover and exotic species richness were higher at drier sites than wetter pre-flood sites. This result indicated that environmental water allocations may improve resilience of non-woody wetlands: increased hydrological connectivity may promote a stronger wetland response to flood pulses.

A positive response of native species richness, coupled with community assemblages characterised by wetland-dependent species during a natural flood event in 2016–17, indicated that wetland species remained viable and that communities retained expression of a wetland state (rather than transitioning to a terrestrial state). However, we require monitoring of vegetation community responses over a future comparative time period to infer the long-term conservation status of the Macquarie Marshes.



Wet pre-flood sites (<3 years since inundation in 2015-16 water year)
- *Ludwigia peploides* (ARp)
- *Paspalum distichum* (ATe)
- *Cyperus difformis* (Atl)
- *Ranunculus undosus* (ATe)

Dry pre-flood sites (>3 years since inundation in 2015-16 water year)
- *Einadia nutans* (Tdr)
- *Salsola australis* (Tdr)
- *Sclerolaena muricate* (Tdr)
- *Polygonum aviculare* (Tda)
- *Alternanthera denticulate* (Tda)
- *Xanthium spinosum** (Tdr)

Figure 4-2 Ordination plots of non-woody wetland assemblages in 2017-18.

Wet pre-flood sites (<3 years since inundation in 2015–16 water year) are shown in blue (●). Dry pre-flood sites (>3 years since inundation in 2015–16 water year) are shown in brown (●). The top ten species are listed from the mvabund analysis based on the treatment effect size. * Exotic species; ATe: Amphibious fluctuation tolerator – emergent; ARp: Amphibious fluctuation responder – plastic; Atl: Amphibious fluctuation tolerator – low-growing; ARf: Amphibious fluctuation responder – floating; ATe: Amphibious fluctuation tolerator – emergent; Tdr: Terrestrial dry; Tda: Terrestrial damp (after Casanova (2011)).

Figure 4-3 Non woody wetland community change in the Macquarie Marshes from (a) 2016–17 (wet phase) to (b) 2018–19 (Dry phase)

Photos: David Preston EES, Paul Keyte, EES.

Of the 28 river red gum forest and woodland (LTWP objective NV4a,b) sites surveyed across the Macquarie Marshes, we recorded a total of 183 plant species during the reporting period. We detected 51 exotic species.

Cover of amphibious species declined after 2016–17 during the reporting period, while native and exotic species richness peaked during 2016–17. Bare ground cover increased while terrestrial species cover decreased after 2015–16. These trends may reflect the intensification of drought conditions. There was a trend of decreasing cover of amphibious species and strong evidence for decreasing exotic species richness as time since last inundation increased. As expected, inundation duration was significantly related to amphibious species cover. Exotic species richness was marginally negatively related to inundation duration. Expression of wet-phase wetland responses appeared to decrease over the study period.

In 2017–18, the river red gum wetlands of the Macquarie Marshes displayed limited evidence of differences in species assemblages between wetter pre-flood sites (< 3 years since inundation in the 2015–16 water year) and with drier pre-flood sites (> 3 years since inundation in the 2015–16 water year). All univariate metrics were similar when comparing drier and wetter sites after the flood pulse. We found some evidence for differences in species assemblages at wetter pre-flood sites (< 3 years since inundation in the 2015–16 water year) compared with drier pre-flood sites (> 3 years since inundation in the 2015–16 water year). The analysis identified two amphibious species, one damp terrestrial species and one terrestrial species that associated with wetter pre-flood sites. The analysis identified one damp terrestrial species and five terrestrial species that were associated with drier pre-flood sites (Figure 4-4).

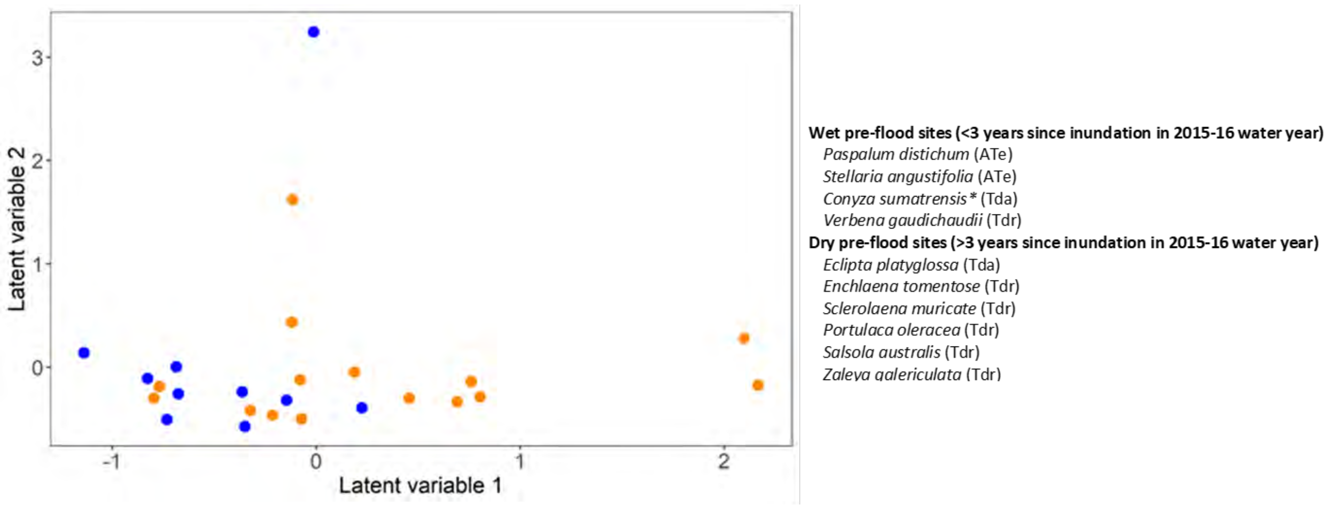


Figure 4-4 Ordination plots of river red gum wetland assemblages in 2017–18.

Wet pre-flood sites (<3 years since inundation in 2015–16 water year) are shown in blue (●). Dry pre-flood sites (>3 years since inundation in 2015–16 water year) are shown in brown (●). The top ten species are listed from the mvabund analysis based on the treatment effect size. * Exotic species; Te: Amphibious fluctuation tolerator – emergent; ARp: Amphibious fluctuation responder – plastic; Atl: Amphibious fluctuation tolerator – low-growing; ARf: Amphibious fluctuation responder – floating; ATe: Amphibious fluctuation tolerator – emergent; Tdr: Terrestrial dry; Tda: Terrestrial damp (after Casanova (2011).

Gwydir Wetlands[1]

- Non-woody vegetation metrics in the Gwydir Wetlands displayed linear responses across water years. This result contrasted the non-linear patterns in the Macquarie Marshes where the 2016–17 water year elicited strong vegetation responses to the wetter phase experienced across both catchments. Linear trends in the Gwydir Wetlands may be real or may reflect insufficient sample size.
- Coolibah woodlands in the Gwydir Wetlands responded well to wet phases during the reporting period.

From 2014–19, we detected 102 plant species during survey of non-woody sites in the Gwydir Wetlands, including 31 exotic species. Figure 4-5 demonstrates changes in non-woody community in the Gwydir wetlands during the study period.

[1] See the Macquarie section for ‘What was expected’ and the ‘Reporting process’

Figure 4-5 Wetland community in a wet phase a) and a dry phase b) in non woody wetland in the Gwydir Wetlands from (a) 2014-15 to (b) 2017-18[2]

Photos: Sharon Bowen, Department of Planning, Industry and Environment—Water).

In the Gwydir Wetlands, amphibious species cover, terrestrial species cover, and the number of native species decreased, while cover of bare ground increased over the reporting period. During the same period, amphibious species cover increased as inundation duration increased. Terrestrial species cover and the number of exotic species increased as time since last inundation increased.

We require monitoring of vegetation community responses over a future comparative time period to infer the long-term wetland condition of Gwydir non-woody wetlands. Within the reporting period, we saw a change in vegetation condition from wet to dry phase responses. A change in community assemblage between wet and dry water years may indicate that wetland species maintain viability and that communities are retained in a wetland state (rather than transitioning to a terrestrial state).

Recommendations (objectives NV2a)

The following recommendations should be considered to improve evaluation of the native vegetation theme in future evaluation periods (see Table 4-4 for further detail).

- Where landscape and regulatory conditions allow, augment natural flow events with environmental water to increase extent and duration of watering events and reinstate overbank flows and mid-range floods.
- Ground truth vegetation classifications in 2020 to validate a novel multitemporal landsat map product.
- Increase spatial coverage of floodplain vegetation monitoring across NSW Murray–Darling Basin to better assess responses to water management across a greater number of water sources and conditions.

[2] Note that these photo points do not correspond with the community structure analysis but do show the condition change over the reporting period.

Case study – Sunshower Lagoon (objective NV2a)

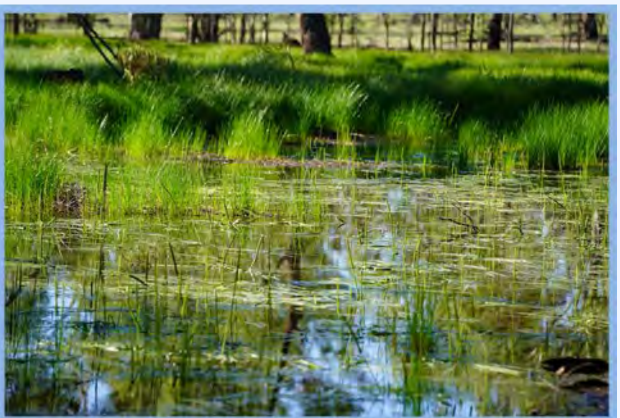
Sunshower Lagoon, located in the mid-Murrumbidgee, has been regularly monitored since 2010. The availability of this long-term data set increases our understanding of wetland recovery following the restoration of more natural flow regimes.

Over the last decade, Sunshower Lagoon has undergone periods of wetting and drying with four main watering events. The wetland was inundated by a combination of natural and managed flows between spring 2010 and autumn 2012, to a lesser extent during a small flow in 2015, and then filled completely when higher river flows occurred over spring and summer 2016. Environmental water was then used to reconnect the wetland to the river system in 2017 to further support vegetation growth.

After a few dry years, vegetation communities in the lagoon began to be dominated by river red gum seedlings. These seedlings were encroaching on areas that normally support non-woody wetland vegetation. Looking for watering options to help the wetland recover, pumping infrastructure, complete with carp screen as carp are known to uproot aquatic plants, was installed in spring 2019 to allow for wetland inundation without the need for rising river levels.

Pumping water into the wetland plus carp exclusion has led to significant increases in non-woody vegetation. River red gum seedlings are less prolific, large mats of spiny mudgrass have established and there has been an increase in aquatic species diversity when compared to previous years.

Sunshower Lagoon (Drone photo: Vincent Bucello)



Aquatic plants in Sunshower Lagoon (Vince Bucello)

Recent monitoring surveys have also detected the threatened southern bell frog, which has not been heard at Sunshower Lagoon since 2010, as well as large groups of grey teals, Pacific black ducks and chestnut teals, along with eastern long-necked turtles.

To find out more go to https://spaces.hightail.com/space/h38URplWem

Woody vegetation

Findings

Woody vegetation (composite of NV4 objectives):

In the Macquarie Marshes

- Woody vegetation communities were generally maintained in intermediate to intermediate/poor condition.
- All communities responded to a larger total annual inundation with increased tree stand condition scores in the following water year
- Stand condition of some river red gum communities declined after two consecutive drier water years.
- River red gum communities supported a wide spread of trees across all size classes, indicating a healthy demographic profile
- During the early drier years of the monitoring program, coolibah and black box grassy woodlands were dominated by a few large trees. Following the wetter period in 2016–17, more trees were recruited into the middle size classes.
- Lignum shrubland improved condition from 2013–14 to 2016–17 from intermediate/poor-intermediate range but decreased to intermediate/poor in 2018-19 after two dry years, in 2018–19.

In the Gwydir Wetlands

- In Central and Lower Gingham, coolibah-river cooba-lignum wetland woodlands tree stand condition declined from good to intermediate in 2014–15. This condition was then maintained.
- In the Mehi–Mallowa, coolibah-river cooba-lignum wetland woodlands tree stand condition was maintained in intermediate condition until 2018–19. It then increased to good condition to match the river red gum forest sites.
- River red gum forest sites in the Mallowa contained a wide spread of trees across all size classes, indicating a moderately healthy demographic profile.
- Coolibah-river cooba-lignum wetland woodlands had a wide spread of trees across all size classes, indicating a healthy demographic profile. There was a low proportion of dead trees in most middle and larger size classes until many died in 2017–18 after two dry years. This suggests that groundwater connectivity is important in maintaining larger trees.
- The sporadic nature of coolibah recruitment indicates a strong connection between recruitment and flooding, demonstrating the importance of inundation in maintaining population structure.
- The marsh club-rush tall sedgeland endangered ecological community recovered over the monitoring period after a wildfire in 2014. Community condition increased from intermediate/poor range in 2013–14. Subsequent years of moderate flows increased and maintained the condition to within the intermediate range from 2014–15 to 2017–18. The condition score was in the good range in 2018–19.

In the Narran

- The river red gum woodlands were in intermediate tree stand condition in 2015–16 to 2017–18 when a small inflow was received but declined to very poor in 2019 after two years of no inflow to the lakes.

- Coolibah-river cooba-lignum woodlands were in intermediate tree stand condition in 2015–16 to 2017–18 and tree stand condition had declined to intermediate/poor in 2019–20 after two years of no inflow.
- River red gum woodland supported large numbers of smaller river red gum trees, but many more in the middle size classes. There was a wide spread of trees across all size classes, indicating a moderately healthy demographic profile.
- Lignum shrubland condition was in the intermediate range from 2015–16 to 2016–17 but declined to intermediate/poor in 2017–18 after one year without lake inflows. In 2019 after two more dry years, the community condition had declined further within the intermediate to poor range.

What was expected

Most studies agree that the cumulative effects of inundation events over several years is an important factor in the health of native flood-dependent woody vegetation (Reid and Quinn 2004; Cunningham et al. 2013; Cunningham et al. 2014; Bowen 2019). For this reason, it was expected that woody vegetation condition would improve in response to wetter phases of 2 to 3 years, dependent on appropriate inundation duration and extent, and condition to decline in response to longer dry phases.

For communities dominated by long-lived tree species (for example, river red gum, coolibah and black box woodlands and forest), structural changes are expected to be slow, unlike communities dominated by herbaceous species (Bowen 2020; Bowen 2019; Bino et al. 2015). This means that a response such as improved canopy health or increased survival of trees in woody vegetation communities can lag a season behind the hydrologic conditions.

Methods

Change in inundation frequency and duration are key drivers of flood-dependent vegetation community responses in the Murray–Darling Basin (Bowen 2019, Bino et al. 2015, Thomas et al. 2010). The appropriate regime of inundation frequency and duration is required to maintain wetland plant community condition. While inundation frequency and duration are important over longer time periods, water depth, duration of flooding and season delivered are important components of the annual watering regimes for plants (Roberts et al. 2000). If the regime changes from an acceptable range, then the community may still exhibit wet and dry phases but will cease to function at an optimum level.

Our model applies temporal and hydrological dimensions to illustrate vegetation community condition in response to changes in water availability. Long-term water availability, referred to as ‘regime’ appears from left to right in Figure 4-6. Short-term availability is referred to as ‘seasonal’ and appears from bottom to top of Figure 4-6. Vegetation community condition is shown as four simplified vegetation states: wet/sub-optimal, wet/good, dry/sub-optimal and dry/good. This acknowledges that a floodplain wetland can be in a dry phase but remain in good condition and conversely a wetland can be in a wet phase but exhibit a sub-optimal condition if the regime scale water requirements of the dominant species are not being met (Bowen 2019; Bowen 2020).

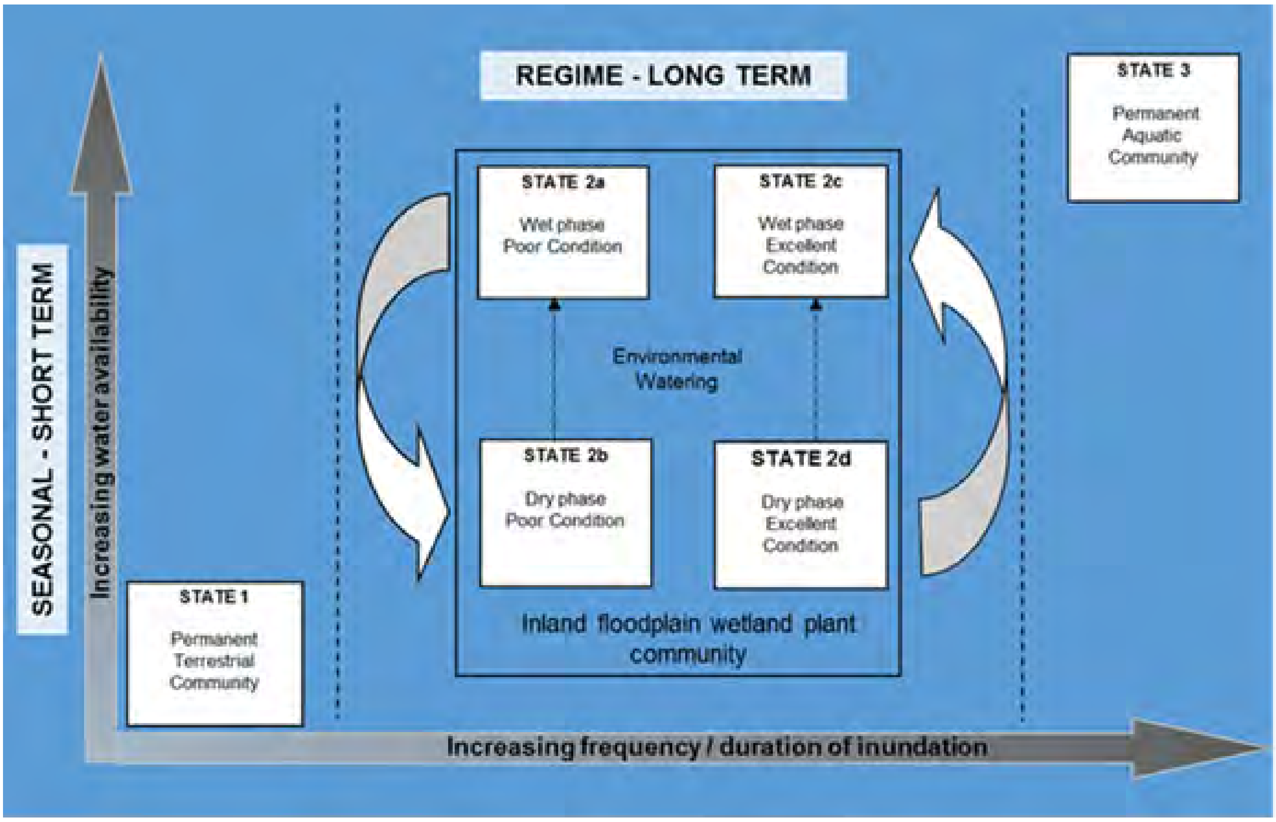


Figure 4-6 Conceptual process model of flood-dependent plant communities (Bowen 2019)

NSW Plant Community Types (PCTs) are the finest level in the hierarchical vegetation classification system used in vegetation survey, mapping and conservation assessment in NSW (NSW DPIE-EES 2020a). PCTs have been used to describe wetland vegetation communities in our response model. A condition score index was developed for flood dependent PCTs in NSW (Bowen 2019). The score range for each condition class are listed in Table 4-2. Figure 4-7 demonstrates what various condition classes might look like for river red gum woodland.

Table 4-2 Plant Community Type Community Class Ranges (Bowen 2019)

Score range	Condition class
0–8.9	Very Poor
9–1.9	Poor
12–14.9	Intermediate/poor
15–17.9	Intermediate
18–19.9	Good
20	Excellent/Benchmark

Good Intermediate Poor

Figure 4-7 Examples of tree stand condition classes

Photos: Sharon Bowen Department of Planning, Industry and Environment–Water

Tree stand condition and demographic condition in woodlands and forests

Native flood-dependent woody vegetation provides important habitat for many species particularly insects, waterbirds and fish. By maintaining or improving flood-dependent vegetation condition, many other species also benefit.

The structural, demographic and community condition of key flood-dependent woody riverine and wetland vegetation communities were monitored at fixed nested 0.1ha/0.04 ha monitoring plots in the Macquarie Marshes, Gwydir Wetlands and Narran wetlands in the northern Murray–Darling Basin. The woody NSW Plant Community Types (PCTs) monitored were: river red gum (*Eucalyptus camaldulensis*) forest (PCT36), river red gum wetland woodland (PCT 36A), river red gum grassy woodland (PCT 454), coolibah (*E. coolabah*) grassy woodland (PCT 40), coolabah-river cooba (*Acacia stenophylla*) - lignum (*Duma florulenta*) woodland (PCT 39) and black box (*E. largiflorens*) woodland (PCT 37) (Bowen and Simpson 2010a; Bowen and Simpson 2010b; Bowen et al 2014; Bowen et al 2015; Bowen et al. 2017; Bowen et al. 2018). For descriptions and diagnostics of each PCT refer to NSW (NSW DPIE-EES 2020b).

Tree stand condition (tree and canopy health) scores were generated for each tree dominated PCT (river red gum, coolibah and black box woodlands and forest) for each water year. Scores were derived from measurements of canopy density, proportion of live to dead trees, tree structural health and the percentage of tree canopy that was alive or dead (Bowen 2016). On ground measures of tree stand health are important in monitoring and are used to train and enhance remote sensing metrics (Ellis et al. 2017; Cunningham et al 2009; Cunningham et al. 2013a; Cunningham et al. 2013b; Newel et al. 2017).

A population or stand of trees can be considered healthy if it follows a reverse J curve and has trees in a range of size classes (Smith et al. 1997). Larger sized trees are essential in the population as they provide hollows for fauna (Ellis et al. 2015), and act as ecosystem engineers in the population (Gillen 2017). Tree stand demographic profiles (histograms of numbers of trees per size class) for red gum, coolibah and black box communities were generated for each water year from measurements of the Diameter at breast height (Dbh) of all trees in the plots. These metrics are described in Bowen (2016), Bowen (2019), Bowen (2020) and Bowen et al. (2018).

Lignum shrubland and Marsh club-rush tall sedgeland condition

Lignum shrubland woody wetland (Figure 4-8), was monitored at fixed 50 m transects within the Macquarie Marshes and Narran Nature Reserve in the northern Murray–Darling Basin. Marsh club-rush (*Bolboschoenus fluvitalis*) tall sedgeland (PCT 205), was monitored at fixed 100 m transects in the Gwydir Wetlands.

Community condition scores were generated from measures of dominant species height, percentage cover and structure, cover of bare ground and the percentage cover of functional wetland and non-wetland species (Casanova 2011; Bowen 2016; Bowen 2019 Bowen 2020; Bowen et al. 2018).

PCT 247: Lignum Shrubland– Macquarie Marshes   PCT 205: Marsh club-rush tall sedgeland – Gwydir Wetlands

Figure 4-8 Lignum shrubland and marsh club-rush sedgelands

Photos: Sharon Bowen Department of Planning, Industry and Environment—Water

Results

Lower Macquarie River catchment

Tree stand condition scores

The Lower Macquarie supports a variety of native flood-dependent woody vegetation communities (Figure 4-9). By assessing tree stand condition scores we can determine if tree communities are maintaining their canopy seasonally and retaining their biomass over time. Reductions in flow in one water year can be reflected in the condition score in the following year. This delayed response reflects trees utilisation of sub surface water. Yearly changes in flow response are less important than the overall range across several (five) years.

PCT 36: River red gum forest – Macquarie Marshes

PCT 36A: River red gum woodland – Macquarie Marshes

PCT 40: Coolibah Grassy Woodland – Macquarie Marshes

PCT 36A: River red gum grassy woodland – Macquarie Marshes

Figure 4-9 Lower Macquarie River woody vegetation communities

Photos: Sharon Bowen Department of Planning, Industry and Environment—Water

Stand condition results for the Macquarie Marshes are presented separately for the three main water management areas of the Lower Macquarie Catchment monitored during 2013–14 to 2018–19: the Northern, Southern and Eastern Macquarie Marshes. Inflow data is from the nearest major river gauge to indicate the magnitude of flows in each year. Note that there were significant flow volumes in the large inundation event of 2016 that circumvented those gauges – particularly in the Northern and Eastern Marshes.

In the Northern Macquarie the tree stand condition of river red gum forest (PCT 36) declined from intermediate in 2014–15 to intermediate/poor during the next two drier years. The significantly higher inflows in 2016–17 appeared to arrest the decline in condition, with scores remaining around the intermediate/poor class from 2017–18 to 2018–19 (Figure 4-10). Monitoring more forest sites would assist in better assessing the condition of this PCT.

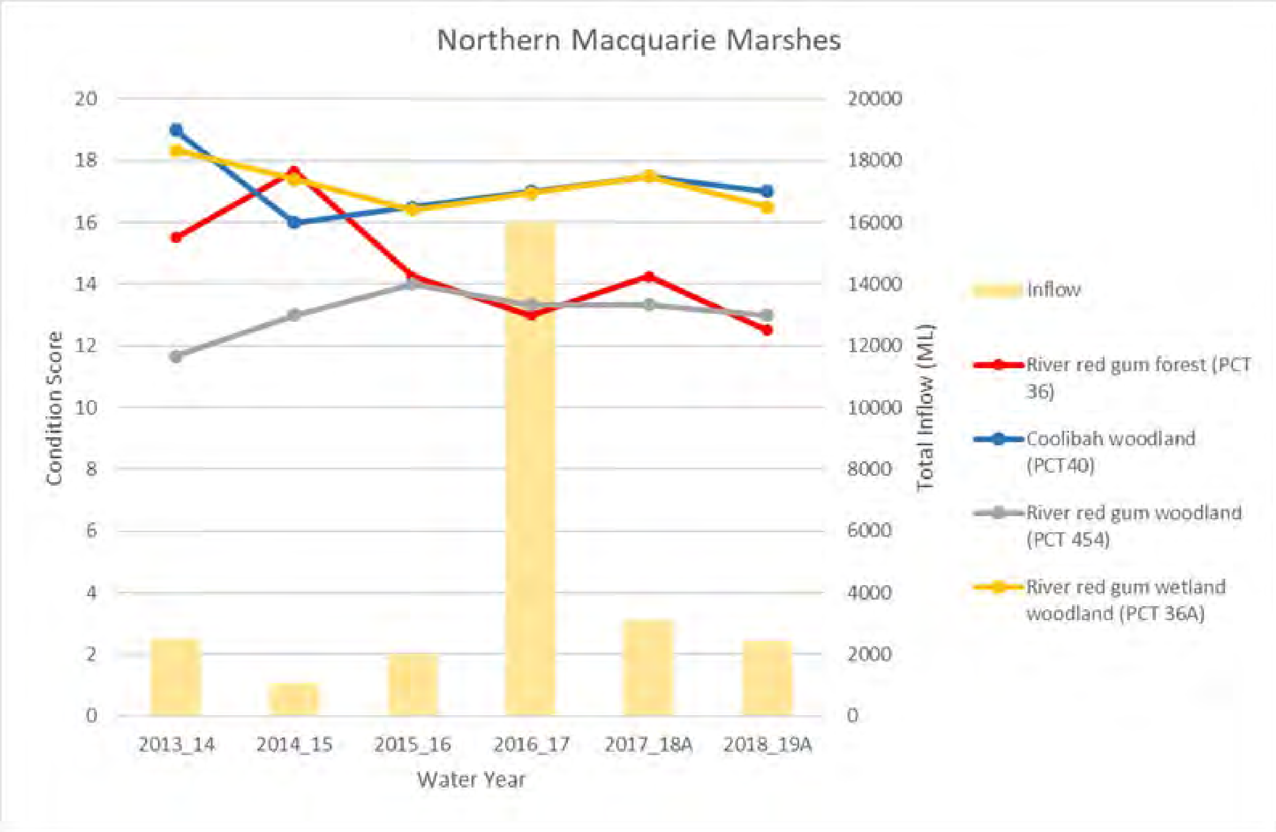


Figure 4-10 Tree stand condition in the Northern Macquarie Marshes water management areas of the Lower Macquarie catchment, 2013–14 to 2018–19

River red gum woodland wetlands (PCT 36A) and coolibah grassy woodlands (PCT 40) in the Northern Marshes also declined from good condition in 2013–14 to intermediate in 2014–15, but responded well to the wetter year in 2016–17 and remained in an intermediate condition class throughout the monitoring period (Figure 4-10).

River red gum grassy woodlands (PCT 454) in the Northern Marsh were in poor tree stand condition in 2013–14 but condition improved to intermediate/poor over the 2014–15 to 2018–19 period (Figure 4-10). These trees are on the drier, higher part of the floodplain, away from channels and receive less flooding than the other wetland sites.

In the Southern Macquarie Marshes, river red gum woodlands (PCT 454) retained consistent intermediate condition scores (Figure 4-11).

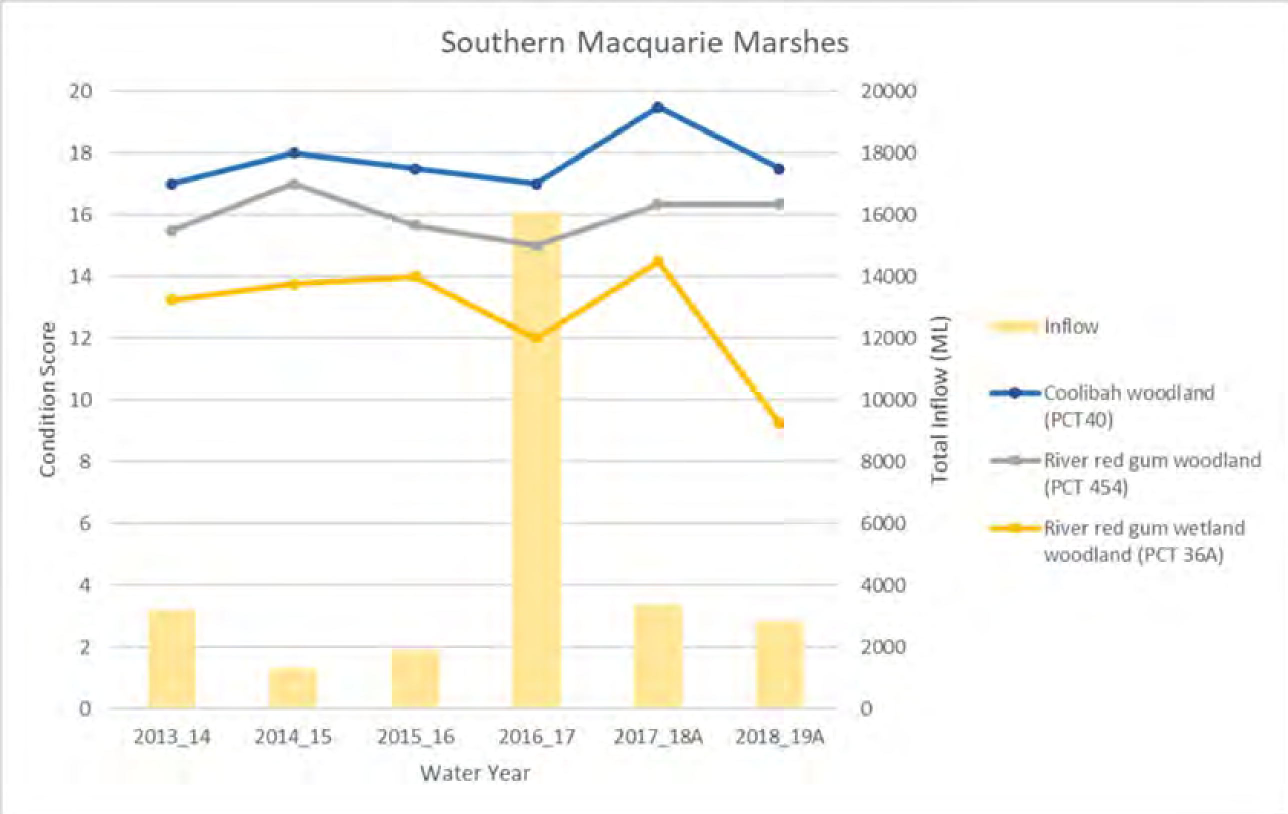


Figure 4-11 Tree stand condition in the Southern Macquarie Marshes water management area of the Lower Macquarie catchment, 2013–14 to 2018–19

River red gum woodland wetlands (PCT 36A) in the Southern Marshes declined in condition from intermediate/poor to poor two years following a large flooding event in 2016–17 (Figure 4-11). These trees are located at sites that have impediments to flows and may not be receiving adequate inundation durations or depths to replenish shallow groundwater systems to maintain tree health.

Coolibah grassy woodlands (PCT 40) in the Southern Marshes were maintained in an intermediate to good tree stand condition (Figure 4-11), with an improvement in condition following the high flows of 2016–17. This response demonstrates the known groundwater dependencies of these woodlands (Maher 1995; Gillen 2017; Costelloe et al.; 2008, Costello 2016; Doody et al., 2009; Holland et al., 2006). If groundwater connections are maintained, flooding in 2016–17 may have replenished the shallow groundwater system, allowing the condition of coolibah woodlands to be sustained.

River red gum woodland wetlands (PCT 36A) in the Eastern Marshes were in intermediate to good condition until two years post a large inundation year in 2016–17 (Figure 4-12). The response saw an increase in condition in the 2017–18 year, but the condition had declined to intermediate/poor after two drier years in 2018–19.

Black box woodland in the Eastern Marsh is monitored at sites that are not very frequently flooded and thus likely to be accessing subsurface aquifers. Condition declined from intermediate to intermediate/poor in the monitoring period, though they did respond in the year after the largest inflow (2016–17) (Figure 4-12). More sites of this community in other locations would assist in monitoring this PCT.

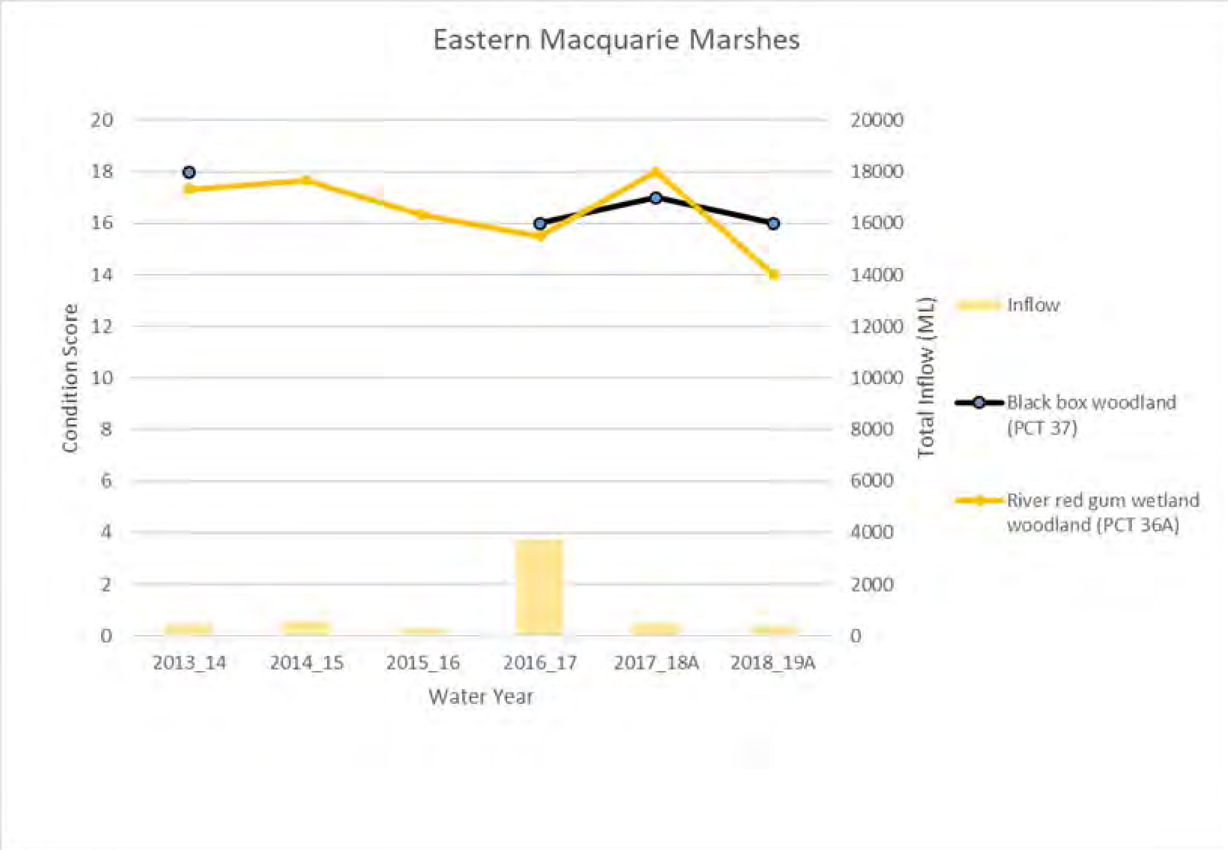


Figure 4-12 Tree stand condition in the Eastern Macquarie Marshes water management area of the Lower Macquarie catchment, 2013–14 to 2018–19

Tree stand demographic condition

Data from all monitored trees from each water management area were pooled for this analysis and is presented for the Macquarie as a whole.

River red gum forests in the Lower Macquarie River catchment contained larger numbers of smaller river red gum trees and progressively fewer trees in the larger size classes This wide spread of trees across all size classes indicates a healthy demographic profile (Figure 4-13). The number of small trees that increased in size from the <10 cm to 10 cm to 19 cm Dbh size class increased after 2015–16, however many died during the drier years between 2016 to 2018 as their watering requirements were not being met (Figure 4-13 row 1). The subdominant tree species river cooba also followed this profile, noting that the upper limit of river cooba tree size is naturally much smaller that river red gums (Figure 4-13 row 2).

The river red gum wetland woodlands and river red gum grassy woodlands retained the pattern of a larger number of small trees and fewer larger trees throughout the monitoring period (Figure 4-13 row 3 and row 5). Small tree mortality was greatest in the river red gum grassy woodlands which are located further from the main river channels in the floodplain and therefore less frequently inundated.

Coolibah and black box woodlands displayed the opposite demographic profile to the river red gum dominated PCTs. These communities are dominated by a few large trees and have very episodic recruitment of smaller trees (Gillen 2017; Costelloe and Russell 2014; Puckridge et al. 2000). This is demonstrated by gaps in the profile in the middle range of tree size classes (for example: 20 to 29 cm Dbh size class). Following the wetter period in 2016–17 more trees were recruited into the middle size classes. This pattern in size distribution was the most common demographic profile displayed by coolibah and black box communities in the northern Murray–Darling Basin Figure 4-13 row 4).

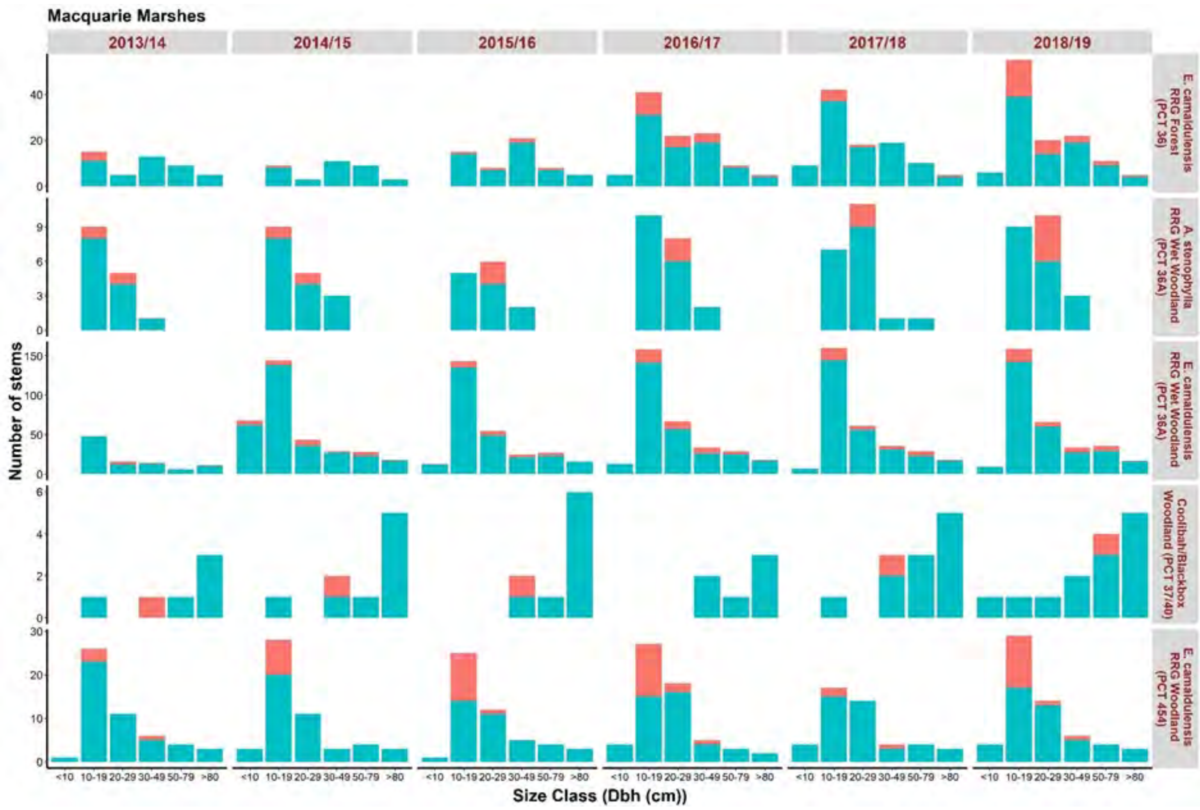


Figure 4-13 Tree demographic profiles in the Lower Macquarie catchment 2013–14 to 2018–19.

(Row 1 and 2 = river red gum forest; row 3 = river red gum wetland woodland; row 4 = coolibah and black box woodlands; row 5 = river red gum grassy woodland. Blue indicates live trees; red indicates dead trees).

Lignum shrubland community condition

Data from lignum transects located in both the east and north water management areas of the Lower Macquarie catchment were pooled for analysis. Lignum shrubland condition was in the intermediate/poor- intermediate range from 2013–14 to 2016–17 (Figure 4-14). The wetter year in 2016–17 is likely to have replenished the groundwater source that these lignum plants need to grow woody stems, replenish underground storage organs and flower. However, after two dry years the condition of lignum shrubland decreased again to intermediate/poor in 2018-19 (Figure 4-14).

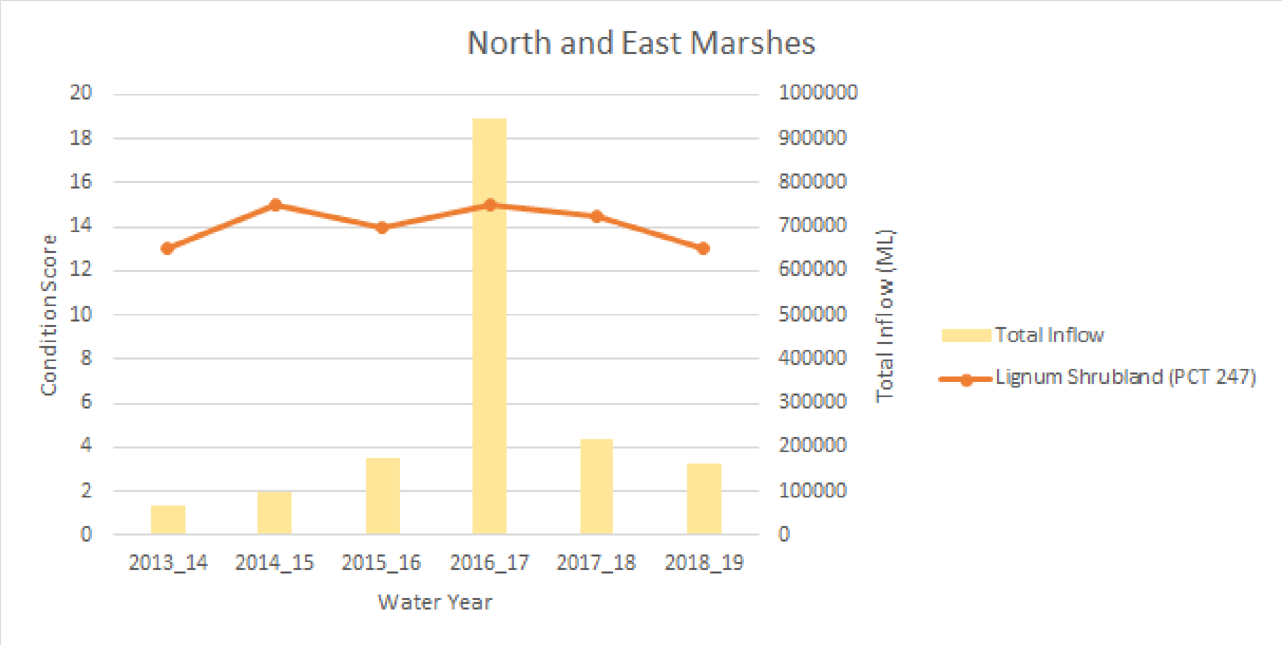


Figure 4-14 Lignum shrubland community condition scores in the Lower Macquarie catchment, 2013–14 to 2018–19

Lower Gwydir River Catchment

Tree stand condition scores

As demonstrated in the Macquarie Marshes, the Gwydir Wetlands support a variety of flood-dependent woody vegetation communities (Figure 4-15).

