The Living Murray Condition Monitoring: Hattah Lakes 2022–23, Part A

Prepared for: Mallee Catchment Management Authority

Document information

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Owner	Ecology Australia Pty Ltd	
Project	22-034	
Author	Butler F, Palmer G, Bloink C, Linn M, Murrell J, Kerr N, van Asten T, *McPhan L, Halliday B, Walker G, *Lewis S	
File	The Living Murray Condition Monitoring 2022-23 Hattah Lakes Part A FIN01	
Bioregion	Robinvale Plains, Lowan Mallee and Murray Mallee	
Distribution	Emma Collins	Mallee Catchment Management Authority
	David Wood	Mallee Catchment Management Authority

Document History

Status	Changes	Author	Reviewer	Date
Draft 1	First draft	Butler F, Palmer G, Bloink C, Linn M, Murrell J, Kerr N, van Asten T, *McPhan L, Halliday B, Walker G, *Lewis S	Preston T, Ewing A	02/08/2023
Final	Incorporated comments from MCMA	Butler F, Palmer G, Bloink C, Linn M, Murrell J, Kerr N, van Asten T, *McPhan L, Halliday B, Walker G, *Lewis S	Preston T	25/08/2023

Citation: Butler F, Palmer G, Bloink C, Linn M, Murrell J, Kerr N, van Asten T, *McPhan L, Halliday B, Walker G, *Lewis S (2023). The Living Murray Condition Monitoring: Hattah Lakes 2022–23, Part A. Report to Mallee Catchment Management Authority, Ecology Australia Pty. Ltd., Thomastown, Victoria.

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Cover photo: Hattah Lakes black box tree condition site B22 H.

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Acknowledgments

This report was funded by The Mallee Catchment Management Authority through The Living Murray. The Living Murray is a joint initiative funded by the New South Wales, Victorian, South Australian and Commonwealth Governments, coordinated by the Murray-Darling Basin Authority.

The authors would like to thank the following for their assistance in undertaking this project:

- Emma Collins and David Wood from the Mallee CMA for their assistance throughout the project

- Kate Thurkle, Cassie Neate, Lee O'Shea, Katie Kinnear and Marty White for their assistance with the vegetation surveys

- Steve Saddlier, Julian Arriagada and Nick Vey for their assistance with fish surveys

- Alice Ewing and Dylan McLean for their assistance with the bird surveys

- Wayne Robinson for his assistance with the population structure analyses and fish indices

Summary

Ecology Australia was commissioned by the Mallee Catchment Management Authority (MCMA) to undertake the 2022–23 condition monitoring of the Hattah Lakes icon site, as part of The Living Murray (TLM) Condition Monitoring Program. Monitoring encompassed the assessment of five vegetation components (river red gum, black box, wetland vegetation communities, floodplain vegetation communities and lignum) as well as waterbirds and fish communities.

TLM is a joint initiative of the Australian Government and the governments of New South Wales, Victoria and South Australia, and was initiated in response to the demonstrable long-term decline in the health of the Murray River system. The primary goal of the program is to achieve a healthy, working river through the accrual and release of environmental flows to benefit the ecology of the system.

TLM monitoring of the Hattah Lakes icon site began in 2006–07, and has been undertaken annually since, with the exception of 2014–15 due to a lack of program funding. A summary of the 2022–23 results is provided in Table 1.

Table 1 Summary of whether ecological objectives have been met for each project component for 2022–23

Component	Objective	Achieved	Partially achieved	Not achieved
River red gum	Improve condition and maintain extent from baseline (2006) levels of river red gum (*Eucalyptus camaldulensis*) to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030.			
Black box	Improve condition and maintain extent from baseline (2006) levels of black box (*Eucalyptus largiflorens*) to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030.			
Wetland vegetation	Improve species richness and abundance of native water-dependent floodplain and wetland aquatic vegetation at Hattah Lakes icon site by 2030.			
Floodplain vegetation	Improve species richness and abundance of native water-dependent floodplain and wetland aquatic vegetation at Hattah Lakes icon site by 2030.			
Lignum	Improve condition and maintain extent from baseline (2006) levels of lignum (*Duma florulenta*) to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030.			

Component	Objective	Achieved	Partially achieved	Not achieved
Waterbirds	Provide feeding habitat for a range of waterbirds by 2030			
	Have successful nesting by colonially nesting waterbirds at Hattah Lakes icon site by 2030.			
Fish communities	By 2030, improve native fish populations (large and small-bodied fish) across Lindsay-Mulcra-Wallpolla icon site and their relative abundance and diversity; including indices based improvements in the number of native species recorded per site, small-bodied fish recruitment and native species biomass			

River red gum

River red gum trees saw a marked increase in condition between 2021–22 and 2022–23, with the percentage of trees with a Tree Condition Index (TCI) score ≥10 increasing from 55.1% to 81.7%. This placed river red gum communities at Hattah Lakes above the ecological target of 70% of sampled trees with a TCI ≥10 for the fifth time since monitoring began in 2008–09. This was the first time the target was achieved since 2019–20. River red gums are likely responding positively to widespread natural and environmental flows that occurred across Hattah Lakes during the 2022–23 season. The annual mortality rate target of <1% of sampled trees was also met for river red gums at Hattah Lakes with a rate of 0.6% recorded for 2022–23.

A mean river red gum population status index of 0.89 (pooling indices between water regime classes) was recorded for the current three-year period at Hattah Lakes, exceeding the minimum threshold of 0.80.

River red gum communities met the specific targets for annual mortality, population structure index and the TCI target. Therefore, the objective to 'improve condition and maintain extent from baseline (2006) levels of river red gum *E. camaldulensis* to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030' has been met in 2022–23.

Black box

Black box sites at Hattah Lakes recorded a modest increase in the percentage of trees with a TCI score ≥10 (from 56.4% in 2021–22 to 66.2% 2022–23). Despite an increase, this represents the ninth consecutive year (excluding 2014–15 where monitoring did not take place) in which the 70% target has not been met for black box. While a more substantial improvement in TCI scores due to flooding may have been expected in 2022–23, it is possible that apparent growth and recovery of black box in response to flooding is delayed due to the slow growth rates of black box. Additionally, the lack of site-specific inundation data makes analysing the response of black box to flooding difficult. No new dead black box were recorded at Hattah Lakes in 2022–23, resulting in a 0% mortality rate, which meets the annual target of <1%.

A mean black box population status index of 0.95 was recorded for the current three-year period at Hattah Lakes, exceeding the minimum threshold of 0.80.

In 2022–23, black box communities at Hattah Lakes met the specific targets for annual mortality and population structure index scores, while failing to meet the target for TCI. Therefore, the objective to 'improve condition and maintain extent from baseline (2006) levels of black box *E. largiflorens* to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030 can be considered partially achieved.

Wetland vegetation communities

Whole-of-icon-site scores for both species richness and abundance decreased from the previous monitoring period. Across the icon site, 5 transects were compliant with the native water-responsive species richness index, while 4 were compliant with native water-responsive species abundance targets. This represents a slight overall decrease in compliance from 2021–22 surveys.

Due to the 2022-23 flood event, all wetland sites were inundated above levels seen in previous years. High levels of inundation have largely driven the decrease in the proportion of compliant sites for the 2022-23 surveys. Lake Kramen (the only episodic wetland site) was also inundated in 2022–23, whereas it was in a drying phase the previous 2 years. This led to a large shift in the plant functional groups recorded across the site, from over 90% combined terrestrial dry and terrestrial damp species, shifting to 100% amphibious emergent woody tolerator species.

icon site scores for species richness and abundance decreased for the 2022–23 survey period. Wetland vegetation is highly dynamic, responding to wetting and drying cycles with changes in species richness and abundance. Compliant transects for species richness and abundance were only found at persistent temporary wetlands. Therefore, the objective to 'improve species richness and abundance of native water-dependent floodplain and wetland aquatic vegetation at Hattah Lakes icon site by 2030' can only be considered partially met in 2022–23.

Floodplain vegetation communities

Whole-of-icon-site scores show there has been a marked increase in species richness and abundance for floodplain vegetation communities since the last survey. Widespread inundation following extremely high river flows in late 2022 and early 2023, as well as environmental watering that occurred in 2022, has facilitated the establishment of a number of species across the icon site.

The proportional abundance of drought-tolerant species functional groups at the often- and sometimes-flooded sites continued the gradual decline seen since 2019–20. Substantial increases in the proportion of terrestrial damp species were found at the often-flooded sites. This was associated with a decrease in the proportion of terrestrial dry species.

Floodplains are highly dynamic, and their species richness and abundance respond rapidly to inundation events. As such, the fluctuating levels of species richness and abundance in this survey period may not accurately portray the health of the floodplain communities at Hattah Lakes; rather, they are likely a symptom of the current stage of the ecosystem in a wetting and drying cycle.

icon site scores for 2022–23 represent an increase in both species richness and abundance and represents a trajectory towards achievement of the ecological objective to 'improve species richness and abundance of native water-dependent floodplain and wetland aquatic vegetation at Hattah Lakes icon site by 2030'. Results therefore suggest that the ecological objective for 2022–23 has been met.

Lignum

The site level target for lignum condition states that 70% or more lignum plants at Hattah Lakes have an LCI score of ≥4; in 2022–23 this target was met across the whole icon site, as well as within all individual WRCs (Lignum Shrubland, Lignum Swamp and Lignum Woodland). The increase in lignum condition over this survey period and last is consistent with environmental water delivery and the rainfall event that occurred over 2021-22, coupled with the unprecedented flooding event that occurred over this survey period.

At an icon site level, 89.8% of lignum plants recorded an LCI score of ≥4, while scores of 79.9%, 97.0% and 92.3% were recorded in Lignum Swamp, Lignum Shrubland and Lignum Woodland WRCs, respectively. Based on these results, the ecological objective to 'improve condition and maintain extent from baseline (2006) levels of lignum *Duma florulenta* to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030' was met.

Waterbirds

During the spring, summer and autumn waterbird surveys at the Hattah Lakes icon site, all of the 15 surveyed wetlands contained water and provided foraging habitat for waterbirds. Between the spring, summer and autumn surveys across all surveyed wetlands, 10 of the 11 common waterbird species set out to be recorded annually over the 2020–30 period, under the Hattah Lakes objectives, were recorded. The pied stilt was the only of the 11 common waterbird species to be recorded annually under ecological objective HL7, not observed during any of the 2022–23 surveys.

Large numbers of great cormorants were observed actively nesting at Lakes Cantala and Mournpall in autumn, as well as some breeding by Australasian darters. Juvenile darters and cormorants were also observed. Furthermore, actively breeding darters and/or cormorant species were recorded at 13 of the 15 surveyed wetlands. Other, non-target juvenile waterbirds were recorded at most of the Hattah Lakes wetlands, predominantly in summer.

The overall 10-year objective to provide feeding habitat for waterbirds at the Hattah Lakes icon site is largely on track, with one target species not recorded over the 2022–23 monitoring period. The objective to stimulate successful breeding by colonial waterbirds is on track to be met by 2030. The summer surveys proved valuable in detecting nesting and successful breeding by a range of waterbirds.

As a noteworthy observation, 4 juvenile musk ducks, listed as vulnerable in Victoria, were seen at Lake Bitterang in autumn.

Fish communities

The 2022–23 flooding event was one of the largest on record and easily the largest over this monitoring program. For the Hattah Lakes, the flooding event occurred only around 12 months since the lakes and wetlands were refilled (large-scale environmental watering event) and fish community essentially reset, after being dry over the 2019–2021 period.

The most obvious fish community composition response to the flooding was a very large increase in the abundance of carp. The carp abundance captured in 2022–23 was over three times greater than the previous record high following flooding in 2014. The 2022–23 record carp abundance was driven by very strong recruitment, with young-of-year (YOY) and juvenile carp the dominate size class captured.

The YOY golden and silver perch detected in the Hattah Lakes in 2022 were absent in 2023 and no recruitment for these species was detected at the Murray River sites. The flooding event would have provided a natural exit pathway for juvenile golden and silver perch to emigrate from Hattah Lakes to the Murray River. The flooding would have also provided an opportunity for all fish species, both native and introduced, to disperse easily between wetlands and channels and the Murray River.

No ecological objective targets for fish were met in 2023. The non-attainment in 2023 is largely due to the very high abundance of YOY and juvenile carp detected in the Hattah Lakes.

1 Introduction

Ecology Australia was commissioned by the Mallee Catchment Management Authority (MCMA) to undertake the 2022–23 condition monitoring of the Hattah Lakes icon site, as part of TLM Condition Monitoring Program. Monitoring encompassed the assessment of five vegetation components (river red gum, black box, wetland vegetation communities, floodplain vegetation communities and lignum) as well as waterbird and fish communities.

TLM is a joint initiative of the Australian Government and the governments of New South Wales, Victoria and South Australia, and was initiated in response to the demonstrable long-term decline in the health of the Murray River system (MDBA 2011). The primary goal of the program is to achieve a healthy, working river through the accrual and release of environmental flows to benefit the ecology of the system (MDBA 2011). To measure the long-term ecological benefits to the Hattah Lakes icon site, a monitoring program has been in place guided by the Hattah Lakes Condition Monitoring Program plan (MCMA 2021a). This plan has been reviewed regularly with the latest review completed in 2020–21. Monitoring for TLM Condition Monitoring Program began in 2006–07, and has been undertaken annually since, with the exception of 2014–15 due to a lack of program funding.

During the 2022–23 survey period, all except three vegetation condition monitoring sites (across the five different components) were assessed at Hattah Lakes. This was despite widespread inundation from the historically significant flood event which impeded access to a large proportion of vegetation and bird monitoring sites for much of the survey season. The three sites (two tree condition sites and one lignum site) not assessed were all inundated throughout the entire season, making assessment not possible. Due to inundation of large parts of Hattah Lakes throughout late 2022 and early 2023, vegetation assessments were delayed and occurred from February through to May. Waterbird surveys were conducted at most target wetlands in spring and summer 2022–23 and at all wetlands in autumn 2023. Despite the flooding, fish surveys were conducted within the typical Autumn survey period in 2023, commencing in late February and concluding in early May. Vegetation condition monitoring in 2022–23 followed the same methods as during the 2021–22 season (consistent with the updated Condition Monitoring Plan [MCMA 2021b]). This included the survey of black box and river red gum condition sites, which were newly established in 2020–21 (in addition to the previously established sites), as well as the omission of a number of tree condition parameters such as mistletoe extent, new tip growth, reproductive extent, leaf die-off, and bark cracking, which were found to not provide meaningful data, particularly when collected at a coarse, annual time-scale (MCMA 2021b) .

Reporting for the 2022–23 condition monitoring has been split into two documents: Part A (this report) provides the ecological objectives, methods, results and discussion for each of the monitoring components; while Part B provides supporting information such as site data, photographs and species lists.

2 Study Area

The Hattah Lakes icon site is located in northwest Victoria and covers approximately 13,000 ha of lakes and floodplain set within the 48,000 ha Hattah–Kulkyne National Park and the Murray–Kulkyne Park (MCMA 2021a; Figure 1). It is situated within Mildura Rural City local government area and the Mallee Catchment Management Authority region, and straddles three bioregions: Robinvale Plains, Lowan Mallee and Murray Mallee.

Hattah Lakes is set within a predominantly agricultural landscape, with extensive irrigated horticulture, dryland cropping, and stock grazing undertaken on surrounding private land (MCMA 2021a). Pastoralism and logging in the area which now makes up Hattah-Kulkyne National Park date back as far as 1847. Extensive grazing by sheep and rabbits throughout much of the 19th and 20th Centuries led to significant damage to native vegetation and soils, and in 1915 a sanctuary was established, which eventually led to the creation of Hattah-Kulkyne National Park and Murray-Kulkyne Park. Today, the icon site continues to be threatened by a drying climate, exotic species invasion, grazing, and over-extraction and regulation of flows in the Murray River for agriculture, industry and urban use (Butcher and Hale 2011; MCMA 2021a).

Hattah Lakes is one of six icon sites that are the focus of the TLM program. These sites were chosen because of their high ecological and economic value and their cultural heritage significance to Aboriginal people and the broader community (MDBA 2011). Hattah Lakes was selected as a TLM icon site due to the extent, condition, diversity and habitat value of the lake and floodplain communities, as well as the social and cultural importance of the lakes (MCMA 2021a). Twelve lakes within the icon site are Ramsar listed due to their provision of important waterbird refugia and for their significant biodiversity values (MCMA 2021a). The Hattah Lakes Ramsar site supports a high level of floristic diversity, with soil seed bank studies showing a comparable species richness to that of entire floodplain systems such as Narran Lakes (Butcher and Hale 2011). The icon site also supports over 300 vertebrate species (GHD 2009), including an array of fish and bird species which are protected under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and international migratory bird agreements.

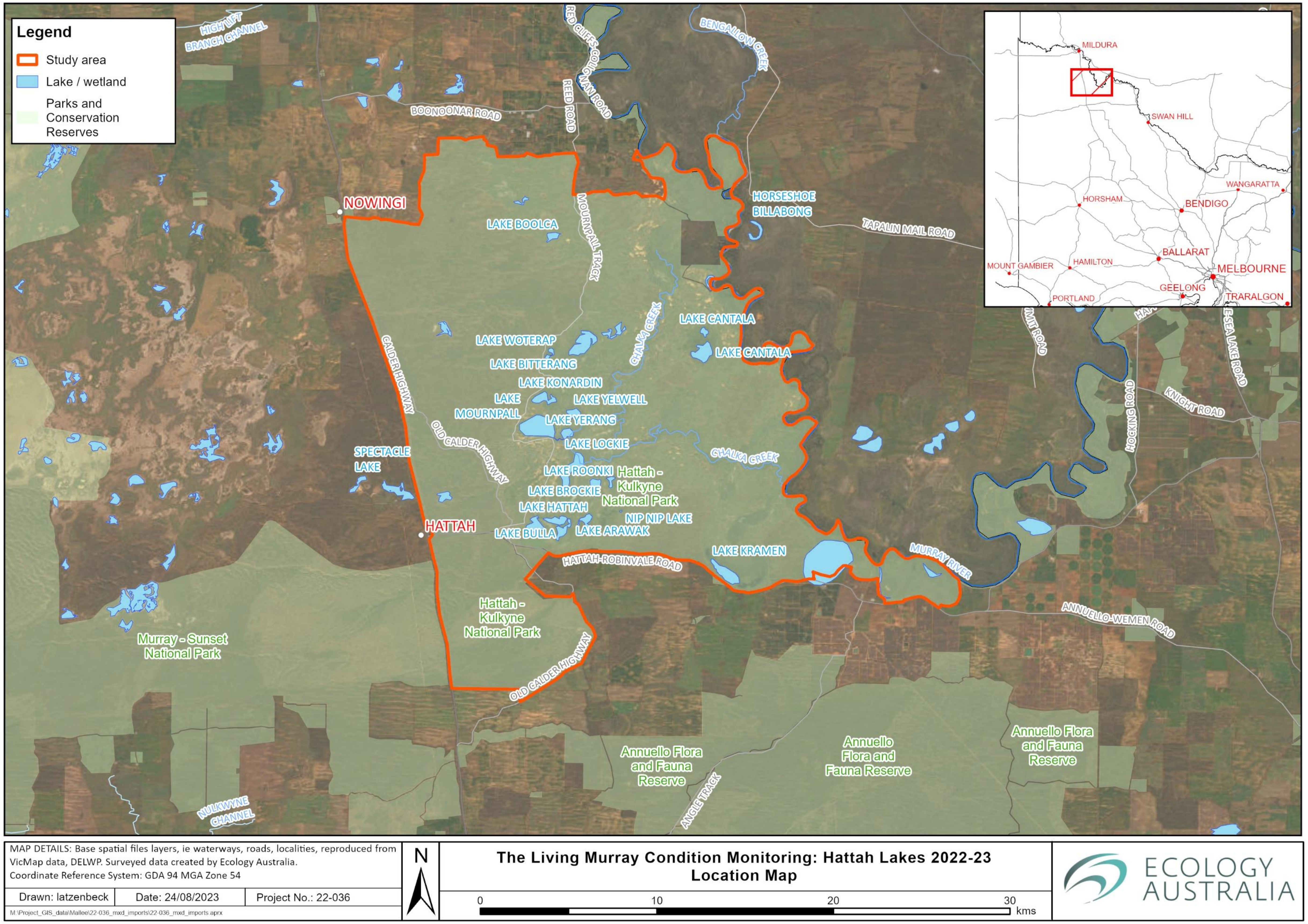


Figure 1 Boundary of Hattah Lakes icon site

2.1 Hydrology

2.1.1 Murray River

The Murray River is a highly regulated river with a series of weirs and dams placed in the system from the mouth to the source. The regulation and impoundment of sections of the river has restricted the natural flow and seasonal hydrological cycle. The lower section of the Murray River between the Murray mouth and Mildura (880 km) consists of a series of 11 locks and their weir pools; each weir pool is approximately three vertical metres higher than the downstream one. Upstream of Mildura the locks and weirs are further apart, with the next weir upstream of Mildura (Lock 11) being Lock 15 at Euston (approximately 220 river kilometres away).

The large distance between Lock 11 and Lock 15 means that the Murray River flowing past the Hattah Lakes icon site is relatively unregulated, as it is outside the influence of the Lock 11 weir pool. The hydrograph of flow downstream of Lock 15 shows similar characteristics to the many parts of the mid to lower Murray, with the return period between large peaks increasing since 1993 (Figure 2).

Historically, the significant trigger point for flows that affect the Hattah Lakes was 37,600 ML/d flow at Euston (MCMA 2021a). This flow volume is the level that water entered the lakes system under natural conditions. From 1975 (earliest historical data) to 1993, water entered the lakes system in most years, even if this was only a small volume to top up some of the lakes. As part of the TLM program, the sill height at Chalka Creek was lowered in 2012 so that flows of about 23,000 ML/d could enter the lakes (MCMA 2021a). Chalka Creek is the main channel that delivers water through the Hattah Lakes system from the Murray River. Flows have since exceeded this level in 2016, 2021 and 2022 due to natural flooding events.

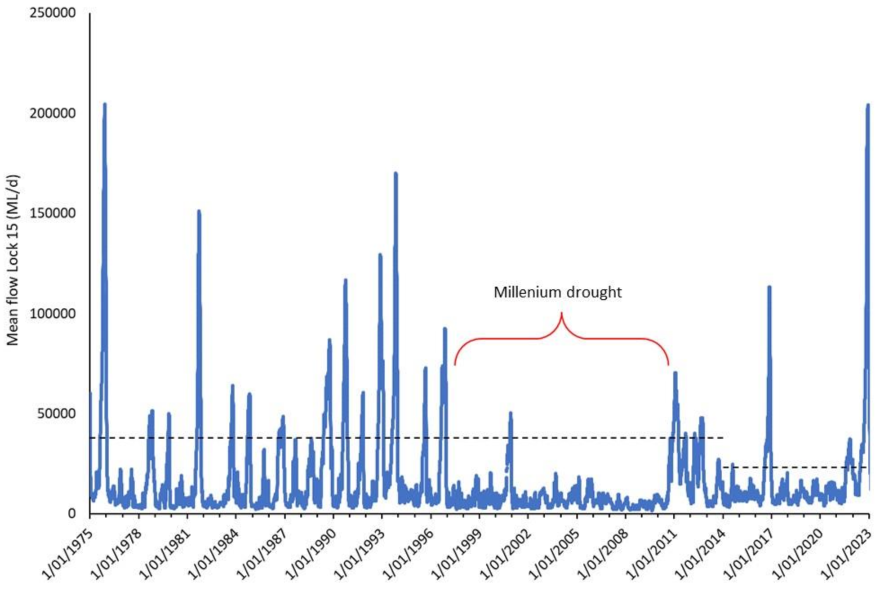


Figure 2 Mean daily discharge (ML/day) hydrograph for the Murray River downstream of the Euston Weir, 1975–2023 (source: https://livedata.mdba.gov.au/euston-weir-downstream). The Millennium Drought is outlined in red and the dashed lines represent significant flooding trigger points.

2.1.2 Wetland watering history

The first environmental water delivery at Hattah Lakes took place in 2005–06, with water delivered to several of the lakes via a set of temporary pumps, pumping water into Chalka Creek from the Murray River (Table 2). This was in response to the persisting Millennium Drought (1996–2010) and an attempt to prevent complete loss of wetland values in some of the Hattah Lakes. This was followed up in 2006–07 and 2009–10 with more of the semi-permanent lakes receiving environmental water. The drought was eventually broken by the flood event of 2010–11, which delivered water to many of the lakes throughout the system at Hattah (Table 2).

Completion of TLM water delivery infrastructure in 2012 has led to significant changes in watering patterns at Hattah Lakes. Completed TLM infrastructure includes a pumping station at Messenger's Crossing, sill lowering in Chalka Creek, the construction or refurbishment of 5 regulators and the construction of stop banks at several locations (MCMA 2021a). This has allowed more water to be delivered through large permanent pumps to simulate medium to large floods that have been lost as a result of river regulation. Since the completion of TLM water delivery infrastructure in 2012 there have been 8 environmental water delivery events targeting various locations across Hattah (Table 2).

Historically significant flooding occurred across large areas of the Hattah Lakes icon site in late 2022 and early 2023 in response to extremely heavy rainfall and flooding events throughout Queensland, New South Wales and Northern Victoria (Figure 2). While environmental flows were delivered to Hattah Lakes in spring 2022 (DCCEEW 2023), the magnitude of the natural flood event would have rendered the delivery of this environmental water somewhat redundant. While flow monitoring records do not date back to the 1930s, the 2022-23 flood event is most likely surpassed only by the 1931 and 1956 flood events throughout north eastern Victoria. The scale of flooding that occurred throughout late 2022 and early 2023 resulted in significant delays to all components of vegetation surveys for the 2022-23 season. With the exception of six lignum sites and two black box population structure sites, all sites were either too inundated for surveys or inaccessible due to tracks being inundated or damaged until February 2023. Thus, all other surveys did not begin until floodwaters had receded in February 2023.

Environmental and natural flows reached all surveyed wetlands across Hattah Lakes in 2022–23 except for Lake Kramen, which received only natural flows (Table 2). Red gum floodplain sites received a combination of natural and environmental flows, whilst black box floodplain sites received natural flows only (Table 2). Mean daily discharge downstream of Euston Weir peaked at 204,232ML/d in December 2022. This was the largest flow recorded downstream of Euston Weir since 1975, where it peaked at 204,643ML/d in November, shortly after monitoring began in January 1975 (Figure 2). Flooding in 2022–23 reached large expanses of the floodplain, including the upper floodplain where more infrequently inundated black box woodlands received natural flows (Table 2). All lakes surveyed as part of TLM monitoring were inundated during the 2022–23 survey period. During the previous 2 years prior the majority of surveyed lakes across Hattah also received environmental water.

Table 2 **The inundation history of the Hattah Lakes from 2005 to 2023 (source: MCMA). This table reflects whether water was received at any point during the year, with timing of inundation variable between sites and years. 2013–14 marks the start of water delivery using the TLM water delivery infrastructure.**

Wet	Drying	Dry

Key: E = Environmental water used, N = Natural inundation

Site	Flow component achievement over time																	
	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23
Lake Arawak		E			E	N			E	E		E/N	E			E	E	E/N
Lake Bitterang						N			E	E		N	E				E	E/N
Lake Boich					E	N			E	E		E/N	E			E	E	E/N
Lake Brockie		E				N			E	E		E/N	E			E	E	E/N
Lake Bulla	E	E		E	E	N			E	E		E/N	E			E	E	E/N
Lake Cantala						N				E		N	E				E	E/N
Lake Hattah	E	E		E	E	E/N			E	E		E/N	E			E	E	E/N
Lake Konardin					E	N			E	E		N	E			E	E	E/N
Lake Kramen						E				E					E			N
Lake Little Hattah	E	E		E	E	E/N			E	E		E/N	E			E	E	E/N
Lake Lockie	E	E		E	E	E/N			E	E		E/N	E			E	E	E/N

Site	Flow component achievement over time																	
	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23
Lake Marramook		E			E	N			E	E		E/N	E			E	E	E/N
Lake Mournpall		E			E	E/N			E	E		E/N	E			E	E	E/N
Lake Nip Nip						N			E	E		N	E				E	E/N
Lake Roonki					E	N			E	E		E/N	E			E	E	E/N
Lake Tullamook					E	N			E	E		E/N	E			E	E	E/N
Lake Yelwell					E	N			E	E		E/N	E			E	E	E/N
Lake Yerang	E	E		E	E	E/N			E	E		E/N	E			E	E	E/N
Floodplain																		
Redgum woodland						N			E	E		N	E				E	E/N
Blackbox woodland						N				E		N	E					N

3 Tree condition

3.1 Introduction

Hydrology strongly influences vegetation condition at multiple levels of ecological organisation (i.e. individual plants, plant populations and species, vegetation communities, and across vegetated landscapes). For example, survival, growth and reproduction of individual plants in these environments are strongly influenced by past hydrological conditions (e.g. timing and duration of flood events and time since inundation [Nilsson and Svedmark 2002; Brock et al. 2006]). Changes to flow regimes as a result of river regulation have substantially affected floodplain vegetation condition along the lower Murray River. Black box and river red gums are ecologically important floodplain tree species whose health is monitored as part of TLM Program.

River red gums are large native trees which grow to 40 m high (VicFlora 2023). This species forms Red Gum Forest and Red Gum Woodland vegetation communities occurring in riparian and floodplain areas along the Murray River (MCMA 2021a). River red gum communities are important habitats and sources of food for birds (including colonial nesters and migratory birds), mammals, and reptiles (MCMA 2021a). Black box trees grow to 20 m high and occur on seasonally inundated riverine floodplains (VicFlora 2023). This species is common on the floodplains of the Murray River, forming Black Box Woodlands where infrequent flooding plays a major role in the recruitment of this species (MCMA 2021a). Black box provides important habitat for both terrestrial and riverine fauna (MCMA 2021a).

Assessing the condition of both river red gum and black box is fundamental to informing progress toward the ecological objectives of the TLM program across the majority of TLM icon sites. The ecological objectives for river red gum and black box developed and refined in the Hattah Lakes Condition Monitoring Plan (CMP) (MCMA 2021) are:

Objective HL4 Condition and extent of floodplain vegetation

Improve condition and maintain extent from baseline (2006) levels of river red gum *Eucalyptus camaldulensis*, black box *E. largiflorens* and lignum *Duma florulenta* to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030.

The following revised targets have been established in the Hattah Lakes Environmental Water Management Plan (MCMA 2021a) relating to river red gum and black box populations under Objective HL4:

- In standardised transects that span the floodplain elevation gradient and existing spatial distribution, ≥70% of river red gum trees with Tree Condition Index ≥10, with annual mortality <1%.
- In standardised transects that span the floodplain elevation gradient and existing spatial distribution, ≥70% of black box trees with Tree Condition Index ≥10, with annual mortality <1%.

This report section will compare crown extent and density of river red gum and black box against established targets to assess the condition of populations at Hattah Lakes.

3.2 Methods

3.2.1 Tree condition index

A summary of the method for assessing tree condition is provided below. Refer to the Condition Monitoring Program design for Hattah Lakes (MCMA 2021b) for a detailed account. The tree condition assessment for river red gum and black box is determined by ground survey, based on a determination of the condition of 30 trees representative from within a particular assessment site. The condition of the trees at each site is determined by combining an assessment of crown extent and crown density.

For river red gums, tree condition was assessed at 32 locations distributed across the icon site (out of a total of 33 established river red gum tree condition sites). River red gum site R33 H could not be assessed in 2022–23 due to the sustained depth of inundation at the site during the survey season, precluding access to the trees for identification via their tags and measurement of DBH. For black box, tree condition was assessed at 21 sites (out of a total of 22 established sites) across Hattah in 2022–23. B19 H was also not able to be assessed due to depth of inundation at the site during the survey season. Sites are arranged across Hattah Lakes to be representative of the different river red gum and black box communities present, based on Ecological Vegetation Classes (EVCs) and Water Regime Classes (WRCs). Consequently, the number of transects located in each EVC/WRC is proportional to the relative area of that EVC/WRC.

Each site comprised of a minimum of 30 tagged trees. To compensate for the loss of sample trees due to mortality, a replacement was selected (next closest live tree) for each live tree lost. To indicate a replacement tree, a decimal number shall be included on the tag (i.e. if tree # 384 is replaced, the new tree will be marked 384.1).

At each site, the individual condition of 30 marked trees was measured to provide an on-ground assessment of tree condition. All assessments were undertaken by two observers. Assessment of the condition of each tree was undertaken by evaluating the crown of the tree for extent and density. Each measurement was recorded as a percentage (to the nearest 5%). Where observer scores differed by more than 10% on any one measure, discussion of the variance was undertaken between observers and the component re-assessed. In addition to assessing the crown, the diameter of each river red gum tree at breast height (1.3 m above the ground) (DBH) was measured to determine growth of target trees (in alternate years with black box DBH measurement). At each site, one or two photos were taken from established photo points (one photo exists for each of the original Hattah Lakes tree condition sites, whereas 2 photopoints were established at each of the tree condition sites established by Ecology Australia in 2020–21). Assessments were undertaken between September 2022 and June 2023.

As per MCMA (2021b), the percentage of sampled trees within each Tree Condition Index (TCI) class ≥10 was calculated per site and averaged across all sites. The Tree Condition Index (TCI) for each tree is calculated by adding the scores for both crown extent and density (Table 3) for a maximum possible TCI score of 14. For each site, the number of trees in each category is determined and the percent of viable (or live) trees with a TCI score ≥10 is calculated. Whilst dead trees were not included, trees which were deemed “possibly dead but may recuperate” and not replaced in 2022–23 (see below paragraph for further explanation) were included in this analysis.

Table 3 Categories used to determine score for crown extent and crown density based on field assessed percent.

Percent	Score
0	0
1-10	1
11-20	2
21-40	3
41-60	4
61-80	5
81-90	6
91-100	7

In recent years, Ecology Australia staff have noted instances of trees being presumed dead (due to an absence of live leaves) and replaced by surveyors, only to recuperate and resprout in following years. This has resulted in cases of more than 30 live trees being present within a site. With the aim of preventing this going forward, Ecology Australia staff have adopted a more cautious approach to declaring a tree dead and replacing it. Where a tree appears to have potentially recently senesced (i.e. it has no live leaves but still retains some dead leaves, fine twigs or a complete covering of bark), Ecology Australia staff have scored the tree 0% for extent and density (reflective of the lack of leaves) but not replaced the tree. In these cases, trees were not categorised in the data as 'alive' or 'dead' but were instead noted to be 'possibly dead but may recuperate'. This tree can then be reassessed the following year to ascertain whether the tree has recuperated or has more clearly senesced (i.e. it has lost its fine twigs and portions of the bark to a point where resprouting is not likely) and can be replaced with a new tree.

Ecology Australia staff have also noted instances of tree numbering "double ups" across a select few tree condition sites. This occurs where a tree is replaced, only to not be relocated in subsequent years and be replaced again with the same number used. This leads to issues in data analysis and comparison between years with different trees with the same tag number being recorded between years, leading to variation in DBH and condition scores. This seems to be due to insufficient consolidation of new tree condition GPS coordinates (taken when a new tree is established) each year into a master database or where a coordinate has not been taken for a new tree, resulting in an incomplete database of tree condition waypoints to use for mapping of sites for navigation to, and identification of, established sample trees. This appears to be a long-running (though reasonably minor) issue for the tree condition assessment component, with GPS coordinates for some trees appearing not to have been provided to Ecology Australia at the hand-over of the program. To attempt to rectify this issue, Ecology Australia staff have begun removing "double up" trees in the field. Additionally, we aim to provide a consolidated set of tree condition coordinates each year to the MCMA (which Ecology Australia will continue to use for updating maps as needed to reflect the addition or removal of trees).

3.2.2 Tree mortality rate

The total number of newly dead trees in condition monitoring sites was calculated from a comparison of the data with the previous year. The percent death rate was calculated by dividing the number of newly dead trees from the 2022–23 season by the total number of live trees at the end of the previous year's sampling. As not all sites were surveyed in 2022–23 due to accessibility, only sites which were surveyed in 2022–23 were considered in the count of live trees from 2021–22.

3.3 Results

3.3.1 Tree condition index

Black box

The proportion of trees with a TCI of 10 or more was calculated for each of the 21 black box sites within the Hattah Lakes study area. The target of 70% for black box was not met in 2022–23, with 66.2% of sampled trees having a TCI of 10 or more (Figure 3). This was despite an increasing trend in TCI at Hattah Lakes black box condition sites since 2021–22. This was the ninth consecutive year (excluding 2014–15 where monitoring was not undertaken) where the black box tree condition target has not been met at Hattah Lakes.

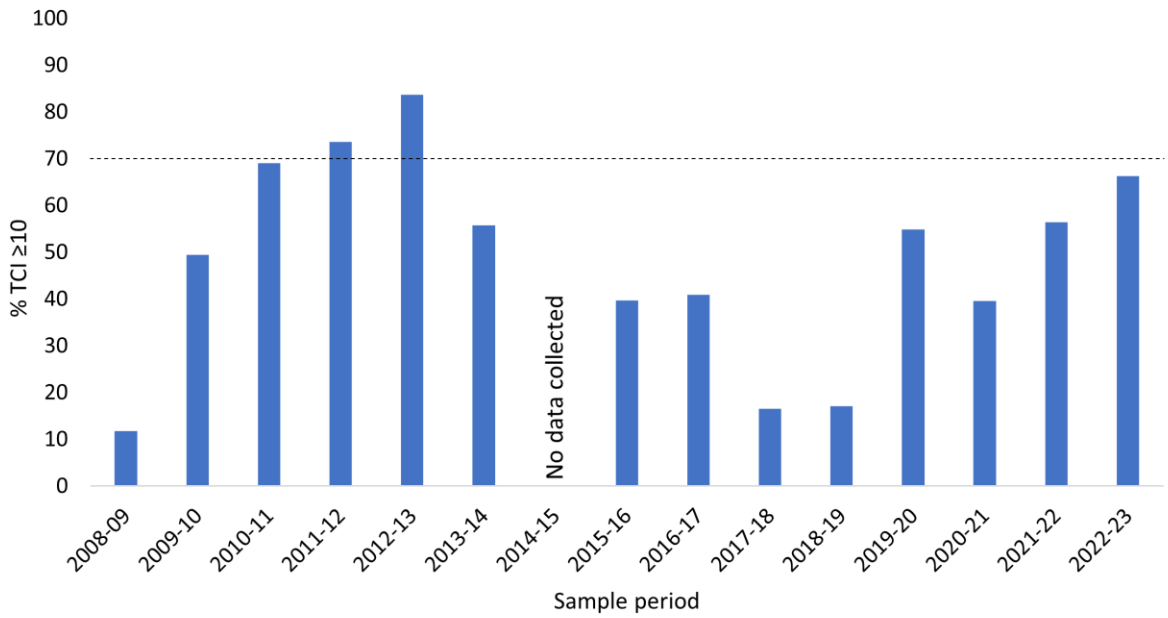


Figure 3 Percentage of black box trees with TCI ≥ 10 for each survey period across black box Tree Condition sites at Hattah Lakes. An overall target of 70% was used to determine if the Hattah Lakes black box population was healthy and sustainable.

Across all black box sites, substantial variation was present in the percent of trees with a TCI ≥10 (Table 4; Figures 5-7, Part B Report Butler et al. 2023a). The average percent of black box with a TCI ≥10 across all sites at Hattah Lakes was 66.2. This represents an increase of 8.8% since 2021–22 (Table 4). Across black box sites the lowest percentage of trees at a site with a TCI ≥10 was 33.3%, recorded at B18 H (a 66.7% drop from the 100% compliance rate recorded the previous year). Conversely, 100% of trees exceeded the target at B15 H (with a 13% increase on last year's compliance figure). These changes in percent TCI ≥10 since 2021–22 (Table 4) highlight the significant inter-annual variability in TCI scores at the site level. However, while a select few sites saw large decreases in TCI (e.g. B11 H and B18 H) the majority of sites recorded an increase in percent TCI ≥10 since 2021–22.

Table 4 Percentage of live trees at each black box site with a Tree Condition Index (TCI) score ≥10, Hattah Lakes, 2022–23. Change in percent of trees with a TCI ≥10 since 2021–22 has also been provided for each site.

Site	% TCI ≥10	Change in % TCI compliance since 2021–22
B1 H	73.3	26.7
B2 H	70.0	26.7
B3 H	76.7	3.3
B4 H	53.3	13.3
B5 H	46.7	33.3
B6 H	46.7	33.3
B7 H	73.3	13.3
B8 H	60.0	30.0
B9 H	50.0	3.3
B10 H	90.0	20.0
B11 H	40.0	-60.0
B12 H	96.7	20.0
B13 H	74.2	54.2
B14 H	90.0	6.7
B15 H	100.0	13.3
B16 H	56.7	10.0
B17 H	53.3	-26.7
B18 H	33.3	-66.7
B19 H	Not surveyed in 2022–23	N/A
B20 H	63.3	6.7
B21H	96.7	3.3
B22 H	46.7	20.0
Average across all sites:	66.2	8.8

River red gum

The proportion of trees with a TCI of 10 or more was calculated for each of the 32 river red gum tree condition sites. In contrast to black box condition, the target of 70% of river red gums with a TCI of 10 or more was met in 2022–23 with 81.7% of trees in condition sites meeting or exceeding the target (Figure 4). This was the first time the target had been met since 2019–20, with a substantial increase on the condition scores recorded in 2021–22 and 2020–21.

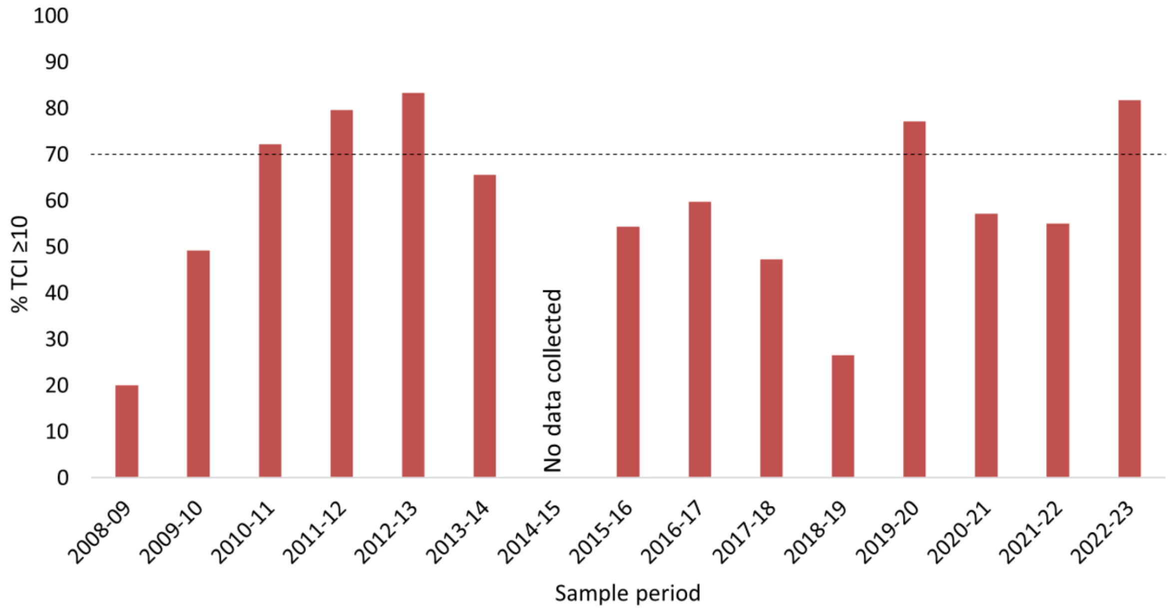


Figure 4 Percentage of river red gum trees with TCI≥ 10 for each survey period across the river red gum Tree Condition sites at Hattah Lakes. An overall target of 70% was used to determine if the Hattah Lakes river red gum tree population was healthy and sustainable.

The average percent of river red gums with a TCI greater than or equal to 10 across all sites was 81.6, representing an increase of 27.2% since 2021–22. The lowest percent TCI ≥10 was 36.7% (recorded at site R5 H), whilst at 5 sites 100% of trees exceeded this target (Table 5). Detailed results relating to each site are shown in the Part B report in Figures 1–4 (Butler et al. 2023a).

Table 5 Percentage of live trees at each river red gum site with a Tree Condition Index (TCI) score ≥10, Hattah Lakes, 2022–23. Change in percent of trees with a TCI ≥10 since 2021–22 has also been provided for each site.

Site	% TCI ≥10	Change in % TCI compliance since 2021–22
R1 H	73.3	40.0
R2 H	83.3	24.7
R3 H	93.3	16.7
R4 H	93.5	66.9
R5 H	36.7	-33.3
R6 H	100.0	66.7
R7 H	90.3	17.0
R8 H	83.3	74.8
R9 H	56.7	53.3
R10 H	100.0	6.7
R11 H	100.0	36.7
R12 H	76.7	-10.0
R13 H	93.3	33.3
R14 H	93.3	56.7
R15 H	46.7	6.7
R16 H	90.0	35.2
R17 H	73.3	-10.0
R18 H	80.0	50.0
R19 H	100.0	40.0
R20 H	83.3	-3.3
R21 H	51.6	-18.4
R22 H	66.7	40.0
R23 H	83.3	16.7
R24 H	40.0	-3.3
R25 H	80.0	63.3
R26 H	93.3	3.3
R27 H	90.0	36.7
R28 H	100.0	36.7
R29 H	96.7	36.7
R30 H	86.7	26.7
R31 H	80.0	56.7
R32 H	96.7	6.7
R33 H	Not surveyed in 2022–23	NA
Average across all sites:	**81.6**	27.2

The percentage of trees with a TCI score ≥10 has been persistently lower for black box compared with river red gum. Whilst river red gum tree condition sites met the 70% target in 5 of 14 years, black box sites have only met the target in 2 years (Figure 3; Figure 4). Furthermore, the percentage of river red gums with a TCI ≥10 was higher than black box in 11 of 14 years monitored.

