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Murray-Darling Basin Long Term Intervention Monitoring Project

2018–19 Basin-scale evaluation of Commonwealth environmental water – Biodiversity

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Murray–Darling Basin Long Term Intervention Monitoring Project 2018–19 Basin-scale evaluation of Commonwealth environmental water — Biodiversity Report

Report prepared for the Department of the Environment and Energy, Commonwealth Environmental Water Office by La Trobe University, Centre for Freshwater Ecosystems.

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Cover Image: Cormorants at War Plain, Barmah Forest Ramsar Site

Photographer: Keith Ward

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Contents

Summary of annual Basin-scale evaluation 2018–19

Key Basin-scale evaluation findings

- Commonwealth environmental water was delivered to maintain refuge habitats in a drying landscape in 2018–19. This resulted in sustained records for waterbird and frog diversity in the Gwydir and Murrumbidgee Selected Areas.
- The nationally listed endangered Australasian bittern (*Botaurus poiciloptilus*) was recorded in the Gwydir river systems at wetlands that received Commonwealth environmental water in 2017–18.
- The nationally listed vulnerable southern bell frog (*Litoria raniformis*) was recorded in wetlands in the Murrumbidgee system at sites that received Commonwealth environmental water, with evidence of breeding.
- Watering of wetlands along the Lower Murray resulted in a network of inundated habitats supporting habitat for frogs and a high diversity of waterbird species, including 44 species at Qualco.
- Commonwealth environmental water contributed to maintaining the ecological character of ten Ramsar listed wetlands in 2018–19.
- Inundation of floodplain marshes at Barmah Forest resulted in improved vegetation condition and a diversity of waterbirds, with the nationally threatened Australasian bittern recorded in response to watering.
- Commonwealth environmental water contributed to maintaining populations of Murray cod and other native fish in Gunbower Creek.

Key contribution to Basin Plan objectives

- 8.05(2) protect and restore a subset of all water-dependent ecosystems..(a) declared Ramsar wetlands that depend on Basin water resources maintain their ecological character – by delivering environmental water to nine of the 16 Ramsar Wetlands in the Basin.
- 8.05(2) protect and restore a subset of all water-dependent ecosystems..(b) species listed under the Bonn Convention, CAMBA, JAMBA or ROKAMBA – by supporting a small number of migratory shorebirds at inland sites and a large number in the Coorong.
- 8.05(3) protect and restore biodiversity..(a) listed threatened species – by supporting threatened native fish species, waterbirds (Australasian bittern, regent parrot, superb parrot) and the southern bell frog.
- 8.05(3) protect and restore biodiversity..(b) representative populations and communities of native biota – by supporting greater than one percent of the population of eight species of waterbird.

Summary of multi-year Basin-scale evaluation outcomes 2014–19

Key Basin-scale evaluation findings

- A total of 76 species of wetland dependent birds have been recorded at sites that received Commonwealth environmental water in Selected Areas 2014–19.
- Waterbird abundance and to a lesser extent, diversity, is greater in wetlands than are partially full rather than completely inundated, indicating the importance of wetting and drying cycles of wetland ecosystems.
- Two nationally listed endangered waterbird species have been recorded at wetlands that received Commonwealth environmental water in Selected Areas: the Australasian bittern and Australian painted snipe.
- The nationally listed vulnerable southern bell frog was recorded in wetlands in the Murrumbidgee system in all years, with good evidence that Commonwealth environmental water has contributed to maintain populations at several wetland sites.
- Commonwealth environmental water has contributed to maintaining the ecological character of 11 of the 16 Ramsar sites in the Basin over the five years of the LTIM project. There is very good evidence that Commonwealth environmental water used as part of multi-year strategies has contributed to the restoration of ecological character at Hattah-Kulkyne Lakes and Banrock Station, helped to maintain several critical components and processes at the Macquarie Marshes and improved native fish populations in Gunbower Creek.
- Fifty-four significant species were recorded at sites that received environmental water in 2014–19. This includes 18 international migratory waterbird species, 18 nationally listed threatened species and 21 species listed under state legislation.
- Over the past four years 101 waterbird species and over one million individuals have been recorded at sites that received Commonwealth environmental water, with more than one percent of the population supported for 22 species.

Key contributions to Basin Plan objectives

- 8.05(2) protect and restore a subset of all water-dependent ecosystems..(a) declared Ramsar wetlands that depend on Basin water resources maintain their ecological character – by delivering environmental water to 11 of the 16 Ramsar wetlands in the Basin.
- 8.05(2) protect and restore a subset of all water-dependent ecosystems..(b) species listed under the Bonn Convention, CAMBA, JAMBA or ROKAMBA – by supporting a small number of migratory shorebirds at inland sites and a large number in the Coorong.
- 8.05(3) protect and restore biodiversity..(a) listed threatened species – by supporting 54 listed threatened species over the five years of LTIM.
- 8.05(3) protect and restore biodiversity..(b) representative populations and communities of native biota – by supporting greater than one percent of the population of 22 species of waterbird.

1 Project Details

1.1 Introduction

The Murray–Darling Basin (the Basin) contains over 23 000 square kilometres of lakes and wetlands, 50 000 square kilometres of floodplain and 600 000 kilometres of mapped river channel (Brooks 2017). Sixteen wetlands of international importance, listed under the Ramsar Convention, are located within the Basin, as are over 200 nationally important wetlands (Leblanc et al. 2012). These ecosystems support a broad range of species and ecological communities that are inundation dependent, or dependent on vegetation communities that are classified as wetland or floodplain systems. The Basin's aquatic ecosystems also support a large number of nationally and internationally significant plant and animal species, including 95 species listed as threatened under national or state legislation (Leblanc et al. 2012).

An objective of the Basin Plan is to protect or restore biodiversity that is dependent on the Basin's water resources. This is achieved through supporting listed threatened species or listed threatened ecological communities and ensuring that representative populations and communities of native biota are protected and, if necessary, restored (Basin Plan, section 8.05(3)).

Species and communities can be dependent on water regimes for all or parts of their life-cycle. Most of the aquatic ecosystem-dependent biota within the Basin are adapted to cycles of wetting and drying, with many important breeding, migration or germination cues linked to water regime (Brock & Casanova 1997; Young et al. 2001; Roberts & Marston 2011). In a climate of increasing pressures on water resources, environmental watering actions can play a crucial role in maintaining species and ecosystem diversity (Beesley et al. 2009; Brandis 2010).

The Biodiversity component of the Commonwealth Environmental Water Office's (CEWO's) Long Term Intervention Monitoring (LTIM) Project aims to evaluate the contribution of Commonwealth environmental water to achieving diversity-related objectives of the Basin Plan (section 8.05 (2) and (3)). This is accomplished through the consolidation of information from multiple sources to provide a summary of species and communities that potentially benefitted from Commonwealth environmental water to address the following evaluation questions:

What did Commonwealth environmental water contribute to species diversity?

- How did Commonwealth environmental water affect the presence, distribution and abundance of plant, fish, bird, frog, turtle and aquatic ecosystem dependent mammal species?
- What listed threatened species and ecological communities benefitted from Commonwealth environmental water?
- What migratory species listed under international agreements (Bonn Convention, CAMBA, JAMBA or ROKAMBA[1]) benefitted from Commonwealth environmental water?

1.2 Summary of watering actions 2018-19 for biota

Commonwealth environmental water contributed to 131 watering actions in the 2018–19 water year with expected outcomes directly related to aquatic ecosystem dependent plant and vertebrate species (Appendix A). Of these, 64 watering actions had expected outcomes for fish; 94 for plant species or vegetation communities; 59 for waterbirds, 44 for frogs, 8 for reptiles and 1 for mammals (platypus). This is broadly consistent with previous LTIM years, where the largest number of watering actions have been

[1] JAMBA (Japan–Australia Migratory Bird Agreement); CAMBA (China–Australia Migratory Bird Agreement); ROKAMBA (Republic of Korea– Australia Migratory Bird Agreement).

delivered with expected outcomes for vegetation, fish and waterbirds, with a smaller number of actions targeting frogs, turtles and occasionally mammals (Figure 1).

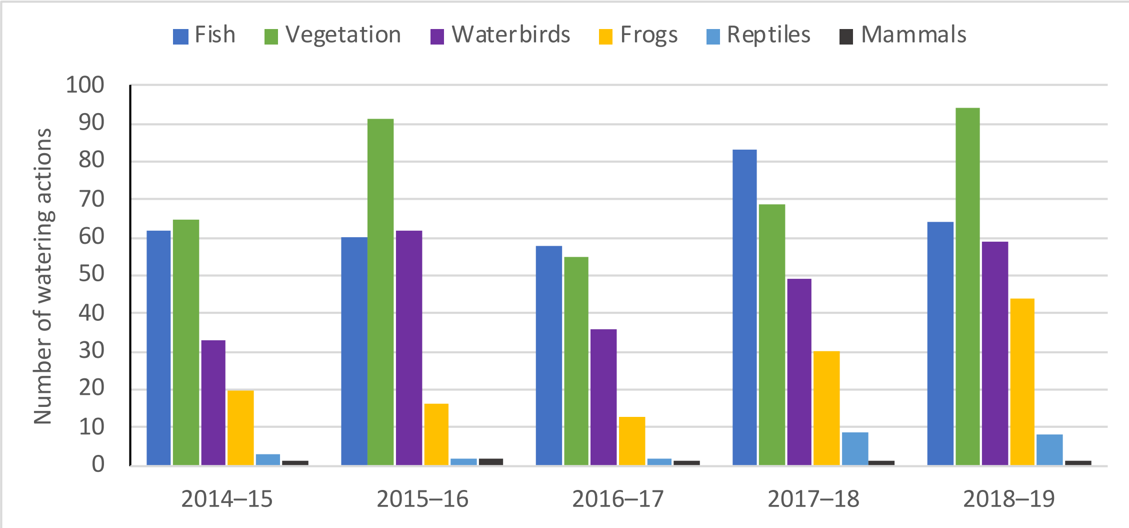

Figure 1. Summary of the number of watering actions with expected outcomes related to biodiversity across the five years of LTIM.

1.3 Methods

1.3.1 General approach

The main output of the Biodiversity evaluation is an aggregated list of species and communities that potentially benefitted from Commonwealth environmental water each year. This list has been derived from a number of sources, including other Basin Matter reports, Selected Area reports and monitoring programs (external to LTIM).

Determining if a species or community benefitted from Commonwealth environmental water is not straightforward. The presence of a species at a site that received Commonwealth environmental water does not necessarily indicate that the species benefitted, nor does it provide any indication of the temporal or spatial scale over which that species may have benefitted. The Biodiversity Basin Matter (formerly termed “generic diversity”) undertakes a qualitative evaluation of expected outcomes of watering actions undertaken by CEWO. The approach uses information from different sources to identify species that potentially benefitted from Commonwealth environmental water. The sources of information include (Figure 2):

- evaluations from other Basin Matters (Vegetation, Fish, Ecosystem Diversity)
- monitoring at Selected Areas
- monitoring/observations at sites watered but not monitored as part of LTIM
- a case study approach for wetlands that are internationally recognised as important (i.e. listed under the Ramsar Convention)
- assessment of benefits to vegetation communities and waterbirds using a combination of remote sensing and on-ground data from multiple sources.

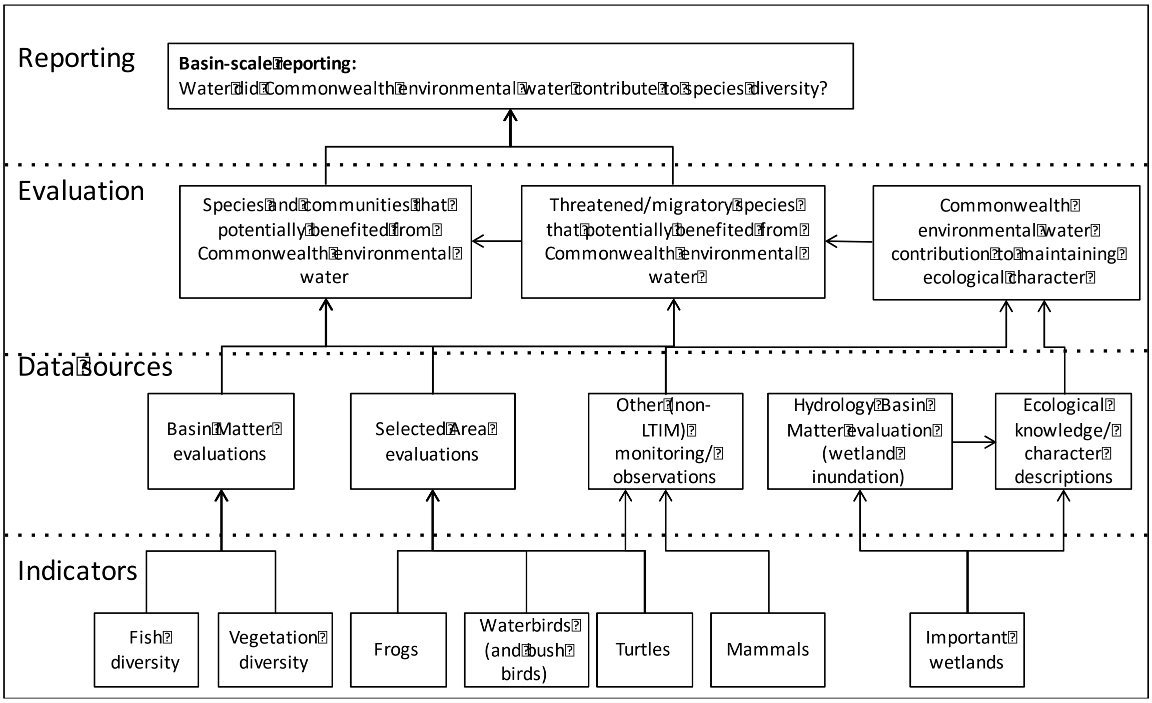

Figure 2. Basin evaluation of biodiversity.

General information about a species life-history or habitat requirements and broad assumptions about the hydraulic outcomes are used to infer benefit. Increased confidence in the assessment that a species or community benefitted from environmental water is assigned as a result of repeated observations over space and time. That is, as a species or community is observed at sites that receive Commonwealth environmental water at different locations in the Basin and in multiple years, confidence that the species benefitted from environmental water is increased.

1.3.2 Other Basin Matters

The effects of Commonwealth environmental water on vegetation, fish and ecosystem diversity have been evaluated as other Basin Matters. These evaluations adopted different approaches and methods for assessing the effect of Commonwealth environmental water, which are documented in each report. Species and communities that were identified in each of these evaluations as benefiting (or potentially benefiting) from Commonwealth environmental water have been extracted and included in the aggregated list of species in Appendix B.

1.3.3 Waterbirds, frogs, turtles and mammals

Selected Area outcomes

In the 2018–19 watering year, two Selected Areas were monitored for waterbirds, frogs and/or turtles (Figure 3); noting that aquatic ecosystem–dependent mammals were not included in any LTIM monitoring:

- Gwydir river system – waterbird diversity
- Murrumbidgee river system – waterbird diversity, frogs and turtles.

Information collected from Selected Area monitoring has been collated and summarised to identify species that potentially benefitted from Commonwealth environmental water in 2018–19.

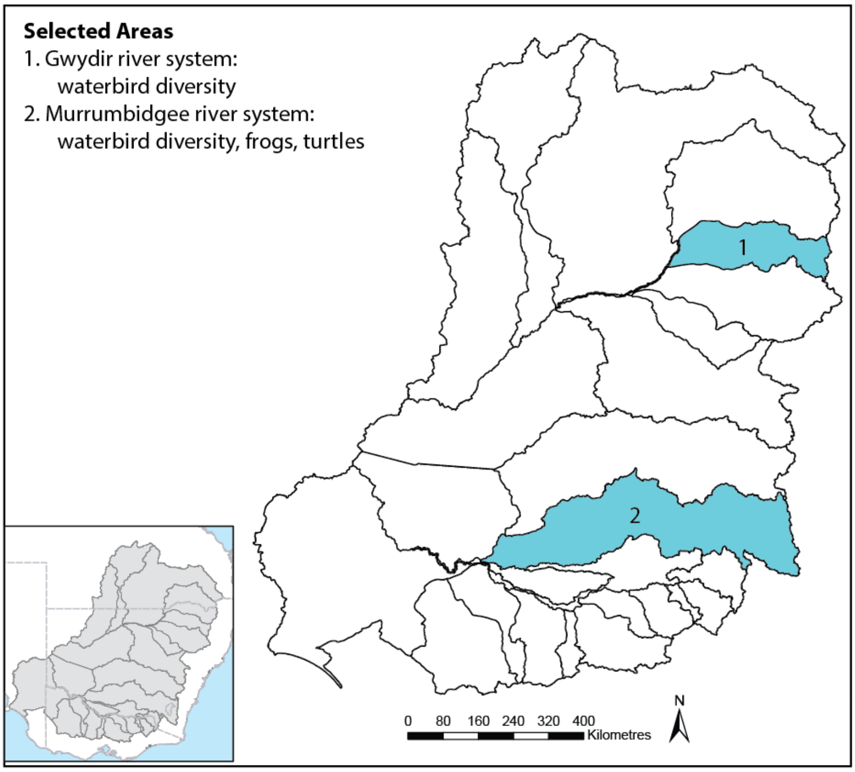

Figure 3. Locations of Selected Area monitoring for waterbirds, frogs and turtles 2018–19.

Unmonitored sites

In this report 'unmonitored' refers to sites that received Commonwealth environmental water but were not measured as part of the LTIM project. These sites had varying degrees of information available regarding ecological responses to watering. There are sites that were monitored under state or Murray–Darling Basin Authority (MDBA) programs (e.g. The Living Murray program); sites at which there are observations documented in CEWO acquittal reports (unpublished); and sites at which there may be general information available on the species likely to be present, but at which no direct information related to the ecological outcomes of environmental watering could be sourced.

Where information on the effects of environmental watering in the 2018–19 watering year was available, this has been extracted and aggregated into a list of species and communities for each aquatic ecosystem. A consolidated list over the five years of LTIM (2014–19) has also been provided.

In addition, several case studies have been explored for internationally recognised Ramsar wetland sites. These sites are identified as being significant at national or international scales because of the species and communities they support. They are some of the most diverse and species-rich wetlands in the Basin. As case studies, they provide examples of the benefits of environmental watering and contributions to meeting Basin Plan objectives for both diversity and for maintaining the ecological character of Ramsar wetlands.

For case study sites, information related to the watering action, known species and habitats at the site and any complementary monitoring data were used to evaluate the effects of the watering action through the following questions:

- What was the expected outcome?
- What information is available about the watering action?
- What evidence is available to evaluate the outcome?
- What species and communities potentially benefitted from Commonwealth environmental water?

Water, wetland types and biodiversity: integrating data from multiple sources

In this final year of LTIM a trial using data from multiple sources was undertaken to evaluate the potential linkages between water, aquatic ecosystem type and some aspects of biodiversity not covered by other Basin Matters. This trial took two forms (see Appendix C for more details on workflow):

1. Waterbirds, inundation and wetland type at Ramsar sites - integrating the Wetland Insight Tool from Geoscience Australia, the Australian National Aquatic Ecosystem (ANAE) mapping and MDBA aerial waterbird survey data to explore the relationships between inundation, wetland type and waterbird abundance and diversity.
2. Threatened species - intersecting records for four threatened species from the Atlas of Living Australia with the ANAE and inundation with Commonwealth environmental water to explore the potential effects of watering.

Waterbirds, inundation and wetland type

Three main sources of data from Basin Ramsar sites were used in this trail evaluation:

- Wetland Insight Tool (WIT) – a spatiotemporal summary of water and vegetation within a wetland derived from the Australian Landsat archive, as provided by Geoscience Australia. It uses fractional cover from the Joint Remote Sensing Research Program, Water Observations from Space and a Tasseled Cap Wetness Index formulation applied to surface reflectance to describing the percentage of the wetland polygon as vegetation fractional cover, open water and wet vegetation through time (Dunn *et al.* 2019).
- Murray-Darling Basin ANAE data set – using the interim ANAE classification framework applied to the best available jurisdictional mapping for Basin wetlands, floodplains and rivers to provide a spatial map of aquatic ecosystem types in the Basin (Brooks 2017).
- Murray Darling Basin Aerial Waterbird Surveys (2007–2018) – an annual survey of waterbird populations and recruitment at 38 important wetland and river sites in the Murray-Darling Basin, collected by the University of New South Wales in October – November each year (https://data.gov.au/dataset/ds-dga-89e008fb-f11c-4acb-8bcb-a05cddcb52b8/details).

Waterbirds were divided into groups based on their foraging, water depth and emergent macrophyte density preferences (McGuinness in prep.). To simplify the analysis, ANAE types were also grouped into broader types of:

- Treed floodplains (comprising river red gum forests and woodlands, black box woodlands and coolibah woodlands)
- Marshes – wetlands without a tree canopy, but dominated by with emergent vegetation
- Shrubs – lignum shrublands
- Permanent lakes – wetlands not dominated by vegetation, that hold water for > 80 % of the time.
- Temporary Lakes – wetlands not dominated by vegetation that hold water for < 80 % of the time[2].

Waterbird records (species, abundance and group) were intersected with ANAE types and wetland type groups and matched to WIT percentages of open water and wet vegetation using GIS methods (see Appendix C). Spearman rank correlations between abundance of waterbird groups and percentage of wetlands inundated (open water, and wet vegetation plus open water) were completed to explore the relationship between inundation, wetland type and waterbirds.

It should be noted that the outcomes of this evaluation are preliminary in nature and represent a pilot study of what might be possible in future evaluations with available data products. A discussion of the

[2] Note that for several analyses permanent and temporary lakes were combined to create a single "Lake" category.

limitations and the technical difficulties in aligning the different datasets is provided in Appendix C. We anticipate that the spatial products available will become more sophisticated and better aligned in scale to the ANAE and the scale at which biotic data, such as waterbird counts are made.

Threatened species, wetland type and inundation

The potential effects of Commonwealth environmental water on four threatened species was explored using:

- presence records 1980–2019 (sourced from the Atlas of Living Australia)
- Murray-Darling Basin ANAE data set (Brooks 2017)
- Commonwealth environmental water Inundation 2014–2019 (Stewardson & Guarino 2020)

The four species selected were Australasian bittern (*Botaurus poiciloptilus*); Australian painted snipe (*Rostratula australis*), brolga (*Grus rubicunda*) and southern bell frog (*Litoria raniformis*) on the basis that they were:

- listed as threatened under national (EPBC) or State species legislation
- are not included in analyses by other Basin Matters
- are known to have some degree of site fidelity (that is, if recorded in a particular wetland it was likely that it would be present in that wetland at another time).

Spatially attributed presence records of each species from within the Basin were downloaded from the Atlas of Living Australia (https://www.ala.org.au/). These were intersected with ANAE classification and Commonwealth environmental water inundation. Summary statistics were calculated to represent the number of distinct wetland polygons each species was recorded in and in which years these were inundated with Commonwealth environmental water.

2 Basin-scale evaluation 2018–19

2.1 Key findings

- Commonwealth environmental water was delivered to maintain refuge habitats in a drying landscape in 2018–19. This resulted in sustained records for waterbird and frog diversity in the Gwydir and Murrumbidgee Selected Areas.
- The nationally listed endangered Australasian bittern was recorded in the Murrumbidgee and Macquarie Marshes at wetlands that received Commonwealth environmental water in 2018–19.
- The nationally listed vulnerable southern bell frog was recorded in wetlands in the Murrumbidgee system at sites that received Commonwealth environmental water, with evidence of breeding.
- Watering of wetlands along the Lower Murray resulted in a network of inundated habitats supporting habitat for frogs and a high diversity of waterbird species, including 44 species at Qualco.
- Commonwealth environmental water contributed to maintaining the ecological character of ten Ramsar listed wetlands in 2018–19.
- Inundation of floodplain marshes Barmah Forest resulted in improved vegetation condition and a diversity of waterbirds, with the nationally threatened Australasian bittern recorded in response to watering.
- Commonwealth environmental water contributed to improvement in populations of Murray cod and other native fish in Gunbower Creek.

2.2 Synthesis of Selected Area outcomes for biodiversity (waterbirds, frogs, turtles) in 2018–19

The outcomes of monitoring of waterbirds, frogs and/or turtles in 2018–19 in the Murrumbidgee river system and Gwydir river system are summarised in Table 1. More detail is provided in section 3.2, across the five years of LTIM.

2.3 Unmonitored area outcomes for biodiversity (waterbirds, frogs, turtles, mammals) in 2018–19

Information on the ecological responses of waterbirds, frogs, turtles and mammals is summarised in Table 2. This table does not include important wetland sites such as Barmah Forest and Macquarie Marshes, which are considered in more detail in Section 2.4. The majority of the information collated is qualitative and includes very little additional evidence about the site that received Commonwealth environmental water or how species or communities responded to the water regime.

Table 1. Summary of monitored watering actions related to waterbird, frog and turtle diversity at Selected Areas in 2018–19.

Selected Area (watering action reference)	Dates[1]	Commonwealth environmental water volume (ML)[1]	Flow component[1]	Expected ecological outcome[1]	Monitored site(s)[2]	Observed ecological outcome[2]	Influences[2]
Gwydir (10085-01)	18/07/18 - 07/02/19	30 000	Wetland, Fresh	Support waterbird diversity and abundance.	Lower Gwydir River and Gingham watercourse – 17 locations	50 species of waterbird recorded including two species listed as vulnerable in NSW (brolga; *Grus rubicunda* and freckled duck; *Stictonetta naevosa*) as well as two international migratory species (Latham's snipe and marsh sandpiper). Breeding activity observed for brolga and Australian wood duck (*Chenonetta jubata*).	Availability and timing of inundated habitat; productivity (vegetation and food sources) responses to watering.
Gwydir (10085-02)	20/09/18 - 14/02/19	16 950	Wetland, Fresh	Increase connectivity and provide habitat for a range of waterbirds.	Mallowa Wetlands (Valetta, Bunganyah, Coombah, Gundare)	36 species of waterbird recorded, including two international migratory species (Latham's snipe; *Gallinago hardwickii* and marsh sandpiper; *Tringa stagnatilis*). Breeding of hardhead (*Aythya australis*).	Environmental water accounted for 98% of the total flow in this system; all waterbird responses can be directly linked to environmental water
Murrumbidgee (10082-02)	20/08/18 - 31/01/19	10 500	Wetland	Provide refuge habitat for waterbirds, native fish, frogs and turtles.	Two Bridges, Piggery Lake	37 species of waterbird recorded including the nationally endangered Australasian bittern. Breeding of Australian bittern, Australian little bittern (*Ixobrychus dubius*) as well as a number of colonial nesting cormorants and Australasian darter (*Anhinga novaehollandiae*). Six species of frog including the vulnerable southern bell frog.	Increased area of inundated habitat supported a greater diversity and abundance of waterbirds. Timing of inundation (spring-summer) supports productivity.
Murrumbidgee (10082-03)	17/09/18 - 25/01/19	30 000	Wetland				
Murrumbidgee (10082-04)	01/12/18 - 23/05/19	1505	Wetland	Maintain critical refuge habitat requirements for waterbirds, native fish, turtles and frogs, including for the vulnerable southern bell frogs.	Eulimbah, Avalon, Telephone	23 species of waterbird dominated by ducks and fish-eating species. 6 species of frog including the vulnerable southern bell frog. Refuge habitat for turtles at Telephone Creek.	
Murrumbidgee (10082-08)	16/11/18 - 18/01/19	2013.7	Wetland	Maintain important refuge habitat for wetland dependant fauna, including for the southern bell frog.	Yarradda Lagoon	24 species of waterbird. Breeding of Australasian darter. 6 species of frog, including the vulnerable southern bell frog.	