Results are presented separately for the three main water management areas of the Lower Gwydir Catchment; the Central and Lower Gingham Watercourse, the Central Lower Gwydir (Big Leather) Watercourse and the Mehi–Mallowa Wetlands[3] (Figure 4-16). River red gum forest data was only collected from one site in the Mehi-Mallowa.

In the Central and Lower Gingham, coolibah-river cooba-lignum wetland woodlands, were in good condition in 2013–14 after two previous wet years (Figure 4-16). Tree stand condition declined to intermediate in 2014–15 and remained that way until 2018–19, even with a larger total inflow in 2016–17. It may be that the inflow was insufficient to top up groundwater aquifers that these communities rely on as the conditions were very dry for all other years.

In the Central Lower Gwydir, coolibah-river cooba-lignum wetland woodlands were in intermediate/poor condition in 2013–14 (Figure 4-16). Tree stand condition increased to intermediate in 2015–16 and remained that way until 2018–19 even with a larger total inflow in 2016–17. Most years had moderate inflows in the monitoring period.

[3] Note that total inflow volumes in the Lower Gwydir River management areas are much less than those displayed in the Lower Macquarie River catchment data.

PCT 39 : Coolbah –River coobah-lignum woodland – Mallowa wetlands

PCT 39: Coolibah -River Cooba – Lignum Woodlands – Central Lower Gwydir

PCT 36: River red gum forest– Mehi-Mallowa wetlandS

PCT 39: Coolibah river coobah –lignum woodland – Central Gingham wetlands

Figure 4-15 Lower Gwydir catchment woody vegetation communities

Photos: Sharon Bowen Department of Planning, Industry and Environment—Water

In the Mehi–Mallowa, coolibah-river cooba-lignum wetland woodlands were in intermediate condition in 2013–14 (Figure 4-16). Tree stand condition was maintained in intermediate condition until 2018–19 when they increased to good after slightly increased inflows, despite minimal inflows in the intervening period. The sites in the Mehi–Mallowa are on low-lying floodplain close to channels and may have access to groundwater sources. Most trees were very mature with correspondingly large underground root systems to access water and this is likely to assist them to maintain health during dry periods.

The river red gum forest sites in the Mehi–Mallowa, were in intermediate condition until condition improved in 2018–19 (Figure 4-16). However, this data is only from two sites on the Mallowa Creek and were likely to be accessing water from instream. Data collection was suspended in 2018–19 as the sites were no longer available and had been cleared of some trees.

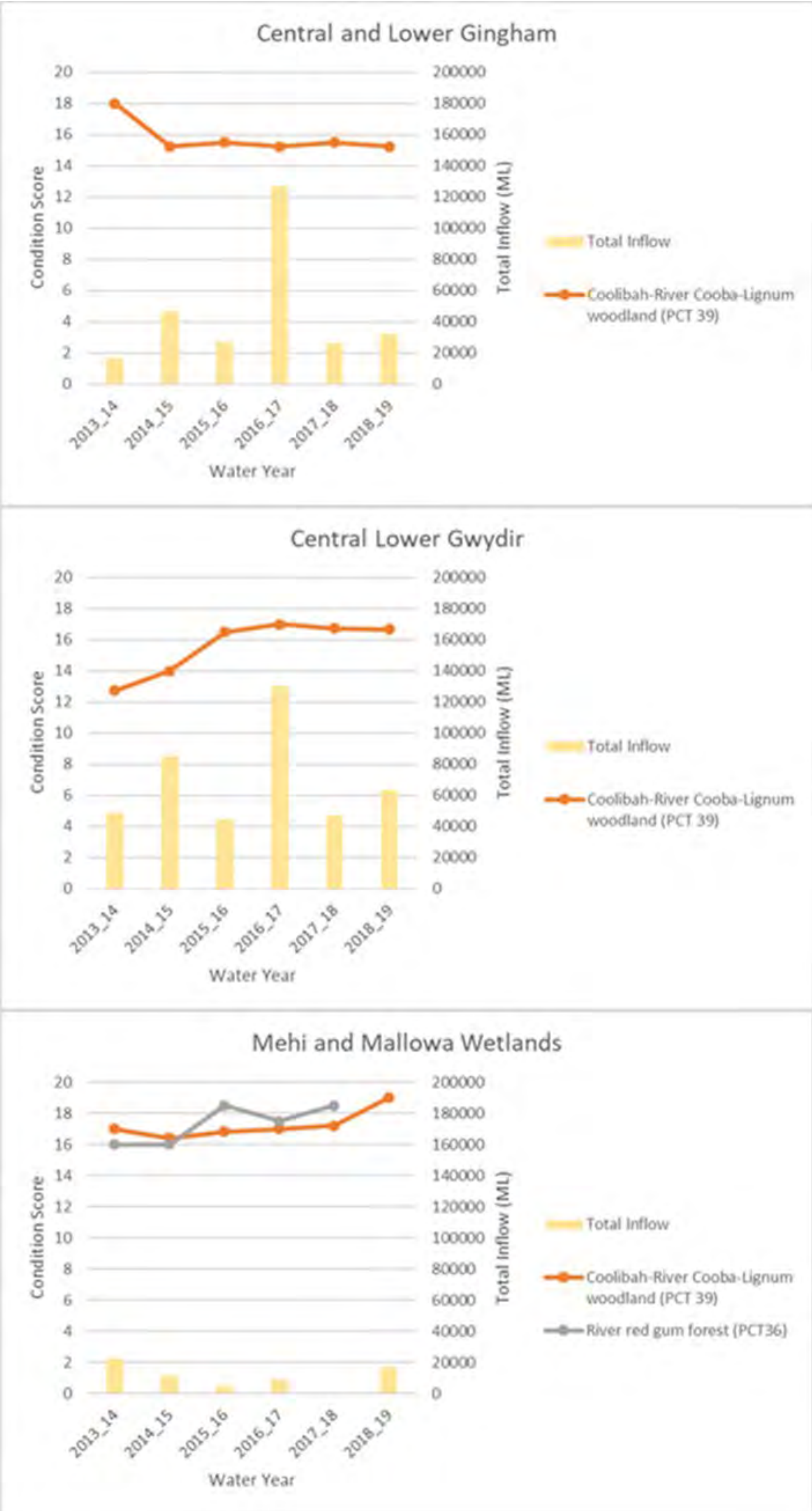


Figure 4-16 Tree stand condition in the three water management areas of the Lower Gwydir catchment wetlands 2013–14 to 2018–19

Tree stand demographic condition

Data from all trees from all water management areas were pooled for this analysis and is presented for the Lower Gwydir as a whole.

The river red gum forest site in the Mehi–Mallow contained large numbers of smaller river red gum trees, with very few trees in the middle size classes. The smaller trees appeared to have barely grown over the monitoring period, only increasing to the 10 cm to 19 cm Dbh size class (Figure 4-17 row 1). The subdominant tree species river cooba displayed the opposite distribution curve, with more trees in the middle size class ranges. The river cooba trees were quite mature, and some larger trees were nearing senescence, although still alive, thus this population structure may indicate a turnover of dominant individuals in the population (Figure 4-17 row 2).

Coolibah-river cooba-lignum wetland woodlands in the Lower Gwydir River had a wide spread of trees across all size classes, indicating a healthy demographic profile. While a large proportion of trees in the small size class (10 to 19 cm Dbh) died in 2014–15, there was a low proportion of dead trees in most middle and larger size classes during this period. However, many of the middle and large sized trees died in 2017–18. This indicates that smaller trees tend to be lost first during drier periods and then mid-sized trees may die if the dry period extends for too long (Figure 4-17 row 4).

The subdominant tree species, river cooba, displayed a different response, with more trees in the smaller size class ranges. About one third of river cooba trees in the three larger size classes were dead in each year (note that data was not collected from all sites in 2018) (Figure 4-17 row 3).

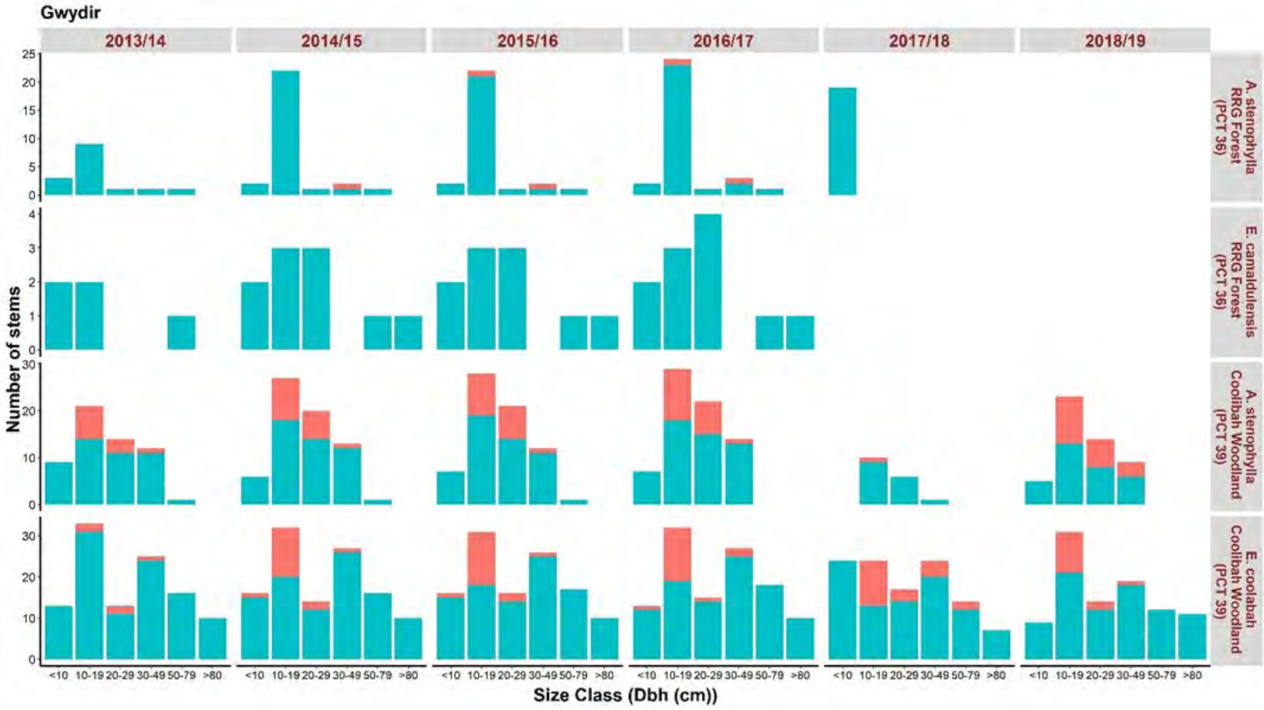


Figure 4-17 Tree demographic profiles in the Lower Gwydir catchment 2013–14 to 2018–19.

Row 1 and 2 = river red gum forest; row 3 and 4 = coolabah-river cooba-lignum woodland). Blue indicates live trees; red indicates dead trees).

Marsh club-rush tall sedgeland community condition

The marsh club-rush tall sedgeland endangered ecological community only occurs in one place in the world, a small remnant patch of around 200 ha in the Central Lower Gwydir water management area. A lightning strike ignited a wildfire which burnt most of this community in 2014.

Marsh club-rush condition was in the intermediate/poor range in 2013–14. Subsequent years of moderate flows increased and maintained the condition to within the intermediate range from 2014–15 to 2017–18. The wetter year in 2016–17 is likely to have replenished shallow groundwater sources that these large sedges need to grow and flower. The condition score was in the good range in 2018–19 (Figure 4-18).

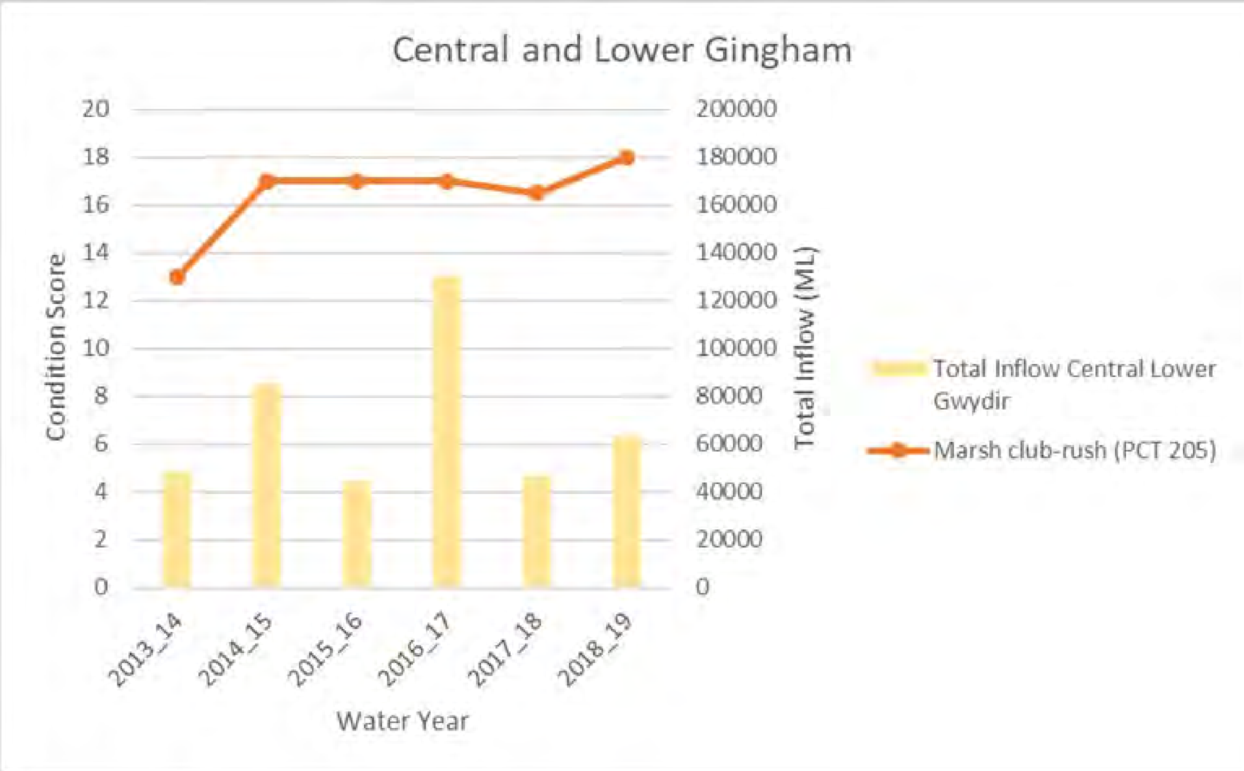


Figure 4-18 Marsh club-rush sedgeland community condition scores in Lower Gwydir catchment 2013–14 to 2018–19

The Narran

Tree stand condition scores

As not all water years were sampled in the Narran during the monitoring period, we have included data collected in 2019–20 to better illustrate the most current tree stand condition of the woody vegetation communities.

The river red gum woodland in the Narran lakes were in intermediate condition in 2015–16 to 2017–18 when a small inflow was received. By the next sampling period in 2018–19, condition had declined to very poor after two years of no inflow to the lakes (Figure 4-19).

Similarly, the coolibah-river cooba-lignum woodlands in the Narran were in intermediate condition in 2015–16 to 2017–18. After two years of no inflows condition had declined to intermediate/poor (Figure 4-19).

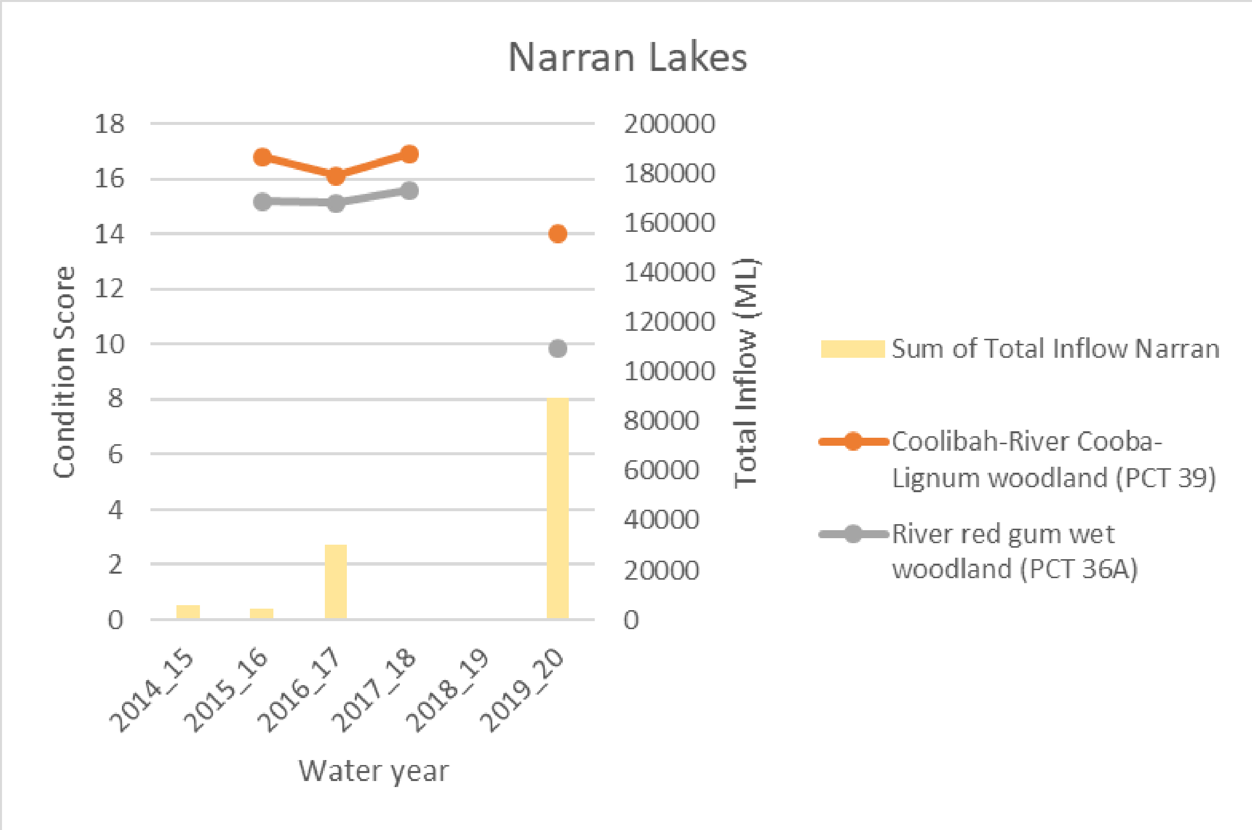


Figure 4-19 Tree stand condition in the Narran Lakes 2015–16 to 2019–20

Tree stand demographic condition

River red gum woodland sites in the Narran displayed a large spread of tree class sizes, with large numbers of smaller river red gums and even greater numbers of trees in the middle size classes (Figure 4-20). Many sites contained mid-size trees as the most abundant size class indicating episodic tree recruitment. There was a wide spread of trees across all size classes, indicating a moderately healthy demographic profile. However, in all size classes at least one eighth of the trees were dead. The data collected from the 2019–20 water year represents only some of the monitoring sites but indicates that demographic health at these sites had declined since 2017–18. At these sites many trees in the middle size classes had died, and trees in all size classes had died including large trees (<80 cm Dbh) since the 2017–18 water year (Figure 4-20 row 1).

Coolibah-river cooba-lignum wetland woodlands in the Narran had a wide spread of trees across all size classes, indicating a healthy demographic profile in the period 2015–16 to 2017–18. There were a low proportion of dead trees in most middle and larger size classes. However, a larger proportion of trees in the middle size class (30 cm to 49 cm Dbh) had died in 2019–20. This indicates that the population condition will continue to decline as the community loses mature middle-sized trees, if the dry period extends for too long (Figure 420 row 2). Note that only a subset of sites was sampled in the 2019–20 water year.

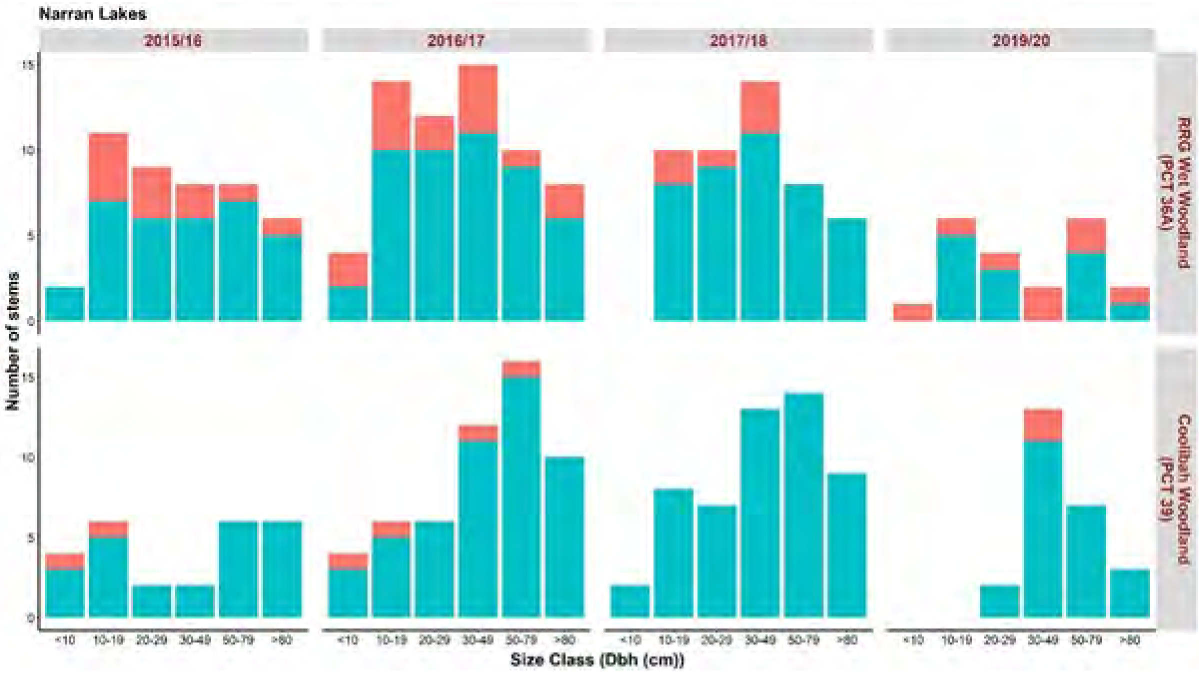


Figure 4-20 Tree demographic profiles in the Narran Lakes 2015–16 to 2018–19

Row 1 = river red gum forest; row 2 = coolibah-river-cooba-lignum shrubland). Blue indicates live trees; red indicates dead trees.

Lignum shrubland community condition

As stated previously, not all water years were sampled in the Narran during the monitoring period. To compensate for this lack of data, we have included information collected in 2019-20 to illustrate the most current community condition of lignum shrublands in the Narran.

Lignum shrubland was in intermediate condition from 2015–16 to 2016–17 and then declined to intermediate-poor condition in 2017–18 after one year without inflow to the lakes. In 2019-–20 the community condition had declined further within the intermediate/poor range. The wetter year that eventuated in 2019-–20 is likely to assist in replenishing the groundwater source that these lignum plants need to grow woody stems, replenish underground storage organs and flower (Figure 4-21).

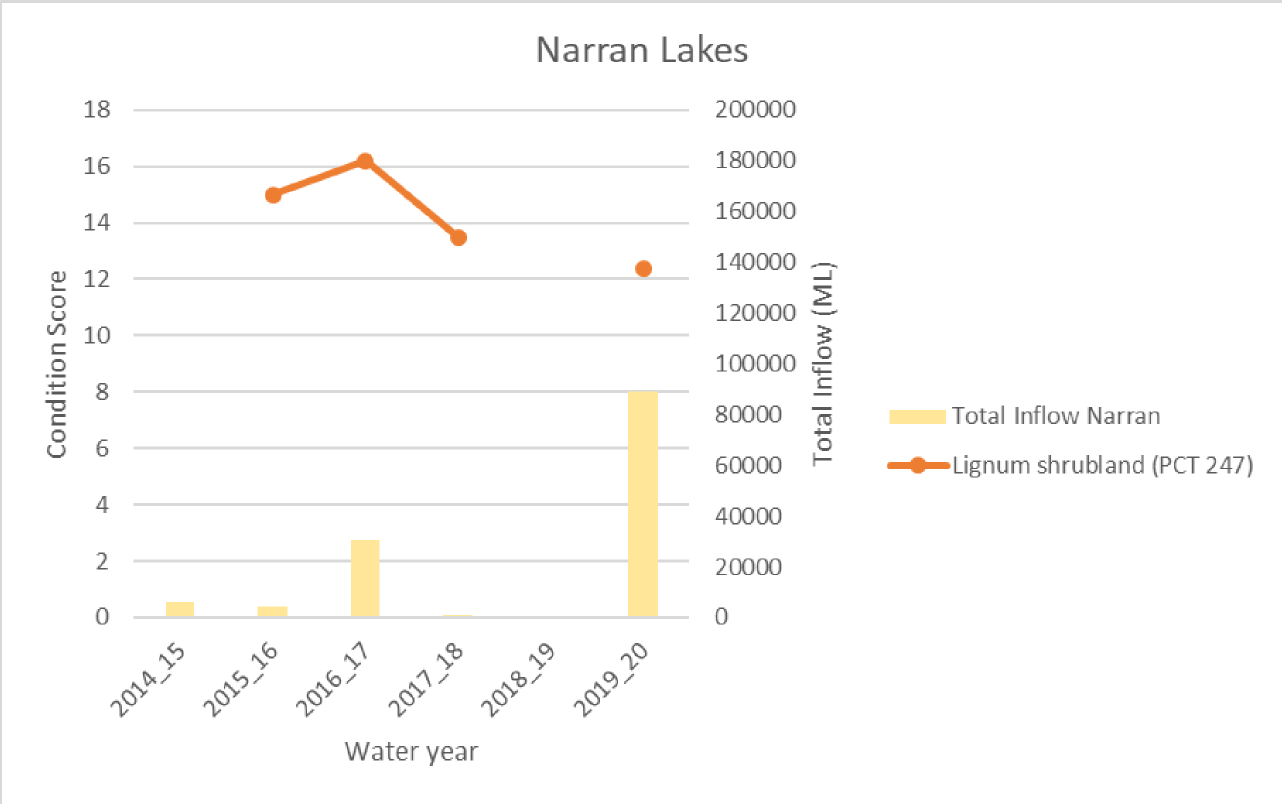


Figure 4-21 Lignum shrubland community condition scores in the Narran Lakes, 2015–16 to 2019–20

PCT 36A: River red gum woodland– Narran Lakes

PCT 39: Coolibah - River Cooba – Lignum woodland – Narran Lakes

PCT 36A: River red gum woodland – Narran River

PCT 247: Lignum shrubland – Narran Lakes

Figure 4-22 Narran woody vegetation communities

Photos: Sharon Bowen Department of Planning, Industry and Environment—Water

Recommendations

The following recommendations should be considered to improve evaluation of the native vegetation theme in future evaluation periods (see Table 4-4 for more detail):

- Where landscape and regulatory conditions allow, augment natural flow events with environmental water to reinstate a more natural flow regime.
- Increase understanding of the role of groundwater in maintaining woody floodplain vegetation and groundwater-dependent ecosystems.
- Expand field monitoring of river red gum forests and woodlands, coolibah and black box woodlands, and lignum shrublands across priority sites within the NSW Murray–Darling Basin to better assess responses to water management across a variety of landscapes.

Vegetation case study – Murray Private Property Wetlands

Objectives NV2, NV4

The Private Property Wetlands Watering Project (PPWWP) is a voluntary program in which the Department of Planning, Industry and Environment's Environment, Energy and Science group works with landholders in the Murray Irrigation Limited (MIL) area to deliver environmental water to wetlands and ephemeral creeks to maintain or improve their condition. The MIL area is located within the Riverina area of NSW (Figure 4-23).

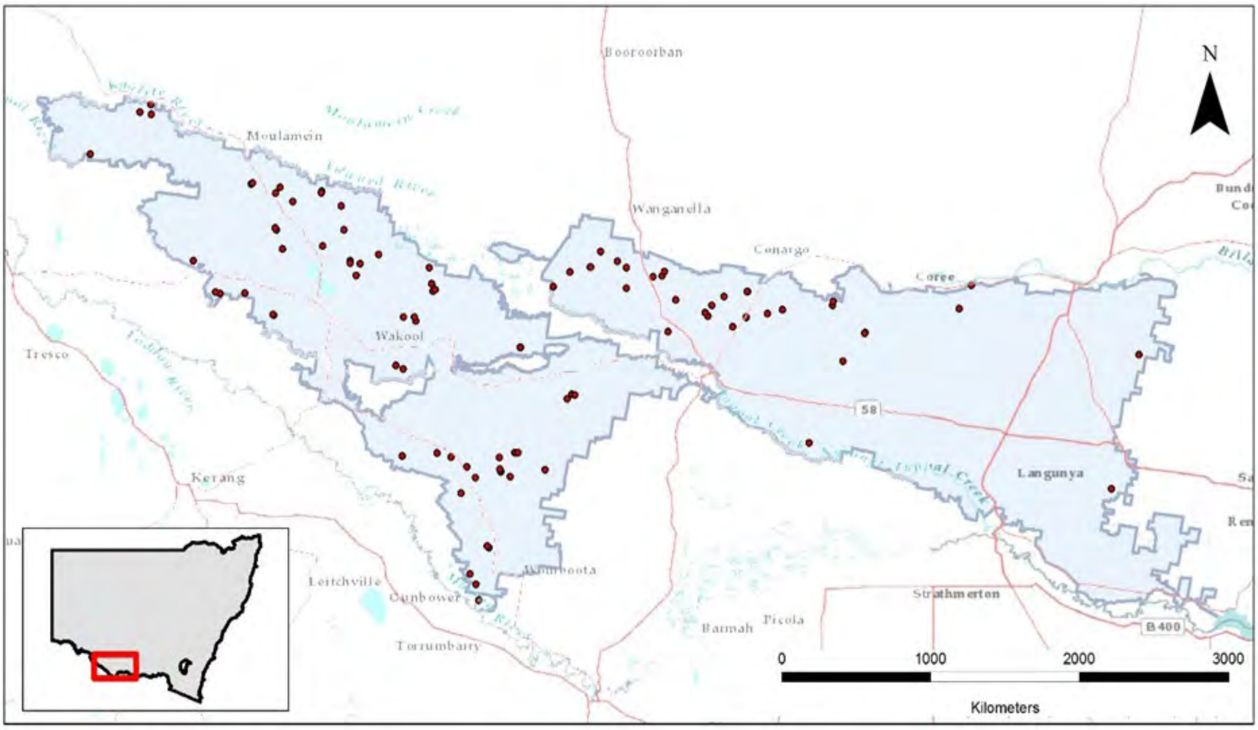


Figure 4-23 The Murray Irrigation Area (blue shaded) and the Private Property Wetland Watering Project sites (red dots)

Findings

- Non-woody vegetation is being maintained and is currently on track to meet 2024 LTWP targets.
- River red gum forest and black box woodland condition is being maintained and is currently on track to meet 2024 LTWP condition targets.
- River red gum woodland condition is declining and is currently not on track to meet 2024 LTWP condition targets.
- Environmental water requirements for mixed woodland (comprising river red gum and black box) have not been met resulting in a decline in condition.
- Trends in lignum extent and condition could not be identified as further monitoring is required.

What was expected

It was expected that, through the provision of appropriate ecological water regimes, ecological objectives and ecological targets would be met. Ecological watering requirements incorporate the frequency, timing and duration of inundation that is needed to ensure the health of floodplain-dependent vegetation. If these requirements are met it is expected vegetation will respond positively, and ecological targets met, unless there are mitigating factors preventing such a response.

Non-woody wetland plant diversity has been found to increase with variability in flow frequency, timing and duration (DPIE 2019b). This indicates that, while wetland watering should be within the minimum-maximum thresholds identified in the Murray–Lower Darling LTWP, its delivery should be variable in space and time. This variability in watering across wetlands is likely to increase diversity at the landscape scale.

Methods

A subset of PPWWP wetlands were selected to represent vegetation communities most common by area. The vegetation communities most common by area were river red gum forest, river red gum woodland, black box woodland and lignum shrubland. Tree condition, recruitment and non woody-vegetation composition and structure were assessed.

Results

A total of 81 non-woody plant taxa were recorded over the 2018 and 2019 sampling periods. Open non-woody Private Property wetlands were inundated every 2 to 5 years in 10, with a maximum dry period of 3 to 6 years. This water regime ensures variability between wetlands while also meeting the minimum and maximum flow regime thresholds identified in the Murray–Lower Darling LTWP. Ephemeral understorey associated with forests and woodland communities experienced similar flooding frequency throughout the 2-year survey period, but seasonal variability resulted in large fluctuations in extent and species composition.

The 5-year targets for the maintenance of river red gum forest and black box woodland populations appear on track to meet LTWP 2024 targets (Table 4-3). Conversely, the trend for river red gum woodland condition indicates that the 5-year LTWP targets for population maintenance is not on track as stressed trees continue to decline.

For mixed woodland (comprising river red gum and black box), environmental water requirements were not met as the time between inundation events exceeded 5 years. Consequently, tree condition has declined with an increasing proportion of trees in poorer condition. The 2024 LTWP condition targets for mixed woodland are unlikely to be met unless the time between inundation events can be reduced.

While comparative data for lignum shrublands are available for Autumn 2019 and Spring 2019, it is not possible to identify trends in extent and condition at this stage of the monitoring program. The capacity to identify temporal trends associated with lignum extent and condition will improve with ongoing monitoring.

Recruitment targets for river red gum, black box and lignum only apply to degraded areas. Though no monitored sites are currently considered degraded, recruitment data continues to be collected at all sites so regeneration responses can be monitored and reported.

Table 4-3 Results summary table: vegetation condition with respect to LTWP targets.

Objective	Vegetation community	5-year target Over a 5-year rolling period:	EWR met	Current condition	Trend	On track to meet target
NV2a	Non-woody vegetation communities*	Maintain the extent of non-woody vegetation occurring in wetlands and floodplains.	n/a**	Not categorised	Stable	Yes
NV2b	Ephemeral understorey vegetation	Maintain the extent of non-woody, vegetation occurring in wetlands and floodplains	Mostly	Not categorised	Red gum - Insufficient data	RRG - Insufficient data
NV2b	Ephemeral understorey vegetation	Maintain the extent of non-woody, vegetation occurring in wetlands and floodplains	Mostly	Not categorised	Black box - declining	BB - no
NV4a	River red gum forest	Maintain the proportion of river red gum forests in moderate or good condition	Yes	Moderate-good	Stable	Yes
NV4a	River red gum forest	No further decline in the condition of river red gum forests in poor or degraded condition.	Yes	Moderate-good	Stable	Yes
NV4a	River red gum forest	Increase the abundance of river red gum seedlings and saplings in **degraded** river red gum forests on the activity-managed floodplain.	Yes	Not categorised	Stable	Not currently applicable
NV4b	River red gum woodland	Maintain the proportion of river red gum woodlands in moderate or good condition	Yes	Very poor-good	Declining	No
NV4b	River red gum woodland	No further decline in the condition of river red gum woodlands in poor or degraded condition.	Yes	Very poor-good	Declining	No
NV4b	River red gum woodland	Increase the abundance of river red gum seedlings and saplings in degraded river red gum woodlands on the activity-managed floodplain.	Yes	Not categorised	Stable	Not currently applicable
NV4c	Black box woodland	Maintain the proportion of black box woodlands in moderate or good condition.	Yes	Poor-good	Condition stable	Yes
NV4c	Black box woodland	No further decline in the condition of black box woodlands in poor or degraded condition.	Yes	Poor-good	Condition stable	Yes

Objective	Vegetation community	5-year target Over a 5-year rolling period:	EWR met	Current condition	Trend	On track to meet target
NV4c	Black box woodland	Increase the abundance of black box seedlings and saplings in degraded black box woodlands on the activity-managed floodplain	Mostly	Not categorised	Stable	Not currently applicable
NV4bc	River red gum and black box woodland	Maintain the proportion of black box/river red gum woodlands in moderate or good condition.	No	Poor-good	Declining	No
NV4bc	River red gum and black box woodland	No further decline in the condition of black box/river red gum woodlands in poor or degraded condition.	No	Poor-good	Declining	No
NV4bc	River red gum and black box woodland	Increase the abundance of black box/red gum seedlings and saplings in degraded black box woodlands on the activity-managed floodplain.	No	Not categorised	Stable	Not currently applicable
NV4e	Lignum shrublands	Maintain or increase the proportion of lignum communities in intermediate or good condition.	Yes	Not categorised	Insufficient data	Insufficient data
NV4e	Lignum shrublands	No further decline in the condition of lignum shrublands poor condition.	Yes	Not categorised	Insufficient data	Insufficient data
NV4e	Lignum shrublands	Increase the abundance of lignum recruits in degraded lignum shrublands.	Mostly	Not monitored	Not monitored	Not monitored

Recommendations

The following recommendations should be considered to improve evaluation of the native vegetation theme in future evaluation periods (see Table 4-4 for more detail):

- River red gum woodlands and mixed woodlands of the PPWWP program are not on track to meet the 5-year condition targets and should be priorities for water delivery actions.
- The condition of black box woodland has remained stable but there is a large proportion of trees in poor condition. Appropriate watering actions should be undertaken to improve tree condition and maintain the associated understorey community.
- Improve the effectiveness of the monitoring program by increasing the number of monitoring sites to better inform adaptive management, evaluation and reporting.
- Collect more information on other drivers of vegetation condition, extent and recruitment, for example, grazing pressure, as it can have significant impacts on tree recruitment and non-woody vegetation extent and composition.

Table 4-4 Recommendations for the management, monitoring and evaluation native vegetation in the NSW Murray–Darling Basin for future evaluation and reporting

Indicator	LTWP Objective	Recommendations for: Management	Recommendations for: Monitoring	Recommendations for: Evaluation
Extent and condition of non-woody native vegetation	**NV1:** Maintain the extent and viability of non-woody vegetation communities occurring within channels **NV2a:** Maintain or increase the extent and improve the condition of non-woody vegetation communities within semi-permanent, intermittent, temporal and ephemeral wetland and floodplain areas (Murray–lower Darling, Murrumbidgee, Macquarie and Namoi WRPs only) **NV2b:** Maintain or increase the extent and improve the condition of ephemeral understorey vegetation within forests, woodland and open floodplain areas (all WRPs except Barwon–Darling and Border Rivers)	Maintain a mosaic of healthy native non-woody vegetation communities within NSW Murray–Darling Basin channels and floodplains by ensuring environmental water needs are met. Emphasis should be place on augmenting natural flow events with environmental water to increase extent and duration of watering events and reinstate overbank flows and mid-range floods. Collaborate with others to use of management levers such as weed control to improve watering outcomes.	Continue to develop and improve our understanding of appropriateness, efficiency and effectiveness of environmental water management for non-woody vegetation the NSW Murray–Darling Basin through maintaining or improving monitoring programs to better support the evaluation of this objective in 2024 (DPIE 2020b) Specifically, ground truth vegetation classifications to validate the multi-temporal landsat map product. Increase spatial coverage of riverine and floodplain vegetation monitoring across NSW Murray–Darling Basin. Improve knowledge of other drivers of vegetation condition, extent and recruitment, e.g. grazing pressure.	As a minimum maintain bi-annual ground surveys at targeted locations. Develop improved remote-mapping approaches for non-woody vegetation to better inform the 2024 evaluation of this objective.

Indicator	LTWP Objective	Recommendations for: Management	Recommendations for: Monitoring	Recommendations for: Evaluation
Extent and condition of flood-dependent woody vegetation communities Extent and condition black box communities Extent and condition of coolibah communities Extent and condition of lignum	**NV3:** Maintain the extent and improve the condition of river red gum communities closely fringing river channels **NV4a,b:** Maintain or increase the extent and maintain or improve the condition of river red gum forest and woodland **NV4c:** Maintain or increase the extent and maintain or improve the condition of black box woodlands on floodplains **NV4d,f:** Maintain or increase the extent and maintain or improve the condition of coolibah woodlands and coolibah wetland woodlands on floodplains **NV4e:** Maintain or increase the extent and maintain or improve the condition of lignum shrublands	Maintain a range of healthy forest, woodland and shrubland communities within NSW Murray–Darling Basin channels and floodplains by ensuring environmental water needs are met. Emphasis should be place on augmenting natural flow events with environmental water to increase extent and duration of watering events and reinstate overbank flows and mid-range floods. Collaborate with others to use of management levers such as weed control to improve watering outcomes.	Continue to develop and improve our understanding of appropriateness, efficiency and effectiveness of environmental water management for woody vegetation the NSW Murray–Darling Basin through maintaining or improving monitoring programs to better support the evaluation of this objective in 2024 (DPIE 2020b). Increase spatial coverage of floodplain vegetation monitoring across NSW Murray–Darling Basin. Increase understanding of the role of groundwater in maintaining woody floodplain vegetation and groundwater-dependent ecosystems. Improve knowledge of other drivers of vegetation condition, extent and recruitment, e.g. grazing pressure.	As a minimum maintain bi-annual ground surveys at targeted locations. Continue to improve the Stand Condition Assessment Tool to improve remote-mapping approaches and better support the evaluation of this objective in 2024.

Waterbirds

Waterbirds are highly mobile, relying on a network of wetland habitats within and outside the NSW Murray–Darling Basin to complete critical parts of their life cycle. Many wetlands in NSW Murray–Darling Basin are recognised as nationally and internationally important for supporting waterbird populations. Waterbirds are a priority environmental asset under the Murray–Darling Basin Plan. As such, they are targets for the allocation of water for the environment. Watering objectives have been established to improve waterbird populations by maintaining and improving their habitat to increase their distribution and abundance as well as providing breeding opportunities (Table 4-5). All indicators, metrics and LTWP objectives relate to the one WSP objective: WRP provides strategic support via the WSP Objective ‘Support environmental watering to contribute to the maintenance or enhancement of ecological condition in streams, riparian zones, dependant wetlands and floodplains within the water source, including for the purposes outlined in the WSP’ (Table 4-5).

Table 4-1 Waterbird Metrics and Related LTWP and WSP Objectives

Indicator	Metrics	LTWP objectives 2024
Number of waterbird species	Total number of species	WB1: Maintain the number and type of waterbird species.
Total waterbird abundance – all functional groups	Total waterbird abundance Total abundance of the five waterbird functional groups	WB2: Maintain total waterbird abundance across all functional groups.
Non-colonial waterbird breeding	Number of breeding species Total abundance of non-colonial breeding waterbirds	WB3: Maintain opportunities for non-colonial waterbird breeding.
Colonial waterbird breeding	Number of breeding species Number and size of colonial waterbird breeding events Proportion of successful^ breeding events	WB4: Increase (where possible*) opportunities for colonial waterbird breeding.
Waterbird habitat	Extent and condition of vegetation in known waterbird breeding and foraging sites	WB5: Maintain the extent and improve condition of waterbird habitats. *This objective is linked to native vegetation extent and condition objectives for known colonial waterbird breeding sites.*

^Successful breeding relates to completion of nests where fledglings and juvenile birds are observed at the end of each breeding event.