3.3.2 Tree mortality rate

During the 2022–23 monitoring season, 6 newly dead river red gums were recorded across tree condition monitoring sites, whilst no newly dead black box were recorded. This translates to a 0.6% mortality rate for river red gums at Hattah Lakes, and a 0% rate for black box. The combined mortality rate across both species was 0.4%. This places both species well below the established mortality rate target of <1% per annum.

It should be noted, however, that these values do not include trees whose death could not be confirmed in 2022–23 i.e., trees which had recently lost all leaves but could not conclusively be called dead due some perceived potential to resprout. These trees were left in the 30-tree data set but scored with zeros for extent and density and labelled as “possibly dead may recuperate” in the data sheets (see Section 3.2.1 for further explanation). Five river red gums and 4 black box were deemed inconclusively dead in 2022–23. If these individuals were to be included in the mortality rates it would increase the river red gum mortality rate to 1.1%, the black box rate to 0.5% and the overall mortality rate to 0.8%.

3.4 Discussion

The percentage of trees with a TCI score greater than or equal to 10 increased at both river red gum and black box sites in 2022–23. A significant increase in TCI scores at river red gum sites during this round of monitoring placed them over the 70% target for the first time since 2019–20. Whilst black box sites did not exceed the 70% target in 2022–23 there was a continued increasing trajectory in TCI scores following a low recorded in 2020–21.

Widespread flooding occurred at Hattah Lakes across in late 2022 and early 2023 due to a combination of natural flows and environmental water delivery. Increases in TCI scores across river red gum and black box sites are likely attributable to this increased water availability (in addition to less significant flooding also experienced across Hattah during the 2020–21 and 2021–22 seasons). Flood events have been demonstrated to produce a pulse period of growth in black box which may last between 2–5 years (George 2005). Growth in response to flooding includes the initiation of new leaves or epicormic growth (Roberts and Marston 2011). However, increased growth rates due to flooding may take many months to become apparent. As such, it is possible that increases in TCI scores observed during this year’s monitoring are also attributable to long-term gains in response to inundation experienced during 2020–21 and 2021–22. Due to slow growth rates, the full response of black box to this year’s inundation event may also not have been apparent at the time of surveying. It is possible that increases in TCI scores due to this year’s inundation event may be evident for some years to come as the post-flooding pulse period of growth continues.

Variability in tree condition from year to year can be due to a number of factors, including long- and short-term inundation histories and other environmental variables. However, a paucity of site-specific fine-resolution inundation data for the sites surveyed makes the relation of flooding regimes to tree health difficult. This is further constrained by a lack of empirical data around the water requirements of floodplain vegetation, particularly for black box (Doody et al. 2021; Moxham et al. 2017). The end of the Millennium Drought and the delivery of environmental water led to an increase in TCI scores from 2009–10 to 2012–13 for both black box and river red gum communities. After this point, however, scores become more variable between years, with results generally, but not always, mirrored between river red gum and black box communities. For example, river red gum health was higher in 2017–18 than 2018–19 but black box health plateaued between the two periods with a lower percentage TCI score. Access to site-specific inundation data for analysis and consideration alongside the annual tree condition monitoring results would enable further investigation to draw apart the causes of these fluctuations, allowing for more targeted recommendations around the delivery of environmental water to specific areas of the icon site. It would also be of use given the paucity of research surrounding optimal flooding regimes for black box communities.

Across all years, higher percentages of trees with a TCI score of 10 or more were generally found at river red gum sites than at black box sites. This likely reflects the proximity of river red gum sites to river channels and wetlands, resulting in increased access to water resources. By contrast, black box sites tend to occur at higher elevations and experience less frequent and more short-lived inundation.

3.5 Objectives and target attainment

The target of 70% or more trees with a TCI ≥ 10 was not met for black box, while the annual mortality target of <1% was met. This suggests the ecological objective to ‘improve condition and maintain extent from baseline (2006) levels of black box *E. largiflorens* to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030’ is only being partially met in terms of tree condition and annual mortality.

For river red gum, the target of 70% or more trees with a TCI ≥ 10 was met, as was the annual mortality target of <1%. Therefore, the ecological objective to ‘improve condition and maintain extent from baseline (2006) levels of river red gum *E. camaldulensis* to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030’ was met in terms of tree condition and annual mortality.

A summary of target attainment relating to the objectives is provided below in Table 6.

Table 6 Summary of tree condition target attainment in 2022–23.

Objective HL4	**Attained**	**Partial attainment**	**Not attained**
Improve condition and maintain extent from baseline (2006) levels of river red gum *Eucalyptus camaldulensis*, black box *E. largiflorens* and lignum *Duma florulenta* to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030.			
Specific target: ≥70% of River Red Gum and Black Box trees with Tree Condition Index ≥10			
• Black box			
• River red gum			
Annual mortality <1%			
• Black box			
• River red gum			

3.6 Recommendations

The percentage of black box with a TCI score ≥10 has typically been lower than river red gums since the inception of TLM condition monitoring at Hattah Lakes. Furthermore, black box sites have only met the 70% TCI ≥10 target in 2 of 14 years monitored (although not this year), compared with 5 years for river red gums. This suggests that over the long-term the species has likely not been receiving the necessary flood frequency or duration required to flourish and sustain healthy populations at Hattah Lakes. Improvements in black box TCI scores have been seen over the last 2 years with these likely attributable to widespread inundation events, particularly prior to the 2022-23 surveys, and increased rainfall across the icon site. No newly dead black box were recorded at tree condition sites during this monitoring period at Hattah Lakes, further implying the beneficial impacts of several years of increased water-availability in maintaining healthy black box populations. Considerable variation in TCI scores was present between sites, with some exhibiting particularly low levels of trees with a TCI score ≥10. Further investigation should be undertaken to assess the cause of low site-wide TCI scores.

Provision of site-specific flood history mapping and added scope for further analysis to investigate associations between flood histories and tree condition would enable a greater understanding of the impacts of flood frequency on tree condition across time. Further inundation related analyses would also help address the dearth of research surrounding optimal flow timing, frequency, and depth for black box and river red gum community restoration and sustainability. This would allow for more efficient planning and targeted delivery of environmental flows to address declining health of floodplain eucalypt communities. Groundwater is another important source of moisture for floodplain tree species (Pettit and Froend 2018; Roberts and Marston 2011). The recommendations put forward by Wood et al. (2018) to monitor the quality and depth of groundwater are therefore appropriate and important, especially for monitoring and interpreting long-term trends in these communities.

Multiple instances of trees being presumed dead (due to an absence of live leaves) and replaced by surveyors, only to recuperate and resprout in following years have occurred. Thus, we recommend explicitly stating in the CMP (MCMA 2021b) that if a tree appears to have potentially recently senesced (i.e. it has no live leaves but still retains some dead leaves, fine twigs or a complete covering of bark) it is scored with a 0% for extent and density (reflective of the lack of leaves) but not replaced. Trees are then to be reassessed the following year to ascertain whether the tree has recuperated or has more clearly senesced (i.e. it has lost its fine twigs and portions of the bark to a point where resprouting is not likely) and can be replaced with a new tree. This technique has been implemented by Ecology Australia staff in recent years and thus far appears to be effective in avoiding pre-emptive replacement of trees which are wrongly assumed to have senesced.

4 Population Structure

4.1 Introduction

Investigations of population age structure can provide insight into regeneration patterns of plant populations and how these populations respond to their environment. However, establishing the age of eucalypts in semi-arid regions is problematic, where rainfall and seasonal temperatures constrain the production of annual tree rings (cf. George et al. [2005] and references therein). Instead, tree size measured as trunk (or bole) diameter is commonly used as a surrogate for tree age, and this approach has been used here (George et al. 2005; Roberts and Williams 2004).

Assessing the population structure of both river red gum and black box is fundamental to informing progress toward the ecological objectives of the TLM program. The ecological objective for river red gum and black box developed and refined in the CMP (MCMA 2021b) is:

Objective HL4 Condition and extent of floodplain vegetation

Improve condition and maintain extent from baseline (2006) levels of river red gum *Eucalyptus camaldulensis*, black box *Eucalyptus largiflorens* and lignum *Duma florulenta* to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030.

Specific targets outlined in the CMP (MCMA 2021b) for river red gum and black box woodlands under objective HL4 are:

- River red gum follow the appropriate J-curve defined by Smith et al. (1997) in George et al. (2005) for tree population structure with an Index value of ≥0.8
- Black box follow the appropriate J-curve defined by Smith et al. (1997) in George et al. (2005) for tree population structure with an Index value of ≥0.8.

4.2 Methods

Population structure of river red gum and black box is assessed on a rolling three-year cycle so that each year approximately one third of sites are sampled; transects were established in 2006–07, 2007–08 and 2008–09 (Wood et al. 2018). This method seeks to capture data on the spatial arrangement and age (using trunk diameter as a surrogate) of river red gum and black box along transects set perpendicular to key environmental gradients, such as water bodies and elevation (MCMA 2021b). This year's monitoring assessed Round 2 sites, including 9 river red gum transects and 6 black box transects.

At each transect, the Diameter at Breast Height (DBH) of each live river red gum or black box 10 m either side of the transect line was measured and location marked using a GPS (this allows for later comparison of transect alignment between previous years). For large trees (> 3 m high), trunk diameters were recorded at a height of 1.3 m. For trees with multiple trunks, the DBH of all trunks were measured, each converted to a cross-sectional area, the areas totalled, then the total area converted to a proxy DBH measurement for comparison to single trunk trees. For smaller trees (< 3 m), seedling and saplings, trunk diameter were measured above the tree base and below the first bifurcation. Water Regime Class (WRC) strata for each species were allocated as follows:

- River red gum
    - Red Gum Forest (RGF)
    - Red Gum with Flood-Tolerant Understorey (RFGTU)
    - Fringing Red Gum Woodland (FRGW)
- Black Box
    - Black Box Swampy Woodland (BBSW)
    - Riverine Chenopod Woodland (RCW)

4.2.1 Population status (J-curve)

The change in population structure of trees for both species over time was visualised by plotting the square-rooted frequency of DBH, in 15 cm size classes, of all trees surveyed at Hattah Lakes population status sites, for each rolling three-year period. This process was repeated for trees with DBH <15 cm, with 1 cm size classes.

Analysis of population status over time followed the methods outlined in MCMA (2021b). As DBH data is collected in a rolling three-year schedule, the 2021–24 period so far only contains surveys from 2021–22.

DBH data for each site were plotted as a histogram, in 15 cm bins, and compared to an ideal reference population structure, i.e. an inverse J curve (George et al. 2005). The distance between the observed data and the reference data for each site was assessed using Spearman's rho coefficient (ρ), and a J curve index, with a value between 0 and 1, was calculated from rho as follows:

$$\rho = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}}$$

$$Index = (\rho + 1)/2$$

Following Robinson (2014), a linear mixed effects model with repeated measures was fitted, to assess how the index varied over time, with WRC strata as a fixed effect and site as a random effect nested within strata. All calculations were made in R (R Development Core Team 2018). The lme4 package (Bates et al. 2015) was used to estimate fitted values for each time period within each stratum and standard deviation (SD) was estimated using bootstrapping. The Student's t-distribution was used to calculate 95% confidence intervals from the SD. Differences in the index between time periods were examined using the lmerTest package (Kuznetsova et al. 2017), which calculates P-values for the F-test using a Satterthwaite approximation for the numerator degrees of freedom. The mean index (± 95% confidence intervals) across time periods was plotted to track the status of the population structure for both species at the Hattah Lakes icon site over time, in relation to the minimum threshold of a mean J curve index of 0.8 for river red gum and black box, which is based on previous data and aligns with records at the end of the Millennium Drought (Brown et al. 2016).

4.3 Results

The current sampling period (2022–23) is round 2 of the 2021–24 three-year sampling period and therefore represents only approximately 2/3 of the study sites. This should be considered when interpreting the following results.

4.3.1 Black box

A mean black box population status index of 0.95 (pooling indices between WRCs) was recorded for the current three-year period at Hattah Lakes, exceeding the minimum threshold of 0.80 (Figure 5).

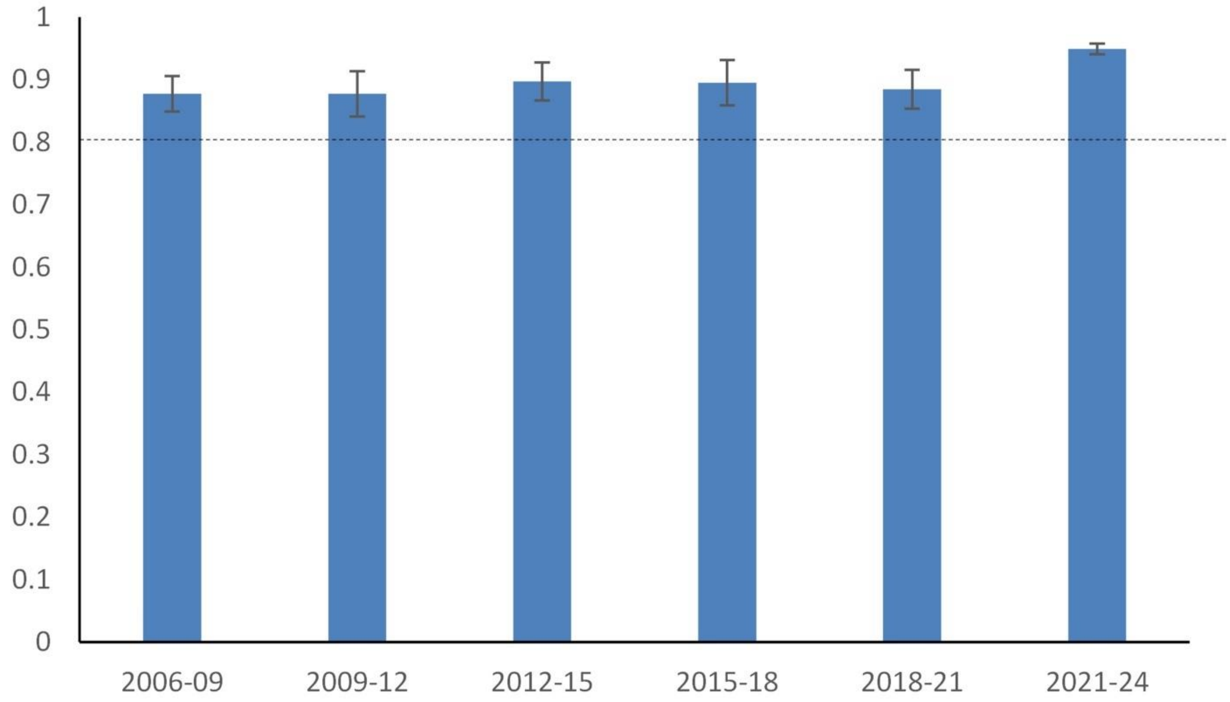


Figure 5 Mean population status index (± 95% CI) for black box at the Hattah Lakes icon site, based on correlation with an ideal population structure, the 'inverse J-curve'. A minimum threshold of 0.80 is set for black box at Hattah Lakes. Population status indices are pooled between WRCs in each survey period.

A linear mixed effect model detected a significant effect of survey period on black box population status index across any three-year period ($P < 0.01$), with relatively wide confidence intervals for the amount of variation within periods (Table 7). However, Water Regime Class (WRC) did not have a significant effect on the degree to which black box at each site approximated an ideal population structure ($P = 0.2$), though trees within the Riverine Chenopod Woodland (RCW) category had a higher index mean than those within Black Box Swampy Woodland (BBSW).

Table 7 Least squares mean index values from a linear mixed effect model exploring the effect of WRC on the black box population status index at the Hattah Lakes icon site, over time, with site as a random effect.

Parameter	Index mean	Standard error	Lower 95% CI	Upper 95% CI
BBSW	0.8477	0.03324	0.7799	0.9154
RCW	0.9123	0.03137	0.8483	0.9762
2006-09	0.8296	0.02845	0.7729	0.8862
2009-12	0.8526	0.02755	0.7977	0.9075
2012-15	0.8753	0.02755	0.8204	0.9302
2015-18	0.8614	0.02758	0.8065	0.9164
2018-21	0.8744	0.02658	0.8214	0.9274
2021-24	0.9865	0.02944	0.9279	1.0452

The total number of live black box individuals is lower than previous three-year monitoring periods in most size classes. However, this cannot be interpreted as a decline in the total number of trees, as this monitoring period is Round 2 of the current three-year monitoring period, with a third of total sites yet to be assessed.

Previous monitoring periods do show a declining trend in the juvenile population (0–15 cm) since the 2012–15 monitoring period (Figure 6). However, numbers for this size class in the current three-year period are almost as high as the 2018-21 period with one year of surveys to go. Higher numbers of juveniles (0-15 cm) compared to previous monitoring periods are mostly explained by the increase in seedlings ≤1 cm DBH and higher numbers of all size classes except the 1-2 cm size class (Figure 7).

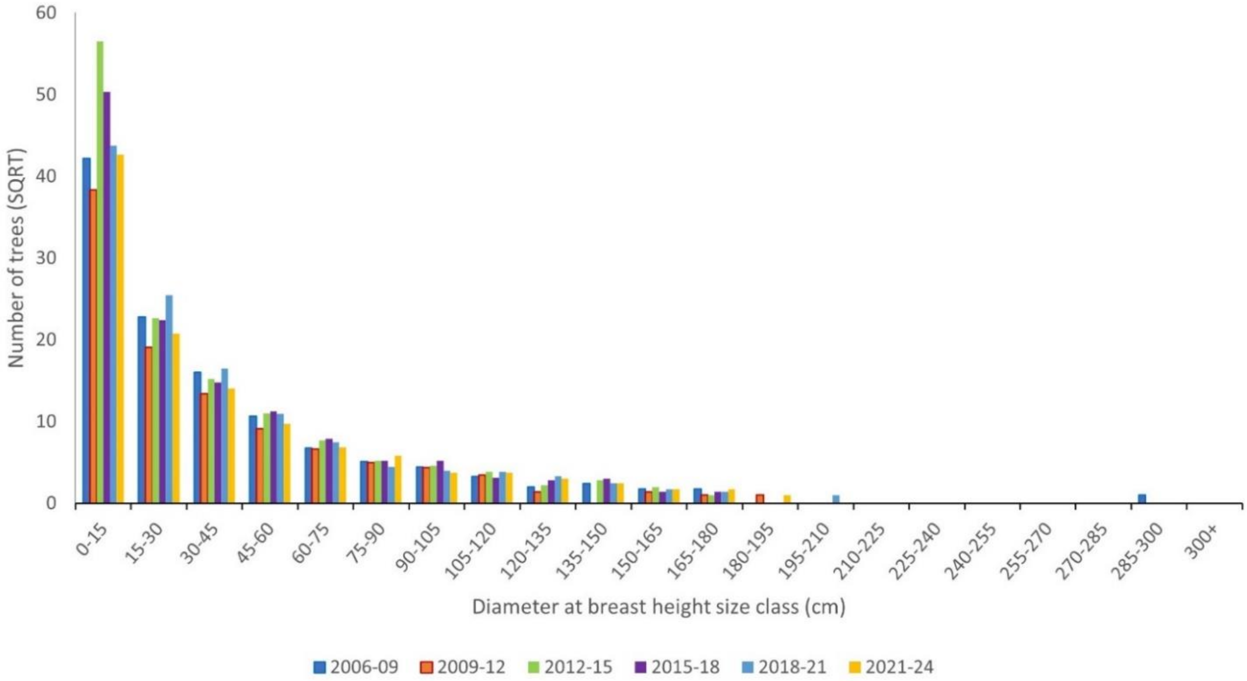


Figure 6 Frequency of black box trees (square-root transformed) for each DBH size-class (0–300+ cm) for each three-year period, pooled within the Hattah Lakes icon site.

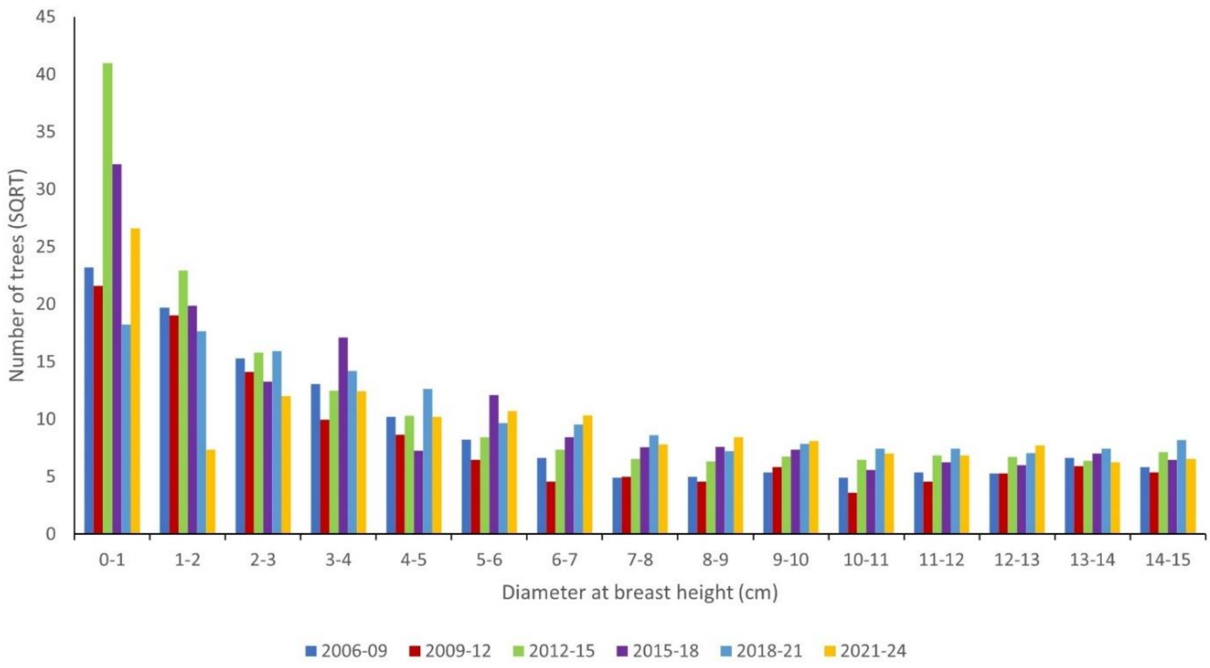


Figure 7 **Frequency of black box trees (square-root transformed) for each DBH size-class (0–15 cm) for each three-year period, pooled within the Hattah Lakes icon site.**

4.3.2 River red gum

A mean river red gum population status index of 0.89 (pooling indices between WRCs) was recorded for the current three-year period at Hattah Lakes, exceeding the minimum threshold of 0.80 (Figure 8).

Figure 8 **Mean population status index (± 95% CI) for river red gum at the Hattah Lakes icon site, based on correlation with an ideal population structure, the 'inverse J-curve'. A minimum threshold of 0.80 is set for black box at Hattah Lakes. Population status indices are pooled between WRCs in each survey period.**

A linear mixed effect model did not detect a significant effect of survey period on river red gum population status index across any three-year period (P = 0.1), with relatively wide confidence intervals for the amount of variation within periods (Table 8). A significant effect of WRC was detected (P = 0.02), with the mean population status index significantly higher in Red Gum Forest (RGF) compared to Red Gum with a flood-tolerant understorey.

Table 8 Least squares mean index values from a linear mixed effect model exploring the effect of WRC on the river red gum population status index at the Hattah Lakes icon site over time, with site as a random effect.

Parameter	Index mean	Standard error	Lower 95% CI	Upper 95% CI
FRGW	0.8778	0.01874	0.8401	0.9154
RGF	0.952	0.03056	0.8907	1.0133
RGFT	0.8373	0.02317	0.7908	0.8838
2006-09	0.8736	0.02003	0.8341	0.9132
2009-12	0.8674	0.02004	0.8279	0.907
2012-15	0.8781	0.01995	0.8388	0.9175
2015-18	0.9159	0.02143	0.8736	0.9582
2018-21	0.8816	0.01979	0.8425	0.9207
2021-24	0.9175	0.02174	0.8746	0.9604

Juvenile river red gums (0–15 cm DBH) continue to dominate the river red gum population, however the total number of juveniles in the 2018–21 monitoring period dropped considerably compared to the previous 2015–18 and 2012–15 monitoring periods and this trend is so far continuing in the current monitoring period (Figure 9). This is almost entirely driven by a decline in the ≤1 cm seedlings (Figure 10). However, the majority of the juvenile size classes showed an increase in the number of individuals in the 2018–21 and 2021-24 monitoring period compared to the previous periods.

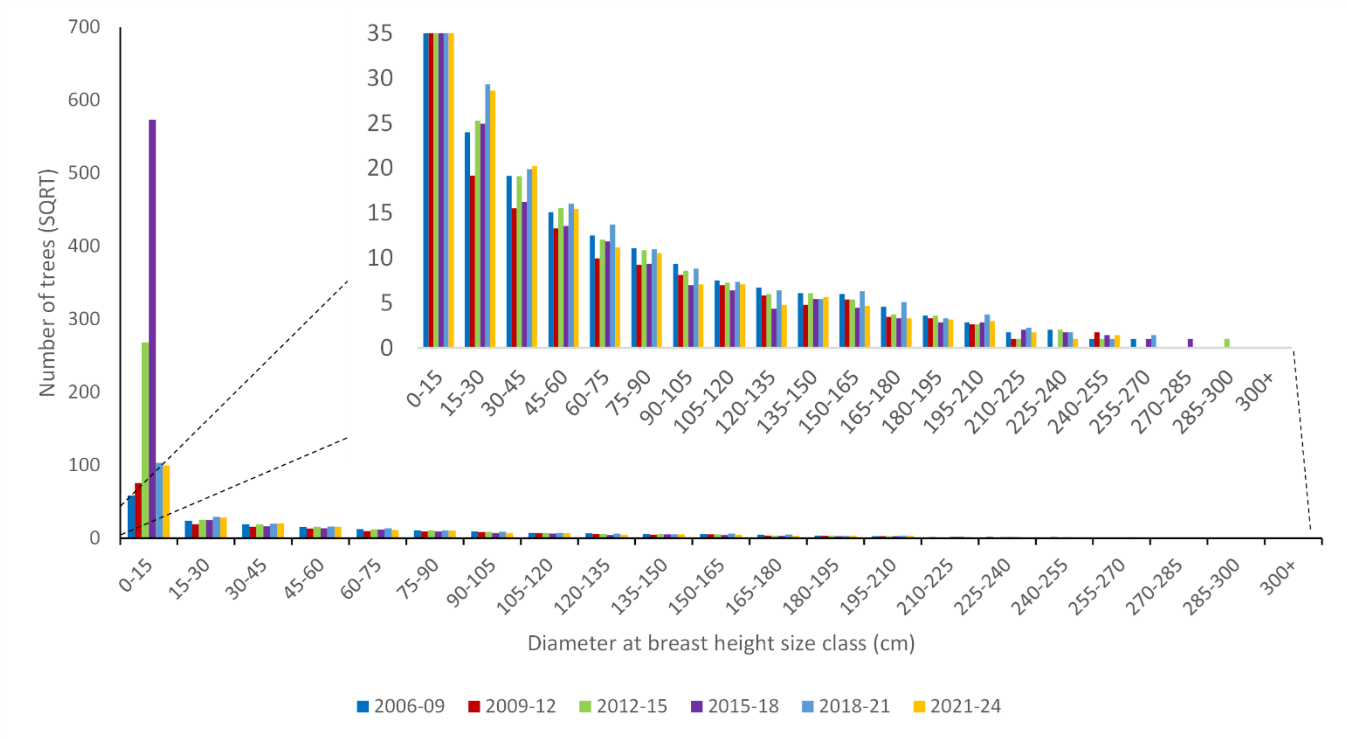


Figure 9 Frequency of river red gum trees (square-root transformed) for each DBH size-class (0–300+ cm) for each three-year period, pooled within the Hattah Lakes icon site.

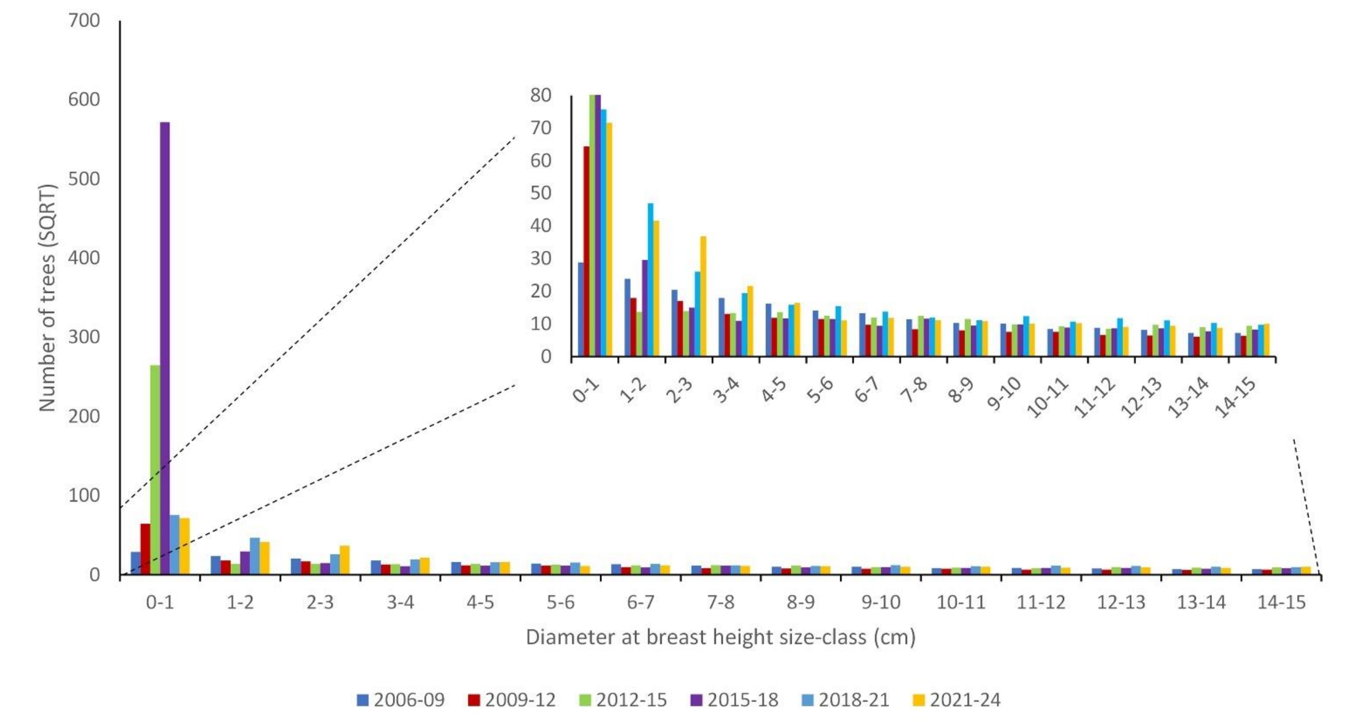


Figure 10 Frequency of river red gum trees (square-root transformed) for each DBH size-class (0–15 cm) for each three-year period, pooled within the Hattah Lakes icon site.

4.4 Discussion

For the second year in a row, a black box population status index of 0.95 was recorded for 2022–23, well above the minimum threshold of 0.80. When looking at size classes, trends from this season's results follow a similar pattern to last year. Relatively high numbers of black box were recorded across all size classes, particularly in the 0–1 cm size class, while the general size-class distribution of black box trees within Hattah Lakes follows the inverse J-curve shape required to reflect an ideal population structure. The factors promoting seed germination in black box are not well understood, while little is also known about the influence of watering events on seed production and seed fall. However, widespread flooding as well as the delivery of environmental water has resulted in increases in the number of black box recorded in the 0-1 cm size class.

For river red gums, a population status index of 0.89 was recorded which was also well above the minimum threshold of 0.80. Substantial river red gum recruitment during the 2015–18 period was followed by a marked decline in recruitment in 2018–21. This likely relates to the 2018–19 and 2019–20 survey seasons being predominantly dry or drying periods, which may have promoted less germination than the preceding 2 years where water was delivered to the majority of wetlands and floodplains across Hattah Lakes (Table 2). Despite only two years of the current monitoring period being conducted, numbers of juveniles (0–15 cm) for the current monitoring period have almost reached the same levels as the entire 2018–21 period. River red gum seed germination will occur in response to drawdown following inundation events, as well as in response to heavy rain (Di Stefano 2002). It is highly likely recent flooding as well as the delivery of environmental water has played a role in the large number of red gum seedlings recorded.

For both black box and river red gum, only two years of data have been collected as part of the 2021–24 survey period. Thus, any interpretation of results for this period needs to account for the incomplete dataset, and results may change depending on data collected over the next two survey periods.

4.5 Objective and target attainment

Black box communities recorded a population status index value of 0.95, exceeding the set target index value of ≥0.8. This represents the highest index value of any given three-year period since monitoring began, and a continued trend of black box exceeding the target index value in every three-year period. The objective to 'improve condition and maintain extent from baseline (2006) levels of black box *E. largiflorens* to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030' can be considered as being met in terms of black box population structure.

River red gum communities recorded a population status index value of 0.89, exceeding the set target index value of ≥0.8. This continued trend of river red gum exceeding the target index value in every three-year monitoring period. As such, the objective to 'improve condition and maintain extent from baseline (2006) levels of river red gum *E. camaldulensis* to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030' can be considered as being met in terms of river red gum population structure.

A summary of target attainment relating to the objectives is provided below in Table 9.

Table 9 Summary of population structure target attainment for 2022–23.

Objective HL4	Attained	Partial attainment	Not attained
Improve condition and maintain extent from baseline (2006) levels of river red gum *Eucalyptus camaldulensis*, black box *E. largiflorens* and lignum *Duma florulenta* to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030.			
Specific target: River Red Gum and Black Box follow the appropriate J-curve defined by Smith et al. (1997) in George et al. (2005) for tree population structure with an Index value of ≥0.8.			
• Black box			
• River red gum			

4.6 Recommendations

Similar to tree condition, population age structure of floodplain trees is strongly linked with the timing, frequency and duration of flow events (Roberts and Marston 2011; Rogers 2011). Results suggest environmental water delivery, as well extremely high natural flows in late 2022 and early 2023 have aided in river red gum recruitment, with the 2022–23 floods reaching the lower (river red gum) and upper (black box) floodplains across Hattah Lakes (Table 2).

High numbers of black box seedlings (< 1cm) were recorded during the 2022-23 surveys. We recommend conducting regular surveys of both black box and red gum seedlings that may have germinated following the recent flood event to gain an understanding of survival rates of seedlings of these species. This will also aid in gaining an understanding of any local factors that may be resulting in seedling mortality.

Whole-of-site indices are not necessarily providing an accurate measure of population viability among individual sites. At a whole-of-site scale, among-site variability in population structure is not being considered. A range of localised factors can influence population structure at individual site scale for each species, including local-scale water availability and variability in topographic features. We therefore recommend increased scope for among-sites variation to be included in future analyses of tree population age structure.

5 Wetland Vegetation Communities

5.1 Introduction

Water regime is a major factor influencing plant community development and patterns of plant zonation in wetlands (Casanova and Brock 2000). In undisturbed wetland systems, the frequency and duration of floodplain wetland inundation is affected by the location of the wetland in the landscape and/or capacity to retain water. Anthropogenic changes to the quantity of water (e.g. changes to natural frequency, duration and extent) in waterways and wetlands, impacts wetland vegetation communities through changes in plant community composition and zonation, and increases the potential for invasions of introduced species (Brook 2003). In particular, increased drying of wetlands shows a decline in water responsive species (diversity and cover), and an increase in dryland terrestrial species, including exotic plant species (Brook 2003). Environmental water is used to assist in protecting and restoring the environmental values of waterways, floodplains and wetlands that have had their natural flow cycle adversely disrupted.

The Hattah Lakes icon site comprises the Hattah Lakes wetland complex and the adjoining floodplain area, with the floodplain extent defined by the largest flood on record (in 1956) (MCMA 2021a). The hydrology of the Hattah wetlands has changed substantially because of the regulation and diversion of Murray River flows, resulting in a reduction in the frequency and duration of flooding. This has had flow-on effects on the associated vegetation, including tree deaths, transitioning to an increasingly terrestrial understorey, reduction in habitat for a range of fauna, and changes to the diversity and abundance of wetland flora (MCMA 2021a). Part of the TLM program is to deliver environmental water to Hattah Lakes icon site to restore the floodplains to a condition prior to water regulation (MCMA 2021a). Vegetation condition monitoring of twelve wetlands within the icon site has been undertaken to determine change over time and inform ongoing management of the watering program. The twelve sites have been divided into three water regime classes — semi-permanent wetlands (3 sites); persistent temporary wetlands (8 sites); and episodic wetlands (1 site).

The following section presents the findings of the vegetation condition monitoring of the twelve wetlands. It:

- assesses native water-responsive species richness and abundance in wetlands against a point of reference;
- assesses the condition of wetlands across the whole icon site using native water-responsive species richness and abundance scores; and
- examines the presence or absence of drought tolerant vegetation in wetlands.

Ecological objectives for the Hattah Lakes icon site are set out in the CMP (MCMA 2021b) are:

Objective HL3 Species richness and abundance aquatic vegetation

Improve species richness and abundance of native water-dependent floodplain and wetland aquatic vegetation at Hattah Lakes icon site by 2030.

The Specific targets relating to wetland vegetation communities under objective HL3 are:

By 2030, maintain or improve:

Reference target for wetland water responsive vegetation species richness maintained or improved across semi-permanent, persistent temporary and episodic wetlands (Brown et al. 2016).

- Semi-permanent wetlands water responsive species richness 80th percentile is ≥3.86
- Persistent temporary wetlands water responsive species richness 80th percentile is ≥3.07
- Episodic wetland (Lake Kramen) water responsive species richness 80th percentile is ≥3.84

Reference target for wetland water responsive species abundance maintained or improved across semi-permanent, persistent temporary and episodic wetlands (see Brown et al. 2016):

- Semi-permanent wetlands water responsive species abundance 80th percentile is ≥23.86
- Persistent temporary wetlands water responsive species abundance 80th percentile is ≥20.28
- Episodic wetland (Lake Kramen) water responsive species abundance 80th percentile is ≥27.48

Relevant functional groups include those identified in Huntley et al. (2016): amphibious plants, amphibious floating plants, amphibious herbs, amphibious woody plants, floating plants, and terrestrial and drought tolerant functional groups.

5.2 Methods

Twelve sites have been established for monitoring wetland vegetation communities within the Hattah Lakes icon site, of which nine were established in 2007–08, and one each were established in 2010–11, 2011–12 and 2012–13 (Huntley et al. 2016). Each wetland site has been assigned to one of three water regime classes (semi-permanent wetlands, persistent temporary wetlands, episodic wetlands). All sites have been surveyed annually since their establishment, with the exception of 2014–15 (Wood et al. 2018).

Assessments were undertaken between February and June 2023. An overview of methods followed for data collection and statistical analysis are provided below; for further details on the project methodology see MCMA (2021b).

5.2.1 Data collection

Four established transects (three at Lakes Brockie and Boich) were surveyed at each site. Perpendicular to the transect line, between three and six quadrats (15 x 1 m^2) were sampled (as 15 x 1 m x 1 m cells); these quadrats had been previously established to reflect differing elevation within the wetland (Figure 11). For the number of transects, quadrats and elevations at each individual wetland, see Table 10.

Table 10 The number of transects, quadrats and elevations at each of the 12 wetlands in Hattah Lakes.

Site	No. of transects	No. of quadrats per transect	Elevations surveyed (cm)
Chalka Creek	4	4	0, 50, 100, 150
Chalka Creek North	4	4	0, 30, 60, 90
Lake Bitterang	4	6	0, 50, 100, 150, 200, 250
Lake Boich	3	3	0, 30, 60
Lake Brockie	3	5	0, 30, 60, 90, 120
Lake Bulla	4	6	-100, -50, 0, 50, 100, 150
Lake Hattah	4	7	-100, -50, 0, 50, 100, 150, 200
Lake Kramen	4	5	50, 100, 150, 200, 250
Lake Little Hattah	4	3	0, 30, 60
Lake Mournpall	4	7	-100, -50, 0, 50, 100, 150, 200
Lake Nip Nip	4	3	0, 50, 100
Lake Yerang	4	3	0, 50, 100

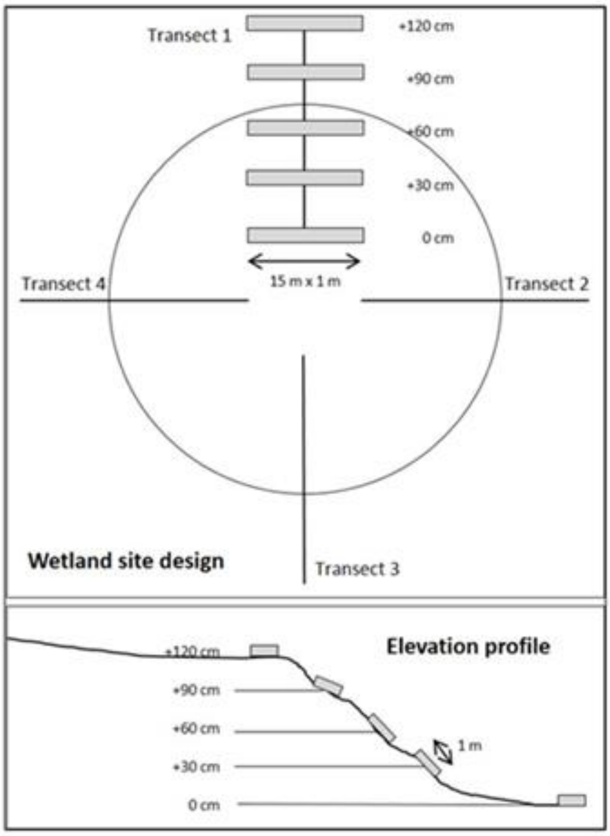


Figure 11 Schematic of the survey design used to assess wetland vegetation communities under the TLM program at the Hattah Lakes icon site (adapted from Wallace [2009] in MCMA 2022b).

Survey methods use the presence/absence of vegetation species within quadrats located along transects to produce a frequency score for each species. Species abundance in each quadrat is determined by recording the presence of each species that have live plants rooted within each cell. This provides a frequency score for each species in each quadrat of between 0 and 15. Bare earth and coarse woody debris are included as taxa (e.g. cells containing no live plants are given a bare ground score of 1).

Where an asterisk (*) precedes a plant name, it is used to signify a non-indigenous taxon, those species which have been introduced to Victoria or Australia. A hash (#) is used to denote Victorian native plants that are not indigenous to the relevant vegetation type.

The seasonality of some plant species may prove to be a limitation to the survey. Some species may have been overlooked because they were inconspicuous when the surveys were conducted or have been identified to genus level only due to the absence of fertile material. Furthermore, transects within each wetland and floodplain site are often at different stages of inundation, drawdown and drying to one another within and between seasons, affecting the growth stages and identification of species present. While these limitations may affect comparison of species level data from year to year, as Huntley et al. (2016) points out, the use of plant functional groups (see below) ameliorates this issue to a large extent.

5.2.2 Plant species identification

Species identification

Plant taxonomy and the use of common names follow the Victorian online plant census (VicFlora 2022), the Victorian Biodiversity Atlas database (DELWP 2022) and for taxa not acknowledged in Victoria the NSW online flora (PlantNET 2023). Species of state and/or national conservation significance were determined by reference to listings under the Victorian *Flora and Fauna Guarantee Act 1988* and the Federal *Environment Protection and Biodiversity Conservation Act 1999*.

Plant functional groups

Plant species recorded in surveys at Hattah Lakes are classified into functional groups (Table 11). As specified in Huntley et al. (2016), the classification of plant species into these groups is based largely on Brock and Casanova (1997) and Reid and Quinn (2004), and species that are not classified in either of these studies are assigned to functional groups based on field observations and information in VicFlora (2022) and Cunningham et al. (1992). An additional floating (F) functional group is added to identify species not attached to the substrate. Functional group T (instead of Tdr or Tda) and A (instead of Ate, Atl, Arf or Arp) are assigned where species are identified to genus or family level only (Huntley et al. 2016).

Table 11 Plant functional groups used to classify species recorded during surveys of Hattah wetlands.

FG	Description
S	Aquatic submerged species (established plants do not tolerate drying).
F	Aquatic floating, unattached species (established plants do not tolerate drying).
Arf	Amphibious, fluctuation-responder, floating species which have floating leaves in their aquatic phases and also grow stranded on damp ground.
Arp	Amphibious, fluctuation-responder, floating species, with various growth characteristics, that feature morphological plasticity in response to water level fluctuations.
Atl	Amphibious, fluctuation-tolerant, emergent species which are dicotyledons and require damp conditions (low growing plants that tolerate wetting and drying).
Ate	Amphibious, fluctuation-tolerant, emergent species which are mostly monocotyledons (emergent plants that tolerate wetting and drying).
Atw	Amphibious, fluctuation-tolerant, emergent plants which are woody (trees and shrubs that tolerate wetting and drying).
A	Amphibious species (plants that tolerate both flooding and drying).
T	Terrestrial species (plants that do not tolerate flooding).
Tda	Terrestrial species that typically occur in damp habitats.
Tdr	Terrestrial species that typically occur in dry habitats.