[1] As reported by the Commonwealth Environmental Water Office (CEWO) see Stewardson & Guarino (2020) for definitions of flow components.
[2] As reported by the Monitoring and Evaluation (M&E) team for each Selected Area in Selected Area reports for 2018–19.

Table 2. Summary of observations and other information from unmonitored watering actions with expected outcomes for waterbirds, frogs, turtles and mammals in 2018–19. Note that many of these actions involved multiple water sources (in addition to Commonwealth environmental water). Additional information on the portfolio of environmental water can be found in the Basin Matter Hydrology report (Stewardson & Guarino 2020). Ramsar wetlands are considered in section 2.4.

Surface water region/asset	Commonwealth environmental water volume (ML)[1]	Dates[1]	Flow component[1]	Expected ecological outcome[1]	Observed ecological outcome	Source of information
Edward Wakool – Pollack Swamp	2000	08/10/18 - 25/01/19	Wetland	Provide opportunity and support for waterbirds breeding. Continue to improve wetland vegetation health and condition of nest trees.	Wetland inundation resulted in improved vegetation condition and foraging for waterbirds. A total of 15 species of waterbird recorded.	CEWO acquittal report (unpublished)
Lower Murray - Renmark Floodplain Wetlands (Namoi Street)	59.69	16/08/18 - 30/05/19	Wetland	Increase diversity and abundance of waterbirds and frogs through aquatic habitat improvements.	A total of nine species and 169 waterbirds were recorded following delivery of environmental water. Including straw-necked ibis (*Threskiornis spinicollis*), masked lapwing (*Vanellus miles*) and Australian shelduck (*Tadorna tadornoides*). Spotted grass frogs (*Limnodynastes tasmaniensis*) recorded.	CEWO acquittal report (unpublished)
Lower Murray - Renmark Floodplain Wetlands (Twenty-sixth Street)	45.38	16/08/18 - 30/05/19	Wetland	Increase diversity and abundance of waterbirds and frogs through aquatic habitat improvements.	A total of four species of waterbird including the international migratory wood sandpiper (*Tringa glareola*). Breeding of black swan (*Cygnus atratus*). Two species of frog recorded Spotted grass frogs and eastern sign-bearing froglet (*Crinia parinsignifera*).	CEWO acquittal report (unpublished)
Lower Murray - Greenways Landing	40	26/10/18 - 07/11/18	Wetland	Provide food source for waterbirds, roosting and nesting sites, aquatic plants, macroinvertebrates, native fish and frogs.	Two waterbird species of conservation significance recorded: the SA listed freckled duck and the nationally vulnerable regent parrot (*Polytelis anthopeplus*).	CEWO acquittal report (unpublished)
Lower Murray – Milang Snipe Sanctuary	13.31	13/11/18 - 15/03/19	Wetland	Promote temporary aquatic community and riparian vegetation, frogs, waterbirds.	22 species of waterbird recorded including the international migratory Latham's snipe and the nationally endangered Australasian bittern	CEWO acquittal report (unpublished)
Lower Murray - Qualco	502.77	07/09/18 - 03/05/19	Wetland		44 species of bird recorded with 2166 individuals counted in May 2019. Included the nationally listed vulnerable regent parrot.	CEWO acquittal report (unpublished)
Lower Murray – Pike Lagoon	31.05	10/05/19 - 15/05/19	Wetland		Nationally vulnerable southern bell frog recorded breeding in response to environmental water.	CEWO acquittal report (unpublished)

[1] As reported by the Commonwealth Environmental Water Office (CEWO) (unpublished).

2.4 Important wetland case studies in 2018–19

Ten Ramsar sites were the target of Commonwealth environmental water in 2018–19 and had expected outcomes related to diversity (See Appendix A). These included several sites within Selected Areas (e.g. Gingham and Lower Gwydir (Big Leather) watercourses) as well as several sites for which little information on the effects of environmental water could be sourced (e.g. Calperum Station portion of the Riverland Ramsar Site, Fivebough Swamp). Four Ramsar sites were selected as case studies to assess the effects of Commonwealth environmental water on important wetlands in 2018–19:

- Banrock Station Wetland Complex
- Barmah Forest
- Gunbower Forest
- The Macquarie Marshes.

2.4.1 Banrock Station Wetland Complex

What was the expected outcome?

The expected outcomes were:

- *Protect the extent and condition of blackbox woodland and native riparian vegetation communities and provide reproduction and recruitment opportunities.*
- *Improve cover and condition of understorey vegetation including lignum.*
- *Enhance survival of seedlings arising from 2011 flood event.*
- *Establish more diverse healthy habitat for other native species including the southern bell frog.*
- *Improve the condition of the associated red gum woodland vegetation communities that are hosting one of the few colonies of regent parrot in South Australia.*
- *Establish more diverse and healthy habitat for both wetland and migratory bird species found in the surrounding Ramsar area.*

What information is available about the watering action?

A total of 570 megalitres (ML) of environmental water was delivered between November 2018 and May 2019 to Wigley Reach within Banrock Station, all of which was Commonwealth environmental water. Inundation of approximately 37 hectares (ha) of aquatic ecosystems occurred within the Ramsar site boundary (Figure 4 and Table 3). Environmental water in 2018–19 was part of a multi-year strategy to restore the ecological character of the Ramsar site. Commonwealth environmental water was first delivered via pumping to the site in 2015–16 and there was broader inundation during 2016–17 due to natural flooding.

What evidence is available to evaluate the outcome?

Banrock Station was listed as a Ramsar site in 2002, primarily for its role in supporting threatened species (the endangered regent parrot and the vulnerable southern bell frog) as well as supporting a variety of waterbirds during critical life stages of migration, breeding and moulting (Butcher *et al.* 2009). Information on the effects of the environmental water delivery are largely limited to observations contained within the CEWO acquittal report (unpublished) in addition to aerial waterbird surveys conducted in November 2018 (MDBA unpublished). These provide qualitative evidence and the confidence in attributing benefits from environmental water to species must be considered in this context.

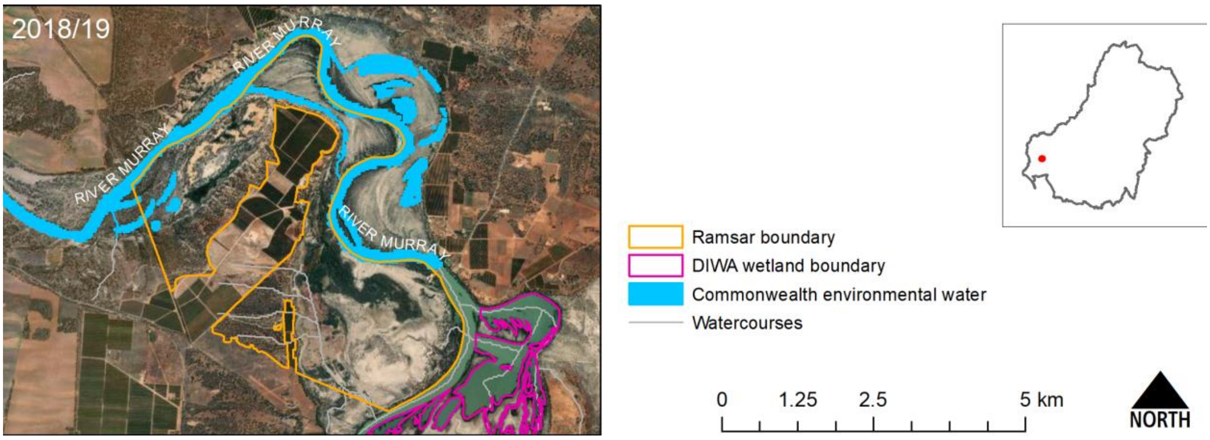

Figure 4. Extent of inundation at Banrock Station during environmental watering in 2018–19.

Table 3. ANAE wetland and floodplain types inundated from environmental watering in 2018–19 at Banrock Station Ramsar site.

Australian National Aquatic Ecosystem (ANAE) wetland type	Area inundated (hectares)
F1.2: River red gum forest riparian zone or floodplain	3
F1.4: River red gum woodland riparian zone or floodplain	10
F1.8: Black box woodland riparian zone or floodplain	3
F2.2: Lignum shrubland riparian zone or floodplain	2
Pt1: Temporary swamp	5
Pt2.1.2: Temporary tall emergent marsh	3
Pt4.1: Floodplain or riparian wetland	1
Total	**27**

What species/communities potentially benefitted?

There is some observational evidence to suggest that a range of species benefitted from Commonwealth environmental water at Banrock Station in 2018–19 (Table 4).

Table 4. Species and communities that potentially benefitted from Commonwealth environmental water at Banrock Station in 2018–19 (CEWO unpublished; MDBA unpublished).

Community/species	Evidence
Wetland and riparian vegetation	A total of 60 plant species responded directly to watering as evidenced by germination, flowering or fruiting. Waterwort (*Elatine gratioloides*) and spiny lignum (*Duma horrida*), listed as rare in South Australia were observed germinating and flowering. Recruitment of black box (*Eucalyptus largiflorens*) and germination of river red gum (*E. camaldulensis*).
Frogs	Four species of frog recorded including the nationally listed vulnerable southern bell frog. Monitoring indicates stable population of southern bell frog at the site since 2008.
Waterbirds	80 species of bird including 17 species of waterbird recorded, comprising over 800 individual waterbirds. Breeding of two colonial nesting species Australian white ibis (*Threskiornis moluccus*) and straw-necked ibis with a total of 80 nests.
Regent parrot	Consistent sightings of the regent parrot at all sites that received water. Improved condition (canopy cover) of river red gum trees, suggesting that Commonwealth environmental water is helping to support the nesting habitat of this species. Consistent records of regent parrot with up to 17 nests recorded.

2.4.2 Barmah–Millewa Forest

What was the expected outcome?

The expected outcomes for this watering action were (CEWO, unpublished):

- *Maintain current species diversity, extending distributions and improve breeding success and numbers of short, moderate and long-lived native fish.*
- *Maintaining the extent and condition of riparian and in-channel vegetation by:*
    - *Increasing periods of growth for non-woody vegetation communities (e.g. Moira grass; Pseudoraphis spinescens) that closely fringe or occur within the River Murray channel, anabranches and low elevation floodplain wetlands.*
    - *Maintaining the extent and condition of inundation dependent river red gum, black box, lignum and non-woody vegetation within low-lying areas of floodplain, with scale of contribution subject to seasonal conditions.*
- *Maintaining current species diversity, extending distributions and improving breeding success and numbers of water dependent bird species by:*
    - *Supporting suitable habitat conditions and food resources for water bird growth and survival, maintenance of population condition and diversity, along the River Murray valley and within the Coorong lagoons.*
    - *Supporting waterbird breeding events if seasonally appropriate.*

What information is available about the watering action?

The delivery of water to the Barmah–Millewa Forest is complex and was part of a broader watering action designed to affect the River Murray and associated floodplains and wetlands from Hume Dam to the Murray Mouth. A total of 86 814 ML of water, of which 38 527 (44 %) was Commonwealth environmental water was delivered to the Barmah-Millewa Forest from November 2018 to January 2019.

The acquittal report estimates that 30 % of the Barmah Forest was flooded; and a smaller portion (around 5%) of Millewa Forest receiving water. Mapping indicates around 12 890 ha of mapped wetland types within the Ramsar sites were inundated (Figure 5 and Table 5).

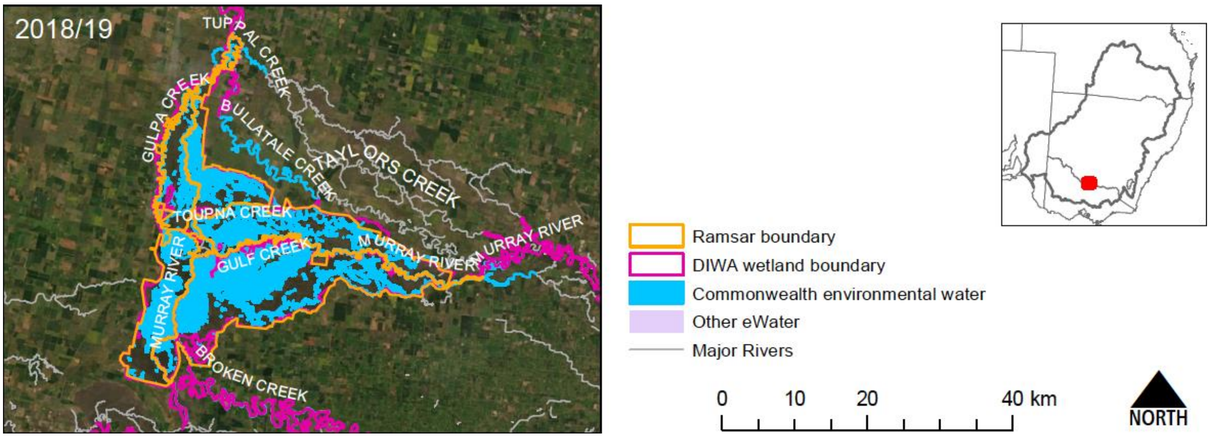

Figure 5. Extent of inundation at Barmah–Millewa Forest during environmental watering in 2018–19.

Table 5. ANAE wetland and floodplain types inundated from environmental watering in 2018–19 at Barmah–Millewa Forest (note that inundation of types < 10 hectares shown collectively as "other").

Australian National Aquatic Ecosystem (ANAE) wetland type	Area inundated (hectares)
F1.12 Woodland riparian zone or floodplain	44
F1.2: River red gum forest floodplain	3659
F1.4: River red gum woodland floodplain	128
Lp1.1: Permanent lake	399
Lt1.1: Temporary lake	73
Pp4.2: Permanent wetland	303
Pt4.2: Temporary wetland	163
Pt1.1.2: Temporary river red gum swamp	6208
Pt1.6.2: Temporary woodland swamp	368
Pt2.1.2: Temporary tall emergent marsh	299
Pt2.2.2: Temporary sedge/grass/forb marsh	435
Pt2.3.2: Freshwater meadow	91
Other	427
Total	12 893

What evidence is available to evaluate the outcome?

Barmah–Millewa Forest is listed as a single Directory of Important Wetlands (DIWA) and TLM Icon site but is part of two separate Ramsar sites: Barmah Forest, which lies in Victoria, and Millewa Forest, which is part of the NSW Ramsar site 'Central Murray Forests'. Barmah Forest was listed as a Ramsar site in 1982 and Central Murray Forests in 2003. The reasons for designation of the two sites are largely the same, in that together they form the largest intact floodplain forest in the bioregion; they support several threatened species, including Australasian bittern, superb parrot (*Polytelis swainsonii*), Murray cod (*Maccullochella peelii*), silver perch (*Bidyanus bidyanus*) and trout cod (*Maccullochella macquariensis*); and are important for breeding waterbirds, particularly colonial nesting species.

Aspects of biodiversity were monitored as part of the long-term icon site monitoring of the Barmah–Millewa Forest and included vegetation (Ward 2019), fish (Raymond *et al.* 2019) and birds (Borrell 2018, 2019; Belcher *et al.* 2019). The 2018–19 watering year was dry and the responses of biota to environmental watering across the Barmah–Millewa Forest need to be considered in this context.

Vegetation

Monitoring of moira grass (*Pseudoraphis spinescens*) and the nationally endangered river swamp wallaby-grass (*Amphibromous fluitans*) indicated an increase in cover at wetlands where the species was present with the highest cover at Little Rushy Swamp in Barmah Forest, where exclusion fencing has been installed to protect the species from grazing by non-native animals such as feral horses (Ward 2019). Sites that were inundated with environmental water exhibited a greater degree of native species than sites that remained dry. Overall, plant cover across the inundated floodplain comprised native species, but cover was sparse due to dry conditions.

Fish

The overall condition of fish in the Barmah–Millewa Forest in 2018–19 was "good" with most indices showing stable or increased scores from previous years (Raymond *et al.* 2019). Ten native fish species were recorded in 2018–19, including all three threatened species: Murray cod, silver perch and trout cod. Six native species in both river and wetland habitats successfully recruited individuals into their populations in 2019, indicating recovery from previous years where blackwater events impacted on native fish.

Waterbirds

Monitoring in Barmah-Millewa indicated a range of waterbird species utilising the wetlands benefiting from environmental water delivery. A total of 4118 waterbirds were recorded across four seasons and 12 wetlands in 2018–19, representing 42 species (Borrell 2019). This included records of four threatened species:

- Australasian bittern – targeted surveys indicating 48 males, representing almost 10% of the population of this species[3].
- Australian little bittern – a total of 24 individuals in seven wetlands (Belcher *et al.* 2019)
- eastern great egret (*Ardea modesta*) – at Barmah Lake and Steamer Plain
- superb parrot – recorded in winter and spring (Borrell 2018).

The inundation of wetlands by environmental water provided feeding and suspected breeding habitat for the endangered Australasian bittern. The number of males represents almost 10% of the total population of this species (estimated at 500 individuals – Wetlands International 2012). Given that males are suspected to be polygamous (breeding with more than one female) it is possible that the site supported more than a third of the total population during environmental watering.

A total of four species of colonial waterbird were recorded nesting in Millewa Forest in 2018–19 (Borrell & Webster 2019):

- Australian white ibis – 148 pairs
- little pied cormorant (*Microcarbo melanoleucos*) – 125 pairs
- little black cormorant (*Phalacrocorax sulcirostris*) – 17 pairs
- Australasian darter – 14 pairs

What species/communities potentially benefitted?

Environmental water significantly extended the duration and extent of inundation across the site. In the absence of Commonwealth environmental water, many aquatic habitats would not have been inundated and duration would have likely been insufficient to complete cycles of breeding. There is good evidence to suggest that a number of species benefitted from Commonwealth environmental water at Barmah–Millewa Forest in 2018–19 (Table 6).

Table 6. Species and communities, critical to the ecological character of the Ramsar Sites that potentially benefitted from Commonwealth environmental water at Barmah–Millewa Forest in 2018–19.

Community/species	Evidence
River red gum forest and woodland	No empirical evidence, but it is likely that inundation of over 10 000 hectares of river red gum forest and woodland would have helped maintain or improve tree condition.
Moira grass	Evidence of improved condition as a result of multiple management actions, including environmental water.
Native fish	Spawning and recruitment recorded for all three threatened species (Murray cod, trout cod and silver perch).
Australasian bittern	Almost 10 % of the population recorded within the inundated wetland habitats.
Waterbirds	Forty-two species with a maximum abundance of over 600 individuals supported by inundated wetland habitats. Breeding of Australian white ibis, little pied cormorant, little black cormorant and Australasian darter supported by Commonwealth environmental water.

[3] Wetlands International 5th Waterbird Population Estimates (2012).

2.4.3 Gunbower Forest[4]

What was the expected outcome?

The expected outcomes were:

- *Maintain the diversity and condition of small and large-bodied native fish populations in Gunbower Creek through the provision of habitat and opportunities for breeding and recruitment.*
- *Improve water quality and hydrological connectivity between Gunbower Forest and Gunbower Creek to support native fish, aquatic invertebrates and nutrient and carbon movement.*

What information is available about the watering action?

A total of 18 922 ML of Commonwealth environmental water was delivered over the full year (July 2018 to June 2019) as baseflows. Since 2013–14, a "fish hydrograph" has been provided in Gunbower Creek to facilitate successful spawning and recruitment of Murray cod.

Prior to the delivery of environmental water in Gunbower Creek, the system dried to a series of residual pools in the off-irrigation system. This was recognised as having a deleterious effect on fish recruitment and survival. Large-bodied native fish such as Murray cod were found to have a fractured population structure, with no individuals in size classes that represent fish less than three years of age (Sharpe *et al.* 2014). While the prescribed "fish hydrograph" was not able to be implemented in 2018–19, due to floodplain watering of the Gunbower Forest with TLM and State water, an altered flow regime aimed at maintaining baseflows and facilitating floodplain connectivity was implemented with Commonwealth environmental water.

What evidence is available to evaluate the outcome?

The fish community of Gunbower Forest has been monitored under the MDBA TLM program since 2006. A total of nine native fish species were recorded in spring 2018, with abundance considered average. In terms of size classes, the population structure of Murray cod had declined from 2017 but was still improved compared to the 2009 baseline. Although three invasive fish species were recorded in the creek, the relative abundance of natives was high, with around 85 % of fish captured representing native species (Bloink *et al.* 2018).

Murray cod were recorded spawning in the spring 2018 sampling in Gunbower Creek, albeit in smaller numbers. This confirms that Murray cod still spawned in Gunbower Creek during implementation of the altered hydrograph. The reasons for the lower abundance of larvae is unknown and the authors hypothesized that it may be due to altered hydrology or due to warmer water temperatures earlier in the season meaning that the peak larval abundance was not captured (Bloink & Gwinn 2019).

What species/communities potentially benefitted?

There is clear evidence that Murray cod have benefitted from the restored hydrology in Gunbower Creek through the provision of Commonwealth environmental water.

[4] Note that Commonwealth environmental water was delivered to Gunbower Creek, a portion of which lies within the Gunbower Forest Ramsar Site.

2.4.4 The Macquarie Marshes

What was the expected outcome?

The expected outcomes were:

- *Maintain and improve the condition of semi-permanent and permanent wetland vegetation in the Macquarie Marshes by inundating up to 19,000 ha of wetland vegetation (reedbeds, water couch, mixed marsh and river red gum forests).*
- *Maintain and provide access to feeding, foraging and breeding habitat for waterbirds, fish, frogs and other aquatic species.*
- *Contribute to movement, breeding, recruitment and dispersal opportunities for flow generalists and in-channel specialist native fish species such as Murray cod in the mid-Macquarie River, Marshes and lower Macquarie.*

What information is available about the watering action?

Water was delivered across two watering actions:

- A winter priming flow delivered between 24 July and 24 August 2018 of a total of 9070 ML, of which 6349 ML (70 %) was Commonwealth environmental water.
- A winter / spring flow delivered between 25 August and 11 December 2018 of a total of 117 407 ML of which 45 052 ML (38 %) was Commonwealth environmental water.

Commonwealth environmental water contributed to the inundation of approximately 15 000 hectares of the Macquarie Marshes in the 2018–19 water year (Thomas *et al.* 2020). This included around 5600 hectares within the Ramsar boundary (Figure 6 and Table 7).

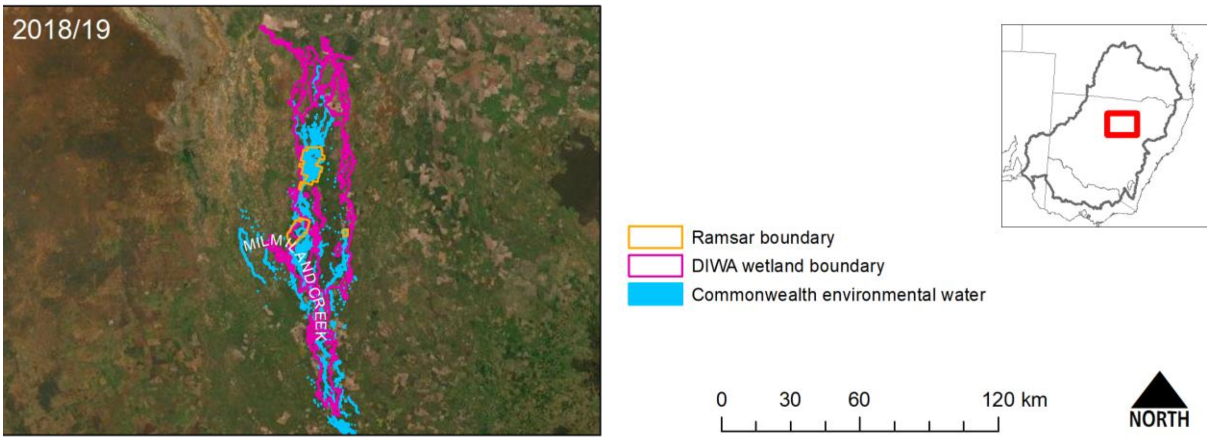

Figure 6. Extent of inundation at the Macquarie Marshes by Commonwealth environmental in 2018–19.

The Ramsar site comprises the northern and southern sections of the Macquarie Marshes Nature Reserve as well as two additional disjunct areas, ‘U-block’ and ‘Wilgara’. Within the Ramsar site, the inundation was predominantly of ANAE wetland type ‘permanent wetland’. It should be noted, however, that ANAE classifications are broad, and the ecological character description for the site indicates that the area described as ‘permanent wetland’ in Table 7 is more accurately described as intermittent marsh with emergent vegetation, such as common reed (*Phragmites australis*), cumbungi (*Typha* spp.) and water couch (*Paspalum distichum*) (Office of Environment and Heritage 2012).

Table 7. ANAE wetland and floodplain types inundated from Commonwealth environmental watering in 2018–19 at the Macquarie Marshes Ramsar site.

Australian National Aquatic Ecosystem (ANAE) wetland type	Area inundated (hectares)
Pp4.2: Permanent wetland	5147
F1.4: River red gum woodland riparian zone or floodplain	102
Pt2.2.2: Temporary sedge/grass/forb marsh	92
Pt1.8.2: Temporary shrub swamp	67
F1.10: Coolibah woodland and forest riparian zone or floodplain	20
Pt1.2.2: Temporary black box swamp	45
Pt2.1.2: Temporary tall emergent marsh	34
F1.2: River red gum forest riparian zone or floodplain	23
F1.11: River cooba woodland riparian zone or floodplain	8
F2.2: Lignum shrubland riparian zone or floodplain	7
Lt1.1: Temporary lake	8
F1.8: Black box woodland riparian zone or floodplain	2

What evidence is available to evaluate the outcome?

The Macquarie Marshes was listed as a Ramsar site in 1986 for its extensive wetland vegetation communities; abundance of waterbirds; supporting migratory birds listed under international treaties; supporting waterbird breeding, particularly colonial nesting species; the native fish community and supporting threatened species – Australasian bittern, Australian painted snipe, superb parrot, Murray cod and basalt peppercress (*Lepidium hyssopifolium*) (Office of Environment and Heritage 2012).

Available data comprise data on waterbirds and frogs from the NSW BioNet Atlas (http://www.bionet.nsw.gov.au/) as well as a summary of information on ground surveys conducted for vegetation, frogs and waterbirds (Thomas *et al.* 2020) and an aerial survey of waterbirds commissioned by the MDBA.

Vegetation monitoring was conducted at 79 sites of which 27 of which were inundated with environmental water in 2018–19. On average, there was a decline in both pant cover and native species richness in river red gum and water couch communities in the Macquarie Marshes. This coincided with an increase in the cover of bare ground, likely in response to continued dry conditions across much of the Macquarie Marshes (Thomas *et al.* 2020).

The site supported a diversity of waterbirds with 42 species recorded in ground surveys including several threatened species (Australasian bittern, brolga) as well as international migratory waders (Latham’s snipe and sharp-tailed sandpipers) (Thomas *et al.* 2020). Aerial surveys recorded over 73 000 waterbirds in the Macquarie Marshes, with nearly 25 000 Pacific black duck (*Anas superciliosa*), over 7000 grey teal (*Anas gracilis*) and moderate numbers of large wading birds and fish-eating species (MDBA unpublished). The inundation provided a variety of feeding and foraging habitats, which supported the diversity of birds. Although breeding activity was low in 2018–19, approximately 20 nests of Australian white ibis were recorded (Thomas *et al.* 2020).