*In line with expected outcome in BWS (Murray–Darling BasinA 2014) for, by 2024, an increase in breeding events (the opportunities to breed rather than the magnitude of breeding per se) of colonial nesting waterbirds.

Findings

1. Ground and aerial surveys indicated that the total number of waterbird species has been maintained in monitored areas of the NSW Murray–Darling Basin from July 2014 to June 2019.
2. Long-term annual aerial surveys have shown significant declines in total number of individual waterbirds, across all waterbird functional groups, in the NSW Murray–Darling Basin from 1983 to 2018.
3. There were also long-term declines in waterbird breeding activity (1983 to 2018) with large waterbird breeding events in the 2014-19 period only recorded in 2016–17, when there was widespread natural flooding and environmental water delivered to key wetlands in the NSW Murray–Darling Basin.

What was expected

Where overbank flooding inundates floodplain wetlands it can provide feeding and breeding habitat for a range of waterbird species (Figure 4-24). Colonially-nesting waterbirds, such as egrets and ibis, can be sensitive to inundation duration and water depth, which needs to be maintained to cover the breeding period from laying through to fledging of young (Figure 4-25). The 2014-19 reporting period included a range of flow conditions in monitored areas including very dry conditions (Figure 2-1 and Figure 2-3), small managed overbank events and large natural overbank events (Figure 3-5 and Figure 3-6) that were augmented with water for the environment. It was expected that there would be increases in total species richness, abundance and breeding activity in waterbird species with increasing magnitude of overbank flows. Overbank flows more than three months in duration over spring and summer were expected to result in greater opportunities for successful waterbird breeding (that is increased number of breeding species, increased number of total nests and/or broods, increased number of colony sites).

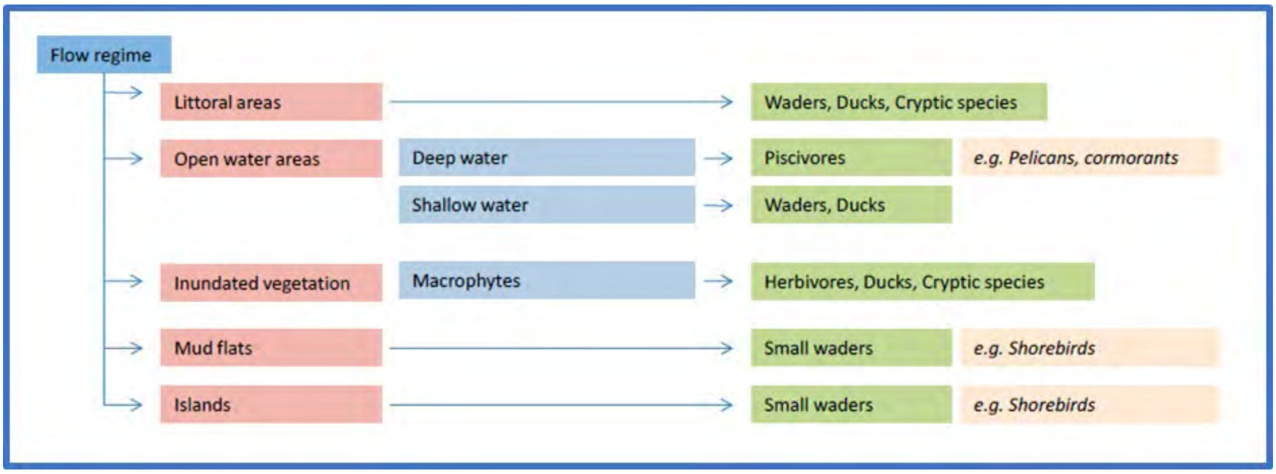


Figure 4-24 A conceptual model of inundation and waterbird habitats.

Waterbird species can be grouped according to their habitat requirements which is influenced by the flow regime (reproduced from Brandis et al. 2009).

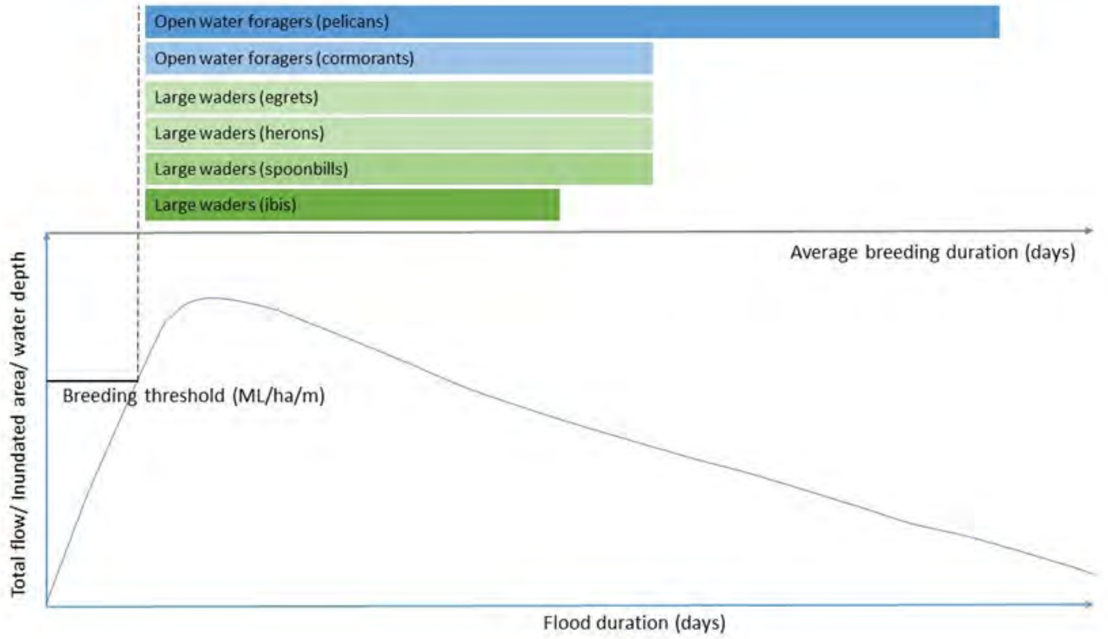


Figure 4-25 A conceptual model of how key flow parameters (total river flow, inundated area, water depth and flood duration) influence colonial waterbird breeding

Different waterbird groups respond to a breeding threshold at which flow volumes are sufficient to trigger the initiation of breeding (adapted from Brandis and Bino 2016).

Methods

Long-term data on changes in wetland extent and waterbird populations has been collected as part of the Eastern Australia Annual Waterbird Survey program. Ten aerial survey bands (30 km wide) (Figure 4-26) have been monitored across eastern Australia each spring since 1983, providing an effective long-term measure of waterbird species richness, total abundance and breeding activity (Kingsford and Porter 2009; Kingsford et al. 2020).

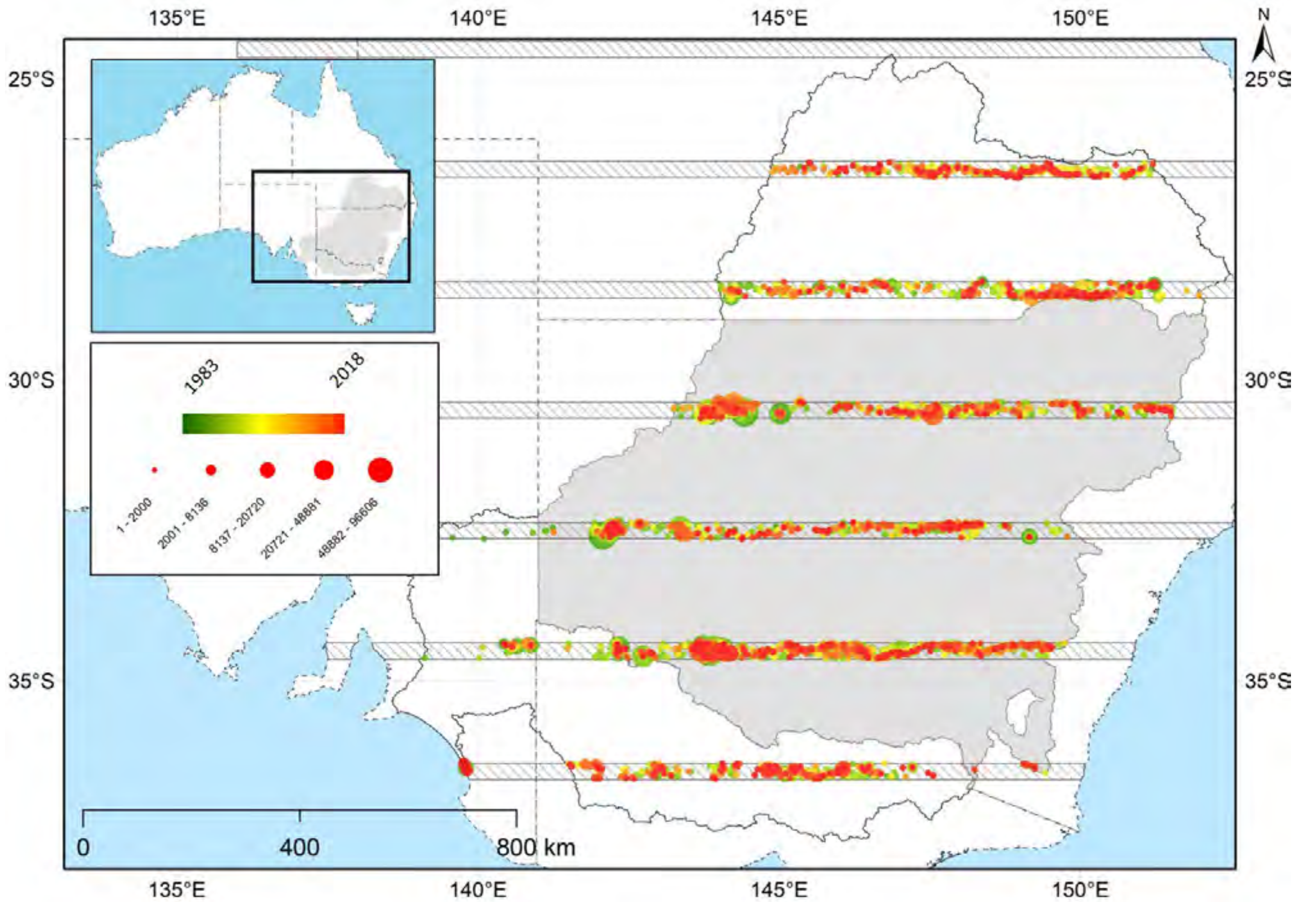


Figure 4-26 The Eastern Australian Annual Waterbird Survey Locations and Total Waterbird Abundance

Ground surveys have also been undertaken across NSW Murray–Darling Basin wetlands by the Department of Planning, Industry and Environment and partners from 2008 onwards which has provided information on less abundant or threatened and/or cryptic species, and the timing and extent of colonial waterbird breeding events (Spencer et al. 2018). The ground survey coverage varies among wetland systems, but most have been surveyed each spring from 2012 onwards with additional event-based colony surveys in spring and summer months (Spencer 2017; Spencer et al. 2018; 2019; Thomas et al. 2020). The Commonwealth Environmental Water Office supported detailed monitoring of nesting success and drone-based counts of large ibis and spoonbill colonies in 2016–17, which were coordinated by UNSW in the Macquarie Marshes, Lower Lachlan (Figure 4-27 and Figure 4-28), Lower Murrumbidgee Floodplain and Barmah-Millewa Forest (Brandis 2017; Dyer et al 2017; McGinness et al. 2019; Wassens et al. 2018).

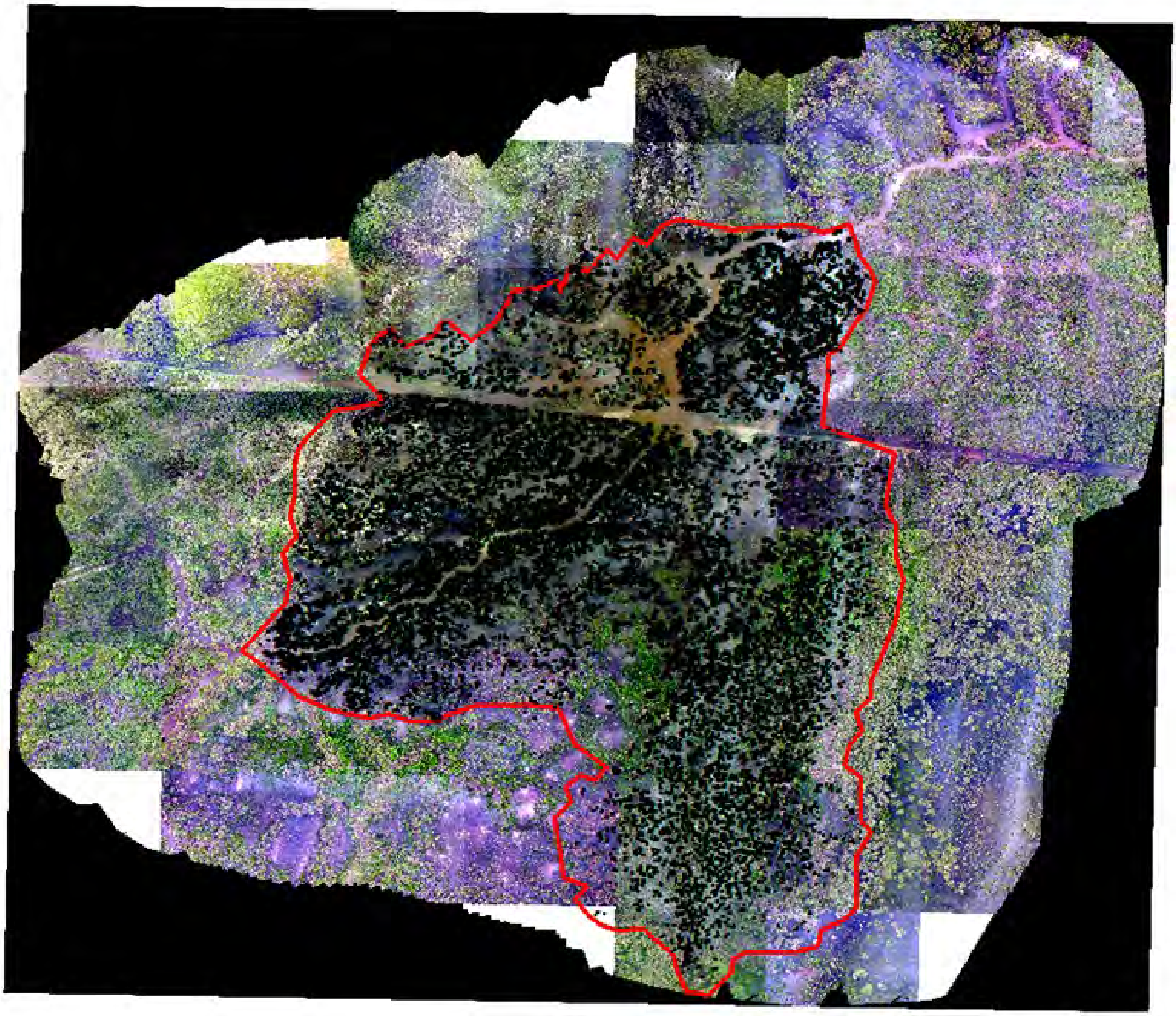


Figure 4-27 Drone Survey Image of a Straw Necked Ibis Colony in the Lower Lachlan, Spring 2016

This imagery was used to determine the extent of the colony and undertake detailed nest counts (supplied by Centre for Ecosystem Science).

Figure 4-28 Ibis nests in the Macquarie Marshes in spring 2016.

Photo: Rachael Thomas, NSW Department of Planning, Industry and Environment

Results

Ground and aerial survey data collected over the reporting period indicate there has been no overall decline in the total number of waterbird species recorded in key wetlands in the NSW Murray–Darling Basin (Figure 4-29 and Figure 4-30). This is consistent with long-term trends where total number of waterbird species have not declined over the 1983–2018 period (Table 4-6).

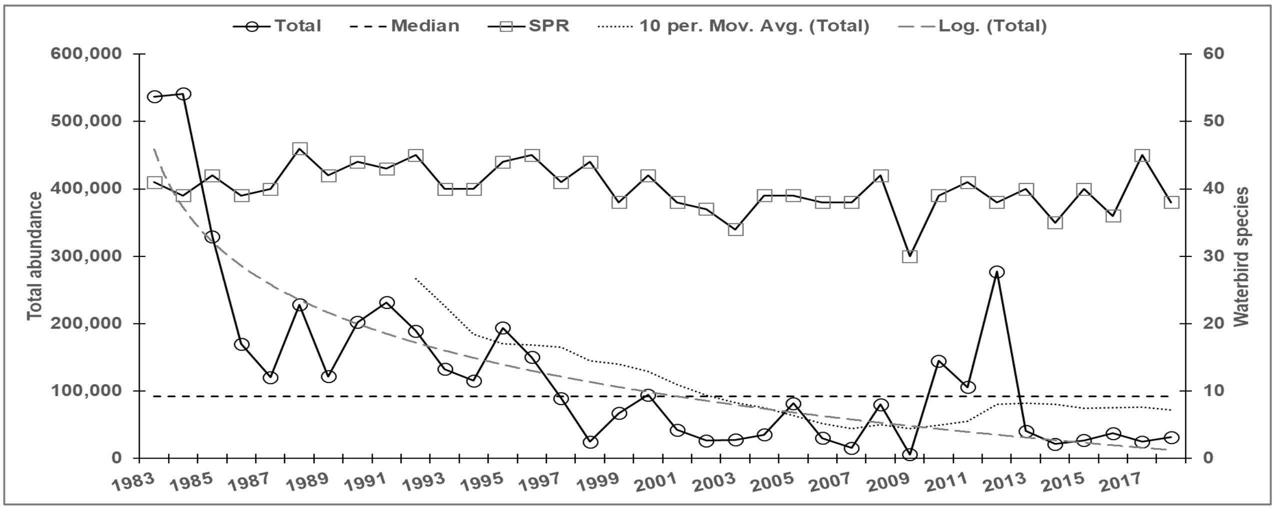


Figure 4-29 Total annual waterbird abundance (left), long-term median (Dashed), 10-year moving average and log scaled trend and species richness (right)

From long-term annual aerial surveys of NSW Murray–Darling Basin wetlands 1983-2018 (supplied by the Centre for Ecosystem Science University of New South Wales)

Long-term aerial survey data indicates that there have been significant declines in total waterbird abundance, across all functional groups, over the 1983–2018 period (Table 4-6 and Figure 4-30). Similarly, there have been long-term declines in total waterbird breeding abundance (number of broods and nests) (Figure 4-31).

Table 4-2 Summary of long-term trends (1983-2018) in waterbird populations in the NSW Murray–Darling Basin compared to the 2014–2019 reporting period

Waterbird metric	1983–2018 Average	1983–2018 SD	1983–2018 Median	1983–2018 Annual decline	2014–18 Avg	2014–18 SD	2014–18 Median
Total number of species (SPR)	40.1	3.4	40.0	-0.3%	38.8	4.0	38.0
Total waterbird abundance	127,631	129,882	91,964	-6.8%	28,413	6,128	27,085
Total ducks	65,239	74,119	41,912	-8.3%	11,197	7,476	10,790
Total herbivores	24,129	24,944	15,953	-7.4%	3,496	2,126	3,189
Total large waders	18,202	21,809	9,873	-7.0%	8,472	14,446	2,033
Total piscivores (fish-eaters)	12,840	11,619	7,759	-5.3%	3,458	1,731	3,564
Total shorebirds	7,221	11,344	3,467	-7.4%	1,790	1,266	1,877
Total number of breeding species	5.2	5.2	4.0	-5.1%	1.6	2.5	1.0
Total breeding (nests & broods)	3,959	10,831	47.0	-11.5%	4,374	9,762	9.0

Note that the 2014–19 evaluation period encompasses five years of annual aerial spring surveys (supplied by the Centre for Ecosystem Science, University of New South Wales)

Figure 4-30 Total number of waterbird species recorded in six wetland regions by NSW Department Planning, Industry and Environment spring ground surveys in 2012-2018

(Dotted line shows the median). Wetland regions included: GWY = Gwydir Wetlands, MAC = Macquarie Marshes, LOLA = Lower Lachlan, MID = Mid-Murrumbidgee Wetlands, LOW = Lowbidgee Floodplain and MMU = Mid-Murray (Millewa Forest only). Note that Lower Lachlan surveys started in spring 2016 and no surveys were completed in Millewa Forest in spring 2013. Millewa Forest waterbird data was collected through the MDBA's Living Murray Program.

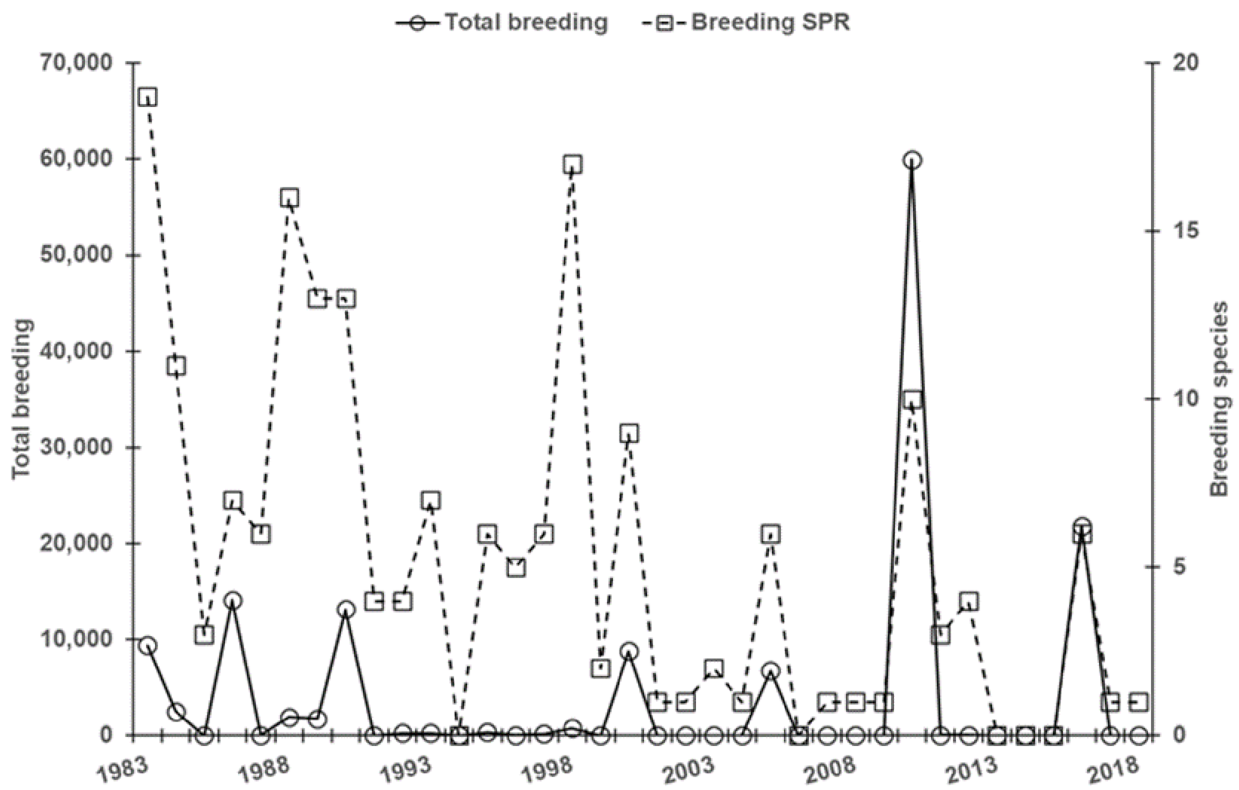


Figure 4-31 Total annual waterbird breeding (nests and broods) abundance (left) and numbers of breeding species (right) from long-term annual aerial surveys 1983-2018

Supplied by the Centre for Ecosystem Science, University of New South Wales

Colonial waterbird breeding was recorded in the monitored wetland regions in every year of the 2014–19 period (Figure 4-32). Significant breeding events were recorded in four WRPAs in 2016–17, which coincided with large natural flooding and the delivery of water for the environment (Figure 3-5 and Figure 3-6). No significant waterbird breeding events were recorded in the Gwydir Wetlands in the 2014–19 period (Figure 4-33). At least 83 colony sites (around 40% of known sites in NSW) were active in the monitored regions in 2016–17 (Spencer et al. 2018).

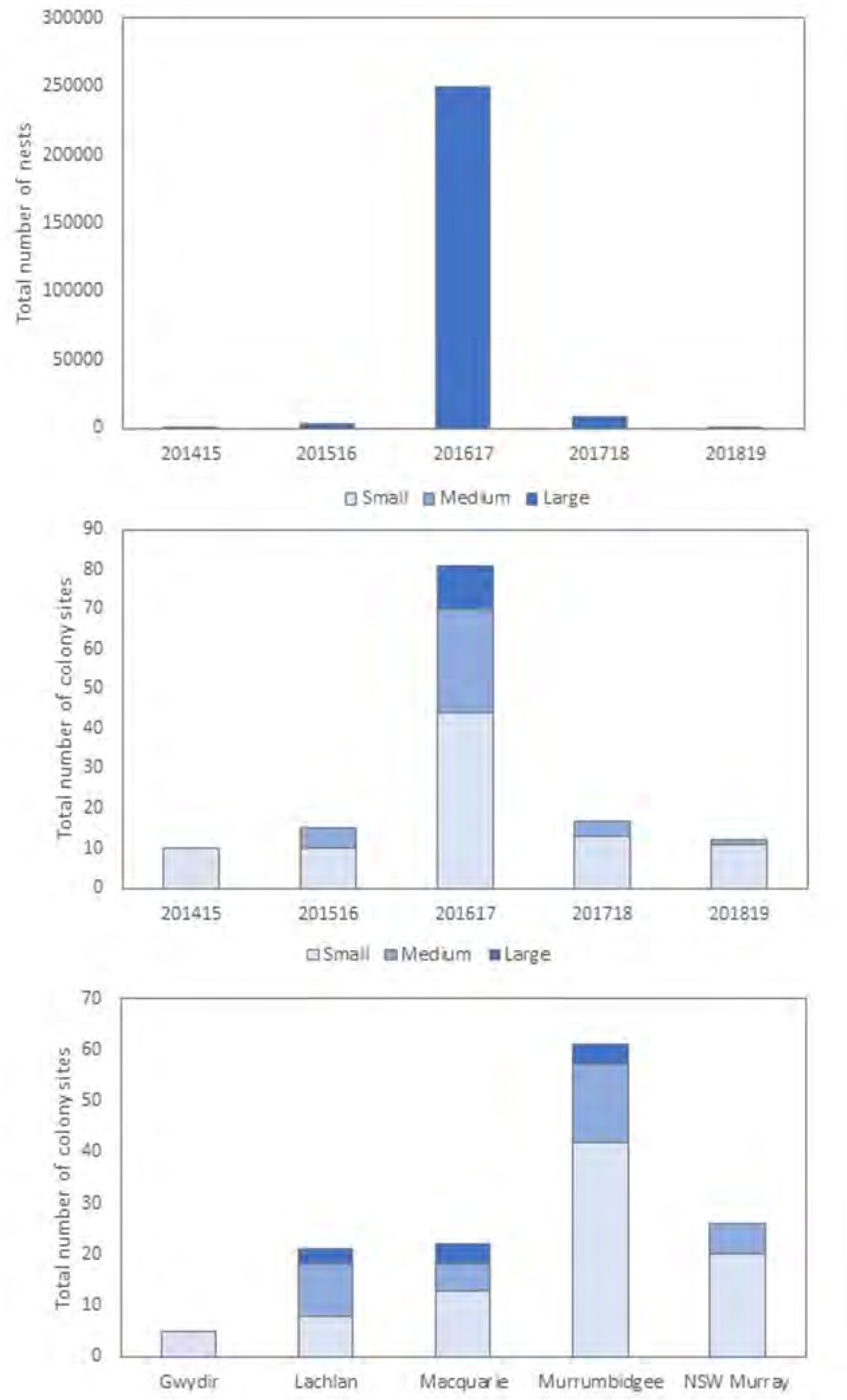


Figure 4-32 Total number of waterbird nests (top) and total number of colonies per year (middle) and per valley (bottom) from ground and aerial surveys of monitored wetland regions of the NSW Murray–Darling Basin from July 2014 to June 2019.

Major colonies (>5000 nests), medium size colonies (>250-<5000 nests) and small (<250 nests) colonies were monitored by NSW Department of Planning, Industry and Environment, UNSW and other partners in five WRPAs in 2014-19 (lower).

Water for the environment was delivered to many wetland regions in 2016–17 to extend the duration of inundation in some colonies and surrounding foraging habitats to allow species to complete their nesting cycle (Figure 4-32 Figure 4-33). Smaller colonies (generally less than 250 nests) were also supported with environmental water in years either side of the widespread flooding in 2016–17 (Figure 4-32) (Spencer 2017; Spencer et al. 2018, 2019; Thomas et al. 2020). Detailed nest monitoring of ibis and spoonbill colonies active in 2016–17 provided some evidence of breeding success (Brandis 2017; Dyer et al 2017; McGinness et al. 2019; Wassens et al. 2018) (Table 4-7).

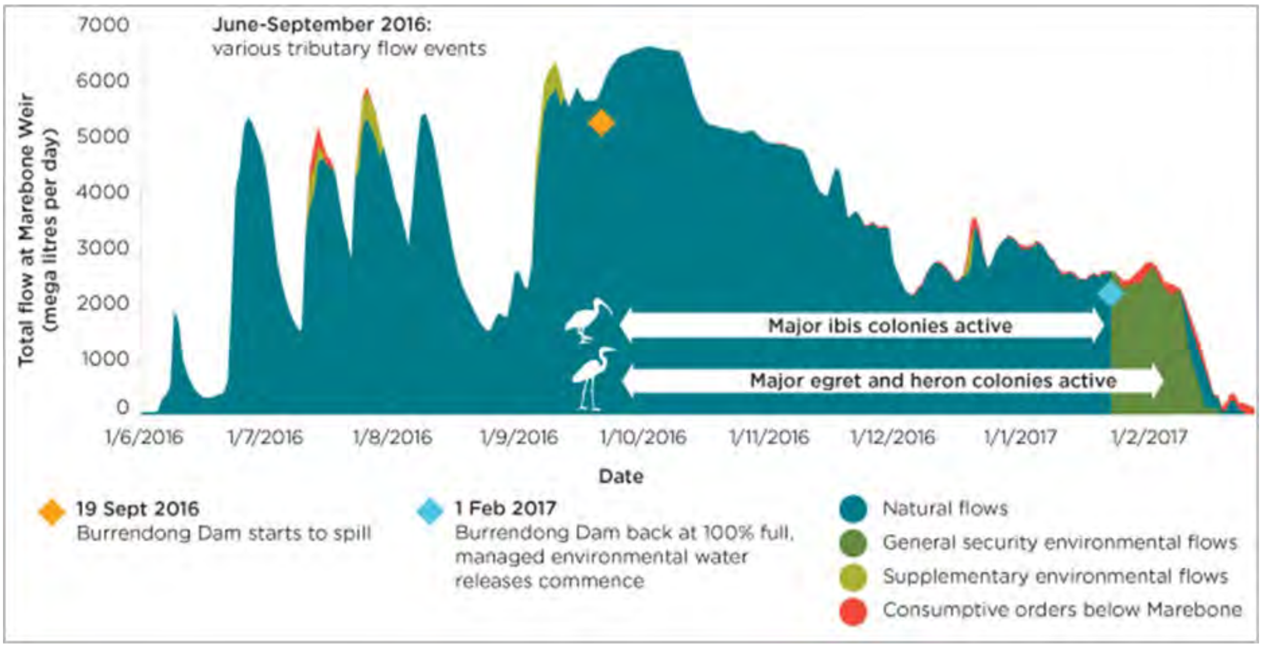


Figure 4-33 Flow type releases from Burrendong Dam and Flow volumes at Marebone weir in relation to water bird breeding in the Macquarie Marshes (reproduced from OEH 2017)

Table 4-3 Summary of waterbird colony size and reproductive for Straw-necked Ibis colonies active in 2016–17

NSW WPRA	Wetland region	Colony site	Number of nests	Overall success rate
Macquarie–Castlereagh	Macquarie Marshes	Zoo Paddock	21,210	65.8%
Macquarie–Castlereagh	Macquarie Marshes	Monkeygar Swamp	15,000	63.3%
Lachlan	Lower Lachlan	Upper Merrimajeel	101,360	77.1%
Lachlan	Lower Lachlan	Booligal Block Bank	8,000	57.6%
Murrumbidgee	Lower Murrumbidgee	Eulimbah Swamp	14,994	59.4%
Murrumbidgee	Lower Murrumbidgee	Telephone Bank	30,000	#
Murrumbidgee	Lower Murrumbidgee	Tori Swamp	6,000	39.7%
NSW Murray–Lower Darling	Barmah–Millewa	Reedbeds Swamp	1,645	62.9%

Telephone Bank was not monitored for the duration of breeding due to lack of access during flooding. As a result, no reproductive success rate was measured (supplied by the Centre for Ecosystem Science, University of New South Wales).

Figure 4-34 shows the expansion and contractions of large overbank flows in spring 2016, which inundated wetland habitat in the Millewa Forest, NSW Central Murray Forests Ramsar Site, supporting an ibis and spoonbill colony in the Reedbeds complex that was active from October 2016 to January 2017. Large areas of Millewa Forest were inundated by large natural overbank flows in early spring and environmental water delivery ensured water levels persisted in the main colony area from early November 2016 to late January 2017 (Figure 4-34). The overall success rate (63%) of this colony was comparable to other large ibis colonies active in NSW Murray–Darling Basin during 2016–17 (Table 4-7)

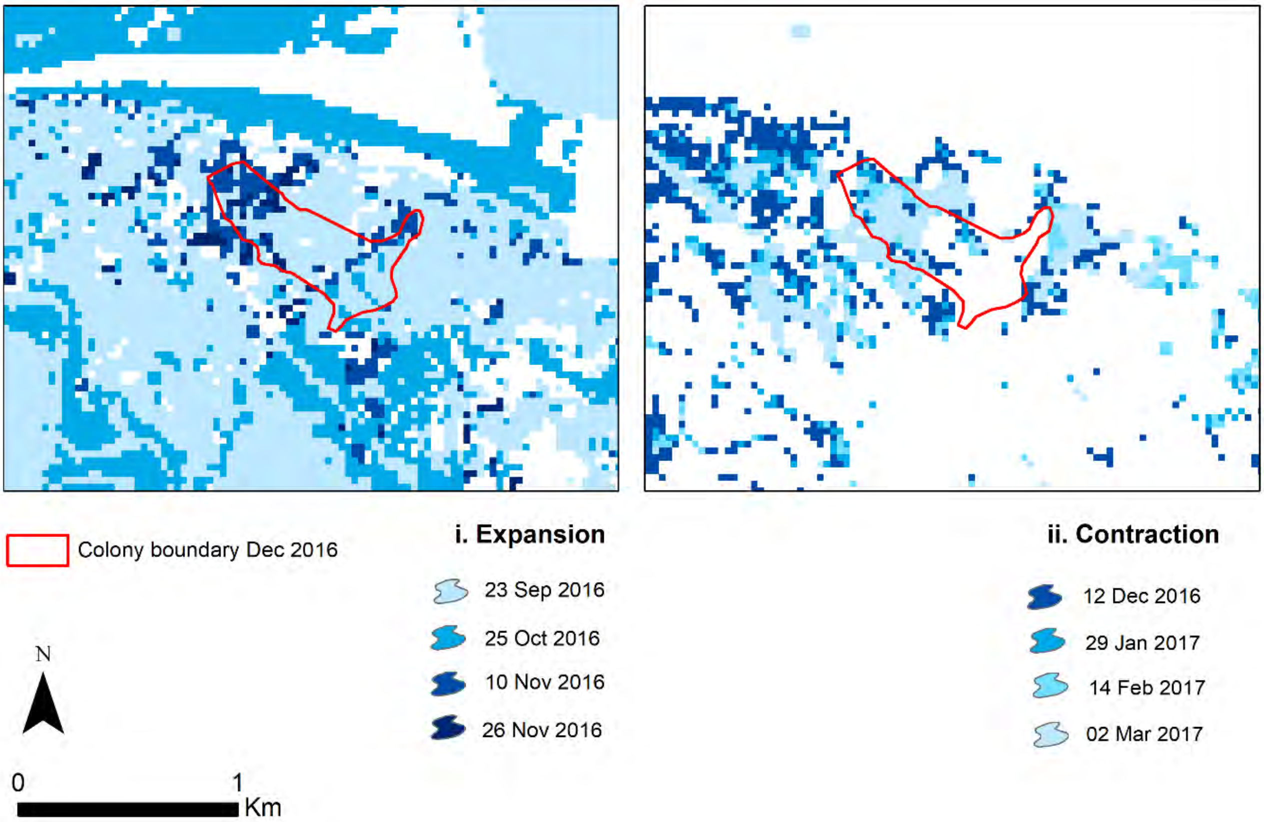
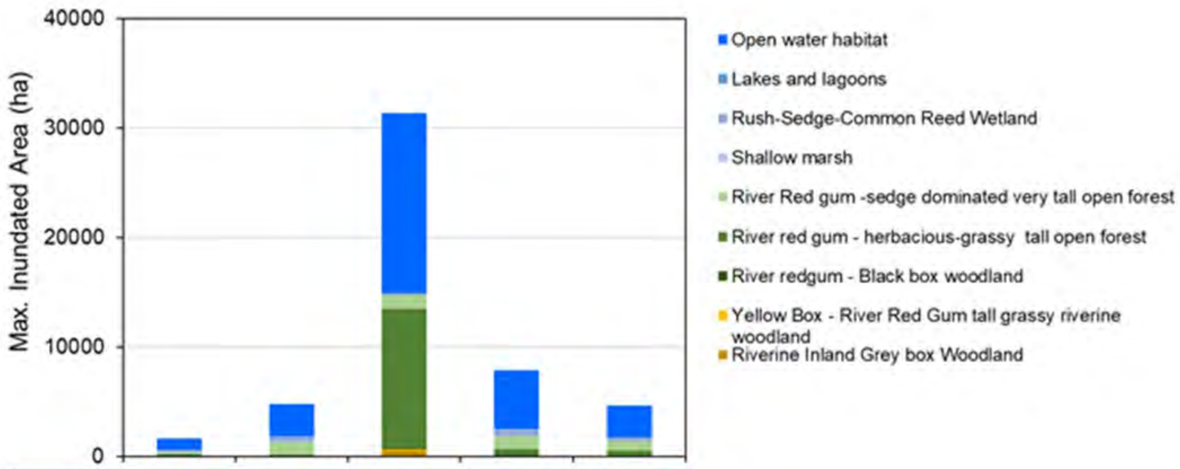


Figure 4-34 Inundation of waterbird breeding habitat in the Millewa forest, Spring 2016

The long-term water planning in regulated WRPAs of the NSW Murray–Darling Basin include objectives for colonial waterbird breeding that focus on delivering flows to known colony sites and adjoining foraging grounds to support successful breeding. Environmental water is also delivered to provide seasonal flooding (Figure 4-35) to maintain the condition and productivity of key waterbird foraging habitat (spike-rush sedgelands, marsh grasslands, lignum shrublands, open lagoons and lakes).



	2014-15	2015-16	2016-17	2017-18	2018-19
EWR Flow category	Small & large freshes & bank full	Large fresh & bank full	Large freshes * small, medium& large overbanks	Large freshes & small overbank	Large freshes & small overbank
Flood magnitude	4,204 (7%)	14,507 (21%)	62,406 (93%)	23,722 (32%)	14,124 (18%)
Season	Winter-Spring	Winter-Spring	Winter-Spring	Late winter-Late spring	Spring-Late spring

Figure 4-35 Habitat availability for waterbirds in the Millewa Forest 2014-2019

Habitat availability is based on the maximum inundated area (ha) in each habitat for each water year (upper) and the size, type and seasonality of flows (lower). The Environmental Water Requirements (EWR) flow categories are based on flows on the Murray River @ Yarrawonga. Flood magnitude is the annual inundated extent of the floodplain (ha) (% of floodplain boundary). Season represents the flow peak and the subsequent flooding peak.

Case study: NSW MDB Ramsar Sites and Waterbirds

Five Ramsar sites in the NSW MDB received water for the environment over the 2014-19 period. Ground and aerial surveys showed these wetlands are important for supporting a diverse range of waterbird species when conditions are suitable (Porter et al. 2018; Spencer et al. 2018).

In 2016–17 Fivebough-Tuckerbil Swamp Ramsar site supported the most waterbird species overall, including migratory shorebirds (Figure 4-35 and Figure 4-36), followed by the Macquarie Marshes Ramsar site, Narran Lakes Ramsar site, Gwydir Wetlands Ramsar site and Central Murray Forests Ramsar site (Spencer et al. 2018).

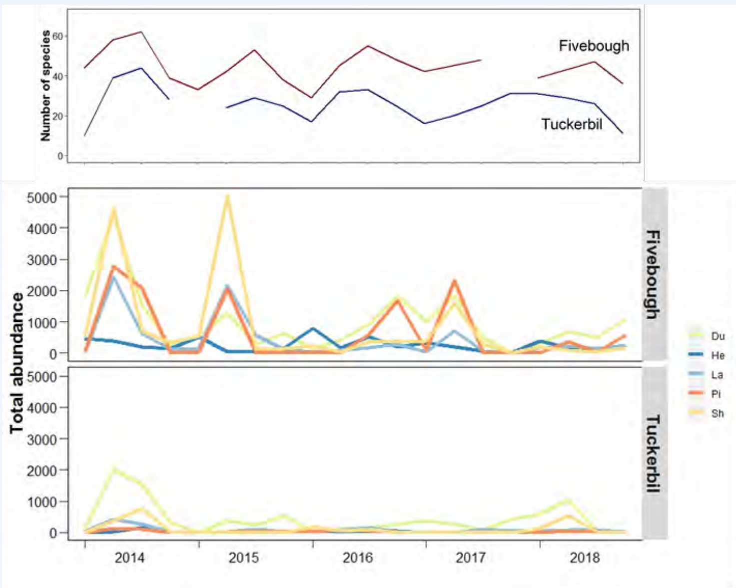


Figure 4-37 Total Number of waterbird species (top) and total waterbird abundance (in functional groups) recorded in Fivebough (middle) and Tuckerbill (bottom) swamps in surveys 2014-2019

Waterbird functional groups include ducks and small grebes (Du), herbivores (He), large waders (La), piscivores (Pi) and shorebirds (Sh) (data supplied by Dr K. Hutton).

Figure 4-36 At least 12 migratory shorebird species were recorded in Fivebough Swamp (right) over the 2014-19 period including the sharp tailed sandpiper (top left) and wood sandpiper (bottom left) (Photos: Carmen Amos, NSW Department of Planning, Industry and Environment).

Recommendations

The following recommendations should be considered to improve evaluation of the waterbird theme in future evaluation periods (see Table 4-8 for more detail):

1. Ensure the condition of waterbird foraging and breeding habitats are maintained and improved, and opportunities for successful waterbird breeding are maximised by protecting, and where required, augmenting natural flows with environmental water, and undertaking complementary management actions, including feral animal control.
2. Maintain and improve monitoring programs for waterbirds and their habitats in the NSW Murray–Darling Basin to inform progress towards meeting waterbird objectives and targets and to support adaptive management.
3. Commit long-term funding to waterbird monitoring programs, including annual aerial and ground surveys, and habitat mapping to support comprehensive evaluation of this objective in 2024. Targeted investment in research addressing key knowledge gaps including site fidelity, breeding habitat condition, foraging ranges, breeding success, the impact of disease and other pressures on survival rates and recruitment will also be essential for interpreting waterbird responses to water management.