5.2.3 Data analysis

Point of reference assessment

Wetlands are classified into three Water Regime Classes (WRC; semi-permanent wetlands, persistent temporary wetlands and episodic wetlands). For each WRC a point of reference index of the 80th percentile has been developed for both species' richness and abundance (MCMA 2021b) (Table 12). The point of reference includes native plant species that are considered water-responsive and excludes drought-tolerant species (MCMA 2021b).

Table 12 Point of reference indices for wetland vegetation communities at the Hattah Lakes icon site (adapted from MCMA 2021b).

Water Regime Class	Wetlands in Water Regime Class	Index 1: water responsive species richness (80th percentile)	Index 2: water responsive species abundance (80th percentile)
Semi-Permanent Wetlands	Lake Bulla, Lake Hattah, Lake Mournpall	3.86	23.86
Persistent Temporary Wetlands	Chalka Creek, Chalka Creek North, Lake Bitterang, Lake Boich, Lake Brockie, Lake Little Hattah, Lake Nip Nip, Lake Yerang	3.07	20.28
Episodic Wetlands	Lake Kramen	3.84	27.48

As outlined in Wood et al. (2018) wetland vegetation is considered to be in good condition when:

- native water-responsive species richness in a WRC is at or above the 80th percentile reference index (Table 12, adapted from MCMA 2021b)
- native water-responsive species abundance in a WRC is at or above the 80th percentile reference Index (Table 12, adapted from MCMA 2021b).

To calculate if water-responsive species richness was in good condition for wetlands (adapted from MCMA (2021b)):

- all years of data were used, including only native water responsive plant species (e.g. species associated with the following functional groups; S, F, Arf, Arp, Atl, Ate, Atw, A and Tda) and excluding records classified only to genus level
- the total number of species were averaged across all quadrats for each transect for each year
- for each WRC in each year, transects with water responsive species richness at or above the 80th percentile (Index 1 in Table 12) score = 1 (compliant), and transects with water responsive species richness below the point of reference score = 0 (non-compliant)
- the proportion of compliant transects across all wetlands within each WRC was plotted over time.

The same steps (above) were applied to determine if water responsive species abundance was in good condition for each WRC. Abundance measures for each species in each quadrat (i.e. maximum of 15 per species) were summed and then a transect abundance measure was estimated by averaging the quadrat abundance measures within each transect.

In 2022–23, all previous years were re-analysed to assess compliance against targets for native water-responsive species richness and abundance as it was noted that previous analyses had been inconsistent in using only native species, with some also including exotic species as per Huntley et al. 2016. It appears that the decision to exclude exotic species was only made formal in the MCMA 2020 Draft CMPs, where formerly it was not specified whether to exclude exotic species.

Whole-of-icon-site wetland scores were calculated by weighting the strata scores for both the richness and abundance of native water-responsive species, considering the total number of wetlands in each water regime class (WRC) in the Hattah Lakes icon site, and the number of transects sampled within each WRC. Scores were weighted using the example shown in Brown et al. (2016), informed by methods to estimate an overall mean from a stratified sample (Sutherland 2006). The number of wetlands in each of the WRCs at the Hattah Lakes icon site was converted to total number of possible transects, to ensure that the number of surveyed transects represents a sub-sample (Table 14). The total number of possible transects assumes that each wetland has four potential transects, except for the Lake Boich and Lake Brockie wetlands, where three transects have been surveyed. To determine 95% confidence intervals, t-values were calculated in excel using the T.INV.2T function for $P = 0.05$ (two-sided), using the degrees of freedom method shown in Sutherland (2006). The whole-of-icon site scores were calculated for each survey year since 2007–08 (excluding 2014–15) and presented with 95% confidence intervals.

icon site scores were plotted as a time series to examine the effect environmental watering has had on the richness and abundance of water responsive species at an icon site scale. The inundation status of sites for each year was also displayed on the time series figure. The inundation status of wetland sites was based upon data compiled by the MCMA (Table 2). In 2022–23 Ecology Australia staff updated the water history information displayed on time series figures for all previous years of monitoring as it was noted that there were some discrepancies between information originally used by Ecology Australia staff for compiling these figures and updated information provided by the MCMA. Ecology Australia has been advised by the MCMA that water history information is sometimes refined over time by the MCMA as they gain a more accurate understanding of site inundation history which may account for discrepancies. Watering events are simplified in the Whole-of-icon site score graphs to display if across the whole icon site, there was no flooding across any sites, e-water delivery at any sites, natural flooding at any sites, or a combination of both natural flooding and e-water at any sites.

Drought-tolerant vegetation in wetlands

One of the original ecological objectives ‘non-macrophyte vegetation in lakes’ was intended to identify if there was an encroachment of drought tolerant plant species (i.e. species from the Tdr functional group) into wetlands (Huntley et al. 2016). Analysing the presence/absence of plant species through functional group representation in each WRC in each survey year was used to make this determination (Wood et al. 2018). This was to be considered with respect to whether or not the presence of drought tolerant species is a natural occurrence (e.g. the presence of a drought tolerant community may be a reflection of the natural dry phase of an ephemeral wetland) (Wood et al. 2018). Therefore, this objective may only be relevant to some wetlands in some years (Huntley et al. 2016).

Charts were produced to display the proportion of functional group abundance data for each survey year, in each WRC. For display purposes, functional groups A, Arf, Arp, Ate, Atl (for definitions see Table 11) were combined into one amphibious group ‘A’. Functional group ‘T’ was excluded from these graphs as it was not possible to determine if these species were drought tolerant (Tdr) or terrestrial damp (Tda) species.

Species richness and abundance among sites

Mean species richness and abundance across wetland sites was calculated from the total number of species recorded at each wetland and the total number of times species were recorded at each wetland. Richness and abundance were calculated for both native and introduced species.

5.3 Results

5.3.1 Data summary

A total of 58 vascular plant taxa were recorded from the twelve Hattah wetland sites during the 2022-23 monitoring. Of these, 50 (86%) were indigenous and eight (14%) were exotic. This represents a decrease in the number of taxa identified from the previous 2021-22 survey period (68 taxa), while the percentage of native and exotic taxa changed by one percent.

Although most transects at wetland sites were inundated during surveys, two species (matted water-starwort *Callitriche sonderi* and Indian cudweed *Gnaphalium polycaulon*) were recorded in transects for the first time since monitoring began. Six species listed as threatened under the *Flora and Fauna Guarantee Act 1988* (FFG Act) were recorded (Table 13), which represents a slight decrease from eight in the previous survey period. All six threatened species are classified as endangered under the Act. Each of these species has been recorded across the monitoring program in previous years. For further details on plant species recorded please refer to the 2022-23 Part B report (Butler et al. 2023a).

Table 13 Threatened plant species recorded across Hattah Lakes wetland sites during TLM Condition monitoring, 2007–08 – 2022–23. The number of transects each species was recorded in during each survey period is also displayed.

Key: P = Protected flora species under the FFG Act, vu = listed as vulnerable under the FFG Act, e = Listed as endangered under the FFG Act, cr = Listed as critically endangered under the FFG Act.

Scientific name	Common name	Status	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	All years pre-2022-23 combined	2022-23
Ammannia multiflora	Jerry-jerry	en P					2			1	2				6	11	2
Asperula gemella	Twin-leaf bedstraw	en P					4									4	
Austrobryonia micrantha	Mallee cucumber	en P	13	3	5	3	7	1		1	1	1			1	36	3
Bergia trimera	Small water-fire	en P											4		3	7	
Calotis cuneifolia	Blue burr-daisy	en P		1		8	7	13	4		10	7	2	10	13	75	2
Chenopodium desertorum subsp. *desertorum*	Frosted goosefoot	en P		5	1											6	
Chenopodium desertorum subsp. *rectum*	Frosted goosefoot	en P												1		1	
Convolvulus clementii	Desert bindweed	en P											2	3		5	
Cyperus pygmaeus	Dwarf flat-sedge	en P								1						1	1
Eragrostis australasica	Cane grass	cr P			1						1					2	
Eragrostis lacunaria	Purple love-grass	en P		1								10				11	
Glossostigma diandrum	Spoon-leaf mud-mat	en P													1	1	
Gratiola pumilo	Dwarf brooklime	en P			5	1	2								5	13	
Phyllanthus lacunarius	Lagoon spurge	en P						1		2	4				3	10	4
Sclerolaena patenticuspis	Spear-fruit copperburr	vu P						1								1	
Swainsona microphylla	Small-leaf swainson-pea	en P					2	2	1				3	2		10	1
Trigonella suavissima	Sweet fenugreek	en P						6							5	11	
Vittadinia condyloides	Club-hair New Holland daisy	en P												1		1	
Vittadinia pterochaeta	Winged New Holland daisy	en P			3											3	

5.3.2 Point of reference assessment

Water-responsive species richness

For the third year in a row, no transects within the semi-permanent WRC (SPW) were compliant with the native water responsive species richness index (Table 14; Figure 12). Compliance rates within the episodic WRC (EPW) decreased from 50% compliance in 2020-21 to 0 compliant transects in 2022-23. Meanwhile, compliance rates within the persistent temporary WRC (PTW), were 17% as was the case in 2021-22. This meant that 17% of transects within PTWs met or exceeded the target of 3.07 species per transect, averaged across all elevations. Across the icon site, compliance decreased from 16% of transects (7 transects) in 2021-22, to 11% compliant in 2022-23 (5 transects).

Table 14 Number of transects compliant with ecological targets relating to species richness and abundance of native water-responsive species, in each water regime class (WRC) at the Hattah Lakes icon site, as surveyed in the 2022-23 season. Also shown are stratum scores for each WRC, a weighted icon site wetland score (with 95% confidence intervals for two sampled comparisons with normally distributed error variance) and the surveyed and total number of wetlands in each category. Stratum scores were weighted by the total number of possible transects in each WRC (in parentheses) to reflect the number of wetlands.

Water regime class (WRC)	No. wetlands at icon site	No. surveyed wetlands	Species richness			Species abundance		
			No. compliant transects	Strata score	icon site score	No. compliant transects	Strata score	icon site score
Semi-permanent (SPW)	5	3	0 of 12	0	0.107 (±0.057)	0 of 12	0	0.085 (±0.052)
Persistent temporary (PTW)	13	8	5 of 30	0.167		4 of 30	0.133	
Episodic (EPW)	2	1	0 of 4	0		0 of 4	0	

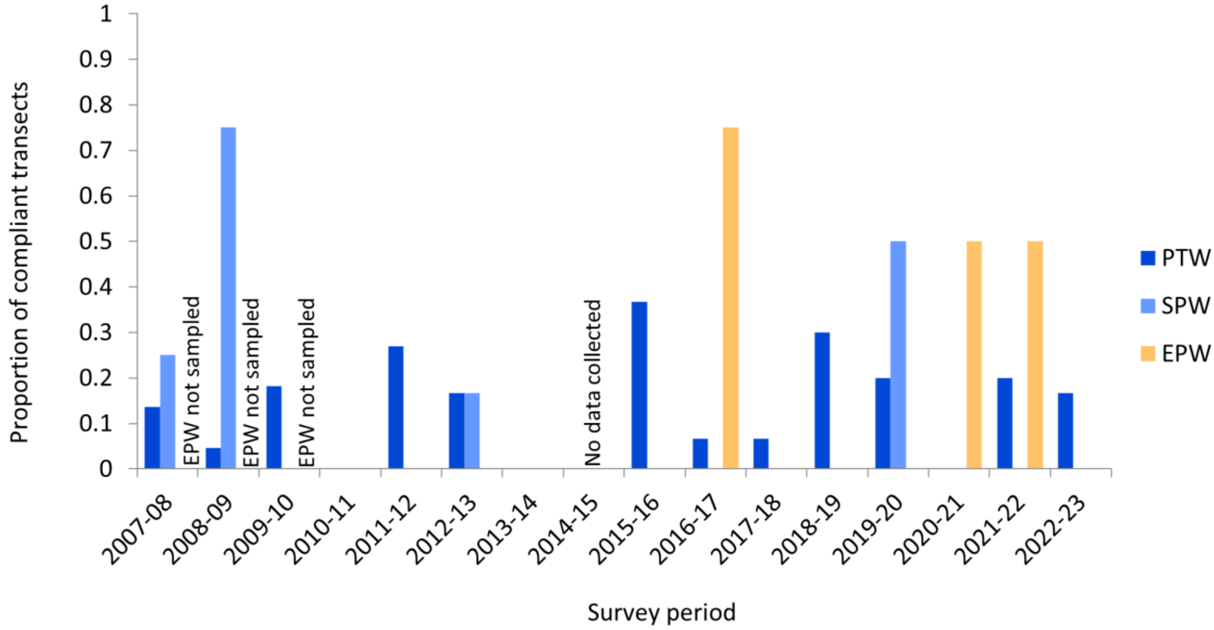


Figure 12 Proportion of transects from wetlands in WRCs at the Hattah Lakes icon site considered compliant with the native water-responsive species richness index (transects with a mean species richness score above the 80th percentile).

Water responsive species abundance

In 2022–23 only 13% of PTW sites had any compliant transects in Hattah Lakes wetlands. This represented no change from levels recorded for PTW wetlands in 2021–22. This meant that 13% of PTW transects met or exceeded the target of 20.28 for species abundance, which is average across all elevations within a given transect. No EPW sites were compliant in 2022–23, as compared with a 50% compliance rate in 2021–22. No SPW sites have been compliant in terms of species abundance since 2019-20.

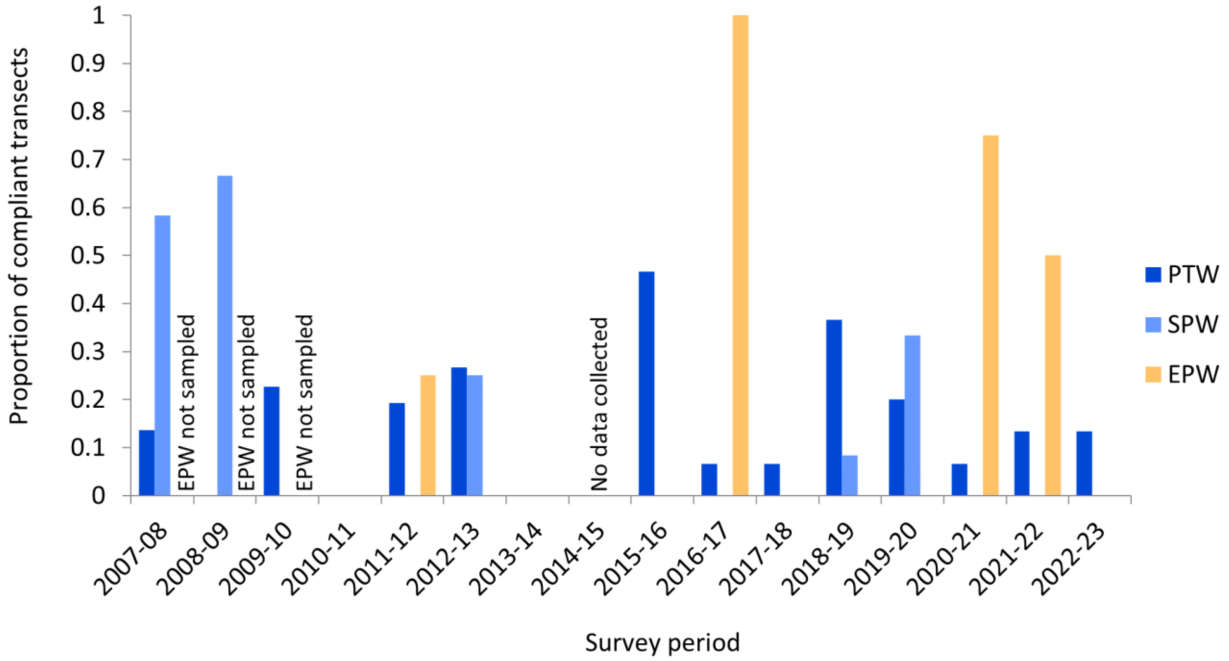


Figure 13 Proportion of transects from wetlands in WRCs at the Hattah Lakes icon site considered compliant with the native water-responsive species abundance index (transects with a mean species abundance score above the 80th percentile).

Table 15 Hattah Lakes icon site – summary of compliant transects.

Wetland	No. of compliant transects		Potential Factors affecting compliance
	Richness	Abundance	
Persistent Temporary Wetlands			
Chalka Creek	0 of 4	0 of 4	All transects below +150 cm inundated. Non-inundated transects consisting mostly of aquatic species including river red gums, eumong and small spike-rush
Chalka Creek North	4 of 4	2 of 4	High water-responsive species richness and abundance in non-inundated transects (+30 to +90 cm), including FFG-listed species lagoon spurge and mallee cucumber.
Lake Bitterang	1 of 4	2 of 4	Only non-inundated transects were +250. Most abundant species included river red gum, common sneezeweed and spreading nut-heads.
Lake Boich	0 of 3	0 of 3	No species recorded due to inundation depths being too great at designated transect elevations to sustain aquatic flora.
Lake Brockie	0 of 3	0 of 3	Only one emergent amphibious species present, river red gum, due to inundation depths being too great to

Wetland	No. of compliant transects		Potential Factors affecting compliance
	Richness	Abundance	
			sustain aquatic flora at designated transects elevations.
Little Lake Hattah	0 of 4	0 of 4	Only one emergent amphibious species present, river red gum, due to inundation depths being too great at designated transect elevations to sustain aquatic flora.
Lake Nip Nip	0 of 4	0 of 4	Only one emergent amphibious species present, river red gum, due to inundation depths being too great at designated transect elevations to sustain aquatic flora.
Lake Yerang	0 of 4	0 of 4	No species recorded due to inundation depths being too great at designated transect elevations to sustain aquatic flora.
Semi-Permanent Wetlands			
Lake Hattah	0 of 4	0 of 4	Only two emergent amphibious species (river red gum and spiny flat-sedge) present due to inundation depths, including at higher elevations.
Lake Mournpall	0 of 4	0 of 4	Only two emergent amphibious species (river red gum and spiny flat-sedge) present due to inundation depths, including at higher elevations.
Lake Bulla	0 of 4	0 of 4	Only one emergent amphibious species (river red gum) present due to inundation depths.
Episodic Wetlands			
Lake Kramen	0 of 4	0 of 4	Only one emergent amphibious species (river red gum) present due to inundation depths.

Whole-of-icon site score

The proportion of transects compliant with native water-responsive species richness indices at Hattah Lakes differed across WRCs (Table 14). Of the total 46 transects, five transects were compliant in PTW, with no compliant transects in the EPW or SPW WRCs. The icon site score for native species richness at wetlands during the current survey (0.107) represents a decrease compared to the previous survey period (0.179) (Figure 14).

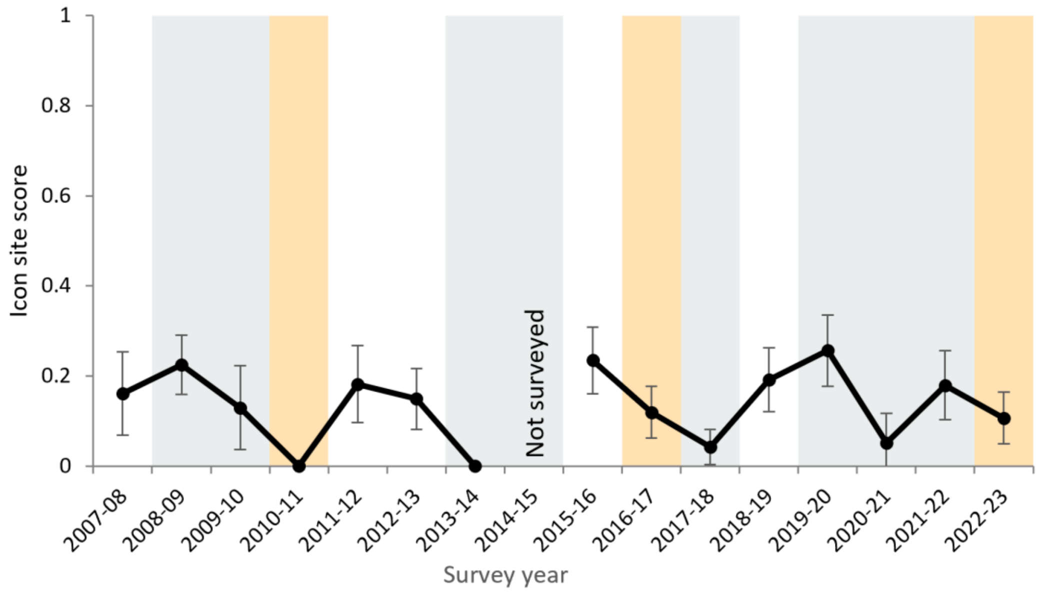


Figure 14 icon site scores for the Hattah Lakes icon site wetlands based upon native water-responsive species richness indices and weighted across each WRC (± 95% confidence intervals for two sampled comparisons with normally distributed error variance) across survey years. Water events are shaded (grey: e-water; orange: natural flooding and e-water; white: non-flooded). Inundation history was provided by the MCMA and is detailed in Table 2.

Mean icon site species richness scores in wetlands slightly higher in seasons without flooding, compared to seasons with environmental water delivery (0.18 and 0.13, respectively) (Figure 15). Mean icon site scores for wetland species richness in years with both natural flooding and environmental water had the lowest Mean icon site score of 0.08.

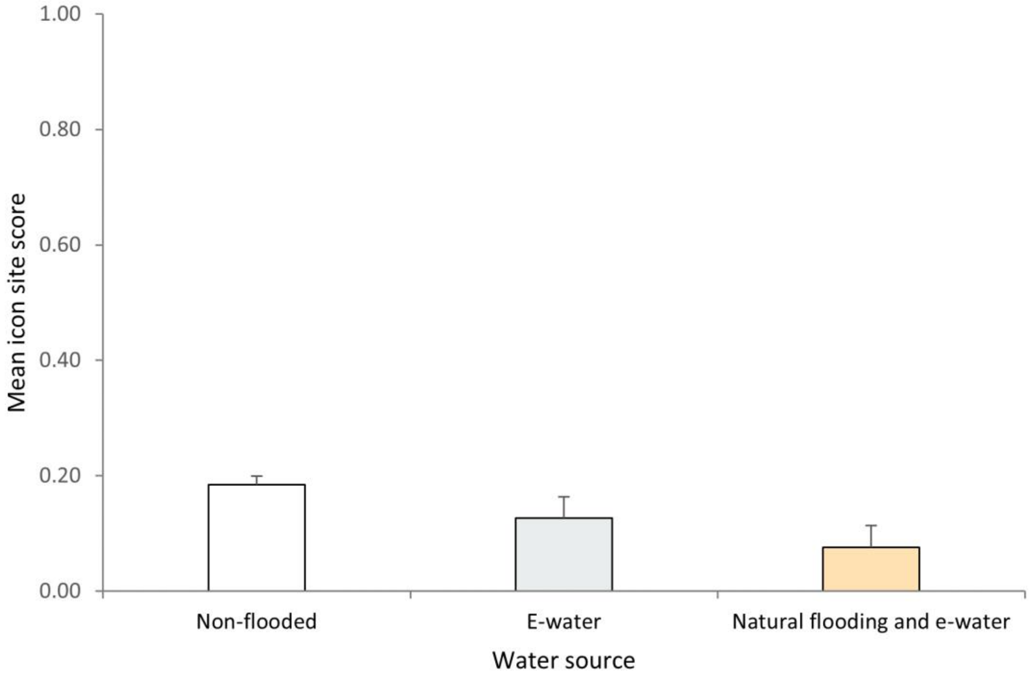


Figure 15 Mean icon site wetland scores based upon native water-responsive species richness indices, for the Hattah Lakes icon site (± standard error), for each water event type. Non-flooded years n = 5, natural flooding n = 0, e-water n = 7, natural flooding and e-water n = 3. Inundation history was provided by the MCMA and is detailed in Table 2.

In 2022–23, 4 of the 46 transects were compliant in terms of species abundance within Hattah Lakes wetlands, all of which were PTW WRCs (Table 14). This translated to an icon site score of 0.085 across the three WRCs. This represents a slight decrease from the icon site of 0.137 recorded in 2021–22 (Figure 16).

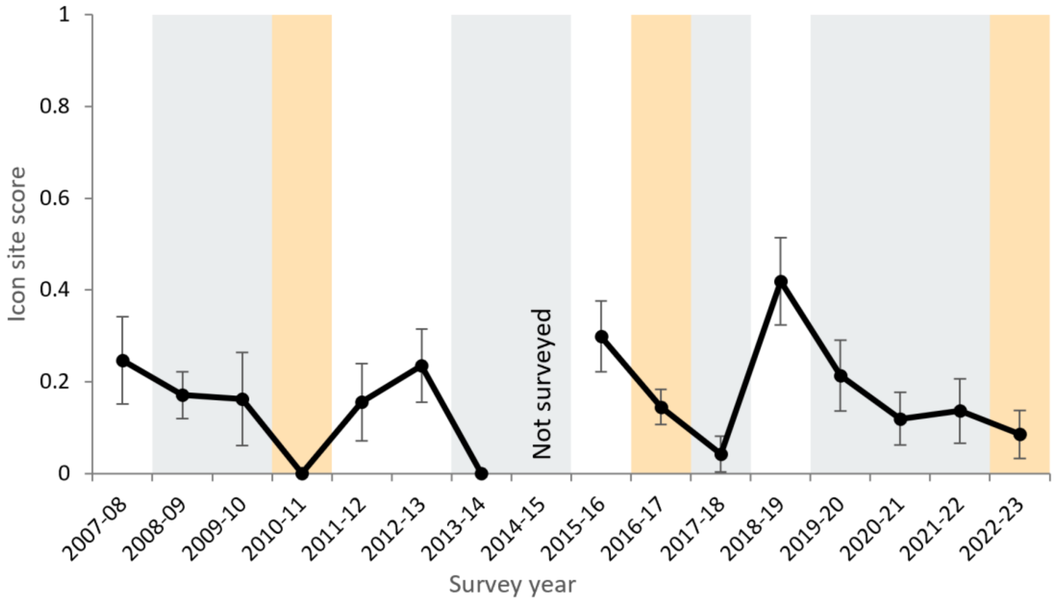


Figure 16 icon site scores for the Hattah Lakes icon site wetlands based upon native water-responsive species abundance indices and weighted across each WRC (± 95% confidence intervals for two sampled comparisons with normally distributed error variance) across survey years. Water events are shaded (grey: e-water; orange: natural flooding and e-water; white: non-flooded). Inundation history was provided by the MCMA and is detailed in Table 2.

Results indicate Mean icon site scores for native water-responsive species abundance across wetlands at Hattah Lakes were higher in seasons without flooding (0.27), compared to seasons where wetlands received water, either naturally or through e-water events (Figure 17). The Mean icon site score was higher in years that only received e-water (0.12) compared to years which received both natural flooding and e-water (0.08).

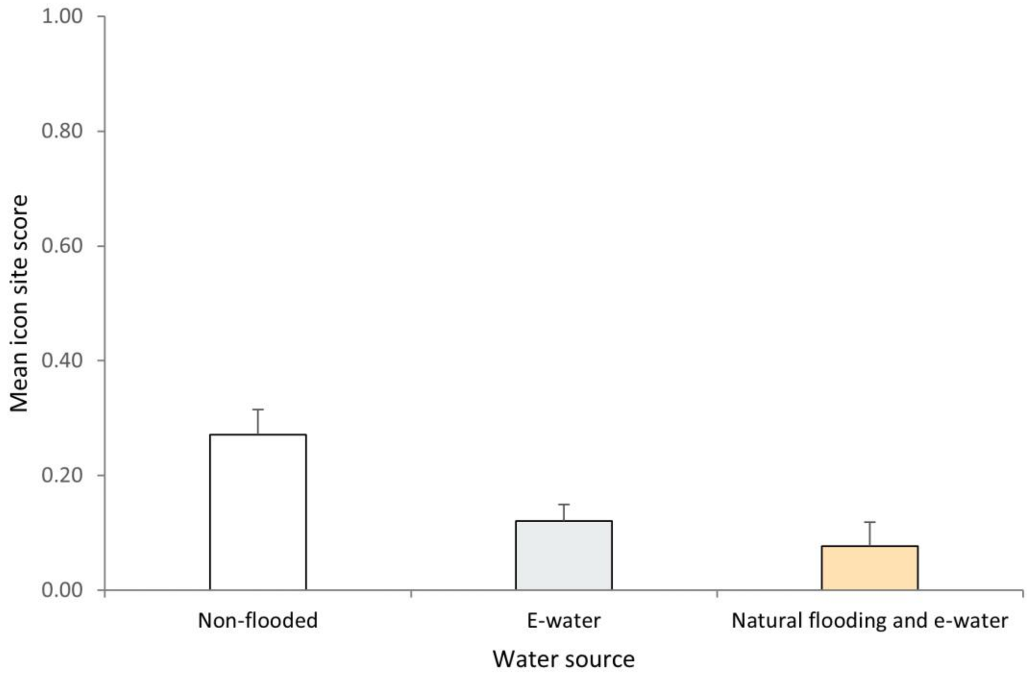


Figure 17 Mean icon site wetland scores based upon native water-responsive species abundance indices, for the Hattah Lakes icon site (± se), for each water event type. Non-flooded years n = 5, natural flooding n = 0, e-water n = 7, natural flooding and e-water n = 3. Inundation history was provided by the MCMA and is detailed in Table 2.

Drought-tolerant vegetation in wetlands

The inundation of all wetlands within the SPW category for the second year in a row has led to a dominance of amphibious species recorded across the wetlands (Figure 18). Similar to 2021-22, no terrestrial dry (Tdr) or damp (Tda) species were recorded across any of the SPW wetlands, with all transects being inundated across the three sites. This lack of terrestrial species has led to a substantial increase in the proportional abundance of woody amphibious fluctional tolerators (Atw) since 2020-21 (12%), which increased to 76% in 2021-22 and again to 85% in 2022-23 (the highest abundance for this functional group within SPW since the inception of monitoring).

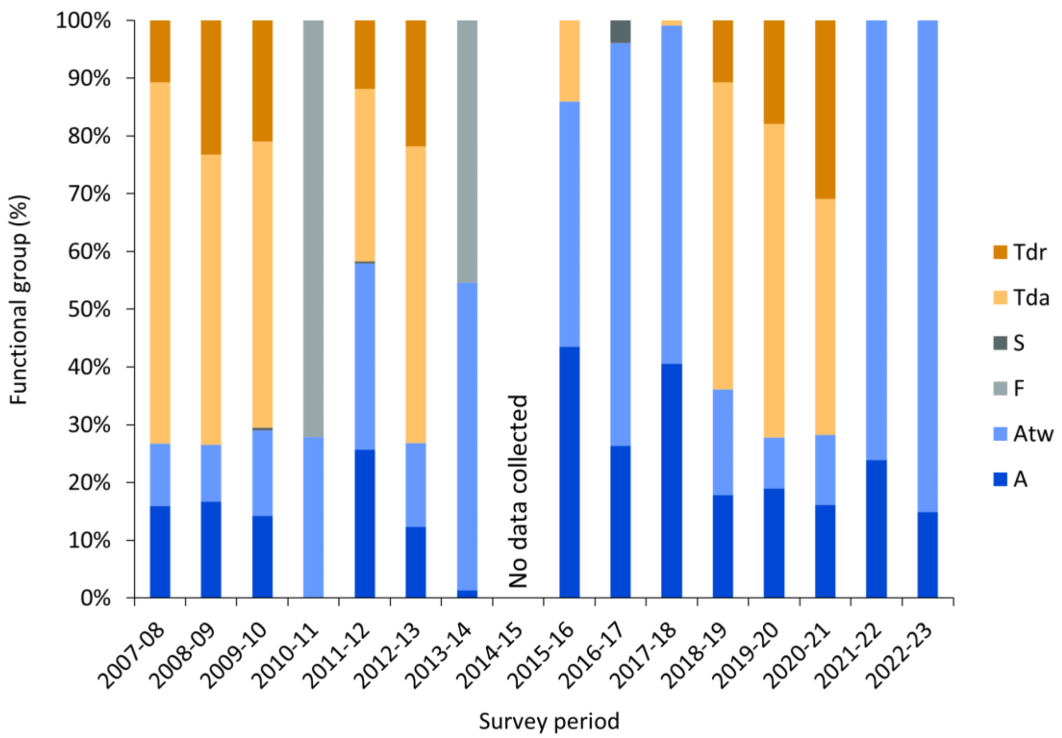


Figure 18 Semi-Permanent Wetland WRC (SPW), proportion of sum of abundance for each functional group at the Hattah Lakes icon sites for each survey period.

Complete inundation of all wetlands across the PTW class over the last two years has led to an increase in the proportional abundance of amphibious and aquatic species and a decrease in terrestrial functional groups. The abundance of woody amphibious fluctuation tolerators (Atw) increased from 11% in 2021-22 to 14% in 2022-23. The abundance of aquatic and amphibious functional groups (A) has remained steady with 2021–22 levels at 27% (Figure 19). The proportional abundance of terrestrial dry species (Tdr) remained steady with 2021-22 at 15%, and the proportion abundance of terrestrial damp species (Tda) decreased from 48% in 2021-22 to 44% in the current survey period.

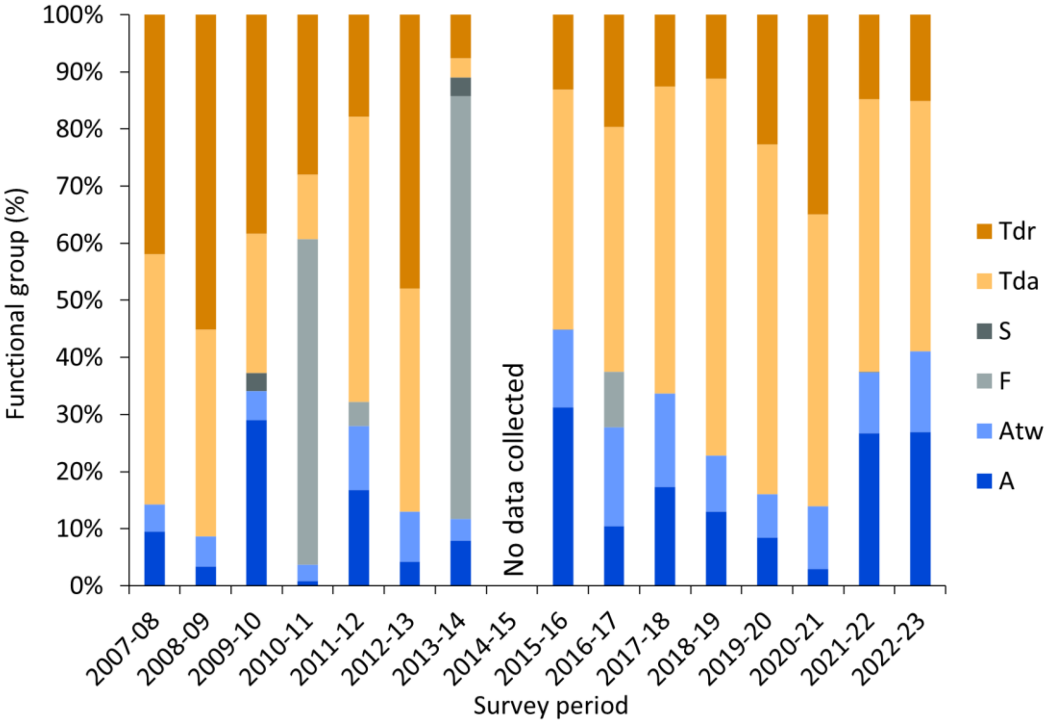


Figure 19 Persistent Temporary Wetland WRC (PTW), proportion of sum of abundance for each functional group at the Hattah Lakes icon sites for each survey period.

Lake Kramen (the only EWP site surveyed) was inundated in 2022, leading to a large shift in the plant functional groups recorded across the site. In 2021–22 Lake Kramen recorded over 90% combined terrestrial dry and terrestrial damp species, which shifted to 100% amphibious emergent woody tolerator species (trees and shrubs which can cope with flooding) in the current survey period (Figure 20). All Atw species recorded at Lake Kramen in 2022–23 were established river red gums.

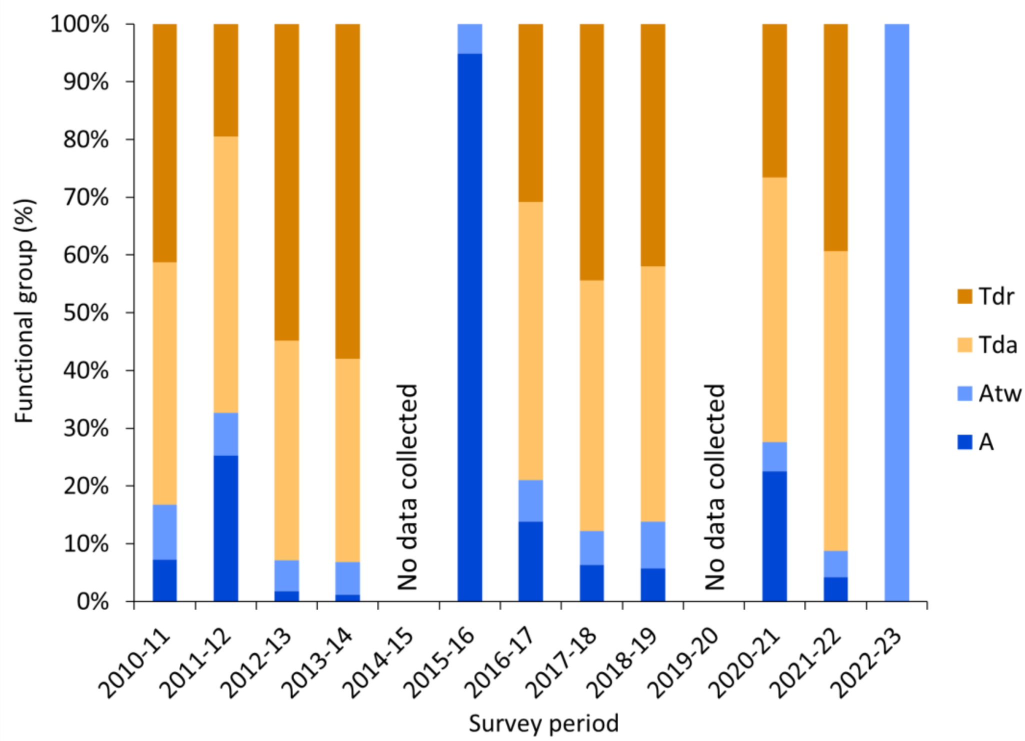


Figure 20 Episodic Wetland WRC (EPW), proportion of sum of abundance for each functional group at the Hattah Lakes icon sites for each survey period.

5.3.3 Species richness and abundance among sites

With the exception of Lake Kramen (the only episodic wetland surveyed), inundation across the Hattah icon site in late 2022 and early 2023 did not have a great influence on species richness or abundance (Figure 21, Figure 22). While in the late stages of drawdown in the 2021-22 season, Lake Kramen was completely inundated throughout the 2022-23 season, resulting in extremely low levels of richness and abundance. Additionally, increased levels of inundation at wetland sites in 2022-23 have led to lower levels of abundance across persistent temporary wetlands in 2022-23.

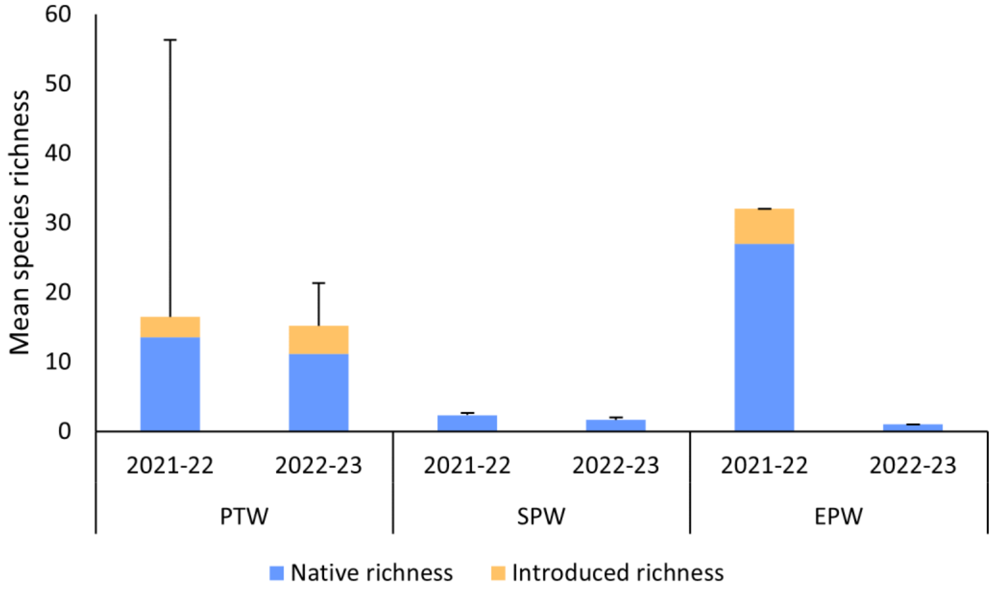


Figure 21 Mean species richness across wetland sites (±SE)

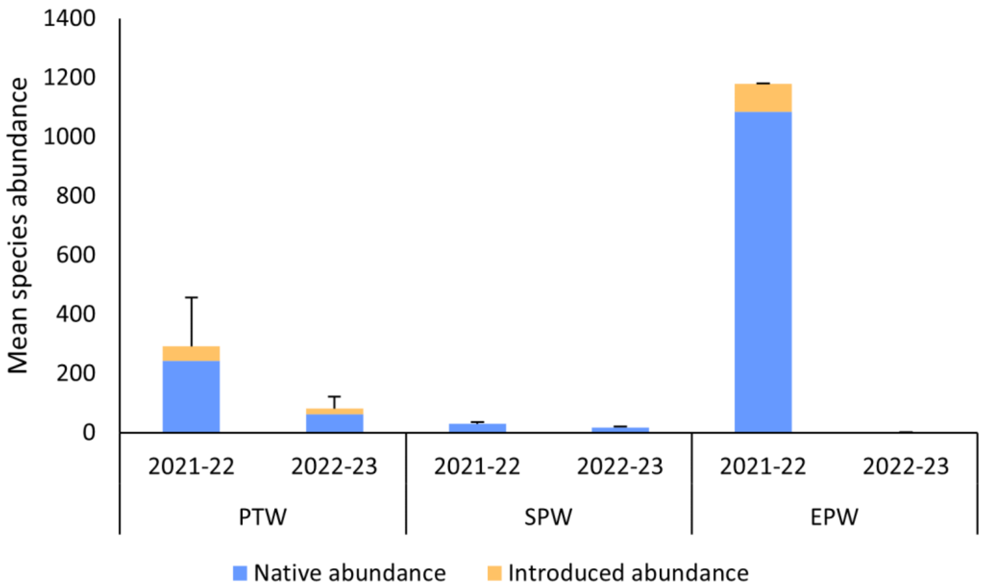


Figure 22 Mean species abundance across wetland sites (±SE)

5.4 Discussion

5.4.1 Persistent temporary wetlands

As was the case in 2021-22, five of the 30 transects surveyed across the persistent temporary wetlands (PTW) were compliant for water-responsive species richness. This still represents a substantial increase from no compliant transects in the 2020-21 survey period, although this is a slight decrease since the two surveys prior (2019–20 [6] and 2018–19 [9]).

In 2022–23 the number of compliant transects for species abundance held steady with 2021–22, with 4 compliant transects (13%) recorded across both periods. This persistently low compliance for species abundance reflects the ongoing partial or complete inundation of all wetlands across the icon site in 2021–22 and 2022–23. This heavily influences both species richness and abundance levels recorded throughout the survey period and does not necessarily represent a decrease in wetlands conditions across the icon site.

For the second year in a row, a proportional shift in functional groups has occurred at PTW sites from a largely terrestrial dry and terrestrial damp flora dominated community to a greater number of amphibious species. High levels of inundation throughout the 2022–23 survey period can be attributed to a combination of environmental watering received as well as the historically high flow levels in late 2022 and early 2023. High inundation levels across PTW transects with minimal drawdown occurring have meant low numbers of species were recorded at these sites during this survey period, while also contributing to the increased proportion of amphibious species.

Trends in functional group occurrence across time are consistent with previous findings, where aquatic and amphibious species (S, F and A functional groups) are dominant during flooding and watering events, while Tda (terrestrial damp) and amphibious species tend to increase in richness and abundance during drawdown phases, followed by dominance of Tdr species during extended dry periods.

5.4.2 Semi-permanent wetlands

As was the case in 2021-22, none of the three wetlands that comprise the semi-permanent wetland (SPW) WRC were found to be compliant for species richness or abundance in the current survey period. The last time any SPW sites were compliant for either species richness or abundance was in 2019–20.

The only survey periods which saw compliant transects for SPW sites were during non-flooded seasons, where wetland drawdown had recently occurred, and few transects were inundated. These survey periods coincided with a higher proportion of terrestrial damp species, while amphibious genera were also retained. As found in Casanova and Brock (2000), soils which remain damp but not inundated have the highest species richness and biomass. During periods of inundation, fewer terrestrial damp species, and fewer species in general, were present. During extended dry conditions, such as in 2020–21, a shift in functional group composition occurred such that terrestrial dry species became more dominant, thus reducing water-responsive species richness and abundance. Following extensive inundation over the last two survey periods, amphibious species have been the only species found at SPW transects.