The three most common flow-responsive frog species (barking marsh frog, *Limnodynastes fletcheri*; spotted marsh frog, *Limnodynastes tasmaniensis* and eastern sign-bearing froglet, *Crinia parinsignifera*) were very active in September in the Macquarie Marshes in response to the delivery of environmental water. In total six species were recorded, with evidence of breeding and potential recruitment with metamorphs recorded in November (Thomas *et al.* 2020).

What species/communities potentially benefitted?

There is evidence to suggest that a number of species and communities potentially benefitted from Commonwealth environmental water at the Macquarie Marshes in 2018–19 (Table 8).

Table 8. Species and communities that potentially benefitted from Commonwealth environmental water in the Macquarie Marshes in 2018–19.

Community/species	Evidence
Emergent marsh vegetation	Growth of emergent marsh vegetation in response to watering.
Waterbirds	42 species recorded spanning the full range of functional groups. Includes records of Australasian bittern, Latham's snipe and brolga.
Frogs	Six species recorded, breeding and juvenile recruitment.

3 Cumulative Basin-scale evaluation 2014–19

3.1 Key findings

- A total of 76 species of wetland dependent birds have been recorded at sites that received Commonwealth environmental water in Selected Areas 2014–19.
- Two nationally listed endangered waterbird species have been recorded at wetlands that received Commonwealth environmental water in Selected Areas: the Australasian bittern and Australian painted snipe.
- The nationally listed vulnerable southern bell frog was recorded in wetlands in the Murrumbidgee system in all years.
- Commonwealth environmental water has contributed to maintaining the ecological character of 11 of the 16 Ramsar sites in the Basin over the five years of the LTIM project. There is very good evidence that Commonwealth environmental water used as part of multi-year strategies has contributed to the restoration of ecological character at Hattah-Kulkyne Lakes and Banrock Station, helped to maintain several critical components and processes at the Macquarie Marshes and improved native fish populations in Gunbower Creek.
- Fifty-four threatened species were recorded at sites that received environmental water in 2014–19.
- Over the past four years 101 waterbird species and over one million individuals have been recorded at sites that received Commonwealth environmental water, with more than one percent of the population supported for 22 species.

3.2 Synthesis of Selected Area outcomes for biodiversity (waterbirds, frogs, turtles) 2014–19

Waterbird diversity

A total of 76 wetland-dependent species were recorded at aquatic ecosystems in the Gwydir, Murrumbidgee and Warrego-Darling[5] Selected Areas that received Commonwealth environmental water across the five years (Appendix B). This included several species that are listed as threatened. Two nationally listed endangered species have been recorded at wetlands that received Commonwealth environmental water; the Australasian bittern in the Murrumbidgee (all five LTIM years) and in the Gwydir in 2016–17; and Australian painted snipe in the Gwydir in 2017–18. Six additional species listed as vulnerable in New South Wales (NSW) were also recorded at least once across the four years: comb-crested jacana (*Irediparra gallinacea*), black-necked stork (*Ephippiorhynchus asiaticus*), brolga, freckled duck, magpie goose (*Anseranas semipalmata*) and white-bellied sea eagle (*Haliaeetus leucogaster*). In addition, a number of species listed under international migratory bird agreements were present at sites that received Commonwealth environmental water, including eight species that are part of the East Asian–Australasian Flyway.

Six of the 76 species were recorded in sites that received Commonwealth environmental water in all three Selected Areas across all years, comprising four species of duck, Australian pelican, and white-faced heron (*Egretta novaehollandiae*). By contrast, 11 species were recorded at only one Selected Area and in one year. This includes three species of international migratory shorebirds, the spotless crake (*Porzana tabuensis*) and several fish-eating species (see Appendix B).

Species richness varied across the Selected Areas and the five years but was greatest in the Gwydir river system (Figure 7). The number of aquatic ecosystem dependent bird species increased in each of the

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[5] Noting that waterbirds were not monitored in the final year of LTIM (2018–19) in the Warrego-Darling Selected Area.

Selected Areas from 2014–15 to 2016–17 and then declined in 2017–18 noting that locations within a Selected Area that received Commonwealth environmental water have changed between the five periods. In terms of species richness, fish-eating species (piscivores) were the dominant functional group in all locations and years (Figure 7).

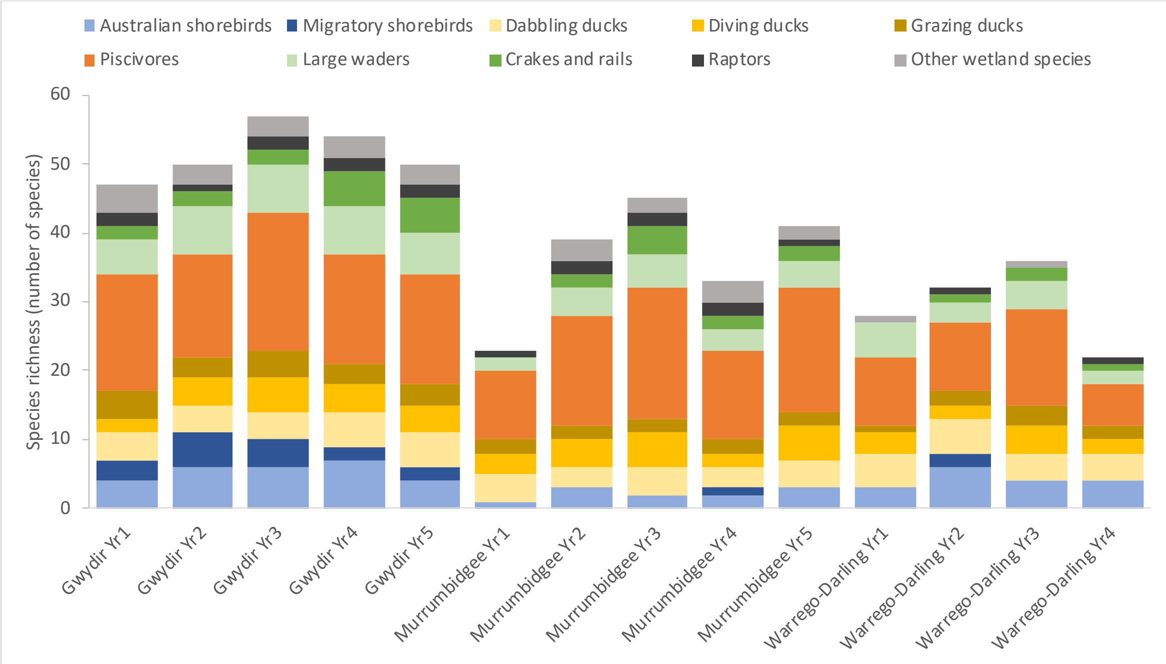

Figure 7. Species richness of functional groups in the three Selected Areas monitored for waterbirds as part of the LTIM project in 2014–15 (Yr1), 2015–16 (Yr2) 2016–17 (Yr 3), 2017–18 (Yr4) and 2018–19 (Yr5). Noting that waterbirds were not monitored in 2018–19 in the Warrego-Darling Selected Area. See Appendix B for waterbird functional group descriptions.

Waterbird breeding

Evidence of breeding has been recorded in sites that received Commonwealth environmental water for a total of 45 species across the three Selected Areas in the five years of LTIM. This comprised a mix of both colonial nesting species and other waterbirds (Figure 8). The greatest number of species observed breeding was during 2016–17. While modest numbers of birds were recorded breeding in years most years, there were large scale waterbird breeding events recorded for colonial nesting species in 2016–17. Close to 70 000 nests of ibis, herons, cormorants, egrets and pelicans were recorded in targeted monitoring in the Murrumbidgee and Lachlan Selected Areas in 2016–17 at sites that received Commonwealth environmental water, highlighting the importance of widescale floodplain inundation for these species.

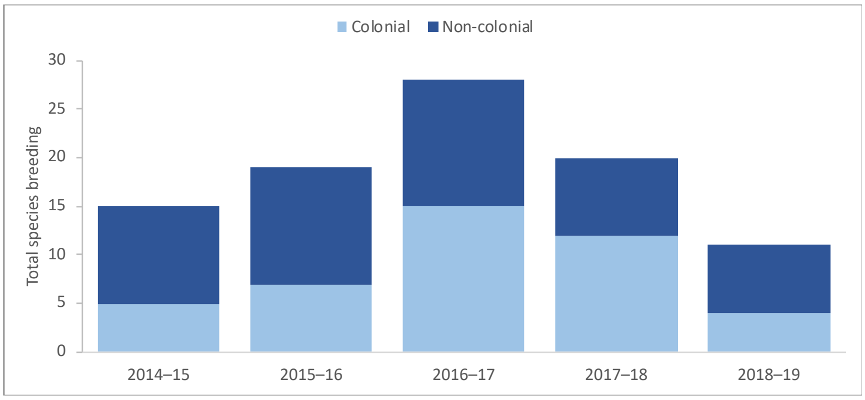

Figure 8. Total number of species observed breeding across the three Selected Areas in each watering year.

Frogs

Frogs were monitored in the Murrumbidgee Selected Area in all five LTIM years, and for a smaller number of years in three other Selected Areas: the Junction of the Warrego and Darling rivers, the Gwydir and Lachlan river systems. A total of 16 species of frog have been recorded at sites that received Commonwealth environmental water, including the nationally listed vulnerable southern bell frog.

Table 9. Frog species recorded at sites in Selected Areas that received Commonwealth environmental water. Note that data from 2017–18 (yr 4) in the Gwydir provided by NSW OEH (Ocock et al. 2017).

Common name	Species name	Lachlan	Murrumbidgee					Gwydir		Warrego–Darling			
		Yr2	Yr1	Yr2	Yr3	Yr4	Yr5	Yr2	Yr4	Yr1	Yr2	Yr3	Yr4
Desert froglet	*Crinia deserticola*									X		X	X
Plains froglet	*Crinia parinsignifera*	X	X	X	X	X	X	X	X		X	X	
Striped burrowing frog	*Cyclorana alboguttata*								X				
Water-holding frog	*Cyclorana platycephala*												X
Barking marsh frog	*Limnodynastes fletcheri*		X	X	X	X	X	X	X	X		X	X
Inland banjo frog	*Limnodynastes interioris*	X		X	X	X	X						
Salmon striped frog	*Limnodynastes salmini*								X			X	
Spotted marsh frog	*Limnodynastes tasmaniensis*	X	X	X	X	X	X	X	X	X	X		X
Green tree frog	*Litoria caerulea*								X	X		X	X
Broad-palmed rocket frog	*Litoria latopalmata*							X	X				
Peron's tree frog	*Litoria peronii*	X	X	X	X	X	X	X	X	X	X	X	X
Southern bell frog[1]	*Litoria raniformis*		X	X	X	X	X						
Desert tree frog	*Litoria rubella*									X			X
Sudell's frog	*Neobatrachus sudallae*											X	
Ornate burrowing frog	*Platyplectrum ornatum*								X				
Small-headed toadlet	*Uperoleia capitulata*												X

[1] Listed as vulnerable nationally under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Monitoring methods varied between Selected Areas and so a comparison of breeding and recruitment success is not possible. The frogs recorded in Table 9, largely represent calls and could be considered to represent attempts at breeding.

In the Murrumbidgee, frog abundance was greatest during the flood year, 2016–17, reaffirming the importance of widescale floods for frog populations. There is, however, solid evidence from this Selected Area that Commonwealth environmental water contributed to maintaining frog diversity and abundance (Wassens *et al.* 2020). In addition, the listed southern bell frog has been supported by Commonwealth environmental water in the Murrumbidgee through the watering of refuge sites following the 2016–17 flood (Wassens *et al.* 2020).

Turtles

Turtles were monitored in the Murrumbidgee river system in all five LTIM years, with three species recorded at sites that received Commonwealth environmental water:

- eastern long-necked turtle (*Chelodina longicollis*)
- broad shelled turtle (*Chelodina expansa*)
- Macquarie river turtle (*Emydura macquarii*).

There is evidence that Commonwealth environmental ware has contributed to these species by maintaining refuge habitats, particularly for broad-shelled turtle (Wassens *et al.* 2020).

3.3 Synthesis of outcomes for biodiversity across the Basin 2014–19

3.3.1 Waterbirds

Aerial surveys from the MDBA Aerial Waterbird Survey provides data across a number of wetlands in the Basin. A total of over one million individual waterbirds have been recorded at sites that received Commonwealth environmental water over the past five years (data from MDBA) (Figure 9). Of note is that the Coorong and Lower Lakes generally represents the largest number of waterbirds of the sites that receive Commonwealth environmental water. In 2014–15; 2015–16; 2017–18 and 2018–19, the Coorong supported between 65 and 90 % of the total waterbird abundance at sites included in aerial surveys that received Commonwealth environmental water. In 2016–17, however, when there was widescale inundation of inland landscapes (augmented by environmental water) the Coorong and Lower Lakes Site represented just 14 % of the total abundance. This highlights the continental scale distributions of many waterbirds and their ability to respond to climatic conditions, moving opportunistically to areas of highest productivity (Kingsford *et al.* 2010; Wen *et al.* 2016).

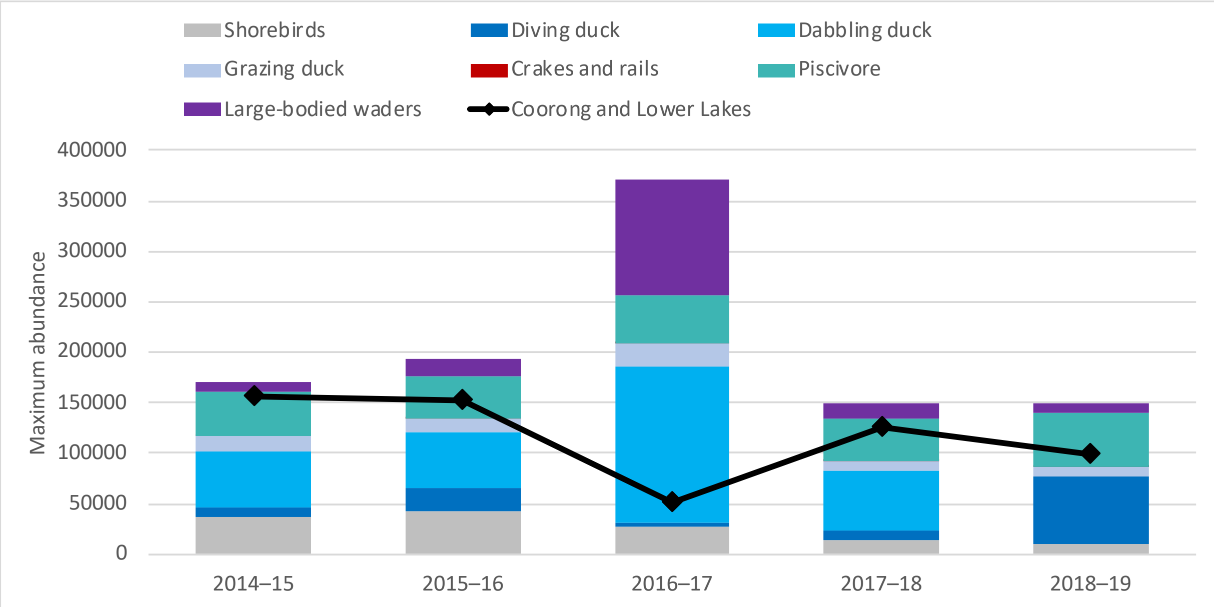

Figure 9. Total abundance of waterbirds from sites that received Commonwealth environmental water (source MDBA Aerial Waterbird Survey; data provided by MDBA). Note that several small shorebirds cannot be distinguished to species in aerial surveys and so Australian shorebirds and migratory shorebirds are combined into a single group.

Wetlands International (2012) provides population estimates for waterbirds across the globe and in Australia. Supporting greater than one percent of the population of any species of waterbird is considered to be significant with respect to maintaining that species and is one of the criteria for listing a wetland of international importance under the Ramsar Convention. Cumulative totals (within a single year but across sites) indicate that Commonwealth environmental water is likely to have supported greater than one percent of the population of 22 waterbird species (Figure 10).

Inland sites that received Commonwealth environmental water supported greater than one percent of the relevant populations of 13 species, mostly ducks and large bodied waders. For a small number of species (Australasian bittern, white-necked heron and yellow-billed spoonbill) significant numbers of individuals were recorded in multiple LTIM years. Conversely, there were several species for which Commonwealth environmental water contributed to supporting significant numbers during 2016–17, when large natural inundation occurred.

Fourteen species of waterbird were supported in significant numbers in the Coorong and Lower Lakes. This comprised mainly fish-eating species such as cormorants and small shorebirds such as red-necked stint (*Calidris ruficollis*), red-necked avocet (*Recurvirostra novaehollandiae*) and sharp-tailed sandpiper (Figure 10).

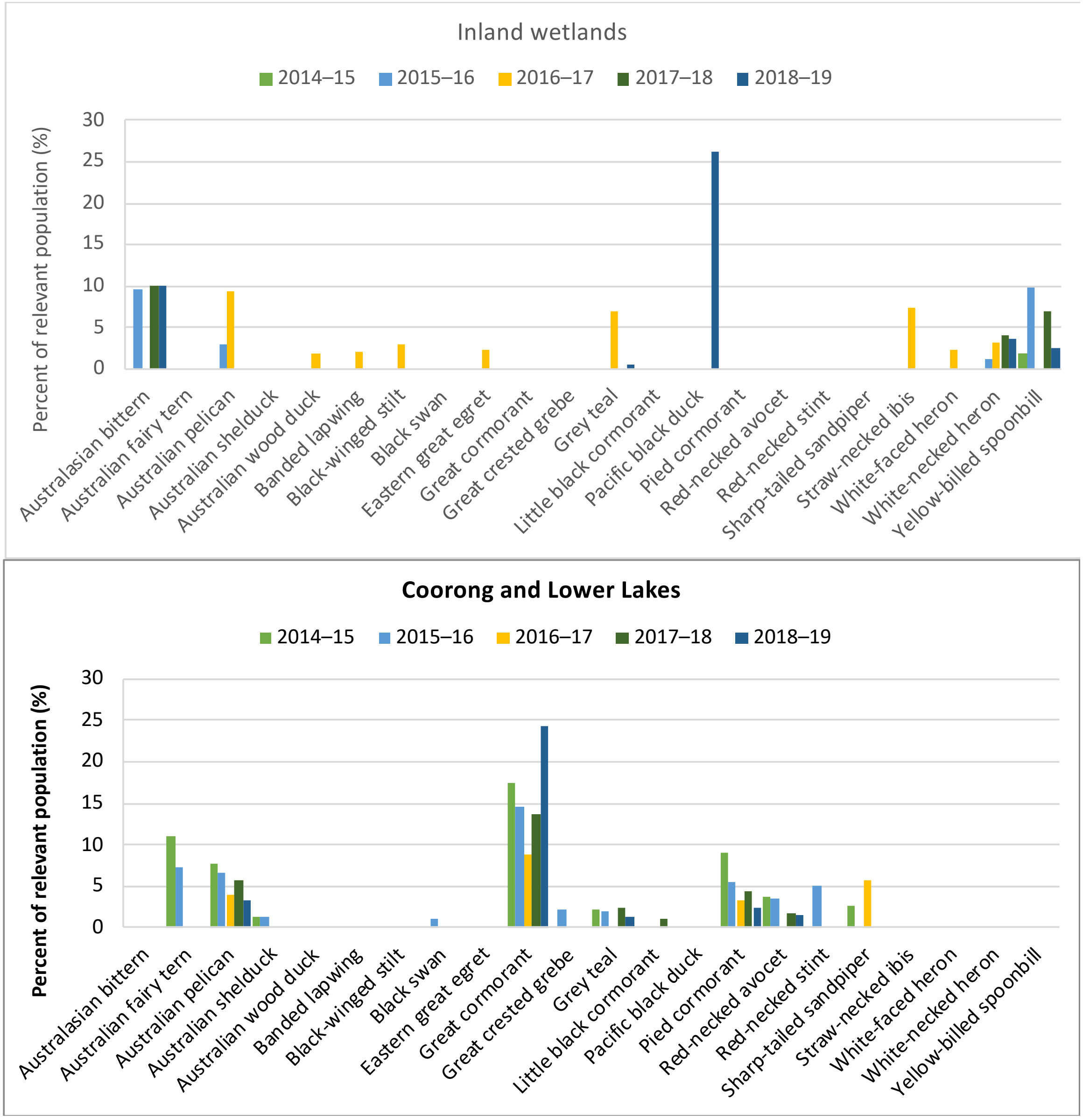

Figure 10. Waterbird species for which greater than one percent of the population have been recorded in a single year at sites that received Commonwealth environmental water (data provided by MDBA, with data from several ground surveys added; BioNet Atlas; Coorong waterbird database). Population estimates from Wetlands International (2012).

Waterbirds, inundation and wetland type

Waterbird foraging groups were developed by McGuinness (in prep), on the basis of their:

- diet (omnivore, herbivore, insectivore, piscivore)
- foraging style (wading, swimming, aerial);
- preferred water depth (no preference, shallow water, damp sediment/very shallow water) and
- preferred emergent macrophyte density (open water, low density, moderate density, dense macrophytes).

There were 16 of waterbird foraging present in the Basin Ramsar sites (from aerial waterbird surveys) over the period 2007 to 2018. Using the Geoscience Australia WIT (Dunn et al. 2019) it is clear than almost all of these groups are present in greater numbers in wetlands that were less than 50 % inundated at the time of the survey (Figure 11). Although limitations with the methods and alignment of different data sources, affects confidence with observed patterns, there are a few key messages that arise from this analysis, that are supported by other lines of evidence.

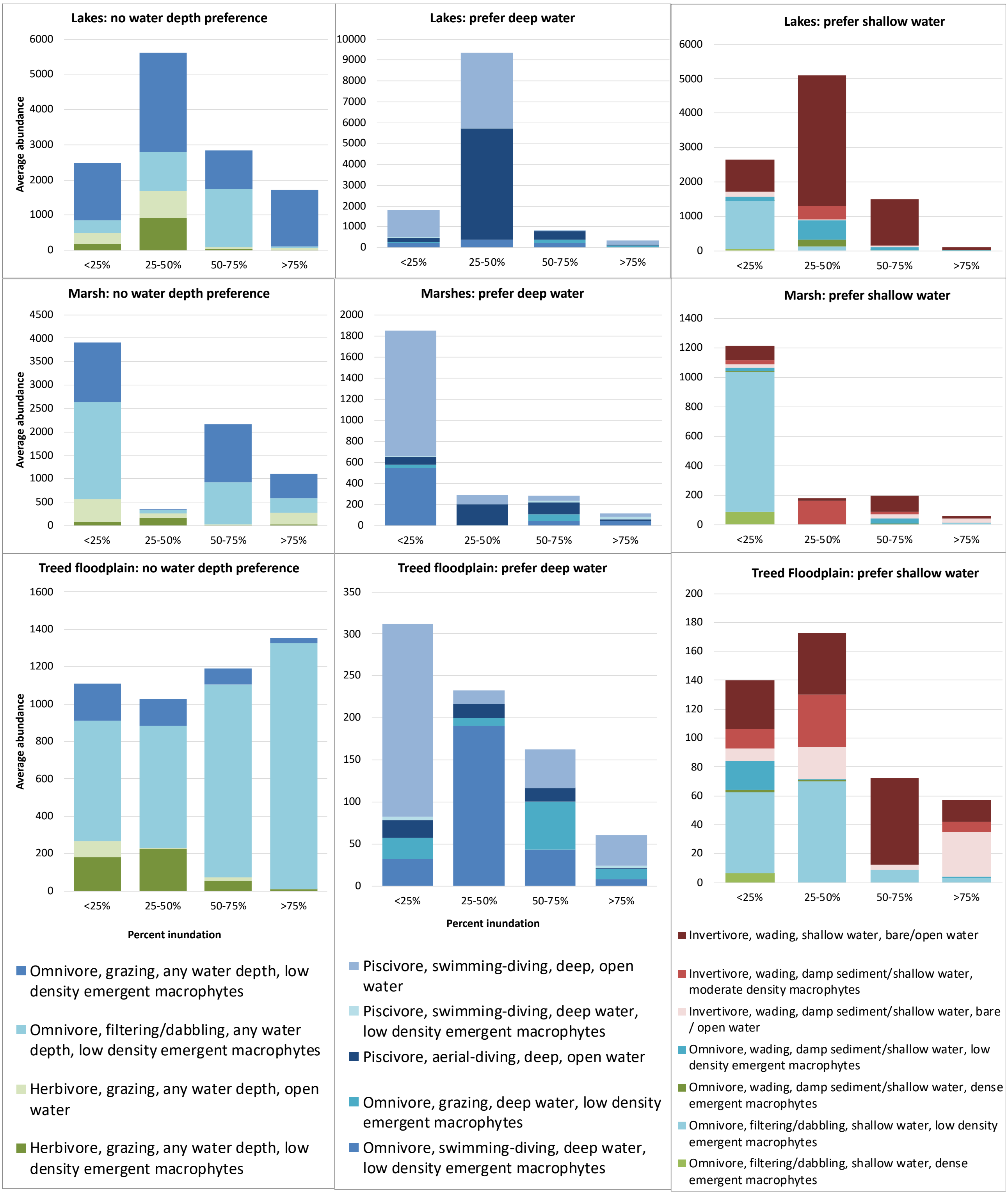

Figure 11: Average abundance (per survey 2007 - 2018) of waterbird foraging guilds in Ramsar wetlands in inundation quartiles (represented by the sum of open water and inundated vegetation) in three broad wetland groups: treed floodplains, marshes, permanent lakes and temporary lakes. Waterbird data from MDBA aerial surveys (2007–2018), inundation from the Geoscience Australia WIT (Dunn *et al.* 2019); wetland types derived from the ANAE (Brooks 2017). Note that the aerial survey does not capture cryptic waterbirds and that the spatial scale of each of the data sets does not align well spatially in the treed floodplain and some marsh ecosystem types. In addition, the number of surveys in lignum shrublands was too small to include.

Disturbance regimes such as flood pulses and wetting and drying cycles in wetlands, drive biodiversity in Australian aquatic ecosystems (Kingsford *et al.* 1999; Leigh *et al.* 2010; Bino *et al.* 2015). The act of filling and drying a wetland stimulates a number of processes such as nutrient and carbon cycling, primary productivity and creates a range of habitat niches (Boon *et al.* 2014). The results of the LTIM preliminary analysis indicate that there is a greater abundance of waterbirds across most functional groups and broad ecosystem types in wetlands that are partially full. This would cover wetlands in both the filling and drying phase as well as wetlands for which only a portion of the wetland area is inundated regularly.

This is consistent with previous studies on waterbirds in arid zone lakes in Australia, where increased abundance and diversity was found in unregulated wetlands that filled and drained, compared to wetlands managed for water storages (Kingsford *et al.* 2004). In the Ramsar sites of the Basin, this result of increased abundance of waterbirds in partially filled wetlands was seen across groups and statistically significant for marshes and lakes ($p < 0.004$). The pattern is evident (and statistically significant) even for waterbirds such as gulls and terns (piscivore, aerial-diving deep open water), that prefer deeper water (Figure 11). The association of waterbird abundance with partially filled wetlands is less obvious in treed floodplains and was not statistically significant for this ecosystem group. The reasons for this are likely inherent in the data, where the mismatch of scale for waterbird surveys (smaller locations within a floodplain forest) and inundation (across the entire floodplain Ramsar site) may be distorting the results. For example, it is not possible to determine when waterbirds in a large Ramsar site were concentrated in small wet areas, versus being distributed across an inundated floodplain.