Table 4-4 Recommendations for the management, monitoring and evaluation of waterbirds in the NSW Murray–Darling Basin for future evaluation and reporting

Indicator	LTWP Objective	Recommendations for management	Recommendations for monitoring	Recommendations for evaluation
Number of waterbird species	WB1: Maintain the number and type of waterbird species	Maintain a mosaic of wetland habitat types to provide foraging opportunities for a range of waterbird species by ensuring seasonal watering of waterbird assets in the NSW Murray–Darling Basin.	Maintain and improve monitoring programs for waterbirds and their habitats in the NSW Murray–Darling Basin to support adaptive management and enable greater evaluation of this objective in 2024.	As a minimum maintain annual aerial and ground surveys, and habitat mapping to support evaluation of this objective in 2024.

Indicator	LTWP Objective	Recommendations for management	Recommendations for monitoring	Recommendations for evaluation
Total waterbird abundance – all functional groups	WB2: Maintain total waterbird abundance across all functional groups	As below in WB3, WB4 and WB5 provide increased opportunities for breeding to increase total waterbird abundance. Maintain inundation of key foraging grounds for more than four months after the commencement of breeding and/or neighbouring catchments to support successful breeding and promote the survival of young birds. Prioritise watering in water years following large breeding events within wetland regions that support breeding and in neighbouring catchments to promote survival of first year birds.	Continue to develop and improve our understanding of appropriateness, efficiency and effectiveness of environmental water management for waterbirds in the NSW Murray–Darling Basin through maintaining or improving monitoring programs to better support the evaluation of this objective in 2024 (DPIE 2020b).	As a minimum maintain annual aerial and ground surveys, and habitat mapping to support evaluation of this objective in 2024.
Non-colonial waterbird breeding	WB3: Maintain opportunities for non-colonial waterbird breeding	As outlined in WB1, WB2 and WB4 increase habitat availability for non-colonial species and provide increased opportunities for breeding through seasonal watering and extending the duration of natural flow events.	Continue to develop and improve our understanding of appropriateness, efficiency and effectiveness of environmental water management for waterbirds in the NSW Murray–Darling Basin through maintaining or improving monitoring programs to better support the evaluation of this objective in 2024 (DPIE 2020b).	As a minimum maintain annual aerial and ground surveys, and habitat mapping to support evaluation of this objective in 2024.

Indicator	LTWP Objective	Recommendations for management	Recommendations for monitoring	Recommendations for evaluation
Colonial waterbird breeding	WB4: Increase opportunities for colonial waterbird breeding	Extend duration of flooding and maintain adequate water depths in any active colony sites, where possible, to support breeding events through to completion (minimum of three to four months from egg laying to fledging plus post-fledging care for most species). Undertake targeted feral animal control (pigs, foxes), where needed, in active colony sites.	Continue to develop and improve our understanding of appropriateness, efficiency and effectiveness of environmental water management for waterbirds in the NSW Murray–Darling Basin through maintaining or improving monitoring programs to better support the evaluation of this objective in 2024 (DPIE 2020b).	As a minimum maintain annual surveys and repeated ground surveys and habitat mapping to support comprehensive evaluation of this objective in 2024. Support research addressing key knowledge gaps including site fidelity, foraging ranges, breeding success, the impact of disease and other pressures on survival rates and recruitment.
Waterbird habitat	WB5: Maintain the extent and improve condition of waterbird habitats. *This objective also links to native vegetation condition and extent objectives for known colonial waterbird breeding sites.*	Maintain and restore known and potential colonial waterbird breeding habitats to maximise opportunities for breeding when conditions are suitable.	Continue to develop and improve our understanding of appropriateness, efficiency and effectiveness of environmental water management for wetland vegetation the NSW Murray–Darling Basin through maintaining or improving monitoring programs to better support the evaluation of this objective in 2024 (DPIE 2020b)	Support research addressing key knowledge gaps including the impact of breeding habitat condition on the likelihood of breeding and overall breeding success.

Native fish

Healthy and diverse populations of native fish and crayfish provide significant cultural, social, recreational and economic values (MDBA 2017; 2019). Recreational fishing in Inland NSW is worth approximately $350 million annually (McIlgorm and Pepperell 2013), including the substantial flow of money and social benefits to regional communities (NSW DPI 2018).

Native fish depend on healthy aquatic ecosystems. Thriving, diverse populations of native fish require access to abundant, high-quality aquatic habitats to live, feed and breed. This means rivers, lakes and other waterways need to be managed in ways that meet their ecological needs.

Native fish are priority environmental assets under the Basin Plan. As such, they are targets for the allocation of water for the environment. Watering objectives have been established to help protect native fish species, increase their distribution and abundance, and improve angling opportunities (Table 4-9).

Different species of native fish respond to different conditions. However, within these differences, there are groups of fish species (known as guilds) that share similar life spans, habitats, flow responses and experience similar angling pressures. This is reflected in the watering objectives, which cater for the needs of the different guilds.

This section details five years of NSW Department of Primary Industries (DPI) Fisheries monitoring under the Basin Plan Environmental Outcomes Monitoring program (2014–15 to 2018–19). Results are presented for ten Native Fish Objectives (NF1 to NF10), incorporating information derived from a new Population Health Index (PHI) developed for this project.

The report describes the condition of fish species and fisheries-relevant assets in the NSW portion of the Murray–Darling Basin. Recommendations are provided to help managers apply the findings to achieve objectives for native fish species recovery. Ultimately, this means healthier aquatic ecosystems, better fishing opportunities and stronger regional economies.

Flows, habitat and connectivity are essential for healthy native fish populations, with flows playing a range of important roles (Figure 4-38).

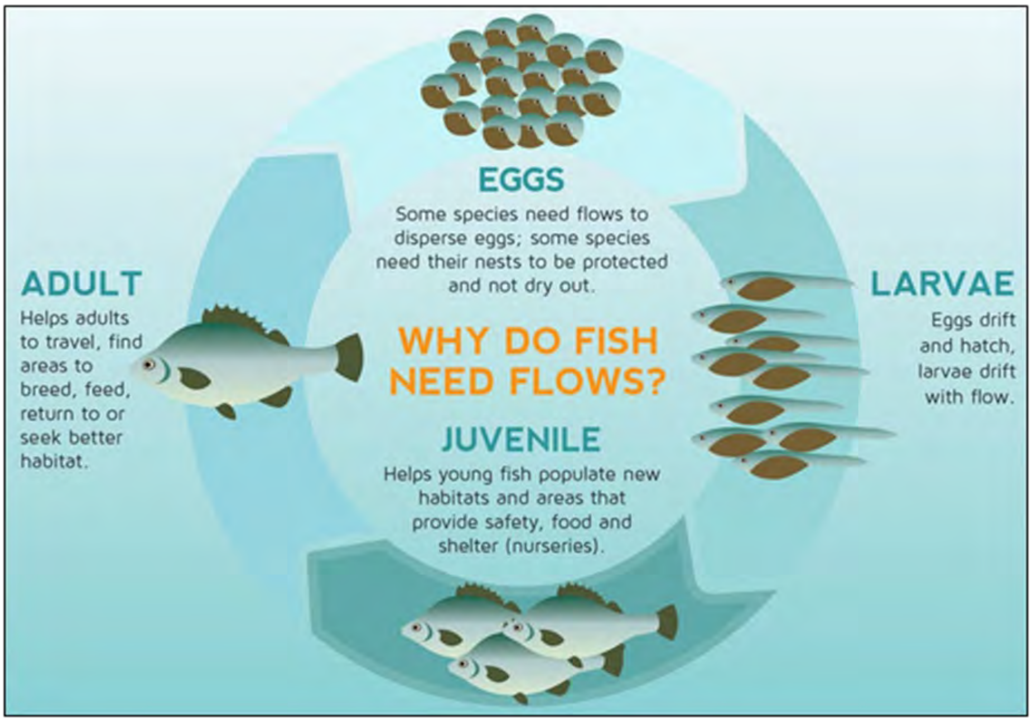


Figure 4-38 The influence of flow on different life cycle stages of native fish

(adapted by DPI Fisheries from MDBA 2019).

Table 4-1 Native Fish Metrics and Related LTWP and WSP Objectives.

Indicator	Metrics	LTWP objectives 2024	Related WSP objective
Number of native fish species	Species Presence/Absence (NF1a, NF1b)	NF1: No loss of native fish species	Protect and contribute to the enhancement of the following over the term of this plan: the recorded **distribution** or **extent** of target native fish and native vegetation over the term of this Plan
Native fish abundance	Trend in abundance within five-year reporting period (NF2b, NF3b, NF6a). Trend in abundance over a 10-year or three-generation interval (whichever is longest) (NF2b, NF3b, NF6a). Change in abundance between five-year reporting periods (NF2b, NF3b, NF6a)	NF2: Increase the distribution and abundance of short to moderate-lived generalist native fish species NF3: Increase the distribution and abundance of short to moderate-lived floodplain specialist native fish species NF6: A 25% increase in abundance of mature (harvestable sized) golden perch and Murray cod	Protect and contribute to the enhancement of the following over the term of this plan: the recorded **distribution** or **extent** of target native fish and native vegetation over the term of this Plan
Distribution of native fish species	Prevalence (NF2a, NF3a, NF7a, NF8a, NF9a, NF10). Extent of Occurrence (NF2a, NF3a, NF7a, NF8a, NF9a, NF10). Fish movement[1]	NF2 & 3 as above. NF7: Increase the prevalence and/or expand the population of key short to moderate-lived floodplain specialist native fish species into new areas (within historical range). NF8: Increase the prevalence and/or expand the population of key moderate to long-lived riverine specialist native fish species into new areas (within historical range). NF9: Increase the prevalence and/or expand the population of key moderate to long-lived flow pulse specialists native fish species into new areas (within historical range). NF10: Increase the prevalence and/or expand the population of key moderate to long-lived diadromous native fish species into new areas (within historical range).	Protect and contribute to the enhancement of the following over the term of this plan: the recorded **distribution** or **extent** of target native fish and native vegetation over the term of this Plan.

Indicator	Metrics	LTWP objectives 2024	Related WSP objective
Native fish populations	Presence/Absence of young-of-year individuals (NF4b, NF5b). Presence/Absence of immature individuals (NF2c, NF3c, NF4a, NF5a, NF7c, NF8c, NF9c). Presence/Absence of adult individuals (NF4a, NF5a, NF6b, NF7b, NF8b, NF9b). Abundance of young-of-year size class (NF4c, NF5c). Abundance of harvestable sized individuals of fished species (NF6a).	NF2 & 3: No more than one year without detection of immature fish (short lived) or more than two years without detection of immature fish (moderate lived species). NF4: Improve native fish population structure for moderate to long-lived flow pulse specialist native fish species NF5: Improve native fish population structure for moderate to long-lived riverine specialist native fish species NF6: As above	Regulated and Unregulated 2a (i) Protect and contribute to the enhancement of the following over the term of this plan: the recorded **distribution or extent**, and **population structure** of target ecological populations. Target ecological populations in these water sources may include known or predicted populations of Native fish including Murray cod, flat-headed galaxias, southern pygmy perch, trout cod, golden perch and silver perch

Findings

A total of 43% of the environmental watering objectives were met for native fish during the current reporting period. The total number of objectives reported were 193, with 83 (43%) achieved and 110 (57%) not achieved. While 64% of objectives were met for the presence of species, only 9% were met for distribution and 18% for abundance. 46% of recruitment/population structure objectives were met, but these were mostly for generalist species without strong ecological links to flow conditions.

Native fish species with reasonable populations sizes were detected during the sampling period. However, five species with smaller populations (for example, threatened species) were not. Many species were found to be occupying restricted distributions in low numbers and most specialist species exhibited low levels of recruitment.

Population Health Index ratings reflected these results. The overall PHI was calculated for a total of 28 fish species (23 detected, plus 5 undetected non-vagrant species). It was Excellent for 0 species, Good for 1 species, Moderate for 10 species, Poor for 10 species and Very Poor for 7 species (Figure 4-39).

The findings for individual native fish objectives were as follows.

- **NF1: species presence.** Partly achieved. No loss of native fish species, but not all potentially present species detected and not all known species detected annually.
- **NF2: short to moderate-lived floodplain generalists.** Partly achieved. PHI Abundance, Distribution and Recruitment objectives met for some target species.
- **NF3: short to moderate-lived floodplain specialists.** Partly achieved. 4 of 6 target species detected, but PHI ratings Very Poor for all but 2 of the 6 species.
- **NF4. moderate to long-lived flow pulse specialists.** Partly achieved. 50% of species detected every year. Only one significant recruitment event recorded over 5 years. PHI Recruitment indicator ratings Poor or Very Poor.
- **NF 5: moderate to long-lived riverine specialists.** Partly achieved. Annual detection and significant recruitment recorded for some species. Overall PHI ratings Poor for most species.

- **NF 6: increase in key recreational fishing species.** Achieved. PHI ratings Moderate for Murray cod and golden perch. Population targets set for future monitoring periods.
- **NF 7: floodplain specialist prevalence and range expansion.** Not achieved. 2 of 5 species detected in low numbers, with most PHI Distribution indicator ratings Very Poor.
- **NF 8: riverine specialist prevalence and range expansion.** Partly achieved. All target species detected during reporting period, but only 2 of 8 detected annually. Immature fish regularly detected for 6 of 8 species.
- **NF 9: flow pulse specialist prevalence and range expansion.** Partly achieved. Immature fish detected for the 2 target species in this group, but only 1 species was detected annually. PHI Distribution indicator ratings Poor and Moderate.
- **NF 10: diadromous species prevalence and range expansion.** Not achieved. No diadromous species detected. Expected given vagrant status of these species.

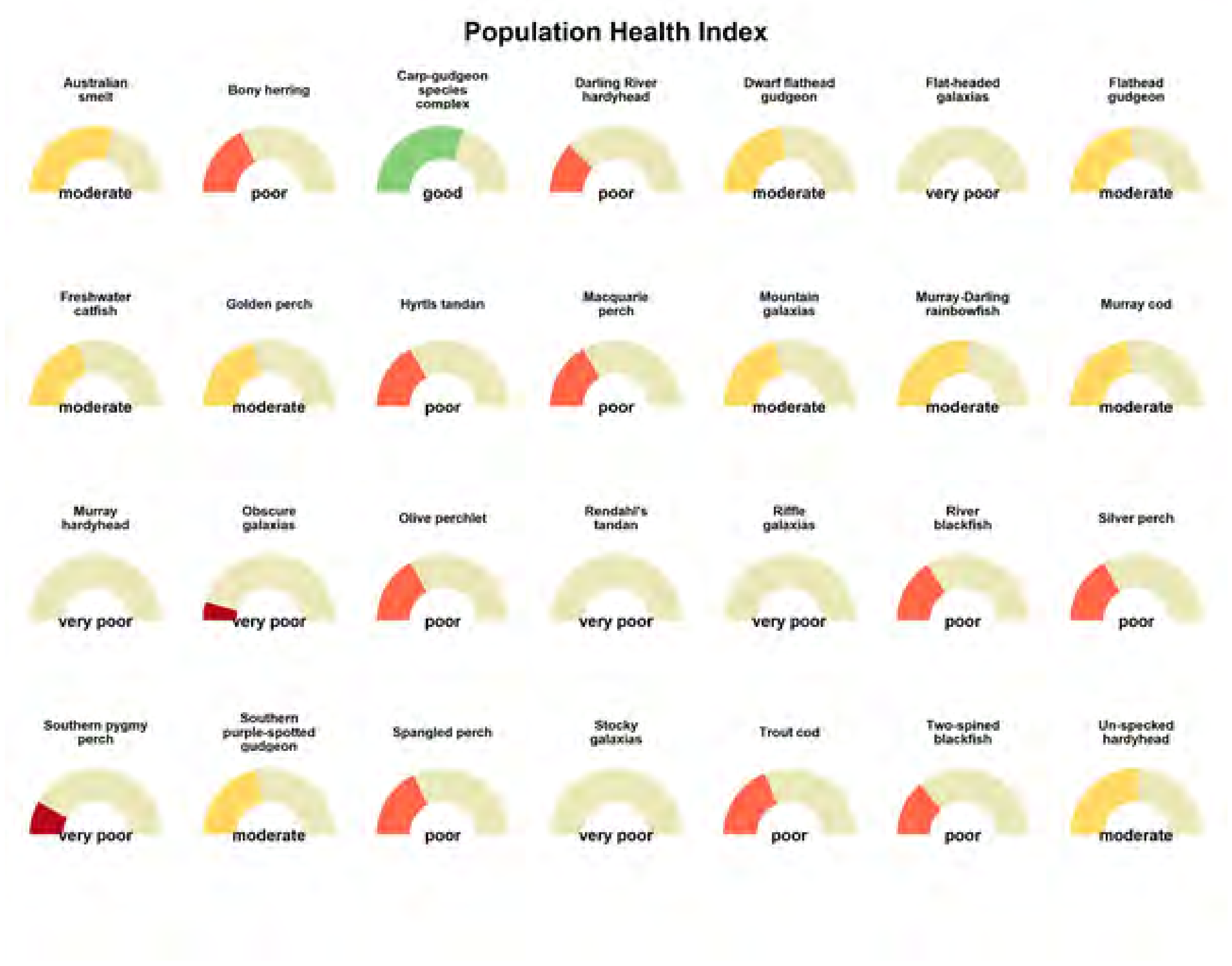


Figure 4-39 Population Health Index ratings for 28 native fish species in the NSW portion of the Murray–Darling Basin for the period 2014-2019.

Undetected species were flat-headed galaxias, Murray hardyhead, Rendahl's tandan, riffle galaxias and stocky galaxias. The rating for these species was Very Poor, together with obscure galaxias and southern pygmy perch, which were detected during sampling.

What was expected

For native fish, the overall expected outcome from implementation of the Basin Plan is a diverse community with sustainable populations occupying a greater proportion of their historic distribution than is currently the case. The following broad outcomes are expected by 2024 (MDBA 2019):

- no loss of native fish species currently present within the Basin
- improved population structure of key fish species through regular recruitment
- increased movement of key fish species
- increased abundance and expanded distributions of key fish species and populations in the northern and southern Basin
- improved recreational fisheries for Murray cod and golden perch
- improved community structure of key native fish assemblages.

Previous large-scale monitoring programs have shown that native fish populations are in a degraded state across the NSW Murray–Darling Basin. The NSW Rivers Survey (Harris & Gehrke 1997), Sustainable Rivers Audit (SRA) (Davies 2008; MDBA 2012), NSW State of the Catchments (NSW Government 2010) and State of Environment (SoE) reports (NSW State of the Environment 2009, 2012, 2015) raised concerns for populations of many threatened native fish species, with several fish communities found to be dominated by non-native species.

The results of the current five-year reporting period were expected to be consistent with those previous reports, particularly given widespread drought conditions during the monitoring period and the lack of full implementation of the Basin Plan.

Condition monitoring also provides data on the status and distribution of rare and threatened species, to inform recovery plans.

Methods

Field surveys

NSW DPI Fisheries established 1,208 field sampling sites within nine river catchments of the NSW portion of the Murray–Darling Basin. These sites comprised key aquatic habitats, such as main channels of rivers, tributary streams, anabranches, lakes and floodplain wetlands (Figure 4-40).

A combination of standardised methods, consistent with previous monitoring programs (NSW Rivers Survey, Sustainable Rivers Audit and NSW Riverine Health Monitoring Evaluation & Reporting), were used to undertake annual surveys (see Gilligan et al. (in prep.) for details). Catch data were analysed and assessed against each native fish objective – under the LTWP and related WSP – to determine if the objectives had been met for the relevant target species.

Population health index

As mentioned above, a new statistical tool – the native fish Population Health Index (PHI) – was developed to assist this process. The PHI provides an objective rating – a snapshot for the reporting period – of the health status of each species. This is important because it will allow natural resource managers to track how native fish populations are responding to long-term conservation interventions, like the delivery of future environmental flows.

The PHI was calculated for each species by combining four indicators. These were as follows.

- **Abundance**: Are abundances of a species increasing or decreasing?
- **Distribution**: How is the population of a fish species spread across the sampling area? Are they being caught where they are expected to occur?
- **Recruitment**: Is a species breeding successfully and are larval fish surviving to become juveniles and adults?

- **Condition**: How healthy are individual fish? Do they show signs of disease or parasites?

These four indicators were themselves calculated from a series of biological and ecological metrics. The results and the overall PHI are presented for each species in relation to the relevant Native Fish Objective.

Further details of the calculation methodology and an overview of the PHI results for all native fish species encountered during this reporting period are provided in the Native Fish Population Health Index section below. Full details of the PHI will be available in Gilligan et al. (in prep.).

New tool for native fish management

NSW DPI Fisheries built a new statistical tool to measure and track the health of native fish.

The Population Health Index provides data on:

- the abundance of each species;
- how widespread each species is;
- how well they are reproducing; and,
- the condition of individual fish.

These insights allow targeted actions to be identified to help the most vulnerable species, and environmental flows to be delivered in ways that provide the biggest benefits.

Ultimately, that means healthier native fish populations and better fishing.

Percentages of watering objectives achieved

The percentages of watering objectives achieved (Table 4-10) were calculated by cross-referencing each fish guild, with its associated species, against broad categories derived from the objectives themselves. The categories were species presence, distribution, abundance, recruitment/population structure and recreational fishing. These should not be confused with the PHI Indicators listed above, despite having similar names.

Whether a target was achieved or not achieved, for a given species in a given category, was determined by examining fish survey data in combination with the objective requirements (for example, regularity of recruitment) and colour-coded accordingly. Green indicates the objective was achieved, orange indicates it was not achieved and red indicates it was not achieved and the trajectory was in the opposite direction. Grey was used to denote objectives that were not reported against in this round of sampling, but which can be reported for in the next five-year monitoring period, while white was used if no target was applicable.

Not all categories of objectives were applicable to every species. These results are colour-coded in Table 4-10, but not used towards the calculation of the percentages of watering objectives that were achieved (these cells lack any white text stating the associated NF objective). Conversely, if a species had more than one associated NF objective in a particular category, then the outcomes for each individual objective were used towards the overall calculation. The number of NF objectives achieved and not achieved were then summed for each category of objective to calculate the respective percentages.

For example, the presence category has two associated NF targets relevant to golden perch. This cell was assigned a value of 2 objectives achieved. Hyrtl's tandan, a few cells below, had one NF target achieved and one not achieved. Summing these numbers down the columns gives 39 NF objectives achieved and 22 non achieved for the presence category. This equates to 64% achieved and 36% not achieved. Fish community status was not reported for any category, so excluded from the calculation.

This process was repeated for each category and the percentages calculated. For the recreational fishing category, 2 objectives (50%) were achieved and 2 (50%) were not reported. These will be reported in future rounds, as mentioned above.

Figure 4-40 Habitat types sampled over the 2014-2019 reporting period.

Objective outcomes

The BWS builds on the Basin Plan and is intended to help environmental water holders, Basin state governments and waterway managers plan and manage environmental watering at a Basin scale, and over the long-term to meet the environmental objectives. This includes making the best use of all water, including held and planned environmental water as well as consumptive water deliveries, to achieve these objectives. Complementing the outcomes of the BWS are objectives and targets in the WRPs and LTWPs (Appendix 1).

The Basin-wide outcomes were transferred to NSW Murray–Darling Basin valleys using the latest information on fish distribution to identify relevant fish community objectives and species-specific targets relating to improved fish outcomes (Appendix 1). The process ensured that valley scale objectives and targets for native fish had a direct line of sight to the overarching BWS outcomes whilst being ecologically relevant to the management and monitoring activities within each valley.

NF1- No loss of Native Fish Species (NF1a); All known species detected annually (NF1b).

Findings

- 23 of 33 expected native fish species and 9 of 14 expected species of native crustaceans were detected. Refer to Appendix 3 for list of the species.
- Four native fish species and three crustacean species had very low catches, with less than 10 individuals detected over the five years.
- Of the 23 fish species detected, 10 were not detected on an annual basis. Of the nine decapod crustacean species, five were not detected annually.

Results

Thirty-three native fish species, 9 alien fish species and 14 decapod crustacean species (crayfish, crabs and shrimp) are known or suspected to occur in at least some part of the NSW portion of the Murray–Darling Basin.

Thirteen of these 33 native fish species are listed as threatened species or populations in NSW under the NSW *Fisheries Management Act 1994*, or nationally under the *Environment Protection and Biodiversity Conservation Act 1999*. Five of the 33 native fish species are only likely to be vagrants to the area.

Standardised fish community sampling was performed at 1,208 sites between 2014–15 and 2018–19. A total of 127,460 fish and decapod crustaceans were detected, including 41,475 individuals of alien fish species (33% of total catch; Appendix 3).

Twenty-three native fish species, eight alien fish species and nine crustacean species were detected. Conversely, 10 native fish species (including the five vagrant native fish species), one alien fish species and five decapod crustacean species, suspected to potentially occur within the NSW portion of the Murray–Darling Basin, were not detected (Figure 4-41). However, some of these were detected by other studies during the reporting period (Appendix 3).

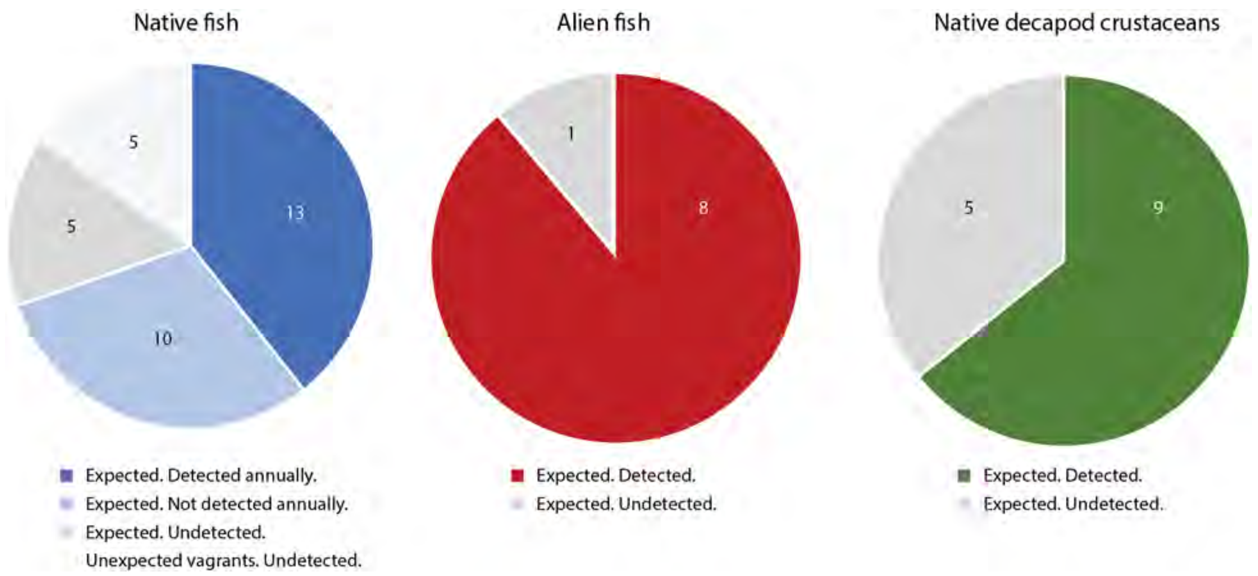


Figure 4-41 Summary of species detections in the NSW Murray–Darling Basin during the 2014-2019 reporting period.

Ten of the 23 native fish species detected during this study were not detected on an annual basis. Four native fish species and three native crustaceans were only found in low numbers, with a total of less than 10 individuals detected over the five-years of sampling.

Two of these rarely detected native fish species are recognised as threatened species (southern purple-spotted gudgeon and southern pygmy perch). Together with the other rarely detected species, these species require further management action such as habitat protection, threatening process remediation, translocations and/or conservation stocking efforts, and targeted monitoring, to avoid local extinction of Murray–Darling Basin populations.

Recommendations

- Maintain the native fish Basin Plan Environmental Outcomes Monitoring program to monitor changes by 2024, 2029 and 2039.
- Undertake higher-resolution, targeted sampling for rare and undetected species. This may include environmental DNA surveys across a large number of small waterbodies.
- Prioritise flow management activities that aid in the recovery of populations of species most at risk of local extinction in NSW (southern pygmy perch, southern purple-spotted gudgeon).

NF2: Increase the distribution (NF2a) and abundance (NF2b) of short- to moderate-lived generalist native fish species; No more than one year without detection of immature fish (short-lived) or more than two years without detection of immature fish (moderate-lived species) (NF2c).

Target species

- Darling River hardyhead (*Craterocephalus amniculus*)
- Un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*)
- Riffle galaxias (*Galaxias arcanus*)
- Mountain galaxias (*Galaxias olidus*)
- Obscure galaxias (*Galaxias oliros*)
- Stocky galaxias (*Galaxias tantangara*)
- Carp-gudgeon species complex (*Hypseleotris* spp.)
- Murray–Darling rainbowfish (*Melanotaenia fluviatilis*)
- Bony herring (*Nematalosa erebi*)
- Flat-headed gudgeon (*Philypnodon grandiceps*)
- Australian smelt (*Retropinna semoni*)

Findings

1. The PHI Abundance indicator for target species were mixed over the five-year reporting period. Un-specked hardyhead, Murray–Darling rainbowfish and Australian smelt ratings were Good. Darling River hardyhead, bony herring and flathead gudgeon ratings were Poor. All other generalist species remained stable.
2. The PHI Distribution indicator for most target species was Moderate or Good. However, for un-specked hardyhead and obscure galaxias it was Poor, and for Darling River hardyhead Very Poor.
3. All generalist species detected, other than Darling River hardyhead and obscure galaxias, met the recruitment regularity target. Both these species exhibited Very Poor PHI Recruitment indicator ratings. Despite meeting these targets, bony herring and Murray–Darling rainbowfish exhibited Poor PHI Recruitment indicator ratings during the reporting period.
4. No riffle galaxias or stocky galaxias were detected.

Results

The generalist flow-response guild contains several species that were generally found in high abundance on an annual basis (Appendix 3). The PHI Abundance indicator ratings of most generalist species was rated as Moderate or Good. Murray–Darling rainbowfish, Australian smelt and un-specked hardyhead were found to be improving, while the abundance of Darling River hardyhead, flat-headed gudgeon and bony herring were in decline (Figure 4-42).

The PHI Distribution indicator of the carp-gudgeon species was rated as Good (Figure 4-42) - indicative of an expanding distribution and high rate of detection within their range. Mountain galaxias, Murray–Darling rainbowfish, bony herring, flat-headed gudgeon and Australian smelt Distribution ratings were all Moderate (Figure 4-42) – reflecting a stable distribution during the reporting period. However, the PHI Distribution indicators of the two hardyhead species and obscure galaxias were rated as Poor and Very Poor (Figure 4-42). This is a result of the low rate of detection within their known range and a contracted extent of occurrence.

This pattern was particularly severe for Darling River hardyhead, which were detected at very few sites where they were expected to occur and only detected in two of the five sampling years. Many of the habitats known to be formerly occupied by Darling River hardyhead were dry as a result of the drought.

Even without full implementation of the Basin Plan, NF2 recruitment regularity targets (that is number of years with detection of immature fish) were achieved for 7 target species and the PHI Recruitment indicator for generalist fishes was rated as Moderate or Good for 5 target species. The two species rated as Poor for PHI Recruitment despite meeting the recruitment regularity targets were Murray–Darling rainbowfish and bony herring.

Darling River hardyhead and obscure galaxias both failed the recruitment regularity target and were rated as Very Poor (Figure 4-42). Poor to Very Poor PHI Recruitment ratings were driven by a lack of 'significant' recruitment events (that is <80th percentile of historic recruitment; see Gilligan et al. (in prep.) and the low proportion of immature fish within the population. Immature Darling River hardyhead, were only detected in one year (2014–15) and no obscure galaxias were detected within the reporting period.

The single population of Critically Endangered stocky galaxias occurring in Tantangara Creek was not targeted by this sampling program within the reporting period as it was already being intensively studied by a University of Canberra PhD student at the time. No riffle galaxias were reported anywhere within the NSW Murray–Darling Basin during the reporting period. Additional targeted sampling for these two taxa is required in subsequent sampling rounds.

Recommendations

- Prioritise flow management activities that:
    - aid in increasing the distribution and recruitment of Darling River hardyhead in the Border Rivers, Gwydir and Namoi Water Source Areas; and,
    - provide dispersal opportunities for un-specked hardyhead into adjacent zones.
- Determine the flow requirements that lead to:
    - increases in abundance of flat-headed gudgeon and prioritise those flow conditions within zones occupied; and,
    - significant recruitment events for bony herring and Murray–Darling rainbowfish and deliver those flows within occupied zones.

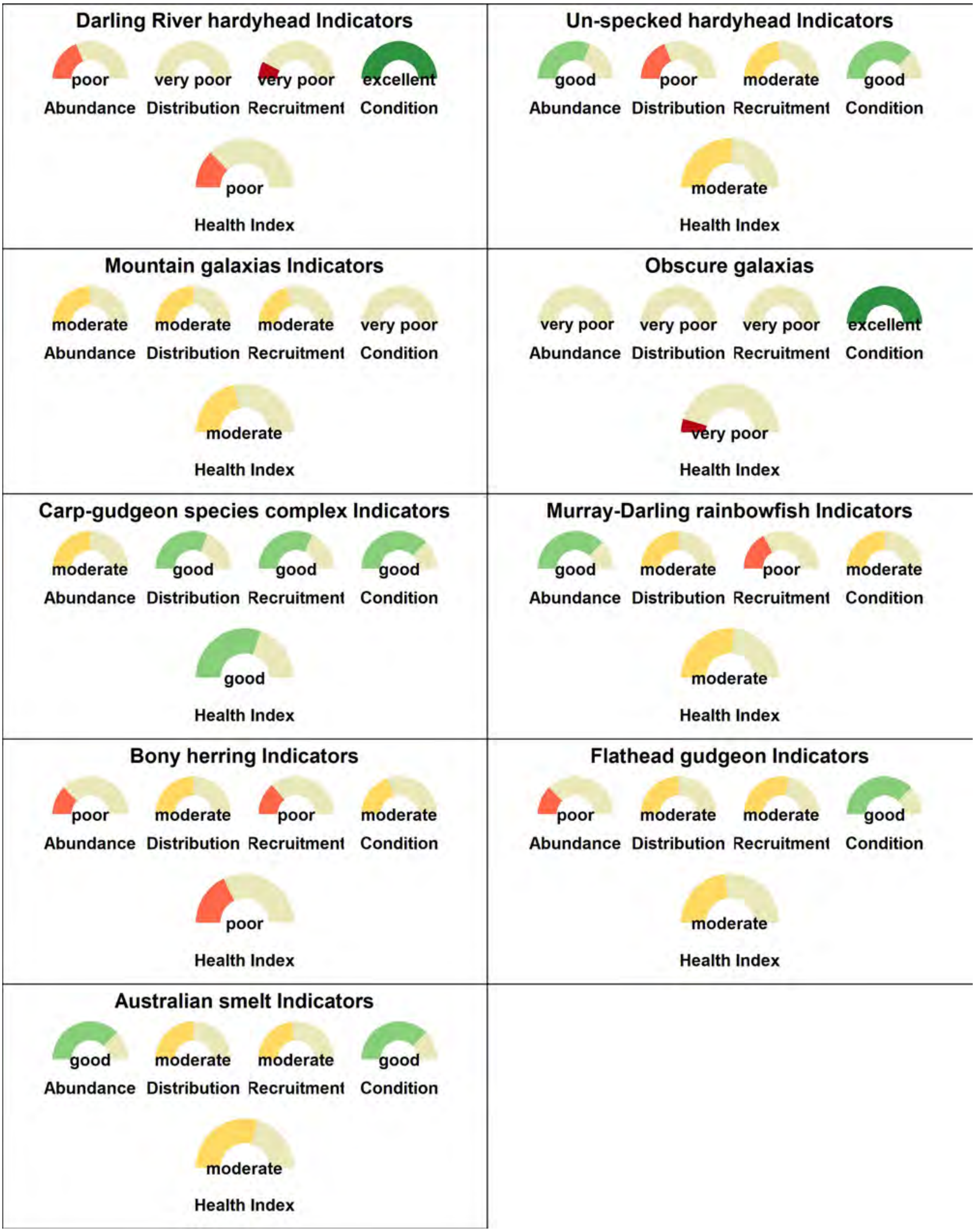


Figure 4-42 Population Health Index and contributing indicator ratings for short to moderate lived generalist native fish species.

No riffle galaxias or stocky galaxias were detected within the reporting period.

NF3: Increase the distribution (NF3a) and abundance (NF3b) of short- to moderate-lived floodplain specialist native fish species; No more than one year without detection of immature fish (short-lived), or more than two years without detection of immature fish (moderate-lived species) (NF3c).

Target species

- Olive perchlet (*Ambassis agassizii*)
- Murray hardyhead (*Craterocephalus fluviatilis*)
- Flat-headed galaxias (*Galaxias rostratus*)
- Southern purple-spotted gudgeon (*Mogurnda adspersa*)
- Southern pygmy perch (*Nannoperca australis*)
- Dwarf flat-headed gudgeon (*Philypnodon macrostomus*)

Findings

- Only four of the six target species within the floodplain specialist guild were detected over the five-year sampling period.
- Olive perchlet increased in abundance over the five-year reporting period. However, abundances of southern pygmy perch and dwarf flat-headed gudgeon decreased.
- The PHI Distribution indicator rating of all floodplain specialists was Very Poor, except for dwarf flat-headed gudgeon which had a Moderate rating.
- Olive perchlet were the only floodplain specialist species that met the recruitment regularity target, and this is a positive environmental outcome for this species asset.

Results

Neither Murray hardyhead nor flat-headed galaxias were detected in the NSW portion of the Murray–Darling Basin. See further discussion of Murray hardyhead under NF7.

The PHI Abundance indicator rating of olive perchlet was Good, with increase in abundance over the five-year reporting period (Figure 4-43). However, it was Poor for Dwarf flatheaded gudgeon and southern pygmy perch due to a decrease in abundance over the five-year reporting period ($p<0.2$). The rating was Moderate for southern purple-spotted gudgeon, with no change in abundance over the short (five-year reporting period) and long-term (three generation intervals) (Figure 4-43).

The PHI Distribution indicator rating of all floodplain specialist species was Very Poor, except for dwarf flat-head gudgeon that had a Moderate rating (Figure 4-43). As a result of the drought, 54% of the floodplain wetland and lake habitats selected for sampling throughout the reporting period were dry. Half of all sites where floodplain specialist fishes were found were river channels rather than wetland habitats.

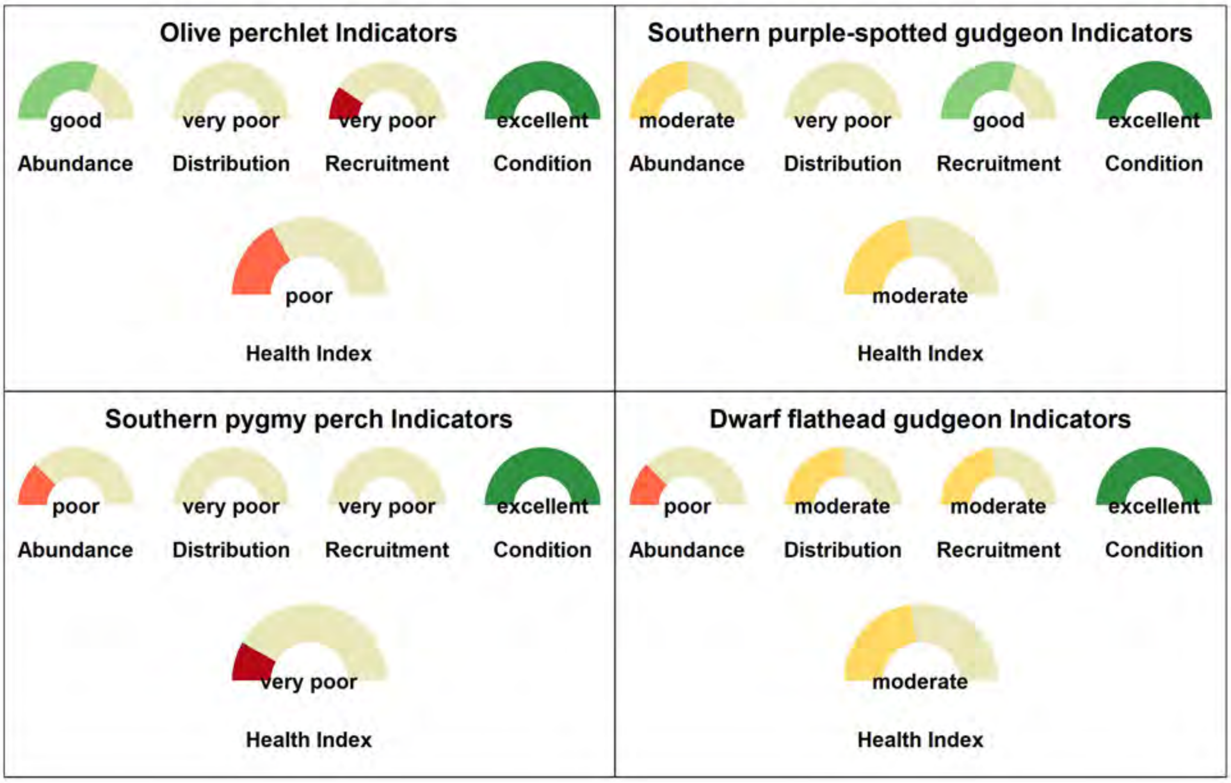


Figure 4-43 Population Health Index and contributing indicator ratings for short to moderate lived floodplain specialist native fish species.

The PHI Recruitment indicator rating of floodplain specialist fishes was rated as Good for southern purple-spotted gudgeon, Moderate for dwarf flat-headed gudgeon, and Very Poor for Southern pygmy perch and olive perchlet as a result of the lack of 'significant' recruitment events within the reporting period and a generally low proportion of abundance and low proportion of immature fish within the population throughout the reporting period. See Gilligan et al. (in prep) for details on the Recruitment indicator calculations.

NF3c recruitment regularity targets were only achieved for olive perchlet, with immature fish detected in all years except 2015–16. The recruitment regularity target was not met for dwarf flat-headed gudgeon, with two consecutive years where immature fish were not detected. The same was true for southern pygmy perch (immature fish detected only in the 2014–15 sampling year) and southern purple spotted gudgeon (immature fish detected only in 2017–18 and 2018–19).

Recommendations

- Prioritise flow management to:
  a) promote habitat quality within occupied zones; and,
  b) provide dispersal opportunities for southern pygmy perch, southern purple-spotted gudgeon and olive perchlet into adjacent zones.
- Determine the flow requirements that lead to:
  a) significant recruitment events for target species and deliver those flows within occupied zones.
  b) increases in abundance of target species and prioritise those flow conditions within zones occupied.
- Undertake higher-resolution, targeted sampling for rare and undetected species. This may include environmental DNA surveys across a large number of small waterbodies.

NF4: Improve native fish population structure for moderate- to long-lived flow pulse specialist native fish species: Juvenile and adult fish detected annually (NF4a); No more than two consecutive years without recruitment in moderate-lived species or four consecutive years without recruitment in long-lived species (NF4b); Minimum of one significant recruitment event in five years (NF4c).

Target species

- Silver perch (*Bidyanus bidyanus*)
- Spangled perch (*Leiopotherapon unicolor*)
- Golden perch (*Macquaria ambigua*)
- Hyrtl's tandan (*Neosilurus hyrtlii*)

Findings

- New recruits (young-of-year), juvenile and adult spangled perch and golden perch were sampled in every year. However, the PHI Recruitment indicator rating was still Poor and Very Poor for these species, respectively.
- None of the three NF4 population structure targets were met for Hyrtl's tandan in the NSW Murray–Darling Basin, with a PHI Recruitment indicator rating of Very Poor.
- Silver perch juveniles and adults were detected every year, but no new recruits (young-of-year) were detected anywhere within the NSW Murray–Darling Basin over the five-year reporting period. As a result, the PHI Recruitment indicator rating was Very Poor.
- Only one significant recruitment event was observed for any flow pulse specialist native fish species (spangled perch) over the five-year reporting period.