5.4.3 Episodic wetlands

Lake Kramen is the only wetland within the episodic wetland group and is therefore limited in sample size. No transects at Lake Kramen were found to be compliant for either species richness or abundance, representing a decrease from 2021-22, where two of the four transects were found to be compliant for species richness and three out of four were compliant for species abundance. While Lake Kramen was in a drawdown phase in both 2020-21 and 2021-22, it was completely inundated during the 2022-23 period. The only other instances of compliance over the duration of the monitoring program, occurred during survey periods that coincided with wetland drawdown.

Historically, the distinct differences in species composition at Lake Kramen compared to the other wetland sites are likely driven by the cumulative effects of spatial separation and a different temporal watering regime. In previous years, Lake Kramen has undergone drawdown while other wetlands were inundated. This has led to a greater proportion of terrestrial dry species being associated with this WRC. Furthermore, the inundation history of the wetlands at Hattah Lakes have generally been uniform across the duration of the monitoring program, with the exception of Lake Kramen. This difference in watering regime has potentially driven the divergence in species composition found at Lake Kramen, with inundation duration and frequency identified as key influences on the formation of wetland plant communities (Casanova and Brock 2000). In 2022-23, all species recorded at Lake Kramen were Atw species (see Table 11), however these were all established river red gums.

5.4.4 Whole of icon site

Across the whole icon site, 11% of transects were compliant for water-responsive species richness while 9% were compliant for water-responsive species abundance. This represents a slight decrease in compliance from the last survey period for species richness (18% in 2021–22) and species abundance (14% in 2021–22). Decreases in species richness and abundance can be attributed to the high levels of inundation across wetlands during the previous 2 survey periods. Opportunities for population growth were limited to the few higher elevation transects at inundated sites where some drawdown had occurred, thus greatly restricting richness and abundance levels. With gradual drawdown following the current inundation levels at each of the sites, it is highly likely that a substantial increase in both water-responsive species richness and abundance will be detected during future survey periods.

5.4.5 Change in condition and progress towards objectives

Wetland vegetation in arid and semi-arid regions such as Hattah Lakes is highly dynamic and responds rapidly to watering and drying events across different temporal and spatial scales (Capon 2003). Conclusively establishing whether or not ecological objectives have been met at a whole of site scale is problematic as it does not accurately allow for such rapid responses to short-term fluctuations in water availability.

Assessing changes in wetland species composition between years when any given individual wetland could be in different wetting or drying phases makes it difficult to assess progression towards the ecological objectives over time. Wetlands assessed as part of this monitoring program are regularly in differing stages of inundation when being surveyed. During the 2022-23 surveys, the only wetland sites with non-inundated transects were some higher elevation transects at Lake Bitterang, Chalka Creek and Chalka Creek North. In recent years prior to 2020-21 however, all wetlands have either been dry or only partially inundated. Variability in inundation levels can also be found between sites in any given year. While higher flows in the Murray River result in water flowing into Chalka Creek and through the Hattah Lakes complex, Lake Kramen, disconnected from the main Hattah Lakes complex, is often dry while all other lakes throughout the icon site are full.

Wetlands that have recently undergone drawdown or are dry during surveys are far more likely to be compliant for species richness and abundance compared to those that are inundated. As almost all wetland transects were completely inundated at the time of surveys, compliance scores for richness and abundance in 2022-23 were either at similar levels to last year or lower. Conducting surveys while sites are inundated will lead to longer-term results indicating species richness and abundance is not increasing, which may not necessarily be the case.

Wetland transect compliance scores that do not take into account these varying stages of wetting and drying are unlikely to provide an accurate indication of the trajectory of wetland condition across time. Furthermore, lower or similar species richness and abundance this year compared to last year does not necessarily mean long-term condition is not improving. However, it does indicate that richness and abundance tends to be lower when sites are inundated.

5.5 Objectives and target attainment

The icon site scores for native water-responsive species richness and abundance at wetlands during the current survey were lower than the scores recorded in the previous survey period. The cumulation of results across the duration of the monitoring program suggest that wetland drawdown, following an inundation event, facilitates a shift in wetland vegetation communities from a terrestrial dry species dominated composition, to a community with a higher proportion of amphibious and terrestrial damp species. A corresponding increase in compliance in water-responsive species richness and abundance can be seen during these periods.

The percentage of PTW transects compliant with species richness and abundance targets remained constant with 2021–22 levels, with a compliance rate of 13%. Decreases were recorded for richness and abundance for EPW, while no changes were found for SPW sites. This suggests only partial progress has been made towards the overarching objective, to ‘improve species richness and abundance of native water-dependent floodplain and wetland aquatic vegetation at Hattah Lakes icon site by 2030’. However, as surveys were conducted while the vast majority of transects were inundated, these scores do not necessarily indicate the condition across sites has worsened.

No guidance is provided in the CMP as to what definitions should be used for determining overall compliance with the objectives provided below i.e., what percentage of transects need to be compliant for specific species richness and abundance targets for objectives to be considered as attained, partially attained or not attained. Therefore, overall objective and target attainment was defined as follows: not attained was defined as no transects across the Whole-icon-Site being compliant for species richness or abundance targets. Partial attainment was defined as at least one of the transects meeting compliance targets for species richness and abundance. Full attainment was defined as the majority of transects meeting compliance targets for species richness and abundance or displaying a positive trend of compliance over time.

Table 16 Summary of Hattah Lakes wetland target attainment in 2022–23.

Objective HL3 Improve species richness and abundance of native water-dependent floodplain and wetland aquatic vegetation at Hattah Lakes icon site by 2030.	**Attained**	**Partial attainment**	**Not attained**
Specific targets:			
Species richness			
• Average water-responsive species richness of each transect within semi-permanent wetlands (SPW) is greater than or equal to the reference target 80th percentile (≥3.86)			
• Average water-responsive species richness of each transect within persistent temporary wetlands (PTW) is greater than or equal to the reference target 80th percentile (≥3.07)			
• Average water-responsive species richness of each transect within the episodic wetland (EPW) (Lake Kramen) is greater than or equal to the reference target 80th percentile (≥3.84)			
Species abundance			
• Average water-responsive species abundance of each transect within semi-permanent wetlands (SPW) is greater than or equal to the reference target 80th percentile (≥23.86)			
• Average water-responsive species abundance of each transect within persistent temporary wetlands (PTW) is greater than or equal to the reference target 80th percentile (≥20.28)			
• Average water-responsive species abundance of each transect within the episodic wetland (EPW) (Lake Kramen) is greater than or equal to the reference target 80th percentile (≥27.48)			

5.6 Recommendations

More informative assessments of change in individual wetlands could be made by developing indices for wetlands at varying wetting/drying stages. This would allow comparisons of wetlands in the same wetting or drying phase to be made across seasons. As the wetlands at Hattah Lakes are of varying elevations and depths, individual wetlands hold water for varying periods of time, allowing a mosaic of vegetation communities to develop following inundation events. Thus, we also recommend developing objectives/indices that focus on maintaining as much spatial heterogeneity in plant community composition and structure across the landscape as possible, rather than broad scores based on overall transects compliant for richness and abundance. Regular (approx. every 3-6 months) vegetation monitoring of wetlands following drawdown is also highly recommended. Inundation events provide a valuable opportunity to gain an accurate assessment of wetland species composition as well as seedbank composition and assist in determining where further management actions (e.g. grazing enclosures) are needed at a more localized scale.

6 Floodplain Vegetation Communities

6.1 Introduction

Floodplains are dynamic features of the riverine landscape. Floodplains include both aquatic and terrestrial habitats, making them highly productive and diverse ecosystems, often supporting large and diverse populations of plants and animals. In temperate and tropical regions, flow has been found to be the primary determinant of floodplain plant community composition and structure, and crucial to the maintenance of the floodplain ecosystem (Capon 2004). Frequency and duration of flooding across a floodplain affects the distribution of vegetation communities and their composition, which changes both temporally and spatially. Anthropogenic changes to the frequency of flooding can result in significant changes to plant community and composition, including loss of native species and increased invasion of exotic species (Capon 2004). For example, many plant species are adapted to regular disturbance by floods and will be replaced by more drought tolerant (including invasive) species if flooding frequencies are reduced. Changes to floodplain hydrology can also lead to a decline in the condition of the dominant riparian tree species (Holland et al. 2013).

The Hattah Lakes floodplain's hydrology has changed substantially as a result of the regulation and diversion of Murray flows, resulting in a reduction in the frequency and duration of flooding, which has caused a decline in the condition of floodplain vegetation communities (MCMA 2021a). With the delivery of environmental water to the Hattah Lakes icon site, it is hoped that the condition of floodplain vegetation will improve. Monitoring at six locations within the Hattah icon site has been established to investigate the overall condition of the floodplain vegetation community at the icon site. The monitoring program has also provided the opportunity to examine the efficacy of the watering program.

The objective developed and refined in the CMP for understorey vegetation at the Hattah Lakes icon site is:

Objective HL3 Species richness and abundance of aquatic vegetation

Improve species richness and abundance of native water-dependent floodplain and wetland aquatic vegetation at Hattah Lakes icon site by 2030.

The specific targets relating to floodplain vegetation communities under objective HL3 are as follows:

Reference target for floodplain water responsive vegetation species richness maintained or improved at three flood return frequencies for the Hattah Lakes icon site by 2030 (lower, mid and upper floodplain).

- Lower floodplain water responsive species richness 80th percentile is ≥6.15
- Mid floodplain water responsive species richness 80th percentile is ≥5.95
- High floodplain water responsive species richness 80th percentile is ≥1.6

Reference target for floodplain water responsive species abundance maintained or improved at three flood return frequencies (lower, mid and upper floodplain (Brown et al. 2016)).

- Lower floodplain water responsive species abundance 80th percentile is ≥37.35
- Mid floodplain water responsive species abundance 80th percentile is ≥22.9

- High floodplain water responsive species abundance 80th percentile is ≥7.15

The following section presents the findings of the 2022-23 monitoring program. It:

- assesses native water-responsive species richness and abundance on Hattah Lakes floodplains against a point of reference
- assesses the condition of the whole icon site using native water-responsive species richness and abundance scores
- analyses change in vegetation community composition over time.

6.2 Methods

Six locations (H1–H6) for monitoring floodplain vegetation communities within the Hattah Lakes icon site were initially established. As specified by Wood et al. (2018), these locations were established to each represent three different flood return frequencies, often, sometimes and rarely, which relate to floodplain elevations as outlined in Figure 23. Site H4C is no longer monitored due to this site having been incorrectly established on a dune system. A total of 17 sites are therefore monitored within these 6 locations (Table 17).

Since the establishment of sites in 2007–08, surveys have been undertaken annually with the exception of 2014–15. In 2010–11, only 14 sites were surveyed as flooding prevented access to some sites (Wood et al. 2018). Data collection for this round of monitoring was undertaken in between February and June 2023 and all sites were surveyed.

An overview of methods followed for data collection and statistical analysis are provided below; for further details on the project methodology see MCMA (2021b).

Table 17 Flood return frequencies (FRFs), floodplain elevation, commence-to-flow (CTF) level and associated floodplain site names for TLM Program at the Hattah icon site. The FRFs were determined using commence-to-flow data (source: Wood et al. 2018).

Flood return frequency	Floodplain elevation	Commence to flow	Site names
Often	Lower floodplain	35 000–60 000 ML/day^{-1}	H1A; H2A; H3A; H4A; H5A; H6A
Sometimes	Mid floodplain	60 000–100 000 ML/day^{-1}	H1B; H2B; H3B; H4B; H5B; H6B
Rarely	Higher floodplain	> 100 000 ML/day^{-1}	H1C; H2C; H3C; H5C; H6C

6.2.1 Data collection

Each of the 18 sites contains four permanently established quadrats, spaced 50 m apart and each consisting of 15 x 1 m x 1 m cells (Figure 23). Floodplain vegetation surveys follow the methods described in Section 5.2.1. The methods to identify plant species and the use of plant functional group are described in Section 5.2.2.

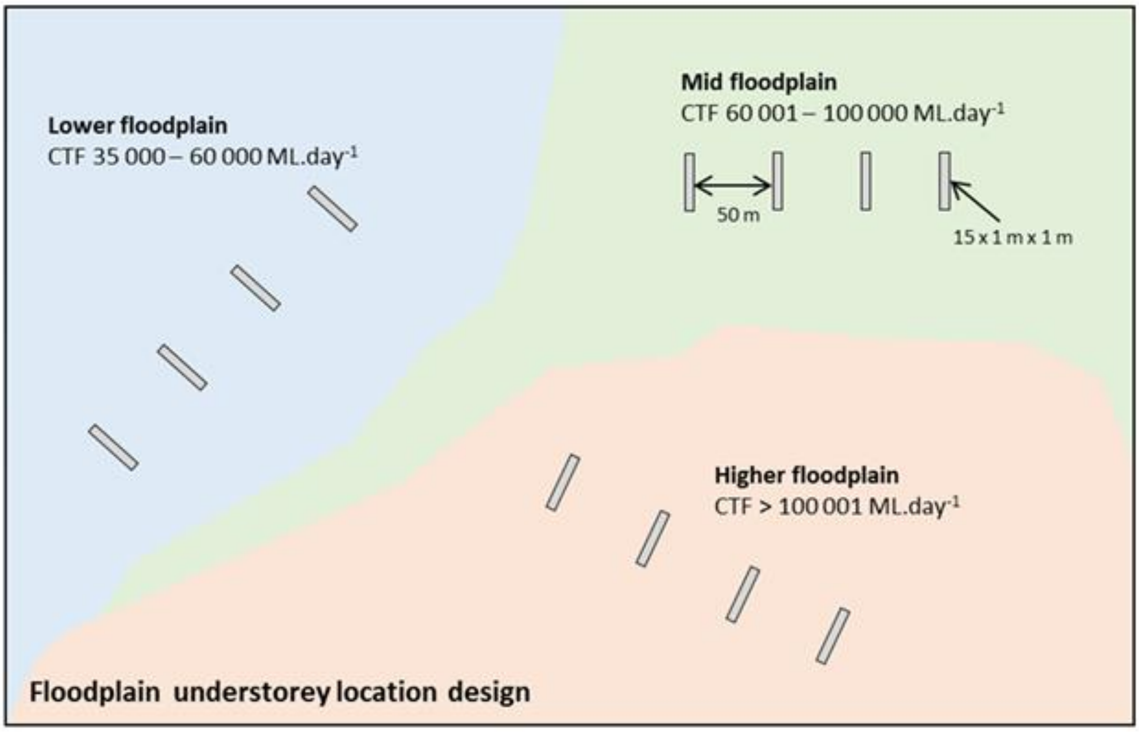


Figure 23 Schematic of the survey design used to assess floodplain understorey vegetation communities under the TLM program at the Hattah Lakes icon site (Huntley et al. 2016).

6.2.2 Data analysis

Point of reference assessment

There are three flood return frequency (FRF) classifications for the Hattah Lakes icon site: lower, mid and higher floodplain (Huntley et al. 2016). For each FRF, a point of reference index was developed by Brown et al. (2016) for species richness and species abundance using TLM condition monitoring data for floodplain understorey communities (Table 18). The point of reference includes plant species that are considered water responsive and excludes drought-tolerant species.

As detailed in Wood et al. (2018), floodplain vegetation is deemed to be in good condition when:

- Native water-responsive species richness in a FRF is at or above the 80th percentile (adapted from Huntley et al. 2016)
- Native water-responsive species abundance in a FRF is at or above the 80th percentile (adapted from Huntley et al. 2016).

Table 18 Ecological targets for floodplain understorey vegetation at the Hattah Lakes icon site (MCMA 2021b).

Flood return frequency	Floodplain elevation	Index 1: water responsive species richness (80th percentile)	Index 2: water responsive species abundance (80th percentile)
Often	Lower floodplain	6.15	37.35
Sometimes	Mid floodplain	5.95	22.9
Rarely	Higher floodplain	1.6	7.15

As outlined by MCMA (2021b), to calculate if water responsive species richness was in good condition (targets have been met) for floodplains:

- all years of data were used, including only native water-responsive plant species (e.g. species associated with the following functional groups; S, F, Arf, Arp, Atl, Ate, Atw, A and Tda) and excluding any records classified only to genus level.
- the total number of species were averaged across all quadrats for each transect in each year.
- transects with water responsive species richness at or above the 80th percentile (Table 18) score = 1 (i.e. compliant) and transects with water responsive species below the point of reference score = 0 (i.e. non-compliant).
- the proportion of compliant transects across all wetlands was plotted over time.

The same steps (above) were applied to determine if water-responsive species abundance was in good condition using the sum of abundance. Abundance measures for each species in each quadrat (i.e. maximum of 15 per species) were summed and then a transect abundance measure was estimated by averaging the quadrat abundance measures within each transect.

In 2022–23, all previous years were re-analysed to assess compliance against targets for native water-responsive species richness and abundance as it was noted that previous analyses had been inconsistent in using only native species, with some also including exotic species as per Huntley et al. 2016. It appears that the decision to exclude exotic species was only made formal in the MCMA 2020 Draft CMPs, where formerly it was not specified whether to exclude exotic species.

Whole-of-icon site floodplain scores were calculated by weighting the strata scores for both the richness and abundance of native water-responsive species, considering the total area of each FRF in the Hattah Lakes icon site, and the number of sites sampled within each FRF. Scores were weighted using the example shown in Brown et al. (2015), informed by methods to estimate an overall mean from a stratified sample (Sutherland 2006). To determine 95% confidence intervals, t-values were calculated in excel using the T.INV.2T function for $P = 0.05$ (two-sided), using the degrees of freedom method shown in Sutherland (2006). These whole-of-icon site scores were calculated for each survey year since 2007–08 (excluding 2014–15).

icon site scores were plotted as a time series to examine the effect environmental watering has had on the richness and abundance of water responsive species at an icon site scale. The inundation status of sites for each year was also displayed on the time series figure. The inundation status of floodplain sites was based upon data compiled by the MCMA from yearly TLM floodplain monitoring (Table 21). Inundation status was assessed for each site at the time of annual monitoring. In 2022–23 Ecology Australia staff updated the water history information displayed on time series figures for all previous years of monitoring as it was noted that there were some discrepancies between information originally used by Ecology Australia staff for compiling these figures and updated information provided by the MCMA. Ecology Australia has been advised by the MCMA that water history information is sometimes refined over time by the MCMA as they gain a more accurate understanding of site inundation history which may account for discrepancies. Watering events are simplified in the Whole-of-icon site score graphs to display if across the whole icon site, there was no flooding across any sites, e-water delivery at any sites, natural flooding at any sites, or a combination of both natural flooding and e-water at any sites.

Plant functional groups

As outlined by MCMA (2021b), the use of plant functional groups is a widely accepted method of interpreting disturbance related changes in plant communities, while minimising the effects of changes in species composition or inconsistencies in taxonomic classification (Brock and Casanova 1997; Campbell et al. 2014). Functional groups assist in demonstrating the influence of flood inundation on community composition (Wood et al. 2018). Consistent with the previous approach (Wood et al. 2018), charts were produced to display the proportion of functional group abundance data for each survey year, in each FRF (see Table 11 for functional group definitions). For display purposes, functional groups A, Arf, Arp, Ate, Atl were combined into one amphibious functional group ‘A’. Functional group ‘T’ was excluded from these charts because it was not possible to determine if these species were drought tolerant (Tdr) or terrestrial damp species (Tda) (Wood et al. 2018). Both indigenous and introduced species were included in the analysis because both groups are expected to respond to changes in hydrology across the wetlands.

Watering event data were provided by the Mallee CMA in June 2023 (see Table 2). These data are simplified in the Whole-of-icon site score graphs to display if across the whole icon site, there was no flooding across any sites, e-water delivery at any sites, natural flooding at any sites, or a combination of both natural flooding and e-water at any sites.

Species richness and abundance among sites

Mean species richness and abundance across floodplain sites was calculated from the total number of species recorded at each floodplain site and the total number of times species were recorded at each floodplain. Richness and abundance was calculated for both native and introduced species.

6.3 Results

6.3.1 Data summary

A total of 125 vascular plant taxa were recorded from the six Hattah floodplain sites during the 2022-23 monitoring. Of these, 99 were indigenous and 26 were exotic. This represents a slight increase in the total number of taxa identified during the 2021–22 survey period (121 taxa), however there has been decrease in the number of native species recorded from 89% to 79%, at the same time the number of exotic species has increased from 11% to 21%.

Several species rarely or never recorded at Hattah Lakes TLM floodplain sites were recorded following the widespread inundation in late 2022 and early 2023. This included 5 FFG Act-listed endangered or critically endangered species which had never been recorded before in Hattah TLM floodplain monitoring. These were dwarf amaranth *Amaranthus macrocarpus* var. *macrocarpus* (Figure 24), compact sneezeweed *Centipeda crateriformis* subsp. *compacta*, soda bush *Neobassia proceriflora*, slender spurge *Sauropus trachyspermus* (Figure 25) and branching groundsel *Senecio cunninghamii*. Dwarf amaranth has not been recorded within Hattah NP since 1984, while slender spurge has not been collected since 1981. Both tend to occur on Murray River floodplains following significant rain or flooding (VicFlora 2023). In total, 12 species listed under the *Flora and Fauna Guarantee Act 1988* (FFG Act) were recorded, a slight decrease from 13 in the previous survey period. Of the 12 species listed, 11 were classified as endangered and one as critically endangered.

Several non-threatened but previously rarely recorded species were also encountered including slender carpet-weed *Glinus oppositifolius,* which had only previously been recorded twice during Hattah TLM floodplain monitoring in 2011–12. This species is fairly uncommon throughout Victoria and is found on drying lake beds. Indian cudweed *Gnaphalium polycaulon* was also recorded for the first time in Hattah TLM floodplain monitoring. This species is confined to floodplains of the Murray River. For further details on plant species recorded please refer to the 2022-23 Part B report (Butler et al. 2023a).

Figure 24 Dwarf amaranth *Amaranthus macrocarpus* var. *macrocarpus* which was recorded from Hattah Floodplain 2, February 2023

Figure 25 Slender spurge *Sauropus trachyspermus* which was recorded at Hattah Floodplain 4, June 2023. Note: this photo was taken by Ecology Australia staff at the Lindsay-Mulcra-Wallpolla icon site.

Table 19 Threatened plant species recorded across Hattah Lakes floodplain sites during TLM Condition monitoring, 2007–08 – 2022–23. The number of transects each species was recorded in during each survey period is also displayed.

Key: P = Protected flora species under the FFG Act, vu = listed as vulnerable under the FFG Act, e = Listed as endangered under the FFG Act, cr = Listed as critically endangered under the FFG Act.

Status	Scientific name	Common name	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	All years pre-2022-23 combined	2022-23
en P	*Amaranthus macrocarpus* var. *macrocarpus*	Dwarf amaranth																3
en P	*Ammannia multiflora*	Jerry-jerry								5	2	7				6	20	2
en P	*Aristida holathera* var. *holathera*	Tall kerosene grass		2	2	2	2		1	1			2	3	3	2	20	
en P	*Asperula gemella*	Twin-leaf bedstraw		1	2								1				4	
en P	*Asperula wimmerana*	Wimmera woodruff												4		5	9	5
en P	*Austrobryonia micrantha*	Mallee cucumber			1						15					6	22	21
en P	*Austrostipa trichophylla*	Spear-grass		1													1	
en P	*Bergia ammannioides*	Jerry water-fire														1	1	
en P	*Bergia trimera*	Small water-fire					1									4	5	2
cr P	*Boerhavia coccinea*	Scarlet spiderling					1			2	7						10	
en P	*Calotis cuneifolia*	Blue burr-daisy	10				3			1	1	4	2		1		22	5
en P	*Centipeda crateriformis* subsp. *compacta*	Compact sneezeweed																1
en P	*Chenopodium desertorum* subsp. *desertorum*	Frosted goosefoot		5									2	2			9	
en P	*Chenopodium desertorum* subsp. *rectum*	Frosted goosefoot													3	2	5	
en P	*Cullen pallidum*	Woolly scurf-pea				2	2	1		1			2		2	2	12	
cr P	*Eragrostis australasica*	Cane grass	8			1											9	
en P	*Eragrostis lacunaria*	Purple love-grass		1		1	1					1					4	
vu P	*Eremophila divaricata* subsp. *divaricata*	Spreading emu-bush	1	1	2		1	1	2			2	2	1	1	1	15	
en P	*Minuria denticulata*	Woolly minuria	4													2	6	
cr P	*Neobassia proceriflora*	Soda bush																1
en P	*Phyllanthus lacunarius*	Lagoon spurge			2			1		2	15	11				7	38	21
en P	*Rorippa eustylis*	Dwarf bitter-cress	1				8									4	13	14
en P	*Sauropus trachyspermus*	Slender spurge																1
vu P	*Sclerolaena patenticuspis*	Spear-fruit copperburr		2							2					1	5	
en P	*Senecio cunninghamii*	Branching groundsel																3
en P	*Sida ammophila*	Sand sida	1		1	6	2		1	1		7					19	
en P	*Sida fibulifera*	Pin sida											9	3			12	
en P	*Sida intricata*	Twiggy sida		1													1	
en P	*Swainsona microphylla*	Small-leaf swainson-pea	1		2	1		1	1	1			1	2			10	
en P	*Vittadinia condyloides*	Club-hair New Holland daisy													7		7	
en P	*Vittadinia pterochaeta*	Winged New Holland daisy				1											1	

6.3.2 Point of reference assessment

Water-responsive species richness

The proportion of compliant transects has been increasing over the past two years across all FRFs in terms of the native water-responsive species richness index (Table 20; Figure 26). The rarely-flooded sites saw the greatest increase in compliance rates, increasing from 20% in 2020–21 to 100% in 2022-23. This meant that 100% of the rarely flooded transects met the native water-responsive species richness target of 1.6 species per transect, averaged across all elevations. The often and sometimes-flooded sites also displayed substantial increases with sometimes flooded sites increasing from 33% to 83% compliance and an increase from 50% to 67% compliance at often flooded sites in 2022-23.

Table 20 Number of sites compliant with ecological targets relating to the species richness and abundance of native water-responsive species, in each flood return frequency category (FRF) at the Hattah Lakes icon site, as surveyed in the 2022-23 season. For each FRF, the stratum scores, a weighted icon site floodplain score (with 95% confidence intervals for two sampled comparisons with normally distributed error variance) and the surveyed and total areas are shown.

Flood Return Frequency (FRF)	FRF area (ha)	Surveyed area of FRF (ha)	Species richness			Species abundance		
			No. compliant transects	Strata score	icon site score	No. compliant transects	Strata score	icon site score
Lower floodplain (often)	1229.04	0.036	4 of 6	0.667		4 of 6	0.667	
Mid floodplain (sometimes)	3969.81	0.036	5 of 6	0.833	0.955 (±0.072)	5 of 6	0.833	0.96 (±0.07)
Higher floodplain (rarely)	18870.03	0.03	5 of 5	1.000		5 of 5	1.000	

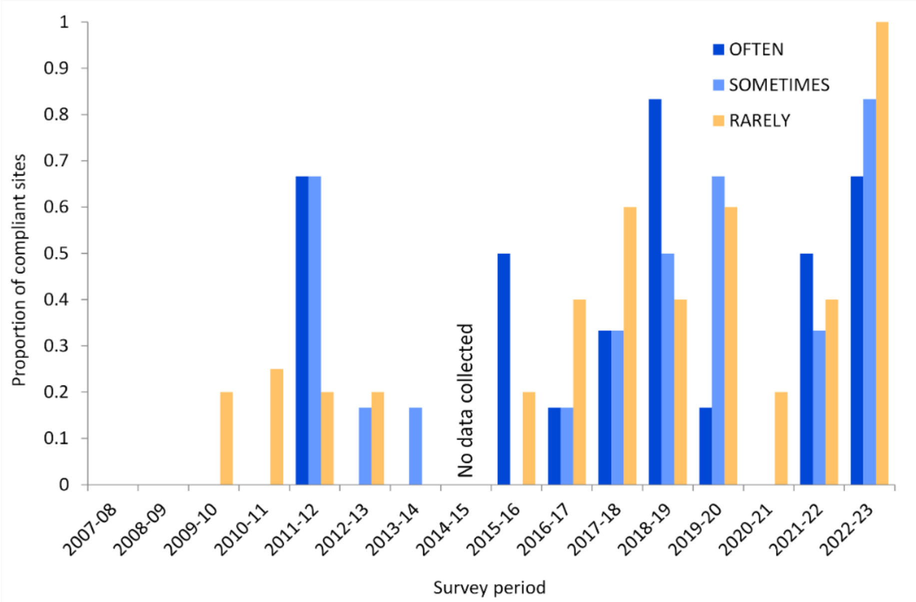


Figure 26 Proportion of compliant sites within each FRF at the Hattah Lakes icon site with native water-responsive species richness at or above the 80th percentile, across years.

Water-responsive species abundance

Similar to the increases in species richness compliance rates across all flood return frequencies, there was a large increase in the proportion of sites compliant in terms of species abundance when compared with 2021-22 (Figure 27). Compliance at rarely-flooded sites increased dramatically from 20% to 100%, the first time that any FRF was fully compliant since the inception of monitoring. Sometimes-flooded sites increased from 33% to 83%, and often-flooded sites increased from 33% to 67%, both representing the highest compliance recorded at each FRF since 2011-12.

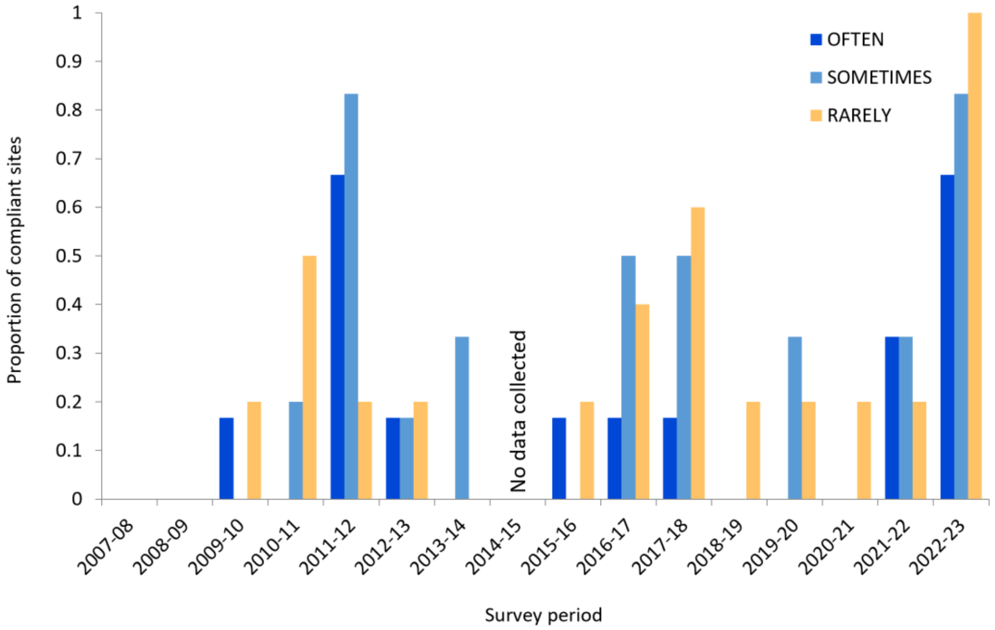


Figure 27 Proportion of compliant sites within each FRF at the Hattah Lakes icon site with native water-responsive species abundance at or above the 80th percentile, across years.

Whole-of-icon site score

Of the 17 floodplain sites surveyed across Hattah lakes, 14 were compliant in terms of water-responsive species richness, the largest number of compliant sites since the inception of monitoring and a substantial increase from five compliant transects in 2021-22 (Table 20). Correspondingly, the icon site score for native species richness on floodplains has increased substantially from 0.39 in 2021-22 to 0.96 in 2022-23 and is the highest score recorded since the start of the monitoring program (Figure 28). Although environmental water and natural flooding occurred at Hattah Lakes in 2022–23, inundation data provided by the MCMA indicates that only natural flooding directly reached TLM floodplain monitoring sites (Table 21).

The inundation history shown in Figure 28-Figure 31 is based upon inundation data for each floodplain monitoring site provided by the MCMA. This inundation history has been provided below in Table 21 to accompany these figures and give greater clarity on the number of sites which were inundated during monitoring.

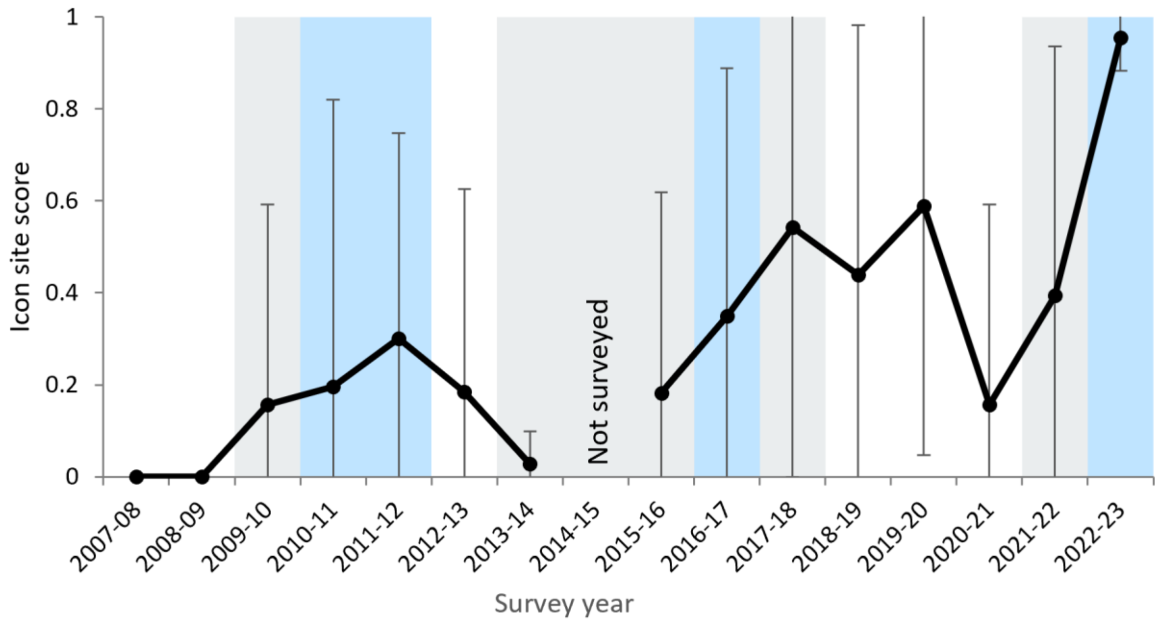


Figure 28 icon site scores for the Hattah Lakes icon site floodplains based on native water-responsive species richness indices and weighted across each FRF (± 95% confidence intervals for two sampled comparisons with normally distributed error variance) across survey years. Water events are shaded (blue: natural flooding; grey: e-water; white: non-flooded) Inundation history was provided by the MCMA and is detailed in Table 21. Note: Figure does not indicate which particular sites received water in any given period, just that natural flooding, environmental water or no flooding occurred within the Hattah Lakes icon site.

Table 21 Inundation history of TLM floodplain monitoring sites (source MCMA). Key: E = Environmental water, N = Natural inundation

Wet	Dry

Site	Yearly inundation of Floodplain Vegetation Condition Monitoring Sites Hattah															
	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23
Floodplain Height (m AHD)							43.65	44.68		44.51	44.84			43.1	44.07	
HFP1OFT				N						N	E					N
HFP1SOM				N						N	E					N
HFP1RAR										N						N
HFP2OFT				N						N						N
HFP2SOM				N						N						N
HFP2RAR				N						N						N
HFP3OFT				N						N						N
HFP3SOM				N						N						N
HFP3RAR																N
HFP4OFT				N			E	E		N	E				E	N
HFP4SOM				N			E	E		N	E				E	N
HFP4RAR																N
HFP5OFT				N	N		E	E	E	N	E				E	N
HFP5SOM				N			E	E		N	E				E	N
HFP5RAR				N			E	E		N	E				E	N
HFP6OFT			E	N			E	E		N	E				E	N
HFP6SOM				N			E	E		N	E				E	N
HFP6RAR										N	E					N

Seasons that received a natural flooding had a higher Mean icon site score (0.45) compared to all other watering event types (Figure 29). Seasons that received no flooding scored the lowest with a Mean icon site score of 0.23, followed by a slight increase in Mean icon site score for years that received environmental water (0.26). However, the large standard errors recorded across the 3 treatments indicate a high level of variability within each inundation event type (Figure 29).

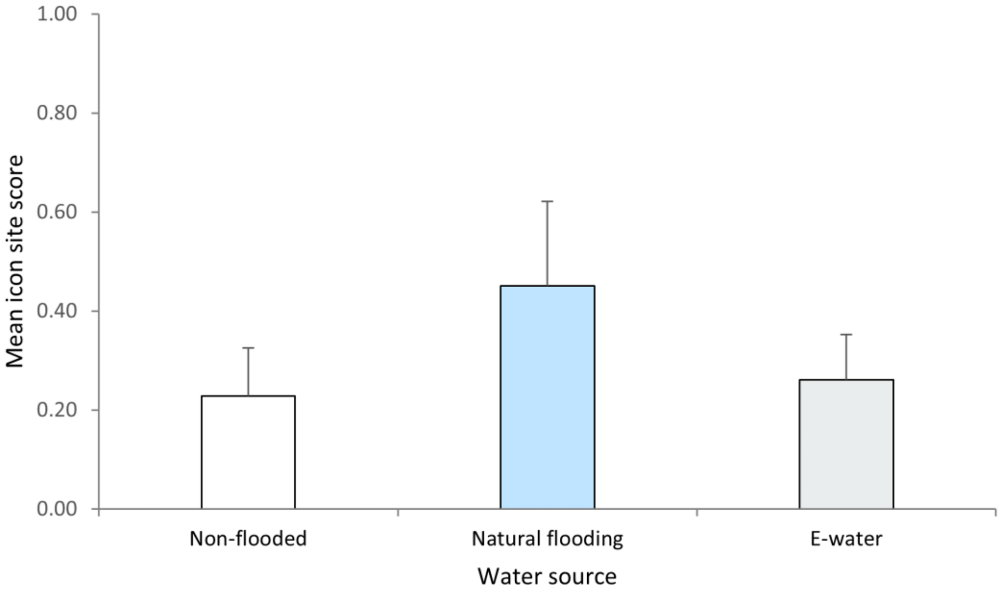


Figure 29 Mean icon site floodplain scores based upon native water-responsive species richness indices, for the Hattah Lakes icon site (± standard error), for each water event type. Non-flooded years n = 6, natural flooding n = 4, e-water n = 5. Inundation history was provided by the MCMA and is detailed in Table 21.

Of the 17 Hattah Lakes floodplain sites assessed in 2022–23, 14 were compliant in terms of water-responsive species abundance, compared to five in 2021–22 (Table 20). Correspondingly, the icon site score has increased dramatically since the last survey period (0.229 in 2021–22 and 0.955 in 2022–23). This represents the highest icon site score since the inception of the monitoring program (Figure 30). The 5 highest icon site scores recorded across the program for native water-responsive species abundance (2010–11, 2011–12, 2016–17, 2017–18 and 2022–23) were all associated with either environmental water or natural inundation of the floodplains.

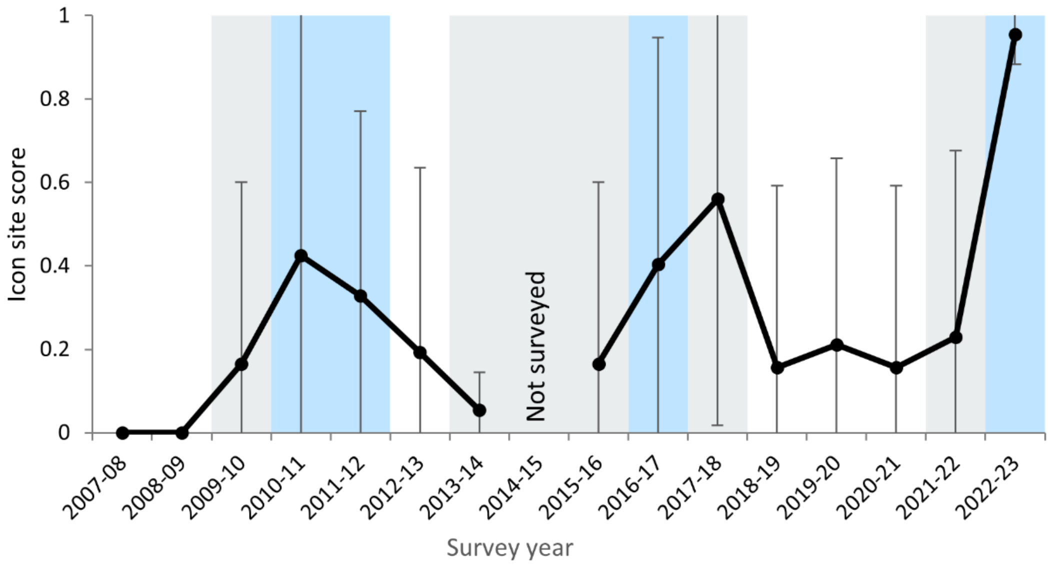


Figure 30 icon site scores for the Hattah Lakes icon site floodplains based on native water-responsive species abundance indices and weighted across each FRF (± 95% confidence intervals for two sampled comparisons with normally distributed error variance) across survey years. Water events are shaded (blue: natural flooding; grey: e-water) Inundation history was provided by the MCMA and is detailed in Table 21. Note: Figure does not indicate which particular sites received water in any given period, just that natural flooding, environmental water or no flooding occurred within the Hattah Lakes icon site.

Mean icon site scores for water-responsive species abundance at the Hattah Lakes floodplain sites were substantially greater across years that received natural flooding, compared with years which received environmental water or were non-inundated (Figure 31). Mean icon site scores were also higher for years where floodplain sites received environmental water compared with years where no inundation occurred.

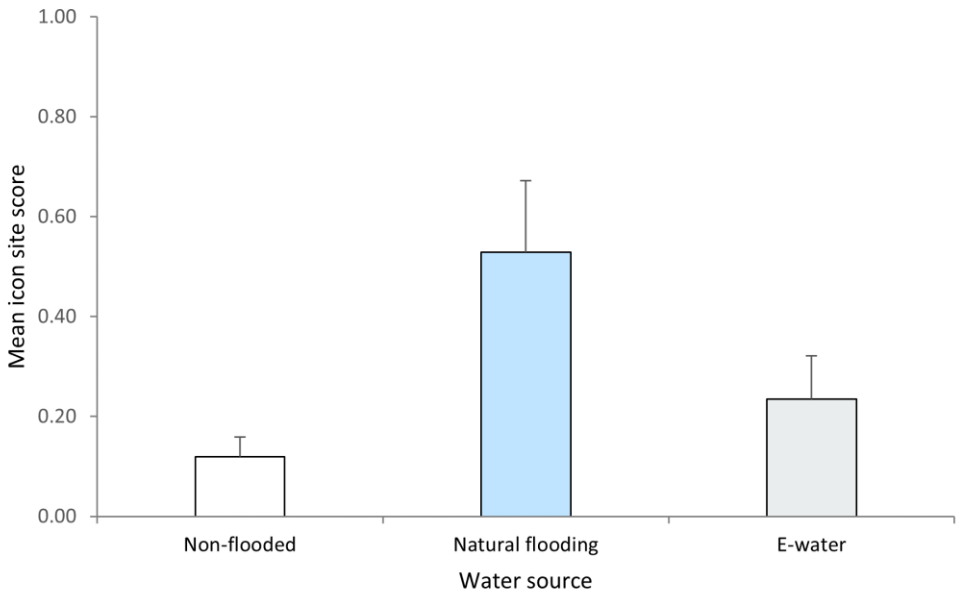


Figure 31 Mean icon site floodplain scores based upon native water-responsive species abundance indices, for the Hattah Lakes icon site (± standard error), for each water event type. Non-flooded years n = 6, natural flooding n = 4, e-water n = 5. Inundation history was provided by the MCMA and is detailed in Table 21.

Plant functional groups

Often-flooded sites across Hattah Lakes saw a slight proportional decrease in the abundance of terrestrial dry (Tdr) species in 2022-23, following a decreasing trend since 2019-20 (Figure 32). Meanwhile, the proportion abundance of terrestrial damp species (Tda) has been on a steady increasing trend since 2019-20. The proportion of amphibious species (A) has remained steady while woody amphibious tolerator species (Atw) displayed a slight decrease from 12% in 2021-22 to 10% in 2022-23.