On average, partially full lakes supported the greatest numbers of the group “piscivore, aerial-diving deep open water” which comprises a number of gulls and terns, as well as “omnivore, filtering/dabbling, any water depth, low emergent macrophyte density” which includes teal and Pacific black duck. Partially full lakes also supported the greatest number of “Invertivore, wading, shallow water, bare/open water”, which includes a range of Australian shorebirds such as stilts. Marshes in general supported greater abundances of the “omnivore, grazing, any water depth, low density emergent macrophytes” group which includes Eurasian coot as well as “piscivore, wading, shallow water, low density emergent macrophytes” which comprises herons, egrets and spoonbills. Overall the average abundances of waterbirds in treed floodplains was considerably lower than in marshes and lakes, which may reflect the difficulty in detecting birds in canopied wetlands from aerial surveys or the difficultly in counting waterbirds over such large wetland areas.

The effect of inundation extent on species richness followed a similar pattern, but with a lower strength of relationship. Across all broad wetland type groups, the greatest number of species we recorded in wetlands that were partially full (Figure 12).

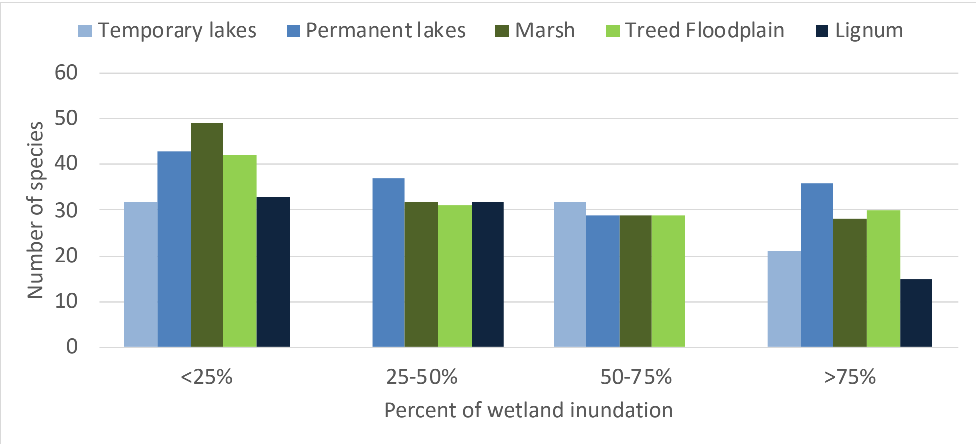

Figure 12: Species richness in Ramsar wetlands in inundation quartiles (represented by the sum of open water and inundated vegetation) in five broad wetland groups. Waterbird data from MDBA aerial surveys (2007–2018), inundation from the Geoscience Australia WIT (Dunn *et al.* 2019); wetland types derived from the ANAE (Brooks 2017). Note that the aerial survey does not capture cryptic waterbirds.

Correlations between inundation and the abundance of foraging groups of waterbirds were explored using Spearman rank correlations; to account for the skewed distribution of the data which was heavily influenced by a small number of very large (> 10,000) individual counts. Some patterns emerged for several groups in the three broad ecosystem types. Around one third of the variance in ranked abundance of piscivorous aerial-diving foragers (gulls and terns) and herbivorous swimming grazing foragers (black swans and Australian wood duck) on lake ecosystems was explained by the proportion of inundated vegetation (*p* < 0.001; Figure 13). This is likely due to the open water preferences of both of these groups of waterbirds, however, the average extent of inundated vegetation in the lakes groups was < 5 %, indicating that even a small amount of encroachment of vegetation across these lakes systems may influence the abundance of waterbirds with these foraging preferences.

In the marsh and treed floodplain wetlands the foraging group "insectivorous, wading foragers that prefer shallow water and moderate density macrophytes" (glossy ibis) had a positive correlation with inundation extent where open water and inundated vegetation were summed (*p* < 0.001; Figure 14). This is consistent with other studies linking the abundances of ibis to floods and total annual flow in the Macquarie Marshes (Poiani 2006). Data from the Macquarie Marshes were excluded from the analysis presented here (see Appendix C) suggesting that the correlation described for ibis and water regimes in Poiani (2006) for the Macquarie- Marshes may also hold true for other floodplain ecosystems.

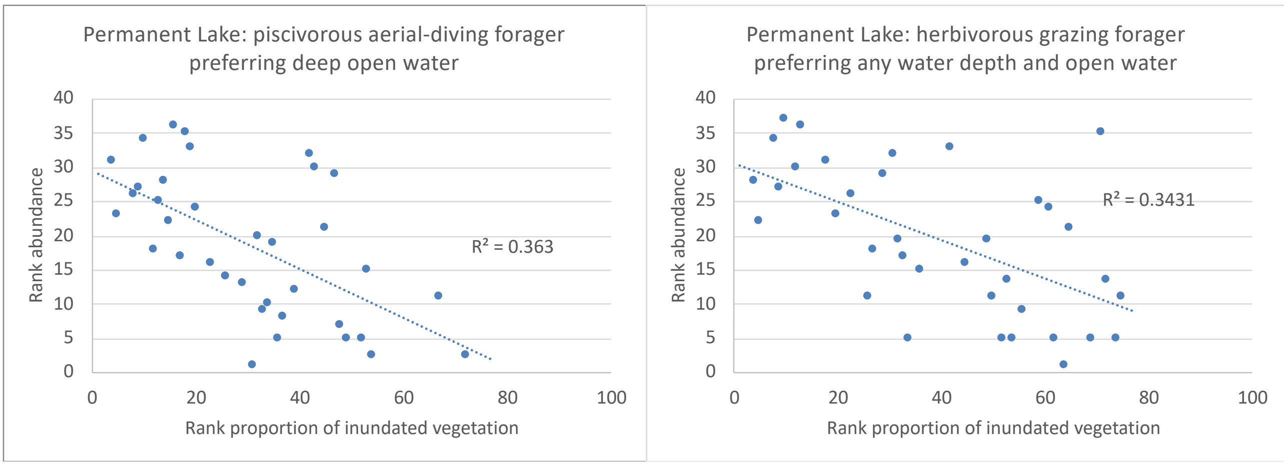

Figure 13: Correlation between waterbird abundance and extent of inundated vegetation in lakes. Waterbird data from MDBA aerial surveys (2007–2018), inundation from the Geoscience Australia WIT (Dunn *et al.* 2019); wetland types derived from the ANAE (Brooks 2017).

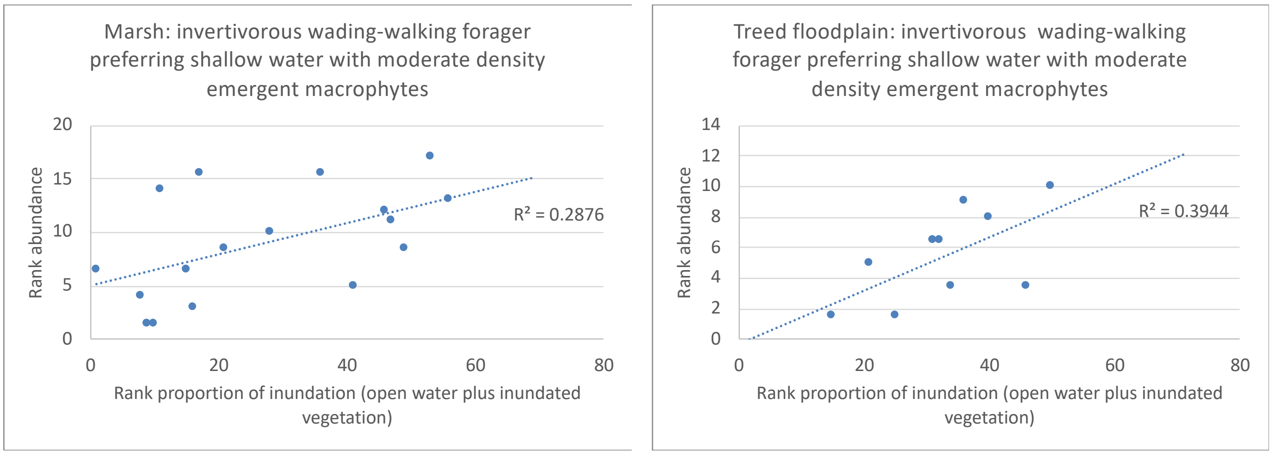

Figure 14: Correlation between waterbird abundance and extent of inundation in treed floodplains and marshes. Waterbird data from MDBA aerial surveys (2007–2018), inundation from the Geoscience Australia WIT (Dunn *et al.* 2019); wetland types derived from the ANAE (Brooks 2017). Note that the aerial survey does not capture cryptic waterbirds and that the spatial scale of each of the data sets does not align well spatially in the treed floodplain and some marsh ecosystem types.

The results of this trail have revealed some preliminary relationships between waterbirds, inundation extent and wetland type. Most of the results, however, are too uncertain to be used to predict responses of waterbirds to environmental water at sites that were not monitored. It seems possible that when issues of aligning spatial and temporal scales are resolved, that this approach could be developed further. In addition, it does provide some empirical evidence to strengthen our conceptual understanding of waterbird-water regime relationships and could be used to inform the management of water for waterbird outcomes in the Basin (see section 4.1).

3.3.2 Threatened species

Fifty-four significant species were recorded at sites that received environmental water in 2014–19 (Table 10). This includes 18 international migratory waterbird species, 19 nationally listed threatened species and 21 species listed under state legislation.

Table 10. Listed species that were recorded at sites that received Commonwealth environmental water 2014–19.

Group	Common name	Species name	Significance[1]
Birds	Australasian bittern	*Botaurus poiciloptilus*	Endangered (EPBC)
	Australasian shoveler	*Anas rhynchotis*	Vulnerable (Vic)
	Australian fairy tern	*Sternula nereis nereis*	Endangered (EPBC)
	Australian little bittern	*Ixobrychus dubius*	Endangered (Vic, SA)
	Australian painted snipe	*Rostratula australis*	Critically endangered (EPBC)
	Ballion's crake	*Porzana pusilla*	Vulnerable (Vic)
	Banded lapwing	*Vanellus tricolor*	Vulnerable (SA)
	Bar-tailed godwit	*Limosa lapponica*	V (EPBC), JAMBA, CAMBA, ROKAMBA
	Black-necked stork	*Ephippiorhynchus asiaticus*	Endangered (NSW)
	Black-tailed godwit	*Limosa limosa*	JAMBA, CAMBA, ROKAMBA
	Blue-billed duck	*Oxyura australis*	Endangered (Vic), Vulnerable (NSW)
	Brolga	*Grus rubicunda*	Vulnerable (NSW, SA, VIC)
	Common greenshank	*Tringa nebularia*	JAMBA, CAMBA, ROKAMBA
	Common sandpiper	*Actitis hypoleucos*	JAMBA, CAMBA, ROKAMBA
	Curlew sandpiper	*Calidris ferruginea*	CE (EPBC), JAMBA, CAMBA, ROKAMBA
	Eastern curlew	*Numenius madagascariensis*	CE (EPBC), JAMBA, CAMBA, ROKAMBA
	Eastern great egret	*Ardea modesta*	Vulnerable (VIC)
	Freckled duck	*Stictonetta naevosa*	Vulnerable (SA, NSW)
	Grey plover	*Pluvialis squatarola*	JAMBA, CAMBA, ROKAMBA
	Hardhead	*Aythya australis*	Vulnerable (VIC)
	Hooded plover	*Thinornis rubricollis*	Vulnerable (EPBC)
	Intermediate egret	*Ardea intermedia*	Endangered (VIC)
	Latham's snipe	*Gallinago hardwickii*	CAMBA, ROKAMBA
	Little egret	*Egretta garzetta*	Endangered (VIC)
	Little tern	*Sternula albifrons sinensis*	Endangered (SA)
	Magpie goose	*Anseranas semipalmata*	Vulnerable (NSW)
	Marsh sandpiper	*Tringa stagnatilis*	JAMBA, CAMBA, ROKAMBA
	Musk duck	*Biziura lobata*	Vulnerable (VIC)
	Oriental plover	*Charadrius veredus*	JAMBA, CAMBA, ROKAMBA
	Pacific golden plover	*Pluvialis fulva*	JAMBA, CAMBA, ROKAMBA
	Red-necked stint	*Calidris ruficollis*	JAMBA, CAMBA, ROKAMBA
	Regent parrot	*Polytelis anthopeplus*	Vulnerable (EPBC)
	Ruddy turnstone	*Arenaria interpres*	JAMBA, CAMBA, ROKAMBA
	Ruff	*Calidris pugnax*	JAMBA, CAMBA, ROKAMBA
	Sanderling	*Calidris alba*	JAMBA, CAMBA, ROKAMBA
	Sharp-tailed sandpiper	*Calidris acuminata*	JAMBA, CAMBA, ROKAMBA
	Superb parrot	*Polytelis swainsonii*	Vulnerable (EPBC)
	Whimbrel	*Numenius phaeopus*	JAMBA, CAMBA, ROKAMBA
	White-bellied sea eagle	*Haliaeetus leucogaster*	Endangered (SA) Vulnerable (Vic)

Group	Common name	Species name	Significance[1]
	Wood sandpiper	*Tringa glareola*	JAMBA, CAMBA, ROKAMBA
Fish	Freshwater catfish	*Tandanus tandanus*	Endangered (NSW, VIC)
	Flat-headed galaxias	*Galaxias rostratus*	Critically endangered (EPBC)
	Murray cod	*Maccullochella peelii*	Vulnerable (EPBC)
	Murray hardyhead	*Craterocephalus fluviatilis*	Endangered (EPBC)
	Olive perchlet	*Ambassis agassizii*	Endangered population (NSW)
	Purple-spotted gudgeon	*Mogurnda adspersa*	Endangered (NSW)
	Silver perch	*Bidyanus bidyanus*	Endangered (EPBC)
	Trout cod	*Maccullochella macquariensis*	Endangered (EPBC)
Frogs	Southern bell frog	*Litoria raniformis*	Vulnerable (EPBC)
Plants	Basalt peppercress	*Lepidium hyssopifolium*	Endangered (EPBC)
	Glistening dock	*Rumex crystallinus*	Vulnerable (VIC)
	Rigid water milfoil	*Myriophyllum porcatum*	Vulnerable (EPBC)
	River swamp wallaby-grass	*Amphibromous fluitans*	Vulnerable (EPBC)
	Winged peppercress	*Lepidium monoplocoides*	Endangered (EPBC)

[1] CAMBA = China–Australia Migratory Bird Agreement; JAMBA = Japan–Australia Migratory Bird Agreement; ROKAMBA = Republic of Korea – Australia Migratory Bird Agreement; EPBC = *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Two iconic and nationally listed threatened bird species were recorded at inland sites that received Commonwealth environmental water. The Australasian bittern was recorded in all five years and the Australian painted snipe in 2015–16 and 2017–18. There is very good evidence that Commonwealth environmental water is contributing to maintaining populations of Australasian bittern with over 10 % of the estimated population of the species recorded at the Barmah-Millewa Forest sites. The species prefers shallow wetlands with emergent vegetation (Menkhorst 2012), which has been the target of environmental water at this Ramsar site in three of the past five years.

In addition, several national listed species are regularly supported at the Coorong and Lower Lakes sites including the Australian fairy tern (*Sternula nereis nereis*) and four international migratory waders that are also listed as vulnerable or critically endangered under EPBC Act: bar-tailed godwit (*Limosa lapponica*), curlew sandpiper (*Calidris ferruginea*), eastern curlew (*Numenius madagascariensis*) and red knot (*Calidris canutus*).

Two species of parrot that are listed nationally as vulnerable (regent parrot and superb parrot) are often considered 'wetland dependent' for their reliance on river red gum as nesting trees. These two species were recorded in sites that received Commonwealth environmental water in all years and watering actions aimed at maintaining tree health would be sustaining nesting habitat.

There are indications of benefits to Murray cod, in Gunbower Creek with a restoration of age structure in the population following the implementation of the "fish hydrograph" with Commonwealth environmental water (CPS Enviro 2018); and to freshwater catfish from a number of locations around the Basin including the Border Rivers (CEWO unpublished).

There are a relatively large number of records for southern bell frog from several locations around the Basin that received Commonwealth environmental water including the Murrumbidgee wetlands, Banrock Station and wetlands along the Lower Murray (CEWO unpublished; Thomas *et al.* 2020). This species of frog is considered "flow dependent" and has been shown to move in response to inundation of floodplain habitats, rather than rainfall (Wassens *et al.* 2010) indicating that it can benefit from environmental watering at key habitats.

Threatened species, wetland type and environmental water

Four case studies selected to explore the potential effect of Commonwealth environmental water on threatened species have yielded starkly different results. There is evidence to suggest that Commonwealth environmental water has supported Australian bittern at a significant proportion of the wetlands where this species has been recorded. Australasian bittern has been recorded in a little over 1100 mapped ANAE wetlands in the Basin since 1980, and over the five years of LTIM, Commonwealth environmental water has been delivered to 42 % of these. This includes of 75 % of temporary sedge/grass/forb marshes and 68 % of temporary tall marsh known to support the species (Figure 15). On average, the wetlands where Australasian bittern have been recorded that received Commonwealth environmental water, were watered three times in the past five years.

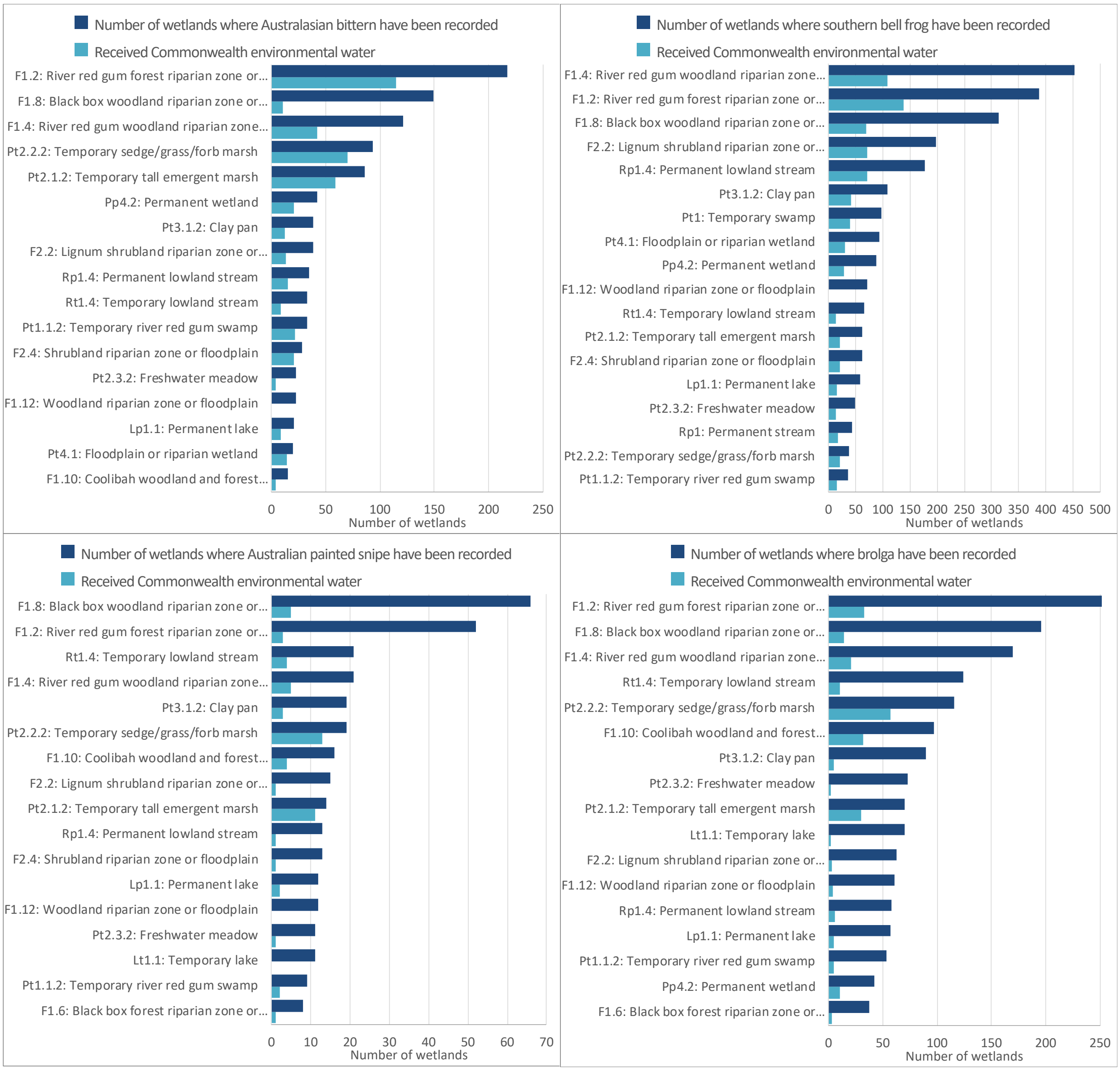

Figure 15. Wetlands where four threatened species (Australasian bittern, southern bell frog, Australian painted snipe and brolga) have been recorded since 1980 (Atlas of Living Australia) and have received Commonwealth environmental water over the five years of LTIM 2014–2019.

The southern bell frog has been recorded in around 2500 mapped wetlands in the Basin since 1980, of which, around 30 % have received Commonwealth environmental water at least once in the five years of the LTIM Project (2014–19). This includes about 40 % of temporary swamps and temporary river red gum swamps and around one third of the river red gum and black box forests known to support the species

(Figure 15). Similar to the Australasian bittern, sites known to support southern bell frog that received Commonwealth environmental water, did so on average in three out of the five LTIM years.

Commonwealth environmental water was delivered to around 15 % of wetlands that are known to support brolga and / or Australian painted snipe. While this represented a significant proportion of temporary sedge grass and forb wetlands and temporary tall emergent marshes (42 – 78 %), it was a very small proportion of other wetland types (typically < 10 %; Figure 15). Interestingly, while all four species were commonly recorded in floodplain wetland sites (e.g. river red gum forest riparian zone or floodplain), the proportion of the individual locations where the four species were recorded that were watered were considerably different. While 53 % of this wetland type where Australasian bittern have been recorded received Commonwealth environmental water, the proportion was around 35 % for southern bell frog, 12 % for brolga and just 6 % for Australian painted snipe (Figure 15).

Significant uncertainties remain with respect to whether these species occurred at these sites when environmental water was delivered and if attributes of water delivery such as timing, depth and duration of inundation matched habitat requirements. There are, however, multiple lines of evidence to support the assertion that Commonwealth environmental water has benefitted both the Australasian bittern and southern bell frog. Both species are all known to have a degree of site fidelity (Heard *et al.* 2012; Williams *et al.* 2019) which improves the likelihood that species' may have been present when environmental water was delivered, even in the absence of monitoring. There are also several results from on-ground monitoring programs that have recorded benefits to these species from environmental water, including surveys at Barmah-Millewa Forest for bitterns (Belcher *et al.* 2019) and results from the Murrumbidgee Selected Area for southern bell frog (Wassens *et al.* 2020).

There is less certainty that Commonwealth environmental water has benefitted brolga and Australian painted snipe. Although brolga are also known to have a degree of site fidelity for breeding (King 2008), only 15 % of sites where the species has been recorded received Commonwealth environmental water over the five years of the LTIM project. Few of the sites where Australian painted snipe have occurred have received Commonwealth environmental water and while the Basin is considered to be important for the species, knowledge on the distribution and movement of the Australian painted snipe is still poor (Lane & Rogers 2000).

3.3.3 Maintaining the ecological character of Ramsar sites

There are 16 Ramsar sites in the Basin and over the five years of the LTIM Project, Commonwealth environmental water has been delivered to 11 of these sites (Table 11). The sites that have not received Commonwealth environmental water over this period either represent site for which environmental water cannot be delivered (e.g. Ginni Flats in the alpine region of the ACT) or which have been the target of other environmental water (e.g. Kerang Wetlands).

Table 11. Ramsar sites that have been the target of Commonwealth environmental watering actions in the five years of the LTIM Project.

Ramsar site	Commonwealth environmental water				
	2014–15	2015–16	2016–17	2017–18	2018–19
Banrock Station Wetland Complex		X		X	X
Barmah Forest		X		X	X
NSW Central Murray Forests		X	X	X	X
The Coorong, and Lakes Alexandrina and Albert Wetland	X	X	X	X	X
Fivebough and Tuckerbil Swamps				X	X
Gunbower Forest		X	X	X	X
Gwydir Wetlands: Gingham and Lower Gwydir (Big Leather) Watercourses	X	X	X	X	X
Hattah-Kulkyne Lakes	X	X		X	
The Macquarie Marshes	X	X	X	X	X
Narran Lake Nature Reserve			X		
Riverland	X	X	X	X	X

For several of these sites, evaluating the effect of Commonwealth environmental water on ecological character is hampered by several factors such as a lack of information on ecological responses (e.g. Fivebough and Tuckerbil Swamps); the relatively small spatial and / or temporal scale of environmental water (e.g. Riverland, Narran Lakes) and the complexity of the hydrological effect of environmental water (e.g. the Coorong and Lower Lakes). There are several sites, however, where Commonwealth environmental water contributed to multi-year strategic inundation of Ramsar Sites designed specifically to maintain ecological character. These are explored in further detail below.

Banrock Station

Commonwealth environmental water has been delivered to Banrock Station Ramsar Site in three of the five LTIM years, with natural flooding negating the need for environmental water in 2016–17 (Figure 16). GeoScience Australia's Wetland Insight Tool (WIT) (Dunn *et al.* 2019) provides an indication of the conditions at Banrock Station prior to and after the instigation of environmental watering at the site (Figure 17). While the WIT provides percentages of inundation within the Ramsar Boundary as a whole, including the terrestrial landscape within the Ramsar Site, it is evident that a seasonal wetting and drying of the lagoons at the site has been facilitated by Commonwealth environmental water since 2014, with an increase in the proportion and persistence of "open water" and inundated vegetation.

The ecological character description for the Banrock Station Ramsar Site identifies components, process and services critical to ecological character (Butcher *et al.* 2009). The potential contribution of Commonwealth environmental water to maintaining each of these identified critical components, processes and services is provided in Table 12. It is clear that Commonwealth environmental water has contributed to maintaining ecological character with respect to hydrology, vegetation, small-bodied native fish, waterbirds and the EPBC listed threatened species regent parrot and southern bell frog.