Results

The objective of the annual detection of young-of-year, juvenile and adult size classes was met for golden perch and spangled perch. However, it should be noted that golden perch are among the most widely and frequently stocked freshwater fish species in NSW. It is highly likely that some recruitment signals could be influenced by fish stocking. A fish genetics project is underway that will allow identification of stocked fish from naturally recruited fish. This will allow future accounting of fish stocking in assessment of native fish targets.

Only one 'significant' recruitment event was observed for any flow pulse specialist native fish species over the five-year reporting period. The catch per unit effort of young-of-year spangled perch exceeded the 99th percentile of records from the pre-Basin Plan (1994-2014) dataset within the Barwon River (Boomi River Confluence to Upstream Mogil Mogil Weir Pool) Planning Unit of the Barwon–Darling Water Source Area within the 2018–19 sampling round. As a result, spangled perch were the only flow pulse specialist species for which all three NF4 population structure targets were met. This is a positive outcome.

While the current project did not detect a 'significant' recruitment event by golden perch within the reporting period (as measured by an abundance of young-of-year fish). CEWO monitoring of the lower Darling River golden perch population in winter 2018 confirmed the survival of the spring 2016 golden perch year-class within the Lower Darling River population, where they dominated (36 per cent) the population structure (see Summary section below).

None of the NF4 targets were met for Hyrtl's tandan within the NSW Murray–Darling Basin during the reporting period. Young-of-year recruits and juveniles were only detected in 2015–16. Adults were absent from samples detected in 2015–16 and 2018–19. This result was partly attributable to the high proportion of dry sites (80%) within the Intersecting Streams Water Source Area throughout the five-year reporting period.

While juvenile and adult silver perch were detected in every sampling year, no young-of-year recruits were detected for this species anywhere within the NSW Murray–Darling Basin during the reporting period. As a result, only one of the three NF4 targets was met for silver perch.

PHI Abundance ratings of silver perch, golden perch and Hyrtl's tandan were Moderate, suggesting generally stable populations of all three species. However, the results for Golden perch illustrate a complex response, with average abundance during the reporting period being substantially lower than recorded during the pre-Basin Plan period (1994-2014, $p < 0.05$), but counteracted by a statistically significant, although much lower magnitude increase in abundance within the recent five-year period (2014–19, $p < 0.05$). The spangled perch Abundance rating was Poor. (Figure 4-44).

The PHI Distribution indicator was rated as Moderate for golden perch and Hyrtl's tandan, but Poor for silver perch and spangled perch (Figure 4-44). The distribution status of spangled perch was a result of the northward contraction of the species within the Darling River.

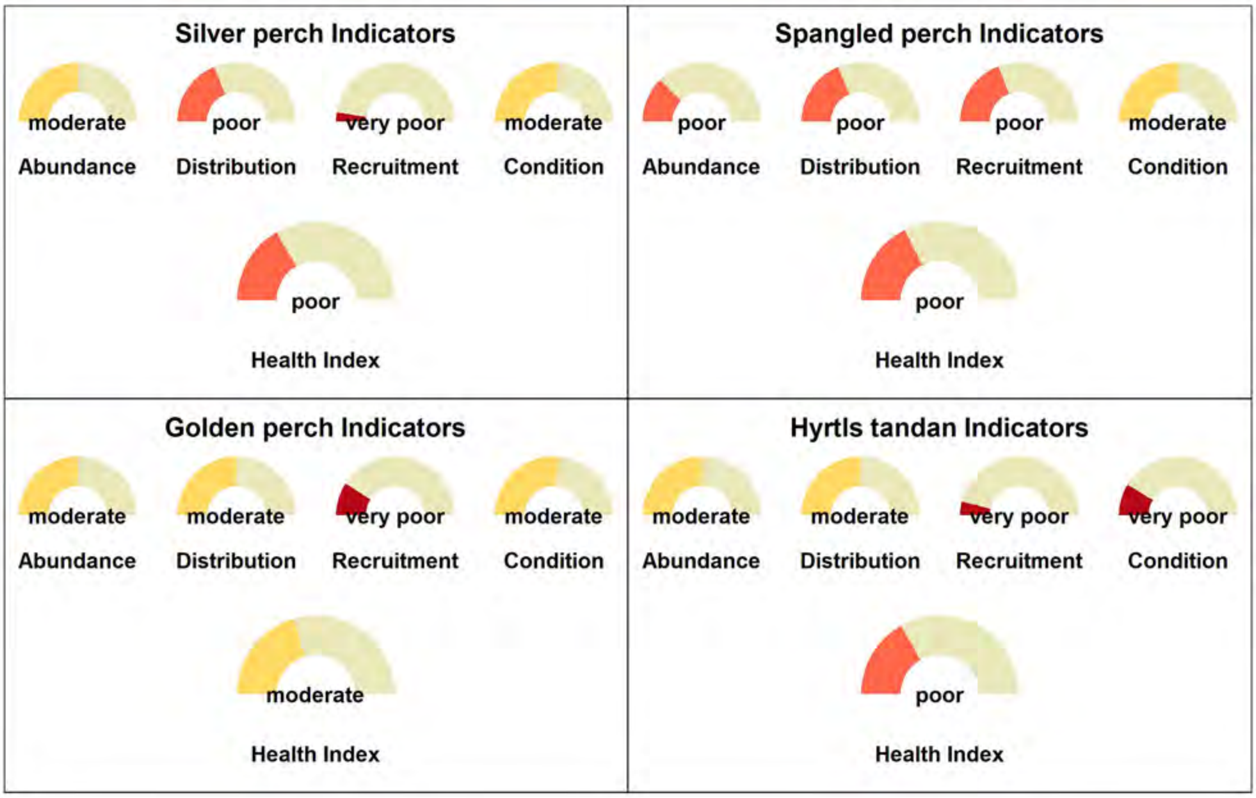


Figure 4-44 Population Health Index and contributing indicator ratings for moderate to long lived flow pulse specialist native fish species.

Recommendations

- Prioritise flow management that provides dispersal opportunities for silver perch and spangled perch into adjacent zones.
- Determine the flow requirements that lead to significant recruitment events for all flow pulse specialist species and deliver those flows within occupied zones.

NF5: Improve native fish population structure for moderate- to long-lived riverine specialist native fish species: Juvenile and adult fish detected annually (NF5a); No more than two consecutive years without recruitment in moderate-lived species, or four consecutive years without recruitment in long lived species (NF5b); Minimum of one significant recruitment event in five years (NF5c).

Target species

- Murray crayfish (*Euastacus armatus*)
- River blackfish (*Gadopsis marmoratus*)
- Two-spined blackfish (*Gadopsis bispinosus*)
- Trout cod (*Maccullochella macquariensis*)
- Murray cod (*Maccullochella peelii*)
- Macquarie perch (*Macquaria australasica*)
- Freshwater catfish (*Tandanus tandanus*)

Findings

1. The objective of annual detection of juvenile and adult fish was met for three of the seven target species within riverine specialist guild: freshwater catfish, Murray cod and trout cod.
2. Young-of-year fish of most species were detected annually, with the exception of two-spined blackfish.
3. Murray cod and Macquarie perch were the only species within this flow-response guild with significant recruitment events detected by this study.

Results

The objective of annual detection of both juvenile and adult fish was met for freshwater catfish, Murray cod and trout cod. Neither juveniles nor adults were detected on an annual basis for any of the other four guild members.

Young-of-year recruits were detected for all riverine specialist target species, except two-spined blackfish. No two-spined blackfish recruitment was detected between 2016–17 and 2018–19, exceeding the maximum two-year target.

Significant recruitment events were recorded for two species: Murray cod and Macquarie perch. The abundance of young-of-year Murray cod and Macquarie perch exceeded the 99th percentile from the 1994-2014 dataset at four sites and one site for each species, respectively. For Murray cod, these sites were in the Murrumbidgee Infrastructure Dependent Floodplain Wetlands of the Murrumbidgee Water Source Area during 2018–19, Mole River in the Border Rivers Water Source Area during 2018–19, and Upper Wakool River and Yallakool Creek in the Murray and Lower Darling Water Source Area in 2015–16. There were no reported releases (stocking) of Murray cod fingerlings within these zones in the 12 months prior to sampling. For Macquarie perch, the single significant recruitment event occurred within the Upper Murrumbidgee River–Tantangara to Burrinjuck Planning Unit of the Murrumbidgee Water Source Area during 2014–15. This was a natural recruitment event associated with stable moderate flow conditions during the spring breeding season following a late August flow pulse.

The PHI Abundance indicator rating for Murray cod, trout cod, freshwater catfish and Murray crayfish was Moderate (stable) for this reporting period (Figure 4-45). It was Poor for river blackfish, two-spined blackfish and Macquarie perch because catch rates declined for each species throughout the five-year reporting period.

The PHI Distribution indicator rating was Moderate for Murray cod, but Poor or Very Poor for all other riverine specialist species (Figure 4-45). This was driven by a low rate of detection within their known ranges and a decrease in their extent of occurrence.

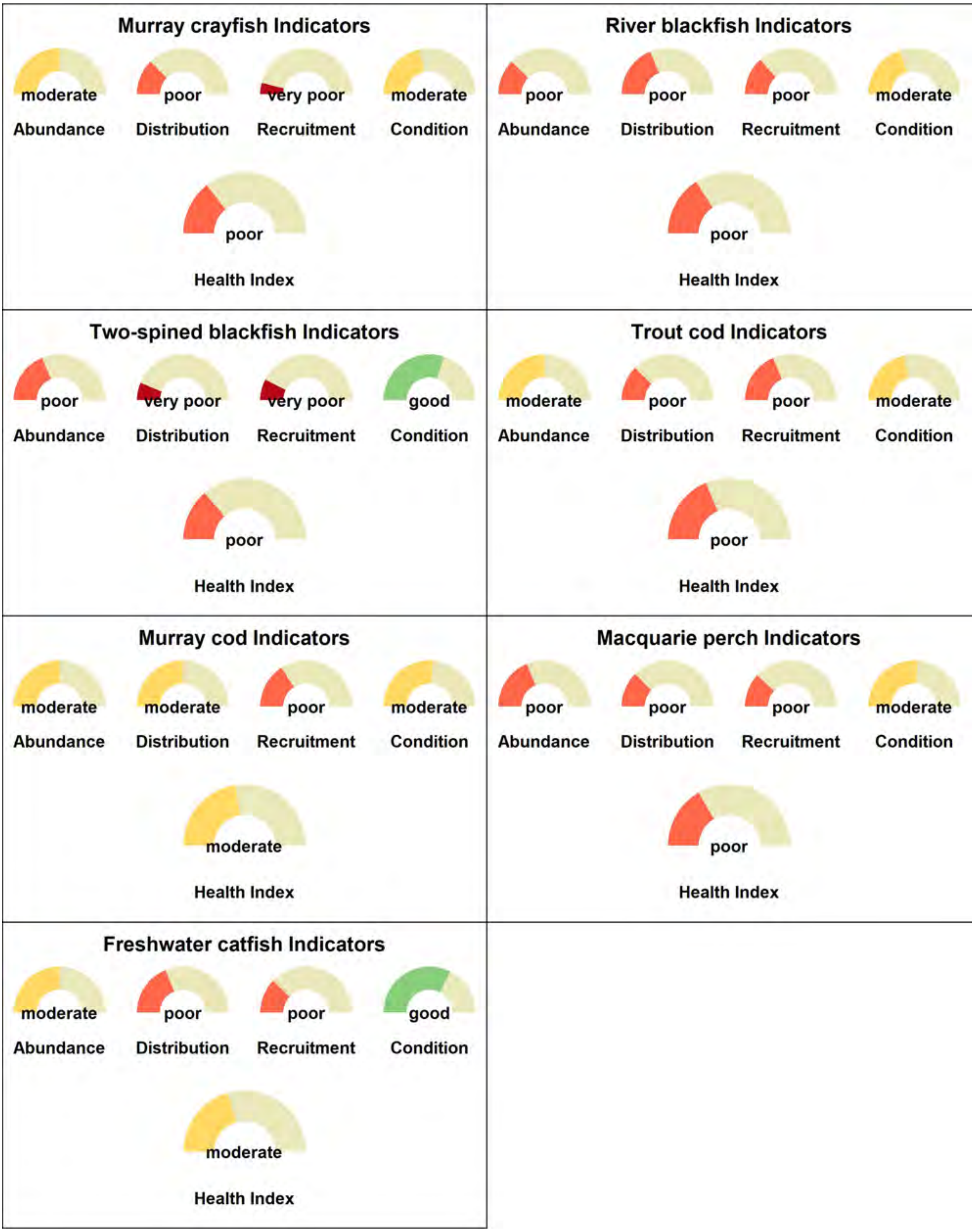


Figure 4-45 Population Health Index and contributing indicator ratings for moderate to long-lived riverine specialist native fish species.

Recommendations

- Prioritise flow management that provides dispersal opportunities for freshwater catfish, Macquarie perch, trout cod, river blackfish, two-spined blackfish and Murray crayfish into adjacent zones.
- Determine the flow requirements that lead to:
  a) increases in abundance of Macquarie perch, river blackfish and two-spined blackfish and prioritise those flow conditions within zones occupied; and,
  b) significant recruitment events for all riverine specialist species and deliver those flows within occupied zones.

NF6: A 25% increase in abundance of mature (harvestable-sized) golden perch and Murray cod (NF6a): Length-frequency distributions include size classes of legal take size for golden perch and Murray cod (NF6b).

Findings

- In total, 62% of all golden perch and 14% of all Murray cod detected were of legal size to be potentially harvested by recreational anglers.
- The size structure of the Murray cod population suggests that recreational fishing pressure has a substantial influence in structuring the population.
- For the next five-year reporting period, a target of a 25% increase in abundance of harvestable sized golden perch and Murray cod equates to an average abundance of 0.63 and 0.37 fish per site respectively.

Results

A total of 552 golden perch and 182 Murray cod were detected of ‘harvestable-size’, based on the legal recreational fishing size limits within NSW (minimum 300 mm for golden perch and slot limit of 550 mm–750 mm for Murray cod) (Figure 4-46).

Harvestable fish represent 62% of golden perch and 14% of Murray cod sampled. Harvestable-sized individuals for both species were detected in all sampling years during the five-year study period.

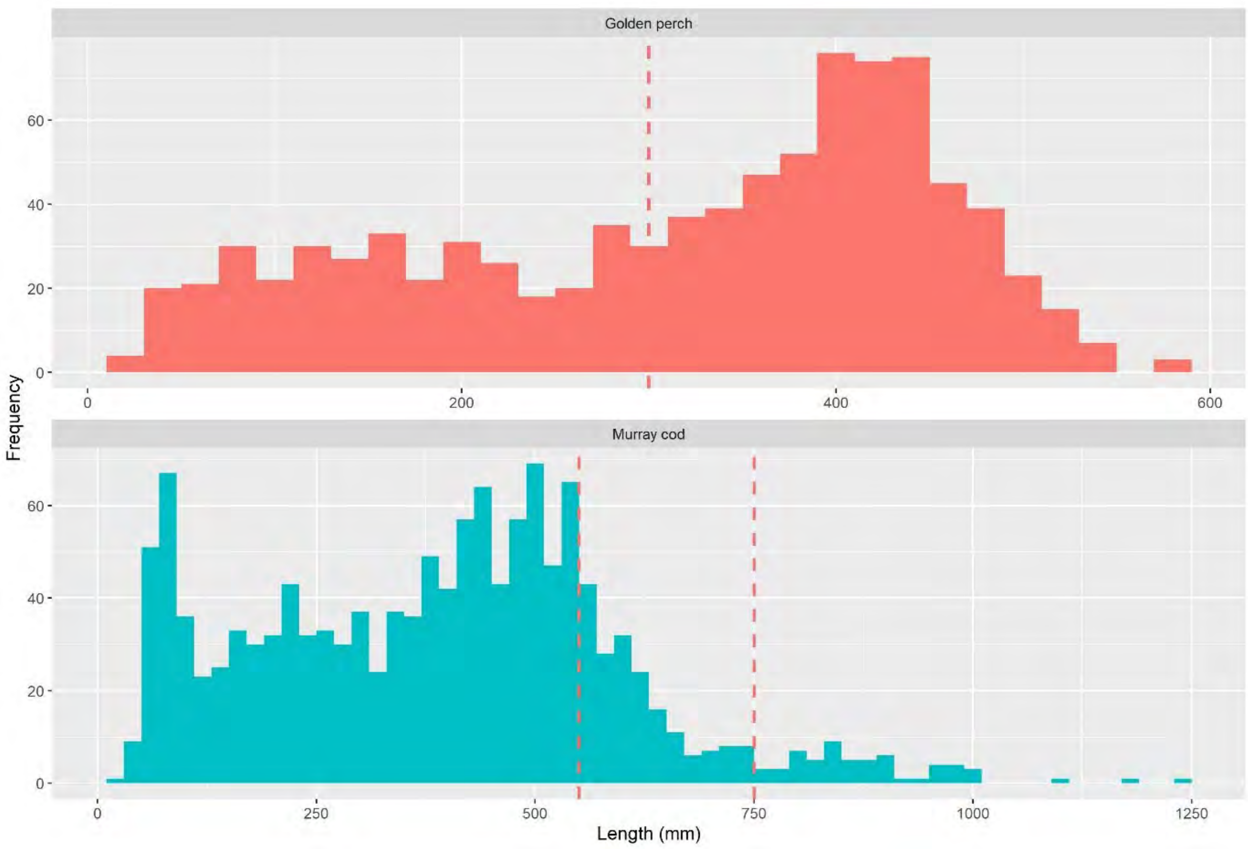


Figure 4-46 Length frequency distribution of golden perch and Murray cod

Vertical dashed lines indicate the current minimum legal length and slot limit for golden perch and Murray cod, respectively.

A total of 60 Murray cod above the maximum harvestable-size limit of 750 mm were detected, representing 5% of the total surveyed population. These individuals were 755 mm–1,240 mm (mean: 888 mm). Only five individuals measuring above the trophy size of 1 metre in length were detected. There was a substantial drop in abundance of size classes of Murray cod within the slot limit. Conversely, size classes with the highest abundance of golden perch were above the minimum legal length (Figure 4-46).

For the next five-year reporting period, a target of a 25% increase in abundance of harvestable sized golden perch and Murray cod equates to an average abundance of 0.63 and 0.37 fish caught per site, respectively, using the standardised sampling techniques (See Gilligan et al. (in prep.)).

Recommendations

- Continue to monitor popular recreational fishing species in the NSW portion of the Murray–Darling Basin.
- Enhance understanding of flow requirements that lead to significant recruitment events for target species.
- Deliver environmental water to improve recruitment success of golden perch and Murray cod within occupied zones.

NF7: Increase the prevalence and/or expand the population of key short- to moderate-lived floodplain specialist native fish species into new areas (within historical range) (NF7a). Adults detected annually in specified Planning Units (NF7b); No more than one year without detection of immature fish in specified planning units (short-lived) or two years without detection of immature fish in specified planning units (moderate-lived species) (NF7c).

Target species within water source area (number of specified planning units)

- Olive perchlet (*Ambassis agassizii*)
    - Murray and Lower Darling (28)
    - Lachlan (23)
    - Murrumbidgee (14)
    - Border Rivers (15)
    - Macquarie–Castlereagh (4)
    - Gwydir (3)
- Murray hardyhead (*Craterocephalus fluviatilis*)
    - Murray and Lower Darling (28)
    - Murrumbidgee (14)
- Flat-headed galaxias (*Galaxias rostratus*)
    - Murray and Lower Darling (28)
    - Lachlan (23)
    - Murrumbidgee (14)
    - Macquarie–Castlereagh (4)
- Southern purple-spotted gudgeon (*Mogurnda adspersa*)
    - Murray and Lower Darling (28)
    - Murrumbidgee (14)
- Southern pygmy perch (*Nannoperca australis*)
    - Murray and Lower Darling (28)
    - Lachlan (23)
    - Murrumbidgee (14)

Findings

- Two target species, Murray hardyhead and flat-headed galaxias, were not detected anywhere within the NSW Murray–Darling Basin during the reporting period.
- No southern purple-spotted gudgeon were detected in specified Planning Units within the Southern Basin.
- PHI Distribution indicator ratings for the two target species that were detected, olive perchlet and southern pygmy perch, were Very poor.
- In general, only very small numbers of these species were detected at occupied sites.
- As a result of the low and infrequent captures, the detection of immature and mature individuals was either non-existent to too irregular for this objective to be met.

Results

NF7 targets for five key floodplain specialist fishes were applicable across 87 specified Planning Units within the NSW Murray–Darling Basin. However, none or only small numbers of these target species were detected.

Olive perchlet (Endangered population)

Olive perchlet were listed in 87 specified Planning Units across six Water Source Areas. Within the five-year reporting period, they were detected at five sites across four specified Planning Units. This represents 5% of specified Planning Units and 1% of sites within those units. One or two individuals were detected from one of eight sites in the Inverell Planning Unit, one of four sites in the Campbells and Camp Creeks Planning Unit, one of two sites in the Yetman Planning Unit and two of 10 sites in the Ottleys Creek Planning Unit – all within the Border Rivers Water Source Area.

A further 25 individuals were detected from one of five samples within the Mungindi to Boomi River Confluence Planning Unit of the Barwon–Darling Water Source Area, which was not specified as a priority Planning Unit. The PHI Distribution indicator for olive perchlet was Very Poor (Figure 4-43), indicating a very low rate of detection within their known range and a contracted extent of occurrence. Prevalence scores were very low at 0.02 - 0.03.

Murray hardyhead (Critically Endangered)

No Murray hardyhead were detected at any sites within the 42 specified Planning Units within the Murray and Lower Darling Water Source Area. Detections were unlikely during sampling, as Murray hardyhead had not been recorded in NSW between 2003–04 and December 2018. In 2018, a re-introduction program commenced, translocating Murray hardyhead from South Australia to a managed wetland within the Lower Murray Floodplain, NSW. While this population appears to have established at the release site, it has not yet had the opportunity to disperse.

Flat-headed galaxias (Critically Endangered)

No flat-headed galaxias were detected at any sites within the 69 specified Planning Units across four Water Source Areas. The last detection of flat-headed galaxias reported in NSW was in December 2013, in an upper Murray River wetland. The species is considered extremely rare, however could appear in any one of several regions across four Water Source Areas.

Southern purple-spotted gudgeon (Endangered)

No southern purple-spotted gudgeon were detected at any sites within the 42 specified Planning Units within the Murrumbidgee or Murray and Lower Darling Water Source Areas. Detections were unlikely during sampling, as no southern purple-spotted gudgeon have been reported in the NSW portion of the southern Murray–Darling Basin since 1968 (Llewellyn 2006). However, reports of the species in wetlands in Victoria and South Australia as recently as 2019 suggest that the species may be present in, or could feasibly self-colonise, the Murray and Lower Darling Water Source Area of NSW. Additional targeted, higher-resolution spatial sampling within known occupied habitats is required to determine the extent of each southern basin population.

Southern pygmy perch (Endangered)

Southern pygmy perch were listed in 65 specified Planning Units across three Water Source Areas. However, between 2014–15 and 2018–19 the species was only detected within the Murrumbidgee Water Source Area, where a single individual was detected from the Upper Billabong Creek Planning Unit. These data represent the presence of southern pygmy perch in 2% of specified Planning Units and 0.2% of sites within those units. The PHI Distribution indicator for southern pygmy perch was Very Poor (Figure 4-43), indicating a very low rate of detection within their known range and a contracted extent of occurrence. Prevalence scores were very low at 0.02 - 0.03.

Recommendations

- Support the existing Murray hardyhead reintroduction program by using environmental water to maintain habitat quality within the existing wetland, and to manage additional suitable wetlands to allow establishment of further populations.
- Locate any remnant populations of flat-headed galaxias anywhere within the Murray–Darling Basin, protect those habitats and initiate a conservation stocking program for NSW.
- Conduct additional targeted higher-resolution spatial sampling of southern pygmy perch, southern purple-spotted gudgeon and olive perchlet populations within known occupied habitats is required to determine the extent of each population.
- Prioritise flow management to:
  a) maintain and enhance habitat quality within occupied Planning Units; and,
  b) provide dispersal opportunities into adjacent zones.
- Review priority species and populations to focus opportunities to support enhancement and additional population objectives and targets during the 2020-2024 reporting period.

NF8: Increase the prevalence and/or expand the population of key moderate- to long-lived riverine specialist native fish species into new areas (within historical range) (NF8a). Adults detected annually in specified Planning Units (NF8b); No more than two years without detection of immature fish in specified Planning Units (moderate-lived species) or four years without detection of immature fish in specified Planning Units (long-lived species) (NF8c).

Target species within water source area (number of specified planning units)

- Olive perchlet (*Ambassis agassizii*)
  - Namoi (27)
  - Murray and Lower Darling (17)
  - Lachlan (17)
  - Murrumbidgee (15)
- Murray crayfish (*Euastacus armatus*)
  - Murray and Lower Darling (17)
- Two-spined blackfish (*Gadopsis bispinosus*)
  - Murray and Lower Darling (17)
- River blackfish (*Gadopsis marmoratus*)
  - Namoi (27)
  - Murrumbidgee (15)
  - Macquarie–Castlereagh (6)
- Trout cod (*Maccullochella macquariensis*)
  - Murray and Lower Darling (17)
  - Lachlan (17)
  - Murrumbidgee (15)
  - Macquarie–Castlereagh (6)
- Macquarie perch (*Macquaria australasica*)
  - Murray and Lower Darling (17)
  - Lachlan (17)
  - Murrumbidgee (15)

  - Macquarie–Castlereagh (6)
- Southern purple-spotted gudgeon (*Mogurnda adspersa*)
  - Namoi (27)
  - Murray and Lower Darling (17)
  - Murrumbidgee (15)
  - Border Rivers (12)
  - Gwydir (12)
  - Macquarie–Castlereagh (6)
- Freshwater catfish (*Tandanus tandanus*)
  - Namoi (27)
  - Murray and Lower Darling (17)
  - Murrumbidgee (15)
  - Border Rivers (12)
  - Gwydir (12)
  - Macquarie–Castlereagh (6)
  - Barwon–Darling (2)

Findings

- All eight target species were detected during this five-year study, but only adult freshwater catfish and trout cod were detected annually.
- PHI Distribution indicator ratings for target moderate to long-lived riverine specialist native fish species were Poor or Very Poor.
- Targets for regular detection of immature fish at the NSW Murray–Darling Basin scale were met for six of the eight target species.
- No olive perchlet were detected in NF8 specified Planning Units, although they were detected in several un-specified Planning Units.

Results

NF8 targets for eight riverine specialist fishes were applicable within 17 and up to 108 specified Planning Units. Intermediate abundances of NF8 target species were detected over the five-year reporting period, from a maximum average of 6.8 river blackfish per sample site to minimum average of 1.0 Murray crayfish individuals per sample site.

PHI Distribution indicator ratings for the moderate- to long-lived riverine specialist native fish species were Very Poor (two-spined blackfish, southern purple-spotted gudgeon and olive perchlet) or Poor (all other target species) (Figure 4-45). Extent of occurrence decreased for all species in this guild relative to pre-Basin Plan modelled distributions (1994–2014 vs 2014–19). Furthermore, prevalence was <1 for all six of the target long-lived riverine specialist species, meaning that they were detected at less sites than expected. Trout cod and two-spined blackfish had the highest prevalence scores of ~ 0.3 (present at 30% of sites expected). The remaining four target species had prevalence scores of 0.14 to 0.18.

NF8 targets for regular detection of immature fish at the NSW Murray–Darling Basin scale were met for six of the eight species. The maximum period of no detection of immature moderate-lived river blackfish and two-spined blackfish was one year. The maximum period of no detection of immature long-lived Macquarie perch was two years (immature fish last detected in 2016–17). Immature freshwater catfish and trout cod were detected annually throughout the reporting period. The exceptions were southern purple-spotted gudgeon and olive perchlet.

Trout cod (Endangered) and Macquarie perch (Endangered)

Fifty-five specified Planning Units across four Water Source Areas were prioritised for both trout cod and Macquarie perch. Trout cod were detected at 16 sites within six of the specified Planning Units, 11% of specified Planning Units and 5% of sites within specified Planning Units. A single individual was also detected at a single site within the Upper Macquarie River Planning Unit which was un-specified.

Macquarie perch were detected at 7 sites within three of the specified Planning Units, representing 5% of specified Planning Units and 2% of sites within specified Planning Units. The average catch at sites within specified Planning Units was very similar, at 0.15 ± 0.04 (S.E.) for trout cod and 0.14 ± 0.09 (S.E.) for Macquarie perch.

Two-spined blackfish (Near Threatened) and Murray crayfish (Vulnerable)

Seventeen specified Planning Units within the Murray and Lower Darling Water Source Area were prioritised for two-spined blackfish and Murray crayfish. Two-spined blackfish were only detected at one site in each of two Planning Units; the Indi Water Source and the Upper Murray Tributaries–Swampy Plains, representing 12% of specified Planning Units and 2% of sites within specified Planning Units. They were also detected at one site within Goodradigbee River and three sites within the Upper Tumut–Above Blowering Dam wall Planning Units in the Murrumbidgee Water Source Area, where no priority Planning Units were specified for this species. Average catch at sites within specified Planning Units was 0.21 ± 0.21 (S.E.).

Murray crayfish were only detected at three sites within the Upper Murray Water Source and Murray River–Hume to Yarrawonga Planning Units, representing 12% of specified Planning Units and 3% of sites within specified Planning Units. Average catch at sites within specified Planning Units was 0.04 ± 0.02 (S.E.). It should be noted that the methods used are not particularly effective at sampling large Murray crayfish that occupy main river channel sites, and therefore they would be under-reported by this program. A targeted sampling program has detected Murray crayfish in two of the specified Planning Units where they were un-detected here. Murray crayfish were detected at an additional 18 sites within eight un-specified Planning Units in the Murrumbidgee Water Source Area.

River blackfish (Least Concern)

Forty-eight specified Planning Units were prioritised for river blackfish across the Namoi, Macquarie-Castlereagh and Murrumbidgee Water Source Areas. River blackfish were detected at 4 sites within three of the specified Planning Units, representing 6% of specified Planning Units and 2% of sites within specified Planning Units. Average catch at sites within specified Planning Units was 0.47 ± 0.41 (S.E.). River blackfish were detected at an additional 18 sites, spread across 8 un-specified Planning Units. The average catch at sites within specified Planning Units was 0.47 ± 0.41 (S.E.).

Southern purple-spotted gudgeon (Endangered)

Eighty-nine specified Planning Units across six Water Source Areas were prioritised for riverine populations of southern purple-spotted gudgeon. They were only detected within a single site within the Gwydir downstream of Copeton Planning Unit within the Gwydir Water Source Area, representing just 1% of specified Planning Units and 0.3% of sites within specified Planning Units. The average catch at sites within specified Planning Units was 0.005 ± 0.005 (S.E.). Riverine populations of southern purple-spotted gudgeon were also detected at single sites within the Bonshaw Planning Unit within the Border Rivers and Tycannah Creek within the Gwydir Water Source Area. The Tycannah Creek population represents the discovery of an entirely new remnant population.

Olive perchlet (Endangered Population)

Seventy-six specified Planning Units across four Water Source Areas were prioritised for riverine populations of olive perchlet. None were detected within the specified zones. However, riverine populations of olive perchlet were detected at five sites within four unspecified Planning Units in the Border Rivers Water Source Area.

Freshwater catfish (Endangered Population)

Ninety-four specified Planning Units across seven Water Source Areas were prioritised for freshwater catfish. They were detected at 25 sites within 15 of the specified Planning Units, representing 14% of specified Planning Units and 5% of sites within specified Planning Units. They were also detected at an additional 25 sites within 10 un-specified Planning units. Average catch at sites within specified planning Units was 0.17 ± 0.05 (mean ± S.E.).

Recommendations

- Conduct additional targeted sampling of two-spined blackfish and Murray crayfish.
- Prioritise flow management to:
  a) maintain and enhance habitat quality within the zone occupied by Macquarie perch, two-spined blackfish and trout cod; and,
  b) provide dispersal opportunities into adjacent zones.
- Review priority species and populations to focus opportunities to support enhancement and additional population objectives and targets during the 2020-2024 reporting period.

NF9: Increase the prevalence and/or expand the population of key moderate- to long-lived flow pulse specialists native fish species into new areas (within historical range) (NF9a). Adults detected annually in specified Planning Units (NF9b). No more than one year without detection of immature fish in specified Planning Units (short-lived) or no more than two years without detection of immature fish in specified Planning Units (moderate-lived species) (NF9c).

Target species within water source area (number of specified planning units)

- Silver perch (*Bidyanus bidyanus*)
  - Murrumbidgee (15)
  - Barwon–Darling (14)
  - Murray and Lower Darling (12)
  - Border Rivers (12)
  - Macquarie–Castlereagh (6)
  - Namoi (3)
  - Lachlan (1)
- Hyrtl's tandan (*Neosilurus hyrtlii*)
  - Macquarie–Castlereagh (6)

Findings

1. The target species in this guild were both detected during this five-year reporting period, but only adult silver perch were detected annually.
2. PHI Distribution indicator rating was Poor for silver perch and Moderate for Hyrtl's tandan.
3. Targets for regular detection of immature fish at the NSW Murray–Darling Basin scale were met for both species.

Results

NF9 targets for the two target species were applicable across 6 and 51 specified Planning Units for Hyrtl's tandan and silver perch, respectively. Low numbers of these species were detected over the five-year reporting period.

Specified Planning Units for silver perch were within six Water Source Areas. Silver perch were detected at 20 sites within 12 of the specified Planning Units, representing 24% of specified Planning Units and 5% of sites within specified Planning Units. Average catch at sites within specified Planning Units was 0.07 ± 0.02 (S.E.). Silver perch were detected at an additional 12 sites, spread across six un-specified Planning Units.

No Hyrtl's tandan were detected within the six specified Planning Units within the Macquarie–Castlereagh Water Source Area. However, Hyrtl's tandan were detected at five sites within three un-specified Planning Units within the Intersecting Streams Water Source Area.

The PHI Distribution indicator rating was Moderate for Hyrtl's tandan and Poor for silver perch. Extent of occurrence decreased for both species relative to their pre-Basin Plan modelled distributions (1994-2014 vs 2014-19). Furthermore, prevalence score was <1 (0.07) for both target species, meaning that they were detected at less sites than expected.

Immature silver perch were detected in every year throughout the reporting period, meeting the NF9 targets for regular detection of immature fish at the NSW Murray–Darling Basin scale. However, immature Hyrtl's tandan were only detected once in 2015–16, exceeding the objective of no more than two consecutive years without detection of immature fish target.

Recommendations

- Initiate a widespread conservation stocking program for silver perch in NSW.
- Undertake additional targeted sampling of Hyrtl's tandan in specified Planning Units.
- Prioritise flow management to maintain and enhance habitat quality within zones occupied by silver perch and facilitates dispersal into adjacent zones.
- Protect habitat quality of waterholes within zones occupied by Hyrtl's tandan.
- Review priority species and populations to focus opportunities to support enhancement and additional population objectives and targets during the 2020-2024 reporting period.

NF10: Increase the prevalence and/or expand the population of key moderate- to long-lived diadromous native fish species into new areas (within historical range)

Target species within water source area and (number of specified planning units)

- Short-finned eel (*Anguilla australis*)
  - Murray and Lower Darling (8)
  - Murrumbidgee (4)
- Pouched lamprey (*Geotria australis*)
  - Murray and Lower Darling (8)
  - Murrumbidgee (4)
- Short-headed lamprey (*Mordacia mordax*)
  - Murray and Lower Darling (8)
  - Murrumbidgee (4)

Findings

NF10 targets for diadromous fishes were applicable across 12 priority Planning Units within the Murray and Lower Darling (8 Planning Units) and Murrumbidgee (4 Planning Units) Water Source Areas. However, no diadromous fishes were detected over the five-year reporting period.

The only diadromous fishes ever recorded within the NSW portion of the Murray–Darling Basin are short-headed lamprey, pouched lamprey, short-finned eel, long-finned eel (*Anguilla reinhardtii*) and congolli (*Pseudaphritis urvillii*). However, due to a scarcity of records for all but short-headed lamprey, the other four species cannot be considered more than irregular upstream vagrants within the Murray River. Short-headed lamprey have not been detected within NSW sections of the Murray River since 1993-94.

Recommendations

- Prioritise flow management to enhance and facilitate dispersal into applicable Planning Units for diadromous species.
- Review priority species and populations to focus opportunities to support range extension objectives and targets during the 2020-2024 reporting period.

Native Fish Population Health Index

What it does

The Native Fish Population Health Index (PHI) represents the status of a native fish species. It provides a rigorous snapshot of abundance, distribution, reproduction and health. This allows the condition of fish populations to be tracked over time.

The PHI is important because it empowers natural resource managers and other stakeholders with better information. It allows investment and action to be directed not only towards species that need support, such as threatened species, but at the components of the biology and ecology of those species that are impeding their recovery.

For example, a threatened species might have strong population growth, with good numbers of healthy adult fish reproducing each season. However, the species PHI might still be Poor because the species is only found at a few, isolated sites. Managers could use this information to identify similar habitats nearby and translocate fish or prioritise connecting flows to establish new populations, thereby helping the species recover and improving its PHI.

The PHI is also useful at larger scales. It allows managers to see how species with similar ecological traits or life histories might be managed together. For example, if all fish species that require floodplain habitats for breeding have a low overall PHI due to poor recruitment, managers could recommend delivery of environmental flows to connect main-channel and floodplain habitats during the breeding seasons of those species.

This is the first time such a tool has been made available for native fish in NSW.

How it is calculated

The PHI is calculated using a hierarchical population health assessment framework (Figure 4-47). This framework prescribes the integration of metrics into indicators, and indicators into the overall index. This allows the resilience and viability of native fish populations to be quantified and compared across and within species.

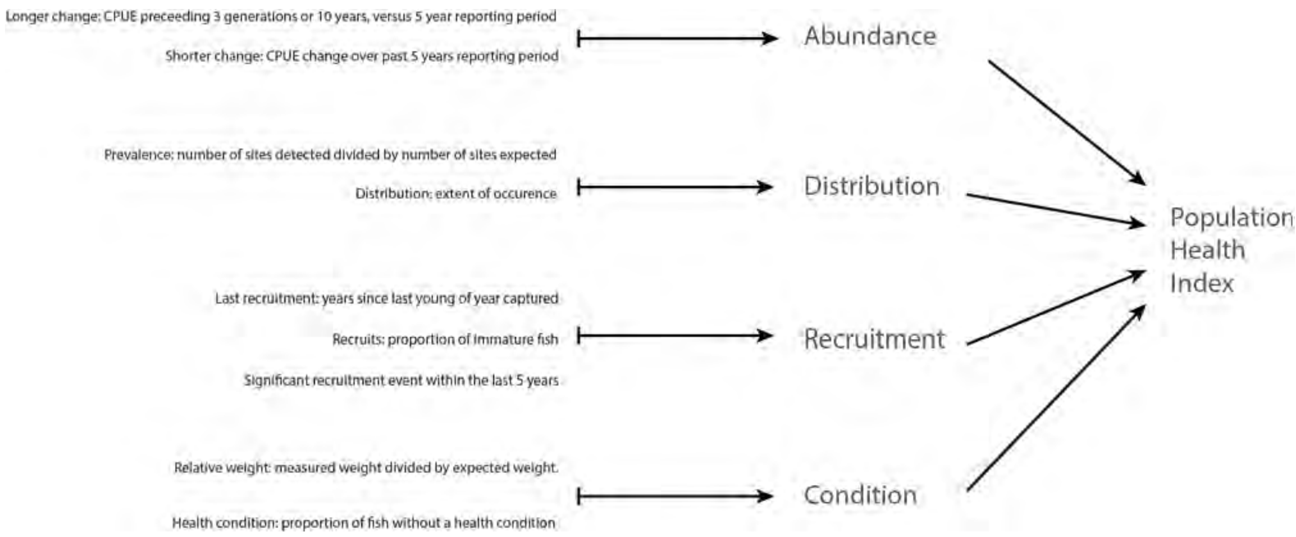


Figure 4-47 The hierarchical design framework used for generating the Population Health Indicator for the NSW Murray–Darling Basin native fish species.

Calculating the PHI for each species involves several steps. First, several metrics are calculated for each species. Second, these metrics are weighted using values derived from an expert-elicitation process. Third, the weighted metrics are aggregated to represent four key health indicators (abundance, distribution, recruitment and condition). Fourth, the weighted indicators are combined into an overall Population Health Index.

Each metric used in the calculation of the indicators (Figure 4-47) was scored between 0–1 based upon predefined values derived from historic data, life history traits of the species and an expert-elicitation process. Metric scores were then weighed as described above and the weighed scores were used in the calculation of the indicator.

Full methodological details will be available in Gilligan et al. (in prep.).

What was found

PHI ratings were Poor or Very Poor for 60% of the native fish sampled in the NSW Murray–Darling Basin during the current reporting period. 35% of species sampled had a PHI of Moderate. Only one taxon, the native carp-gudgeon species complex, had a PHI rating of Good (Figure 4-48).

PHI ratings varied between species based on their degree of habitat specialisation and ecological relationship with river flows. Short-lived generalists with flexible flow and habitat requirements were found to be in better health (albeit not very good health) relative to long-lived specialists with life-cycles strongly linked to flow conditions or floodplain habitats (Figure 4-48).

The generalist flow-response guild had an average PHI of Moderate (mean PHI = 0.41 ± 0.06 S.E.). The exception was the Darling River hardyhead, which was rated as being in Poor population health due to Very Poor recruitment and distribution.

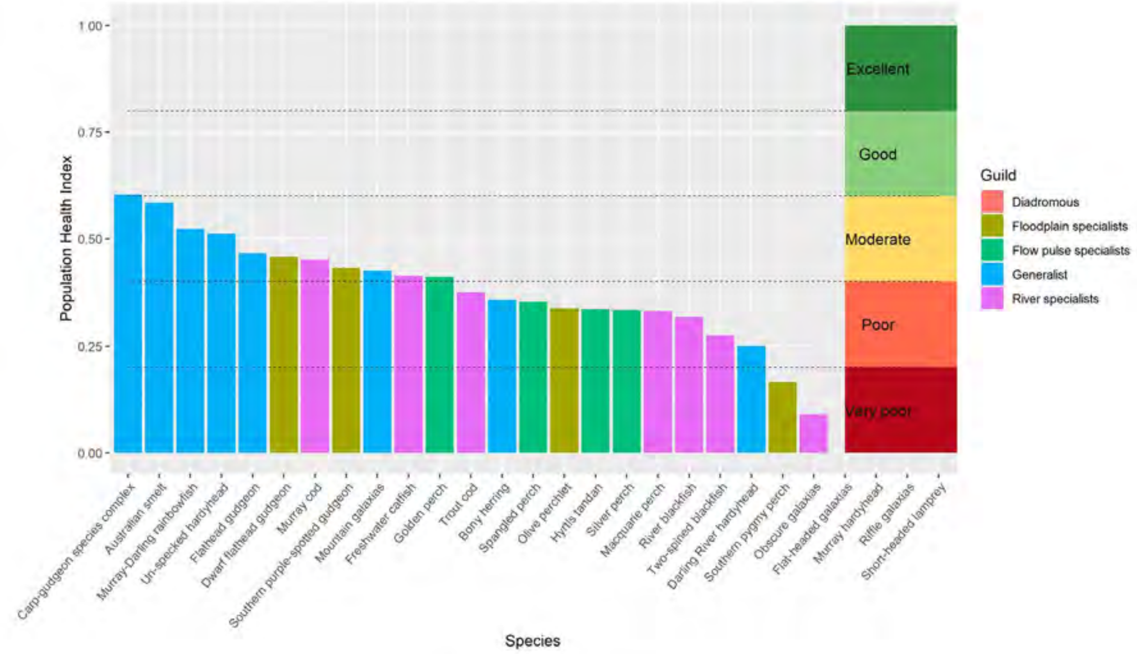
The flow pulse specialist guild had an average PHI of Poor (mean PHI = 0.36 ± 0.04 S.E.). This was only slightly lower than that of generalists, and higher than riverine or floodplain specialist guilds.

The riverine specialist guild had an average PHI of Poor (mean PHI = 0.32 ± 0.04 S.E.). Only two riverine species, Murray cod and freshwater catfish, were rated in Moderate (stable) condition. All other riverine specialists were found to be in decline.