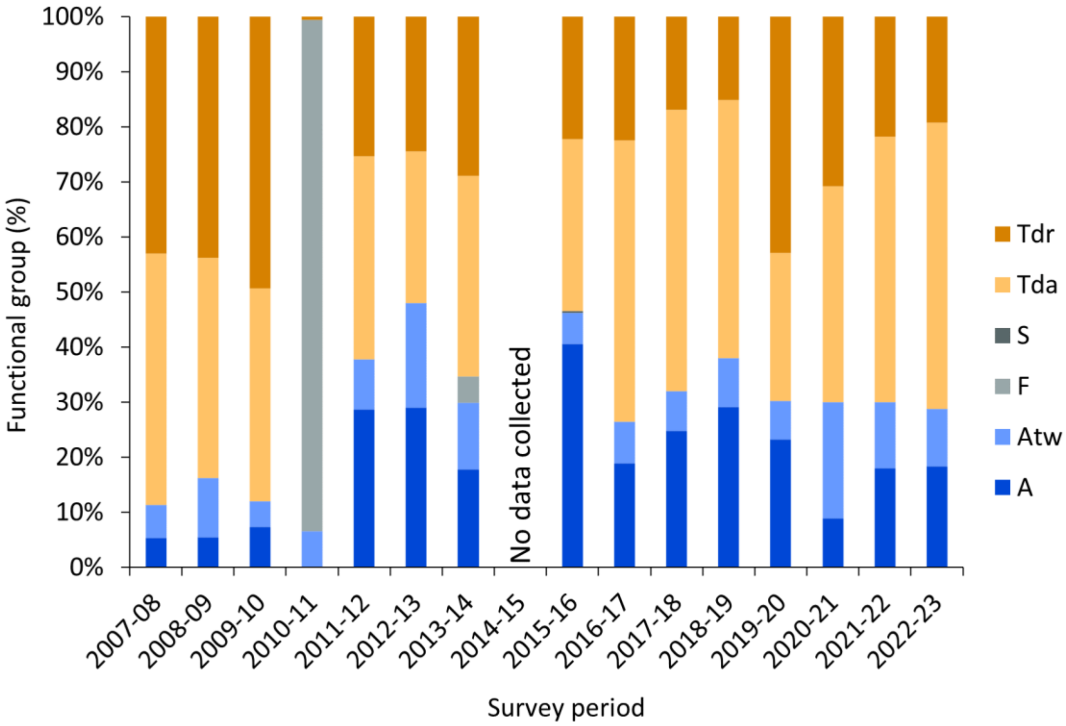


Figure 32 Proportion of the sum of abundance for each plant functional group in each survey period across all often-flooded FRF floodplain sites surveyed at the Hattah Lakes icon site.

As with the often-flooded sites, sometimes-flooded sites displayed a declining trend since 2019-20 in terrestrial dry (Tdr) species abundance (26% in 2022-23 down from 55% in 2019-20). A simultaneous increasing trend in the terrestrial damp species (Tda) since 2019-20 continues to occur (51% in 2022-23 up from 18% in 2019-20) (Figure 33). The proportional abundance of amphibious species (A) increased slightly for a third consecutive year, however, levels remain markedly lower than those recorded between 2011–12 and 2019–20. The proportional abundance of woody amphibious fluctuation tolerators (Atw) is on a decreasing trend since 2020-21, however still remains relatively high compared with levels prior to 2019–20.

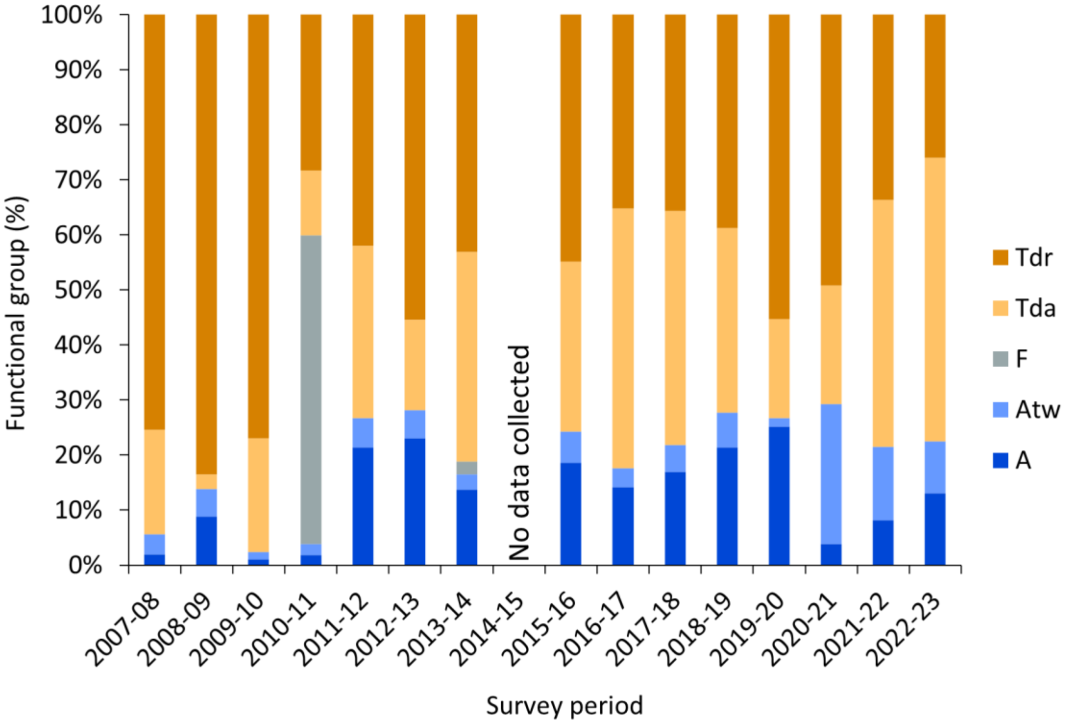


Figure 33 Proportion of the sum of abundance for each plant functional group in each survey period across all sometimes-flooded FRF floodplain sites surveyed at the Hattah Lakes icon site.

The rarely-flooded sites saw a marked decrease in the abundance of terrestrial dry (Tdr) species in 2022-23 for the third year in a row (39% down from 73% in 2021-22) (Figure 34). For the first year since the inception of monitoring, the terrestrial dry functional group was not the most dominant and the terrestrial damp species (Tda) were the highest represented functional group across sites. The proportional abundance of terrestrial damp species rose from 19% in 2021-22 to 52% in 2022-23. The abundance of woody amphibious fluctuation tolerators (Atw) and amphibious species (A) remained relatively constant compared with the previous monitoring period.

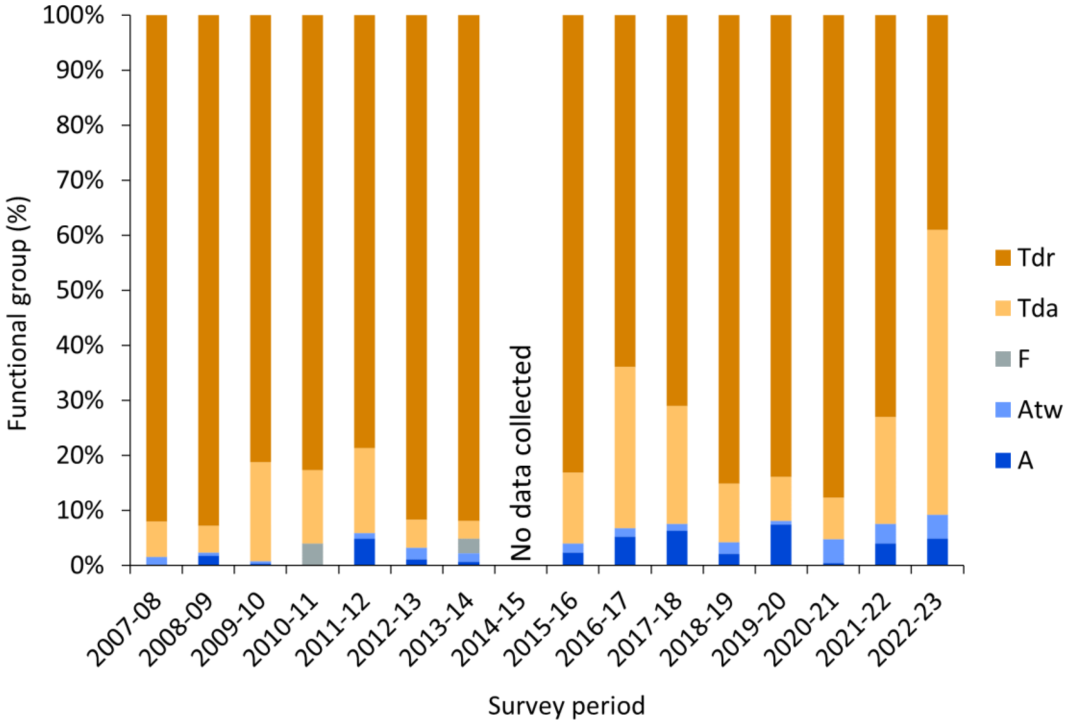


Figure 34 Proportion of the sum of abundance for each plant functional group in each survey period across all rarely-flooded FRF floodplain sites surveyed at the Hattah Lakes icon site.

6.3.3 Species richness and abundance among sites

The widespread inundation throughout late 2022 and early 2023 resulted in increases in species richness at all FRFs, however the most substantial increase occurred at rarely-flooded sites (Figure 35). While native species richness increased, introduced species richness also increased substantially and was also most prominent in rarely-flooded sites. This increase was driven by the occurrence of a number of species including paddy melon *Cucumis myriocarpus* subsp. *Myriocarpus*, flaxleaf fleabane *Erigeron bonariensis*, burr medic *Medicago polymorpha* and black nightshade *Solanum nigrum* that were either not recorded last year or were recorded only in a small number of sites.

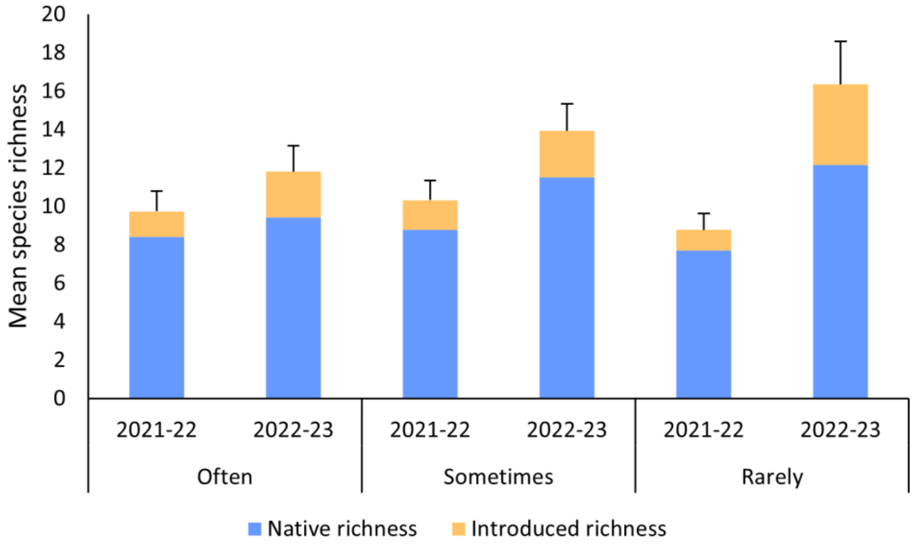


Figure 35 Mean species richness across floodplain sites (±SE)

Species abundance increased substantially across all FRFs following flooding (Figure 36). Similar to species richness, increases in abundance occurred for both native and introduced species. Increases in introduced species abundance were driven by species such as creeping heliotrope *Heliotropium supinum* that have been recorded consistently across sites in previous years but have increased greatly this season following inundation. Meanwhile, increases in native abundance were driven by a much greater abundance of species typically occurring following flooding or large rain events including common joyweed *Alternanthera nodiflora*, Mallee cucumber *Austrobryonia micrantha*, lagoon spurge *Phyllanthus lacunarius*, and common avens *Ranunculus pentandrus var. platycarpus*.

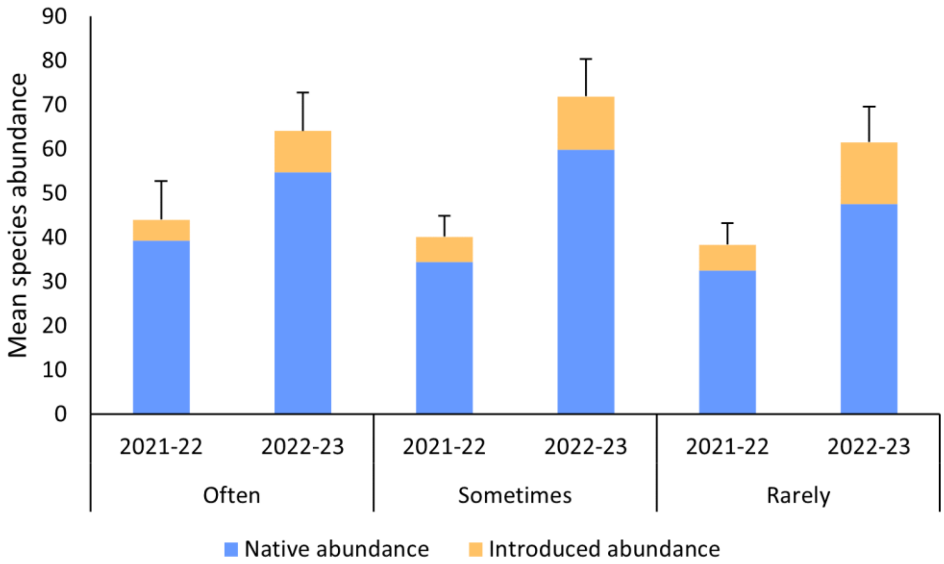


Figure 36 Mean species abundance across floodplain sites (±SE)

6.4 Discussion

6.4.1 Whole-of-icon site score

The icon site scores for both native water-responsive species richness and abundance at Hattah Lakes floodplain sites increased markedly in this survey period from the last. This overall increase in species richness and abundance is likely due to high flows throughout late 2022 and early 2023 and subsequent flooding that occurred across large areas of the floodplain. Similar increases in richness and abundance can be seen following past high rainfall and/or natural flooding events. Results underscore the importance of natural flooding and environmental water delivery for promoting water-responsive species richness and abundance across the floodplains at Hattah Lakes.

6.4.2 Often-flooded

Both water-responsive species richness and abundance at often-flooded sites increased markedly from the last survey period when no sites were considered compliant. The composition of functional groups did not change significantly at all, although a slight increase in the proportion of the terrestrial damp functional group occurred, along with a slight reduction in the terrestrial dry group. The majority of species occurring at often-flooded sites were terrestrial damp species, which were most likely persisting in the soil seed bank and were able to germinate following a brief period of inundation and drawdown.

6.4.3 Sometimes-flooded

As with often-flooded sites, the current season saw a significant increase in the number of transects compliant for water-responsive species richness and abundance since the last survey period. However, the increase in compliance was greater for sometimes-flooded than often-flooded.

A similar pattern of change in functional group proportions was found for sometimes-flooded sites as was found for often-flooded sites, with a slight increase in the proportions of terrestrial damp species and a simultaneous proportional decrease in terrestrial dry species occurring. An increase in amphibious species, consisting almost entirely of *Centipeda* sp. was also found. High river flows leading to inundation of sites are expected to lead to increases in abundance of species such as this, as well as terrestrial damp species that typically occur in damper environments.

6.4.4 Rarely-flooded

The greatest increases in compliance for species richness and abundance were recorded across rarely-flooded sites, where all transects were compliant. Further, a substantial increase in the proportion of terrestrial damp species was found, with an associated decrease in terrestrial dry species. Relatively low transect compliance in previous years indicate inundation of sites throughout late 2022 and early 2023 has driven the increases seen in 2022-23.

The increased occurrence of terrestrial damp species is typical after inundation or high rainfall events, such as at the start of the current survey period, and before that, after the flooding event in late 2016. Specifically, species such as spreading nut heads *Sphaeromorphaea littoralis* (Tda), lesser joyweed *Alternanthera denticulata* (Tda) and hairy carpet-weed *Glinus lotoides* (Tda) were either more common this season than previously seasons or have not been recorded at these sites in more recent seasons.

6.4.5 Change in condition and progress towards objectives

Flooding tends to have an overriding effect on floodplain species richness and abundance, as well as the functional composition of the plant community. While floodplain sites tend not to receive water as regularly as wetland sites, water availability and levels of floodplain inundation during survey periods can greatly influence the levels of species richness and abundance recorded during any given survey.

As seen in this year's results, proportions of transects compliant for species richness and abundance increased greatly following inundation in late 2022-23 (particularly at rarely-flooded sites). This indicates that richness and abundance has increased following inundation and drawdown whereas in more recent seasons, most floodplain sites have not received water and have therefore contained lower richness and abundance. In addition, widespread inundation across floodplain sites is likely to replenish seedbanks and allow for greater germination of species in the future following further inundation.

Proportions of compliant transects do not provide an indication of spatial heterogeneity in species composition typical of arid floodplain landscapes. Spatial patterns in floodplain vegetation communities are most likely driven by how often they are in either drying or wetting processes. Increased prevalence of drier conditions across floodplains could lead to homogenization of plant communities dominated by drought-tolerant species across the icon site. This could in turn lead to a reduction in the ability of these sites to respond to future wetting events if seed banks are not replenished.

6.5 Objective and target attainment

The icon site score for native water-responsive species richness at Hattah Lakes floodplain sites increased markedly in this survey period from the last, with 14 out of 17 transects compliant for both. Patterns observed in species richness and abundance across the duration of the monitoring program suggest that natural flooding events aid in facilitating shifts from floodplain vegetation communities dominated by terrestrial dry species to communities containing a wider variety of species functional groups and thus higher levels of water-responsive species richness.

No guidance is provided in the CMP (MCMA 2021b) as to what definitions should be used for determining overall compliance with the objectives provided below i.e., what percentage of transects need to be compliant for specific species richness and abundance targets for objectives to be considered as attained, partially attained or not attained. Therefore, overall objective and target attainment was defined as follows: not attained was defined as no transects across the Whole-icon-Site being compliant for species richness or abundance targets. Partial attainment was defined as at least one of the transects meeting compliance targets for species richness and abundance. Full attainment was defined as the majority of transects meeting compliance targets for species richness and abundance or displaying a positive trend of compliance over time.

Results from the current survey represent an increase in both species richness and abundance. It appears that a trajectory towards the ecological objective to 'improve the species richness and abundance of native wetland and floodplain aquatic vegetation functional groups by 2030' has started to emerge across recent seasons. However, results across the duration of the monitoring program highlight fluctuations in water-responsive species richness following inundation events and subsequent decreases with time since inundation and must be taken into account.

A summary of target attainment relating to the objectives is provided below in Table 22.

Table 22 Summary of floodplain community target attainment in 2022–23.

Objective HL2	Attained	Partial attainment	Not attained
Improve species richness and abundance of native water-dependent floodplain and wetland aquatic vegetation at Hattah Lakes icon site by 2030.			
Specific targets			
Species richness (water-responsive species)			
Lower floodplain: average water-responsive species richness of each transect within the lower floodplain is greater than or equal to the reference target 80th percentile (≥6.15)			
Mid floodplain: average water-responsive species richness of each transect within the mid floodplain is greater than or equal to the reference target 80th percentile (≥5.95)			
High floodplain: average water-responsive species richness of each transect within the high floodplain is greater than or equal to the reference target 80th percentile (≥1.6)			
Species abundance (water responsive species)			
Lower floodplain: average water-responsive species abundance of each transect within the lower floodplain is greater than or equal to the reference target 80th percentile (≥37.35)			
Mid floodplain: average water-responsive species abundance of each transect within the mid floodplain is greater than or equal to the reference target 80th percentile (≥22.9)			
High floodplain: average water-responsive species abundance of each transect within the high floodplain is greater than or equal to the reference target 80th percentile (≥7.15)			

6.6 Recommendations

As with wetland assessments, we recommend taking into consideration the spatial and temporal complexity inherent in arid floodplain landscapes when developing ecological objectives for floodplains and assessing site health.

Delivery of environmental water to floodplain sites is needed to maintain variable flood regimes across sites. As spatial heterogeneity in species composition is considered a central characteristic of floodplains in arid and semi-arid environments, we also recommend monitoring floodplain community composition following inundation events such as the 2022-23 event at floodplain sites regularly (approx. every 3-6 months) to assess how the community is responding to inundation among differing flood return frequencies. This would allow an accurate assessment to be made of the potential for floodplain sites to maintain heterogeneity across the icon site.

7 Lignum

7.1 Introduction

Tangled lignum *Duma florulenta* is a native branching shrub growing to around 2 m high and 2 m wide (VicFlora 2022). Tangled lignum forms dominant 'Lignum' vegetation communities (such as Lignum Shrubland and Lignum Swamp), which require periodic inundation (MCMA 2021a). The hydrology of Hattah Lakes has changed due to the impacts of diverting and extracting water from the Murray River for agricultural and domestic use (MCMA 2021a). This change has seen a decline in lignum communities, and therefore habitat for flora and fauna, which rely on the periodic flooding of the natural lake system within the icon site (MCMA 2021a).

Monitoring of Lignum at Hattah Lakes as part of the TLM program has been undertaken since 2007, although a new methodology—applying to survey design, data collection and analyses—was implemented in 2016–17. Adoption of the new methodology followed recommendations put forward in Brown et al. (2016), Huntley et al. (2016) and Robinson (2014). As a result of widespread flooding during the 2016–17 survey period, most sites were unable to be assessed (Brown et al. 2017), therefore analyses in this report will be limited to the comparison of data collected in 2017–18, 2018–19, 2019–20 and 2020–21.

This report section will assess lignum condition against an established target at site and icon site levels for 2016–17 to 2021–22.

Ecological objectives for the Hattah Lakes icon site are set out in the CMP (MCMA 2021b) and represent the most current objective for lignum at Hattah Lakes.

Objective HL4 Condition and extent of floodplain vegetation

Improve condition and maintain extent from baseline (2006) levels of river red gum *Eucalyptus camaldulensis*, black box *E. largiflorens* and lignum *Duma florulenta* to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030.

Specific target relating to lignum under objective HL3:

- Condition in standardised transects that span the floodplain elevation gradient and existing spatial distribution, ≥70% of lignum plants in good condition with a Lignum Condition Score (LCI) ≥4 (MCMA 2021b).

7.2 Methods

Condition monitoring of lignum comprised assessments at 15 of 16 established quadrats, with each quadrat measuring 20 x 20 m. Inundation levels were too high at one quadrat (H15) to enable assessment throughout the season. Data collected for each quadrat included:

- condition of every mature lignum plant within the quadrat, determined by combining the % viability and colour scores to result in the Lignum Condition Index (LCI; Table 23)
- gender of each mature lignum plant that is flowering, by examining the flowers and estimating the amount of flowering (e.g. absent; scarce; common; abundant)
- total number of emergent lignum plants (e.g. seedlings or clones) that are present within the quadrat
- total percentage cover of lignum over the whole quadrat.

Assessments were undertaken between September 2022 and June 2023.

The allocation of sites per stratum is as follows:

- Lignum Shrubland: H4, H12, H13, H14, H15
- Lignum Swamp: H17, H18, H19, H20, H21
- Lignum Woodland: H1, H3, H7, H9, H11, H16

Table 23 The Lignum Condition Index (LCI) used to assess lignum plant condition (adapted from Huntley et al. 2016).

% Viable	Score
> 95	6
75 ≤ 95	5
50 ≤ 75	4
25 ≤ 50	3
5 ≤ 25	2
0 ≤ 5	1
0	0

Colour	Score
All green	5
Mainly green	4
Half green, half yellow/brown	3
Mainly yellow/brown	2
All yellow/brown	1
No viable stems	0

7.2.1 Indices and points of reference

As per MCMA (2021b), the percentage of lignum plants with an LCI ≥4 was calculated for each site. The mean proportion of plants within each site with an LCI ≥4 was then compared across survey periods to assess the average condition of lignum within sites, over time.

To report on lignum condition at an icon site level, each site was assessed as being either compliant or non-compliant. Compliant sites, i.e. those where more than 70% of plants had LCI scores ≥4, were considered to be in good condition and to have attained the site-specific target.

The proportion of compliant sites was then used as an icon site index to document variation in lignum condition over time, whereby a change of 0.3 between years will indicate significant changes (Robinson 2014).

7.3 Results

7.3.1 Ecological objectives and targets

The 2022–23 monitoring results indicate an increase in lignum condition from 2021–22, with 3% more plants obtaining an LCI score ≥4, on average across all sites (87% in 2021–22 compared to 90% in 2022–23; Figure 37). This also represents the highest average lignum condition scores across all sites since the revised lignum monitoring began and a positive trend on average since 2018–19.

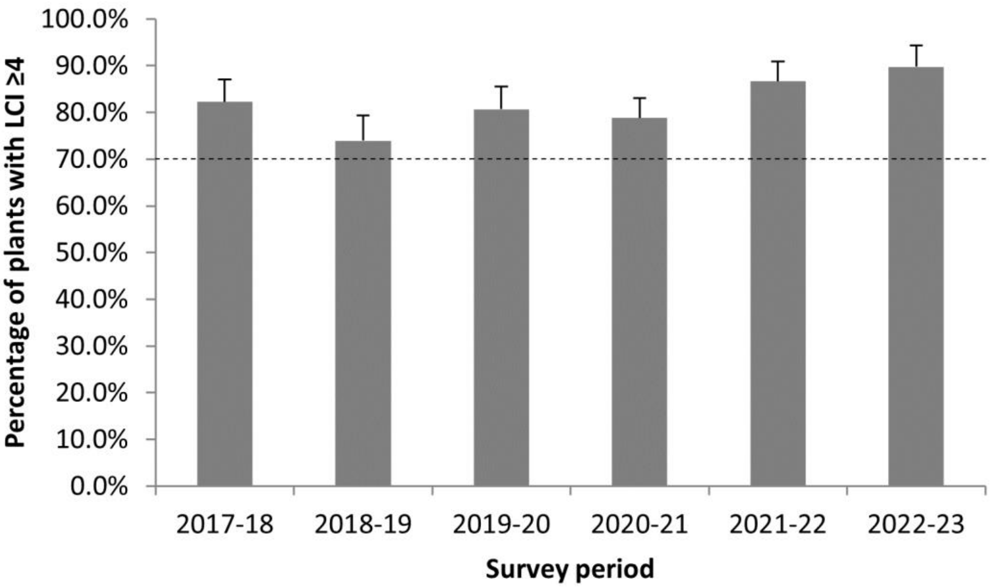


Figure 37 Mean percentage of lignum plants (± SE) that have a Lignum Condition Index (LCI) score ≥4 across the whole Hattah Lakes icon site. The icon site target of 70% is shown for comparison.

While the target is set at 70% of lignum plants having an LCI ≥4, there is considerable difference in condition between LCI 4 and LCI 11. To explore the changes in LCI of all plants, the proportion of LCIs for all plants across each survey period was compared (Figure 38). While there was only a 3% increase of plants with a LCI ≥4, the proportion of plants with a higher condition score of 8, 9 or 10 has increased substantially compared to the 2021–22 period by 7.31%, 15.64% and 5.13% respectively. Furthermore, the proportion of plants with a LCI score of 8 or more (79.07%) is considerably greater than during previous survey periods, with the last time this figure exceeded 60% occurring over the 2017-18 season (74.71%).

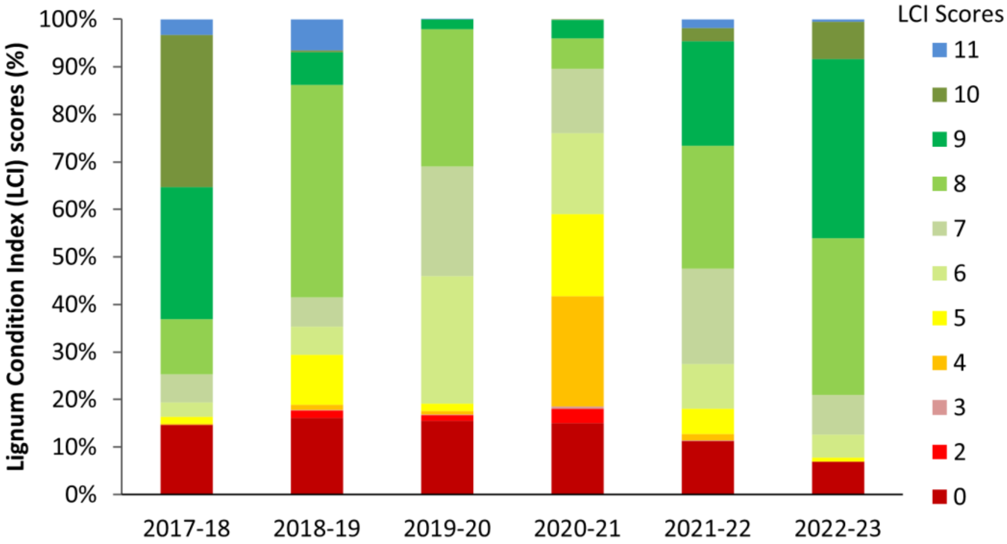


Figure 38 Proportion of sum of lignum plants awarded to each Lignum Condition Index (LCI) score across all Hattah Lakes icon sites, for each survey period.

The results of Lignum Shrubland, Lignum Swamp and Lignum Woodlands Water Regime Classes (WRCs) all displayed a slight increase in average percentage of plants with an LCI ≥4 compared to the last survey period, increasing by 2.29 %, 4.86 % and 0.65 % respectively (Figure 39, Figure 40 and Figure 41). Both the Lignum Shrubland and Lignum Swamp WRCs represent a trend of increasing condition since the 2018–19 survey period. No overall trend in condition is apparent for the Lignum Woodland WRC, which showed only a marginal mean increase in condition since the 2021–22 survey period.

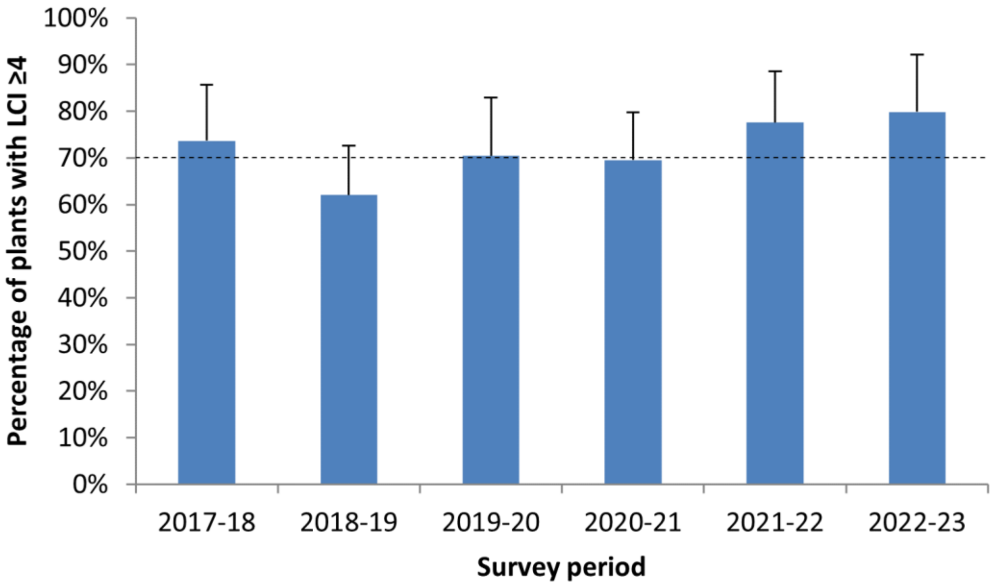


Figure 39 Mean percentage of lignum plants (± SE) within Lignum Shrubland at Hattah Lakes with a LCI score ≥4. The icon site target of 70% is shown for comparison.

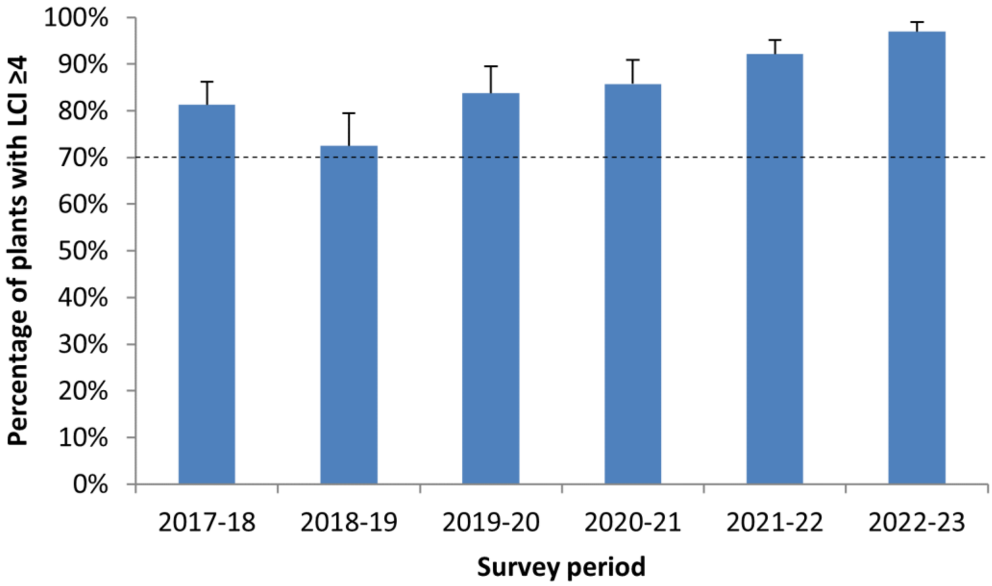


Figure 40 Mean percentage of lignum plants (± SE) within Lignum Swamp at Hattah Lakes with a LCI score ≥4. The icon site target of 70% is shown for comparison.

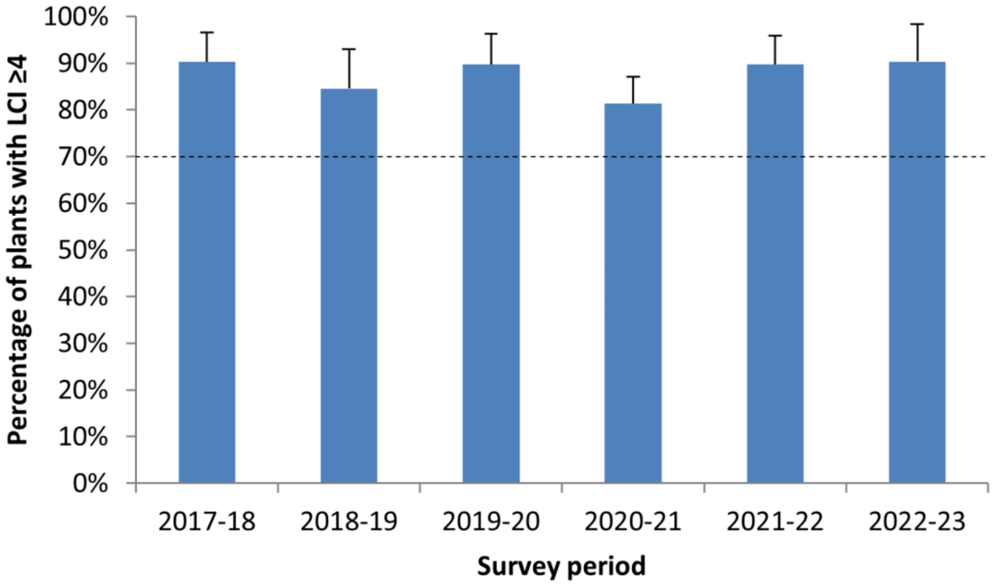


Figure 41 Mean percentage of lignum plants (± SE) within Lignum Woodland at Hattah Lakes with a LCI score ≥4. The icon site target of 70% is shown for comparison.

The average cover of lignum across all Hattah Lakes sites has shown negligible change from the 2021-22 survey period, increasing from 30.3% to 30.5% in 2022-23 (Figure 42). However, a trend in increasing average cover is apparent since 2019-20.

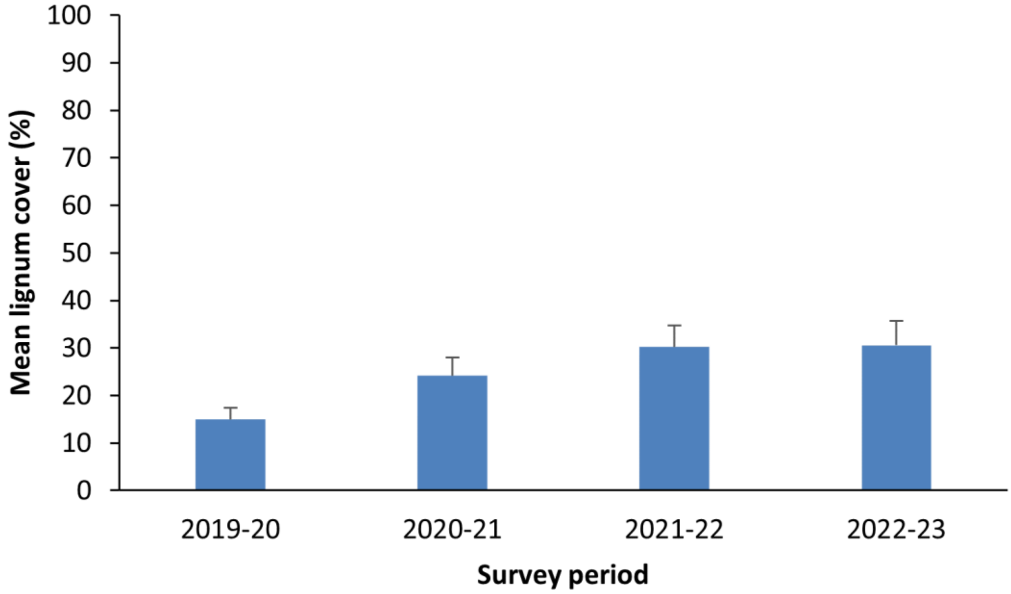


Figure 42 Mean percentage cover of lignum plants across all sites at Hattah Lakes. Recording of lignum cover began in the 2019–20 season.

At an individual site scale, the icon site Index (the proportion of sites that exceed the target of 70% of plants with an LCI ≥4) has decreased from 14 of 16 compliant sites (0.88) in 2021–22 to 12 of 15 sites compliant (0.80) in 2022–23 (Table 24).

Table 24 Proportion of compliant Lignum sites across the Hattah Lakes icon site.

Survey period	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23
No. compliant sites	12/16	9/16	12/16	13/16	14/16	12/15
Proportion compliant	0.75	0.5625	0.75	0.8125	0.875	0.80

7.4 Discussion

7.4.1 Ecological objectives and targets

Data collected for the current round of monitoring represents the sixth year of data collection under the current method where the full complement of sites were assessed (with the exception of site H15, which was inaccessible due to flooding at the time of the survey). When considering lignum condition at the whole-of-icon site level, condition has improved since previous survey periods, reaching the highest level since the new data collection method began in 2017–18 (90% of lignum with an LCI of ≥4), well exceeding the ecological target (>70% plants with an LCI ≥4). As flooding is a major driver of lignum growth (Roberts and Marston 2011), the increase in lignum condition is likely attributable to the unprecedented natural flooding event that peaked in December 2022. This anomalous event, coupled with environmental water delivery and a large rainfall event just prior to monitoring over 2021-22, has likely facilitated the regeneration of lignum stands across the Hattah icon site.

Assessment of lignum plants with a Lignum Condition Score (LCI) ≥ 4 alone indicates an increase in lignum condition during this survey period to a lesser degree than the increase over the previous survey period. However, assessment of the proportion of lignum plants in each LCI category reveals a much more pronounced increase in lignum condition during this survey period, consistent with the widespread flooding event. Lignum can respond rapidly to watering and rainfall (Capon et al. 2009), as seen during the previous survey period. However, the benefits of floods exceed artificial watering (Holland et al*.* 2013), due to the extent and duration of inundation during these events.

The increase in lignum condition across all three WRCs during this survey period and the last is consistent with the artificial watering and rainfall event that occurred over 2021-22 and flooding event that occurred over this survey period. Lignum Shrubland and Lignum Swamp sites exhibited a continuation of the trend of increasing LCIs across these WRCs which has been ongoing since 2019–20. In contrast, Lignum Woodland LCI scores have remained relatively steady over the last five years. As discussed in Wood et al. (2018), variance in lignum condition between each of the three strata/communities is possibly explained by differing spatial distributions and hence flooding frequency. The larger fluctuations in lignum condition across years seen in Lignum Shrubland and Lignum Swamp WRCs compared with the Lignum Woodland WRC are potentially attributable to greater fluctuations in water availability at those sites. Both Lignum Swamp and Lignum Shrubland are more closely associated with wetter sites found in wetlands and wetland verges, respectively. Conversely, Lignum Woodland is often found at drier sites, co-occurring with black box and eumong. Differences between WRCs across years may also be reflective of spatial heterogeneity between WRCs, resulting in a disparity of exposure to environmental watering.

Regardless of the natural fluctuation of lignum condition observed after watering events, the condition of lignum across all WRCs and the wider icon site has continuously exceeded the ecological target (>70% plants with an LCI ≥4) (with the exception of Lignum Shrubland in 2018–19 and 2020–21). This is likely a reflection of adequate frequency and duration of watering events at Hattah Lakes for this species, during this period. In addition to the natural widespread flooding that occurred this year and in 2016-17, there have been environmental water deliveries to Hattah Lakes in 2017–18 and 2021–22. These events combined are likely responsible for maintaining target attainment.

7.5 Objective and target attainment

The site level target for lignum condition states that 70% or more of lignum plants at Hattah Lakes have a LCI score of ≥4. Lignum condition appears to have improved on average across all WRCs and the broader icon site at Hattah in 2022–23. The target was achieved on average across the whole icon site, as well as within each of the three WRCs surveyed (Lignum Woodland, Lignum Shrubland and Lignum Swamp) (Table 25). As such, the ecological objective to 'improve condition and maintain extent from baseline (2006) levels of Lignum *Duma florulenta* to sustain communities and processes typical of such communities at the Hattah Lakes icon site by 2030' has been met in 2022–23.

Table 25 Summary of Lignum target attainment in 2022–23

Objective HL4	Attained	Partial attainment	Not attained
Improve condition and maintain extent from baseline (2006) levels of river red gum *Eucalyptus camaldulensis*, black box *E. largiflorens* and Lignum *Duma florulenta* to sustain communities and processes typical of such communities at Hattah Lakes icon site by 2030.			
Specific target: Condition in standardised transects that span the floodplain elevation gradient and existing spatial distribution, ≥70% of lignum plants in good condition with a Lignum Condition Score (LCI) ≥4.			
Whole of icon site			
Lignum Shrubland			
Lignum Swamp			
Lignum Woodland			

7.6 Recommendations

While the use of a compliance score (e.g. percentage of plants with LCI ≥4) provides an indication of overall lignum health, lignum produces leaves, flowers and shoots rapidly in response to rainfall and flooding. Therefore, current water availability across all lignum sites needs to be considered when assessing the compliance of a site based on the percentage of plants with a LCI ≥4.

Changes to flow regimes will influence the distribution and abundance of species, genetic diversity and genetic structure, and the distribution of lignum populations across floodplains. In addition, minimal lignum recruitment has been observed in recent years while conducting TLM surveys, including following the most recent surveys. Lignum requires approx. 20 days of flooding and wet soils following flood recession for optimal germination to occur (Higgisson 2019). We therefore recommend obtaining accurate historical inundation data for lignum sites to assess how changes in flow regime are influencing both plant health and potentially germination levels.

Too long between inundation or significant rainfall events inevitably leads to declines in lignum condition. This deterioration may become difficult to remediate if declines in health go beyond natural cyclical variation and lead to significant levels of lignum mortality or reductions in population extent. As such, low lignum condition scores may require further remediation with environmental water, preferentially targeting specific sites or WRCs. Although lignum condition scores generally appear to be within desirable ranges at Hattah Lakes, the Lignum Shrubland WRC may require further targeted delivery of environmental water to optimise health outcomes during extended dry periods, given that it generally exhibits the lowest percentage of plants with an LCI of ≥4 of the three WRCs (although improvements have been observed the last two years). The provision of inundation extent data would also allow for more accurate relation of LCI scores to inundation history, leading to more efficient delivery of environmental flows to meet the ecological objectives laid out in the CMP (2021b).

8 Waterbirds

8.1 Introduction

The Hattah Lakes icon site contains 18 wetlands (12 Ramsar-listed) ranging from semi-permanent wetlands to ephemeral wetlands that provide valuable waterbird habitat when containing water. In previous years a wide range of large waterbirds, including pelicans, spoonbills, and egrets, as well as smaller waterbirds and shorebirds, including ducks, cormorants and plovers has been recorded at various Hattah wetlands. Waterbird monitoring at Hattah Lakes is conducted through several surveys annually to assess the effects of flooding events on waterbird habitat and activity in selected wetlands. For the 2022–23 season, monitoring at the Hattah Lakes icon site was conducted in spring, summer, and autumn to allow for better monitoring of waterbird breeding success throughout the year. This chapter presents the findings of the 3 waterbird surveys carried out over the 2022–23 season.

As stated in the Hattah Lakes Condition Monitoring Plan (MCMA 2021b), the 2 objectives relating to waterbirds are:

Objective HL7 Create vital habitat – feeding habitat for waterbirds

By 2030, maintain or improve biodiversity at Hattah Lakes by ensuring that feeding habitat for the dominant guilds of waterbirds, most notably waterfowl, herbivores, and piscivores, are supported.

Specific targets relating to waterbirds under HL7 are:

Feeding habitat defined as a mixture of deep feeding areas (water >1 m) and shallow feeding areas (<0.5 m depth and / or drying mud) with intermittent inundation of densely vegetated shrublands (flooding of lignum habitat for 5–6 months every 2 years).

Support feeding habitat for waterfowl, herbivores and piscivores of waterbirds, 8 years in 10, with the following common species recorded annually:

- Australian pelican *Pelecanus conspicillatus*, Australian wood duck *Chenonetta jubata*, pied stilt *Himantopus himantopus*, Australasian darter *Anhinga novaehollandiae*, great cormorant *Phalacrocorax carbo*, great crested grebe *Podiceps cristatus*, little black cormorant *Phalacrocorax sulcirostris*, masked lapwing *Vanellus miles*, Pacific black duck *Anas superciliosa*, white-faced heron *Egretta novaehollandiae* and yellow-billed spoonbill *Platalea flavipes*.

Objective HL8 Waterbird breeding

By 2030, protect and restore ecosystem functions of water-dependent ecosystems that support successful colonial nesting waterbird species at Hattah Lakes by providing conditions for breeding and fledging at least 3 times every 10 years.