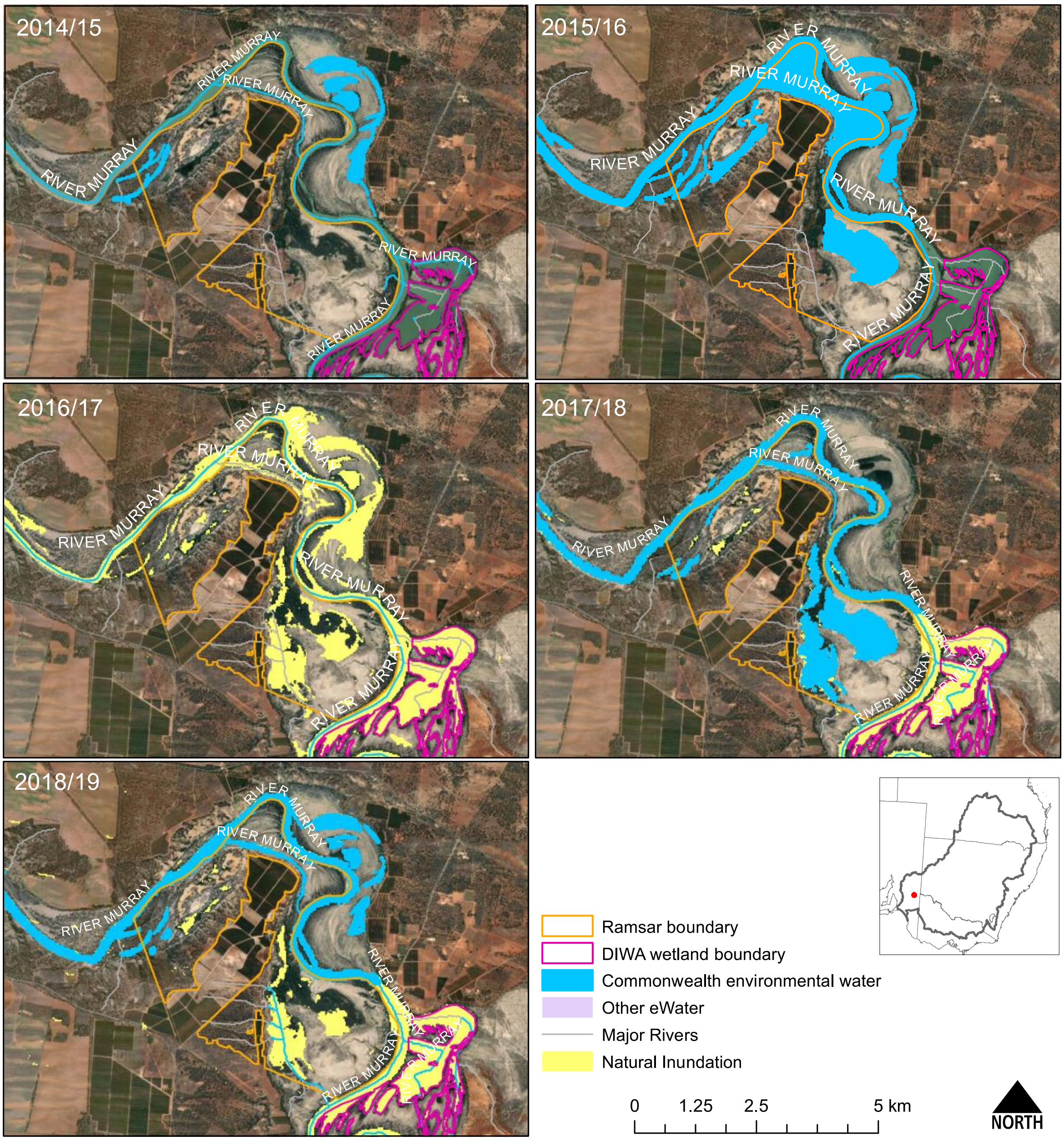

Figure 16. Extent of inundation at Banrock Station 2014–2019. Note that natural inundation is not available for 2014–15 and 2015–16.

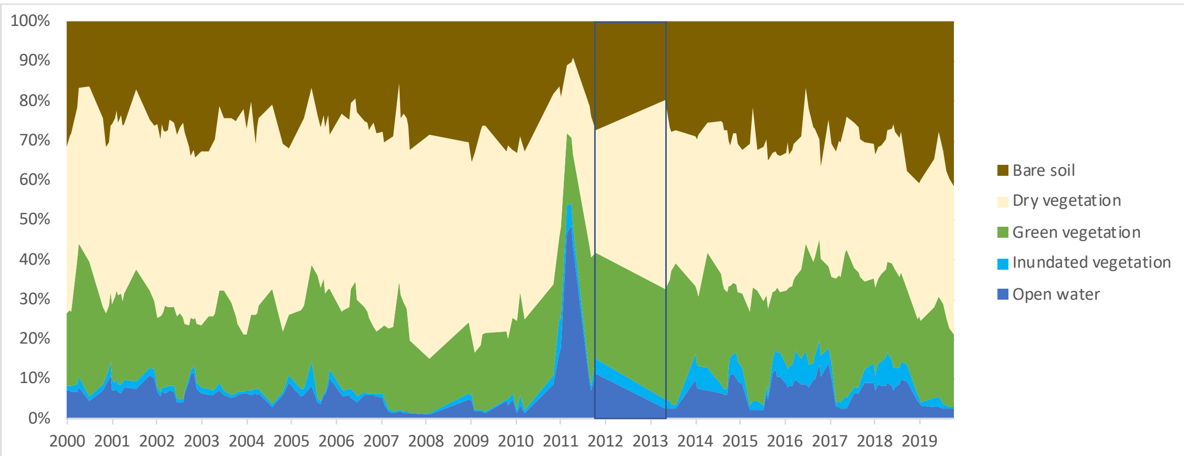

Figure 17. Proportions of open water, inundated vegetation, green vegetation, brown vegetation and bare soils within the Banrock Station Ramsar Site (GeoScience Australia; WIT). Note: no data between October 2011 and May 2013.

Table 12. Contribution of Commonwealth environmental water 2014–19 to maintaining the ecological character of the Banrock Station Ramsar site.

Critical components, processes and services	Description	Contribution of Commonwealth environmental water
Hydrology	Although at the time of listing in 2002 Banrock Lagoon was managed as a permanent wetland, instigation of a wetting and drying cycle for both Banrock and Eastern Lagoon was considered beneficial. The desired water regime was for wetting annually during spring, with a draw down over summer and autumn.	Inundation mapping (Figure 16) and fraction cover (Figure 17) indicate that there has been a wetting and drying cycle instigated at Banrock Station over the past five years. It is certain that Commonwealth environmental water contributed significantly to improving the wetland water regime in at least three of the past five years.
Physical habitat	The three critical wetland vegetation categories are river red gum woodlands, black box woodlands and samphire shrubland.	Monitoring at Banrock has indicated a positive response in the condition of river red gum, black box and lignum shrublands as evidenced by improved canopy cover, germination and flowering (Tourenq 2016).
Fish	Nine native species of fish have been recorded from within the site, dominated by small-bodied native fish.	Several species of small-bodied native fish have been recorded in the lagoon systems following environmental watering, including Bony bream (*Nematalosa erebi*) and unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*).
Waterbirds	Five species of waterbird commonly breed on site: black swan, Australian wood duck, Australian shelduck, grey teal, and purple swamphen. Musk duck have also been recorded breeding on site.	Over 50 species of waterbirds recorded in the four years that Commonwealth environmental water contributed to the inundation of the site. Breeding of cormorants, ibis, spoonbills, musk ducks, blue-billed ducks and Australian spotted crake (CEWO unpublished).
Threatened species	Regent parrot and southern bell frog.	Monitoring indicates stable population of southern bell frog at the site since 2008 (CEWO unpublished). Consistent sightings of regent parrot in the site and improvement to nesting trees (Tourenq 2016).

Barmah Forest and NSW Central Murray Forests (Millewa Forest portion)

Barmah–Millewa Forest is listed as two separate Ramsar sites – Barmah Forest and NSW Central Murray Forests. However, the ecological character descriptions for both sites identify largely the same critical components, processes and services for the site (Hale & Butcher 2011; Harrington & Hale 2011). Commonwealth environmental water contributed to inundation of the Barmah Forest Ramsar site and the Millewa component of the NSW Central Murray Forests Ramsar sites in three of the LTIM years (Figure 18). The WIT provides an indication of the conditions at Barmah Forest (Figure 19) and Millewa Forest (Figure 20) during the Millennium drought and subsequent recovery. There are significant increases in both open water and inundated vegetation from 2013, despite the largely continued dry conditions, which environmental water has significantly contributed.

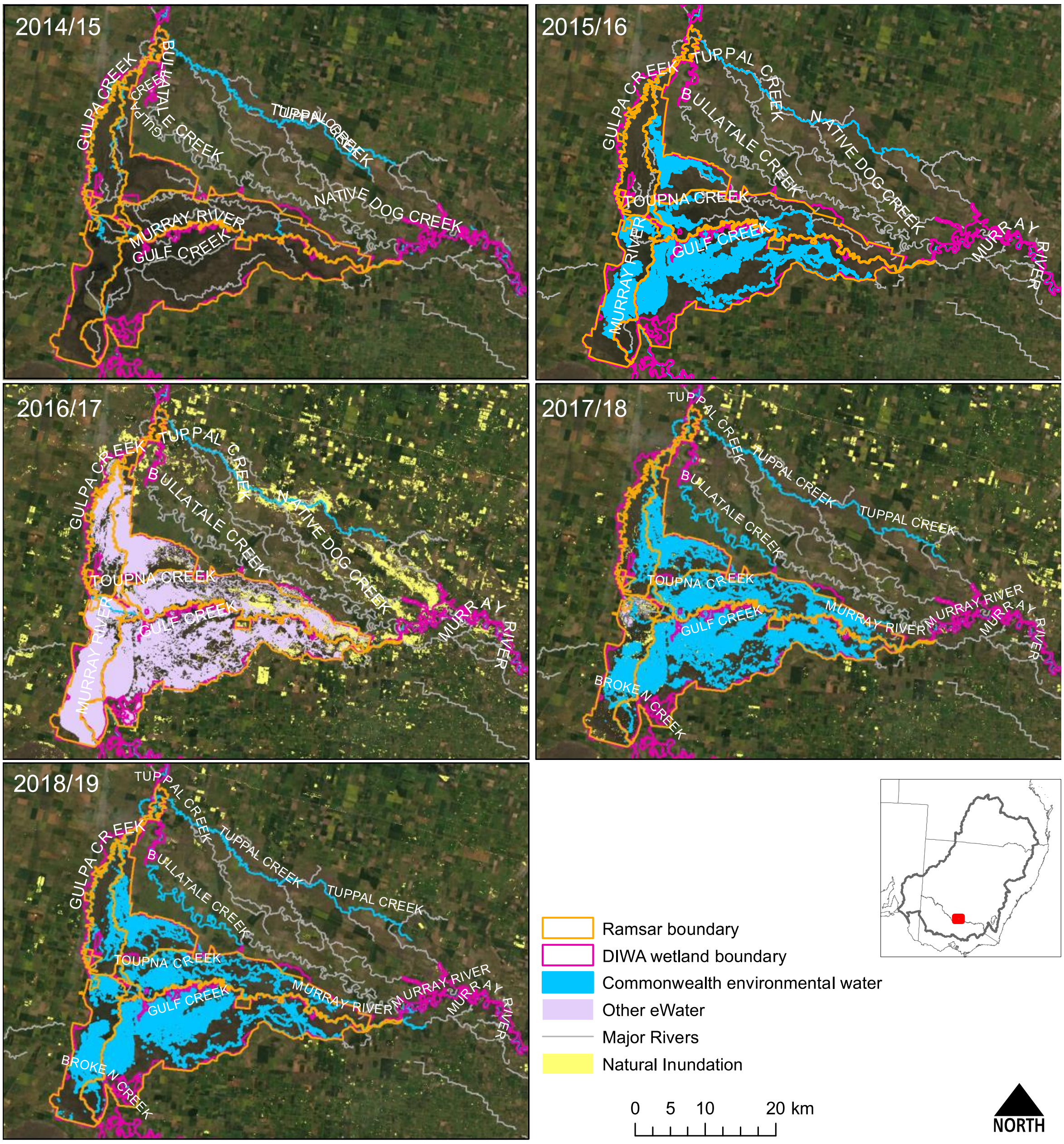

Figure 18. Extent of inundation at Barmah-Millewa Forest 2014–2019. Note that natural inundation and "other environmental water" is not available for 2014–15 and 2015–16.

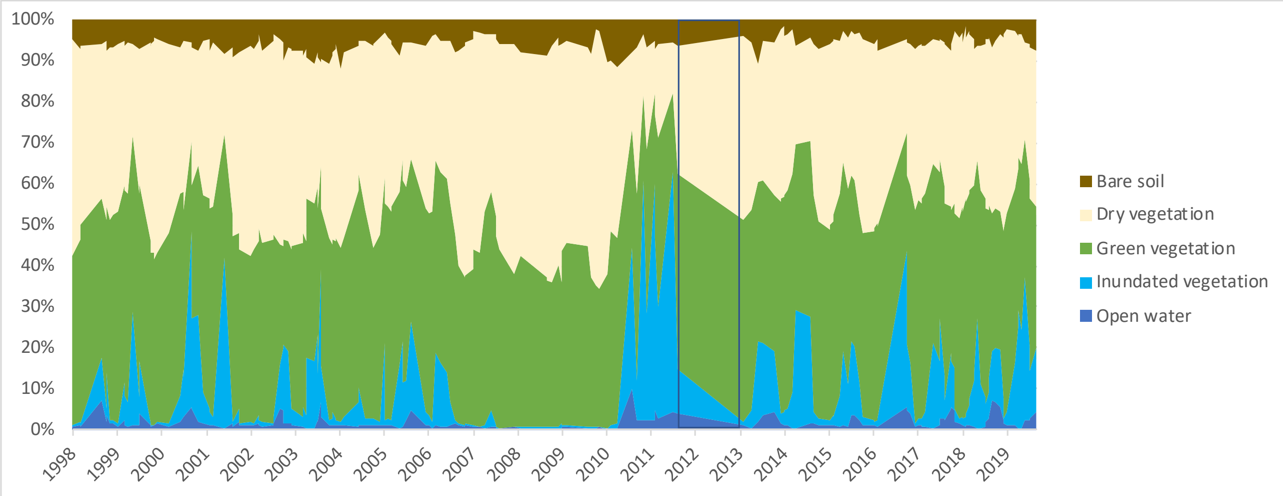

Figure 19 Proportions of open water, inundated vegetation, green vegetation, brown vegetation and bare soils within the Barmah Forest Ramsar Site (GeoScience Australia; WIT). Note: no data between October 2011 and March 2013.

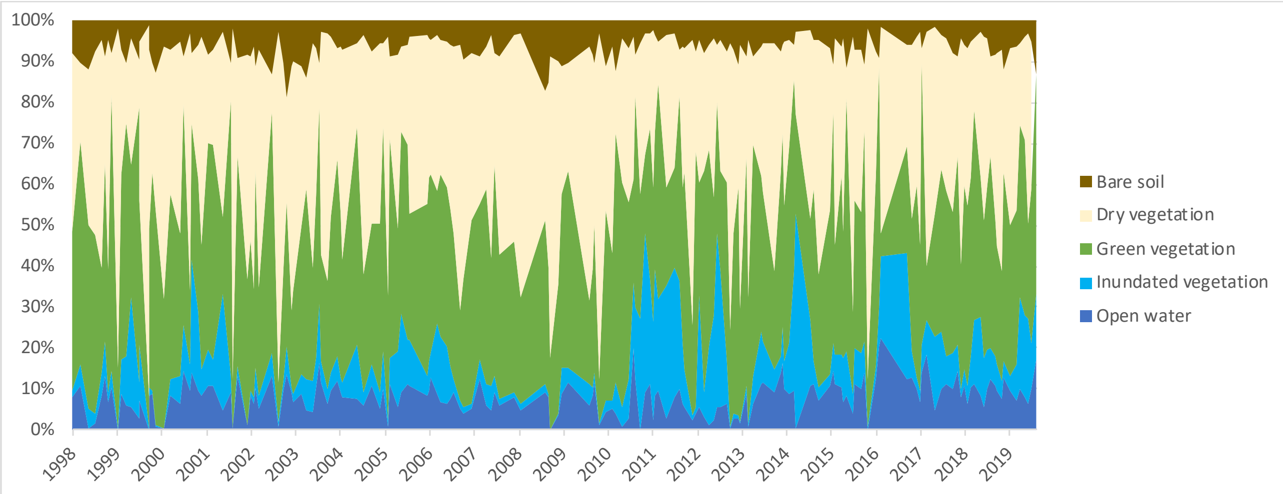

Figure 20. Proportions of open water, inundated vegetation, green vegetation, brown vegetation and bare soils within the Millewa Forest portion of the NSW Central Murray Forests Ramsar Site (GeoScience Australia; WIT).

The potential contribution of Commonwealth environmental water to maintaining critical components, processes and services is provided in Table 13. There is substantial evidence to indicate the contribution of Commonwealth environmental water to maintaining ecological character at these sites, particularly with respect to threatened species (Australasian bittern) and waterbirds.

Table 13. Contribution of Commonwealth environmental water in 2014–19 to maintaining the ecological character of the Barmah Forest and Central Murray Forests Ramsar sites.

Critical components, processes and services	Description	Contribution of Commonwealth environmental water
Hydrology	Inundation of the site is driven largely by flows within the River Murray. Large-scale floods that inundate the forest are generally the result of catchment-scale rainfall events. Moderate- and small-scale inundation is managed through regulators and environmental water.	There is evidence to suggest that Commonwealth environmental water contributed to moderate-scale inundation of the site in 2015–16; 2017–18 and 2018–19. The historical record of observations from space indicates a stark improvement in inundation and vegetation since 2014, particularly in Barmah Forest (Figure 19).
Vegetation	The 2 critical wetland vegetation categories are river red gum forests and floodplain marshes. Approximately 85–90% of the 2 sites are covered by inundation-dependent forest and woodland. Floodplain marshes include moira grass plains which are regionally significant.	It is likely that environmental water contributed to maintaining river red gum health. There have been some improvements in the condition of moira grass in 2017–18 and 2018–19. Fencing from feral grazers, together with improved water regimes, particularly in 2017–18 when winter watering was implemented, have contributed to improved vegetation outcomes.
Fish	17 native species of fish have been recorded from within the site.	11 native species recorded within the site over the three watering events with evidence that environmental water was maintaining habitat for these species.
Waterbirds	67 species of wetland bird have been recorded from the site. This includes 11 species listed under international migratory agreements. The site is significant for supporting breeding of colonial nesting waterbirds and contains a significant breeding population of superb parrot.	Over 45 species of waterbirds recorded in the three years that Commonwealth environmental water contributed to the inundation of the site. Small scale breeding of colonial nesting species recorded on all three occasions that Commonwealth environmental water was delivered to the site. In 2015–16, more than one percent of the population of yellow-spoonbills were recorded nesting in Millewa Forest.
Supports diversity of wetland types	The site supports part of the largest remaining river red gum forest and provides a mosaic of vegetated wetland habitats.	Good evidence that the short-term watering maintained the diversity of wetland types in what would otherwise have been dry conditions.
Provides physical habitat (for waterbirds)	The site provides habitat that supports waterbird breeding and feeding.	Small to moderate scale waterbird breeding supported, and evidence of foraging habitat provided. Aerial surveys recorded several thousand waterbirds in November 2015 and October 2017.
Supports threatened wetland species	Australasian bittern, Australian painted snipe, superb parrot, silver perch, Murray cod, trout cod.	Very large numbers of Australasian bittern recorded in inundated vegetated marshes. Superb parrot recorded feeding and nesting in river red gums. All three threatened fish species recorded at the site with evidence of breeding and recruitment for each.
Biodiversity	The site supports regionally significant range and number of species comparable to other sites within the Murray–Darling Basin. This includes supporting a large number and variety of waterbirds, including breeding habitat for many waterbird species and a rich and diverse flora and seed bank.	The small-scale, short-term environmental watering of the Barmah–Millewa Forest is likely to have helped maintain the diversity of plants and animals at the sites in what would otherwise have been dry periods.
Ecological connectivity	The site provides important migratory routes between riverine, wetland and floodplain habitats for fish spawning and recruitment.	There is evidence that fish moved in and out of the sites in response to environmental watering; maintaining ecological connectivity.

Gunbower Forest

At Gunbower Forest water was delivered each year between 2015–18 as part of a three-year Environmental Water Agreement with the Commonwealth Environmental Water Office (CEWO) to provide the fish hydrograph in Gunbower Creek. Prior to the implementation of environmental water in Gunbower Creek, the system dried to a series of residual pools in the off-irrigation system. This was recognised as having a deleterious effect on fish recruitment and survival with no Murray cod in size classes that represent fish less than three years of age (Sharpe *et al.* 2014). Following the implementation of Commonwealth environmental watering there was evidence of recruitment in five native species: Australian smelt, carp gudgeon, Murray cod, Murray-Darling rainbow fish and unspecked hardyhead (Bloink & Robinson 2016). There has been a marked improvement in the population structure of Murray cod in the system and in 2017–18, the first instances of freshwater catfish recorded in over 15 years (CPS Enviro 2018). In 2018–19, Gunbower Forest was the target of environmental watering by the MDBA and State Agencies. As a consequence, the "fish hydrograph" could not be provided in Gunbower Creek, due to operational constraints with delivering water to the forest. Commonwealth environmental water did, however, contribute to maintaining baseflows in Gunbower Creek for the entire year and maintained fish populations. While these actions were aimed at only a small number of critical components, processes and services (native fish, threatened fish species) there is good evidence to suggest that Commonwealth environmental water has contributed significantly to maintaining both these aspects of the ecological character of the site.

Hattah-Kulkyne Lakes

The Hattah Lakes are only "naturally" connected to the Murray River at flows in the Murray River at Euston greater than 36 700 ML/day (Butcher & Hale 2011). In 2014, works were completed as part of the Living Murray Program including the construction of a permanent pump station, regulators and environmental levees. These works allow watering of all of the lakes within the Ramsar site at relatively low river flows (typically 5000 to 10 000 megalitres per day). Commonwealth environmental water, together with other environmental water, has contributed to a multi-year strategic watering at the Hattah-Kulkyne Lakes Ramsar Site in three of the past five years (2014–15, 2015–16 and 2017–18). This has resulted in the inundation of all wetlands within the Ramsar site in multiple years at times when they would otherwise have been dry (Figure 21).

The effect of environmental water varies with the different lakes within the site. For example, lakes connected closer to Chalka Creek, such as Lake Hattah, had been receiving environmental water for several years prior to LTIM (Figure 22). For Lakes further removed such as Lake Bitterang, the effect of environmental water post 2014 is stark, representing the first inundation of these wetlands for many years (Figure 23). Similarly, Lake Kramen, which is the most ephemeral of the Lakes, inundation with environmental water has resulted in a restored hydrological regime (Figure 24).

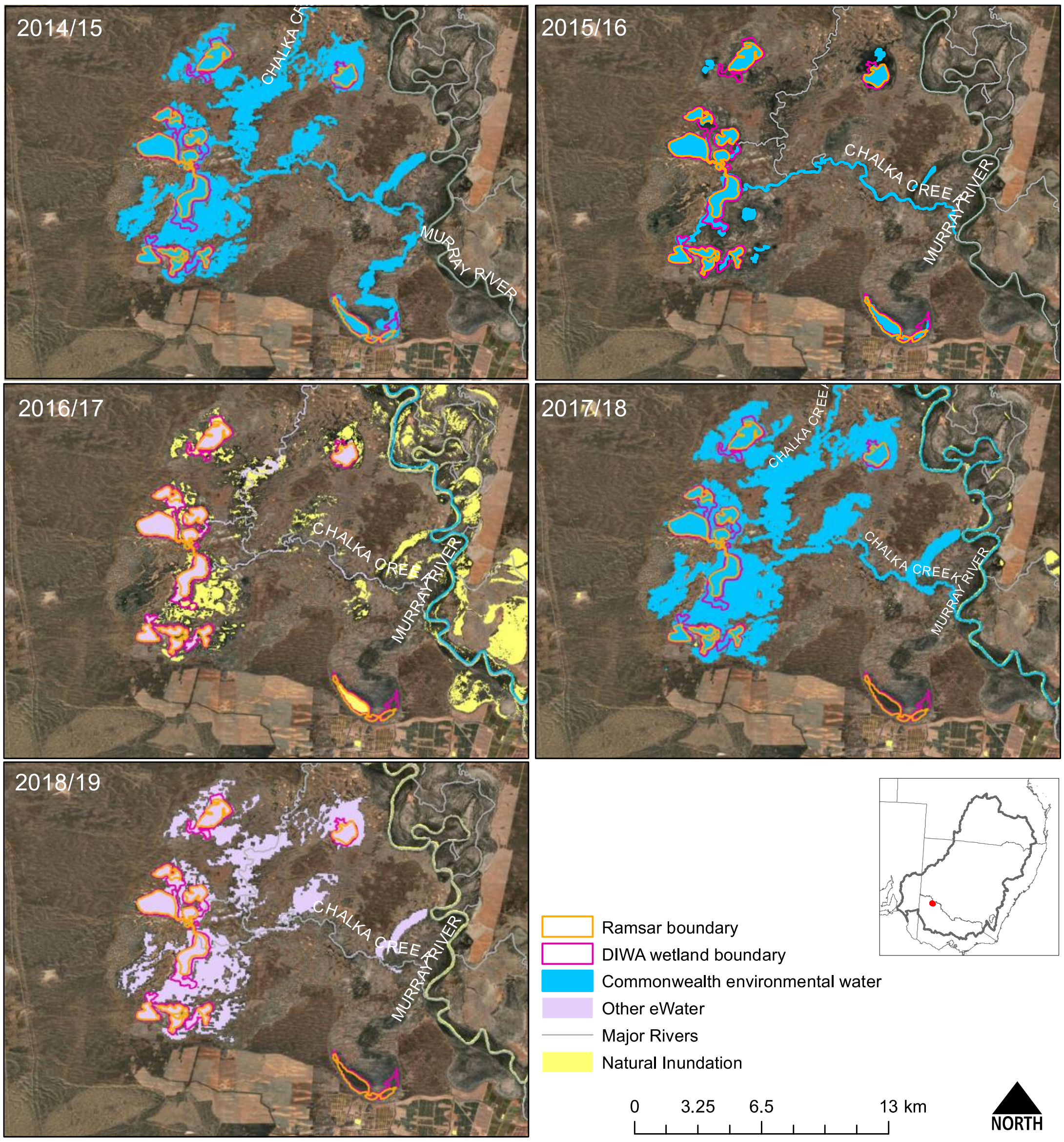

Figure 21. Extent of inundation at Hattah-Kulkyne Lakes 2014–2019. Note that mapping of natural inundation and "other environmental water" was not available for 2014–15 and 2015–16.