The floodplain specialist flow-response guild had an average PHI of Very Poor (mean PHI = 0.23 ± 0.08 S.E.). These species were in the poorest population health relative to the other guilds.

See Table 2 of DPI (2015) for further details on these functional guilds.

A



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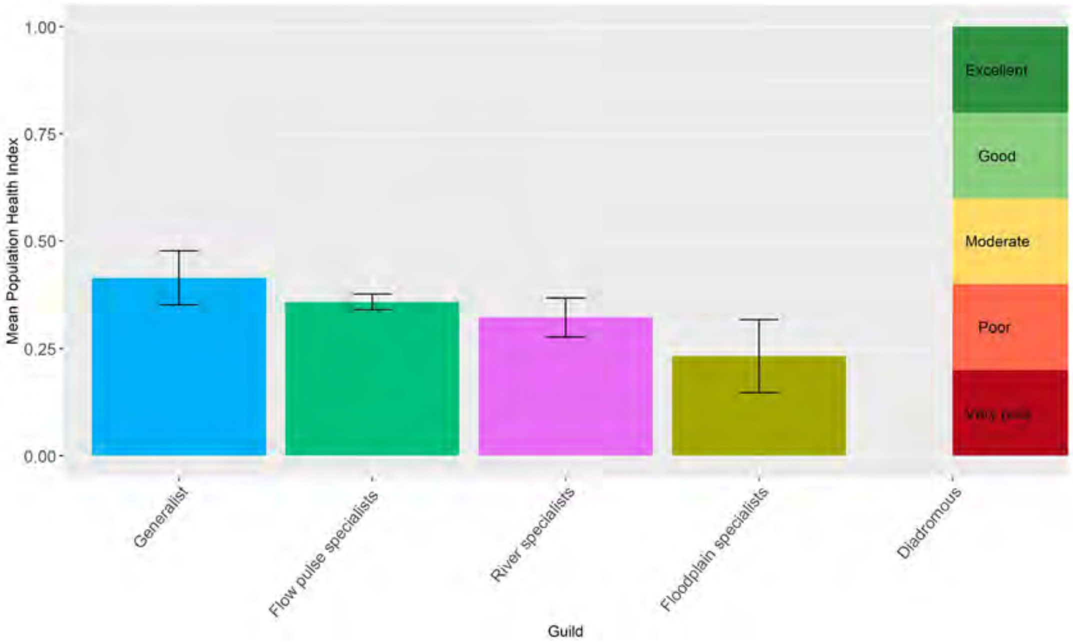

Figure 4-48 Mean Population Health Index value by A) species and B) flow response guild.

Summary

A total of 43% of all native fish objectives were met during the study period (Table 4-10).

This was expected given this is a baseline assessment, conducted prior to full implementation of the Basin Plan, and is consistent with previous reports (Harris & Gehrke 1997; Davies 2008; MDBA 2012; NSW State of the Environment 2009, 2012, 2015; NSW Government 2010). Environmental watering objectives for native fish are not anticipated to be achieved in full until 2024, 2029 or 2039, following full implementation of the Basin Plan. Native fish populations have undergone significant decline and will take considerable time to recover.

Native fish species set to benefit

Native species need different things to thrive. Some species don't need much; others have very specific ecological requirements.

NSW DPI Fisheries found that short-lived generalist species were in better health than long-lived species that use certain habitat types or flow conditions.

This information can be used to identify species that can benefit most from environmental flows and inform how individual flow events can best be delivered in future.

Species such as silver perch, trout cod, Murray crayfish, Macquarie perch and olive perchlet are among those most likely to benefit from held allocations of environmental water.

The percentage of NF objectives met by category were: 64% relating to native fish species' presence in the NSW Murray–Darling Basin; 9% relating to species' distributions; 18% relating to species' abundances; and, 46% relating to recruitment/population structure. This suggests that most species expected to be present were detected. However, many species occupied restricted ranges, relative to their potential extent of occurrence. Where they were detected, most species were not particularly abundant, and many were not able to successfully recruit on a consistent basis during the reporting period.

The health of fish populations varied between species with different life histories, habitat preferences and relationships to river flow conditions.

- Generalist short-lived species without strong links to flows were mostly in Good or Moderate health (for example, carp-gudgeon species complex and Australian smelt).
- Species with more specific life history requirements – such as flow specialists with links to flow pulses were in Moderate to Poor health (for example, golden perch and spangled perch).
- Long-lived species, particularly those dependent on specific habitats (such as healthy main river channels or floodplain habitats) or flow conditions, were generally in Poor health (for example, silver perch, trout cod, Macquarie perch and Murray crayfish).
- However, some of these more-specialised species were in Moderate health (for example, Murray cod and freshwater catfish).

The current report presents the condition of these species at the NSW Murray–Darling Basin scale – it was not intended to examine causal relationships between environmental watering in this reporting period. However, since at least the mid-2000s, there have been many watering actions delivered in the NSW Murray–Darling Basin that have resulted in positive environmental outcomes for native fish. Those involved entitlements held by NSW, the Commonwealth Environmental Water Office (CEWO), and/or The Living Murray initiative. Many event-based monitoring reports are published on the CEWO website.

Major environmental outcomes from these watering events include the following:

- Successful spawning, recruitment and survival of juvenile Murray cod and golden perch in the Lower Darling River in 2016 and 2017, involving managed flows over hundreds of kilometres. Fish spawned during these flows comprised up to 30% of the overall population in following years, adding to the long-term resilience of these species (Sharpe and Stuart, 2018).
- Boosted fish condition in the Dumaresq and Severn rivers in 2017 was achieved by stimulating food production and access to habitats through flow delivery. This benefitted Murray cod (more juveniles), freshwater catfish (more nests and spawning), and unspecked hardyhead and Murray–Darling rainbowfish (more individuals). An additional benefit was no recruitment of common carp.
- Hydrological connection of the lower Macquarie River to the Barwon River for 10 days in March 2017 facilitated fish movements. This was specifically aimed at a target cohort of young-of-year golden perch, which were found migrating upstream in higher numbers following the connection.

These results show that environmental watering can be highly beneficial to a suite of native species, particularly when delivered using information gained from fish survey and condition monitoring. Rigorous research allows these conservation actions to be effective and efficient.

Table 4-2 Outcomes of watering objectives for native fish species in the reporting period.

Green = objective achieved. See Methods for more information.

Guild	Species	Presence	Distribution	Abundance	Recruitment/ Population structure	Recreational fishing
Flow pulse specialists	Golden perch	NF1a, NF1b	NF9a		NF4a, NF4b NF4c	NF6a NF6b
	Silver perch	NF1a, NF1b	NF9a		NF4a, NF9b, NF9c NF4b, NF4c	
	Spangled perch	NF1a, NF1b	NF9a		NF4a, NF4b, NF4c	
	Hyrtl's tandan	NF1a NF1b	NF9a		NF4a, NF4b, NF4c, NF9b, NF9c	
Generalists	Carp-gudgeon species complex	NF1a, NF1b	NF2a	NF2b	NF2c	
	Bony herring	NF1a, NF1b	NF2a	NF2b	NF2c	
	Un-specked hardyhead	NF1a, NF1b	NF2a	NF2b	NF2c	
	Murray-Darling rainbowfish	NF1a, NF1b	NF2a	NF2b	NF2c	
	Australian smelt	NF1a, NF1b	NF2a	NF2b	NF2c	
	Mountain galaxias	NF1a, NF1b	NF2a	NF2b	NF2c	
	Stocky galaxias	NF1a NF1b	NF2a	NF2b	NF2c	
	Riffle galaxias	NF1a, NF1b	NF2a	NF2b	NF2c	
	Obscure galaxias	NF1a NF1b	NF2a	NF2b	NF2c	
	Flat-headed gudgeon	NF1a, NF1b	NF2a	NF2b	NF2c	
	Darling River hardyhead	NF1a NF1b	NF2a	NF2b	NF2c	
Floodplain specialists	Olive perchlet	NF1a NF1b	NF3a, NF7a	NF3b	NF3c, NF7c NF7b	
	Murray hardyhead	NF1a NF1b	NF3a, NF7a	NF3b	NF3c, NF7b, NF7c	
	Flat-headed galaxias	NF1a, NF1b	NF3a, NF7a	NF3b	NF3c, NF7b, NF7c	
	Southern pygmy perch	NF1a NF1b	NF3a, NF7a	NF3b	NF3c, NF7b, NF7c	
	Southern purple-spotted gudgeon	NF1a NF1b	NF3a, NF7a	NF3b	NF3c, NF7b, NF7c	
	Dwarf flat-headed gudgeon	NF1a NF1b	NF3a	NF3b	NF3c, NF7b, NF7c	
Riverine specialists	Murray cod	NF1a, NF1b			NF5a, NF5b, NF5c	NF6a NF6b
	Freshwater catfish	NF1a, NF1b	NF8a		NF5a, NF5b, NF8b, NF8c NF5c	
	Two-spined blackfish	NF1a NF1b	NF8a		NF5a, NF5b, NF5c, NF8b, NF8c	
	River blackfish	NF1a NF1b	NF8a		NF5a, NF5c, NF8b NF5b, NF8c	
	Trout cod	NF1a, NF1b	NF8a		NF5a, NF5b, NF8b, NF8c NF5c	
	Murray crayfish	NF1a	NF8a		NF5a, NF5c, NF8b NF5b, NF8c	
	Macquarie perch	NF1a NF1b	NF8a		NF5a, NF8b NF5b, NF5c, NF8c	
Diadromous fish	Short-finned eel	NF1a, NF1b	NF10			
	Short-headed lamprey	NF1a, NF1b	NF10			
	Pouched lamprey	NF1a, NF1b	NF10			
Fish Community Status		NF1c				
Objective outcomes (not incl. fish community status)	% achieved	64	9	18	46	50
	% not achieved	36	91	82	54	50

Recommendations

Table 4-3 Recommendations for the management, monitoring and evaluation of native fish in the NSW Murray–Darling Basin for future evaluation and reporting.

Indicator	LTWP Objective	Recommendations for management	Recommendations for monitoring	Recommendations for evaluation
Number of native fish species	NF1: No loss of native fish species	Prioritise flow management activities that aid in the recovery of populations of species most at risk of local extinction in NSW (southern pygmy perch, southern purple-spotted gudgeon).	Maintain the native fish Basin Plan Environmental Outcomes Monitoring program to monitor changes by 2024, 2029 and 2039. Undertake higher-resolution, targeted sampling for rare and undetected species. This may include environmental DNA surveys across a large number of small waterbodies.	Continue to develop and improve our understanding of casual relationships and attribution of fish response to environmental water management to better support the evaluation of this objective in 2024.
Native fish abundance Distribution of native fish species Native fish populations	NF2: Increase the distribution and abundance of short to moderate-lived generalist native fish species	Prioritise flow management activities that: • aid in increasing the distribution and recruitment of Darling River hardyhead in the Border Rivers, Gwydir and Namoi Water Source Areas; and, • provide dispersal opportunities for un-specked hardyhead into adjacent zones.	Determine the flow requirements that lead to: • increases in abundance of flat-headed gudgeon and prioritise those flow conditions within zones occupied; and, • significant recruitment events for bony herring and Murray–Darling rainbowfish and deliver those flows within occupied zones	Continue to develop and improve our understanding of casual relationships and attribution of fish response to environmental water management to better support the evaluation of this objective in 2024.

Indicator	LTWP Objective	Recommendations for management	Recommendations for monitoring	Recommendations for evaluation
Native fish abundance Distribution of native fish species Native fish populations	NF3: Increase the distribution and abundance of short to moderate-lived floodplain specialist native fish species	Prioritise flow management to: • promote habitat quality within occupied zones; and, • provide dispersal opportunities for southern pygmy perch, southern purple-spotted gudgeon and olive perchlet into adjacent zones.	Determine the flow requirements that lead to: • significant recruitment events for target species and deliver those flows within occupied zones. • increases in abundance of target species and prioritise those flow conditions within zones occupied. Undertake higher-resolution, targeted sampling for rare and undetected species. This may include environmental DNA surveys across a large number of small waterbodies.	Continue to develop and improve our understanding of casual relationships and attribution of fish response to environmental water management to better support the evaluation of this objective in 2024.
Native fish populations	NF4: Improve native fish population structure for moderate to long-lived flow pulse specialist native fish species	Prioritise flow management that provides dispersal opportunities for silver perch and spangled perch into adjacent zones.	Determine the flow requirements that lead to significant recruitment events for all flow pulse specialist species and deliver those flows within occupied zones.	Continue to develop and improve our understanding of casual relationships and attribution of fish response to environmental water management to better support the evaluation of this objective in 2024.
Native fish populations	NF5: Improve native fish population structure for moderate to long-lived riverine specialist native fish species	Prioritise flow management that provides dispersal opportunities for freshwater catfish, Macquarie perch, trout cod, river blackfish, two-spined blackfish and Murray crayfish into adjacent zones.	Determine the flow requirements that lead to: • increases in abundance of Macquarie perch, river blackfish and two-spined blackfish and prioritise those flow conditions within zones occupied; and, • significant recruitment events for all riverine specialist species and deliver those flows within occupied zones.	Continue to develop and improve our understanding of casual relationships and attribution of fish response to environmental water management to better support the evaluation of this objective in 2024.

Indicator	LTWP Objective	Recommendations for management	Recommendations for monitoring	Recommendations for evaluation
Native fish abundance Native fish populations	NF6: A 25 % increase in abundance of mature (harvestable sized) golden perch and Murray cod	Deliver environmental water to improve recruitment success of golden perch and Murray cod within occupied zones.	Continue to monitor popular recreational fishing species in the NSW portion of the Murray–Darling Basin. Enhance understanding of flow requirements that lead to significant recruitment events for target species.	
Distribution of native fish species	NF7: Increase the prevalence and/or expand the population of key short to moderate-lived floodplain specialist native fish species into new areas (within historical range).	Prioritise flow management to: • maintain and enhance habitat quality within occupied Planning Units; and, • provide dispersal opportunities into adjacent zones. Support the existing Murray hardyhead reintroduction program by using environmental water to maintain habitat quality within the existing wetland, and to manage additional suitable wetlands to allow establishment of further populations. Review priority species and populations to focus opportunities to support enhancement and additional population objectives and targets during the 2020-2024 reporting period.	Locate any remnant populations of flat-headed galaxias anywhere within the Murray–Darling Basin, protect those habitats and initiate a conservation stocking program for NSW. Conduct additional targeted higher-resolution spatial sampling of southern pygmy perch, southern purple-spotted gudgeon and olive perchlet populations within known occupied habitats is required to determine the extent of each population.	Continue to develop and improve our understanding of casual relationships and attribution of fish response to environmental water management to better support the evaluation of this objective in 2024.
Distribution of native fish species	NF8: Increase the prevalence and/or expand the population of key moderate to long-lived riverine specialist native fish species into new areas (within historical range).	Prioritise flow management to: • maintain and enhance habitat quality within the zone occupied by Macquarie perch, two-spined blackfish and trout cod; and, • provide dispersal opportunities into adjacent zones. Review priority species and populations to focus opportunities to support enhancement and additional population objectives and targets during the 2020-2024 reporting period.	Conduct additional targeted sampling of two-spined blackfish and Murray crayfish	Continue to develop and improve our understanding of casual relationships and attribution of fish response to environmental water management to better support the evaluation of this objective in 2024.

Indicator	LTWP Objective	Recommendations for management	Recommendations for monitoring	Recommendations for evaluation
Distribution of native fish species	NF9: Increase the prevalence and/or expand the population of key moderate to long-lived flow pulse specialists native fish species into new areas (within historical range).	Initiate a widespread conservation stocking program for silver perch in NSW. Prioritise flow management to maintain and enhance habitat quality within zones occupied by silver perch and facilitates dispersal into adjacent zones. Protect habitat quality of waterholes within zones occupied by Hyrtl's tandan. Review priority species and populations to focus opportunities to support enhancement and additional population objectives and targets during the 2020-2024 reporting period.	Undertake additional targeted sampling of Hyrtl's tandan in specified Planning Units.	Continue to develop and improve our understanding of casual relationships and attribution of fish response to environmental water management to better support the evaluation of this objective in 2024.
Distribution of native fish species	NF10: Increase the prevalence and/or expand the population of key moderate to long-lived diadromous native fish species into new areas (within historical range).	Prioritise flow management to enhance and facilitate dispersal into applicable Planning Units for diadromous species.		Continue to develop and improve our understanding of casual relationships and attribution of fish response to environmental water management to better support the evaluation of this objective in 2024.

Other species

Nearly half of the native frog species found in floodplain wetlands of the Murray–Darling Basin are responsive to flows (Ocock et al. 2018), and therefore, can benefit from increased floodplain inundation through environmental watering. Specific long-term watering objectives have been developed for flow-dependent frog species (Table 4-12) in five of the nine NSW Water Resource Plan Areas. All indicators, metrics and LTWP objectives relate to the same WSP objectives: Regulated and Unregulated 2a (i) Protect and contribute to the enhancement of the recorded distribution or extent, and population structure of target ecological populations. Target ecological populations in these water sources may include known or predicted populations of:

•High diversity hotspots and significant habitat for native frogs

•Significant wetlands within this water source

Murray and Lower Darling Regulated WSP 2b WRP provides strategic support via the WSP objective ‘Support environmental watering to contribute to the maintenance or enhancement of ecological condition in streams, riparian zones, dependant wetlands and floodplains within the water source, including for the purposes outlined in the WSP (Table 4-12).

Table 4-1 Other species metrics and related LTWP and WSP objectives

Indicators	Metrics	LTWP objective
Flow-dependent frogs	Total number of flow-dependent frog species Relative abundance of each species Number of sites each species detected	OS1: Maintain species richness and distribution of flow-dependent frog communities
Flow-dependent frog breeding	Calling activity levels Presence of egg masses/tadpoles Relative abundance of metamorphs (juvenile frogs)	OS2: Maintain successful breeding opportunities for flow-dependent frog species
Threatened frog species	Number of sites threatened frog species detected Calling activity levels Presence of egg masses/tadpoles Relative abundance of metamorphs (juvenile frogs)	OS3a: Maintain and increase number of wetland sites occupied by the threatened southern bell frog OS3b: Maintain and increase number of wetland sites occupied by the threatened Sloane's froglet
Other water-dependent species (e.g. turtles)	Total number of flow-dependent species	OS4: Maintain water-dependent species richness

Findings

- Flow-dependent frog species richness was maintained in the monitored areas of the NSW Murray–Darling Basin from July 2014 to June 2019 (see Appendix 4 for list of species and survey coverage).
- Wetland monitoring in the Gwydir, Macquarie–Castlereagh, Lachlan, Murrumbidgee and NSW Murray–Lower Darling in the reporting period showed that the delivery of water for the environment supported breeding activity in flow-dependent frog species.
- Water for the environment provided habitat and breeding opportunities for the nationally vulnerable southern bell frog in the Murrumbidgee and NSW Murray–Lower Darling.

What was expected

Flow-dependent frog species breed in response to overbank flows and, like freshwater turtles, require refuge habitat during periods of low flows when limited habitat is available (Figure 4-49). The 2014-19 period included a range of flow conditions in monitored areas including very dry conditions (See Climate), small managed overbank events and large natural overbank events (See Hydrology).

It was expected that the maintenance of refuge habitat in dry periods would allow flow-dependent frog species to persist in the monitored areas. Larger responses were expected from flow-dependent frog species, including more species of frogs being present, increased site occupancy (each frog species found in a higher proportion of survey sites) and relative abundance (more individual frogs of each species being present). We also expected increased calling activity with increasing magnitude of overbank flows. Greater opportunities for successful breeding (that is high abundance of tadpoles and juvenile frogs detected) were expected when the duration of overbank flows was greater than three months.

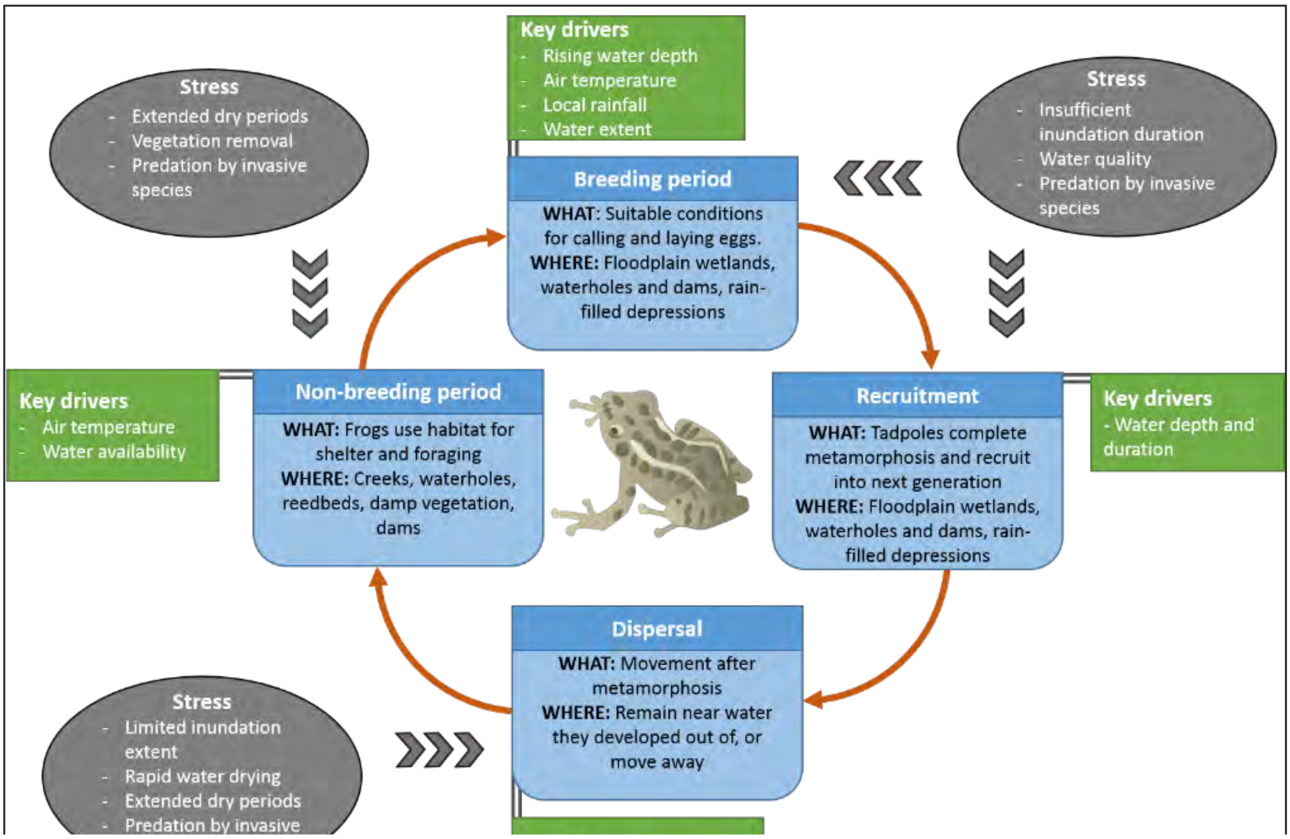

Figure 4-49 The life stages of flow dependant frog species, including key drivers and stresses for each life stage (from Ocock et al. 2018)

Methods

In the 2014–19 reporting period, consecutive years of frog monitoring were completed in the Gwydir Wetlands, Macquarie Marshes, Mid-Murrumbidgee Wetlands, Lower Murrumbidgee Floodplain, Mid-Murray and Lower Murray wetland regions. Limited data was detected in the Lower Lachlan and Lower Darling regions.

In all regions, monitoring comprised repeat visits (minimum of two) to established survey sites over spring and summer months. This timing coincided with water delivery to the wetland regions and the most active time of year for many flow-dependent frog species. Standard frog surveys included a habitat assessment and night-time transect survey for adults and juveniles, with tadpole surveys in some wetland regions (Figure 4-50) (Ocock et al. 2018; Wassens et al. 2014; Waudby 2019). Audio recorders targeting southern bell frogs were also set to record hourly over spring-summer in key wetlands in the Mid-Murrumbidgee Wetlands, Lower Murrumbidgee Floodplain, Mid-Murray and Lower Murray regions as part of monitoring undertaken through the NSW Saving our Species Program (Waudby 2019) and Charles Sturt University research programs (Medlin 2018).

Figure 4-50 Survey methods used to document responses of flow dependant frogs to wetland inundation

Egg masses (A) and calling activity (F) provide the first evidence of frog breeding activity; sweep netting for tadpoles (B) and acoustic monitoring of calling activity (G) also provide evidence of breeding; night-time spotlight surveys (C) can document recently metamorphosed frogs (D) and adult frogs (E) (Photos: Emma Wilson, Joanne Ocock, Carmen Amos NSW Department of Planning, Industry and Environment-EES).

Results

Northern Basin

Department of Planning, Industry and Environment frog monitoring commenced in the Macquarie Marshes in spring 2014 and in the Gwydir Wetlands in spring 2015. Figure 4-51 shows the cumulative inundated area (in hectares) (top row) for each water year, or number of hectares of floodplain wetland cumulatively inundated at least once during each water year. The proportion of monitored sites with recently metamorphosed frogs (middle row), and boxplots showing the total abundance of metamorphs (juvenile frogs) detected in the spring surveys (lower row) is also shown (Figure 4-51) (from Walcott et al. 2020).

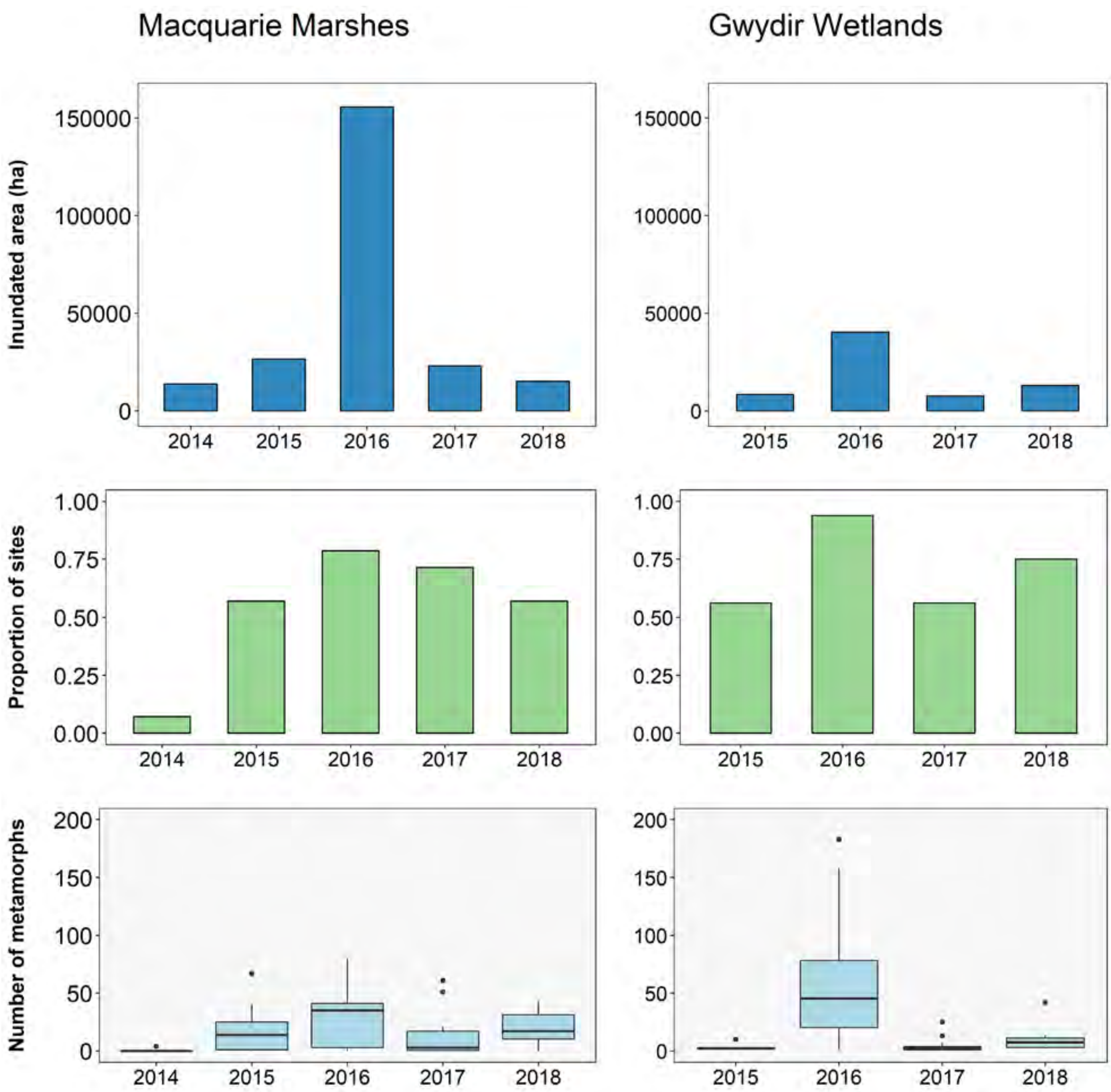

Figure 4-51 Summary of wetland monitoring completed in the Macquarie Marshes (left) and Gwydir Wetlands (right) in the 2014-19 period

Delivery of environmental water to the Macquarie Marshes and the Gwydir Wetlands (Figure 4-52) provided important breeding habitat for flow-responsive frog species in the 2014–19 period. All flow-responsive frog species in the Gwydir Wetlands and Macquarie Marshes were detected during monitoring completed from 2015–16 to 2018–19 and successful breeding was recorded in more than 50% of survey sites (Figure 4-51, Appendix 4). For both systems, wetland inundation, including the extent and timing of inundation, aquatic vegetation response and cumulative river flows leading up to the surveys were the primary drivers of breeding activity in flow-dependent frog species.

Highest calling activity corresponded with years when a larger proportion of survey sites were inundated either by natural and/or managed flows. Widespread and successful breeding was recorded in flow-dependent frog species in both wetland systems in 2016–17 in response to inundation of the survey sites by natural flows and environmental water delivery which persisted into summer (Walcott et al. 2020). In the absence of natural flows and local rainfall, environmental water delivery alone supported widespread outcomes for flow-dependent frog species. In the Gwydir Wetlands our sites were inundated in September 2018 by environmental water and this provided widespread breeding opportunities, second only to the peak breeding activity observed during 2016–17 (Figure 4-51). We also found that site-scale breeding outcomes were possible in very dry years through environmental water delivery.

Figure 4-52 Macquarie Marshes (left) Gwydir Wetlands (right) after inundation

Photos Joanne Ocock, NSW Department of Planning, Industry and Environment-EES

Water for the environment was also delivered to more than 85% of the Gwydir survey sites in 2018–19, supporting widespread frog recruitment (Walcott et al. 2020). Similarly, widespread frog recruitment was recorded in the Macquarie Marshes in 2017–18 (Figure 4-51) in response to the delivery of water for the environment, which inundated all sites in early spring, and water levels persisted into late November 2017 supporting successful frog recruitment (Walcott et al. 2020).

Southern Basin

All previously recorded flow-responsive frog species were detected during monitoring of the Mid-Murrumbidgee and Lower Murrumbidgee Floodplain (Appendix 4) in the reporting period. This included the endangered southern bell frog (NSW Biodiversity Conservation Act 2016) (Wassens et al. 2020). Audio recordings in key wetlands in the Murrumbidgee and NSW Murray–Lower Darling documented calling responses of southern bell frogs following the delivery of water for the environment to key wetlands (Medlin 2018; Walcott and Waudby 2018; Waudby et al. 2020). On-ground surveys detected successful bell frog breeding at a high number of key sites (Wassens et al. 2020; Waudby et al. 2020).

Many sites in the Murrumbidgee catchment have consistently received NSW and Commonwealth water for the environment over the 2014-19 period. Surveys undertaken in the Murrumbidgee Catchment (Figure 4-53), as part of long-term monitoring funded by the Commonwealth Environmental Water Office, revealed that numbers of southern bell frogs and other flow-dependent frog species had increased considerably in reserves and private property wetlands since surveys began in 2007-08. The total number of sites occupied by southern bell frogs more than doubled in the Lowbidgee Floodplain in the reporting period compared to earlier surveys (2007–12) (Figure 4-54). During a night-time survey in March 2019, the total numbers of adult southern bell frogs recorded exceeded 300 individuals at one Lower Murrumbidgee Floodplain site (Wassens et al. 2020), which had been inundated with environmental water from spring 2018 to autumn 2019.

Figure 4-53 Inundated wetlands in the Lowbidgee Floodplain (left) and Mid- Murrumbidgee Wetlands (right) that are managed for the endangered southern bell frog

Photos: Carmen Amos, NSW Department of Planning, Industry and Environment-EES

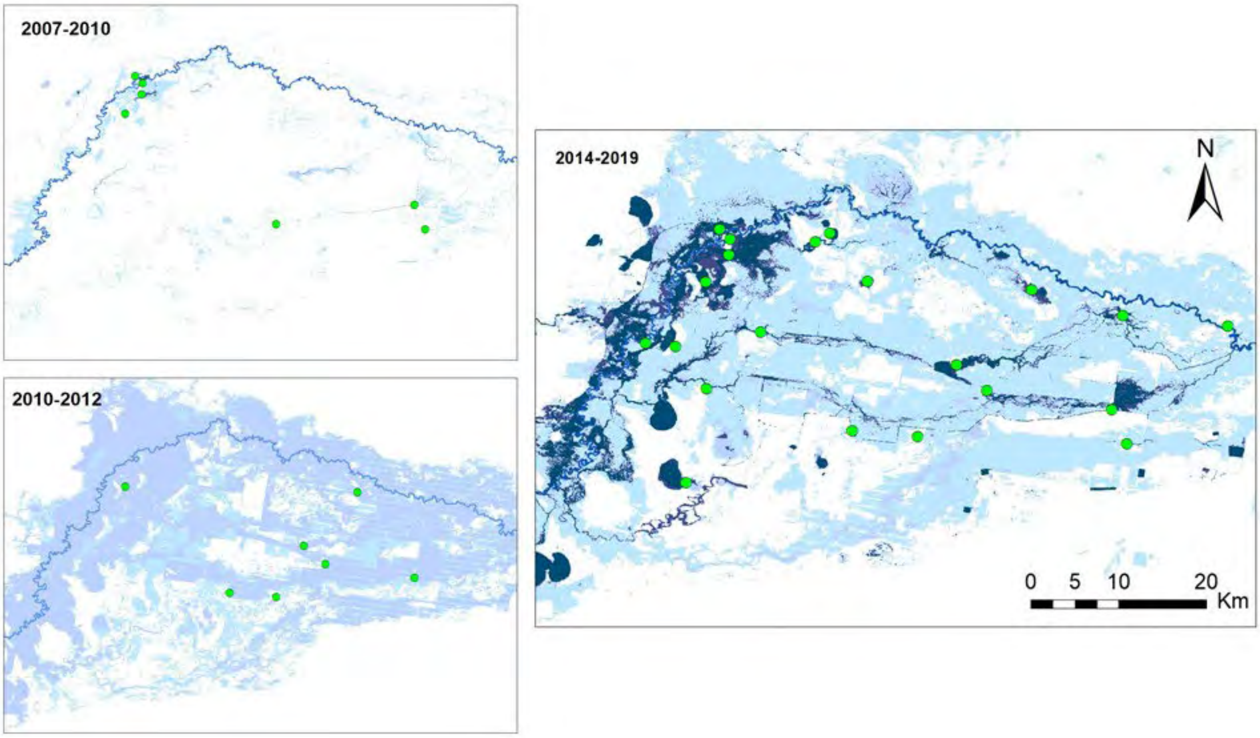

Figure 4-54 The distribution of southern bell frog sites (green dots) during the 2007-10 (top left), 2010-12 (lower left) and 2014-19 (right) periods

Note that the inundation maps show the number of times the location (pixel) was annually inundated in each monitoring period. The 2007–10 map showing small environmental flows delivered over three survey years, the 2010–12 map showing large floods and environmental flows, and the 2014–19 map showing results of surveys over five water years when one large natural flood and environmental flows were delivered.

Case study: Private landholders support saving southern bell frog

Strong private landholder engagement has been extremely important to the success of NSW Saving our Species southern bell frog recovery program (Figure 4 54).

Over 40 sites across the Mid-Murray, Lower Murray, Mid-Murrumbidgee and Lowbidgee valleys are monitored as part of this program.

Targeted delivery of relatively small volumes of environmental water to key wetlands has consistently produced breeding outcomes for southern bell frogs at 80% or more of monitored sites annually.

Figure 4-55 Successful southern bell frog breeding has been recorded in key wetlands in the Lowbidgee Floodplain and Mid-Murrumbidgee Wetlands in the 2014-19 period. Southern bell frog tadpoles (left), young southern bell frog (middle) and juvenile southern bell frog (right). Photos: Helen Waudby, NSW Department of Planning, Industry and Environment—EES

Following consecutive years of environmental watering in the Murrumbidgee, recent surveys have shown numbers of southern bell frogs have reached high densities in targeted wetlands in the Gayini Nimmie-Caira system and neighbouring private wetlands in the Lowbidgee Floodplain.

‘This is a fantastic result for the southern bell frog, which has re-populated key wetlands in the Murrumbidgee and NSW Murray–Lower Darling that received water for the environment over the 2014–19 period.’

Recommendations

The following recommendations should be considered to improve evaluation of this theme in future evaluation periods (see Table 4-13 for more detail):

- Ensure the water requirements for successful breeding by flow-dependent frog species and complementary management interventions are considered when managing flow delivery to floodplain wetlands, most importantly duration of inundation.
- Maintain and where possible, increase targeted watering of key southern bell frog sites to ensure the long-term recovery of this threatened species in the Murrumbidgee and NSW Murray–Lower Darling.
- Maintain and improve the spatial and species coverage of monitoring programs for wetland-dependent fauna in the NSW Murray–Darling Basin to support more comprehensive evaluation of this objective in 2024.

Table 4-2 Recommendations for the management, monitoring and evaluation for the 'other species' theme in future evaluation periods.

Indicator	LTWP Objective	Recommendations for management	Recommendations for monitoring	Recommendations for evaluation
low-dependent frogs	OS1: Maintain species richness and distribution of flow-dependent frog communities	1) Consider additional management interventions for refuge habitats, e.g. carp removal where increased carp numbers, declines in vegetation and tadpole diversity are indicated by long-term monitoring. 2) Inundate floodplain wetlands and maintain refuge habitats and, or regular connection to the river to provide long-term benefits to flow-dependent frog species. 3) Water volumes required to provide frog refuge and support breeding outcomes need to account for wetland persistence through summer.	Continue to develop and improve our understanding of appropriateness, efficiency and effectiveness of environmental water management flow dependant frog species the NSW Murray–Darling Basin through maintaining or improving monitoring programs to better support the evaluation of this objective in 2024 (DPIE 2020b).	Maintain regular (annual) evaluation of existing frog monitoring data. Increased monitoring coverage is needed to support the future evaluation of this objective across the WRPAs. Inclusion of all historical datasets available (e.g. opportunistically collected NSW Murray–Lower Darling frog data for the 2008-2013 and 2016) in future evaluations is also recommended.

Indicator	LTWP Objective	Recommendations for management	Recommendations for monitoring	Recommendations for evaluation
Flow-dependent frog breeding	OS2: Maintain successful breeding opportunities for flow-dependent frog species	1) Watering actions in spring should be considered to enhance frog breeding activity given that many frog species, including southern bell frogs breed in response to rising water levels during spring (October & November). 2) Providing extended wetland inundation where possible is recommended to support successful breeding outcomes. 3) Where necessary, carp removal is recommended to improve breeding habitat quality.	Continue to develop and improve our understanding of appropriateness, efficiency and effectiveness of environmental water management for flow dependent frog species in the NSW Murray–Darling Basin through maintaining or improving monitoring programs to better support the evaluation of this objective in 2024 (DPIE 2020b).	Continued and increased frog monitoring coverage will continue to improve the capacity to evaluate frog responses and inform adaptive management, particularly for the NSW Murray–Lower Darling and Lachlan for which evaluation of this objective is not currently possible.
Threatened frog species	OS3a: Maintain and increase number of wetland sites occupied by the threatened southern bell frog	Maintaining southern bell frog populations in key wetlands and providing breeding opportunities through targeted environmental watering actions will be crucial for ensuring the long-term recovery of this threatened species in the Murrumbidgee and NSW Murray–Lower Darling. If possible, increasing the current extent of watering, particularly in dry years is needed for recovery of this species, particularly in the NSW Murray–Lower Darling.	Monitoring by SOS, CSU, DPIE-EES and environmental water managers has played a critical role in the management of southern bell frog recovery. Continuation of the current monitoring programs is crucial, as are other research projects e.g. post-doctoral research and other projects focused on southern bell frogs (e.g. Turner et al. 2020) to address current knowledge gaps.	Continued evaluation will continue to improve our capacity to understand frog responses and manage resources for southern bell frog recovery.

Indicator	LTWP Objective	Recommendations for management	Recommendations for monitoring	Recommendations for evaluation
	OS3b: Maintain and increase number of wetland sites occupied by the threatened Sloane's froglet	1) Maintain shallow vegetated habitat. If inundated through environmental watering, ensure wetland is targeted early to mid-autumn to promote vegetation growth and coincide with Sloane's froglet winter breeding period. 2) Consider other management options including stock management to protect key Sloane's froglet habitat.	Monitoring by SOS at targeted wetlands from Howlong, Corowa and Albury has played a critical role in understanding their current distribution and status in NSW. A small selection of these monitored sites receive environmental water. Continuation and expansion of this monitoring program is crucial to address current knowledge gaps for the species and improve our knowledge of the importance of environmental watering for the species.	Continued evaluation will continue to improve our capacity to understand frog responses and manage resources for Sloane's froglet.
Other water-dependent species (e.g. turtles)	OS4: Maintain water-dependent species richness	Inundate floodplain wetlands and maintain refuge habitats and/or regular connection to the river which is likely to provide long-term benefits to freshwater turtles and other wetland-dependent fauna species.	Implementation of monitoring programs are needed in all NSW WRPAs to provide baseline information on other water-dependent fauna species.	Future evaluation of this objective will only be possible through implementation of appropriate monitoring programs.

Ecosystem functions

The freshwater ecosystems in the NSW Murray–Darling Basin comprise streams, rivers, lakes, lagoons and semi-permanent wetlands, as well as groundwater-dependent ecosystems. Within these broad habitat types, niche habitats such as aquifers, deep channels, pools and riffles, gravel beds, instream benches, snags, aquatic vegetation and riparian vegetation provide a complex mosaic of habitats that support a great diversity of species and perform a range of functions.

Lateral and longitudinal connectivity throughout the catchment is fundamental to supporting many of the priority ecosystem functions. For example, improved hydrological connectivity along river systems and between rivers and their riparian corridors and floodplain is pivotal to moving nutrients, carbon and sediments, enhancing productivity, allowing organisms to disperse and improving water quality (MDBA 2014).

Ecosystem functions can be complex, spatially, temporally and biologically diverse and difficult to monitor directly. However, they are often directly related to the timing, extent and duration of flows and a relative measure of achievement can be extrapolated from hydrology monitoring. For some ecosystem functions, such the provision of refugia and habitat, it is also important to determine their location, extent and the benefits and quality of the benefits they provide in order to prioritise water management decisions to support them.

Quality diverse habitats

EF1: Provide and protect a diversity of refugia across the landscape

EF2: Create quality instream, floodplain and wetland habitat

Alteration of landscapes and development in the Murray–Darling Basin has had significant impacts on the hydrological and ecological conditions that flora and fauna depend on for survival. For example, as noted in the Native Fish section of this report, the degradation of instream processes and habitat features across most major systems has resulted in the majority of fish communities of the NSW MBD being in poor to moderate condition.

Determining the locations, extent and quality of habitats and refugia is a vital step in protecting and improving the number and diversity of refugia across the landscape. Equally it is important to understand the needs of the biota for habitat in order to manage water as well as protect and create quality instream, floodplain and wetland habitats.