Specific targets relating to waterbirds under HL8:

Increased frequency in successful breeding (success as young fledging) of one or more of the listed colonial nesting species 3 years in 10, when conditions are favourable:

- Australian white ibis *Threskiornis molucca*, glossy ibis *Plegadis falcinellus*, eastern great egret *Ardea alba modesta*, intermediate egret *Ardea intermedia*, Australasian darter, great cormorant, little black cormorant, little pied cormorant *Microcarbo melanoleucos*, white-necked heron *Ardea pacifica*, yellow-billed spoonbill and royal spoonbill *Platalea regia*.

8.2 Methods

The method used for the waterbird surveys was consistent with that used for previous surveys (Bloink et al. 2019, 2020; Palmer et al. 2021, 2022) and follows the BirdLife Australia suggested method (BirdLife Australia 2016). All waterbirds visible from a fixed point on the edge of each wetland (or 2 separate fixed points for large wetlands) were identified to species level and the number of individuals per species was recorded. Counts were conducted for 20 minutes (longer if large numbers of birds were present) by 2 experienced observers using a spotting scope and binoculars. Twenty-minute surveys were also conducted at dry wetlands unlikely to support waterbirds, to record any incidental waterbirds, as well as any other bird species present at these sites (see non-waterbird chapter below). Evidence of current or recent breeding, such as nests and juveniles (where these were discernible), was recorded where observed. For wetlands containing any water, water levels (percentage surface water area compared to full) were estimated using satellite images obtained from the U.S. Geological Survey (USGS 2023) taken in the months surveys were conducted.

The following 15 wetlands were surveyed over the 2022–23 monitoring period:

- Lake Arawak
- Lake Bitterang (2 survey points)
- Lake Brockie
- Lake Bulla
- Lake Cantala
- Lake Hattah
- Lake Konardin
- Lake Kramen (2 survey points)
- Lake Little Hattah
- Lake Lockie (2 survey points)
- Lake Mournpall (2 survey points)
- Lake Nip Nip
- Lake Woterap
- Lake Yelwell
- Lake Yerang

Due to high rainfall and resulting flooding of areas throughout the Hattah Lakes icon site during spring and summer 2022–23, Lakes Brockie and Cantala could not be surveyed in spring, and Lake Bitterang could only be surveyed in autumn.

8.3 Results

The 15 wetlands surveyed at the Hattah Lakes icon site were visited between 13–15 November 2022 (spring), between 19–22 February 2023 (summer) and between 7–9 May 2023 (autumn). The Hattah Lakes received ample natural flows in spring-summer 2022, due to a higher than usual rainfall pattern. As a result, all surveyed wetlands contained water during all surveys, with the exception of Lake Kramen, which was dry during spring, but filled up prior to the summer and autumn surveys (Table 26). Reduced access, due to high water levels related to the extensive flooding event, prevented spring surveys being undertaken at Lakes Bitterang, Brockie and Cantala; Lake Bitterang was also not accessible for the summer 2023 survey.

Table 26 Extent of surface water area of the Hattah Lakes during the 2022–2023 spring, summer and autumn waterbird surveys, and associated observed waterbird densities

Wetland	Total area (ha)	Survey	% Full	Surface water area (ha)	Waterbird density (birds/ha surface water)
Lake Arawak	50	Spring	164	82	0.1
		Summer	92	46	1
		Autumn	80	40	7
Lake Bitterang	156	Spring	160	250	Not surveyed
		Summer	95	148	Not surveyed
		Autumn	91	142	7.8
Lake Brockie	42	Spring	157	66	Not surveyed
		Summer	110	46	1.2
		Autumn	88	37	2.4
Lake Bulla	46	Spring	113	52	0.2
		Summer	83	38	1.4
		Autumn	83	38	11.4
Lake Cantala	108	Spring	333	360	Not surveyed
		Summer	134	145	0.6
		Autumn	125	135	4.2
Lake Hattah	65	Spring	102	66	0.1
		Summer	91	59	2.5
		Autumn	86	56	10.2
Lake Konardin	85	Spring	139	118	0.04
		Summer	105	89	0.4
		Autumn	96	82	1.1
Lake Kramen	87	Spring	0	0	0
		Summer	199	173	0.3
		Autumn	164	143	0.4
Lake Little Hattah	12	Spring	375	45	0.4
		Summer	108	13	8.9
		Autumn	58	7	73.4
Lake Lockie	176	Spring	183	322	0.1
		Summer	118	208	0.1
		Autumn	72	127	1.8
Lake Mournpall	181	Spring	130	235	0.04
		Summer	108	196	0.6
		Autumn	103	187	1.9
Lake Nip Nip	2	Spring	150	3	19
		Summer	125	2.5	12.4
		Autumn	100	2	13
Lake Woterap	33	Spring	130	43	0.2
		Summer	91	30	1.5

Wetland	Total area (ha)	Survey	% Full	Surface water area (ha)	Waterbird density (birds/ha surface water)
		Autumn	79	26	9
Lake Yelwell	59	Spring	188	111	0.1
		Summer	115	68	3.2
		Autumn	102	60	7.8
Lake Yerang	39	Spring	131	51	0.3
		Summer	118	46	1.9
		Autumn	82	32	1.3

Waterbirds were recorded at all wetlands in all surveys, except for Lake Kramen in spring, when it was dry (the exception here being of great cormorants flying over during the survey). A detailed list of waterbird species recorded during each survey round, including individual counts per species, species richness and waterbird density, can be found in Table 7 of the 2022–2023 Part B Report (Butler et al. 2023).

8.3.1 Waterbird numbers and diversity

In total 6,394 waterbirds, comprising 29 species, were recorded (Table 27; Table 28). Waterbird numbers showed the same trend as during the previous monitoring season, when the wetlands received environmental water, with abundance and species richness increasing from the spring to autumn surveys (Table 7, Part B Report [Butler et al. 2023]). Abundance increased from 195 individuals counted in spring, to 1,118 in summer and 5,081 in autumn. Diversity also increased, from 17 species in spring, to 22 species in summer and 27 species in autumn.

One species listed as vulnerable under the Victorian *Flora and Fauna Guarantee Act 1988* (FFG Act), was recorded: musk duck *Biziura lobata*. As during the previous 2 monitoring seasons, the guild with the highest number of individuals recorded in spring were the dabbling ducks (97, 49.7% of waterbirds recorded in spring, Table 27), with grey teal *Anas gracilis* being the most commonly recorded species (84 individuals, Table 7, Part B Report [Butler et al. 2023]). The least common guild were the grebes, with only one Australasian grebe and 4 great crested grebes observed (2.6% of waterbirds). No diving ducks, filter-feeding ducks, shorebirds, or terns were recorded in spring. In summer, fish-eaters were the most abundant guild (634, 56.7% of waterbirds recorded in summer, Table 27), due to large numbers of Australasian darters, great cormorants, and little pied cormorants *Microcarbo melanoleucos* (157, 174, and 187 individuals, respectively; Table 7, Part B Report [Butler et al. 2023]) spread out across all wetlands. Little pied cormorants were the most abundant species overall in summer and were present at every wetland, except Lake Cantala, with 187 individuals recorded. The least abundant guild in summer was the diving duck guild, representing only 0.1% of all waterbirds observed (a single musk duck at Lake Lockie). No filter-feeding ducks were observed in summer. As during the previous monitoring season, fish-eaters were by far the most abundant guild in autumn, with 2,998 individuals observed (59% of all waterbirds, Table 27), mostly due to a large increase in abundance of great cormorants (1,521 individuals, Table 7, Part B Report [Butler et al. 2023]). During the autumn surveys, the least abundant guild was the filter-feeding ducks, representing only 0.1% of all waterbirds observed (2 pink-eared ducks *Malacorhynchus membranaceus* recorded each at Lakes Hattah and Yelwell, Table 27).

On average, waterbird density increased from spring to autumn with 1.9, 2.6, and 10.2 waterbirds per hectare of surface water in spring, summer and autumn, respectively. The highest density was recorded at the smallest wetland surveyed, Lake Little Hattah (27.6 birds/ha on average, with the highest, 73.4 birds/ha in autumn) and at Lake Nip Nip in spring (19 birds/ha, Table 26; Table 7, Part B Report [Butler et al. 2023]). Density was lowest on average at Lakes Konardin and Kramen (0.5 and 0.4 birds/ha, respectively). The lowest density recorded during any of the surveys was in spring at Lakes Konardin and Mournpall (0.04 birds/ha, Table 26; Table 7, Part B Report [Butler et al. 2023]).

Table 27 Number of waterbirds observed during spring 2022 and summer and autumn 2023 surveys by guild and guild representations as a proportion of all waterbirds seen

					% of all waterbirds		
Waterbird feeding guild	**Spring**	**Summer**	**Autumn**	**Total**	**Spring**	**Summer**	**Autumn**
Coots & rails	9	42	63	**114**	4.6	3.8	1.2
Dabbling ducks	97	25	35	**157**	49.7	2.2	0.7
Diving ducks	-	1	44	**45**	-	0.1	0.9
Filter-feeding ducks	-	-	4	**4**	-	-	0.1
Fish-eaters	51	634	2,998	**3,683**	26.2	56.7	59.0
Grazing ducks	18	41	50	**109**	9.2	3.7	1.0
Grebes	5	213	1,707	**1,925**	2.6	19.1	33.6
Large wading birds	15	122	158	**295**	7.7	10.9	3.1
Shorebirds	-	6	22	**28**	-	0.5	0.4
Terns	-	34	-	**34**	-	3.0	-
Total abundance	**195**	**1,118**	**5,081**	**6,394**	**100**	**100**	**100**
Species richness	**17**	**22**	**27**	**29**			

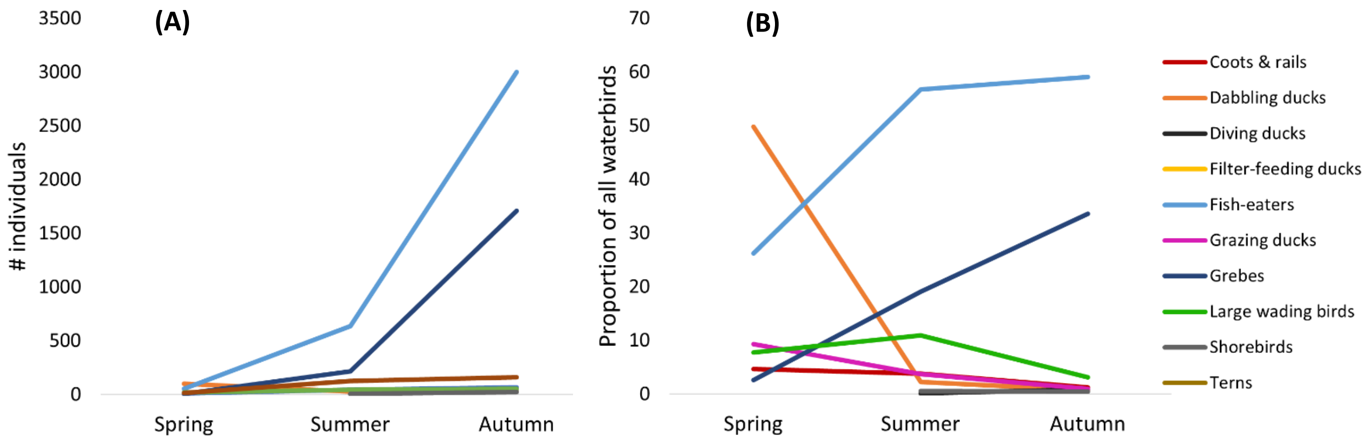


Figure 43 Changes in number of individuals (A) and proportion of all waterbirds recorded (B) over the 3 survey rounds for each waterbird guild at the Hattah Lakes icon site

Table 28 Total counts of waterbirds by species, guild, and wetland for the 2022–23 monitoring season.

Species		Arawak	Bitterang	Brockie	Bulla	Cantala	Hattah	Konardin	Kramen	Little Hattah	Lockie	Mournpall	Nip Nip	Woterap	Yelwell	Yerang	Total
Coots & rails		**2**	**4**	**2**	**1**	**3**	**38**		**8**	**11**	**15**	**11**	**7**	**3**	**6**	**3**	**114**
Black-tailed native-hen	*Tribonyx ventralis*						28						1		3		32
Dusky moorhen	*Gallinula tenebrosa*												1				1
Eurasian coot	*Fulica atra*	2	4	2	1	3	10		8	11	15	11	5	3	3	3	81
Dabbling ducks		**5**	**9**	**3**		**3**	**1**	**2**	**5**	**15**	**16**	**6**	**50**	**12**	**15**	**15**	**157**
Grey teal	*Anas gracilis*	1	5	2		3		2	5	15	13	6	39	10	13	12	126
Pacific black duck	*Anas superciliosa*	4	4	1			1				3		11	2	2	3	31
Diving ducks			**15**					**12**			**14**	**3**			**1**		**45**
Musk duck	*Biziura lobata*		15					12			14	3			1		45
Filter-feeding ducks							**2**								**2**		**4**
Pink-eared duck	*Malacorhynchus membranaceus*						2								2		4
Fish-eaters		**101**	**446**	**93**	**393**	**568**	**177**	**22**	**75**	**481**	**194**	**373**	**19**	**107**	**557**	**77**	**3,683**
Australasian darter	*Anhinga novaehollandiae*	60	13	51	57	16	53	13	6	12	24	17	4	70	95	23	514
Australian pelican	*Pelecanus conspicillatus*		1								35	1				5	42
Great cormorant	*Phalacrocorax carbo*	36	101	35	308	551	61	6	37	66	104	343	13	6	43	16	1,726
Little black cormorant	*Phalacrocorax sulcirostris*	1	261		15	1	28	1	3	314	2	5		6	330	21	988
Little pied cormorant	*Microcarbo melanoleucos*	4	70	7	13		27	2	17	89	27	6	2	25	89	12	390
Pied cormorant	*Phalacrocorax varius*						8		12		2	1					23
Grazing ducks		**10**		**16**	**1**		**11**	**2**	**22**	**2**		**5**	**22**		**14**	**4**	**109**
Australian shelduck	*Tadorna tadornoides*				1		2	2							2		7
Australian wood duck	*Chenonetta jubata*	10		16			9		22	2		5	22		12	4	102
Grebes		**210**	**626**	**21**	**89**	**74**	**452**	**85**	**22**	**25**	**12**	**41**	**11**	**166**	**49**	**42**	**1,925**
Australasian grebe	*Tachybaptus novaehollandiae*	9	1	5	1	13	16	2	4	23	1		6	12	2	3	98
Great crested grebe	*Podiceps cristatus*	68	34	15	13	1	66	19	10	1	2	30	1	5	5	14	284
Hoary-headed grebe	*Poliocephalus poliocephalus*	133	591	1	75	60	370	64	8	1	9	11	4	149	42	25	1,543
Large wading birds		**6**	**9**	**7**	**15**	**6**	**35**	**9**	**2**	**112**	**8**	**15**	**5**	**2**	**57**	**7**	**295**
Australian white ibis	*Threskiornis molucca*				4	3	2	3		8	1	6		2	19	3	51
Eastern great egret	*Ardea alba modesta*	4			6		14	4		75	3		1		9	1	117
Nankeen night-heron	*Nycticorax caledonicus*				3		15		1	19	1				1		40
Straw-necked ibis	*Threskiornis spinicollis*			5													5
White-faced heron	*Egretta novaehollandiae*	1	3	1		3	4	2	1	4	3	2	3		4	2	33
White-necked heron	*Ardea pacifica*		4	1	2					3		4	1				15
Yellow-billed spoonbill	*Platalea flavipes*	1	2							3		3			24	1	34
Shorebirds				**2**			**4**			**2**	**19**	**1**					**28**
Black-fronted dotterel	*Elseyornis melanops*										6						6
Masked lapwing	*Vanellus miles*			2			4			2	7	1					16
Red-kneed dotterel	*Erythrogonys cinctus*										6						6
Terns												**34**					**34**
Whiskered tern	*Chlidonias hybrida*											34					34
	Total number of waterbirds	**334**	**1,109**	**144**	**499**	**654**	**720**	**132**	**134**	**648**	**278**	**489**	**114**	**290**	**701**	**148**	**6,394**
	Species richness	**14**	**15**	**14**	**13**	**10**	**19**	**13**	**13**	**17**	**20**	**18**	**15**	**11**	**20**	**16**	**29**

Overall, guilds were rather skewed during the summer and autumn surveys, with grebes and fish-eaters, in particular, dominating in both seasons. Fish-eaters was clearly the most abundant guild in autumn, with grebes showing a marked increase in numbers in that season also (Figure 43; Table 27).

With regards to species diversity, the large wading birds and fish-eater guilds were best represented, with 7 and 6 species recorded across all surveys, respectively. Coots and rails, grebes, and shorebirds were each represented by 3 species, dabbling ducks by 2 species, and the least diverse guilds, with one species recorded for each, were the diving ducks (musk duck), filter-feeding ducks (pink-eared duck), and terns (whiskered tern *Chlidonias hybrida*) (Table 28).

Species only recorded for one of the 3 surveys were: straw-necked ibis *Threskiornis spinicollis* and whiskered tern in summer, and black-tailed native-hen *Tribonyx ventralis*, dusky moorhen *Gallinula tenebrosa,* pink-eared duck, black-fronted dotterel *Elseyornis melanops* and red-kneed dotterel *Erythrogonys cinctus* in autumn (Table 7, Part B Report [Butler et al. 2023]). Fourteen of the 29 species were seen during every survey round (Table 7, Part B Report [Butler et al. 2023]).

Of the 11 selected species listed to be recorded annually under ecological objective HL7, 10 were recorded at the Hattah Lakes icon site during the 2022–23 monitoring season: 9 during both spring and summer, and 10 in autumn. Only the pied stilt *Himantopus leucocephalus* was not recorded during this monitoring season (Table 29).

Table 29 Waterbird species to be recorded annually at Hattah Lakes to attain objective HL7, and whether these species have been recorded during the spring 2022, summer and/or autumn 2023 surveys.

Target species	2022–23		
	Spring	Summer	Autumn
Australasian darter	✓	✓	✓
Australian pelican	✓	-	✓
Australian wood duck	✓	✓	✓
Pied stilt	-	-	-
Great cormorant	✓	✓	✓
Great crested grebe	✓	✓	✓
Little black cormorant	✓	✓	✓
Masked lapwing	-	✓	✓
Pacific black duck	✓	✓	✓
White-faced heron	✓	✓	✓
Yellow-billed spoonbill	✓	✓	✓

8.3.2 Waterbird breeding

Evidence of waterbird breeding at Hattah Lakes was observed during all surveys, with the most apparent evidence of breeding activity for most species being observed during the autumn survey. (Table 30). The most relevant evidence of breeding related to ecological objective HL8 (Waterbird breeding), was the presence of large numbers of adult great cormorants on nests at Lakes Cantala and Mournpall (500+ and 235, respectively in autumn, Table 30). Other target colonial waterbird species observed breeding at multiple wetlands were Australasian darters, little black cormorants and little pied cormorants. Yellow-billed spoonbill juveniles were recorded at Lake Yelwell in autumn (Table 30).

One significant observation of local breeding activity for a species not listed under ecological objective HL8 is that of 4 juvenile musk ducks in autumn at Lake Bitterang. As mentioned earlier, this species is listed as vulnerable under the FFG Act and signs of it breeding locally are a good indication of the importance of the Hattah Lakes icon site as a contributor to the protection of regional biodiversity.

Table 30 Records of breeding evidence (numbers of adults on nests and juveniles) during each survey round at the surveyed wetlands at Hattah Lakes. Evidence of breeding in colonial waterbirds listed under ecological objective HL8 is shown in bold.

Wetland	Breeding evidence	Species	Spring	Summer	Autumn
Lake Arawak	Adults on nest	**Australasian darter**	**1**	**6**	**11**
		Great cormorant		**4**	**14**
	Juveniles	Great crested grebe		11	26
Lake Bitterang	Adults on nest	**Australasian darter**			**1**
		Great cormorant			**1**
		Little pied cormorant			**5**
	Juveniles	**Australasian darter**			**4**
		Great crested grebe			9
		Little black cormorant			**22**
		Little pied cormorant			**4**
		Musk duck			4
Lake Brockie	Adults on nest	**Australasian darter**		**4**	**11**
		Great cormorant		**5**	
	Juveniles	**Australasian darter**			**2**
		Australasian grebe		1	
		Great crested grebe			7
Lake Bulla	Adults on nest	**Great cormorant**		**3**	**11**
	Juveniles	**Great cormorant**			**4**
		Great crested grebe		1	4
Lake Cantala	Adults on nest	**Great cormorant**			**500+**
	Juveniles	**Australasian darter**			**3**
		Australasian grebe		**2**	
		Eurasian coot		2	
		Great cormorant		**15**	
		Sacred kingfisher		1	
Lake Hattah	Adults on nest	**Great cormorant**		**1**	**1**
	Juveniles	**Australasian darter**		**1**	
		Australasian grebe		4	

Wetland	Breeding evidence	Species	Spring	Summer	Autumn
		Eurasian coot		1	2
		Great cormorant		**2**	
		Great crested grebe		2	20
		Hoary-headed grebe		3	
		Nankeen night-heron		2	
Lake Konardin	Adults on nest	**Great cormorant**		**2**	
	Juveniles	**Australasian darter**			**3**
		Great crested grebe		8	
Lake Kramen	Adults on nest	**Great cormorant**			**1**
		Whistling kite	1	1	
	Juveniles	Eurasian coot		1	3
		Great cormorant			**3**
		Great crested grebe			5
		Little pied cormorant		**1**	**1**
		Nankeen night-heron		1	
Lake Little Hattah	Juveniles	Australasian grebe		5	
		Eurasian coot		3	2
		Great cormorant		**2**	**2**
		Great crested grebe		1	
		Hoary-headed grebe		1	
		Little black cormorant		**1**	
		Nankeen night-heron		6	
Lake Lockie	Adults on nest	**Australasian darter**		**1**	
		Great cormorant		**2**	**38**
	Juveniles	Eurasian coot		2	
		Sacred kingfisher		1	
Lake Mournpall	Adults on nest	**Great cormorant**		**2**	**235**
	Juveniles	Eurasian coot		4	
		Great cormorant			**6**
Lake Nip Nip	Juveniles	Great crested grebe			1
		Laughing kookaburra		1	
Lake Woterap	Adults on nest	**Australasian darter**		**5**	
		Great crested grebe			6
		Little pied cormorant		**1**	**5**
	Juveniles	Australasian grebe		3	
		Great crested grebe			6
		Little pied cormorant		**2**	**3**
		Sacred kingfisher		1	
Lake Yelwell	Adults on nest	**Australasian darter**		**7**	**3**

Wetland	Breeding evidence	Species	Spring	Summer	Autumn
		Great cormorant		**4**	**4**
		Little black cormorant		**4**	**1**
	Juveniles	**Australasian darter**			**6**
	Juveniles	Eurasian coot		3	
	Juveniles	Great crested grebe		1	
	Juveniles	**Yellow-billed spoonbill**			**3**
Lake Yerang	Adults on nest	**Australasian darter**			**1**
Lake Yerang	Juveniles	Great crested grebe			2
Lake Yerang	Juveniles	Grey teal	5		
Lake Yerang	Juveniles	Hoary-headed grebe			2

8.4 Discussion

The Hattah Lakes received an unusually large amount of water in late spring and early summer 2022–23 due to high rainfall in the Murray-Darling basin. This led to widespread flooding of the area and meant that all wetlands contained copious amounts of water and were well-connected by wide, inundated corridors during all 3 survey rounds, especially in summer. Only Lake Kramen was dry in spring but was full past capacity like the other wetlands over summer and autumn. This is in stark contrast to conditions during the surveys prior to the 2021–22 monitoring period, when all wetlands except for Lake Kramen were dry (Palmer et al. 2021). Such flooding has flow-on effects on vegetation structure and resource abundance throughout the Hattah Lakes icon site and the broader region. The exact implications of these differences between years and what they may mean in terms of working towards the Ecological Objectives developed for the Hattah Lakes in relation to waterbirds are discussed here.

8.4.1 Wetland status, bird abundance and species richness

Waterbird species richness was identical to that observed during the 2021–22 surveys (29 species) and very close to the numbers recorded during the 2020–21 surveys (28 species). This similarity in species richness across years is especially interesting considering the differences in water present at Hattah Lakes. Where almost all surveyed wetlands were near capacity to overflowing in 2021–2023, most wetlands were dry during the 2020–21 surveys. Over the previous dry period when only Lake Kramen held water, this wetland acted as a local waterbird refuge, attracting a wide variety of species (Palmer et al. 2021). As the environmental watering event in spring 2021 coincided with generally high water levels in the Murray River, with another high inflow event in spring 2022, this meant that surface water was present throughout the wider region. This in turn provided waterbirds the opportunity to disperse over a larger area, leading to relatively low waterbird numbers and a moderate species count at the Hattah Lakes icon site, despite the abundance of water, especially during the spring 2022 and summer 2023 surveys.

The high amount of water throughout the wetland system especially favoured species with a preference for open, deep water such as dabbling ducks, grebes and fish-eaters, guilds that dominated in numbers throughout the year. Most notable was the clear increase in abundance of fish-eaters from spring to autumn, mostly great cormorants, the same pattern as observed across the wet 2021–22 monitoring period. In spring, the fresh inflow of water would have mainly added smaller fish, eggs, and larvae into the wetlands, adding to the fish stock already present from the previous season. As the year progressed, more fish within the aquatic system would have bred and grown, making the wetlands more attractive for fish-eaters that hunt for larger-bodied fish. A notable observation of a flock of 34 whiskered terns, at Lake Mournpall in summer 2023, indicates that many fish in this wetland would have grown and been the right size for terns to hunt at this time. No terns were recorded at Hattah Lakes in the previous 2 monitoring seasons.

As in the previous monitoring round, the number of great cormorants was especially high at 2 of the larger wetlands, Lakes Cantala and Mournpall, which likely offer higher quality habitat for both foraging and nesting for this species. As the water receded somewhat by the autumn survey, the number of large wading birds, shorebirds, and grazing ducks increased, likely due to increased availability of shallow water and dry land along the wetland margins. Again this was a pattern similar to that observed in the previous, wet monitoring round.

Overall waterbird abundance increased between spring and autumn, which was mostly related to the high influx of great cormorants and grebes in summer and especially in autumn, however, species diversity also increased over the same period. In contrast, there was a decline in abundance in some guilds, such as dabbling ducks, across the spring to autumn survey period. It is possible that an increase in carp numbers from spring to autumn made the water in many of the wetlands too turbid, or reduced the extent or availability of preferred food plants for these species, causing them to move elsewhere to forage.

Waterbird density peaked in autumn at each wetland, except for Lakes Nip Nip and Yerang, where density peaked in spring and summer, respectively. The overarching trend of peaking density in autumn is related to the increasing number of individuals present, combined with the decreasing extent of surface water available, from spring to autumn. The small surface area of Lake Nip Nip, even when full, resulted in high waterbird density in spring due to the presence of a relatively high number of dabbling ducks. At Lake Yelwell, high numbers of fish-eaters and grebes in summer contributed to the peak in waterbird density.

8.5 Objective and target attainment

Ecological objective HL7 aims to, by 2030, create feeding habitat for waterbirds at least 8 out of every 10 years. Feeding habitat is defined as a mixture of deep feeding areas (water >1 m) and shallow feeding areas (<0.5 m depth and/or drying mud) with intermittent inundation of densely vegetated shrublands (flooding of lignum habitat for 5–6 months every 2 years). All surveyed wetlands, except for Lake Kramen, started to fill in spring 2022 and had flooded by summer. They, therefore, provided feeding habitat for waterbirds, as defined in objective HL7, over the 2022–23 season. This also included the flooding of lignum habitat. Lake Kramen was dry in spring and, therefore, did not provide waterbird habitat at that stage, however, in summer and autumn this wetland was nearly full and, as a result, supported waterbirds.

An additional aim of this objective is to record the presence of 11 common waterbird species on an annual basis. Over the 2022–23 season, 10 of the 11 selected species were recorded at the Hattah Lakes icon site; 9 during both spring and summer, and 10 in autumn. The only species not recorded during this monitoring period was the pied stilt. This species is a common visitor to the Hattah Lakes icon site and has been recorded reliably across previous monitoring seasons. However, the high water levels during this season resulted in fewer areas providing the shallow, open water these birds prefer to forage in. Due to the widespread flooding, such areas were likely in higher supply across the broader landscape causing dispersal of the species, so it is possible that pied stilts could have been present within the Hattah Lakes icon site locality, just not at the surveyed wetlands.

The absence of pied stilt this season does mean that at this stage of the 2020–30 10-year period, objective HL7 is no longer on track to be met at the Hattah Lakes icon site (Table 32). It has to be noted, however, that these surveys form a very narrow snapshot of species presence and absence throughout the year. Given that waterbirds are very mobile species, they can easily be absent on survey days, but present directly before or after these dates, or at different times on the same day. It is highly likely that the pied stilt did visit at least one of the monitored wetlands at some stage during the 2022–23 monitoring period, as suitable habitat was observed.

Ecological objective HL8 aims to, by 2030, restore and protect habitat suitable for successful colonial waterbird nesting at least 3 out of every 10 years. This objective specifically aims to increase the frequency of successful breeding by a number of waterbird species (see Section 8.4 for a full list of species). Evidence of successful breeding was observed for the Australasian darter and great, little pied and little black cormorants in both summer and autumn (fledged juveniles and active breeding; Table 30; Table 31). Objective HL8 is, therefore, still on track to be met successfully by 2030 (Table 32).

Table 31 Colonially breeding waterbird species listed under objective HL8 to be recorded breeding at Hattah Lakes with increased success by 2030 and whether any of these species were observed breeding successfully during the 2022–23 survey period. Tick marks indicate breeding and juveniles observed, open circles indicate only either breeding or juveniles observed.

Target species	2022–23		
	Spring	Summer	Autumn
Australasian darter	-	✓	✓
Australian white ibis	-	-	-
Glossy ibis	-	-	-
Great cormorant	-	✓	✓
Eastern great egret	-	-	-
Intermediate egret	-	-	-
Little black cormorant	-	✓	✓
Little pied cormorant	-	✓	✓
Royal spoonbill	-	-	-
White-necked heron	-	-	-
Yellow-billed spoonbill	-	-	-

Table 32 Summary of waterbird target attainment in 2022–23

Objective	Attained	Partial attainment	Not attained
HL7: *Create vital habitat – feeding habitat for waterbirds*			
Annually record common waterbird species			
HL8: *Waterbird breeding*			
Provide conditions for colonial waterbird breeding 3 years out of 10			

8.6 Recommendations

Patterns of waterbird distribution and abundance are dynamic, fluctuating with continental rainfall patterns and the availability of water in the landscape (see Frith 1982; Chambers and Loyn 2006). The results from the current and previous seasons of waterbird monitoring demonstrate these patterns of response, with changes in waterbird abundance and density related to flooding and drying of wetlands at both a local and landscape scale.

Given the recent wet La Niña event and associated widescale flooding providing good volumes of water to the Hattah Lakes icon site, more waterbirds seem to have established at the site as it provides more reliably suitable habitat. As south-eastern Australia is now facing an El Niño event with expected associated drier and hotter conditions, managers should consider the effects this will have on waterbird foraging and breeding opportunities. As the wetlands draw down, opportunities will initially arise for different guilds of waterbirds, such as large wading birds and shorebirds. Colonial waterbirds are likely to become less abundant in the area as the water in many wetlands recedes and becomes too shallow to support large enough fish. As seen over previous seasons, as wetlands in the region dry up or become too shallow for many waterbirds, environmental water can create important refugia for many species.

9 Non-waterbirds

9.1 Introduction

In addition to waterbird counts, the 2022–23 surveys also included 20-minute counts of any non-waterbird species present at each of the wetlands surveyed. These non-waterbird surveys were first conducted during the 2019–20 season, to gain an understanding of how birds, that are not necessarily strongly associated with the presence of open water bodies, use the wetlands during their different stages of inundation. This provides valuable insight into the resources the wetlands provide to other birdlife, throughout their wetting and drying cycles.

9.2 Methods

Non-waterbird species were recorded where present on the lakebed (dry lakes and shorelines), or in the riparian vegetation directly bordering each surveyed wetland. As for the waterbirds, a 20-minute timed count was conducted, where non-waterbird species identified by sight or sound was recorded. Evidence of breeding and recruitment (i.e. nests and juveniles, where these were discernible) were recorded opportunistically.

9.3 Results

Fifteen wetlands in the Hattah Lakes icon site were surveyed for non-waterbird species between 13–15 November 2022 (spring), between 19–22 February 2023 (summer) and between 7–9 May 2023 (autumn). The list of surveyed wetlands can be found in the Waterbirds chapter of this report. In total, 2,789 non-waterbirds comprising 61 species were observed; 990 (41 species) in spring, 774 (40 species) in summer, and 1,025 (42 species) in autumn (Table 8, Part B Report [Butler et al. 2023]).

9.3.1 Number and species richness of non-waterbirds

The highest overall abundance of non-waterbirds (1,173) was observed at Lake Kramen (Table 33), with consistent, relatively high, numbers observed during each survey, mostly due to large flocks of little corellas *Cacatua sanguinea* observed during each survey (Table 8, Part B Report [Butler et al. 2023]). Lake Nip Nip yielded the highest overall diversity of non-waterbird species (31). Lake Mournpall had the second-highest non-waterbird abundance (197 individuals, much lower than numbers observed at Lake Kramen). Across all surveys, the lowest abundance of non-waterbirds was observed at Lake Cantala (51 individuals, likely partly due to the absence of a spring survey at this wetland due to access issues) and the lowest species diversity was recorded at Lake Brockie (11 species, Table 33). Abundance was also relatively low at Lake Bulla, with 58 individuals counted over 3 surveys. This lake consequently also showed relatively low species diversity with just 14 species observed.

As during the previous 2 monitoring seasons, little corellas were by far the most abundant species (898 individuals), largely due to large flocks observed at Lake Kramen during each survey and Lake Bitterang in autumn (62 individuals). The next most abundant non-waterbird species, each with over 100 individuals counted, were galahs *Eolophus roseicapilla* (336 individuals, mostly at Lake Kramen), noisy miners *Manorina melanocephala* (268 individuals, spread across all wetlands), sulphur-crested cockatoos *Cacatua galerita* (217 individuals, spread across most wetlands), regent parrots *Polytelis anthopeplus* (191 individuals, most at Lake Kramen), and magpie-larks *Grallina cyanoleuca* (112 individuals, seen across all wetlands) (Table 8, Part B Report [Butler et al. 2023]). The least encountered species (only one individual) were mulga parrot *Psephotellus varius*, wedge-tailed eagle *Aquila audax*, white-bellied sea-eagle *Haliaeetus leucogaster*, little eagle *Hieraaetus morphnoides*, brown falcon *Falco berigora*, black-eared cuckoo *Chrysococcyx osculans*, white-throated treecreeper *Cormobates leucophaea*, fairy martin *Petrochelidon ariel*, and white-cheeked honeyeater *Phylidonyris niger*.

Table 33 Summary of total number of species and abundance of non-waterbirds recorded at each surveyed wetlands over the 2022–23 monitoring period

Wetland	No. species	Total abundance
Lake Arawak	19	82
Lake Bitterang	18	125
Lake Brockie	11	106
Lake Bulla	14	58
Lake Cantala	19	51
Lake Hattah	17	120
Lake Konardin	28	130
Lake Kramen	30	1,173
Lake Little Hattah	19	175
Lake Lockie	25	142
Lake Mournpall	28	197
Lake Nip Nip	31	147
Lake Woterap	18	86
Lake Yelwell	18	80
Lake Yerang	26	117

Some vulnerable and near-threatened species were recorded. Small to medium-sized flocks of regent parrots, nationally listed under the EPBC Act as vulnerable were observed at 8 of the surveyed wetlands. Most were seen in spring and autumn, but at Lake Kramen regent parrots were observed during all 3 surveys. Two other species listed as vulnerable under the EPBC Act, observed at the Hattah Lakes icon site, were brown treecreeper *Climacteris picumnus* (2 individuals at Lake Lockie and one at Lake Nip Nip), and southern whiteface *Aphelocephala leucopsis* (7 individuals at Lake Nip Nip). Also noteworthy was the presence of a white-bellied sea-eagle, listed as endangered under the FFG Act (Table 9, Part B Report [Butler et al. 2023]), at Lake Bitterang, where an adult and juvenile were observed during the previous monitoring period as well. This wetland therefore may be an established breeding territory for the species, which may be abandoned if the wetland dries up for more than one consecutive breeding season. Apostlebirds *Struthidea cinerea*, listed as vulnerable under the FFG Act, were observed at a number of wetlands during spring and summer, in addition to a little eagle, also listed as vulnerable under the FFG Act, recorded at Lake Kramen in autumn (Table 9, Part B Report [Butler et al. 2023]).

Table 8 in the 2022–23 Part B Report (Butler et al. 2023) lists all non-waterbird species by guild and number of individuals observed at each surveyed wetland.

9.3.2 Non-waterbird breeding

Evidence of breeding in non-waterbirds was observed at several wetlands. During the spring 2022 and summer 2023 surveys, a whistling kite *Haliastur sphenurus* was observed on a nest at Lake Kramen. In summer, sacred kingfisher *Todiramphus sanctus* juveniles were seen at Lakes Cantala, Lockie and Woterap, as well as a juvenile laughing kookaburra *Dacelo novaeguineae* at Lake Nip Nip. This is a reduction in the number of species for which breeding activity was observed, back to the level seen during the 2020–21 survey season (3 species, compared to 9 species recorded during the 2021–22 surveys).

9.3.3 Lakebed use by non-waterbirds

Non-waterbirds were observed using the lakebed at 13 out of the 15 surveyed wetlands. Of all 2,789 non-waterbirds observed during the 2022–23 season, 170 individuals (6.1%), comprising 19 species (30.6% of species recorded) were observed using lakebeds.

Generally, lakebed use by most non-waterbirds was restricted to the shallow banks, fallen or otherwise dead trees in the water, or partially inundated lignum stands. The exception were some aerial predators such as whistling kites or foragers such as swallows and martins, which were observed flying over the water. Most of the non-waterbirds recorded as utilising the lakebed area were observed at Lake Kramen across the 3 surveys (65 individuals), with these mostly being in autumn, when the lake was nearly full.

Species exclusively observed on lakebeds included brown songlark *Cincloramphus cruralis*, emu *Dromaius novaehollandiae*, and white-naped honeyeater *Melithreptus lunatus*. Species recorded using lakebeds in addition to fringing vegetation were Australian magpie *Gymnorhina tibicen*, brown treecreeper, galah, little corella, magpie-lark, noisy miner, rainbow bee-eater *Merops ornatus*, red-rumped parrot *Psephotus haematonotus*, regent parrot, restless flycatcher *Myiagra inquieta*, sacred kingfisher, sulphur-crested cockatoo, whistling kite, white-plumed honeyeater *Ptilotula penicillatus*, willie wagtail *Rhipidura leucophrys*, and yellow rosella *Platycercus elegans flaveolus*.

9.4 Discussion

Non-waterbirds were encountered at every surveyed wetland during each survey, regardless of inundation status. Unlike waterbirds, these species are not dependent on open expanses of water for foraging and breeding and hence can take up residence at ephemeral wetlands year-round, even over dry periods. Dry lakebeds and wetland margins can be valuable food sources for non-waterbirds, especially after recently holding water when many plants revived by the water grow, flower, attract insects and produce seeds.

9.4.1 Wetland status, non-waterbird abundance and diversity

As during the previous 2 monitoring rounds, Lake Kramen had by far the highest count of non-waterbirds (1,173) of the surveyed Hattah Lakes wetlands, nearly 6 times as many individuals as the wetland with next-highest non-waterbird count, Lake Mournpall (197) (Table 33). This suggests Lake Kramen, whether dry or containing water, is an important non-waterbird site within the Hattah Lakes area. Its continued high abundance of non-waterbirds indicates that its location at the edge of the Hattah-Kulkyne National Park with nearby almond plantations and other agricultural areas provides important wetland habitat for birds utilising a variety of habitats, or those moving through the broader landscape to other areas of habitat that support certain species.

As discussed in the 2021–22 report (Palmer et al. 2022), non-waterbird counts were again not related to species richness at the surveyed wetlands. While Lake Kramen recorded the highest number of individuals, the highest species diversity was recorded at Lake Nip Nip (31), even though the number of individuals (147) at this site was almost 8 times lower than at Lake Kramen, which had 30 species (Table 33). Rather than inundation status or wetland size, species diversity is more likely the result of wetland location within the system and variety in habitats surrounding these wetlands, such as hollow-bearing trees, lignum stands and other general variation in vegetation density and height. The greater the variety in these factors, the more niches are available for non-waterbird species to occupy. Presence of water may, therefore, be less important than water management (McGinness et al. 2010); the frequency and duration of flooding events in wetlands affect vegetation type and quality, which in turn affects the diversity and number of non-waterbirds able to use the vegetation for survival and reproduction.

9.4.2 Species in the landscape

During this unusually wet monitoring season, a greater abundance of and species diversity in non-waterbirds were observed than during the previous monitoring season, in which environmental water was delivered to the Hattah Lakes icon site. The number of individuals recorded was instead more similar to that recorded during the much drier 2020–21 monitoring period, although species diversity during the current monitoring period was higher. The prolonged wetter period increased vegetation diversity at the Hattah Lakes icon site (see Chapters 4–7), which has likely resulted in attracting and supporting a greater variety of bird species. Bird abundance, however, appears to be less affected by wetland inundation status and history. These results indicate that periods of inundation at the Hattah Lakes icon site may play an important role in boosting local biodiversity, but not necessarily bird density.

Indications that habitat diversity and food availability, as a result of inundation, affects local bird diversity, comes from the observation of additional bird species (e.g. quail and fan-tailed cuckoo *Cacomantis flabelliformis*) which had not been recorded since the start of non-waterbird monitoring at the Hattah Lakes icon site (2019–20 season). Observations of 2 quail species, as well as bronzewing, indicate the presence of a dense, grassy ground cover and associated provenance of grass seeds. Higher numbers of raptors, including species hunting smaller birds and mammals such as brown goshawk *Accipiter fasciatus* and brown falcon *Falco berigora* indicate an increase in abundance of their prey species. Presence of black-eared cuckoo and fan-tailed cuckoo in spring is a sign of breeding activity by their host species (thornbills, fairy-wrens and other small passerine birds). Finally, observations of a wider range of nectarivorous species than in the previous survey rounds points to the presence of more plants actively flowering in the area.

Nationally vulnerable regent parrots were also observed at 8 of the 15 wetlands (53%), with most individuals being recorded at Lake Kramen, as was the case during the previous 2 survey rounds (Palmer et al. 2021, 2022). Hollow-bearing trees throughout the Hattah Lakes icon site, as well as the proximity to almond plantations may be of importance in supporting the local population of regent parrots. Occasional flooding of the wetlands is important for the survival of old, tall river red gums, particularly those containing hollows, along many of the wetland margins. Therefore, well-planned watering of areas supporting river red gums is essential for the long-term survival of threatened species, such as regent parrots and white-bellied sea-eagles for which they provide important breeding habitat.

9.5 Recommendations

Non-waterbirds rely on vegetation that provides them with food, shelter and breeding opportunities and the surveys from the 2022–23 season show that the Hattah Lakes icon site wetlands currently provide habitat to a substantial number of species, including some of national and state significance. Vegetation quality and, therefore, the bird diversity in association with this, depends on appropriate water management that allows these ecological values to thrive both in abundance and diversity across the wetlands. Consideration should be given to a varied regime of flooding and drying of wetlands which maintains habitat complexity and resource abundance in order to sustain a diverse population of non-waterbirds at the Hattah Lakes icon site.

10 Fish Communities

10.1 Introduction

The TLM fish condition monitoring program undertakes annual sampling of large-bodied and small-bodied fish species at each icon site to assess the condition of the fish community against relevant points of reference, indices and targets that are deemed to be representative of 'good' condition appropriate for that icon site (Robinson 2015).

Fish sampling for the TLM Condition Monitoring program at Hattah Lakes commenced in January 2006 and has been undertaken annually, except for 2009 (because of a switch to autumn) and 2015 (due to lack of funding). The background and methods used is described in the most recent program design report (Mallee CMA 2021b) and in section 10.2.2, and includes boat and backpack electrofishing, coarse- and fine-meshed fyke netting and seine netting.

Several amendments and refinements have been made over the duration of the monitoring program. The most substantial of these was switching the timing of sampling from spring (2005–2009) to autumn (2010 onwards) and the inclusion of backpack electrofishing at wetland sites (2010 onwards). Additional, more minor refinements include:

- The inclusion of seine netting and bait trapping (2010 onwards),
- Improved objectives, indicators, indices and reference points (Robinson 2015)
- The use of a one 'netter' on the front of the electrofishing boat (2019 onwards)
- The removal of bait traps as a sampling technique (2021 onwards)
- The requirement to PIT tag native large-bodied fish (2021 onwards).

Objective HL 9 Native fish recruitment

As outlined in the Environmental Water Management Plan (EWMP) (Mallee CMA 2021b), the environmental watering objective for fish is to:

- Maintain recruitment of populations of small-bodied native fish and presence of large-bodied native fish at Hattah Lakes by 2030.

More specific ecological objectives and targets have been developed for the EWMP (Mallee CMA 2021b), which are summarised in the program design methods document (Mallee CMA 2021a) and reproduced below (Table 34).

Table 34 A summary of ecological objectives and targets of relevance to TLM fish condition monitoring for Hattah Lakes.