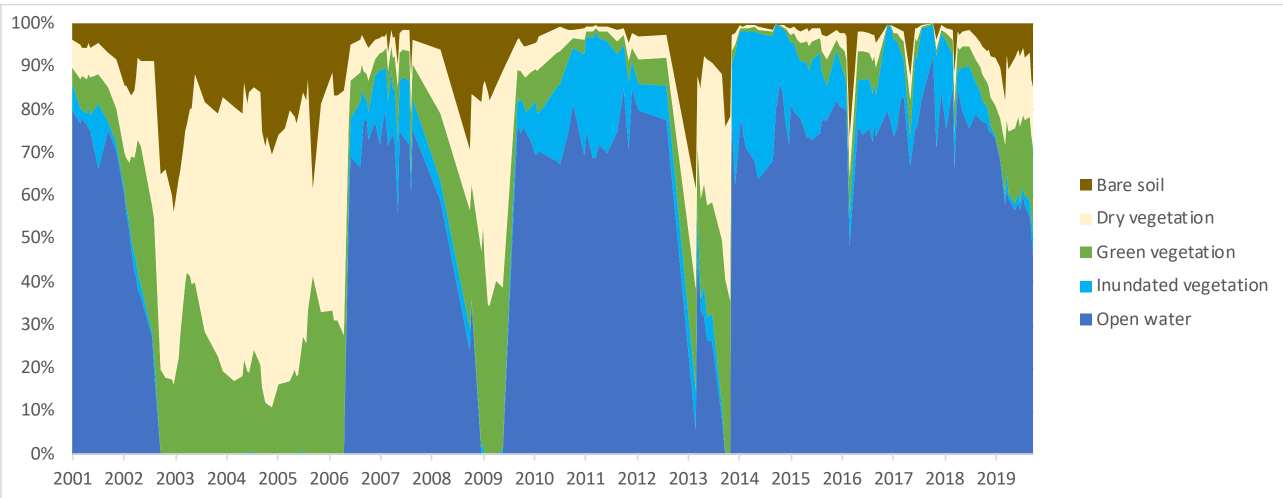

Figure 22: Proportions of open water, inundated vegetation, green vegetation, brown vegetation and bare soils at Lake Hattah in the Hattah-Kulkyne Lakes Ramsar Site (GeoScience Australia; WIT).

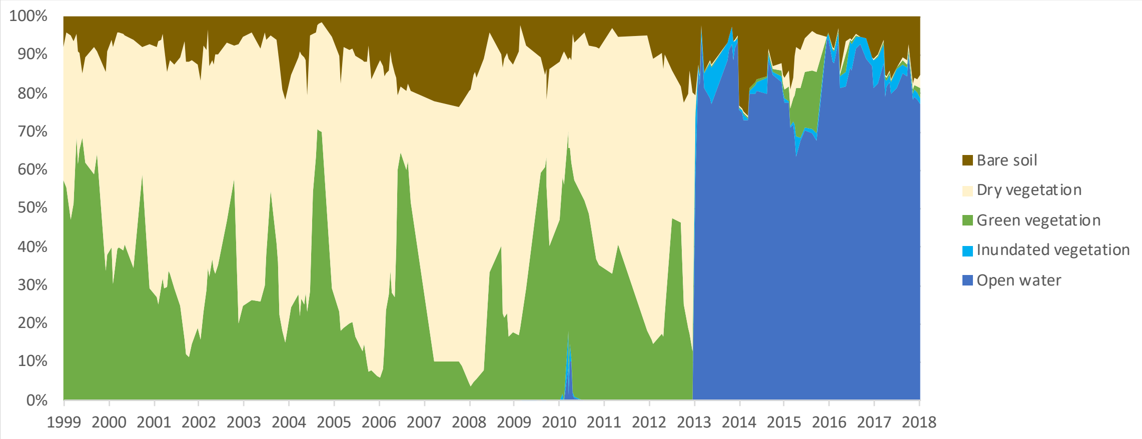

Figure 23. Proportions of open water, inundated vegetation, green vegetation, brown vegetation and bare soils at Lake Bitterang in the Hattah-Kulkyne Lakes Ramsar Site (GeoScience Australia; WIT).

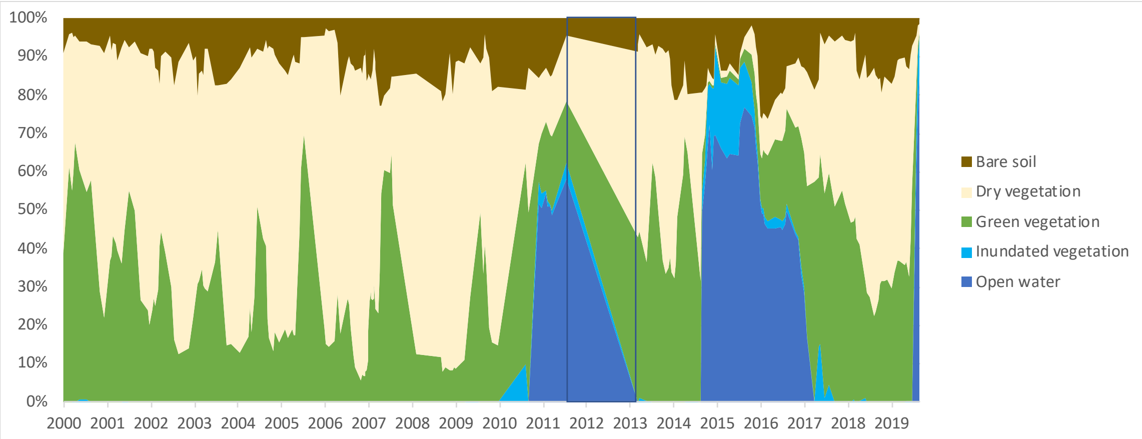

Figure 24. Proportions of open water, inundated vegetation, green vegetation, brown vegetation and bare soils at Lake Kramen in the Hattah-Kulkyne Lakes Ramsar Site (GeoScience Australia; WIT). Note no data between September 2011 and March 2013.

The ecological character description for the Hattah–Kulkyne Lakes Ramsar site identifies four components / processes and five services as critical to ecological character (Butcher & Hale 2011). There is good evidence to indicate that the multi-year watering strategy at Hattah-Kulkyne has contributed significantly to restoring the ecological character of this Ramsar site, which would have largely remained dry in the absence of environmental water (Table 14).

In particular, there has been a reduction in river red gum encroachment into lake beds (Wood *et al.* 2018), an increase in waterbird abundance and diversity, as well as several waterbird breeding events of colonial nesting, fish eating species (Fullagar & McCutcheon 2017). The fish community has been restored with an increase in small-bodied native fish for whom floodplain wetland habitat is important as well as some success in fish recruiting back to river populations with improved ecological connectivity (Brown *et al.* 2015; Wood *et al.* 2015, 2018).

Table 14. Contribution of Commonwealth environmental water in 2014–19 to maintaining the ecological character of the Hattah–Kulkyne Lakes Ramsar site.

Critical components, processes and services	Description	Contribution of Commonwealth environmental water
Hydrology	Lakes are filled via Chalka Creek (now via modified infrastructure). While the majority of the lakes dry within 12 months after inflows cease, lakes Mournpall and Hattah can retain water for several years post flooding.	Environmental water delivered to Hattah Lakes is designed to meet the hydrological needs at the site. This critical process is directly maintained by environmental water, with a restoration of the hydrological regime at all lakes within the Ramsar site boundary.
Lake bed herbland vegetation	Dominant vegetation across all lakes is lake bed herbland. It shifts from being dominated by aquatic and amphibious species with some terrestrial species on the edges in the wet phase, to being dominated by terrestrial species in the dry phase.	Vegetation assessments recorded diverse lakebed herbland communities in response to environmental water and drawdown (Wood *et al.* 2018).
Fish	Fish fauna is dominated by small-bodied native species. Site regularly supports Australian smelt, bony herring, carp gudgeon and unspecked hardyhead.	Evidence that Commonwealth environmental water benefitted a range of fish species and there is strong evidence that small-bodied native fish (Australian smelt, carp gudgeon and unspecked hardyhead) were breeding at the site and maintaining populations. Also, evidence of the movement of large-bodied native fish back into the river in response to flow cues (Brown *et al.* 2015; Wood *et al.* 2015, 2018).
Waterbirds	Supports 70 species of waterbirds, 12 of which are covered by international migratory bird treaties. 34 species have been recorded breeding at the site.	Over 50 species of waterbird recorded at the site 2014–19. High abundances of fish-eating species and >1% of the population of great cormorant in 2014–15 when water levels were high and a greater number of wading species and shorebirds as the lakes dried in 2015–16 (Fullagar & McCutcheon 2017).
Supports near-natural wetland ecosystems	The site represents the largest series of floodplain lakes along the River Murray and is in relatively good condition.	Strong evidence to suggest the environmental water contributed to maintaining the site in good condition across both years.
Provides physical habitat (for breeding waterbirds)	Hattah–Kulkyne Lakes provide habitat that supports waterbird breeding and feeding.	A variety of habitats provided for foraging (shallow, deep and vegetated). Small scale breeding of several species recorded each year (Wood *et al.* 2018).
Supports threatened wetland species	Regent parrot, silver perch, Murray cod and winged peppercress.	Good evidence that environmental water supported silver perch, Murray cod (Wood *et al.* 2018) and regent parrot (Loyn *et al.* 2019).
Biodiversity	The site supports regionally significant number of species comparable to other sites within the Murray–Darling Basin. This includes supporting a large number and variety of waterbirds and a rich and diverse flora and seed bank.	Large number of species and communities potentially benefitted from Commonwealth environmental water in 2014–19 including fish, waterbirds and vegetation (Bloink *et al.* 2019).
Ecological connectivity	Hattah–Kulkyne Lakes are hydrologically and ecologically connected and provide semipermanent surface water in a semi-arid environment, thus ensuring ecological persistence of aquatic habitats.	Evidence of connectivity (hydrological and biological) through the delivery of environmental water and return flows in both years, with good evidence from fish tracking that large-bodied native fish, such as golden perch move back into the river if provided the correct flow cues (Brown *et al.* 2015; Wood *et al.* 2015).

Macquarie Marshes

Commonwealth environmental water contributed to inundation of the Macquarie Marshes Ramsar site in each of the five LTIM years (2014–2019). In four of those years, environmental water was the most substantive source of water to inundate the marshes with the expected outcomes related to maintaining condition in a dry landscape. In 2016–17 there was widespread natural flooding, with Commonwealth environmental water contributing to extending the duration of inundation to allow successful completion of the large colonial waterbird breeding that occurred during that year (CEWO unpublished) (Figure 25). GeoScience Australia's wetness index provides an indication of the conditions at the Macquarie Marshes over the past two decades and the contribution of environmental water to maintaining inundation under the vegetation at the marshes and maintaining vegetation condition Figure 26.

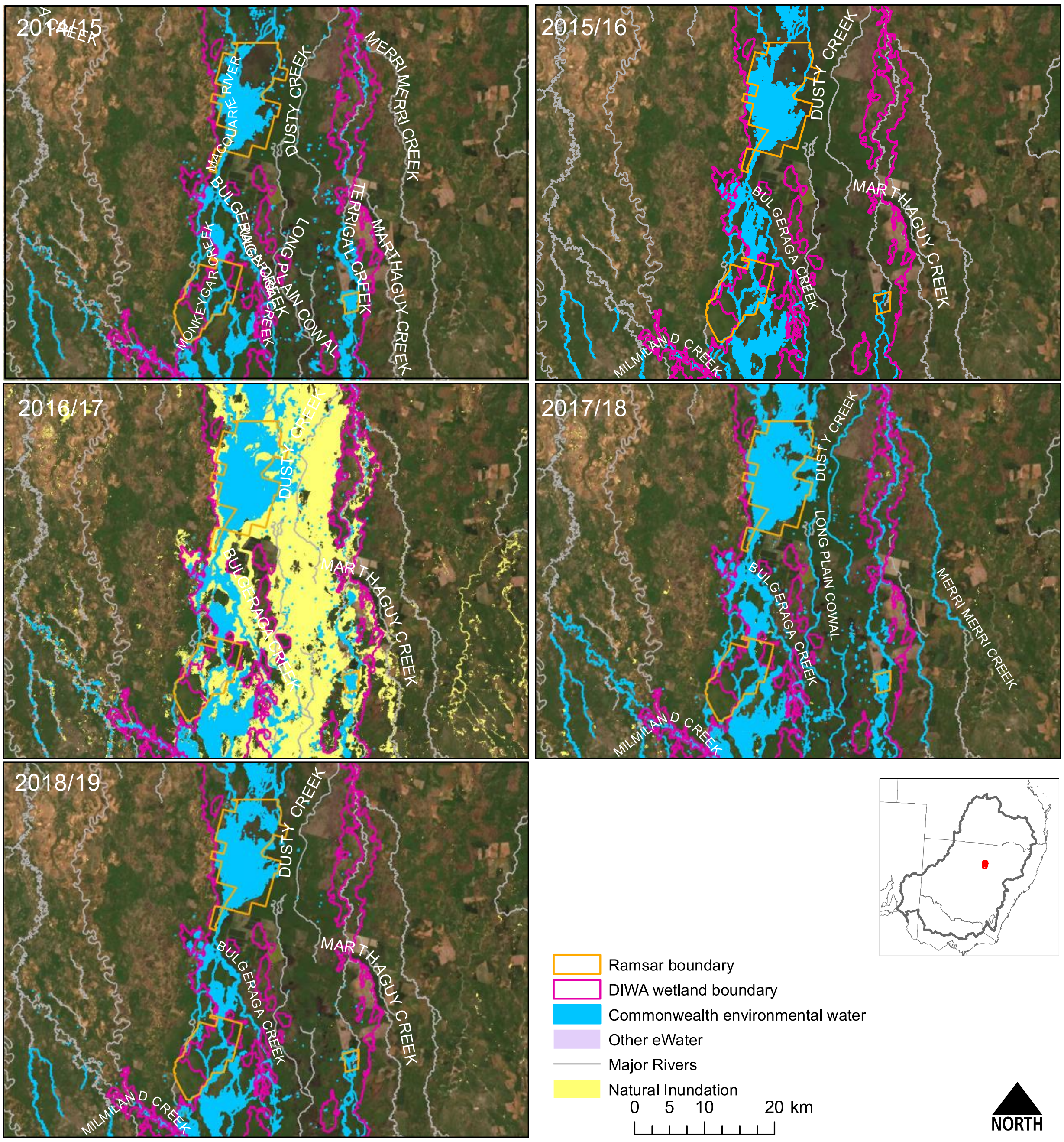

Figure 25. Extent of inundation at Macquarie Marshes 2014–2019. Note that natural inundation and "other environmental water" is not available for 2014–15 and 2015–16.

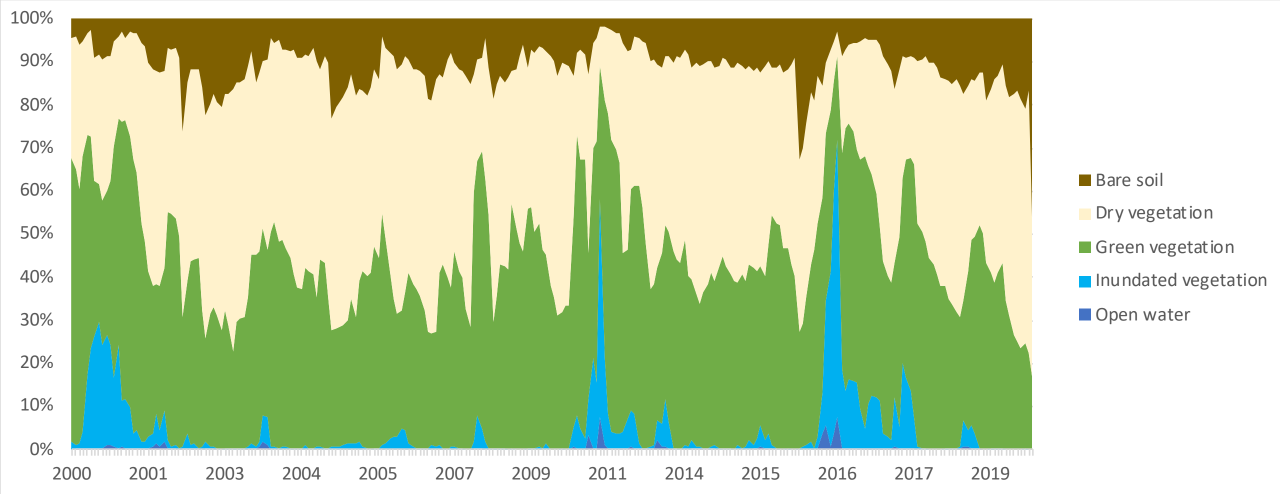

Figure 26. Proportions of open water, inundated vegetation, green vegetation, brown vegetation and bare soils within the Macquarie Marshes Ramsar Site (GeoScience Australia; WIT).

The ecological character description for the Macquarie Marshes Ramsar site identifies seven components/process and services as critical to ecological character (Office of Environment and Heritage 2012). Potential contribution of Commonwealth environmental water to maintaining each of these identified critical components, processes and services is provided in Table 15. While the watering actions inundated only a portion of the Ramsar site and for a relatively short duration, there is some evidence of contributions to maintaining ecological character, especially in terms of drought refuge in a dry landscape and successful waterbird breeding during 2016–17 (Capon *et al.* 2018).

Table 15. Contribution of Commonwealth environmental water in 2014–19 to maintaining the ecological character of the Macquarie Marshes Ramsar site.

Critical components, processes and services	Description	Contribution of Commonwealth environmental water
Wetland types and vegetation	River red gum woodland and forests (6500 hectares) Common reed beds (3350 ha) Cumbungi rushland (280 ha) Water couch marsh (1100 ha) Mixed marsh grasslands (50 ha) Lagoons (90 ha) Coolibah woodland and black box woodland (720 ha) Lignum (200 ha)	Environmental water inundated a range of vegetation communities in the four dry years, although for only a relatively short duration, would have contributed to maintaining condition during a regionally dry period. There is evidence of maintaining tree condition, particularly river red gum communities that were inundated in both years and of growth and reproduction in common reed and water couch emergent marshes (Capon *et al.* 2018).
Aquatic invertebrates	High densities of microinvertebrates, which are am important food source for fish. Also supports a diversity of macroinvertebrate species.	Possible that the inundation of the wetland and floodplain systems resulted in increased productivity and abundance of microinvertebrates for a short period in both years (CEWO unpublished).
Fish species diversity	11 species of native fish recorded. Provides rich productive feeding habitats, and spawning habitat for several species.	Some evidence of spawning of bony bream, and potential increase in productivity from inundation of the Ramsar site. However, very high abundance of exotic fish species (Stocks *et al.* 2015).
Waterbird abundance and diversity	Supports over 70 species of waterbirds, with between 10 000 and 30 000 adult waterbirds reliant on the site each season.	At least 65 species of waterbird have been recorded from within the Macquarie Marshes over the last five years (Spencer *et al.* 2018; Spencer & Ocock 2018). Total abundance ranged from just under 7000 in 2014–15 to over 200 000 in 2016–17 (MDBA unpublished)
Waterbird breeding	16 species of colonial nesting waterbirds, with colonies of more than 500 nests on average in 9 in every 15 years.	While the incidence of breeding within the Ramsar site boundary was low, breeding colonies within the Marshes (but outside the Ramsar boundary) were very high, particularly in 2016–17, where environmental water was specifically used to facilitate successful fledging (Spencer *et al.* 2018).
Migratory birds and waders	17 species listed under international migratory agreements have been recorded at the site.	Four international migratory waders recorded at the site, albeit in small numbers (BioNet Atlas).
Supports threatened wetland species	Australasian bittern, Australian painted snipe, superb parrot, Murray cod and basalt peppercress.	Australasian bittern and Australian painted snipe both recorded using the inundated habitats of the site in multiple years (BioNet Atlas).

4 Contribution to achievement of Basin Plan objectives and adaptive management

4.1 Adaptive management

The biodiversity Basin Matter has largely been a consolidation of monitoring outcomes across the Basin from a variety of sources to develop a list of species and communities that potentially benefited from Commonwealth environmental water. The summary nature of the evaluation has not lent itself to providing adaptive management messages. In this final year of the LTIM Project, however, there are a small number of lessons learned and outcomes that are outlined below.

Biodiversity outcomes are supported by the provision of variable water regimes.

The results of the analysis of waterbirds, inundation extent and wetland type have indicated that waterbird abundance, and to a lesser extent diversity, is promoted by maintaining wetting and drying cycles. To maintain biodiversity outcomes, environmental watering actions should aim to generate a dynamic mosaic of wetting and drying regimes at the wetland and landscape scale, to provide for a full suite of habitats for waterbirds and other biota. Watering actions that act to maintain permanent inundation of lakes will eventually result in reduced habitat quality and diminishing use by biota.

Supporting threatened species across the Basin may require identification of additional watering sites.

While there is strong evidence to suggest that Commonwealth environmental water is supporting many threatened and significant species such as Australasian bittern and southern bell frog, there is increasing evidence that the same locations are the target of environmental water each year. While biodiversity outcomes are undoubtedly being achieved at sites that receive Commonwealth environmental water, it is possible that some species occur largely at sites that do not benefit from Commonwealth environmental water. While it is likely that some locations that are known to support threatened species may be outside the managed floodplain and cannot be the recipient of environmental water, it is also likely that there are wetlands that could be watered but have not been identified as priorities. Strategic approaches that seek to identify critical habitat for vulnerable species at locations that can receive Commonwealth environmental water may improve outcomes for these threatened species.

Multi-year watering approaches are helping to maintain ecological character of Ramsar sites.

Over the five years of the LTIM Project there have been several examples of multi-year wetting and drying strategies aimed at maintaining the ecological character of Ramsar sites. Matching the delivery of environmental water with the needs of critical components, processes and services at wetland in the context of the current and antecedent climatic conditions has been very successful.

Using multiple sources of data to evaluate the effects of environmental water at the Basin scale is promising.

The trial in the final LTIM year of matching waterbird survey data with inundation from the Wetland Insight Tool and aquatic ecosystem mapping of the ANAE has yielded promising results. While there were significant issues with respect to matching the scale of data collected, the available data products are likely to improve over time. As our understanding of the strength of biodiversity-water regime relationships is improved, the predictive capacity of inferring biodiversity outcomes at sites that receive environmental water but are not monitored will become more certain.

4.2 Contribution to Basin Plan objectives

The environmental water outcomes framework is a hierarchy of expected outcomes based around the Basin environmental watering objectives. Expected outcomes are matters that best available science indicates can be achieved from environmental watering (CEWO 2013):

- within a 1-year time frame (1-year expected outcomes)
- within a 1–5-year time frame (5-year expected outcomes).

The outcomes framework provides a template for synthesising outcomes of environmental water and progress towards meeting Basin Plan objectives. There is evidence across the Basin that Commonwealth environmental water has contributed significantly to Basin Plan objectives for ecosystem and species diversity (Table 16).

Table 16. Contribution of Commonwealth Environmental Water Office (CEWO) watering in 2014–19 to Basin Plan objectives.

Basin Plan objectives	Basin outcomes		5-year expected outcomes	1-year expected outcomes	Measured and predicted 1-year outcomes 2018–19	Measured and predicted 1–5-year outcomes 2014–19
Biodiversity (Basin Plan S. 8.05)	Ecosystem diversity		None identified	None identified	Over 246 000 hectares of mapped wetland and floodplain inundated 74% of the different aquatic ecosystem types represented in areas supported by Commonwealth environmental water	75% of the different aquatic ecosystem types supported by Commonwealth environmental water.
	Species diversity	Vegetation	Vegetation diversity	Reproduction Condition	A significant proportion of native species, especially perennial forbs, only present in wetland areas inundated by Commonwealth environmental water at a Basin-scale. Higher species richness in wetlands inundated by Commonwealth environmental water than in dry wetlands at a Selected Area scale. Higher diversity of vegetation communities due to inundation by Commonwealth environmental water at a Basin-scale.	Presence of some native species likely to have been dependent on inundation by Commonwealth environmental water during this period at a Basin-scale. Higher diversity of vegetation communities due to inundation by Commonwealth environmental water at a Basin-scale.
			Growth and survival	Germination Dispersal	Greater plant growth and survival in wetlands inundated by Commonwealth environmental water than in dry wetlands at a Selected Area scale.	Greater plant growth and survival in wetlands inundated by Commonwealth environmental water than in dry wetlands at Selected Area scale and overall at a Basin-scales over this time period.
		Fish	Fish diversity	Condition	There was no systematic change in adult abundance across species in 2018–19 compared with other water years	No loss of native species has occurred despite significant drought across the Basin.
				Larval abundance Reproduction	Large-bodied species were observed spawning in some parts of the Basin, however, there was little evidence found of recruitment for golden perch and limited recruitment of Murray cod, bony herring and common carp. Small-bodied species exhibited some success in spawning and recruitment.	There has been limited spawning and recruitment of golden perch. Murray cod spawned in all Selected Areas in most years. However, the total abundance and recruitment strength was significantly reduced in many Selected Areas due to the widespread fish kill events of 2016-17.
			Larval and juvenile recruitment			
		Waterbirds	Waterbird diversity		70 species of waterbird recorded across all functional feeding groups	101 waterbird species recorded at sites that have received Commonwealth environmental water.
			Waterbird diversity and condition (abundance and population structure)	Survival and condition	Supporting greater than 1% of the relevant populations of eight species of waterbird.	Greater than 1 % of the population of 22 species of waterbird.
				Chicks Fledglings	Breeding recorded for several species in low to moderate numbers.	Smaller scale breeding at localised sites that receive environmental water in drier years. Commonwealth environmental water augmenting large floods in wet periods to improve reproductive success.

Basin Plan objectives	Basin outcomes		5-year expected outcomes	1-year expected outcomes	Measured and predicted 1-year outcomes 2018–19	Measured and predicted 1–5-year outcomes 2014–19
		Other vertebrate diversity		Young	Breeding of many frog species including some temporary wetland specialists. Some evidence of turtle breeding.	Breeding of frogs at several locations across the five years.
			Adult abundance		Six species of frog recorded including the southern bell frog.	Continued foraging habitat provided.