Findings

- The assessment of key refugia, including for threatened fish species, in regulated and unregulated waterways commenced across the NSW Murray–Darling Basin.
- The High Ecological Value Aquatic Ecosystem (HEVAE) method for assigning ecological values to aquatic habitats has been developed and applied.
- A method for determining vegetation extent and condition has commenced, which will establish baseline conditions and provide a consistent method for future monitoring of Groundwater Dependent Ecosystems in collaboration with MDBA.

What was expected

- The identification of water-dependent refugia and habitats and assigning an ecological value in the NSW Murray–Darling Basin was to be completed for the Water Resource Plans.
- Development of EWRs based understanding of habitat location, quality and species preferences.
- Continued monitoring and science investigation to support efficient, effective and adaptive management of water for the environment.

Methods

There are several aquatic and terrestrial habitat management programs that operate in the NSW Murray–Darling Basin. The broad objectives of these are:

- identifying habitats and refugia and understanding the role they play in habitat-life cycle of the flora and fauna they support in order to develop, implement and improve environmental watering requirements
- determining the condition of aquatic habitats and identifying the processes that support, limit and threaten them
- providing data to support the protection and rehabilitation of priority habitats
- conducting robust monitoring and evaluation of the effectiveness of management.

The Fish and Flows in the Northern Basin project included additional in-channel habitat mapping, with the aim of enhancing the project's ability to inform a revision of the EWRs within the Barwon–Darling system (NSW DPI, 2015). As part of this project, detailed habitat mapping was completed along the 1,100 km reach between Walgett and Wilcannia, developing a comprehensive database of in-channel features for this important system of the Northern Basin. This detailed habitat mapping method has been replicated in over 5,000 km of waterways in other priority systems of the NSW MDB including the Dumaresq, Macintyre, Gwydir, Mehi, Lower Macquarie, Barwon, Lower Darling, and Lachlan rivers. This work has helped to identify relationships between flow and habitat access requirements and prioritise future water management actions. Site assessment of priority key refugia, including for threatened fish species, in regulated and unregulated waterways throughout the NSW MBD was also carried out in the reporting period as part of the NSW Native Fish Drought Response program.

The primary objectives of the habitat mapping activities are to:

- document and assess riverbed morphology, including the location, length and depth of pools that may act as drought refugia, as well as in-stream habitat features such as aquatic vegetation, benches, and large woody debris (snags) loading
- determine commence-to-inundate heights for key habitat features, including aquatic vegetation, benches, and snags (Figure 4-56).

Figure 4-56 System for grading the complexity of snags

The HEVAE project used a framework developed by the (then) Australian Government Department of Sustainability, Environment, Water, Populations and Communities (SEWPaC). The national framework identifies surface and groundwater systems of high conservation value at a national scale, so they can be managed to protect and enhance those values. The HEVAE approach is used to identify high conservation value ecosystems in NSW.

The NSW application of the national HEVAE Framework includes four of the five recommended HEVAE criteria; diversity, distinctiveness, naturalness, and vital habitat (Figure 4-57).

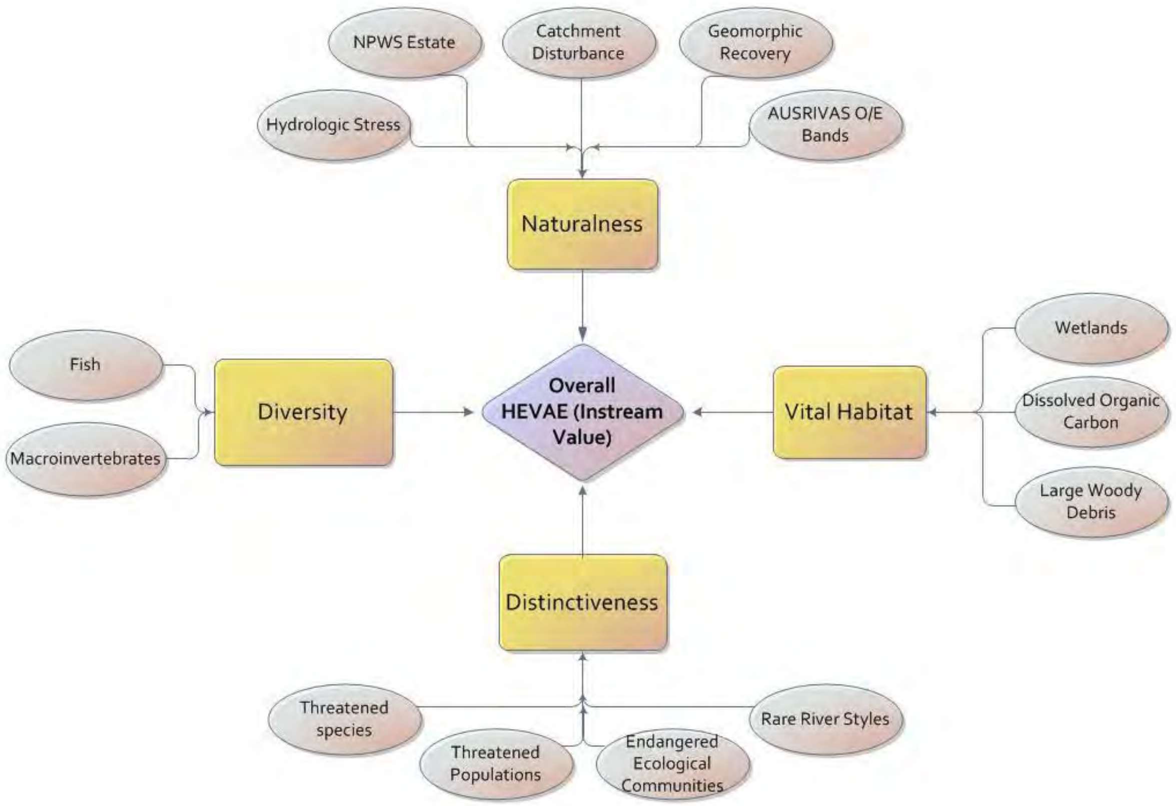

Figure 4-57 The four HEVAE criteria (yellow boxes) and associated attributes (grey ovals)

Assessment of the availability of data for the attributes associated with the four criteria indicated enough useful data could be collated into the HEVAE framework to enable spatial outcomes to be derived at the river reach scale. NSW completed HEVAE mapping and assessments for all NSW inland river valleys during the reporting period (Healey et al 2018). Figure 4-58 shows an example HEVAE map with ranking for the four criteria.

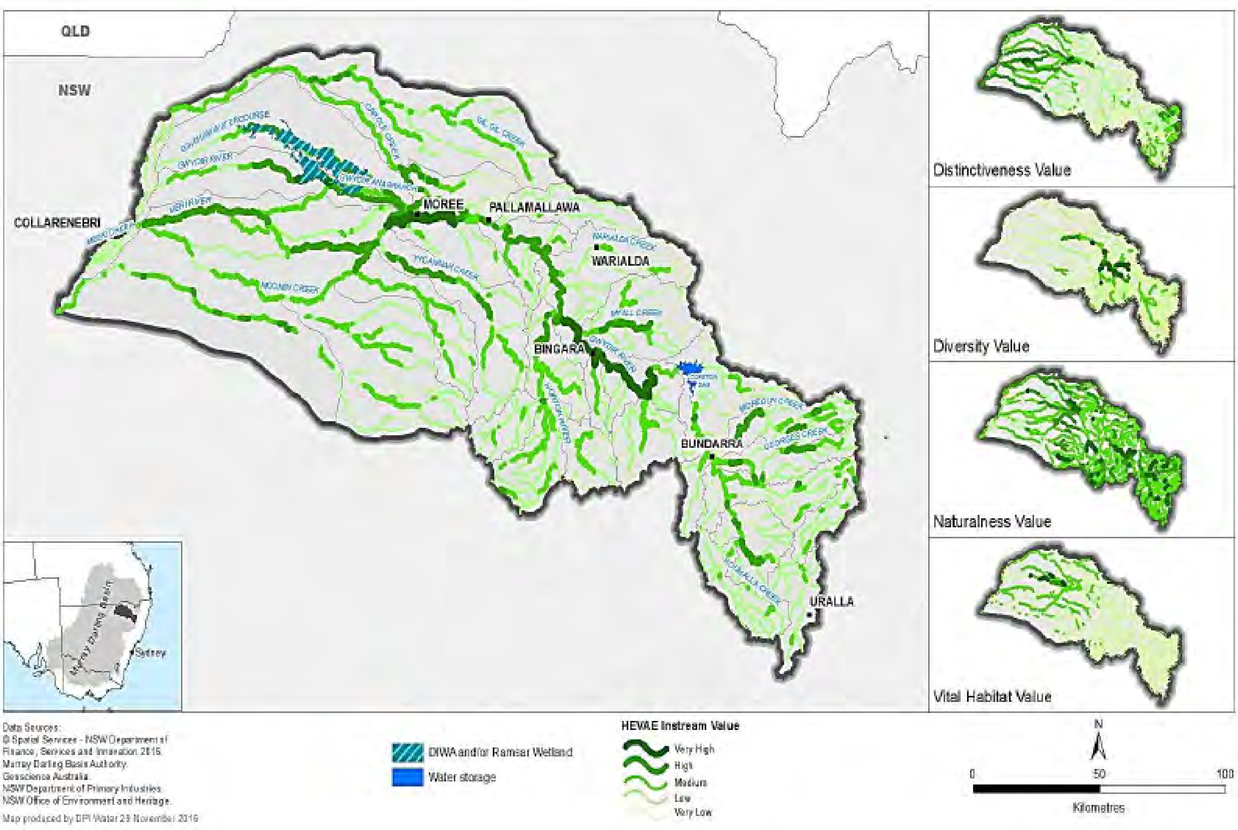

Figure 4-58 The overall HEVAE and associated criteria rakings for the Gwydir Catchment

Combining the knowledge of location, ecological value and environmental watering requirements of habitats and refugia is vital to the efficient and effective management of water for the environment, and most be supported by ongoing monitoring and evaluation in an adaptive management framework.

Recommendations

1. Continue habitat and refugia identification and mapping to support water management and identify any changes to the location, extent or quality of refugia or habitats
2. Investigate how the HEVAE attributes and methods developed for NSW rivers can link with identifying riverine ecosystem functions (for example, hydrologic stress, input of dissolved organic carbon—DOC; lateral connectivity). This will improve outcomes for the naturalness, and vital habitat criteria.
3. Continue support for making HEVAE available to all NSW users via the Department of Planning, Industry and Environment website
4. Use of Light Detection and Ranging (LIDAR) to develop high resolution digital elevation model to improve identification of refugia and to better understand the relationship between hydrology and habitats in the NSW Murray–Darling Basin.

Connectivity

EF3: Provide movement and dispersal opportunities for water-dependent biota to complete life cycles and disperse into new habitats:

- *Within catchments*
- *Between catchments*

Achievement of the lateral and longitudinal connectivity ecosystem function (Figure 4-59) is covered in the Hydrology section of this report.

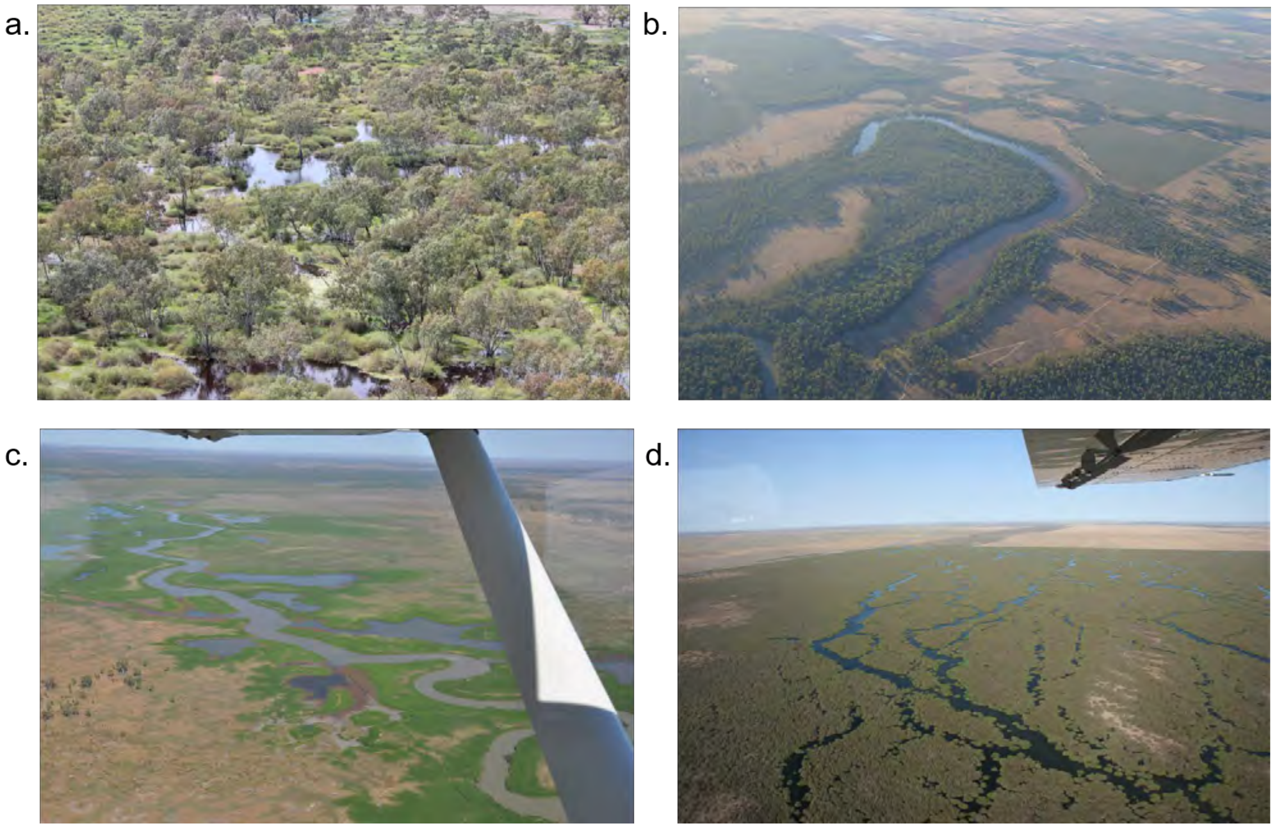

Figure 4-59 Examples of environmental flow delivery for lateral connectivity

a. river flows inundating low-lying wetland and floodplain habitats in the Macquarie Marshes, October 2017 (Photo: Stephanie Suter), b. pumping into Yarradda Lagoon in the mid-Murrumbidgee, November 2015 (Photo: James Dyer) , c. river flows inundating low-lying wetland and floodplain habitats of the Great Cumbung Swamp, November 2015 (Photo: James Dyer), and d. channel diversion into Eulimbah Swamp on the Lowbidgee floodplain, November 2015 (Photo: Wayne Kuo)

Productivity

EF4: Support instream and floodplain productivity

EF5: Support nutrient, carbon and sediment transport along channels, and between channels and floodplains/wetlands

Instream and floodplain productivity is the production and transfer of nutrients and energy through the food web, starting with primary production from photosynthesis in plants that consumers eat and/or are recycled in the environment. Productivity requires input of energy (sunlight or organic carbon), nutrients (often transferred from terrestrial sources), transport of the nutrients and products within waterbodies and, in some cases, exporting them to other catchments. However, the input of too much carbon can result in blackwater events where the microbial consumption of the DOC uses all of the available dissolved oxygen, leaving the water anoxic and producing fish deaths.

Drought, regulation of rivers, water abstraction and flood mitigation all impact productivity by restricting the flow of nutrients (particularly organic carbon, nitrogen, phosphorous) into, along and out of rivers, lakes and wetlands.

Findings

1. The limited flooding during the reporting period hampered the transfer of organic carbon and nutrients into rivers and wetlands in the NSW Murray–Darling Basin.
2. There was evidence that environmental water and protection of freshes and high flows improved ecological condition and water quality.
3. Tributaries are important contributors to productivity because river regulation by large dams has greatly reduced the overall organic carbon load to downstream river systems.

What was expected

1. There is a relationship between flow and resource (organic carbon and nutrients) availability
2. That unregulated tributaries are a critical source of (particularly) terrestrial carbon to downstream ecosystems.
3. Improving carbon and nutrient inputs would increase productivity in NSW MDBA water bodies

Methods

During the reporting period NSW has collaborated in several research programs to trial different metrics/methods for determining primary and secondary productivity and for deriving a relationship between these and flow.

There are several components to productivity, and each has a variety of methods that can be used to measure them. These include:

1. How much production has occurred already: This is the amount of organic carbon (food) that has been put into the system from external sources (terrestrial or allochthonous production). This is generally monitored by measuring the dissolved organic carbon concentrations. To determine how much of the DOC is available for biological production, dark assays are used (no photosynthesis) to measure how much carbon is consumed by bacteria over a specific time frame.

2. How much productivity occurs in the water (autochthonous production): This is in-channel primary producers like phytoplankton, benthic algae or macrophytes, that pass energy up the food web when consumed. Most of the measurement methods for this consisted of light/dark chambers with and without local biofilms (surfaces placed in the water for weeks before use in experiment) to give an indication of benthic and pelagic contributions to productivity (Lindstrom 1991, Vonk et al. 2015, Soares et al. 2017).
3. The transfer of primary production to secondary consumers: This is the primary production good food (quantity and quality) and where does it go (which consumers benefit?)? Methods include directly monitoring species at different trophic levels to assess their numbers and condition and/or biochemistry. Analytical techniques such as DNA and fatty acid analyses can provide information about the structure and condition of communities, the nutritional quality of primary and secondary production and what food sources consumers are using.

The aim of these projects is to develop a robust numerical model of the relationship between climate (antecedent conditions), river flow (hydrology) and riverine primary production that can be applied to a hydrologic model and used to review and optimise the WSP rules and their influence on riverine productivity across the NSW Murray–Darling Basin including:

- successful native fish recruitment and survival that in turn support waterbirds and other fauna
- algal blooms; and
- blackwater event prediction and management.

Results

The anticipated strong flow-resource relationships were not observed on the mainstem of the Macquarie and Gwydir Rivers, with only weak DOC-flow correlations existing for both rivers (O'Brein et al. 2020). However, this is consistent with Nielsen et al. (2016) who found that a small flood event at Barmah-Millewa Forest did not increase DOC concentrations downstream in the Murray River, but a subsequent larger flood caused a large spike in DOC. The drought conditions during the monitoring period may have impacted the DOC-flow relationships as the normal range of high flow events were not detected. Drought may also have suppressed the production of terrestrial organic carbon inputs which reduce the amount of carbon that could be dissolved by high flows.

Upstream and tributary sites were found to be similar to each other with respect to DOC composition, being dominated by larger molecules of allochthonous carbon (Figure 4-60) (Silvester et al. 2020). Regulated and confluence sites contained higher concentrations of autochthonous carbon. However, there was some evidence of an increase in the rates of bacterial growth due to provisioning of food by the tributary river. Bacterial growth responded to nutrient additions suggesting that nutrient limitations may be limiting the capacity for bacteria to use the available DOC as a food source.

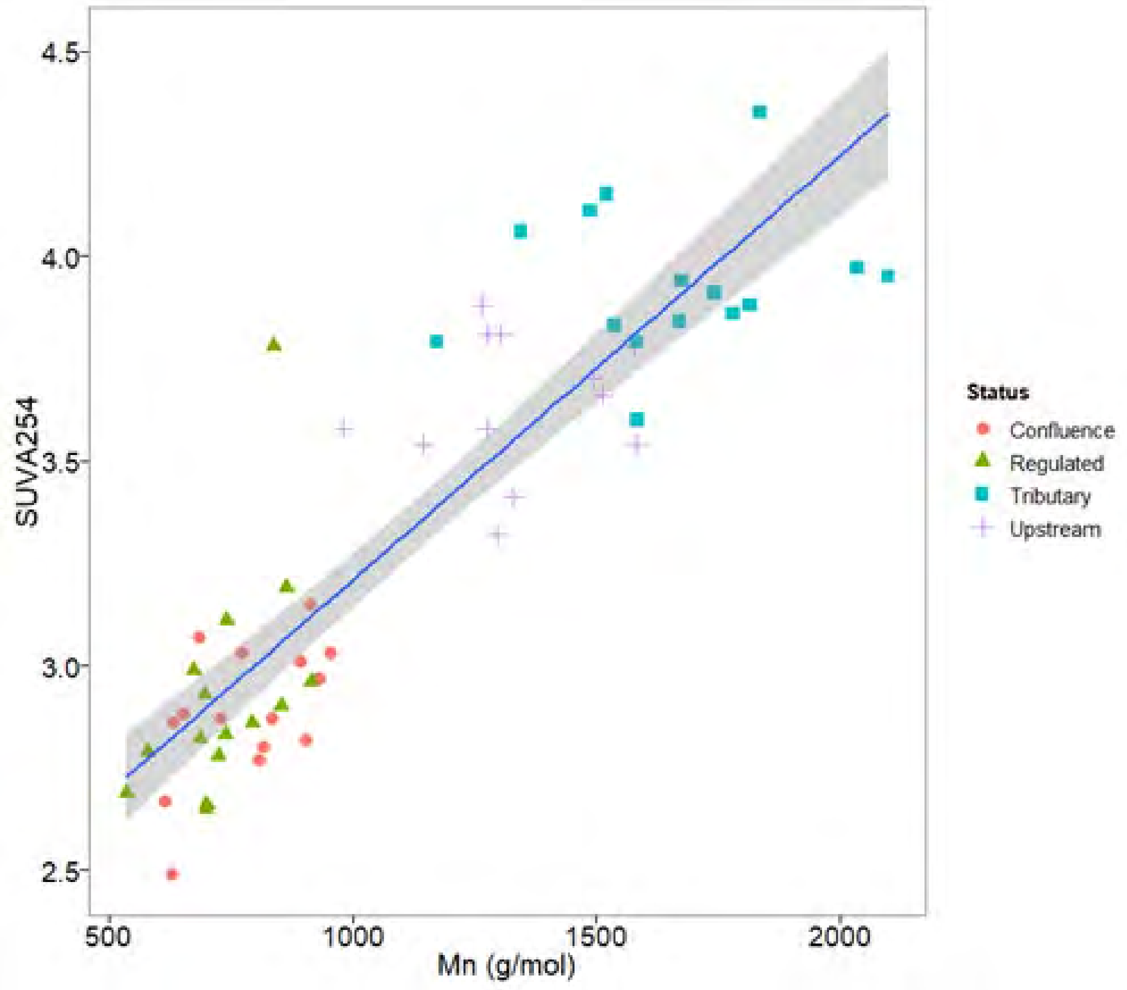

Figure 4-60 Specific absorbance (SUVA254) vs nominal molecular weight of dissolved organic carbon from upstream, tributary, regulated and confluence sites

There were two kinds of spike in secondary productivity (zoo plankton abundance and diversity) after high flows. Some consumers responded to an increase in primary production (as monitored by chlorophyll a concentrations) and others to the increased concentrations of DOC and nitrogen oxides.

As high flows receded, the slower, warmer, clearer water is ideal for primary production. After this growth, consumer numbers and diversity can increase, and the entire food web is supported. Drought conditions during the monitoring period have limited the input of nutrients, the spatial area where primary production can occur and hampered our ability understand and model the relationship between flow and productivity and the capacity of systems to support food webs.

Recommendations

1. Continue research on the relationship between antecedent conditions, flow and aquatic productivity to inform water management.
2. Work with water quality monitoring to ensure that DOC concentration and composition data is collected to inform the development and calibration of a flow/productivity model.
3. Continue to investigate the impacts of the composition/quality of DOC inputs and primary production on the growth and diversity of the rest of the food web.

Support groundwater conditions to sustain groundwater-dependent biota

Groundwater-dependent ecosystems (GDEs) are aquatic and terrestrial regions that require access to groundwater to meet all or some of their water requirements to maintain their communities of plants and animals, ecological processes and ecosystem services (Clifton et al. 2007). GDEs include a broad range of surface, aquatic and subterranean habitats or forms such as aquifers, caves, stream base flow, terrestrial vegetation and wetlands (Figure 4-61) that can range in area from a few metres to hundreds of square kilometres. GDEs often contain highly specialised species and ecosystems that possess unique biotic and abiotic characteristics that 'separate' them from other ecosystems. Their requirements for groundwater can be variable, ranging from partial and infrequent dependence, that is seasonal or episodic, to total, continual dependence.

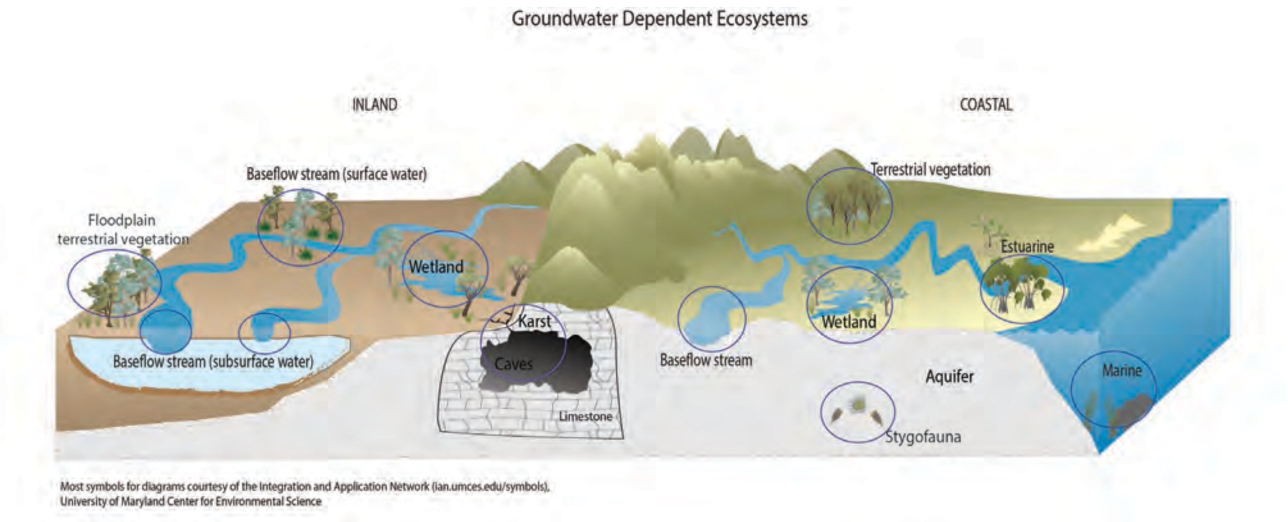

Figure 4-61 A conceptual model of some types of Groundwater Dependant Ecosystems

Very high and high ecological value vegetation GDEs are considered to be key environmental assets and are scheduled in WSPs for management purposes, along with Ramsar and other important wetlands also often associated with vegetation GDEs. Water management related issues such as altering surface water and/or groundwater flow regimes, changes to saline groundwater tables and/or mining and other extractive process could impact ecologically important GDEs in the NSW Murray–Darling Basin. Understanding of the location, extent and condition of these GDEs is essential for surface and groundwater planning and management in NSW.

Findings

- The identification of groundwater-dependent vegetation and assigning an ecological value has occurred across the NSW Murray–Darling Basin.
- Establishment of a groundwater health index and continued groundwater level monitoring across the NSW Murray–Darling Basin has progressed.
- A method for determining vegetation extent and condition has commenced which will establish baseline conditions and provide a consistent method for future monitoring of GDEs in collaboration with MDBA.

What was expected

- The identification of groundwater-dependent vegetation and assigning an ecological value in the NSW Murray–Darling Basin was to be completed for the WRPs.
- Establishment of a groundwater health index in the NSW Murray–Darling Basin to address critical knowledge gap around water quality requirements for GDEs.
- Continued monitoring of groundwater levels.

- Development of methods to monitor groundwater-dependent vegetation extent and condition.

Methods

Groundwater-dependent vegetation extent and condition assessments will be undertaken using methods currently in development. Remote sensing techniques and field condition data collected over a period of 10 years will be used. The aim of this method development is a product that is scientifically robust and cost effective to identify changes in extent and condition of specific vegetation community performance indicators against baseline conditions established for commencement of the WRPs in July 2020. These changes will also be correlated against groundwater level changes. Groundwater levels are routinely measured across the NSW Murray–Darling Basin via telemetry and manual measurements.

The establishment of the groundwater health index in the NSW Murray–Darling Basin will allow for changes in groundwater quality to be monitored over time in a scientifically robust and cost-effective manner specific to GDEs. Baseline conditions will be established for the commencement of the WRPs in July 2020.

Results

The identification and assigning of an ecological value to groundwater vegetation in the NSW Murray–Darling Basin was the first step in enabling NSW to undertake monitoring and management of GDEs within the groundwater water sharing plans and the WRPs (Figure 4-62). The methods for identification and assigning ecological value (Figure 4-63) have undergone external peer review and been published (Kuginis et al. 2016 and Dabovic et al. 2019).

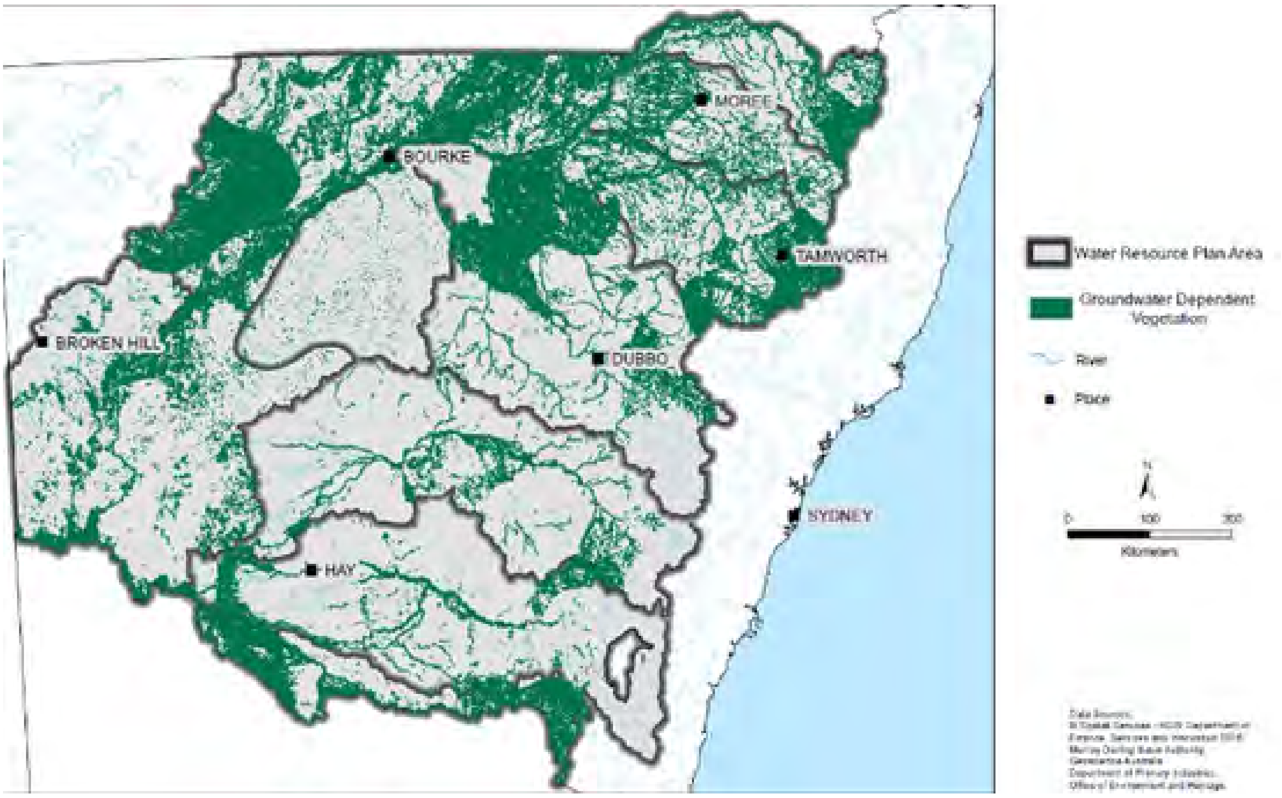

Figure 4-62 Geospatial identification of the location and extent of high probability GDEs in the Murray Darling Basin

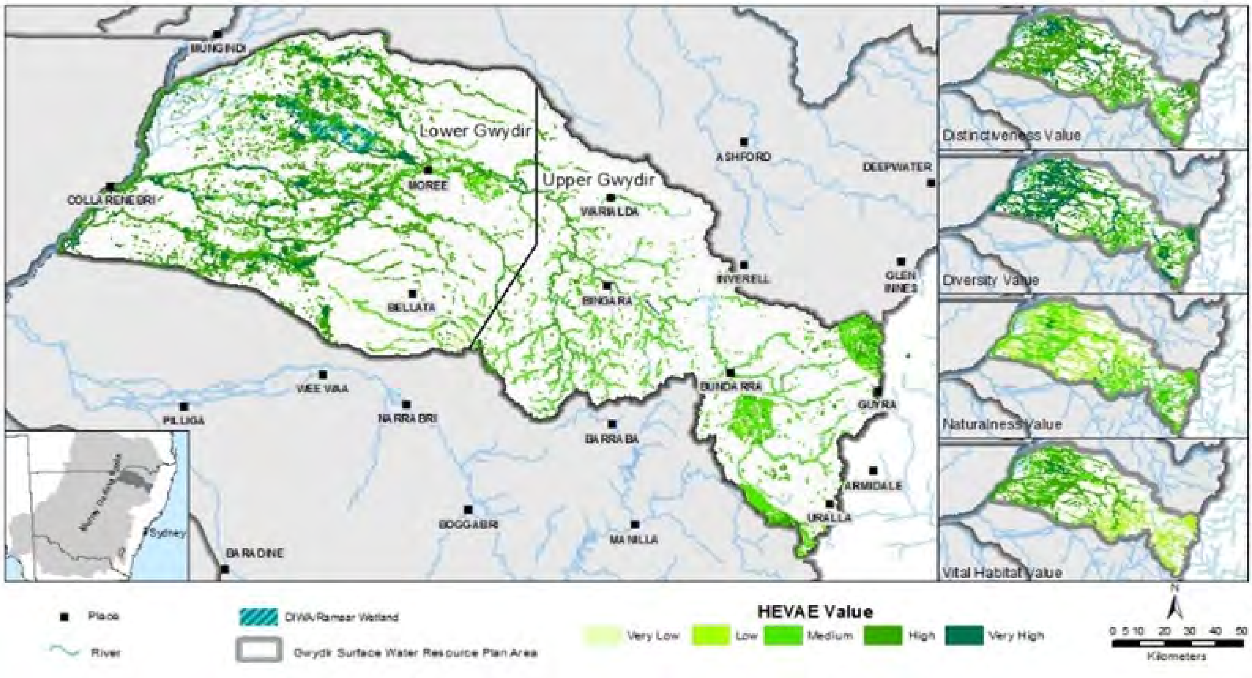

Figure 4-63 The ecological value of GDEs in the Gwydir Catchment

Groundwater-dependent vegetation extent and condition monitoring methods were being developed during the reporting period to establish baseline conditions for the commencement of the WRPS. However, no monitoring of GDEs has been undertaken to specifically meet the objective in the LTWPs. Groundwater level monitoring has been undertaken over a substantial number of years and this information will be used to establish baseline conditions and be used for future monitoring of GDEs.

At the time of writing, the development of the groundwater health index is in the final stages. A baseline index to be ready in time for the accreditation and implementation of the NSW Murray–Darling Basin WRPs. The combination of Geospatial mapping and condition assessment, supported by the HEVAE framework ecological value derivation, will provide NSW efficient and effective tools for monitoring the extent and condition of groundwater-dependent vegetation in future evaluation and reporting.

Recommendations

- Investment in research to fulfil critical knowledge gaps for determining thresholds of impact to GDEs due to groundwater drawdown and changes in quality
- Implement a vegetation condition monitoring programme in areas which have deficient data as most areas with existing field data are limited to wetlands or end of system floodplains. Riparian areas would be of benefit to this work
- Implement a monitoring programme that will gather data required for the groundwater health index.

Chapter 5 Discussion

The reporting period (1 July 2014 to 30 June 2019) was a period of extreme drought in NSW. The NSW Basin was designated as entirely in drought during the 2017–18 water year (ACCC 2019). Since 2012, seasonal dry periods have moved from May through November to occur between September and April (BOM 2019; MDBA 2020). The combination of lower rainfall (Figure 2-1) and higher temperatures (Figure 2-3), and higher than average mean wind speeds results in higher evaporation and less retention of water in the environment.

There has been a shift towards low rainfall occurring into hotter seasons which increased losses of water to evaporation and reduced groundwater recharge rates, while simultaneously increasing evapotranspiration in plants, groundwater extraction, reducing soil moisture and increasing the risks of poor water quality in isolated pools. The combination of hotter temperatures and reduced water availability may result in greater and faster degradation of ecological health and reduce capacity for ecosystems to bounce back when watered.

The drought is also clear in the hydrological record (Figure 3-5 and Figure 3-6), which shows lower that average flows with only one major high flow event, in 2016, for most catchments. Persistent, heavy rain throughout September and into October of 2016 resulted in bank full or overbank flows throughout much of the NSW Murray–Darling Basin. Analysis of the hydrographic record revealed that:

- The flow peak of 2016–17 dominated the hydrological regime of the five-year reporting period in most rivers.
- Whilst the 2016–17 flow peak was large compared to other flows during the five-year reporting period, the 2016–2017 flow peak was relatively small compared to the flow peaks that occurred in the 25 years prior to this reporting period (1999-2014)
- The 2016–17 flow events were larger and lasted longer in the southern NSW MBD that in the north.
- In several of the Northern Murray–Darling Basin catchments the 2016 flows did not meet the Environmental Watering Requirements criteria for overbank flows
- Supporting the flows with water for the environment was critical in achieving the EWRs and environmental outcomes for all themes

The drought also impacted the capacity to deliver water for the environment. Discretionary or Held environmental water are general security allocations that vary from year to year based on the available water in storage, predicted rainfall for the water year, the licence category and size of their individual entitlement. General security licence allocations in the NSW Murray–Darling Basin were limited through the majority of the reporting period, except for in the 2016–17 water year, where there were opportunities to provide flows that increased connectivity between valleys, and ‘piggy-back’ on natural flows to reach wetlands and forests that otherwise would not get water. However, with limited water available during the dry years, the supply of water for the environment was restricted to risk mitigation and ecosystem survival with no capacity for improving ecological outcomes.

The hydrographs also show that prior to 2016, the larger flow events in 2010 and 2012 resulted in several EWRs being met in their 10-year cycle but not in the reporting period (Figure 3-7 and Figure 3-8). This shows the importance of having the longer return period for less frequent flow events in the EWRs. However, it is also important to note that if climate conditions in the next 5-year reporting period are similar to those in 2014-2019, many EWRS will not be met for the 2024 report (that is, in the 10 years 2014–24) and there are likely to be measurable environmental impacts across all themes.

The environmental outcomes in this report are divided into themes. However, the themes are all interdependent, with the outcomes in each theme impacting or being impacted by the outcomes in some or all of the other themes. For example, native vegetation is an important contributor to the primary productivity in rivers through the input of carbon and nutrients from their leaves and debris they drop to the ground. Those inputs are converted by bacteria and zooplankton into food for native fish which in turn feed waterbirds which then return the nutrients back to the land and water and the cycle repeats over and over. If the condition and extent of native vegetation are impacted, it is likely that, over time, the impacts will also be seen in all of the other themes.

Equally where positive environmental outcomes are found in one or more themes it is likely that there will be benefits across other themes even if they are not monitored. An important aspect of the monitoring of, and research on, environmental outcomes is to identify and quantify the relationships between different aspects of the water cycle and ecosystems to inform water management and optimise the use of water for the environment.

In the native vegetation, waterbirds, native fish and other species themes, monitoring has shown that there has been little to no decline in the number of species being found. But the numbers of individuals, spatial extent or density of coverage continue a pattern of decline that has been observed over the past 30-40 years. This is not unique to the NSW Murray–Darling Basin, with many large-scale studies reporting declines in the abundance of fauna and flora species and taxa globally (Deinet et al. 2020, WWF 2018). While this report does not contain monitoring results for all species that benefit from river flows and inundation of floodplain habitats such as turtles, snakes, water rats, bats, insects, platypus and woodland birds, it is likely that these species would have similar responses to conditions to those reported in each theme.

The responses seen from native vegetation, waterbirds, native fish, frogs and other animal numbers after flooding and/or the application of water for the environment make it clear that water availability is a critical factor in maintaining and improving both species diversity and numbers of individuals. However, there are many other influences on environmental outcomes such as development, land management, pests and diseases and extreme events. To ensure that the application of water for the environment is the most efficient and effective it can be, other policy and management measures will be needed. Management measures such as controls on pest species, land management practices such as livestock fencing and greater protections to prevent habitat loss will be required to maintain species diversity and improve individual numbers or density across the themes. These measures are needed to support and enhance the achievement of environmental, social, cultural and economics outcomes from the use of water for the environment.

The native fish theme includes a native fish Population Health Index (PHI) that combines analyses of fish abundance, distribution, reproduction and condition. This is the first time such a tool has been made available for native fish in NSW and will allow NSW to track the condition of fish populations over time. The PHI is important because investment and action can be directed not only towards individual threatened species, but at the components of the biology and ecology of those species that are affecting their recovery.

The PHI ratings were low for almost all species of native fish sampled in the NSW Murray–Darling Basin during the current reporting period. Approximately 35% of species sampled had a PHI of Moderate; 60% had a PHI of Poor or Very Poor. While similar condition indices have not yet been derived for the other themes, the PHI results may be representative of conditions within the other themes. NSW is working on native vegetation condition tools that will inform our understanding the role of vegetation extent and condition on the environmental outcomes in the other themes. For example, extent and condition of native vegetation are likely to be key factors in the site fidelity, breeding habitat condition and foraging ranges of waterbirds, frogs and other species.

This was the first Matter 8 report for NSW, and it was a large undertaking. Reporting on Matter 8 requires large amounts of data, on a wide range of subjects, across large temporal and spatial scales. The data required was collected across huge distances by staff from three agencies and numerous contractors. Careful consideration must be given to ensure that the data collected is appropriate for the analyses that are applied. It must be of sufficient quality, quantity, frequency and distribution to provide adequate certainty in the analyses that is used for. New methods that improve the speed, accuracy and/or coverage of monitoring must also be developed, trialled, and evaluated to ensure efficient and effective environmental outcomes in NSW is continually improved.

This report highlights the importance of environmental outcomes monitoring in identifying issues for water managers and supporting water for the environment by being able to directly attribute outcomes to its use. However, it also makes it clear that NSW cannot monitor all environmental outcomes and must prioritise the use of its limited monitoring and evaluation resources.

Attribution of outcomes will require continued effort in identifying and quantifying all the influences on environmental outcomes across the themes in order to understand the overall contributions that water on other factors have. Understanding not only what influences environmental outcomes but by how much is critical to ensure that water management actions are appropriately prioritised and complemented by appropriate, efficient and effective measures. The reporting process also highlighted the need to better coordinate the monitoring, evaluation and reporting of environmental outcomes to reduce duplication and maximise efficiency, not only within NSW but also with the other state and territory governments and the Commonwealth, as well as research institutions.

NSW prepared this report with the view that it will be the baseline against which ecological outcomes in future Matter 8 reporting can be assessed against. At the time of writing the NSW WRPS had been submitted to MDBA and the monitoring, evaluation and reporting activities associated with the WRPs required for the next reporting period have commenced. The agencies responsible for the monitoring, evaluation and reporting all the Basin Plan Schedule 12 matters will continue to cooperate in their efforts to provide high quality evidence to support water management decisions in NSW and to coordinate their efforts with private and national reporting efforts and other Basin governments.