Objective	Targets
Objective HL 9 Native fish recruitment Maintain recruitment of populations of small-bodied native fish and presence of large native bodied fish at Hattah Lakes by 2030.	Evidence of recruitment of small-bodied native fish species on an annual basis, including: • Australian Smelt (*Retropinna semoni*) • Carp Gudgeon (*Hypseleotris* spp.) • Unspecked Hardyhead (*Craterocephalus fulvus*) Mean proportion of recruits using P-recruits index is ≥0.5 in 80% of sampling events (see Brown et al. 2016).
	Mean proportion of natives using P-native index is ≥0.5 in 80% of sampling events (see Brown et al. 2016).

10.2 Methods

10.2.1 Sampling design

As outlined in the program design (Mallee CMA 2021b), the monitoring program currently includes a total of 27 sites located within and adjacent to the Hattah-Kulkyne National Park, including seven wetlands (3 sites per wetland), Chalka Creek (3 sites) and the Murray River (3 sites) (Table 35). Sampling was undertaken at all sites in 2023, and the location of sites was consistent with previous years.

The sites are established within a nested sampling design, consisting of multiple sites within location reaches that have been assigned to three different flow categories referred to as 'macrohabitats', including:

- 'Riverine' — Murray River: 3 sites
- 'Anabranch', also known as 'Ephemeral channel' — no/slow flow (Chalka Creek): 3 sites
- 'Wetland', also known as 'Floodplain wetland': 21 sites

Table 35 TLM Condition Monitoring fish sites in 2023

Location	Reach	Macrohabitat	Sites sampled (2022)
Hattah Lakes	Lake Arawak	Wetland	Ara1, Ara2, Ara3
	Lake Bulla	Wetland	Bul1, Bul2, Bul3
	Chalka Creek	Anabranch	Cha1, Cha2, Cha3
	Lake Hattah	Wetland	Ha1, Ha2, Ha3
	Lake Little Hattah	Wetland	LH1, LH2, LH3
	Lake Lockie	Wetland	Loc1, Loc2, Loc3
	Lake Mournpall	Wetland	Mour1, Mour2, Mour3
	Lake Yerang	Wetland	Yer1, Yer2, Yer3
Murray River	Hattah	Riverine	Mur1, Mur2, Mur3

As outlined in section 10.1, the major differences in gear use and effort between years were mostly in the early years of the monitoring program due to electrofishing not being used until 2010 at wetland and anabranch sites and sampling occurring in spring rather than autumn from 2006–2008. These differences are substantial enough to warrant exclusion of the pre 2010 data from direct comparisons with subsequent years.

From 2010 onwards, the main discrepancy in gear use/effort relates to wetland and anabranch sites typically being dry in the absence of environmental watering see Table 36.

Table 36 Summary of sampling data continuity over time (2010 onwards). See key below for colour interpretation.

Macrohabitat (bold) & site	Year												
	2010	2011	2012	2013	2014	2016	2017	2018	2019	2020	2021	2022	2023
Anabranch													
Chalka Creek_1													
Chalka Creek_2													
Chalka Creek_3													
Riverine													
Murray River_1													
Murray River_2													
Murray River_3													
Wetland													
Arawak_1													
Arawak_2													
Arawak_3													
Bulla_1													
Bulla_2													
Bulla_3													
Hattah_1													
Hattah_2													
Hattah_3													
Little Hattah_1													
Little Hattah_2													
Little Hattah_3													
Lockie_1													
Lockie_2													
Lockie_3													
Mournpall_1													
Mournpall_2													
Mournpall_3													
Yerang_1													
Yerang_2													
Yerang_3													

Key:

Boat electrofishing & netting used	Only netting used (no electrofishing)
Backpack electrofishing & netting used	Not sampled (e.g. dry)

10.2.2 Sampling method

Fish sampling was undertaken between 27 February and 9 May 2023.

Fish sampling was undertaken in accordance with the methods detailed in Mallee CMA (2021b). At all sites the following methods and effort were deployed:

- Overnight deployment of a pair of fine-meshed (2 mm stretched mesh) 'larval' fyke nets. These nets have previously been referred to as 'small fyke nets' (Mallee CMA 2021a) and have dual 2.5 m long wings (drop of 1.2 m), with a skirt and hoop entrance. The first internal throat is fitted with a 50 x 50 mm rigid plastic meshed exclusion grid to stop entrapment of non-target fauna (e.g. turtles) and larger bodied fish.
- Seine netting comprising a single haul at each site, using a 180-degree arc from the shore with a 5 m long seine net (drop of 1.75 m and a stretched mesh size of 2 mm).

At all Wetland and Anabranch sites the following methods and effort were deployed:

- Backpack electrofishing using Sustainable Rivers Audit (SRA) protocols (e.g. 8 x 150 second shots, MDBA 2011). All backpack electrofishing was undertaken using a Smith Root LR24 or LR20B backpack electrofisher.
- Overnight deployment of a pair of coarse-meshed (28 mm stretched mesh) nets. These nets have previously been referred to as 'large fyke nets' (Mallee CMA 2021b) and have a 10 m central leader (wing) with a drop of 80 cm, and a 'D' entrance.

At all Riverine sites, boat electrofishing using SRA protocols (e.g. 12 x 90 second shots; MDBA 2011). All boat electrofishing was undertaken by two staff (driver and 'netter'). Boat electrofishing was undertaken using Ecology Australia's medium-sized (4.1 m long) electrofishing vessel equipped with a Smith Root Apex electrofishing unit.

Fish processing

A subsample of 50 individuals of each species for each gear type were measured to the nearest millimetre, with measurements collected from fish sub-sampled as evenly as possible across replicates and care taken to avoid/minimise bias during sub-sampling of fish. The length measurements used were Total Length (TL) for round-tailed species and Fork Length (FL) for fork-tailed species.

The subsample of fish that were measured were also weighed, except for small fish < 1 g, due to the high error rates associated with field-based weight measurements (e.g. in windy conditions). The scales used to weigh fish were of a suitable resolution for the individual being measured (i.e. nearest 0.1 g for fish less than 100 g, and nearest 1.0 gram for fish over 100 g). All fish were identified using expert knowledge or standard field guides if required. Carp gudgeon *Hypseleotris* spp. were not identified beyond genus due to long standing taxonomic uncertainty and more recent confirmation of a hemiclonal complex (Thacker et al. 2022), making field-based identification impractical.

Fish tagging

Native fish >300 mm TL (golden perch or silver perch) or >350 mm TL (Murray cod or freshwater catfish) were internally tagged with a 23 mm half duplex (HDX) 134.2 kHz Passive Integrated Transponder (PIT) or 12 mm full duplex (FDX-B) 134.2 kHz PIT and externally tagged with an 87 mm or 125 mm (for large

Murray cod) orange 'EA Fish' PDL dart tag printed with unique identifying number and a reporting phone number. Smaller native fish (120/150–300/350 mm TL depending on species) were tagged with a 12 mm full duplex (FDX-B) 134.2 kHz PIT only (no external tag). The unique identifying numbers of both tags were recorded and carefully checked to ensure accurate transcription. Tagging only occurred if prior scanning did not reveal an existing PIT. The overall condition of each fish was assessed prior to tagging, and any deemed to be in poor condition (e.g. more than minor fin rot, significant lesions or external parasites) were not tagged due to the risk of additional stress that may compromise that individual's survival.

Fish tagging was undertaken to contribute to automated monitoring of fish movement through various fishways with installed readers in the Murray River system. It also provides some insight into fish movement and growth rates within the icon site (i.e. based on biometric data obtained from any researcher recaptures between years). The dart tag also facilitates reporting of angler capture information from recreational anglers, including information on whether the captured individual was released or was retained, and hence whether the internal PIT tag is no longer in active use in the system.

Sampling limitations

During 2022 and 2023, large numbers of juvenile carp and bony herring sampled during boat electrofishing required a modified approach to netting and counting to avoid mortalities associated with over-crowding in holding tubs. We typically collected only the first ten carp or bony herring that were stunned in each shot, recording the remainder as a count at the completion of each shot. Once biometric data had been collected for the requisite 50 individuals of each species, no further collection of these species occurred, and visual counts were recorded for each shot.

10.2.3 Data analyses

Violin plots

Fish size data was summarised using violin plots using the ggplot package in R studio, with the ends of each plot squared off to accurately represent the maximum and minimum lengths. Note that these plots are intended for quick visualisation of the size data and are not intended to be accurate estimations of population structure.

Data preparation

Fish community data preparation included grouping species into three categories to show temporal trends more easily. These included native small-bodied fish, native large-bodied fish, and introduced fish species. Sampling has been conducted using multiple methods across the entire TLM period, largely varying in response to conditions in any given year. For abundance analysis, we used the following decisions to improve uniformity of treatment of fish community data across sites:

- Use small-bodied fish catches for all gear types except for coarse-meshed fykes
- Use large-bodied fish catches from electrofishing (boat and backpack) and coarse-meshed fykes (i.e. not from seine nets or larval fyke nets).

Any large-bodied fish captured from small fykes (e.g. juveniles) and any small-bodied fish captured from coarse-meshed fykes were excluded from analyses due to obvious size/species selectivity relating to net mesh size and exclusion grid mesh size respectively. Collectively, these methods were represented as 'Electrofishing' (including both boat and backpack data) and 'Net Methods' (including coarse and small/larval fyke nets) for further analysis.

Community analyses assessed the total abundance of all species collected across five gear types ("FN (coarse)", "FN (larval)", "Seine net", "EF (Boat)", "EF (BP)"). Further analysis was completed to assess the difference in the fish community collected using only Net methods ("FN (coarse)", "FN (larval)", "Seine net") or Electrofishing efforts ("EF (Boat)", "EF (BP)") across macrohabitat types and years of survey."

Fish community data from Hattah icon site sampling locations were only considered from 2010 onwards, due to expected seasonal differences with earlier sampling years when sampling was undertaken in spring instead of autumn (refer to section 10.2.1). Sampling did not occur in 2015, so 13 sampling events have been analysed in this report. Due to variable formats being used for the reporting of the effort data, Catch Per Unit Effort (CPUE) could not be calculated at this time. As such, the catch of all gears and replicates were summed to a site total for comparison between sites within reaches or macrohabitats. The reaches are assigned to flow-based macrohabitats of interest within the TLM program (i.e.Wetland, Riverine and Anabranch) as outlined in section 10.2.1

Abundance and community structure

To explore the variability of individual species through sampling years, the annual abundance trajectories of individual species were plotted as mean abundance of sites (i.e. mean of all site totals) for a macrohabitat and/or gear type, presented with standard errors. To explore variation in the fish community across years and macrohabitats, a community analysis using Non-metric Multi-dimensional Scaling (NMDS) and Permutational Analysis of Variance (PERMANOVA) was conducted.

PERMANOVA was run for the non-transformed abundance data of species in the community. PERMANOVA was run on site totals across 2010–2023 and across all macrohabitat types to test for significant differences among years and macrohabitats. These factors were structured to include the main effects for both year and macrohabitat and their interaction in a fully factorial model. Additionally, to partition variance within macrohabitat, reach was included as a random block effect within these models. Bray-Curtis distance measures were used for the analysis of abundance data. Subsequently SIMPER analysis was completed to show the species responsible for at minimum 70% of pairwise differences between macrohabitats, years and levels of their interaction.

10.2.4 Indices calculations

The following three indices were calculated:

- Recruitment Index (P recruits):
    - The proportion of indigenous native fish in each site that are recruits (regardless of species). This follows the method of Wood et al. (2018). Recruits are determined using the length at Young-of-Year (YOY).
- Biomass Index (P native):
    - The proportion of native fish biomass within each site. This index was previously referred to as P 'nativeness' and is calculated at site level using length weight relationships to calculate the biomass for each fish species (Robinson 2012).
- Diversity Index (P expected):
    - The number of native indigenous species collected in each site is compared to the number expected, given the sampling protocols used as described in Robinson (2014). The score is the number of species collected divided by number expected per site. If more species than expected occur, the site score is 1, if none occur the site score is 0.

All indices are calculated for each site independently. Each site is given equal weighting in calculating a macrohabitat mean for each index (the recommended scale for reporting). An annual icon site score for each index is generated as a guide only, using least squares means after fitting a linear mixed model. This icon site score is only a guide because it gives each macrohabitat equal weight in the calculation. This is not particularly valid in instances when some habitats are not sampled in some years (e.g. wetlands), and therefore have unequal numbers of sites. Additionally, different macrohabitats represent varying spatial areas within the icon site.

10.3 Results

10.3.1 Raw abundance overview

Total fish numbers for each species across the entire icon site over the 2010–2023 monitoring period are provided in Table 37. Note that sampling effort has varied to some extent over time (see section 10.1), so this summary data is not intended for interpretation. Change in abundance is assessed in section 10.4.3. Some of the most obvious results include:

- Carp *Cyprinus carpio* total numbers in 2023 were the highest recorded over the 13 year monitoring period comprising 41.1% of all fish recorded
- Spangled perch *Leiopotherapon unicolor*, was recorded for the first time in over 10 years with the species last recorded in 2012
- Redfin *Perca fluviatilis* was recorded for the first time during the 13 year monitoring period
- Golden perch *Macquaria ambigua* total numbers were substantially lower than the peak reached in 2022
- Oriental weatherloach *Misgurnus anguillicaudatus* total numbers in 2023 were the highest recorded over the 13 year monitoring period
- All previously detected native fish species were detected during the 2023 monitoring surveys.

Table 37 Summary of the annual total fish numbers for 2010–2023 grouped by fish functional group (Ellis et al. 2016) with large-bodied fish in bold. Note: there are different sampling efforts between years, so data cannot be readily compared, no sampling was conducted in 2015.

		Year												
		2010	2011	2012	2013	2014	2016	2017	2018	2019	2020	2021	2022	2023
		# of sites sampled												
Common name	Scientific name	21	21	27	9	27	21	27	27	15	3	3	27	27
Native - river specialists (lotic)														
Murray Cod	***Maccullochella peelii***	5		1	7	30	52		8	38	49	62	31	7
Native - flow pulse specialists														
Silver Perch	***Bidyanus bidyanus***	11	1	1	1	3	2		5	1	4	1	9	1
Golden Perch	***Macquaria ambigua***	32	78	41	12	35	31	41	34	44	21	40	229	41
Native - generalists														
Australian Smelt	*Retropinna semoni*	401	203	37	27	133	1969	4838	7276	262	124	100	573	879
Bony Herring	***Nematalosa erebi***	672	126	337	270	1190	494	449	513	418	252	177	299	189
Unspecked Hardyhead	*Craterocephalus fulvus*	214	1263	97	19	81	198	25	9	28	187	114	100	29
Carp Gudgeon complex	*Hypseleotris* spp.	213	46029	14700	323	641	11026	34765	24393	8628	64	68	6881	6688
Murray-Darling Rainbowfish	*Melanotaenia fluviatilis*	23	39	10	11	32	98	77	4	31	84	74	69	10
Flat-headed Gudgeon	*Philypnodon grandiceps*	8	191	170	1	1	666	1404	1312	451	17	8	751	1977
Native - uncategorised														
Dwarf flat-headed Gudgeon	*Philypnodon macrostomus*		1				12	41	35	12			8	11
Spangled Perch	***Leiopotherapon unicolor***		1	1										1
Introduced - generalist														
Carp	***Cyprinus carpio***	39	1126	604	81	6950	46	988	104	144	41	45	1564	20428
Goldfish	***Carassius auratus***	32	36	151	1	56	8	5	19		1	6	55	104
Goldfish x Carp	***Carassius auratus X Cyprinus carpio***												1	
Redfin	***Perca fluviatilis***													1
Oriental Weatherloach	*Misgurnus anguillicaudatus*		49	8		54	8		5				1	398
Introduced - floodplain specialist														
Eastern Gambusia	*Gambusia holbrooki*	170	4960	1283	444	2346	12437	6823	25375	404	148	23	20509	18886
Total (all species)		**1820**	**54103**	**17441**	**1197**	**11552**	**27047**	**49456**	**59092**	**10461**	**992**	**718**	**31080**	**49650**

10.3.2 Species detection over time

Native species

The detection of native species over the course of the 2010–2023 monitoring period for each macrohabitat is illustrated in Figure 44 and Figure 45 for large-bodied and small-bodied species respectively.

Bony herring *Nematalosa erebi* and golden perch are the most frequently detected large-bodied native fishes, being detected every year in the River macrohabitat, every year when the Anabranch macrohabitat contains water, and most years when some of the Wetland macrohabitat sites contain water.

Spangled perch were detected for the first time since 2012 and the first time from the Riverine macrohabitat, with the previous detections in 2011 and 2012 being from the Wetland macrohabitat.

Murray cod *Maccullochella peelii* and silver perch *Bidyanus bidyanus* have been more frequently detected across sampling years at Riverine sites than Wetland and Anabranch sites. Murray cod have been detected at Wetland sites in 2010, 2014 and 2019, while silver perch have been detected at Wetland sites in 2010–11, 2014 and 2022. There has only been one detection each of Murray cod and silver perch at Anabranch sites, in 2014 and 2010 respectively.

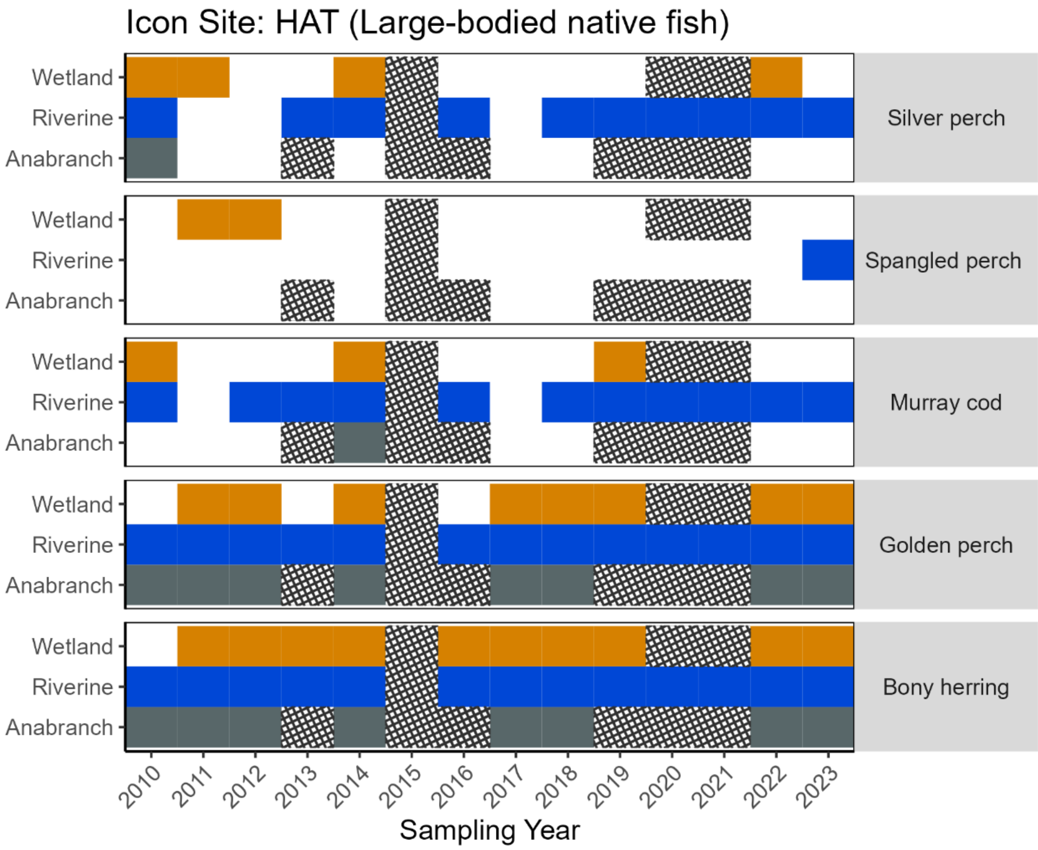


Figure 44 Detection of large-bodied native fish species over the 2010–2023 monitoring period for each macrohabitat. Black pattern fill shading indicates no sampling occurred (see Table 36).

The most frequently detected native small-bodied fishes are carp gudgeon and Australian smelt, both species that are detected during every sampled year in all macrohabitats (aside from Australian smelt at Wetland macrohabitat in 2013). Unspecked hardyhead and Murray Darling rainbowfish are consistently detected from Riverine macrohabitat throughout the monitoring program, but have periodically been undetected from Wetland and Anabranch macrohabitat. Flatheaded gudgeon and dwarf flatheaded gudgeon are more reliably detected from Wetland and Anabranch macrohabitats than from Riverine macrohabitats, with increased detections for both species over the 2016–2023 period compared with the 2010–2014 period, including continuous detections since 2016 for Anabranch (flatheaded gudgeon only) and Wetland (both species) macrohabitats.

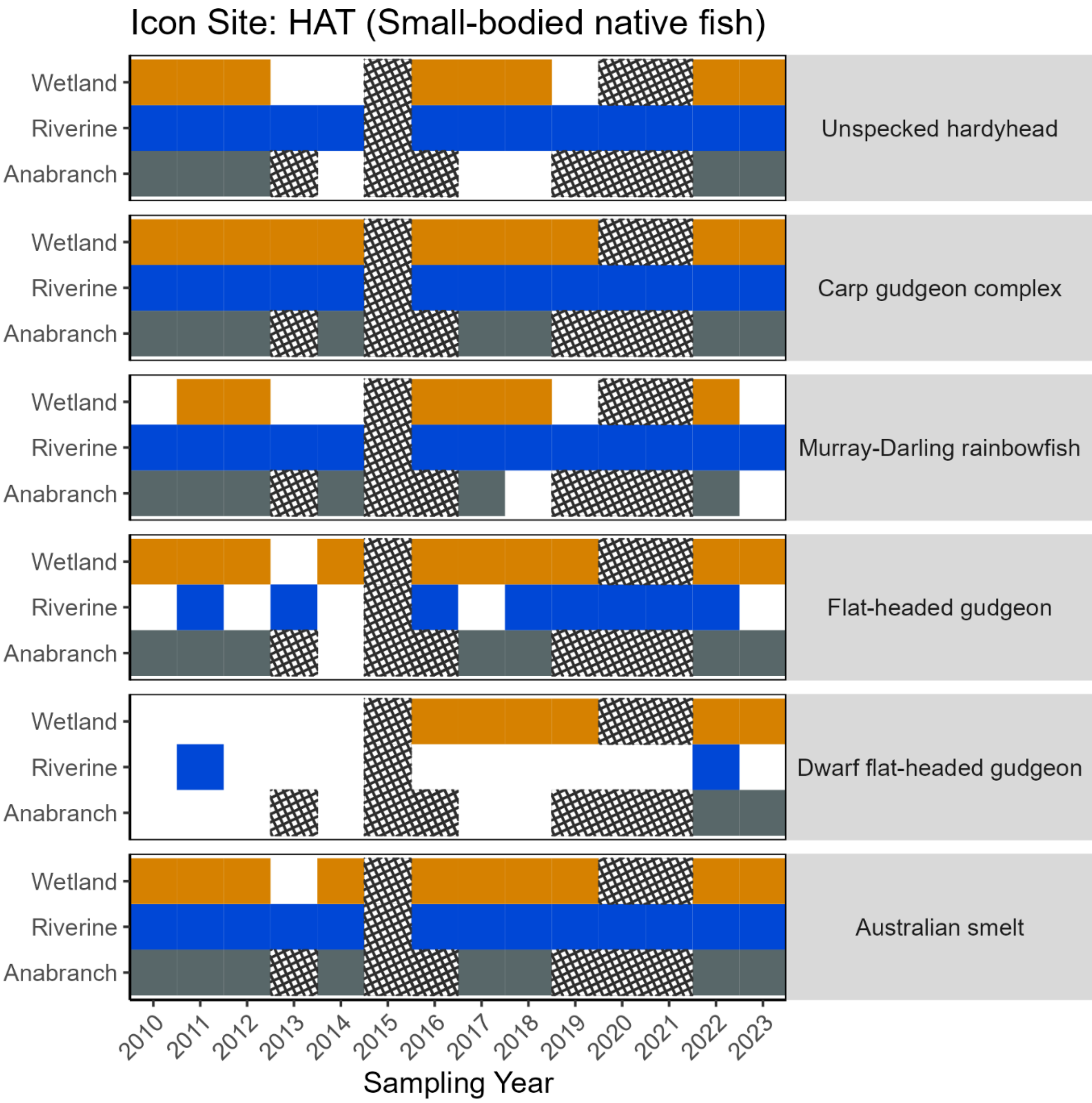


Figure 45 Detection of small-bodied native fish species over the 2010–2023 monitoring period for each macrohabitat. Black patten filled shading indicates no sampling occurred (see Table 36).

Introduced species

Carp and eastern gambusia have been detected in every sampling event since 2010 (Figure 46). Carp have always been detected at all three macrohabitats and eastern gambusia has been detected from all three macrohabitats since 2011. Goldfish have been recorded from all three macrohabitats on six occasions including 2023. Redfin were detected at Riverine macrohabitat in 2023, the first time this species has been detected during the 2010–2023 monitoring period. Aside from redfin, oriental weatherloach has been the most infrequently detected introduced species, being more typically detected at Wetland and to a lesser extent Anabranch sites, with 2023 being only the second time over the 2010–2023 monitoring period that the species has been detected from all macrohabitats.

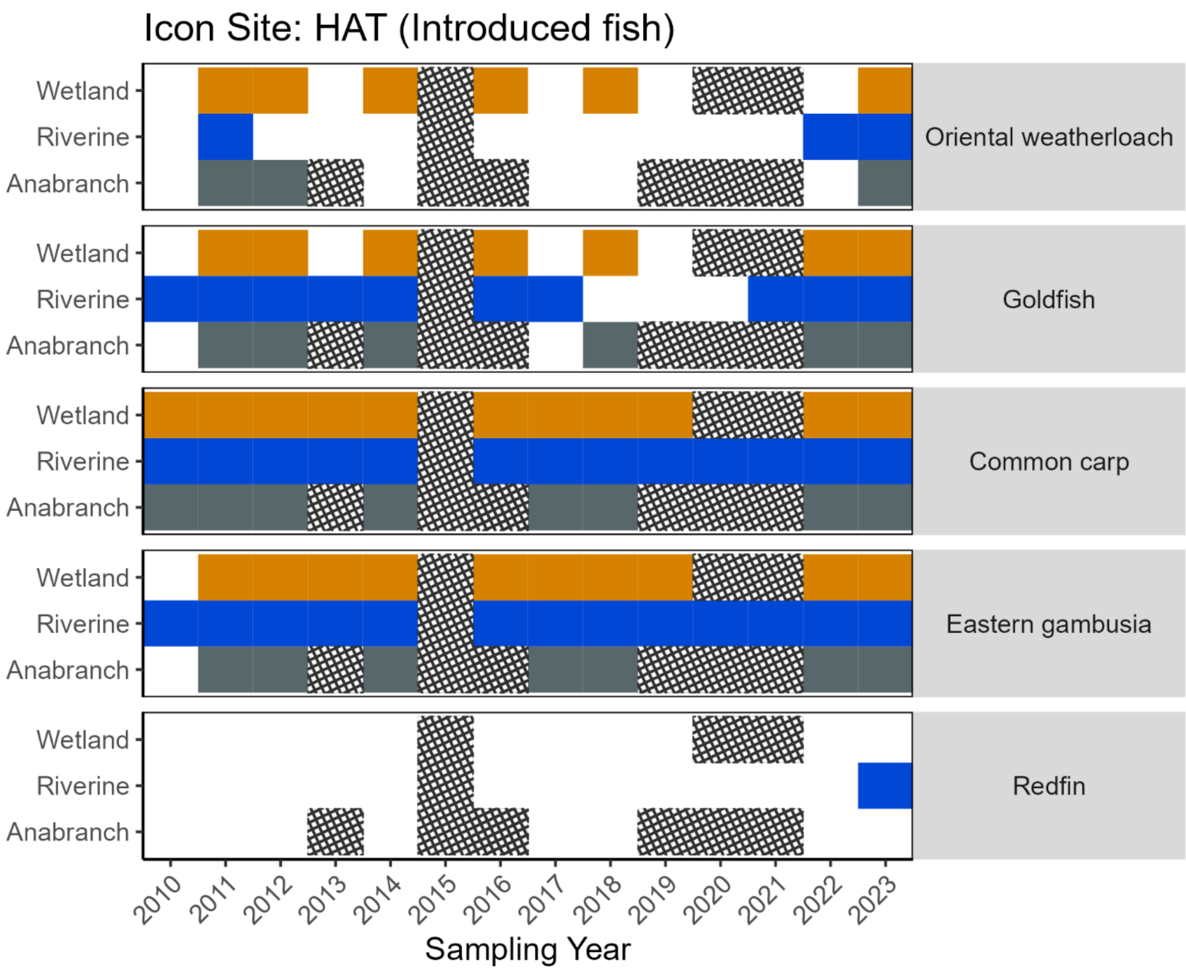


Figure 46 Detection of introduced fish species over the 2010–2023 monitoring period for each macrohabitat. Black pattern fill shading indicates no sampling occurred (see Table 36).

10.3.3 Abundance

Large-bodied native fish

Large-bodied native fish are typically in higher abundance at Riverine sites than either Anabranch or Wetland sites (Figure 47), although a valid comparison cannot be made due to the different sampling gears being used for each macrohabitat (i.e. boat electrofishing is only used at Riverine sites).

Golden perch are typically recorded in higher abundance at Riverine sites, although the difference in sampling gear used for each macrohabitat should be noted (i.e. boat electrofishing is only used at Riverine site). Golden perch are occasionally sampled in reasonable abundance in Anabranch (2010–2011) and Wetland habitats (2011 and 2022), with a peak in abundance recorded at Wetland macrohabitats in 2022. In 2023, golden perch returned to being captured in low abundance in both Wetland and Anabranch macrohabitats.

Murray cod are predominantly captured in Riverine macrohabitat only. However, there has been a steep decline in Riverine sites with 2023 being the lowest on record from this macrohabitat since 2017, although abundance remains notably higher than that recorded in 2017 or over the 2010–2012 period. Murray cod abundance has increased over two distinct periods (2012–2016 and 2018–21) following large declines that coincided with flooding/blackwater events in 2010–11 and 2016–17.

Bony herring abundance has typically been variable in Anabranch and Wetland macrohabitats with generally higher and consistent abundance in the Riverine macrohabitat, although again noting differences in sampling method (e.g. boat electrofishing used for Riverine macrohabitat).

Silver perch have only been captured in very low abundances throughout the sampling program. Since 2010, silver perch have been recorded most years (except 2012 and 2017) but in low and variable abundance, and usually only at the Riverine sites, as was the case in 2023.

Spangled perch is the least abundant large-bodied native fish at the icon site, with non-detection or very low abundance recorded across all years of the monitoring program. Just one spangled perch was recorded in 2023, following detection in very low abundance in 2011–2012.

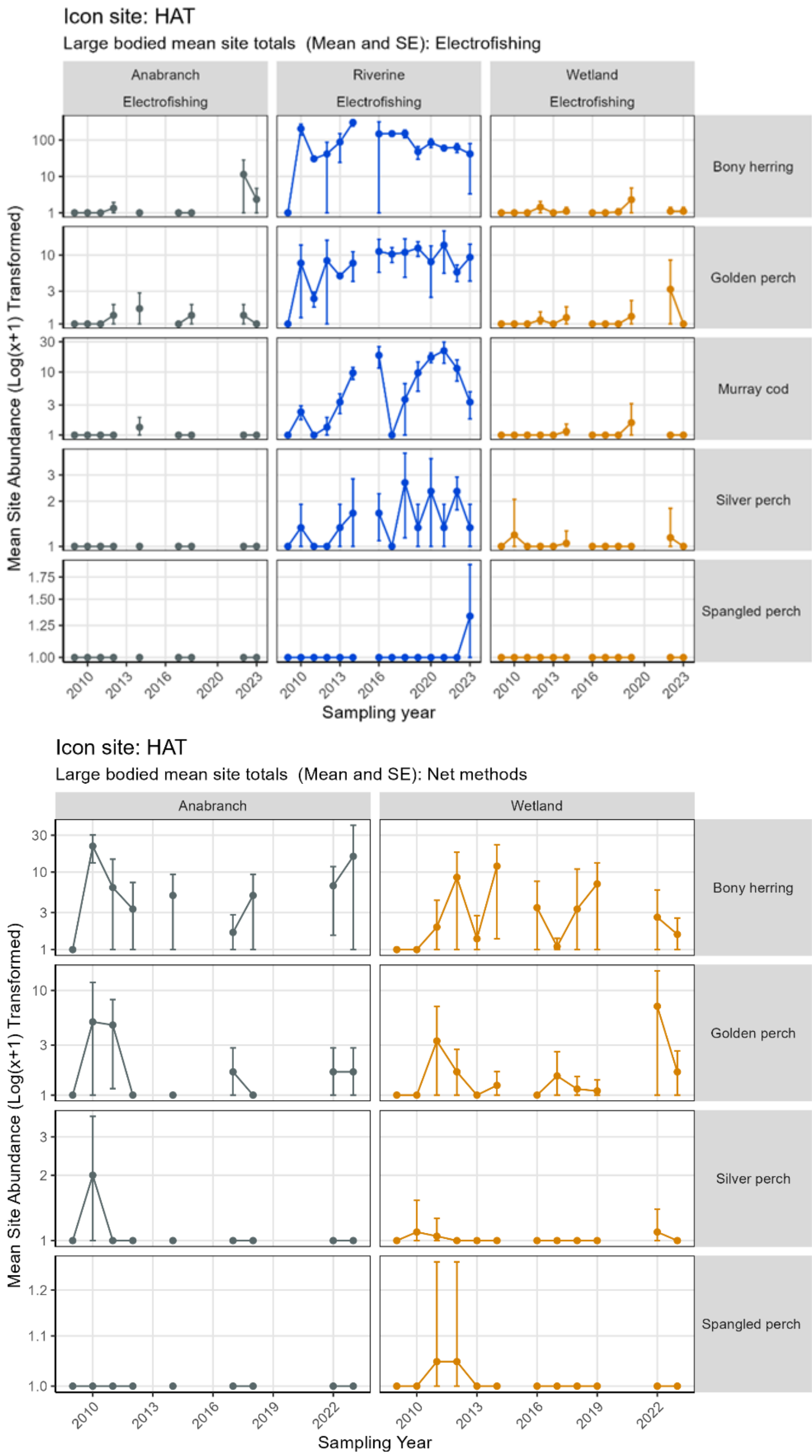


Figure 47 Annual mean total site abundance of large-bodied native species at each macrohabitat, separated by electrofishing (boat and backpack) and net gears (coarse-meshed fyke nets). Note that no sampling occurred 2015, and that Riverine net methods are limited to larval fyke and seine nets.

Small-bodied native fish

Carp gudgeon are typically the most abundant native fish species throughout all years of the monitoring program at all macrohabitats (Figure 48), although their abundance varies considerably between sites based on netting data. Carp gudgeon abundance increased at Wetland and Anabranch macrohabitats in 2023, although the increase at Wetland macrohabitat was only evident based on electrofishing data. Other abundant species include Australian smelt, unspecked hardyhead and in more recent years (2016 onwards), flatheaded gudgeon.

Australian smelt abundance generally peaked over the 2016–2018 period based mostly on Riverine electrofishing data, before declining from 2019–2020 and rising again since (2021–2023). Larger declines in abundance were evident at the Wetland macrohabitat in 2019 (based on electrofishing and netting data) during the later stages of a drawdown at Wetland sites.

Unspecked hardyhead and Murray Darling rainbowfish abundances are typically higher at Riverine sites than at Anabranch and Wetland sites. At Riverine sites, changes in the abundance of both species were similar over the monitoring period based on electrofishing data, with substantial declines in abundance evident from 2010–2012, 2016–2018 and 2021–2023, interspersed by steep increases in abundance between those periods. Unspecked hardyhead abundance at Wetland and Anabranch sites peaked in 2011 at all three macrohabitats based on netting data. Murray Darling rainbow fish abundance was very low in 2023 at Wetland and Anabranch sites (based on netting data) following a small peak in abundance in 2022.

Flat-headed gudgeon has been notably more abundant at Wetland sites than both Riverine or Anabranch sites over the 2016–2023 monitoring period. The abundance of this species has increased considerably over these years compared with the earlier years of the program (2010–2014) at the Wetland macrohabitat based on both the electrofishing and netting data.

Dwarf flat-headed gudgeon have been sporadically detected in low abundance throughout the monitoring program. Although variability between sites is high, they have typically been slightly more abundant at Wetland sites rather than Riverine or Anabranch sites, particularly over the 2016–2019 period.

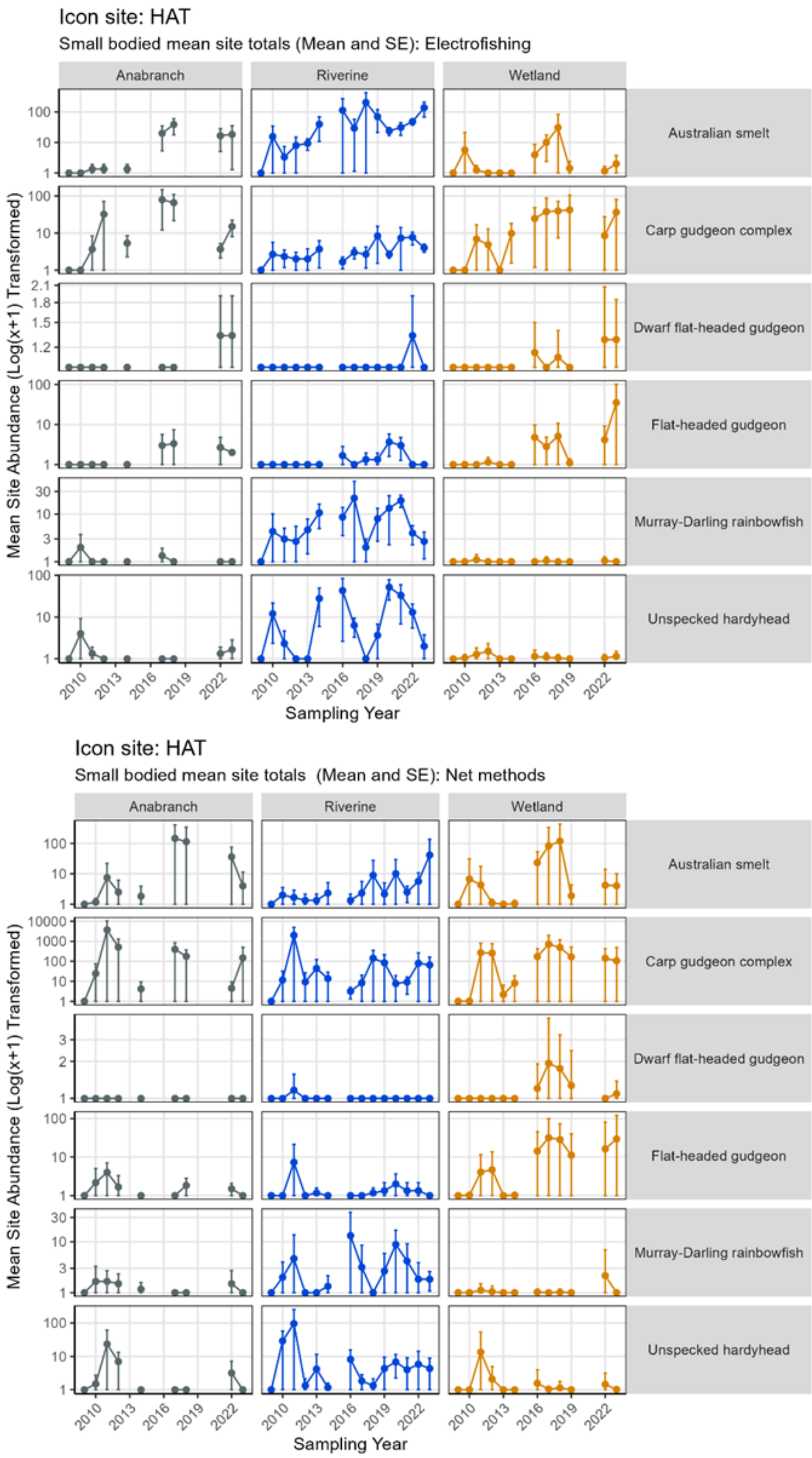


Figure 48 Annual mean total site abundance of small-bodied native species, separated by electrofishing (boat and backpack) and net gears (larval fyke and seine). Note no sampling occurred in 2015.

Introduced fish

The carp abundance in 2023 was the highest recorded over the 2010–2023 monitoring period, far exceeding all previous peaks across almost all macrohabitats and methods, with the exception for a slightly higher peak for electrofishing in Wetland macrohabitat in 2014. The previous year (2022) also detected relatively high carp abundance at all three macrohabitats. Carp abundance has fluctuated throughout the monitoring program with previous large peaks evident in the Riverine macrohabitat in 2017 following the November 2016 flooding event. Other peaks occurred at Wetland sites in 2011, 2014 and 2022, and Anabranch sites in 2011–12 and 2022 (Figure 49). Although, it should be noted that there is usually substantial variation in carp abundance between Wetland sites and between Anabranch sites using netting gear types, with low variation between Riverine sites.

Eastern gambusia abundance in 2023 was the highest that has been recorded from Wetland and Anabranch macrohabitats, second highest from Riverine macrohabitat based on electrofishing data, and amongst the highest recorded at Wetland macrohabitat based on netting data. There were high levels of eastern gambusia abundance variability between sites for Wetland and Anabranch macrohabitats both for the electrofishing and particularly netting data across all years.

Goldfish abundance remains relatively low overall. Goldfish abundance at Riverine sites in 2023 was the highest recorded over the 2010–2023 monitoring period based on electrofishing data, eclipsing previous peaks in 2010 and 2014. Goldfish abundance at Anabranch and Wetland macrohabitats has increased in 2022–23 following very low abundance over the 2016–2019 period and a peak around 2012.

Oriental weatherloach abundance has been low and variable over the 2010–2023 monitoring period, with slightly higher abundances detected in flooding years such as 2011 and 2023, although highly variable between sites.

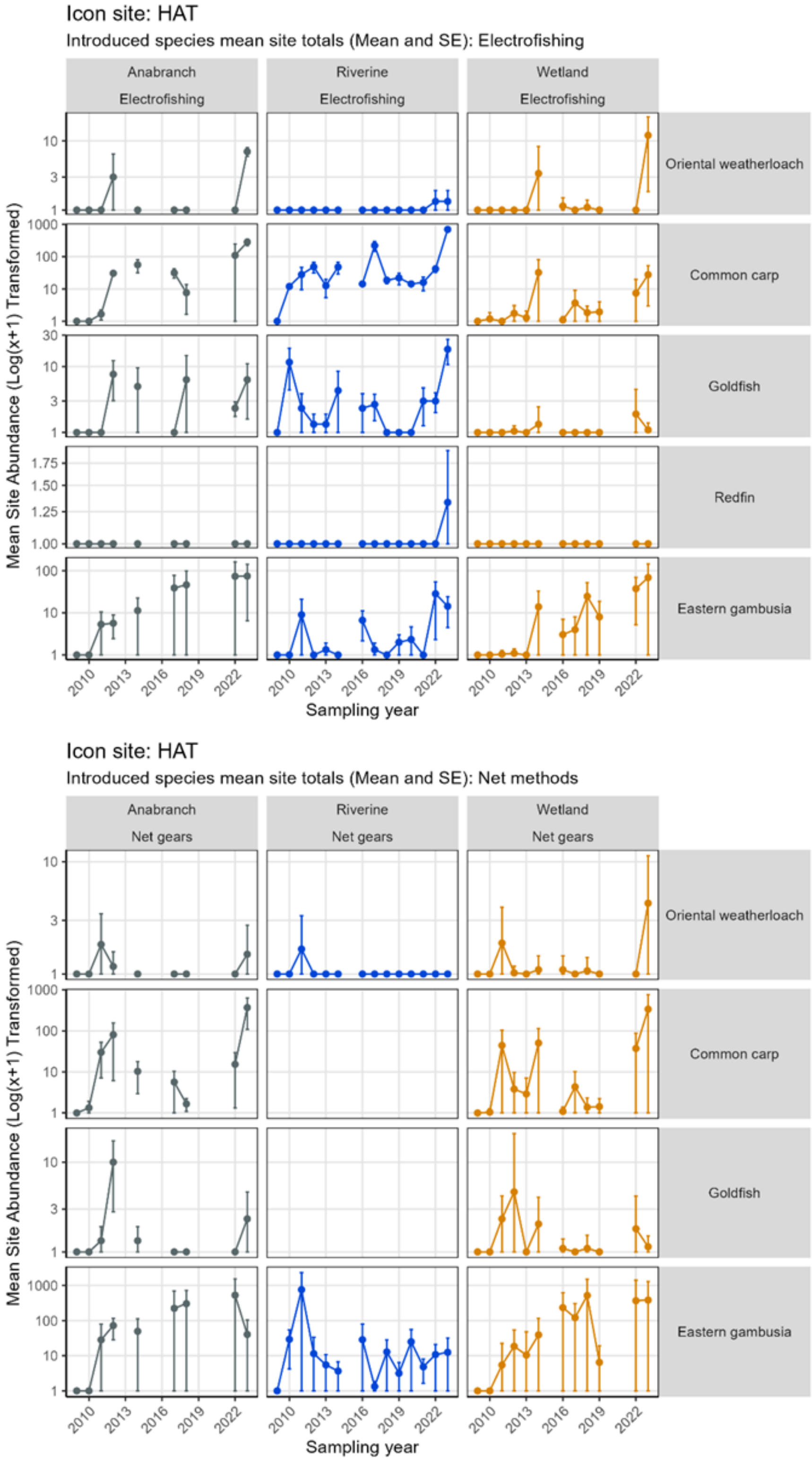


Figure 49 Annual mean total site abundance of introduced species, separated by electrofishing (boat and backpack) and net gears. Note that only coarse-meshed fyke data was used for large-bodied species and this method is not used at Riverine sites. Also note that no sampling occurred in 2015.