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Appendix A: Watering actions contributed to by Commonwealth environmental water in 2018–19 with expected outcomes for fish, vegetation, waterbirds, frogs or other vertebrates

Table A1. *Watering actions contributed to by Commonwealth environmental water in 2018–19 with expected outcomes for fish, vegetation, waterbirds, frogs or other vertebrates.* Expected outcomes have been translated into the categories of the Outcomes Framework for simplicity (Con. = connectivity; Proc. = processes (primary production/decomposition); Res. = resilience; WQ = water quality). *Indicates Ramsar Site. # Indicates Directory of Important Wetlands (DIWA) Site

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Border Rivers: Border Rivers system; Barwon-Darling: Barwon-Darling River and fringing wetlands (Mungindi to Menindee)	10093-01	7400.00	24/4/19 - 15/5/19	Baseflow	X								
Border Rivers: Lower Moonie River and Fringing Wetlands	00111-53	119.70	22/10/18 - 24/10/18	Fresh	X					X		X	
Border Rivers: Lower Moonie River and Fringing Wetlands	00111-53	902.60	20/12/18 - 3/1/19	Fresh	X					X		X	
Broken: Lower Broken Creek	10077-01	401.00	1/7/18 - 8/8/18	Baseflow	X								X
Broken: Lower Broken Creek	10077-01	3468.00	9/8/18 - 19/8/18	Fresh	X	X							X
Broken: Lower Broken Creek	10077-01	875.00	20/8/18 - 31/12/18	Baseflow	X								X
Broken: Lower Broken Creek	10077-01	19079.00	1/1/19 - 31/5/19	Baseflow		X							X
Broken: Lower Broken Creek	10077-01	3716.00	1/6/19 - 30/6/19	Baseflow	X								X
Lower Murray: Coorong, Lower Lakes and Murray Mouth	10078-02	174491.00	1/7/18 - 31/8/18	Baseflow	X								X
Lower Murray: Coorong, Lower Lakes and Murray Mouth	10078-02	133167.00	1/9/18 - 31/12/18	Baseflow	X								X
Lower Murray: Coorong, Lower Lakes and Murray Mouth	10078-02	241762.00	1/1/19 - 30/6/19	Baseflow, fresh	X								X
Campaspe: Campaspe River	10003-05	1189.00	12/9/18 - 28/9/18	Fresh	X	X			X				X
Campaspe: Campaspe River	10003-05	752.00	29/9/18 - 30/11/18	Baseflow	X	X							
Campaspe: Campaspe River	10003-05	1670.00	1/12/18 - 30/4/19	Baseflow	X	X							X

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Central Murray: Gunbower Creek	10079-01	18921.60	1/7/18 - 30/6/19	Baseflow	X					X			
Central Murray: River Murray Channel	10078-01	24975.00	6/7/18 - 31/7/18	Fresh, overbank	X	X	X				X		X
Central Murray: River Murray Channel	10078-01	15009.40	2/9/18 - 14/9/18	Overbank	X								
Central Murray: Barmah-Millewa Forest	10078-01	38527.00	7/11/18 - 3/1/19	Overbank	X	X	X		X				
Edward Wakool: Colligen-Neimur	10083-01	13943.00	21/8/18 - 30/6/19	Baseflow, fresh	X	X							X
Edward Wakool: Yallakool Wakool System	10083-01	19365.00	21/8/18 - 30/6/19	Baseflow, fresh	X	X							X
Edward Wakool: Tuppal Creek	10083-03	2870.00	17/9/18 - 30/6/19	Baseflow, fresh		X				X			X
Edward Wakool: Pollack Swamp	10083-04	2000.00	8/10/18 - 25/1/19	Wetland		X	X						
Goulburn: Lower Goulburn River	10075-01	113131.00	1/7/18 - 2/8/18	Fresh	X	X			X				
Goulburn: Lower Goulburn River	10075-01	7888.00	3/8/18 - 28/9/18	Baseflow									
Goulburn: Lower Goulburn River	10075-01	60471.00	29/9/18 - 4/11/18	Fresh	X	X			X				
Goulburn: Lower Goulburn River	10075-01	18676.00	16/4/19 - 30/6/19	Baseflow		X			X				
Gwydir: Gwydir Wetlands	10085-01	30000.00	18/7/18 - 7/2/19	Wetland, fresh	X	X	X					X	
Gwydir: Mallowa Wetlands	10085-02	16950.00	20/9/18 - 14/2/19	Wetland, fresh	X	X	X	X	X				
Gwydir: Ballin Boora	10085-04	600.00	12/12/18 - 31/1/19	Wetland	X	X	X	X	X				
Gwydir: Mehi River; Barwon River	10093-01	10600.00	2/5/19 - 30/6/19	Fresh, baseflow	X					X		X	X
Lachlan: Lachlan River	10081-01	10391.00	24/8/18 - 10/11/18	Fresh	X						X		
Lachlan: Lachlan River	10081-01	2032.00	17/10/18 - 3/12/18	Baseflow	X								
Lachlan: Yarrabandai Lagoon	10081-02	412.00	18/3/19 - 29/5/19	Wetland	X	X	X	X				X	
Lachlan: Great Cumbung Swamp	10081-03	5338.00	9/6/19 - 28/6/19	Wetland	X	X				X	X		
Loddon: Loddon River	10001-05	2636.00	8/10/18 - 31/10/18	Fresh	X						X		

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Lower Murray: Wingillie Station	10073-01	59.00	16/11/18 - 28/12/18	Wetland	X	X	X	X					
Lower Murray: Calperum Station (Merreti East Floodplain)	10078-07	331.02	18/4/19 - 21/5/19	Wetland		X	X						
Lower Murray: Calperum Station (Thookle Thookle)	10078-07	273.52	15/4/19 - 8/5/19	Wetland		X	X						
Lower Murray: Calperum Station (Amazon floodplain)	10078-07	174.74	16/5/19 - 3/6/19	Wetland		X	X						
Lower Murray: Calperum Station (Amazon upland woodlands)	10078-07	6.06	8/5/19 - 11/6/19	Wetland		X							
Lower Murray: Calperum Station (Reny Lagoon)	10078-07	68.95	9/5/19 - 3/6/19	Wetland		X	X						
Lower Murray: Banrock Station - Wigley Reach Depression	10086-01	570.00	19/11/18 - 7/5/19	Wetland		X	X	X					
Lower Murray: Renmark Floodplain Wetlands (End Namoi St)	10058-02	59.69	16/8/18 - 30/5/19	Wetland		X	X	X		X			
Lower Murray: Renmark Floodplain Wetlands (Johnson's Waterhole)	10058-02	72.01	20/7/18 - 16/10/18	Wetland		X	X	X		X			
Lower Murray: Renmark Floodplain Wetlands (Jane Eliza Woodlot)	10058-02	38.94	15/8/18 - 23/9/18	Wetland		X	X	X					
Lower Murray: Renmark Floodplain Wetlands (Twentysixth St)	10058-02	45.38	16/8/18 - 30/5/19	Wetland		X	X	X		X			
Lower Murray: Renmark Floodplain Wetlands (End Nelwart St)	10058-02	27.21	17/7/18 - 22/9/18	Wetland		X	X	X		X			
Lower Murray: Teringie South	10078-05	500.00	1/3/19 - 31/3/19	Wetland		X	X	X					
Lower Murray: Cadell Temporary Wetland	10078-06	249.84	23/11/18 - 18/2/19	Wetland		X	X	X	X			X	
Lower Murray: Cadell Ephemeral Wetlands	10078-06	73.49	3/5/19 - 16/5/19	Wetland		X	X	X					
Lower Murray: Clarks mature open black box woodland	10078-06	2.31	26/2/19 - 31/5/19	Wetland		X							
Lower Murray: Clarks Floodplain	10078-06	5.33	7/9/18 - 26/2/19	Wetland		X							

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Lower Murray: Disher Creek Depression	10078-06	23.62	27/11/18 - 29/11/18	Wetland		X							
Lower Murray: Loxton Floodplain lagoons	10078-06	29.62	1/4/19 - 20/5/19	Wetland		X							
Lower Murray: Loxton Floodplain lagoons	10078-06	0.84	1/4/19 - 31/5/19	Wetland		X							
Lower Murray: Greenways Landing	10078-06	40.00	26/10/18 - 7/11/18	Wetland	X	X	X	X	X				
Lower Murray: Pike River	10078-06	40.02	22/11/18 - 4/3/19	Wetland		X		X					
Lower Murray: Plush's Bend	10078-06	75.68	11/10/18 - 19/2/19	Wetland		X							
Lower Murray: Qualco main temporary lagoon	10078-06	502.77	7/9/18 - 3/5/19	Wetland		X	X	X					
Lower Murray: Qualco temporary riparian swale wetlands	10078-06	58.57	7/9/18 - 17/4/19	Wetland		X	X	X					
Lower Murray: Rilli Lagoons	10078-06	2.48	11/9/18 - 26/11/18	Wetland		X							
Lower Murray: Westbrooks red gum & lignum swale	10078-06	2.04	21/1/19 - 31/5/19	Wetland		X							
Lower Murray: Riversleigh Lagoon	10078-06	199.62	7/9/18 - 13/11/18	Wetland		X	X	X					
Lower Murray: Riversleigh Black box woodland and lignum swamp	10078-06	37.21	3/12/18 - 10/1/19	Wetland		X							
Lower Murray: Stanitzkis black box floodplain	10078-06	5.26	21/1/19 - 21/2/19	Wetland		X							
Lower Murray: Milang Snipe Sanctuary	10078-06	13.31	13/11/18 - 15/3/19	Wetland		X	X	X					
Lower Murray: Pike River Inner Mundic Flood-runner	10078-06	48.85	30/4/19 - 6/5/19	Wetland		X							
Lower Murray: Pike River Mundic Wetland	10078-06	38.11	14/5/19 - 21/5/19	Wetland		X	X	X					
Lower Murray: Pike Lagoon Flood-runner	10078-06	31.05	10/5/19 - 15/5/19	Wetland		X	X	X					X
Lower Murray: Berri Evaporation Basin	10078-04	1007.00	8/10/18 - 23/4/19	Wetland	X								

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Lower Murray: Disher Creek	10078-04	54.00	4/3/19 - 26/3/19	Wetland	X								
Lower Murray: Wiela Temporary Wetlands	10078-04	596.00	29/11/18 - 5/2/19	Wetland		X	X	X					
Lower Murray: Bookmark Creek	10078-04	386.00	2/10/18 - 30/6/19	Wetland		X	X	X					
Lower Murray: Gerard Lignum Basin	10078-04	147.00	22/11/18 - 23/4/19	Wetland		X							
Lower Murray: Overland Corner Wetlands	10078-04	1045.00	9/10/18 - 22/4/19	Wetland		X	X	X					
Lower Murray: Wigley Reach	10078-04	413.00	3/12/18 - 27/2/19	Wetland		X		X					
Lower Murray: Maize Island	10078-04	150.00	11/12/18 - 11/2/19	Wetland		X							
Lower Murray: Markaranka Flat	10078-04	1916.00	14/11/18 - 8/2/19	Wetland		X	X						
Lower Murray: Hogwash Bend	10078-04	22.00	19/11/18 - 11/12/18	Wetland		X	X						
Lower Murray: Hogwash Bend	10078-04	523.00	10/11/18 - 8/2/19	Wetland		X	X						
Lower Murray: Molo Flat	10078-04	740.00	5/11/18 - 12/2/19	Wetland		X							
Lower Murray: Nikalapko Wetland	10078-04	1036.00	26/11/18 - 23/2/19	Wetland		X							
Lower Murray: Morgan East	10078-04	200.00	24/10/18 - 11/2/19	Wetland		X	X	X					
Lower Murray: Morgan South Lagoon	10078-04	46.00	7/1/19 - 23/2/19	Wetland		X	X	X					
Lower Murray: Morgan North Lagoon	10078-04	290.00	29/11/18 - 21/2/19	Wetland		X	X	X					
Lower Murray: Whirlpool Corner	10078-04	22.00	10/10/18 - 19/11/18	Wetland		X		X					
Lower Murray: Templeton	10078-04	38.00	10/10/18 - 19/11/18	Wetland		X	X	X					
Lower Murray: Murtho	10078-04	4.00	12/10/18 - 19/11/18	Wetland		X							
Lower Murray: Lock 2	10078-02; 10078-08	0.00	15/8/18 - 5/11/18	Fresh	X	X	X				X		X
Lower Murray: Lock 5	10078-02; 10078-08	0.00	15/8/18 - 5/11/18	Fresh	X	X	X				X		X
Lower Murray: Lock 7	10078-02; 10078-08	0.00	1/9/18 - 31/12/18	Fresh	X	X	X				X		X
Lower Murray: Lock 7	10078-02; 10078-08	0.00	1/1/19 - 31/5/19	Fresh	X	X	X				X		X

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Lower Murray: Lock 8	10078-02; 10078-08	0.00	1/7/18 - 30/6/19	Fresh	X	X	X				X		X
Lower Murray: Lock 9	10078-02; 10078-08	0.00	1/7/18 - 30/6/19	Fresh	X	X	X				X		X
Lower Murray: Lock 15	10078-02; 10078-08	0.00	1/7/18 - 1/9/18	Fresh	X	X	X				X		X
Lower Murray: Lock 15	10078-02; 10078-08	0.00	25/12/18 - 3/3/19	Fresh	X	X	X				X		X
Lower Murray: Lock 15	10078-02; 10078-08	0.00	1/5/2019 - 30/5/19	Fresh	X	X	X				X		X
Murrumbidgee: Yanga National Park	10082-02	10500.00	20/8/18 - 31/1/19	Wetland	X	X	X	X	X	X		X	X
Murrumbidgee: Yanga National Park	10082-03	30000.00	17/9/18 - 25/1/19	Wetland	X	X	X	X	X	X		X	X
Murrumbidgee: Nimmie-Caira	10082-04	1505.00	1/12/18 - 23/5/19	Wetland	X		X	X	X			X	
Murrumbidgee: Mainie Swamp (Junction Wetlands)	10082-05	2000.00	10/10/18 - 25/2/19	Wetland		X						X	
Murrumbidgee: Toogimbie IPA	10082-06	900.00	15/10/18 - 22/3/19	Wetland		X		X				X	
Murrumbidgee: Waldaira Lagoon	10082-07	1700.00	24/10/18 - 15/3/19	Wetland			X	X				X	
Murrumbidgee: Yarradda Lagoon	10082-08	2013.70	16/11/18 - 18/1/19	Wetland		X		X				X	
Murrumbidgee: Gooragool Lagoon	10082-09	82.70	23/1/19 - 24/1/19	Wetland	X			X	X			X	
Murrumbidgee: North Redbank	10082-10	6000.00	17/12/18 - 18/1/19	Wetland	X	X	X	X	X			X	
Murrumbidgee: Campbell’s Swamp McCaughey’s Lagoon and Turkey Flats Swamp	10082-11	1594.00	8/11/18 - 18/2/19	Wetland		X	X	X	X				
Murrumbidgee: Fivebough Swamp	10082-12	794.00	25/10/18 - 22/3/19	Wetland			X	X	X				
Murrumbidgee: Sandy Creek	10082-13	400.00	29/9/18 - 12/1/19	Wetland	X	X	X	X	X			X	
Murrumbidgee: Tuckerbil Swamp	10082-14	609.60	24/10/18 - 9/5/19	Wetland			X	X	X				
Murrumbidgee: Darlington Lagoon	10082-15	396.90	20/12/18 - 1/5/19	Wetland		X	X						
Murrumbidgee: Lower Murrumbidgee River	10082-16	3300.00	30/1/19 - 9/4/19	Fresh	X							X	X

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Murrumbidgee: North Redbank	10082-10	500.00	18/9/18 - 19/11/18	Wetland	X	X	X	X	X			X	
Macquarie River: Mid-Macquarie River and Macquarie Marshes	10084-01	45052.00	25/8/18 - 11/12/18	Wetland	X	X	X	X	X				
Macquarie River: Lower Nyngan Weir Pool (Bogan River)	10084-02	150.00	19/3/19 - 30/6/19	Baseflow	X								X
Macquarie River: Methalibah Reservce - Ewenmar Creek	10084-03	520.00	30/4/19 - 1/6/19	Baseflow	X								X
Namoi: Lower Namoi River	10087	5500.00	9/11/18 - 15/12/18	Fresh	X					X		X	X
Ovens: Ovens River	10004-05	123.00	30/3/19 - 31/3/19	Baseflow	X					X			
Warrego: Lower Warrego River and fringing wetlands.	0011-57	4480.00	3/4/19 - 14/4/19	Baseflow	X							X	
Warrego: Lower Warrego River and fringing wetlands.	0011-57	253.00	23/4/19 - 26/4/19	Baseflow	X							X	
Warrego: Lower Warrego River and fringing wetlands.	0011-57	2899.00	2/5/19 - 10/5/19	Baseflow	X							X	
Warrego: Toorale Western Floodplain	00152-11	8106.00	7/5/19 - 20/5/19	Baseflow	X					X	X		
Wimmera: Wimmera River	10007-02	186.00	7/11/18 - 12/11/18	Fresh	X	X			X				X
Wimmera: Wimmera River	10007-02	778.36	25/9/18 - 2/11/18	Baseflow, fresh	X	X			X	X			X
Wimmera: Wimmera River	10007-02	747.64	13/11/18 - 21/12/18	Baseflow, fresh	X	X			X	X			X
Wimmera: Wimmera River	10007-02	4126.00	8/1/19 - 28/6/19	Baseflow, fresh	X	X			X				X

Appendix B: Species and communities that potentially benefitted from Commonwealth environmental water 2014–19

Table B1. ANAE aquatic ecosystem types likely to have been influenced by Commonwealth environmental water 2014–19 (Brooks 2020).

Australian National Aquatic Ecosystem (ANAE) wetland type	Total area in Basin (ha)	Area on Managed Floodplain (ha)	Area receiving Commonwealth environmental water (ha)				
			Y1 '14-'15	Y2 '15-'16	Y3 '16-'17	Y4 '17-'18	Y5 '18-'19
Lt1.1: Temporary lake	459 359	116 742	2593	4505	2485	3730	1291
Lp1.1: Permanent lake	127 388	67 334	1440	4755	6840	15292	3389
Lst1.1: Temporary saline lake	27 897	1349	0	0	0	307	0
Lsp1.1: Permanent saline lake	9419	6039	0	0	0	0	0
Lt1.2: Temporary lake with aquatic bed	9052	8177	0	0	0	0	0
Lst1.2: Temporary saline lake with aquatic bed	2238	180	0	0	0	0	0
Lp1.2: Permanent lake with aquatic bed	2067	196	0	0	0	0	0
Lsp1.2: Permanent saline lake with aquatic bed	181	0	0	0	0	0	0
Pt1.8.2: Temporary shrub swamp	234 412	96 598	1552	2567	2122	2218	1507
Pt1.6.2: Temporary woodland swamp	216 625	151 170	99	417	186	494	579
Pt2.2.2: Temporary sedge/grass/forb marsh	139 937	50 902	17 018	9773	16 917	15 776	15 476
Pt3.1.2: Clay pan	130 927	43 524	3048	3673	1698	1654	1143
Pt2.3.2: Freshwater meadow	125 165	38 747	18 960	1401	20 508	3620	932
Pp4.2: Permanent wetland	77 314	41 111	20 267	21 044	20 095	23 018	21 885
Pt1.1.2: Temporary river red gum swamp	74 721	56 254	9940	28 052	7517	34 910	33 432
Pt2.1.2: Temporary tall emergent marsh	70 837	52 720	3100	3509	3116	4154	4030
Pt1.2.2: Temporary black box swamp	60 272	20 173	1069	1260	228	239	294
Pt1.7.2: Temporary lignum swamp	49 962	18 681	522	33	12 427	446	8
Pst2.2: Temporary salt marsh	40 335	11 575	19	8	1	4	8
Pt4.2: Temporary wetland	22 888	3111	0	578	0	602	586
Pt4.1: Floodplain or riparian wetland	11 214	5944	1118	2469	1008	2495	2082
Pt1.3.2: Temporary coolibah swamp	8271	5146	2	0	0	0	0
Pp2.1.2: Permanent tall emergent marsh	8005	7496	3449	4156	0	3451	4156
Pst1.1: Temporary saline swamp	7157	9	94	0	0	0	316
Pst4: Temporary saline wetland	6180	50	0	0	0	0	0
Pp3: Peat bog or fen marsh	4425	173	0	0	0	0	0
Pt1: Temporary swamp	3767	2822	280	690	132	576	675
Pp2.2.2: Permanent sedge/grass/forb marsh	3590	176	15	15	15	21	17
Pst3.2: Salt pan or salt flat	3249	253	0	0	0	0	0
Psp4: Permanent saline wetland	2093	1222	231	811	172	629	639
Pu1: Unspecified wetland	1763	130	0	0	0	95	0
Pp2.3.2: Permanent grass marsh	1507	248	23	25	96	85	25
Pp2.4.2: Permanent forb marsh	740	146	10	0	30	22	7
Pt1.5.2: Temporary paperbark swamp	412	0	0	0	0	0	0
Psp2.1: Permanent salt marsh	246	0	0	0	0	0	0
Pps5: Permanent spring	130	3	0	0	0	0	0
Psp1.1: Saline paperbark swamp	31	0	0	0	0	0	0
Pp1.1.2: Permanent paperbark swamp	1	1	0	0	0	0	0
F1.10: Coolibah woodland and forest riparian zone or floodplain	1 215 726	294 586	3388	633	1007	1335	2300
F3.2: Sedge/forb/grassland riparian zone or floodplain	833 102	296 420	0	0	32	0	0
F1.8: Black box woodland riparian zone or floodplain	779 639	116 222	2273	5322	844	1830	432

Australian National Aquatic Ecosystem (ANAE) wetland type	Total area in Basin (ha)	Area on Managed Floodplain (ha)	Area receiving Commonwealth environmental water (ha)				
			Y1 '14-'15	Y2 '15-'16	Y3 '16-'17	Y4 '17-'18	Y5 '18-'19
F1.2: River red gum forest riparian zone or floodplain	639 022	294 854	24 589	26 210	6 525	25 708	19 092
F2.4: Shrubland riparian zone or floodplain	408 019	113 257	1115	5973	2554	473	485
F1.4: River red gum woodland riparian zone or floodplain	325 221	134 242	3509	1358	1237	4887	1247
F1.12: Woodland riparian zone or floodplain	318 645	84 203	14	10	136	93	57
F4: Unspecified riparian zone or floodplain	201 086	4613	2	10	9	36	3
F2.2: Lignum shrubland riparian zone or floodplain	143 880	29 764	5430	2154	1164	1474	1538
F1.6: Black box forest riparian zone or floodplain	131 442	30 711	489	1299	118	265	256
F1.11: River cooba woodland riparian zone or floodplain	11 541	3320	1135	236	779	840	1137
F1.13: Paperbark riparian zone or floodplain	17	0	0	0	0	0	0

Table B2. *Fish species that potentially benefitted from Commonwealth environmental water in 2014–19 (extracted from King et al 2020, augmented with species recorded in monitoring outside LTIM).*

Common name	Species name	Listing
Australian smelt	*Retropinna semoni*	
Bony bream	*Nematalosa erebi*	
Carp gudgeon	*Hypseleotris spp.*	
Eel-tailed catfish	*Tandanus tandanus*	Endangered (NSW, Vic)
Flathead gudgeon	*Phylipnodon grandiceps*	
Golden perch	*Macquaria ambigua*	
Hyrtl's catfish	*Neosilurus hyrtlii*	
Murray cod	*Maccullochella peelii*	Vulnerable (EPBC)
Murray–Darling rainbowfish	*Melanotaenia fluviatilis*	Vulnerable (Vic)
Murray hardyhead	*Craterocephalus fluviatilis*	Endangered (EPBC)
Olive perchlet	*Ambassis agassizii*	Endangered population (NSW)
Purple-spotted gudgeon	*Mogurnda adspersa*	Endangered (NSW)
Silver perch	*Bidyanus bidyanus*	Endangered (EPBC)
Spangled perch	*Leiopotherapon unicolor*	
Trout cod	*Maccullochella macquariensis*	Endangered (EPBC)
Unspecked hardyhead	*Craterocephalus stercusmuscarum*	

Note: EPBC = listed under the *Environment Protection and Biodiversity Conservation Act 1999*; NSW = New South Wales, Vic = Victoria.

Table B3. *Native plant species that potentially benefitted from Commonwealth environmental water in 2014–19 (Capon & Campbell 2016; Capon & Mynott 2018; Capon & Campbell 2019).*

Grasses	**Subshrubs/shrubs**	**Sedges/rushes**
Anthosachne kingiana	*Abutilon sp.*	*Carex bichenoviana*
Aristida leptopoda	*Einadia nutans*	*Carex tereticaulis*
Echinochloa inundata.	*Eremophila debilis*	*Cyperus difformis*
Eragrostis australasica	*Lycium australe*	*Cyperus exaltatus*
Eragrostis elongate	*Maireana aphylla*	*Eleocharis pallens*
Hemarthria uncinata	*Sida corrugate*	*Isolepis spp.*
Leptochloa spp.		*Juncus amabilis*
Paspalidium constrictum		*Juncus flavidus*
Paspalum distichum		*Juncus usitatus*
Poa labillardierei		
Themeda triandra		
Phragmites australis		
Rytidosperma		
Forbs	**Forbs**	**Mistletoes**
Ammannia multiflora	*Hypercium gramineum*	*Dendrophthoe* spp.
Azolla filiculoides	*Lemna*	
Brachyscome basaltica	*Lythrum*	
Brachyscome papillosa	*Nymphoides crenata*	
Callitriche	*Mimulus gracilis*	
Calotis cuneate	*Myriophyllum caput-medusae*	
Calotis cuneifolia	*Oxalis exilis*	
Calotis hispidula	*Oxalis perennans*	
Calotis scapigera	*Persicaria hydropiper*	
Chrysocephalum apiculatum	*Plantago cunninghamii*	
Commelina cyanea	*Polygonum plebium*	**Trees**
Craspedia variabilis	*Portulaca oleracea*	*Myoporum acuminatum*
Crassula helmsii	*Potamogeton crispus*	*Acacia dealbata*
Damasonium minus	*Potamogeton octandrus*	*Acacia stenophylla*
Daucus glochidiatus	*Potamogeton tricarinatus*	
Dichondra repens	*Sagittaria montevidensis*	
Euchiton involucratus	*Ranunculus undosus*	
Gnaphalium luteoalbum	*Senecio quadridentatus*	
Gnaphalium sphaericum	*Spirodela polyrhiza*	
Goodenia spp.	*Tetragonia tetragonoides*	
Gratiola pedunculata	*Triglochin procera*	
Haloragis glauca	*Utricularia gibba*	
	Vallisneria gigantea	
	Verbena gaudichaudii	
	Wahlenbergia gracilis	
	Xerochrysum	

Table B4. Frog *species that potentially benefitted from Commonwealth environmental water in 2014–19.*

Common name	Species name	Listing
Barking marsh frog	*Limnodynastes fletcheri*	
Broad-palmed frog	*Litoria latopalmata*	
Crucifix frog	*Notaden bennetti*	
Desert froglet	*Crinia deserticola*	
Desert tree frog	*Litoria rubella*	
Eastern banjo frog	*Limnodynastes dumerilii*	
Green tree frog	*Litoria caerulea*	
Inland banjo frog	*Limnodynastes interioris*	
Ornate burrowing frog	*Platyplectrum ornatum*	
Painted burrowing frog	*Neobatrachus sudelli*	
Peron's tree frog	*Litoria peronii*	
Plains froglet	*Crinia parinsignifera*	
Salmon-striped frog	*Limnodynastes salmini*	
Southern bell frog	*Litoria raniformis*	Vulnerable (EPBC)
Spotted marsh frog	*Limnodynastes tasmaniensis*	
Striped burrowing frog	*Litoria alboguttata*	
Sudell's frog	*Neobatrachus sudallae*	
Water-holding frog	*Litoria platycephala*	
Warty water-holding frog	*Litoria verrucosa*	
Wrinkled toadlet	*Uperoleia rugosa*	

Note: EPBC = listed under the *Environment Protection and Biodiversity Conservation Act 1999*.