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Appendices

Appendix 1 Alignment of Basin Plan, BWS, LTWP and WSP objectives

Basin Plan objectives	BWS expected outcomes (outcomes that are relevant to NSW WRPs only)	LTWP objectives	WSP Objectives (Note: Ecological Objectives are typically located in Clause 8 of the Regulated WSP and Clause 10 of the Unregulated WSP)	How the WSP and LTWP give regard to BWS expected outcomes
Chapter 5: Management objectives and outcomes to be achieved by Basin Plan 5.03 (1)(a), (b), (c), (d) **Chapter 8: Environmental Watering Plan** 8.04 (a), (b), (c) 8.05 (2)(c) 8.06 (3)(a), (b), (c)*, (d)*, (e)*, (f) 8.06 (4) 8.06 (5) 8.06 (6)(a), (b) 8.07 (2) 8.07 (3) 8.07 (4) 8.07 (5) 8.07 (6) 8.51 (1)(b)	**River flows and connectivity theme** • Maintain base flows at least 60% of the natural level • A 10% overall increase in flows in the Barwon–Darling: from increased tributary contributions from the Condamine-Balonne, Border Rivers, Gwydir, Namoi and Macquarie–Castlereagh catchments collectively • A 30% overall increase in flows to the River Murray, from increased tributary contributions from the Murrumbidgee, Goulburn, Campaspe, Loddon and Lower Darling catchments collectively • A 10% to 20% increase of freshes and bank-full events in the Border Rivers, Gwydir, Namoi,	**EF1:** Provide and protect a diversity of refugia across the landscape **EF2:** Create quality instream, floodplain and wetland habitat **EF3:** Provide movement and dispersal opportunities for water-dependent biota to complete life cycles and disperse into new habitats: • Within catchments • Between catchments **EF4:** Support instream and floodplain productivity **EF5:** Support nutrient, carbon and sediment transport along channels, and between	**Regulated and Unregulated WSP:** 2(a)(i) protect and contribute to the enhancement of the recorded distribution or extent, and population structure of, target ecological populations. **Regulated and Unregulated WSP:** 2(a)(ii) protect and contribute to the enhancement of the longitudinal and lateral connectivity within and between water sources to support target ecological processes. *Relevant WSP notes associated with this objective:* 1) Target ecological processes within this water source include (a) carbon and nutrient pathways and (b) fish movement across significant barriers. 2) Connectivity may be within a water source, between connected regulated water sources within a WRP area, or between connected WRP areas. Connected water sources are specified in each WRP. **Regulated and Unregulated WSP:** 2(a)(iii) protect and contribute to the	In order to achieve the WSP and LTWP environmental objectives, strategies were developed to provide the environmental watering requirements (EWRs) of key species and assets. These strategies are consistent with the EWR flow components identified in section 8.51(1)(b) of the Basin Plan. Objective 2(a)(ii) in the regulated and unregulated WSPs aims to protect and contribute to the enhancement of lateral and longitudinal connectivity. However, the provision of river flows and connectivity has generally been treated as part of EWR strategies rather than objectives within the WSP and LTWP. Consequently, the BWS expected outcomes under this theme are implicit in the strategies for a wide range of EWRs.

Basin Plan objectives	BWS expected outcomes (outcomes that are relevant to NSW WRPs only)	LTWP objectives	WSP Objectives (Note: Ecological Objectives are typically located in Clause 8 of the Regulated WSP and Clause 10 of the Unregulated WSP)	How the WSP and LTWP give regard to BWS expected outcomes
Chapter 10: Water Resource Plan requirements 10.27 **Schedule 7: Targets to measure progress towards objectives** 1(a), (b), (c), (d)* 2(a), (b), (c), (d)* * Applies to Murray-lower Darling WRP only	Macquarie-Castlereagh, Barwon–Darling, Lachlan, Campaspe, Loddon and Wimmera catchments • A 30 to 60% increase in the frequency of freshes, bank-full and lowland floodplain flows in the Murray, Murrumbidgee, Goulburn-Broken and Condamine-Balonne catchments • Maintain current levels of connectivity between rivers and floodplains in the Paroo, Moonie, Nebine, Ovens and Warrego catchments	channels and floodplains/wetlands **EF6:** Support groundwater conditions to sustain groundwater-dependent biota **EF7:** Increase the contribution of flows into the Murray and Barwon–Darling from tributaries	enhancement of water quality within target ranges for the water source to support water dependent ecosystems and ecosystem functions **Regulated WSP:** 2(b) support environmental watering in the water source to contribute to maintaining or enhancing ecological condition in streams, riparian zones, dependent wetlands and floodplains **Regulated WSP:** 2(b) Support environmental watering to contribute to the maintenance or enhancement of ecological condition in streams, riparian zones, dependent wetlands and floodplains within the water source **Unregulated WSP:** 2(b) protect significant identified lagoons and wetlands, and upland wetlands of the New England Tablelands Bioregion endangered ecological community within these water sources (applies to the Gwydir and Border Rivers WRPs only) **Unregulated WSP:** 2(c) provide for connectivity with connected regulated river water sources to support actively managed environmental watering that contributes to maintaining or enhancing	

Basin Plan objectives	BWS expected outcomes (outcomes that are relevant to NSW WRPs only)	LTWP objectives	WSP Objectives **(Note: Ecological Objectives are typically located in Clause 8 of the Regulated WSP and Clause 10 of the Unregulated WSP)**	How the WSP and LTWP give regard to BWS expected outcomes
			the ecological condition within these water sources	
Chapter 5: Management objectives and outcomes to be achieved by Basin Plan 5.03 (1)(a), (c), (d) **Chapter 8: Environmental Watering Plan** 8.04 (a), (b), (c) 8.05 (2)(a), (b), (c) 8.05 (3)(a), (b) 8.06 (3)(a), (b), (c)*, (d)*, (e)*, (f) 8.06 (5) 8.06 (6) 8.07 (1) 8.07 (2) 8.07 (4) 8.07 (5) 8.07 (6) **Schedule 7: Targets to measure progress**	***Vegetation theme*** • Maintain the current extent of about 360,000 ha of river red gum, 409,000 ha of black box, 310,000 ha of coolibah forest and woodlands; and existing large communities of lignum (specific target extents apply to each WRP area) • Maintain the current extent of non-woody communities near or in wetlands, streams and on low-lying floodplains • Maintain the current condition of lowland floodplain forests and woodlands of river red gum, black box and coolabah • Improve the condition of southern river red gum • Maintain or improve the extent and condition of specific vegetation communities in each WRP area (specified in BWS Appendix 3)	**NV1:** Maintain the extent and viability of non-woody vegetation communities occurring within channels **NV2:** Maintain or increase the extent and maintain the viability of non-woody vegetation communities occurring in wetlands and on floodplains **NV2a:** Maintain or increase the extent and improve the condition of non-woody vegetation communities within semi-permanent, intermittent, temporal and ephemeral wetland and floodplain areas (Murray-lower Darling, Murrumbidgee, Macquarie and Namoi WRPs only) **NV2b:** Maintain or increase the extent and	**Regulated and Unregulated WSP:** 2(a)(i) protect and contribute to the enhancement of the recorded distribution or extent, and population structure, of target ecological populations *Relevant WSP notes associated with this objective:* 1) Target ecological populations in each water source may include specific vegetation communities, high diversity hotspots and significant habitat for native vegetation. Each WRP specifies locally relevant species and communities. **Regulated WSP:** 2(b) support environmental watering to contribute to the maintenance or enhancement of ecological condition in streams, riparian zones, dependent wetlands and floodplains within the water source *Relevant WSP notes associated with this objective:* Ramsar wetlands, and the associated ecological communities such as waterbirds and lignum shrubland, are	1) Each of the BWS expected outcomes for vegetation is included in either LTWP objectives, WSP objectives or both. The LTWP has a broader range of management actions because it guides the use of held environmental water (HEW) and EWA, hence it contains more objectives that are directed towards wetland and floodplain vegetation. The WSP outlines the operating rules that facilitate the use of HEW and EWA, but does not contain objectives to direct its use. 2) Riparian vegetation is managed collaboratively by the WSP and LTWP, through a combination of Plan rules and strategic water delivery. Priority locations for riparian vegetation management are guided by the Risk Assessment and the LTWP, and will be the focus of activities outlined in the MER Plan.

Basin Plan objectives	BWS expected outcomes (outcomes that are relevant to NSW WRPs only)	LTWP objectives	WSP Objectives (Note: Ecological Objectives are typically located in Clause 8 of the Regulated WSP and Clause 10 of the Unregulated WSP)	How the WSP and LTWP give regard to BWS expected outcomes
towards objectives 1(a), (b), (c), d)*, (e), (f) 2(a), (b), (c), (d)*, (e), (f), (g) * Applies to the Murray-lower Darling WRP only		improve the condition of ephemeral understorey vegetation within forests, woodland and open floodplain areas (all WRPs except Barwon–Darling and Border Rivers) **NV3:** Maintain the extent and improve the condition of river red gum communities closely fringing river channels **NV4:** Maintain or increase the extent and maintain or improve the condition of native woodland and shrubland communities on floodplains – targeted focus on: **NV4a:** river red gum forest (Murray-lower Darling, Murrumbidgee, Macquarie and Namoi WRPs only) **NV4b**: river red gum woodland	primarily managed by the Environmental Watering Advisory Group (EWAG) according to the conditions of the WSP. The objectives and strategies of environmental watering events are guided by each WRP's LTWP and the Annual Environmental Watering Priorities as determined by each EWAG, and may contribute to achieving the broad and targeted environmental objectives of this Plan. **Unregulated WSP**: 2(c) provide for connectivity with connected regulated river water sources to support actively managed environmental watering that contribute to the maintenance or enhancement of the ecological condition within these water sources. *Relevant WSP notes associated with this objective:* The objectives and strategies of actively managed environmental watering events are guided by each WRP's LTWPs, and the Annual Environmental Watering Priorities determined by each EWAG, and may contribute to the broad and targeted objectives of this Plan.	3) BWS Appendix 3 Table 3 outlines expected outcomes for the extent of vegetation communities in each WRP area, however the area estimates are not consistent with NSW Government's own estimates of native vegetation extent. As a consequence, Part A of the LTWPs have different estimates of current extent. Despite this difference, the LTWPs and WSPs are still consistent with the broader BWS expected outcomes because they still seek to maintain or improve extent and condition.

Basin Plan objectives	BWS expected outcomes (outcomes that are relevant to NSW WRPs only)	LTWP objectives	WSP Objectives (Note: Ecological Objectives are typically located in Clause 8 of the Regulated WSP and Clause 10 of the Unregulated WSP)	How the WSP and LTWP give regard to BWS expected outcomes
		NV4c: black box woodland **NV4d:** coolibah woodland (All WRPs except Murrumbidgee and Lachlan) **NV4e:** lignum woodland **NV4f:** coolabah wetland woodland		
Chapter 5: Management objectives and outcomes to be achieved by Basin Plan 5.03 (1)(a), (b), (c), (d) **Chapter 8: Environmental Watering Plan** 8.04 (a), (b), (c) 8.05 (2)(a), (b), (c) 8.05 (3)(a), (b) 8.06 (3)(a), (b), (c)*, (d)*, (e)*, (f) 8.06 (5) 8.06 (6)	***Waterbird theme*** • Number and type of waterbird species present in the Basin will not fall below • Significantly improve waterbird populations in the order of 20-25 % over baseline scenario with increases in all waterbird functional groups current observations • Breeding events of colonial waterbirds to increase by up to 50 % compared to baseline scenario • Breeding abundance (nests and broods) for all of the other functional groups to	**WB1:** Maintain the number and type of waterbird species **WB2:** Increase total waterbird abundance across all functional groups **WB3:** Increase opportunities for non-colonial waterbird breeding **WB4:** Increase opportunities for colonial waterbird breeding **WB5:** Maintain the extent and improve the	**Regulated and Unregulated WSP:** 2(a)(i) protect and contribute to the enhancement of the recorded distribution or extent, and population structure, of target ecological populations *Relevant WSP notes associated with this objective:* Target ecological populations in this water source include high diversity hotspots and significant habitat for waterbirds. **Regulated WSP:** 2(b) support environmental watering to contribute to the maintenance or enhancement of ecological condition in streams, riparian zones, dependent wetlands and floodplains within the water source.	Each of the BWS expected outcomes for waterbirds is included in either LTWP objectives, WSP objectives or both. The LTWP has a broader range of management actions because it guides the use of held environmental water (HEW) and EWA, hence it contains more objectives that are directed towards waterbird breeding sites. The WSP outlines the operating rules that facilitate the use of HEW and EWA, but does not contain objectives to direct its use.

Basin Plan objectives	BWS expected outcomes (outcomes that are relevant to NSW WRPs only)	LTWP objectives	WSP Objectives (Note: Ecological Objectives are typically located in Clause 8 of the Regulated WSP and Clause 10 of the Unregulated WSP)	How the WSP and LTWP give regard to BWS expected outcomes
8.07 (1) 8.07 (2) 8.07 (3) 8.07 (4) 8.07 (5) 8.07 (6) **Schedule 7: Targets to measure progress towards objectives** 1(a), (b), (c), (e), (d)*, (f) 2(a), (b), (c), (d)*, (e), (f), (g) * Applies to Murray-lower Darling WRP only	increase by 30%–40 % compared to benchmark scenario, especially in locations where the Basin Plan improves overbank flow • Each WRP contains specific waterbird assets as listed in BWS Appendix 4	condition of waterbird habitats	*Relevant WSP notes associated with this objective:* Ramsar wetlands, and the associated ecological communities such as waterbirds and lignum shrubland, are primarily managed by the Environmental Watering Advisory Group (EWAG) according to the conditions of the WSP. The objectives and strategies of environmental watering events are guided by each WRP's LTWP and the Annual Environmental Watering Priorities determined by each EWAG, and may contribute to achieving the broad and targeted environmental objectives of this Plan. **Unregulated WSP**: 2(c) provide for connectivity with connected regulated river water sources to support actively managed environmental watering that contribute to the maintenance or enhancement of the ecological condition within these water sources. *Relevant WSP notes associated with this objective:* The objectives and strategies of actively managed environmental watering events are guided by each WRP's LTWP, and the Annual Environmental Watering	

Basin Plan objectives	BWS expected outcomes (outcomes that are relevant to NSW WRPs only)	LTWP objectives	WSP Objectives **(Note: Ecological Objectives are typically located in Clause 8 of the Regulated WSP and Clause 10 of the Unregulated WSP)**	How the WSP and LTWP give regard to BWS expected outcomes
			Priorities determined by each EWAG, and may contribute to the broad and targeted objectives of this Plan.	
Chapter 5: Management objectives and outcomes to be achieved by Basin Plan 5.03 (1)(a), (b), (c), (d) **Chapter 8: Environmental Watering Plan** 8.04 (a), (b), (c) 8.05 (2)(c) 8.05 (3)(a), (b) 8.06 (3)(a), (b), (c)*, (d)*, (e)*, (f) 8.06 (5) 8.06 (6) 8.06 (7) 8.07 (1) 8.07 (2) 8.07 (3) 8.07 (4) 8.07 (5) 8.07 (6)	***Fish Theme*** • By 2024, improved population structure of key fish species through regular recruitment • By 2024, increased movement of key fish species • By 2024, expanded distribution of key species and populations in the northern and southern Basin • No loss of native fish species currently present within the Basin • By 2024, restore distribution and abundance of short-lived species to levels recorded pre-2007. • By 2024, improved population structure for moderate to long-lived species in at least 8 out of 10 years, and at 80% of key sites • By 2024, a 10-15% increase in mature fish for recreational target species (Murray cod	**NF1:** No loss of native fish species **NF2:** Increase the distribution and abundance of short to moderate-lived generalist native fish species **NF3:** Increase the distribution and abundance of short to moderate-lived floodplain specialist native fish species **NF4:** Improve native fish population structure for moderate to long-lived flow pulse specialist native fish species **NF5:** Improve native fish population structure for moderate to long-lived riverine specialist native fish species	**Regulated and Unregulated WSP:** 2(a)(i) protect and contribute to the enhancement of the recorded distribution or extent, and population structure, of target ecological populations *Relevant WSP notes associated with this objective:* 1) target ecological populations include specific native fish species in each WRP area, high diversity hotspots and significant habitat for native fish **Regulated and Unregulated WSP**: 2(a)(ii) protect and contribute to the enhancement of the longitudinal and lateral connectivity within and between water sources to support target ecological processes. *Relevant WSP notes associated with this objective:* Target ecological processes within this water source include (a) carbon and nutrient pathways and (b) fish movement across significant barriers.	1) Each of the BWS expected outcomes for native fish is included in the LTWP objectives and WSP objectives. The LTWP has a broader range of management actions because it guides the use of held environmental water (HEW) and EWA, hence it contains more objectives that are directed towards providing strategic flow events at specific times and of specific magnitudes that are required by fish species. The WSP outlines the operating rules that facilitate the use of HEW and EWA, but does not contain objectives to direct its use. 2) The BWS has outlined specific native fish priorities for each WRP Area that include expanding the range of existing populations and establishing new populations of native fish. In some cases, however, the BWS lists a species in a WRP area that has not been recorded by NSW in recent

Basin Plan objectives	BWS expected outcomes (outcomes that are relevant to NSW WRPs only)	LTWP objectives	WSP Objectives **(Note: Ecological Objectives are typically located in Clause 8 of the Regulated WSP and Clause 10 of the Unregulated WSP)**	How the WSP and LTWP give regard to BWS expected outcomes
Schedule 7: Targets to measure progress towards objectives 1(a), (b), (c), (d)*, (e), (f) 2(a), (b), (c),(d)*, (e), (f), (g) * Applies to Murray-lower Darling WRP only	and golden perch) in key populations • By 2024, annual detection of species and life stages representative of the whole fish community through key fish passages • By 2024, a doubling of the current (mostly restricted) distributions of key species in the northern Basin • Each WRP contains expected outcomes for specific native fish species as listed in BWS Appendix 6	**NF6:** A 25% increase in abundance of mature (harvestable sized) golden perch (Border Rivers, Barwon–Darling, Namoi, Macquarie and Murray–lower Darling WRPs only) and Murray cod (all WRPs except Intersecting Streams) **NF7:** Increase the prevalence and/or expand the population of key short to moderate-lived floodplain specialist native fish species into new areas that are within historical range (All WRPs except Intersecting Streams, Barwon–Darling and Namoi)) **NF8:** Increase the prevalence and/or expand the population of key moderate to long-lived riverine specialist native fish species into new areas that are within historical range	**Regulated WSP:** 2(b) support environmental watering to contribute to the maintenance or enhancement of ecological condition in streams, riparian zones, dependent wetlands and floodplains within the water source *Relevant WSP notes associated with this objective:* The objectives and strategies of environmental watering events are guided by each WRP's Long-term Water Plan and the Annual Environmental Watering Priorities determined by each EWAG, and may contribute to achieving the broad and targeted environmental objectives of this Plan. **Unregulated WSP**: 2(c) provide for connectivity with connected regulated river water sources to support actively managed environmental watering that contribute to the maintenance or enhancement of the ecological condition within these water sources. *WSP notes associated with this objective:* The objectives and strategies of actively managed environmental watering events are guided by each WRP's LTWP, and the Annual Environmental Watering	history. Where a species has not been confirmed within a WRP area by NSW, there is no objective in the LTWP or WSP. 3) Regular monitoring of fish communities will take place during the terms of the WSP and LTWP. If any new species or populations are detected within a WRP Area, the objectives of the WSP and LTWP will change to incorporate it and steps will be taken immediately to prioritise their conservation.

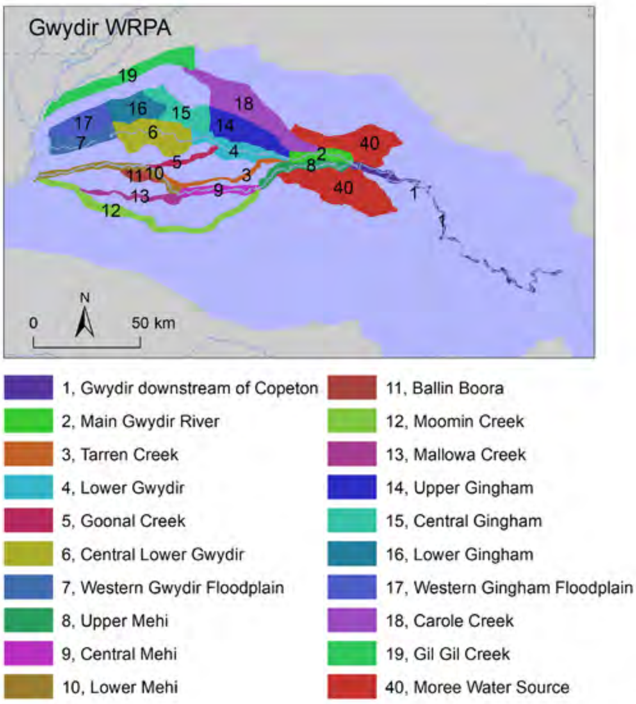
Basin Plan objectives	BWS expected outcomes (outcomes that are relevant to NSW WRPs only)	LTWP objectives	WSP Objectives **(Note: Ecological Objectives are typically located in Clause 8 of the Regulated WSP and Clause 10 of the Unregulated WSP)**	How the WSP and LTWP give regard to BWS expected outcomes
		(all WRPs except Intersecting Streams) **NF9:** Increase the prevalence and/or expand the population of key moderate to long-lived flow pulse specialist native fish species into new areas (Murray-lower Darling, Murrumbidgee, Lachlan, Barwon–Darling and Namoi WRPs only) **NF10:** Increase the prevalence and/or expand the population of key moderate to long-lived diadromous native fish species into new areas that are within historical range (Murray–lower Darling and Murrumbidgee WRPs only)	Priorities determined by each EWAG, and may contribute to the broad and targeted objectives of this Plan.	
Chapter 5: Management objectives and outcomes to be	***No equivalent BWS theme***	**EF1:** Provide and protect a diversity of refugia across the landscape	**Regulated and Unregulated WSP:** 2(a)(i) protect and contribute to the enhancement of the recorded distribution or extent, and population	The LTWP and WSP objectives listed here are not directly referenced in the BWS themes, but are consistent with, and contribute to achieving, the broad

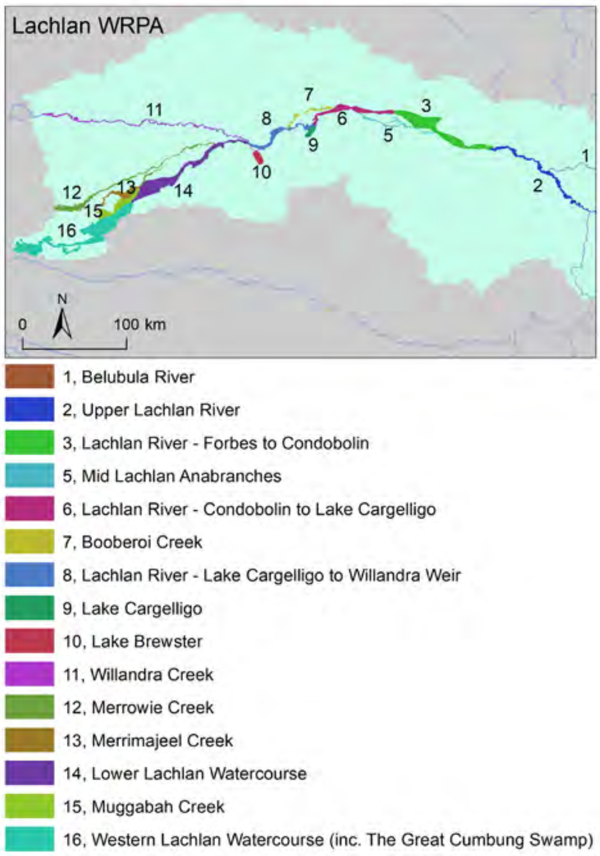
Basin Plan objectives	BWS expected outcomes (outcomes that are relevant to NSW WRPs only)	LTWP objectives	WSP Objectives (Note: Ecological Objectives are typically located in Clause 8 of the Regulated WSP and Clause 10 of the Unregulated WSP)	How the WSP and LTWP give regard to BWS expected outcomes
achieved by Basin Plan 5.03 (1)(a), (c), (d) **Chapter 8: Environmental Watering Plan** 8.04 (a), (b), (c) 8.05 (2)(a), (b), (c) 8.05 (3)(a), (b) 8.06 (3)(a), (b), (c)*, (d)*, (e)*, (f) 8.06 (4) 8.06 (5) 8.06 (6)(a), (b) 8.06 (7) 8.07 (1) 8.07 (2) 8.07 (3) 8.07 (4) 8.07 (5) 8.07 (6) **Schedule 7: Targets to measure progress towards objectives**		**EF2:** Create quality instream, floodplain and wetland habitat **EF3:** Provide movement and dispersal opportunities for water-dependent biota to complete life cycles and disperse into new habitats: • Within catchments • Between catchments **EF4:** Support instream and floodplain productivity **EF5:** Support nutrient, carbon and sediment transport along channels, and between channels and floodplains/wetlands **EF6:** Support groundwater conditions to sustain groundwater-dependent biota	structure of, target ecological populations. *Relevant WSP notes associated with this objective:* target ecological populations in each WRP water source may include high diversity hotspots and significant habitat for native fish, frogs, waterbirds, native vegetation and low-flow macroinvertebrate communities (within unregulated water sources) **Regulated and Unregulated WSP:** 2(a)(ii) protect and contribute to the enhancement of the longitudinal and lateral connectivity within and between water sources to support target ecological processes. *Relevant WSP notes associated with this objective:* Target ecological processes within this water source include carbon and nutrient transport pathways, which are the connected networks of streams, riparian zones, floodplains and wetlands that transport dissolved and suspended organic material and nutrients throughout the water source	Basin Plan and BWS expected outcomes

Basin Plan objectives	BWS expected outcomes (outcomes that are relevant to NSW WRPs only)	LTWP objectives	WSP Objectives **(Note: Ecological Objectives are typically located in Clause 8 of the Regulated WSP and Clause 10 of the Unregulated WSP)**	How the WSP and LTWP give regard to BWS expected outcomes
1(a), (b), (c), (e),(d)*, (f) 2(a), (b), (c), (d)*, (e), (f), (g) * Applies to Murray-lower Darling WRP only		**OS1:** Maintain species richness and distribution of flow-dependent frog communities (Gwydir, Macquarie, Lachlan, Murrumbidgee and Murray-lower Darling only) **OS2:** maintain successful breeding opportunities for flow-dependent frog species (Gwydir, Macquarie, Lachlan, Murrumbidgee and Murray-lower Darling only) **OS3a:** Maintain and increase number of wetland sites occupied by the threatened southern bell frog (Murrumbidgee and Murray-lower Darling WRPs only) **OS3b:** Maintain & increase number of wetland sites occupied by the threatened	**Regulated and Unregulated WSP:** 2(a)(iii) protect and contribute to the enhancement of water quality within target ranges for the water source to support water dependent ecosystems and ecosystem functions **Regulated WSP:** 2(b) support environmental watering in the water source to contribute to maintaining or enhancing ecological condition in streams, riparian zones, dependent wetlands and floodplains. **Regulated WSP:** 2(b) Support environmental watering to contribute to the maintenance or enhancement of ecological condition in streams, riparian zones, dependent wetlands and floodplains within the water source **Unregulated WSP:** 2(b) protect significant identified lagoons and wetlands, and upland wetlands of the New England Tablelands Bioregion endangered ecological community within these water sources (applies to the Gwydir and Border Rivers WRPs only) **Unregulated WSP:** 2(c) provide for connectivity with connected regulated river water sources to support actively managed environmental watering that	

Basin Plan objectives	BWS expected outcomes (outcomes that are relevant to NSW WRPs only)	LTWP objectives	WSP Objectives (Note: Ecological Objectives are typically located in Clause 8 of the Regulated WSP and Clause 10 of the Unregulated WSP)	How the WSP and LTWP give regard to BWS expected outcomes
		Sloane's froglet (Murray-lower Darling WRP only) **OS4:** Maintain water-dependent species richness (Lachlan and Murray-lower Darling WRPs only)	contributes to maintaining or enhancing the ecological condition within these water sources	

Appendix 2 Gwydir and Lachlan WRPA Planning Units from the Long-term Water Plans – used for the EWR assessment





Appendix 3 Average catch per site across sampling years for native fish, decapod crustaceans and alien fish

Average catch per site across sampling years for native fish, decapod crustaceans and alien fish from the Basin Plan Environmental Outcomes Monitoring-Fish (BPEOM-F) project. '✓' represent species not detected by this sampling program, but which were reported in the NSW portion of the basin by others during the reporting period.

	2014–15	2015–16	2016–17	2017–18	2018–19	All years' average
Number of sites sampled	98	320	195	303	292	1,208
Native fish	N/A	N/A	N/A	N/A	N/A	N/A
Carp-gudgeon species complex	49.021	14.491	32.286	18.054	43.912	28.228
Bony herring	22.958	7.223	32.495	12.904	19.658	17.112
Australian smelt	11.884	5.439	16.621	6.436	3.988	7.748
Un-specked hardyhead	3.874	1.697	1.066	3.311	3.842	2.695
Mountain galaxias	3.074	1.983	0.527	1.821	2.754	1.977
Murray-Darling rainbowfish	1.853	0.808	2.374	1.239	1.404	1.406
Murray cod	1.495	1.108	1.253	0.650	1.800	1.212
Flathead gudgeon	3.663	0.972	0.956	1.054	0.481	1.106
Spangled perch	0.611	0.258	1.571	1.014	1.654	1.025
Golden perch	1.242	0.512	0.973	0.729	0.942	0.807
River blackfish	0.726	0.286	0.000	0.239	0.077	0.216
Freshwater catfish	0.179	0.115	0.214	0.079	0.288	0.168
Olive perchlet	0.021	0.000	0.280	0.004	0.035	0.057
Two-spined blackfish	0.158	0.115	0.005	0.014	0.000	0.048
Trout cod	0.053	0.059	0.033	0.025	0.062	0.046
Silver perch	0.116	0.035	0.044	0.032	0.035	0.043
Macquarie perch	0.326	0.003	0.038	0.000	0.008	0.037
Dwarf flathead gudgeon	0.011	0.007	0.000	0.064	0.012	0.022

Darling River hardyhead	0.000	0.038	0.033	0.000	0.000	0.015
Southern purple-spotted gudgeon	0.000	0.000	0.011	0.021	0.004	0.008
Hyrtls tandan	0.011	0.003	0.022	0.007	0.000	0.007
Obscure galaxias	0.000	0.000	0.000	0.000	0.004	0.001
Southern pygmy perch	0.011	0.000	0.000	0.000	0.000	0.001
Stocky galaxias	0	✓*	✓*	✓*	✓*	✓
Pouched lamprey (vagrant in NSW)	0	✓*	0	0	0	✓
Murray hardyhead	0	0	0	0	✓*	✓
Flat-headed galaxias	0	0	0	0	0	0*
Riffle galaxias	0	0	0	0	0	0*
Short-headed lamprey	0	0	0	0	0	0*
Short-finned eel (vagrant in NSW)	0	0	0	0	0	0*
Long-finned eel (vagrant in NSW)	0	0	0	0	0	0*
Congoli (vagrant in NSW)	0	0	0	0	0	0*
Rendahl's tandan (potentially present)	0	0	0	0	0	0*
Alien fishes	N/A	N/A	N/A	N/A	N/A	N/A
Eastern gambusia	17.989	15.882	22.720	13.707	19.677	17.533
Common carp	10.368	5.620	50.989	7.504	8.938	14.767
Goldfish	1.611	1.070	10.978	2.332	2.019	3.293
Redfin perch	1.126	0.544	1.670	1.325	2.046	1.332
Rainbow trout	0.116	0.077	0.181	0.618	0.231	0.271
Brown trout	0.084	0.070	0.159	0.529	0.169	0.226
Oriental weatherloach	0.000	0.007	0.044	0.529	0.004	0.144
Carp-goldfish hybrid	0.000	0.000	0.000	0.000	0.012	0.003

Native Crustaceans	N/A	N/A	N/A	N/A	N/A	N/A
Freshwater long-armed prawn	6.600	8.676	10.297	9.704	9.623	9.248
Yabby	2.632	3.425	5.610	1.461	1.600	2.789
Glass shrimp	2.947	2.958	1.225	0.832	1.512	1.792
Murray crayfish	0.011	0.052	0.016	0.025	0.038	0.033
Riek's crayfish	0.000	0.000	0.093	0.000	0.019	0.020
Alpine spiny crayfish	0.021	0.007	0.000	0.025	0.015	0.014
Freshwater crab	0.000	0.003	0.000	0.000	0.004	0.002
Clayton's crayfish	0.000	0.000	0.005	0.000	0.000	0.001
Sydney Crayfish (Blue Mountains form)	0.000	0.003	0.000	0.000	0.000	0.001
Hanging rock spiny crayfish	0	0	✓*	0	0	✓
Cudgegong giant spiny crayfish	0	0	✓*	0	0	✓
Small mountain crayfish	0	0	0	0	0	0*
Sutton’s crayfish	0	0	0	0	0	0*
Barmah swamp yabby (potentially present)	0	0	0	0	0	0*

* Stocky galaxias (known presence 2015/16 - 2018/19; Allen & Lintermans, University of Canberra, pers. comm.), hanging rock spiny crayfish (last reported 2016–17; Atlas of Living Australia (ALA)), Cudgegong giant spiny crayfish (last reported 2016–17; ALA), and Murray hardyhead (the result of a NSW re-introduction program that commenced in 2018–19; Iain Ellis, NSW DPI-Fisheries, pers. comm.). Small mountain crayfish (last reported 2003/04; ALA), riffle galaxias (last reported in NSW in 2004–05; SRA), short-headed lamprey (last reported in the NSW MDB in 1993/94; ALA), Barmah swamp yabby (last reported from the mid-Murray River; Rob McCormack, pers. comm.), Sutton’s crayfish (last reported in NSW in 2001–02; ALA) and flat-headed galaxias (last detected in NSW in December 2013; Peter Unmack, University of Canberra pers. comm.).

Appendix 4 Flow-responsive frog species recorded in the Murray–Darling Basin and records (Ocock et al. 2018) for wetland areas monitored in the Macquarie, Gwydir and Murrumbidgee Catchments in the 2014-19 period

Species	Common Name	Monitoring area Macquarie Marshes ^	Monitoring area Gwydir Wetlands	Monitoring area Mid and Lower Murrumbidgee
Crinia parinsignifera	eastern sign-bearing froglet	X	X	X
Crinia signifera	common eastern froglet			
***Crinia sloanei* v**	Sloane's froglet			
Limnodynastes dumerilii	eastern banjo frog			
Limnodynastes fletcheri	barking marsh frog	X	X	X
Limnodynastes interioris	giant banjo frog			X
Limnodynastes peronii	striped marsh frog			
Limnodynastes salmini	salmon striped frog	X	X	
Limnodynastes tasmaniensis	spotted marsh frog	X	X	X
Limnodynastes terraereginae	northern banjo frog			
Litoria ewingii	brown tree frog			
Litoria fallax	eastern dwarf sedge frog			
Litoria latopalmata	broad-palmed frog	X	X	
Litoria paraewingi	Victorian frog			
Litoria peronii	Peron's tree frog	X	X	X
***Litoria raniformis* V,e**	southern bell frog			X
Litoria tyleri	Tylers tree frog			
Litoria verreauxii	Verreaux's frog			

Baseline data for the Murrumbidgee was from most recent field surveys 2014–19 through the Commonwealth funded Long-Term Intervention Monitoring (LTIM) Program (Wassens et al. 2020) and NSW Department Planning, Industry and Environment funded surveys in the Macquarie Marshes and Gwydir Wetlands (Walcott et al. 2020). Note that only single season surveys were completed in the Lower Lachlan in 2015–16 (Dyer et al. 2016) and Yanco-Billabong Creek system (Murrumbidgee Catchment) in 2017–18 (Walcott et al. 2018)

Appendix 5

Guild	Species	Presence	Distribution	Abundance	Recruitment/Population structure	Recreational fishing
Flow pulse specialists	Golden perch	NF1a, NF1b (achieved)	NF9a (somewhat achieved)	NA	NF4a, NF4b (achieved)	NF6a
Flow pulse specialists	Golden perch	NF1a, NF1b (achieved)	NF9a (somewhat achieved)	NA	NF4c (not achieved)	BF6b (achieved)
Flow pulse specialists	Silver perch	NF1a, NF1b (achieved)	NF9a (not achieved)	NA	NF4a, NF9b, NF4c (achieved)	NA
Flow pulse specialists	Silver perch	NF1a, NF1b (achieved)	NF9a (not achieved)	NA	NF4b, NF4c (not achieved)	NA
Flow pulse specialists	Spangled perch	NF1a, NF1b (achieved)	NF9a (not achieved)	NA	NF4a, NF9b, NF4c (achieved)	NA
Flow pulse specialists	Hyrtl's tandan	NF1a (achieved)	NF9a (somewhat achieved)	NA	NF4a, NF9b, NF4c, NF9b, NF9c (not achieved)	NA
Flow pulse specialists	Hyrtl's tandan	NF1b (not achieved)	NF9a (somewhat achieved)	NA	NF4a, NF9b, NF4c, NF9b, NF9c (not achieved)	NA
Generalists	Carp-gudeon species complex	NF1a, NF1b (achieved)	NF2a (achieved)	NF2b (achieved)	NF2c (achieved)	NA
Generalists	Bony herring	NF1a, NF1b (achieved)	NF2a (achieved)	NF2b (somewhat achieved)	NF2c (achieved)	NA
Generalists	Un-specked hardyhead	NF1a, NF1b (achieved)	NF2a (not achieved)	NF2b (achieved)	NF2c (achieved)	NA
Generalists	Murray-Darling rainbowfish	NF1a, NF1b (achieved)	NF2a (somewhat achieved)	NF2b (achieved)	NF2c (achieved)	NA

Guild	Species	Presence	Distribution	Abundance	Recruitment/Population structure	Recreational fishing
Generalists	Australian smelt	NF1a, NF1b (achieved)	NF2a (achieved)	NF2b (somewhat achieved)	NF2c (achieved)	NA
Generalists	Mountain galaxias	NF1a, NF1b (achieved)	NF2a (somewhat achieved)	NF2b (somewhat achieved)	NF2c (achieved)	NA
Generalists	Stocky galaxias	NF1a (achieved)	NF2a (not achieved)	NF2b (not achieved)	NF2c (not achieved)	NA
Generalists	Stocky galaxias	NF1b (not achieved)	NF2a (not achieved)	NF2b (not achieved)	NF2c (not achieved)	NA
Generalists	Riffle galaxias	NF1a, NF1b (not achieved)	NF2a (not achieved)	NF2b (not achieved)	NF2c (not achieved)	NA
Generalists	Obscure galaxias	NF1a (achieved)	NF2a (not achieved)	NF2b (not achieved)	NF2c (not achieved)	NA
Generalists	Obscure galaxias	NF1b (not achieved)	NF2a (not achieved)	NF2b (not achieved)	NF2c (not achieved)	NA
Generalists	Flat-head gudgeon	NF1a, NF1b (achieved)	NF2a (somewhat achieved)	NF2b (not achieved)	NF2c (achieved)	NA
Generalists	Darling River hardyhead	NF1a (achieved)	NF2a (not achieved)	NF2b (somewhat achieved)	NF2c (not achieved)	NA

Guild	Species	Presence	Distribution	Abundance	Recruitment/Population structure	Recreational fishing
Generalists	Darling River hardyhead	NF1b (not achieved)	NF2a (not achieved)	NF2b (somewhat achieved)	NF2c (not achieved)	NA
Floodplain specialists	Olive perchlet	NF1a (achieved)	NF3a, NF7a (not achieved)	NF3b (somewhat achieved)	NF3c, NF7c (achieved)	NA
Floodplain specialists	Olive perchlet	Nf1b (not achieved)	NF3a, NF7a (not achieved)	NF3b (somewhat achieved)	NF7b (not achieved)	NA
Floodplain specialists	Murray hardyhead	NF1a (achieved)	NF3a, NF7a (not achieved)	NF3b (not achieved)	NF3c, NF7b, NF7c (not achieved)	NA
Floodplain specialists	Murray hardyhead	Nf1b (not achieved)	NF3a, NF7a (not achieved)	NF3b (not achieved)	NF3c, NF7b, NF7c (not achieved)	NA
Floodplain specialists	Flat-headed galaxias	NF1a, Nf1b (not achieved)	NF3a, NF7a (not achieved)	NF3b (not achieved)	NF3c, NF7b, NF7c (not achieved)	NA
Floodplain specialists	Southern pygmy perch	NF1a (achieved)	NF3a, NF7a (not achieved)	NF3b (somewhat achieved)	NF3c, NF7b, NF7c (not achieved)	NA
Floodplain specialists	Southern pygmy perch	Nf1b (not achieved)	NF3a, NF7a (not achieved)	NF3b (somewhat achieved)	NF3c, NF7b, NF7c (not achieved)	NA

Guild	Species	Presence	Distribution	Abundance	Recruitment/Population structure	Recreational fishing
Floodplain specialists	Southern purple-spotted gudgeon	NF1a (achieved)	NF3a, NF7a (not achieved)	NF3b (somewhat achieved)	NF3c, NF7b, NF7c (not achieved)	NA
Floodplain specialists	Southern purple-spotted gudgeon	Nf1b (not achieved)	NF3a, NF7a (not achieved)	NF3b (somewhat achieved)	NF3c, NF7b, NF7c (not achieved)	NA
Floodplain specialists	Dwarf flat-headed gudgeon	NF1a (achieved)	NF3a (somewhat achieved)	NF3b (not achieved)	NF3c, NF7b, NF7c (not achieved)	NA
Floodplain specialists	Dwarf flat-headed gudgeon	Nf1b (not achieved)	NF3a (somewhat achieved)	NF3b (not achieved)	NF3c, NF7b, NF7c (not achieved)	NA
Riverine specialists	Murray cod	Nf1a, NF1b (achieved)	NA	NA	NF5a, NF5b, NF5c (achieved)	NF6a
Riverine specialists	Murray cod	Nf1a, NF1b (achieved)	Nf8a (not achieved)	NA	NF5a, NF5b, NF5c (achieved)	NF6b (achieved)
Riverine specialists	Freshwater catfish	Nf1a, NF1b (achieved)	Nf8a (not achieved)	NA	NF5a, NF5b, NF8b, NF8c (achieved)	NA
Riverine specialists	Freshwater catfish	Nf1a, NF1b (achieved)	Nf8a (not achieved)	NA	NF5c (not achieved)	NA
Riverine specialists	Two-spined blackfish	Nf1a (achieved)	Nf8a (not achieved)	NA	NF5a, NF5b, NF5c, NF8b (not achieved)	NA
Riverine specialists	Two-spined blackfish	NF1b (not achieved)	Nf8a (not achieved)	NA	NF8c (achieved)	NA
Riverine specialists	River blackfish	Nf1a (achieved)	Nf8a (not achieved)	NA	NF5a, NF5c, NF8b (not achieved)	NA

Guild	Species	Presence	Distribution	Abundance	Recruitment/Population structure	Recreational fishing
Riverine specialists	River blackfish	NF1b (not achieved)	Nf8a (not achieved)	NA	NF5b, NF8c (achieved)	NA
Riverine specialists	Trout cod	Nf1a, NF1b (achieved)	Nf8a (not achieved)	NA	NF5a, NF5b, NF8b, NF8c (achieved)	NA
Riverine specialists	Trout cod	Nf1a, NF1b (achieved)	Nf8a (not achieved)	NA	NF5c (not achieved)	NA
Riverine specialists	Murray crayfish	Nf1a (achieved)	Nf8a (not achieved)	NA	NF5a, NF5c, NF8b (not achieved)	NA
Riverine specialists	Murray crayfish	Nf1a (achieved)	Nf8a (not achieved)	NA	NF5b, NF8c (achieved)	NA
Riverine specialists	Macquarie perch	Nf1a (achieved)	Nf8a (not achieved)	NA	NF5a, NF8b (not achieved)	NA
Riverine specialists	Macquarie perch	NF1b (not achieved)	Nf8a (not achieved)	NA	NF5b, NF5c, NF8c (achieved)	NA
Diadromous fish	Short-finned eel	NF1a, NF1b (not achieved)	NF10 (not achieved)	NA	NA	NA
Diadromous fish	Short-headed lamprey	NF1a, NF1b (not achieved)	NF10 (not achieved)	NA	NA	NA
Diadromous fish	Pouched lamprey	NF1a, NF1b (not achieved)	NF10 (not achieved)	NA	NA	NA
Fish community status	NA	NF1c	NF1c	NF1c	NF1c	NF1c
Objective outcomes (not including fish community status)	% achieved	64	9	18	46	50

Guild	Species	Presence	Distribution	Abundance	Recruitment/Population structure	Recreational fishing
Objective outcomes (not including fish community status)	% not achieved	36	91	82	54	50