10.3.4 Community structure

Fish community structure differs significantly by abundance between years and macrohabitats, and there is a significant interaction between these factors (Table 38). When the interaction effect for macrohabitat and years is examined on the basis of using reach as a 'strata' of macrohabitat, there is no change in the effect on the model.

Table 38 PERMANOVA partitioning and analysis of fish assemblage abundance data between macrohabitats and years (using Bray-Curtis distances), including a test for the effect of 'reach' strata. Significant p-values in bold.

Abundance	Df	SumsOfSqs	R^2	F.Model	Pr(>F)
Macrohabitat	2	6.676	0.089	20.858	**0.001**
Year	12	24.970	0.332	13.003	**0.001**
Macrohabitat:Year	18	9.436	0.126	3.276	**0.001**
Residuals	213	34.085	0.453		
Total	245	75.166	1.000		
Abundance with Reach Strata					
Macrohabitat	2	6.676	0.089	20.858	**0.001**
Year	12	24.970	0.332	13.003	**0.001**
Macrohabitat:Year	18	9.436	0.126	3.276	**0.001**
Residuals	213	34.085	0.453		
Total	245	75.166	1.000		

The nMDS plot (Figure 50) shows the 2023 fish community structure at Hattah is quite different from recent years and is clustered around years such as 2016 (Riverine and Anabranch) and 2022 (Wetland) (Figure 50a). Riverine macrohabitats generally cluster around each other among years, while Wetland and Anabranch are more dispersed between years. When the electrofishing and netting data are separated (Figure 50b), it is clear the majority of the dispersion in the data points is in the electrofishing data, with close clustering of Riverine sites highlighting both differences in community structure and different electrofishing methods (boat rather than backpack) that are not directly comparable.

The 2023 centroids for electrofishing most closely resemble 2011 (Riverine), 2012 (Anabranch) and 2022 (Wetland), while the 2023 centroids for netting methods more closely resemble 2010 (Riverine), 2016 (Anabranch) and 2013 (Wetland). Some caution is required when interpreting these plots due to the high stress values (>0.2), although this may reflect the size of the dataset and difficulty in representing inter-relationship complexity in a two-dimensional plot (Clarke 1993).

The most abundant species such as carp gudgeon, carp, eastern gambusia and to a lesser extent, Australian smelt, unspecked hardyhead and Murray Darling rainbowfish, account for most of the abundance-based differences in community structure between most years (Table 37). Most of the differences between the community structure in 2023 and other years were due to the high abundance of carp and eastern gambusia and/or the low abundance of carp gudgeon.

Table 39 SIMPER analysis results showing the species most influential for a minimum of 70% of pairwise differences (and levels of their interaction) between years based on abundance data for all sites and for all methods. Greatest species contribution to cumulative dissimilarities in each year comparison highlighted in bold. Note: no sampling occurred in 2015.

Year	Species	Year											
		2022	2021	2020	2019	2018	2017	2016	2014	2013	2012	2011	2010
2023	Carp gudgeon complex		0.80	0.77	0.68	0.60	**0.38**	0.88			0.68	**0.43**	
	Common carp	**0.38**	**0.45**	**0.44**	**0.39**	0.87	0.66	**0.34**	**0.42**	**0.50**	**0.41**	0.71	**0.49**
	Eastern gambusia	0.73	0.70	0.67	0.90	**0.32**	0.87	0.66	0.73	0.77	0.91		0.74
2022	Bony herring		0.72	0.70									
	Carp gudgeon complex		0.65	0.60	**0.46**	0.79	**0.50**	0.79	0.85	0.74	**0.45**	**0.57**	0.70
	Common carp								0.65				
	Eastern gambusia		**0.43**	**0.38**	0.82	**0.43**	0.78	**0.45**	**0.39**	**0.47**	0.82	0.87	**0.45**
2021	Australian smelt			0.67						0.61			0.41
	Bony herring			0.56					0.57	**0.20**	0.58		**0.25**
	Carp gudgeon complex			0.78	**0.66**	**0.39**	**0.56**	0.76		0.72	**0.48**	**0.67**	0.65
	Common carp								**0.43**				
	Eastern gambusia			**0.23**		0.77	0.70	**0.40**	0.70	0.35	0.67	0.74	
	Murray darling rainbowfish												0.74
	Unspecked hardyhead			0.41	0.72				0.77	0.48	0.74		0.55
2020	Australian smelt						0.79			0.70			0.71
	Bony herring				0.78				0.55	**0.22**	0.58		**0.25**
	Carp gudgeon complex				**0.61**	**0.39**	**0.56**	0.74		0.80	**0.46**	**0.64**	
	Common carp								**0.39**				
	Eastern gambusia					0.75	0.69	**0.38**	0.68	0.58	0.78	0.73	0.57
	Unspecked hardyhead				0.70				0.78	0.41	0.69		0.42
2019	Carp gudgeon complex					0.79	**0.56**	0.80	**0.51**	**0.72**	**0.73**	**0.73**	**0.70**
	Common carp								0.78				
	Eastern gambusia					**0.44**	0.73	**0.43**					
2018	Carp gudgeon complex						**0.44**	0.79	**0.36**	**0.41**	**0.41**	**0.47**	**0.41**
	Common carp								0.83				
	Eastern gambusia						0.77	**0.41**	0.69	0.80	0.80	0.82	0.80
2017	Carp gudgeon complex							**0.48**	**0.54**	**0.59**	**0.59**	**0.62**	**0.58**
	Common carp								0.68				
	Eastern gambusia							0.76	0.82	0.75	0.75	0.78	0.73
2016	Carp gudgeon complex								0.64	0.79	**0.42**	**0.51**	0.78
	Common carp								0.84				
	Eastern gambusia								**0.33**	**0.41**	0.80	0.84	**0.40**
2014	Bony herring												0.82
	Carp gudgeon complex										**0.43**	**0.62**	
	Common carp									**0.55**	0.76	0.80	**0.54**
	Eastern gambusia									0.75			0.69
2013	Australian smelt												0.85
	Bony herring												0.49
	Carp gudgeon complex										**0.60**	**0.72**	0.69
	Eastern gambusia										0.79		**0.27**
2012	Carp gudgeon complex											**0.74**	**0.55**
	Eastern gambusia												0.70
2011	Carp gudgeon complex												**0.71**

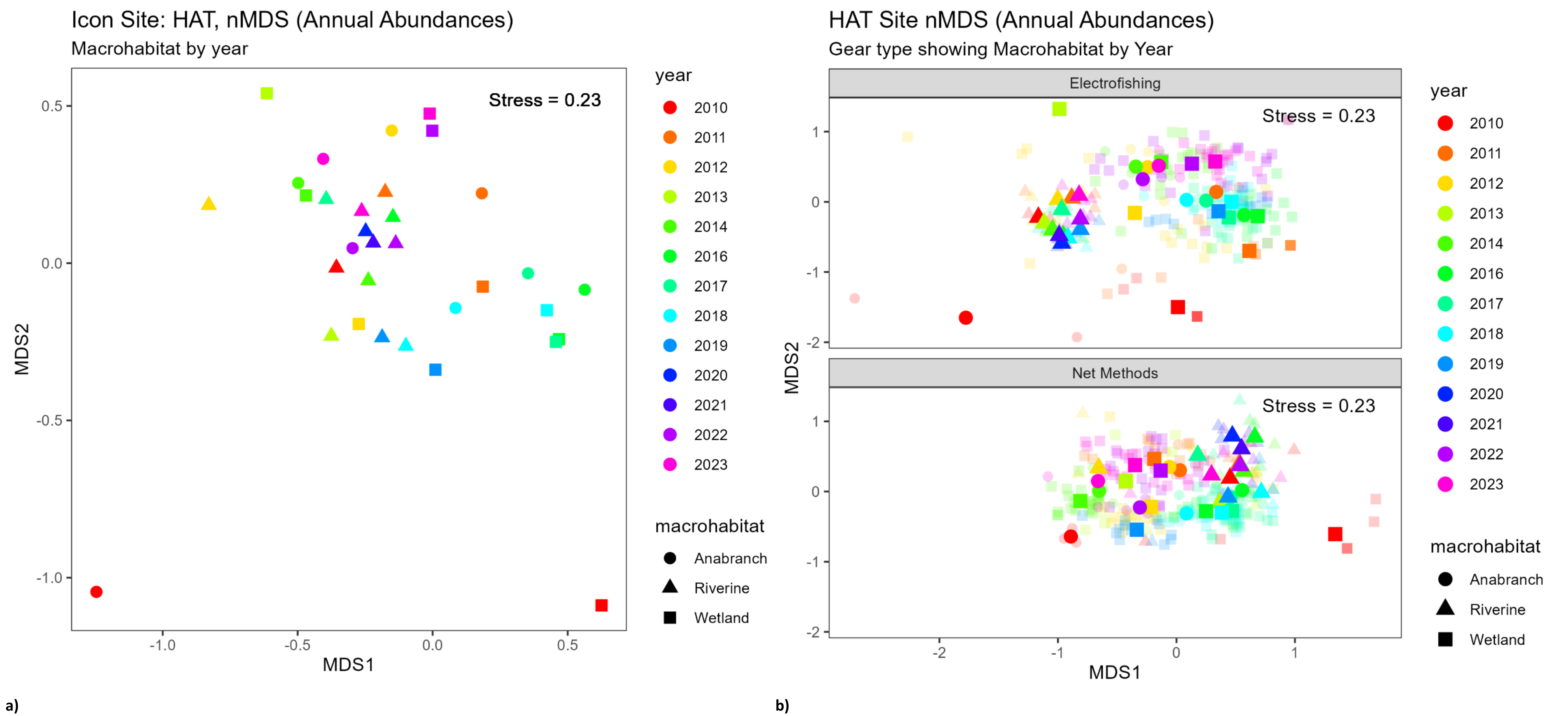


Figure 50 nMDS plot of community composition for annual site abundance by a) macrohabitat and year (centroids only) and b) macrohabitat and year separated by gear type (top – electrofishing and bottom – net gears). Note high stress levels in nMDS plots (i.e. stress = >0.20) means these plots should be used only as a guide.

10.3.5 Size distribution

Recruitment and size distribution information is provided for large-bodied iconic species Murray cod and golden perch as well as carp below. Stocking information is also provided for Murray cod and golden perch.

Murray cod

Murray cod recruitment, as indicated by detection of Murray cod <150 mm TL (noting that growth rates vary between years etc.), and a visualisation of the size distribution data (refer to 10.2.3 , for interpretation information) is provided in Figure 51, and the results are summarised here:

- Following moderate levels of recruitment in 2021–22, no recruitment was evident at the icon site in 2023 for the first time since 2017
- Previous periods of strong recruitment included 2018–2020 and 2013–2014
- In 2023 the dominant cohort was comprised of sub-adults and adults 450–600 mm, recorded from Riverine sites.

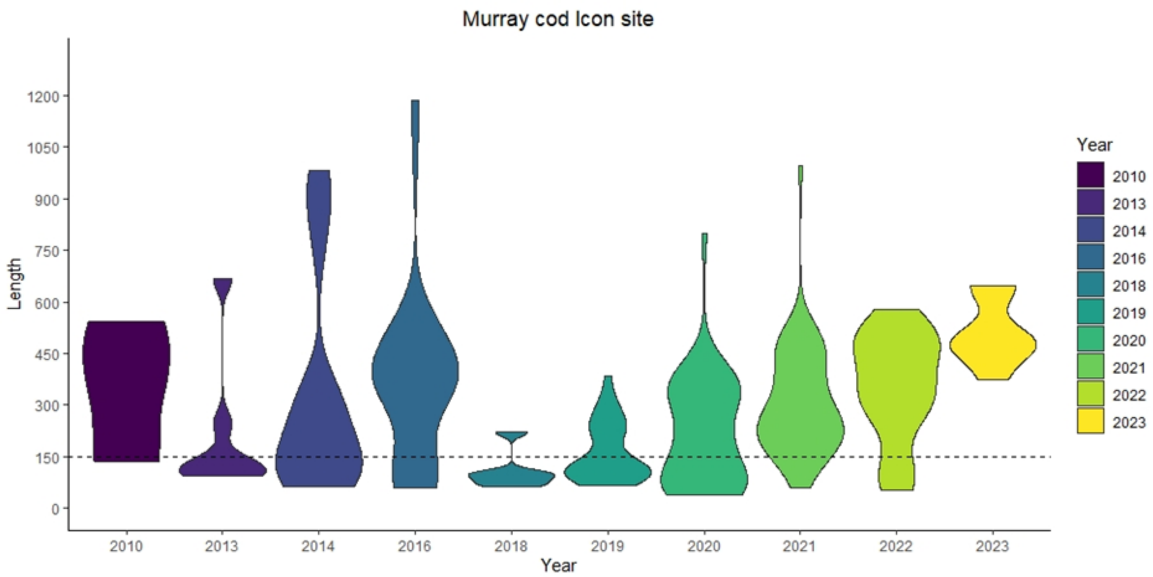


Figure 51 Violin plot depictions of the distribution of fish lengths for Murray cod (mm TL) at the icon site scale over the 2010–2023 period. Each shape represents the distribution of fish lengths, where wider sections indicate higher frequency of those lengths. Missing years indicate no sampling took place (2015) or too few were caught to make violin shapes (2011, 2012 and 2017). Dotted line represents YOY threshold (150 mm TL).

Murray cod are rarely stocked in this section of the Murray River between Lock 11 (Mildura) and Lock 15 (Euston). The last stocking record in the area was 11,500 Murray cod stocked ~6 km upstream of Lock 11 in 2009–2010. However, Murray cod are regularly stocked between Lock 10 (Wentworth) and Lock 11 (Mildura), and upstream of Lock 15 (Euston) (NSW DPI 2023).

Golden perch

Golden perch recruitment as indicated by detection of golden perch <150 mm TL (noting that growth rates vary between years etc.), and size distribution information is provided in Figure 52, and the results are summarised here:

- No golden perch recruitment was evident in 2023
- Strong recruitment of golden perch was evident in 2022 for the first time since 2014
- Over the 2016–2021 period there was very little recruitment, and a cohort of large fish (~375–425 mm TL) became the dominant size class.

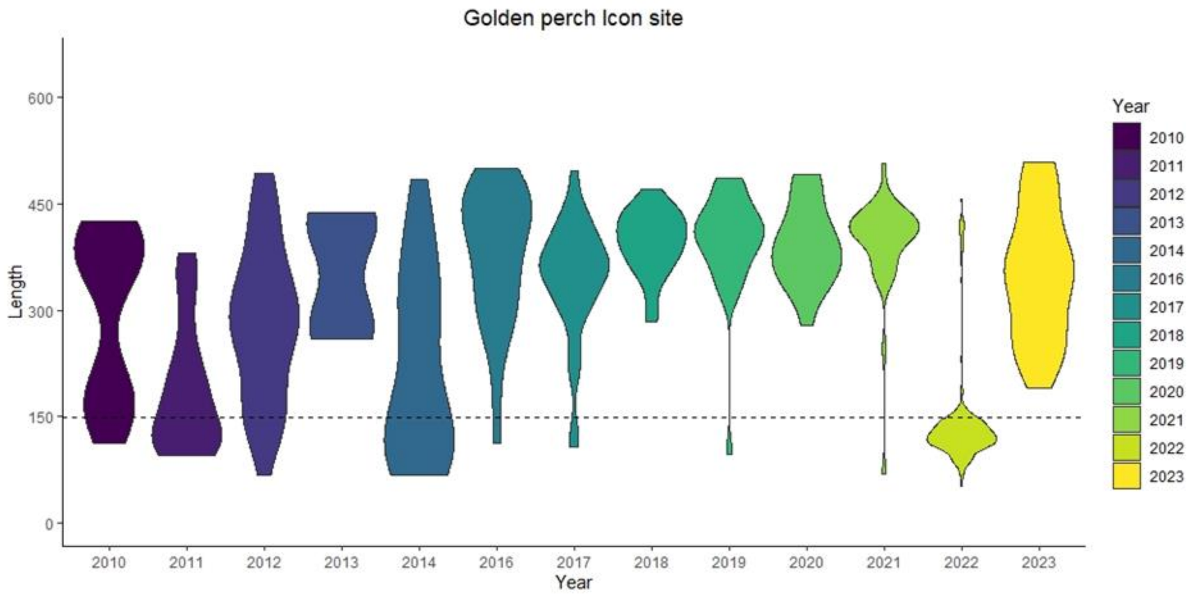


Figure 52 Violin plot depictions of the distribution of fish lengths (mm TL) for golden perch at the icon site scale over the 2010–2023 period. Each shape represents the distribution of fish lengths, where wider sections indicate higher frequency of those lengths. Missing years indicate no sampling took place (2015). Dotted line represents YOY threshold (150 mm TL).

There are no records of golden perch being stocked in this section of the Murray River between Lock 11 (Mildura) and Lock 15 (Euston). However, golden perch are regularly stocked between Lock 10 (Wentworth) and Lock 11 (Mildura), and upstream of Lock 15 (Euston) (NSW DPI 2023).

10.3.6 Carp

Carp recruitment, as indicated by detection of carp <200 mm Fork Length (FL) (noting that growth rates vary between years etc.), and size distribution information is provided in Figure 53, and the results are summarised here:

- Very strong recruitment of carp is evident over two successive years (autumn 2022 and autumn 2023), with YOY carp being the dominant cohorts in both years
- Prior to 2022–23, the previous years of very strong carp recruitment were 2011 (post late summer 2011 flooding), 2014 and 2017 (post spring 2016 flooding).

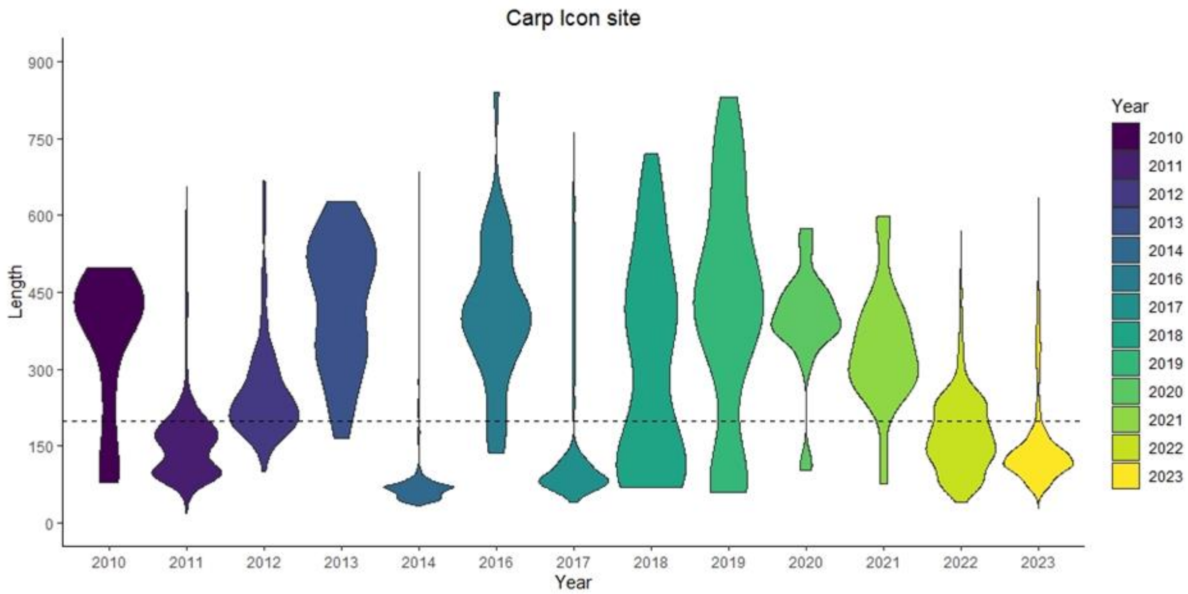


Figure 53 Violin plot depictions of the distribution of fish lengths (mm) for carp at the icon site scale over the 2010–2023 period. Each shape represents the distribution of fish lengths, where wider sections indicate higher frequency of those lengths. Missing years indicate no sampling took place (2015). Dotted line represents YOY threshold (200 mm FL).

10.3.7 Tagged fish recaptures

Since 2019, a total of 142 fish have been tagged during the Hattah TLM project from the three Murray River sites, including 30 in 2023. The fish tagged comprise four large-bodied native species, Murray cod (72 tagged fish), golden perch (66), silver perch (3) and spangled perch (1). None of the tagged fish have been recaptured by researchers during the autumn TLM sampling in subsequent years, and only one fish has been reported as recaptured by an angler. This fish, a golden perch, was recaptured 14 km from its tagging location almost two years after tagging (Table 40).

Table 40 Angler recaptures of fish tagged with Ecology Australia dart tags during the 2021–2023 sampling. Any recaptures of fish tagged between 2019–2020 would have been reported to ARI (ARI dart tags were deployed during this period).

Dart Tag #	PIT #	Species	Length at tagging (mm)	Date tagged	Date recaptured	Time between captures (days)	Location tagged	Location recaptured	Movement description	Movement distance (km)	Released
EA0285	982.126057198799	Golden perch	400	13/04/2021	24/09/2022	529	Mur3	Murray River Wemen	Upstream	14	no

10.3.8 Indices results

Diversity Index: P expected

The 2023 P expected index scores (i.e. the number of native indigenous species collected in each site compared to the number expected) for the Riverine macrohabitat are identical to those recorded over most of the monitoring program (with the exception of 2012). For Anabranch and Wetland, the P expected index scores continue to be high and less variable than the 2011–2013 period but have declined from 2022 (Figure 54).

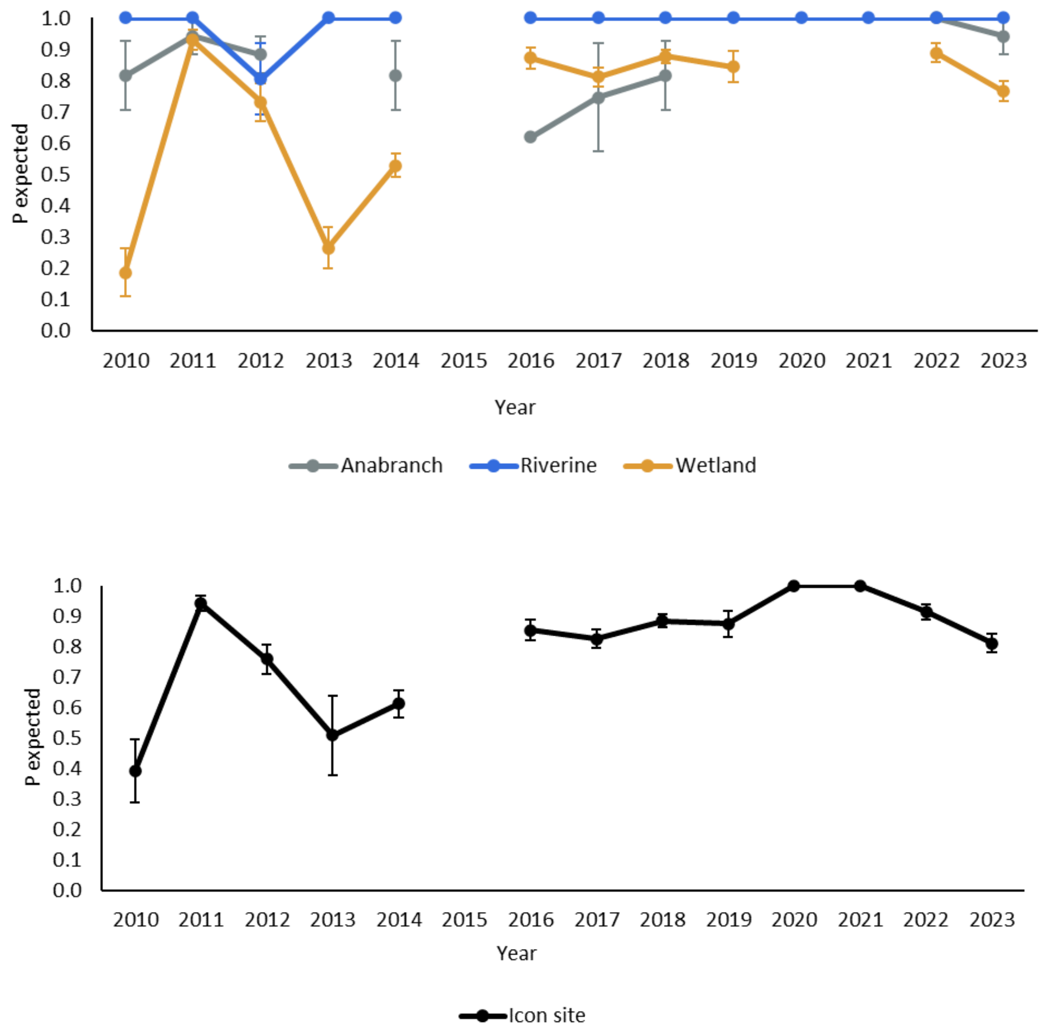


Figure 54 Diversity Index (P expected) scores at the macrohabitat scale (top) and icon site scale (bottom).

Biomass Index: P native

The 2023 P native index scores (previously known as P nativeness, i.e. the proportion of fish biomass within each site that is from native fish species) were the lowest recorded over the 2010–2023 monitoring period for Riverine and Wetland and almost the equal lowest for Anabranch (Figure 55)The scores have fluctuated considerably over time at all macrohabitats. icon site scale scores should be interpreted with caution (refer to 10.3.4), particularly in years where large numbers of Wetland or Anabranch sites were not sampled (i.e. the icon site score will largely reflect Riverine score in those years).

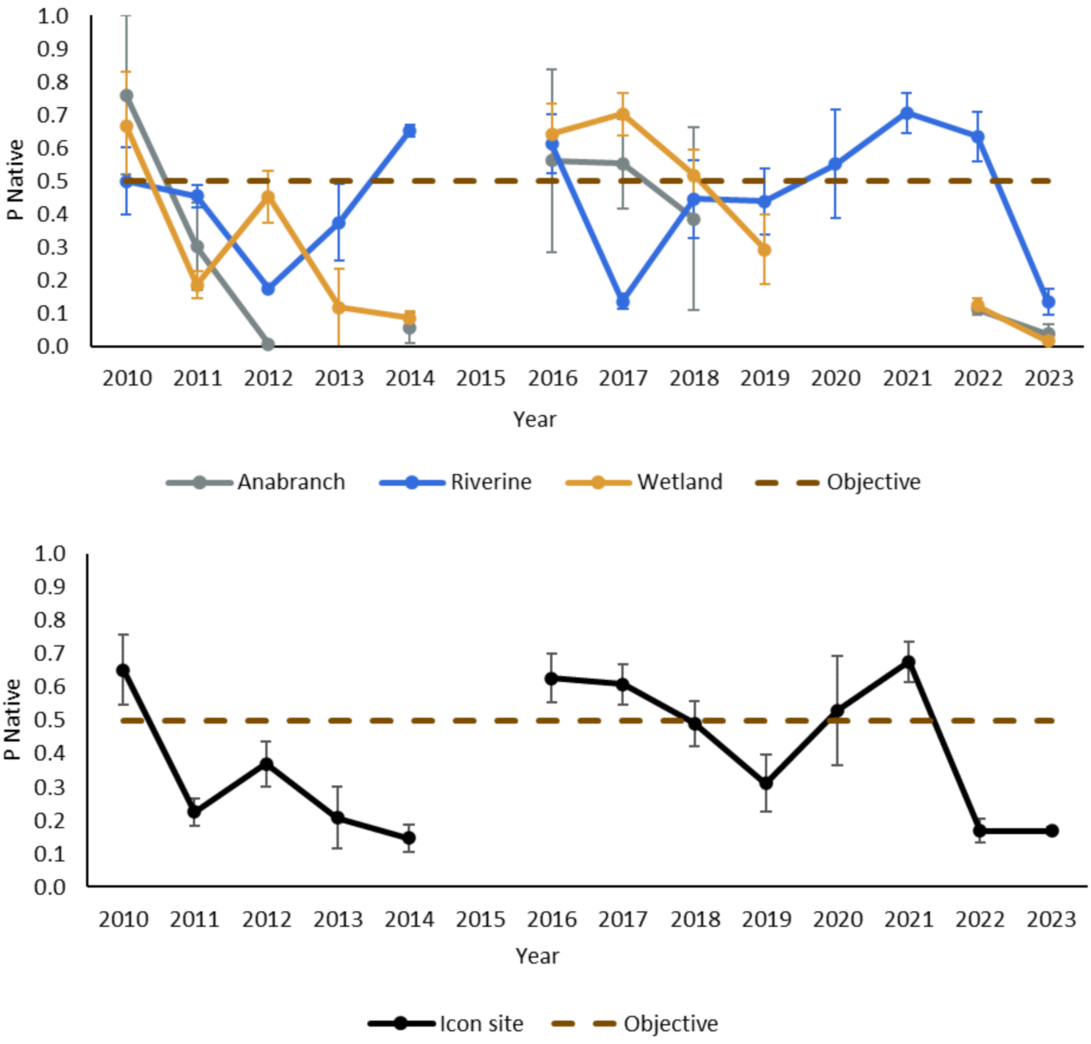
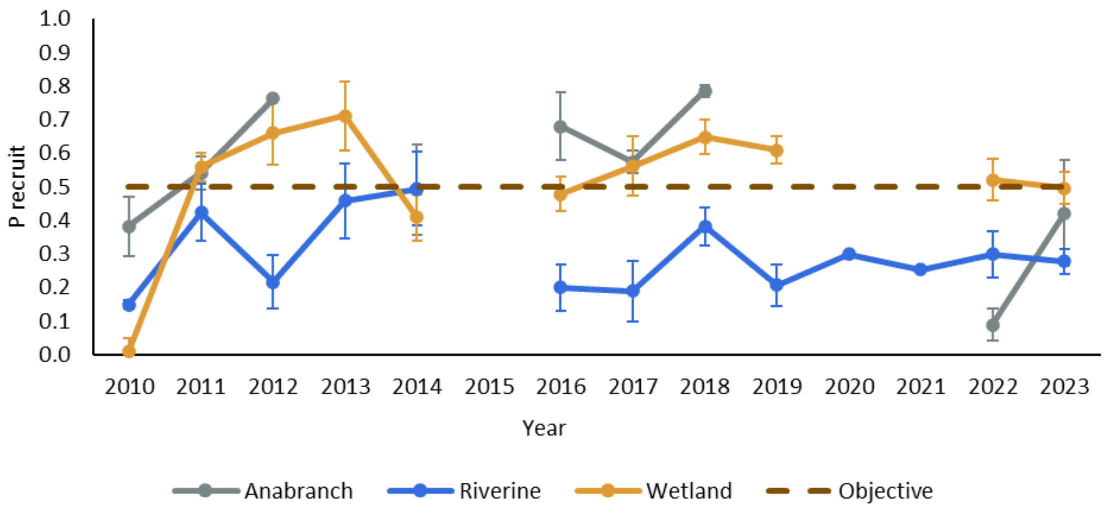


Figure 55 Biomass Index (P native) scores at the macrohabitat scale (top) and icon site scale (bottom). Brown line indicates compliance target for objective (refer to section 0).

Recruitment Index: P recruits

The Recruitment Index (P recruits) scores (i.e. the proportion of indigenous native fish in each site that are recruits) have been relatively low and variable over time, attaining the objective target at the icon site scale in only 6 out of the 13 sampling years (Figure 56). Riverine P recruit scores have remained lowest and stable during the monitoring period, with little change in 2023 compared with 2020–22. Wetland P recruit scores in 2023 were slightly lower but comparable to 2022, while the Anabranch P recruit scores were much higher in 2022, but still below the compliance target. The highest P recruit scores for Wetland and to a lesser extent for Anabranch macrohabitat, have been recorded in 2011–2013 and 2017–2019, years where the compliance target was met at the icon site scale.



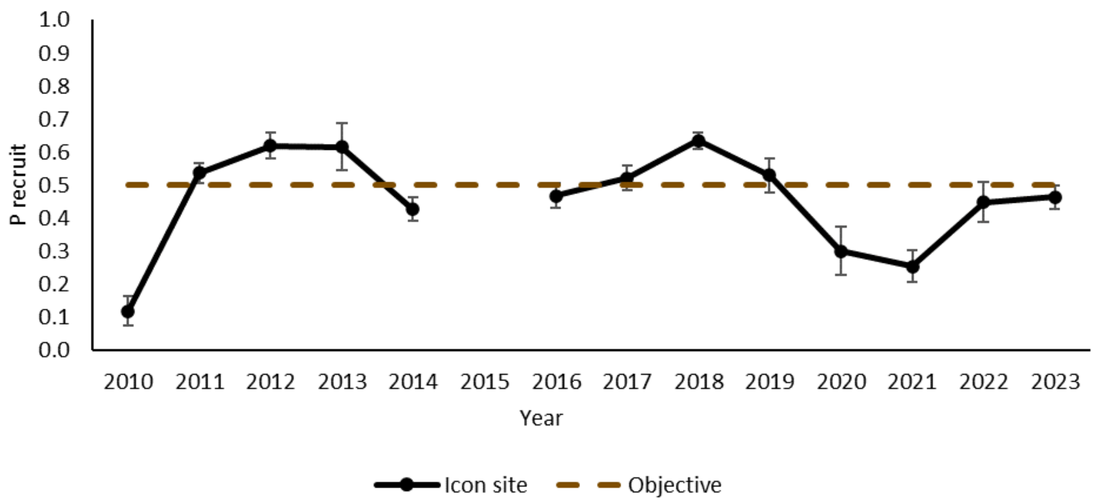


Figure 56 Recruitment Index (P recruits) scores at the macrohabitat scale (top) and icon site scale (bottom). Brown line indicates compliance target for objective (refer to section 0).

10.4 Discussion

The 2022–23 flooding event was one of the largest on record and easily the largest over the monitoring program, eclipsing those of 2011 and 2016. For Hattah Lakes, this natural flooding event occurred only around 12 months after the completion of a large-scale environmental watering event, where the wetlands were re-filled after being dry. The previous significant flooding event (2016–17) occurred approximately 3 years after a similar large scale environmental watering event (again filled from dry except for Lake Mournpall). These drying and subsequent filling phases involve a 'reset' and re-establishment of the fish community via pumped water transfer or flooding. Flooding events exert a large influence on fish communities. While there are benefits including greater longitudinal (e.g. removed or drowned out weirs) and lateral connectivity (overbank flow connection with floodplain habitats), productivity pulses from floodplain inputs, and inundation of nursery habitats for larval and juvenile fishes, two of the most well documented downsides are hypoxic blackwater driven fish kills (e.g. King et al. 2012, Thiem et al. 2017), and very large increases in carp abundance (e.g. Stuart and Jones 2006).

The most obvious fish community composition response to the flooding event at the Hattah icon site was a very large increase in the abundance of carp, with over 20,000 recorded in total (previous record was just under 7,000 in total in 2014). The 2023 increase was driven by very strong recruitment, with Young-of-Year (YOY) juveniles being the dominant size classes captured. Carp are able to breed and recruit under all flow conditions, but are known to increase their spawning and subsequent recruitment in high flow and flood years (e.g. Stuart and Jones 2006, King et al. 2016) and during environmental watering (Koehn et al. 2016). These peaks in carp abundance at Hattah have been evident from sampling that followed previous flooding events of 2010–11 and 2016–17, and from sampling that followed large scale watering events of previously dry wetlands in 2014. Although carp are typically recorded in much higher abundance following flooding and watering events, the translation of YOY into subsequent adult year classes is thought to vary with both hydrological conditions and the abundance of predators in the system (Forsyth et al. 2013, Koehn et al. 2016). A large proportion become a food source for birds, particularly as waters recede and floodplain wetlands dry out, while others become a known food source for large-bodied native fish such as golden perch and Murray cod.

As detailed in Palmer et al. (2022), the entire fish community of the Hattah Lakes icon site was re-established by the autumn and spring 2021 watering events following a 2019–21 period of drawdown and complete drying. All expected native fish species (except Murray cod) and introduced fish species were detected in 2022 despite size and species-specific mortality and injury issues associated with the water delivery method (i.e. pumping) (e.g. Baumgartner et al. 2009). Large numbers of golden perch YOY and some silver perch YOY were found to have become entrained in Hattah Lakes wetlands in autumn 2022, likely via transfer of eggs and larvae during spring 2021 pumping (Palmer et al. 2022). Both of these species can display increased spawning, larval survival and recruitment to floods and high flow conditions (King et al. 2009, Zampatti and Leigh 2013, Zampatti et al. 2015, King et al. 2016, Koster et al. 2017, Tonkin et al. 2019), however none were detected from Wetland sites in 2023 and no recruitment was detected at Riverine sites, possibly due to the hypoxic blackwater that was associated with this event (NSW DPE 2022). The 2022–23 flooding event would have provided a natural exit pathway for juvenile golden perch and silver perch fish to emigrate from Hattah Lakes to the Murray River, allowing them to complete an early life stage grow-out process (Stuart and Sharpe 2020) that may not otherwise have occurred due to lack of natural exit pathways (Palmer et al. 2022). As detailed in Palmer et al. (2022), most small-bodied fishes appeared to have re-established their populations quickly following the spring 2021 pumping, highlighting the ability of these generalist species to recolonise and re-establish given the appropriate conditions. The 2022–23 flooding event would also have provided an opportunity for all fish species to disperse easily between floodplain wetlands and channels and the Murray River, further boosting populations through re-distribution between wetlands and much improved genetic transfer than was likely possible via pumped water transfer.

The 2022–23 flooding event also provided unimpeded longitudinal fish passage in the Murray River (i.e. fishways were able to be bypassed due to removal of Mildura Weir and removal of 'stop-logs' from Locks 6–10 and 15). High flow and flooding events also encourage large scale dispersal of species normally found in the more northern parts of the Murray Darling Basin, such as spangled perch, a species detected during 2023 sampling for the first time since 2012. Additionally, flooding/high flow events provide opportunities for dispersal of threatened species such as olive perchlet (detected at LMW icon site in 2022) and Murray hardyhead; the latter being a species yet to be detected by TLM monitoring at Mallee icon sites, but persists at a few locations in the region and has increased potential to occur following such events.

Although no additional species were recorded from Wetland or Anabranch macrohabitat in 2023, potential remains for Murray cod and other species to have recolonised during the 2022–23 flood and for detection to occur in future years. For small-bodied species it is worth noting that the 2023 YOY carp abundances were so extreme that they are likely to have impacted upon sampling efficiency for small-bodied native fish species, through increased mortality, injury and depredation (due to over-crowding, crushing and asphyxiation) of these species in the larval fyke nets. There is some indication of this in the monitoring data for both carp gudgeon and flatheaded gudgeon, with substantial increases in 2023 based on backpack electrofishing, compared with slight declines (carp gudgeon) or marginal increases (flatheaded gudgeon) based on netting gear. This could also have impacted the ability to detect other small-bodied species typically present in low abundance at Anabranch and Wetland sites, such as Murray-Darling rainbowfish and unspecked hardyhead.

Recolonisation by rare or threatened species would typically be expected to initially result in establishment in very low abundance, remaining below the thresholds of detection until substantial recruitment driven increases in abundance occur. The establishment of a small population of Murray cod at Lake Mournpall was one example of this. The population is thought to have established during the 2016–17 flooding event but remained undetected until 2019, when YOY Murray cod were detected in moderate abundance (Bloink et al. 2019). Although in that case, the ability to detect adult Murray cod was also limited due to the gear selection, with no boat electrofishing used at Hattah Lakes Wetland or Anabranch sites. As suggested previously (Bloink et al. 2019), detection of adults of large-bodied species such as Murray cod at Wetland sites would be enhanced by inclusion of boat electrofishing as a survey method at sites where the method is feasible (i.e. Lake Mournpall and Lake Hattah), either as an additional method, or in combination with backpack electrofishing in the proportions detailed in the SRA fish sampling protocols (MDBA 2011b) (e.g. 6x90 seconds boat electrofishing and 4x150 seconds backpack electrofishing).

The two previous significant flooding events that occurred over the monitoring program (2010–11 and 2016–17), both caused hypoxic blackwater events and mass fish kills in the Murray River downstream of

Barmah stretching for 1800 and 2000 km respectively (Koehn 2021). The effects of both events on fish communities have been well documented (e.g. King et al. 2012, Thiem et al. 2017) and have stood out in the Hattah TLM monitoring datasets, with large peaks in carp abundance and declines for Murray cod (at Riverine macrohabitat) (Palmer et al 2022, McPhan et al. 2022). Murray cod are known to be particularly susceptible to hypoxic blackwater (Small et al. 2014). Although limited to only three Riverine sites, the 2023 Hattah TLM results indicate that a substantial decline in Murray cod abundance occurred, a possible result of mortality and/or emigration away from the monitoring sites. The decline does not appear to have occurred to the same extent as detected following the previous blackwater events of 2016–17 and 2010–11, and with a low-moderate abundance of sub-adult and adult Murray cod remaining at the monitoring sites, there is potential for a faster population recovery than appears to have occurred following the previous 2010–11 and 2016–17 hypoxic blackwater events.

10.4.1 Objective and target attainment

A summary of the relevant targets is provided below (Table 41). No targets were met in 2023 with both the P recruit and P native score (biomass) for all macrohabitats and the icon site below the compliance target.

P native scores for the Riverine macrohabitat have dropped to comparable lows of 2017 and 2012 due to the influence of major floods (2010–11, 2016–17 and 2022–23) on carp abundance. The P native scores for Anabranch and Wetland macrohabitats remained very low and comparable to 2022 and 2014 (years where the lakes were re-filled with environmental water) rather than being comparable to post flood results from 2011 and 2017, likely reflecting the two consecutive years of strong carp recruitment.

Although attainment of some targets has been achieved in some years (e.g. P native scores in 2016), progress is not being made towards the 2030 target attainment at Anabranch or Wetland macrohabitats because Hattah Lakes are periodically drawn down to completely dry (i.e. fish community reset) as occurred in 2020–2021.

Table 41 Summary of target attainment in 2023. Traffic light colours included to assist interpretation.

Objective HL9 Native fish recruitment Maintain recruitment of populations of small bodied native fish and presence of large bodied native fish at Hattah Lakes by 2030			
Targets	**Attained**	**Partial attainment**	**Not attained**
By 2030, evidence of recruitment of small bodied native fish species at enough sites for P recruits (a recruitment index - see section 10.2.4) and P native (a biomass index – see section 10.2.4) to attain targets below in 80% of years between 2020–2030. Species include: Australian smelt (*Retropinna semoni*), carp gudgeon (*Hypseleotris* spp.), unspecked hardyhead (*Craterocephalus fulvus*).			
Mean proportion of recruits using P recruits index is ≥0.5 for each of the three macrohabitats			
Mean proportion of natives using P native index is ≥0.5 for each of the three macrohabitats			

10.4.2 Recommendations

The re-establishment of the Hattah Lakes fish community in 2021–22 increases the fish community values of the icon site and provides an opportunity to consider a management approach that seeks to maintain and enhance those fish community values over time. This would require the avoidance of system 'resets' at some sites, as these involve elimination of the fish community with a subsequent flooding or pumping event required for re-establishment to occur. Some wetlands such as Lakes Hattah and Mournpall were previously classified as 'permanent freshwater lakes' and are thought to have remained wet over 95% of the time under natural conditions (Ecological Associates 2007), while other 'semi-permanent' wetlands such as Lakes Bulla and Arawak, would also have retained water for greater than 90% of the time. Drawdown and complete drying out more permanent wetlands, particularly Lakes Mournpall and Hattah for benefits such as carp eradication should be evaluated against the high cost of eliminating significant fish community values. These periodic system resets also preclude long-term progress towards Anabranch and Wetland fish ecological objectives and targets. It is recommended that future updates to Hattah Lakes monitoring objectives and targets include maintenance of a permanent refuge habitat in Lakes Hattah and Mournpall during periods of regional drought, and the need to distinguish between fish community objectives and target outcomes for retaining fish in permanent wetlands (Lakes Mournpall and Hattah) as opposed to transient subpopulations in semi-permanent wetlands. In the interim, we recommend treating Lakes Hattah and Mournpall as a fourth macrohabitat category in future years, allowing them to be assessed for objective and target attainment separately from the remaining wetlands that undergo regular or periodic fish community resets via dry-down.

The Hattah icon site TLM data is now a robust long-term dataset of annual catches of native and introduced fish populations, that has been conducted during a range of hydro-climatic conditions. Other than PERMANOVA analyses in this report and the previous, the reports to date have had minimal statistical analyses regarding fish population changes over years and have not directly addressed the influence of hydrology or water management changes to any observed fish responses. A further statistical analysis exercise of the monitoring dataset was undertaken (McPhan et al. 2022) to (i) explore fish population abundance patterns across years and among macrohabitats; (ii) determine when major changes in fish population abundances have occurred, and (iii) explore the influence of riverine flows and water management on fish populations. Using a 'multiple lines of evidence' approach, this work is a first step in statistically assessing the impacts of flow and water management on population change of native and introduced fish at the Hattah icon site. McPhan et al. (2022) made several recommendations (outside the scope of annual TLM condition monitoring funding) including the use of similar population density distribution plot analyses to explain the significance of annual catches across icon site and macrohabitats in future years, and to describe future restoration targets and reporting. The analyses could be further enhanced by incorporating sampling detection probabilities into modelling (McPhan et al. 2022). Additionally, we recommend rectifying any effort data format consistency issues, so that effort data can be included in future analyses.

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