Table B2. Turtle *species that potentially benefitted from Commonwealth environmental water in 2014–19.*

Common name	Species name	Listing
Eastern long-necked turtle	*Chelodina longicollis*	
Broad shelled turtle	*Chelodina expansa*	
Macquarie river turtle	*Emydura macquarii*	

Table B3. *Bush bird species that potentially benefitted from Commonwealth environmental water at Hattah Lakes (extracted from Loyn & Dutson 2016, showing species whose abundance increased during or after environmental watering 2014–15 and those that continued to use the previously flooded site in 2015–16).*

Common name	Species name	2014–15	2015–16
Apostlebird	*Struthidea cinerea*	X	X
Australian raven	*Corvus coronoides*	X	X
Australian ringneck	*Barnardius zonarius*	X	X
Black-faced cuckoo-shrike	*Coracina novaehollandiae*	X	X
Blue bonnet	*Northiella haematogaster*	X	X
Blue-faced honeyeater	*Entomyzon cyanotis*	X	
Brown falcon	*Falco berigora*	X	X
Brown treecreeper	*Climacteris picumnus*	X	X
Chestnut-rumped thornbill	*Acanthiza uropygialis*	X	X
Common bronzewing	*Phaps chalcoptera*	X	X
Eastern rosella	*Platycercus eximius*	X	X

Common name	Species name	2014–15	2015–16
Galah	*Eolophus roseicapilla*	X	X
Grey fantail	*Rhipidura albiscapa*	X	X
Grey shrike-thrush	*Colluricincla harmonica*	X	X
Laughing kookaburra	*Dacelo novaeguineae*	X	X
Little corella	*Cacatua sanguinea*	X	X
Little eagle	*Hieraaetus morphnoides*	X	X
Little friarbird	*Philemon citreogularis*	X	X
Magpie-lark	*Grallina cyanoleuca*	X	X
Major Mitchell's cockatoo	*Lophochroa leadbeateri*	X	X
Noisy miner	*Manorina melanocephala*	X	X
Rainbow bee-eater	*Merops ornatus*	X	X
Red-capped robin	*Petroica goodenovii*	X	X
Regent parrot (vulnerable; EPBC)	*Polytelis anthopeplus*	X	X
Restless flycatcher	*Myiagra inquieta*	X	X
Rufous whistler	*Pachycephala rufiventris*	X	X
Sacred kingfisher	*Todiramphus sanctus*	X	X
Singing honeyeater	*Lichenostomus virescens*	X	X
Spiny-cheeked honeyeater	*Acanthagenys rufogularis*	X	X
Spotted pardalote	*Pardalotus punctatus*	X	X
Striated pardalote	*Pardalotus striatus*	X	X
Striped honeyeater	*Plectorhyncha lanceolata*	X	X
Tree martin	*Petrochelidon nigricans*	X	X
Varied sittella	*Daphoenositta chrysoptera*	X	X
Weebill	*Smicrornis brevirostris*	X	X
Welcome swallow	*Hirundo neoxena*	X	
Whistling kite	*Haliastur sphenurus*	X	X
White-backed swallow	*Cheramoeca leucosterna*	X	X
White-bellied sea-eagle (FFG listed)	*Haliaeetus leucogaster*	X	X
White-browed woodswallow	*Artamus superciliosus*	X	X
White-plumed honeyeater	*Lichenostomus penicillatus*	X	X
White-winged chough	*Corcorax melanorhamphos*	X	X
White-winged triller	*Lalage tricolor*	X	X
Willie wagtail	*Rhipidura leucophrys*	X	
Yellow rosella	*Platycercus elegans flaveolus*	X	X
Yellow thornbill	*Acanthiza nana*	X	X
Yellow-rumped thornbill	*Acanthiza chrysorrhoa*	X	X
Yellow-throated miner	*Manorina flavigula*	X	

Note: EPBC = listed under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwth); listed under the FFG = *Flora and Fauna Guarantee Act 1988* (Vic).

Table B4. *Wetland dependent bird species that potentially benefitted from Commonwealth environmental water in 2014–19.*

Common name	Species name	Listing
Australasian bittern	*Botaurus poiciloptilus*	Endangered (EPBC)
Australasian darter	*Anhinga novaehollandiae*	
Australasian grebe	*Tachybaptus novaehollandiae*	
Australasian shoveler	*Anas rhynchotis*	Vulnerable (Vic)
Australian fairy tern	*Sternula nereis nereis*	Endangered (EPBC)
Australian gull-billed tern	*Gelochelidon nilotica*	
Australian little bittern	*Ixobrychus dubius*	Endangered (Vic, SA)
Australian painted snipe	*Rostratula australis*	Critically endangered (EPBC)
Australian pelican	*Pelecanus conspicillatus*	
Australian pied oystercatcher	*Haematopus longirostris*	
Australian pratincole	*Stiltia isabella*	
Australian reed warbler	*Acrocephalus australis*	
Australian shelduck	*Tadorna tadornoides*	
Australian spotted crake	*Porzana fluminea*	
Australian white ibis	*Threskiornis molucca*	
Australian wood duck	*Chenonetta jubata*	
Ballion's crake	*Porzana pusilla*	Vulnerable (Vic)
Banded lapwing	*Vanellus tricolor*	Vulnerable (SA)
Banded stilt	*Cladorhynchus leucocephalus*	
Bar-tailed godwit	*Limosa lapponica*	Vulnerable (EPBC), JAMBA, CAMBA, ROKAMBA
Black swan	*Cygnus atratus*	
Black-faced cormorant	*Phalacrocorax fuscescens*	
Black-fronted dotterel	*Elseyornis melanops*	
Black-necked stork	*Ephippiorhynchus asiaticus*	Endangered (NSW)
Black-tailed godwit	*Limosa limosa*	JAMBA, CAMBA, ROKAMBA
Black-tailed native-hen	*Tribonyx ventralis*	
Black-winged stilt	*Himantopus himantopus*	
Blue-billed duck	*Oxyura australis*	Endangered (Vic), Vulnerable (NSW)
Brolga	*Grus rubicunda*	Vulnerable (NSW, SA, VIC)
Buff-banded rail	*Gallirallus philippensis*	
Cape barren goose	*Cereopsis novaehollandiae*	
Caspian tern	*Hydroprogne caspia*	
Cattle egret	*Ardea ibis*	
Chestnut teal	*Anas castanea*	
Comb-crested Jacana	*Irediparra gallinacea*	
Common greenshank	*Tringa nebularia*	JAMBA, CAMBA, ROKAMBA
Common sandpiper	*Actitis hypoleucos*	JAMBA, CAMBA, ROKAMBA
Common tern	*Sterna hirundo*	
Crested tern	*Thalasseus bergii*	
Curlew sandpiper	*Calidris ferruginea*	Critically endangered (EPBC), JAMBA, CAMBA, ROKAMBA
Dusky moorhen	*Gallinula tenebrosa*	
Eastern curlew	*Numenius madagascariensis*	Critically endangered (EPBC), JAMBA, CAMBA, ROKAMBA
Eastern great egret	*Ardea modesta*	Vulnerable (VIC)
Eurasian coot	*Fulica atra*	
Freckled duck	*Stictonetta naevosa*	Vulnerable (SA, NSW)

Common name	Species name	Listing
Glossy ibis	*Plegadis falcinellus*	
Golden-headed cisticola	*Cisticola exilis*	
Great cormorant	*Phalacrocorax carbo*	
Great crested grebe	*Podiceps cristatus*	
Grey plover	*Pluvialis squatarola*	JAMBA, CAMBA, ROKAMBA
Grey teal	*Anas gracilis*	
Gull-billed tern	*Gelochelidon nilotica*	
Hardhead	*Aythya australis*	Vulnerable (VIC)
Hoary-headed Grebe	*Poliocephalus poliocephalus*	
Hooded plover	*Thinornis rubricollis*	Vulnerable (EPBC)
Intermediate egret	*Ardea intermedia*	Endangered (VIC)
Latham's snipe	*Gallinago hardwickii*	CAMBA, ROKAMBA
Little black cormorant	*Phalacrocorax sulcirostris*	
Little egret	*Egretta garzetta*	Endangered (VIC)
Little grassbird	*Megalurus gramineus*	
Little pied cormorant	*Microcarbo melanoleucos*	
Little tern	*Sternula albifrons sinensis*	Endangered (SA), Vulnerable (NSW, Vic)
Magpie goose	*Anseranas semipalmata*	Vulnerable (NSW)
Marsh sandpiper	*Tringa stagnatilis*	JAMBA, CAMBA, ROKAMBA
Masked lapwing	*Vanellus miles*	
Musk duck	*Biziura lobata*	Vulnerable (VIC)
Nankeen night-heron	*Nycticorax caledonicus*	
Oriental plover	*Charadrius veredus*	JAMBA, CAMBA, ROKAMBA
Pacific black duck	*Anas superciliosa*	
Pacific golden plover	*Pluvialis fulva*	JAMBA, CAMBA, ROKAMBA
Pacific gull	*Larus pacificus*	Endangered (NSW)
Pied cormorant	*Phalacrocorax varius*	
Pink-eared duck	*Malacorhynchus membranaceus*	
Plumed whistling-duck	*Dendrocygna eytoni*	
Purple swamphen	*Porphyrio porphyrio*	
Red knot[2]	*Calidris canutus*	
Red-backed kingfisher	*Todiramphus pyrrhopygius*	
Red-capped plover	*Charadrius ruficapillus*	
Red-kneed dotterel	*Erythrogonys cinctus*	
Red-necked avocet	*Recurvirostra novaehollandiae*	
Red-necked stint	*Calidris ruficollis*	JAMBA, CAMBA, ROKAMBA
Royal spoonbill	*Platalea regia*	
Ruddy turnstone	*Arenaria interpres*	JAMBA, CAMBA, ROKAMBA
Ruff	*Calidris pugnax*	JAMBA, CAMBA, ROKAMBA
Sacred kingfisher	*Todiramphus sanctus*	
Sanderling	*Calidris alba*	JAMBA, CAMBA, ROKAMBA
Sharp-tailed sandpiper	*Calidris acuminata*	JAMBA, CAMBA, ROKAMBA
Silver gull	*Chroicocephalus novaehollandiae*	
Sooty oystercatcher	*Haematopus fuliginosus*	
Spotless crake	*Porzana tabuensis*	
Straw-necked Ibis	*Threskiornis spinicollis*	

Common name	Species name	Listing
Swamp harrier	*Circus approximans*	
Tawny grassbird	*Cincloramphus timoriensis*	
Wandering whistling-duck	*Dendrocygna arcuata*	
Whimbrel	*Numenius phaeopus*	JAMBA, CAMBA, ROKAMBA
Whiskered tern	*Chlidonias hybrida*	
White-bellied sea eagle	*Haliaeetus leucogaster*	Endangered (SA) Vulnerable (Vic)
White-faced heron	*Egretta novaehollandiae*	
White-necked heron	*Ardea pacifica*	
Wood sandpiper	*Tringa glareola*	JAMBA, CAMBA, ROKAMBA
Yellow-billed spoonbill	*Platalea flavipes*	

JAMBA (Japan–Australia Migratory Bird Agreement); CAMBA (China–Australia Migratory Bird Agreement); ROKAMBA (Republic of Korea– Australia Migratory Bird Agreement).

Table B5. *Waterbird functional groups used in the LTIM project* (Hale *et al.* 2014).

Common name	Description
Piscivores	Waterbirds with a diet mainly of fish includes grebes, cormorants and terns
Dabbling ducks	Dabbling and filter-feeding ducks, shallow water feeders
Grazing ducks	Grazing ducks and geese
Diving ducks	Waterfowl that feed by diving beneath the surface, includes black swans
Crakes and rails	Members of the family Rallidae, shoreline foragers
Large wading birds	Storks, ibis, spoonbills; shallow water foragers
Australian shorebirds	Australian breeding Charadiiform shorebirds
Migratory shorebirds	International migratory Charadiiform shorebirds that breed outside Australia
Raptors	Wetland dependent birds of prey (white-bellied sea eagle, osprey, swamp harrier)
Other	Other wetland dependent bird species such as reed inhabiting passerines

Appendix C: Water, wetland types and biodiversity - workflow

Waterbird survey data

1. Waterbird data (species, abundance, date of survey, location) were extracted for Ramsar sites in the Basin from the following sources:
    a. MDBA Aerial waterbird counts (Access database https://data.gov.au/dataset/ds-dga-89e008fb-f11c-4acb-8bcb-a05cddcb52b8/details).
    b. NSW ground counts from Bionet Atlas (http://www.bionet.nsw.gov.au/)
    c. Victorian ground counts from the Victorian Biodiversity Atlas (https://vba.dse.vic.gov.au/vba/index.jsp)
    d. Ground counts from LTIM MDMS.
2. Data were consolidated into an excel spreadsheet and edited to ensure that common and species names were consistent across all records. Obvious errors in location data were corrected where possible (e.g. where latitude and longitude were inverted).
3. After several trials of matching waterbird data to ANAE type and WIT outputs, issues with duplications in records and difficulties in matching the scale of waterbird surveys with the scale of WIT outputs, waterbird data was limited to MDBA Aerial surveys only.
4. Duplicate counts were filtered to extract the maximum count of reach species from each survey.
5. Where waterbird survey data was collected at a finer scale that WIT outputs, data were summed to provide a total abundance per species for each survey in each WIT polygon location.
6. For several Ramsar sites, the scale of attribution of waterbird data was ill suited to the analysis. For example, aerial waterbird counts at the Macquarie Marshes are geo-referenced to a single point in the centre of the system (outside an ANAE mapped wetland) and could not be attributed to the Ramsar site boundary polygons of the WIT. All records attributed to a location > 6000 hectares were removed from the analysis.
7. Remaining waterbird records were assigned to a waterbird foraging groups (McGuinness in prep) and ecohydrological group (University of NSW) using the VLOOKUP function of Excel.
8. The output was an Excel spreadsheet that had fields for: species name, common name, survey date, maximum abundance, Ramsar site, location, latitude, longitude, waterbird functional groups.

Wetland inundation data

1. Geosciences Australia provided WIT outputs for Ramsar polygon boundaries aligned to the national "Ramsar Wetlands of Australia" boundary mapping. WIT outputs for additional boundary polygons were sourced for the Macquarie Marshes, Gwydir Wetlands and Barmah-Millewa Forests to improve alignment of the scale of WIT inundation mapping with the scale at which the aerial waterbird data is collected. For the Macquarie Marshes and Gwydir Wetlands the Ramsar boundary represents only a very small proportion (<10%) of the wetland complex over which the aerial waterbird data was collected. Each output is a hydrological sequence from 1987 to 2019 with fractional cover and water observations at intervals that vary depending on the frequency of cloud-free observations for the area of interest (typically monthly but varying from 1 to 40 observations per year).
2. The WIT hydrographs for each Ramsar boundary were consolidated into a single data set and observations were assigned to annual quartile seasons (Q1: summer, Q2: autumn, Q3: winter, Q4: spring)
3. Inundation at each sample date was measured by adding together the WIT values for percent cover of water and wet vegetation (water+wet). This output is essentially applying a correction to inundation mapping by Water Observations from Space (WOFS) to add in the additional area of water underlying wetland vegetation that WOFS misses.
4. Data were initially summarised using the maximum inundation per season for each Ramsar polygon to allow comparison among sites where sample dates varied. This method, however, proved

problematic as there was often a large variation in inundation extent within a season. The final data alignment was to match the waterbird sampling survey date with the closest available WIT tile.

Combining Data

1. Bird observations were loaded into GIS and attributed with the wetland identifier and ANAE ecosystem type of the closest wetland within a limit of 1km. This captures bird observations within wetlands and also allows for imprecise location data (e.g. where data points record the GPS location of the observer rather than the precise location of the birds in the wetland).
2. ANAE wetland classes were consolidated into higher-order habitat classes to simplify alignment to the waterbird groupings.
    - Treed Floodplains
        - F1.10: Coolibah woodland and forest riparian zone or floodplain
        - F1.11: River cooba woodland riparian zone or floodplain
        - F1.12: Woodland riparian zone or floodplain
        - F1.2: River red gum forest riparian zone or floodplain
        - F1.4: River red gum woodland riparian zone or floodplain
        - F1.6: Black box forest riparian zone or floodplain
        - F1.8: Black box woodland riparian zone or floodplain
    - Shrub-lands
        - F2.2: Lignum shrubland riparian zone or floodplain
        - F2.4: Shrubland riparian zone or floodplain
        - Pt1.7.2: Temporary lignum swamp
        - Pt1.8.2: Temporary shrub swamp
    - Lake
        - Lp1.1: Permanent lake
        - Lt1.1: Temporary lake
    - Marsh
        - Pp2.1.2: Permanent tall emergent marsh
        - Pp4.2: Permanent wetland
        - Psp4: Permanent saline wetland
        - Pt2.1.2: Temporary tall emergent marsh
        - Pt2.2.2: Temporary sedge/grass/forb marsh
        - Pt2.3.2: Freshwater meadow
    - Swamp
        - Pt1.1.2: Temporary river red gum swamp
        - Pt1.2.2: Temporary black box swamp
        - Pt1.6.2: Temporary woodland swamp
3. Waterbird counts were then joined to the WIT hydrology outputs using the wetland identifier and matching dates of bird observation to seasons in the hydrograph.
4. Species richness and total abundance for each waterbird species and functional group was calculated from the multiple observations recorded in each wetland, season and year.

Limitations

The analyses presented here represent a pilot study of using data from different sources to explore the relationships between inundation, environmental water and biodiversity. The results need to be considered in light of the limitations and considered preliminary only:

- Aerial waterbird survey data does not represent all waterbird groups equally. In particular, small shorebirds (Australian resident and international migrants) and cryptic species such as crakes and rails are poorly represented.
- The scale at which waterbird surveys are conducted and attributed often did not match the scale at which WIT outputs were provided or ANAE types are mapped. Three broad scenarios were encountered:

- Waterbird data at finer resolution than asset/hydrology mapping. For example, in Barmah Forest aerial waterbird surveys are assigned at a local scale to smaller areas within the Ramsar site (e.g. Barmah Lake, Boals Deadwood). The WIT, however, is calculated over the entire 29 000 hectare Ramsar site.
  - Waterbird data at coarser resolution than asset/hydrology mapping. For example, in the Macquarie Marshes all aerial waterbird data are assigned to just three locations that represent coarse floodplain mapping with areas of 10 000 to 85 000 ha (most of the DIWA extent, refer Figure 27). This scale represents more than 5000 ANAE wetlands with 20 distinct types. Macquarie Marshes was excluded from further analysis because it was not possible to relate the bird counts to WIT hydrology or ANAE ecosystem type.
  - Good alignment of waterbird data and asset/hydrology mapping. At some locations (e.g. Hattah Lakes, Kerang Wetlands) the Ramsar wetlands, WIT outputs and waterbird data are all at recorded at the same wetland asset scale.
- The WIT outputs are missing for a portion of the record (usually between 2011 to 2012) due to Landsat 7's failed scan line corrector (Dunn *et al.* 2019).
- Waterbird data have been assigned to foraging groups for analysis. It is unlikely, however, that all waterbirds were foraging at the time that surveys were collected. Birds may have been roosting, loafing, moving between habitats or nesting, all of which represent different habitat requirements with respect to inundation, and wetland type.

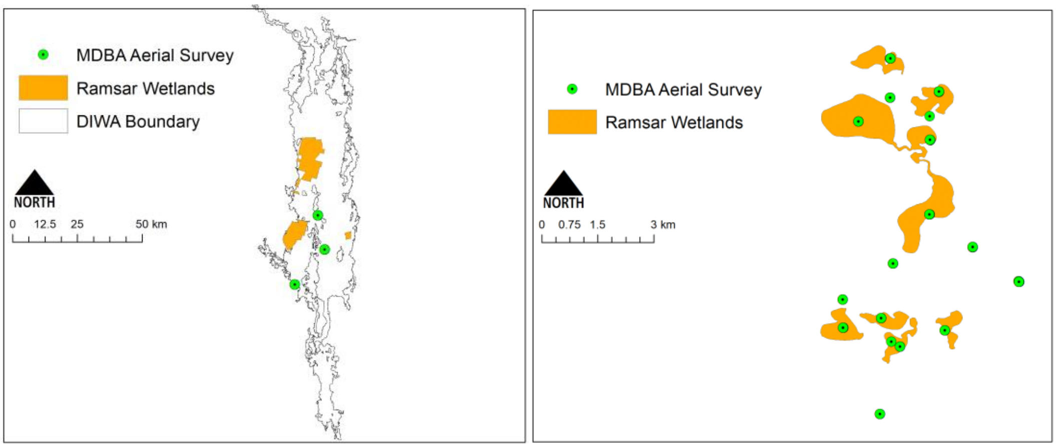

Figure 27. Differing alignment of MDBA aerial waterbird survey points to Ramsar wetlands. In the Macquarie Marshes (left), survey locations are not within the Ramsar boundary and each survey point is attributed to areas between 10000 and 85000 ha representing most of the DIWA area (128,000 ha). At Hattah Lakes (right) bird data were associated with individual lakes for which WIT hydrology data was available.

Lessons learned from using Geosciences Australia WIT data.

Selecting the appropriate scale

Currently the WIT hydrological sequence is produced by Geosciences Australia for specified polygon areas (e.g. wetland or asset boundaries). We found the choice for the scale of WIT mapping needs to align with the questions being asked *and* the scales other complementary data represents.

After finding the mismatch between the scale of the MDBA aerial waterbird data and Ramsar mapping at the Macquarie marshes we requested WIT output for the entire Macquarie Marshes DIWA polygon. This larger landscape scale aligned with the resolution of the waterbird data; however, the WIT output includes the cover of the large expanses of agriculture land around the watercourses and wetlands. The mapped ANAE wetlands (lacustrine+palustrine) represent just 18 % of the DIWA polygon area. This dramatically reduced the sensitivity of detecting change. For example, 100 % inundation of ANAE wetland polygons would represent 18% cover as recorded by the WIT. In practice, during the period of LTIM the WIT showed the maximum inundation in the DIWA polygon to be 50 % during 3 days of extensive natural flooding in October 2016 but outside of that event the maximum inundation was just 4 %. For our question to relate waterbird density to wetland inundation by Commonwealth environmental water the DIWA polygon is too large.

We also found the inverse problem of having WIT mapping at spatial scales too small for the question of interest was an issue. We started our investigation with the intention of using the WIT at the scale of the ANAE wetland polygons. Geosciences Australia have processed all 421 000 ANAE wetland polygons through the WIT. The output is a separate hydrological sequence for each ANAE wetland with differing dates for observations of water and vegetation cover depending on satellite positioning and cloud cover. This presents the challenge of how best to integrate WIT data for larger spatial units that may be comprise of many ANAE ecosystem polygons. For example, the Macquarie Marshes DIWA site is mapped by 5374 ANAE features, the Barmah Ramsar site is mapped by 400 ANAE polygons. We present three possible approaches to help inform future efforts:

1. Use the WIT output to interpolate daily cover values for WIT parameter for each ANAE polygon (i.e. fill in the gaps between observations). The cover data could then be aggregated to represent a larger area of interest on any date. An advantage of this approach is that it can be achieved using the pre-processed WIT ANAE data without needing to reprocess the satellite imagery.
2. Represent the assets by larger polygons to begin with (our attempted solution). The choice of boundary is critical. Our choice of the DIWA polygon to represent the Macquarie Marshes was not successful for reasons stated above. It is likely that we could have achieved a better result by aggregating (dissolving) the ANAE polygons into larger subunits to provide a boundary map for the larger scale asset without including the surrounding terrestrial landscape. We chose not to pursue this further given limitations of the waterbird data at this site.
3. Develop Basin (or National) raster products that represent the WIT wet-vegetation cover parameter on a per-pixel basis in a similar manner to how WOFS is currently managed. Essentially the outcomes would complement or add to WOFS to include the water underlying vegetation. The advantage of this data model is that it allows the user to choose the relevant temporal resolution (seasonal, annual or summary data for the period of record) and clip the data to any boundary of interest.

5.1.1 Missing the peak

The WIT provides a powerful tool for capturing the long term variation in water cover but the outputs need to used cautiously when interpreting specific events. The WIT is limited to clear observations of the earth surface and therefore does not map peak inundation that occurs on cloudy days (Figure 28, Figure 29). The underestimation of peak inundation will be greatest at “flashy” sites were inundation recedes rapidly (before the next clear satellite view). Delivery of Commonwealth environmental water from storages may be less impacted than natural flood events with associated rain clouds.

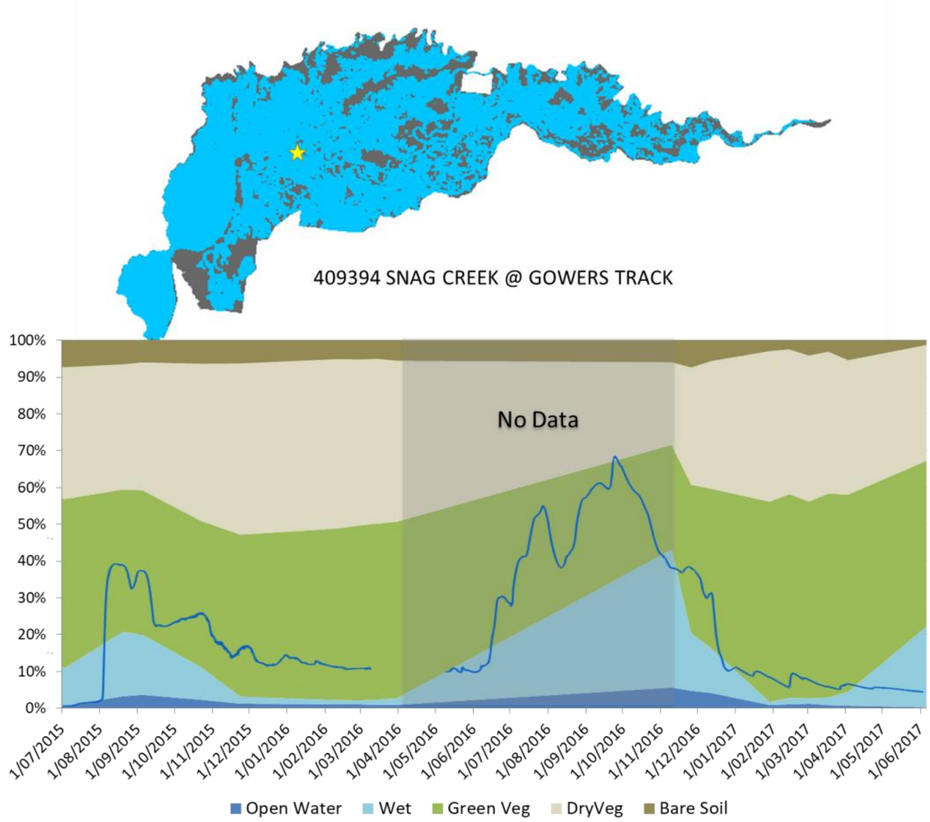

Figure 28. WIT surface cover output for the Barmah Forest for the 16/17. This year includes a natural flood that peaked in October 2016 at 67% cover of the site as mapped by the line hydrograph from Snag Creek and surface mapping by the VEWH. The WIT (open water+wet) inundation measure misses the flood peak due to excessive cloud cover and picks up the next measurement in November on the receding limb 25% lower than the peak.

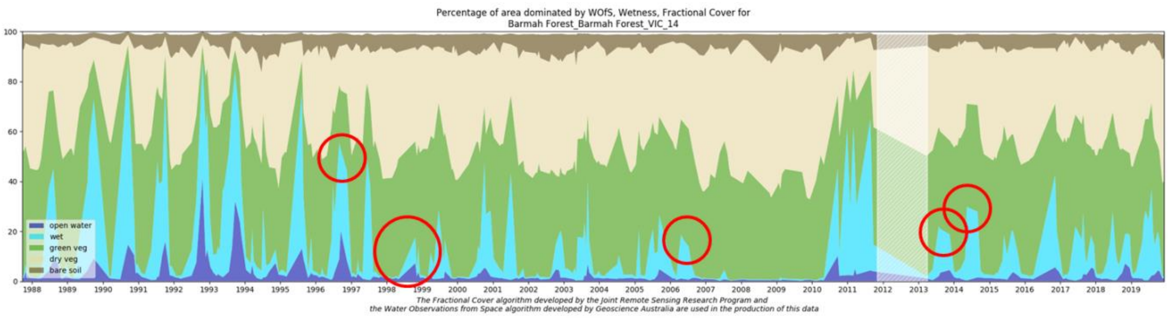

Figure 29. Complete WIT hydrograph for Barmah Forest. Truncated peaks (circled) potentially indicate missing peak inundation on cloudy days. This "plateau" pattern was not observed in 2016 because the entire rising limb during the 4 months prior to the peak is not mapped.