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The Living Murray Condition Monitoring: Hattah Lakes 2021–22, Part A

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Cover photo: River red gum tree condition site with an abundance of Warrego summer-grass *Paspalidium jubiflorum* growth after the floods and rain. Photo: Nina Kerr

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Acknowledgments

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Summary

Ecology Australia was commissioned by the Mallee Catchment Management Authority (CMA) to undertake the 2021–22 condition monitoring of the Hattah Lakes Icon Site, as part of The Living Murray 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.

The Living Murray 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 Murray system for the benefit of all Australians. The program also aims to deliver the objectives and outcomes of the Murray-Darling Basin Plan (MCMA 2021a).

Monitoring for The Living Murray 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. A summary of the 2021–22 results is provided in Table 1.

Table 1 Summary of whether ecological objectives have been met for each project component for 2021–22

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			

Component	Objective	Achieved	Partially achieved	Not achieved
	such communities at Hattah Lakes Icon Site by 2030.			
Waterbirds	Provide feeding habitat for a range of waterbirds, and have successful nesting by colonially nesting waterbirds at Hattah Lakes Icon Site by 2030.			
Fish communities	Maintain recruitment of populations of small bodied native fish and presence of large bodied native fish at Hattah Lakes by 2030.			

River red gum

For the 2021–22 survey period, the mean percentage of trees with a Tree Condition Index (TCI) score of 10 or more decreased at river red gum sites in 2021–22 (from 57.1% to 55.1%). This represents the second consecutive year where the TCI target of 70% has not been met for river red gums. Declines in river red gum TCIs at some sites may be related to inundation at the time of surveying causing temporary flood-related stress to trees. However, relationships between flooding and TCI scores could be better investigated with the provision of long-term inundation data or mapping for tree condition sites. The annual mortality target of <1% of trees sampled was met for river red gums (0.2%). A mean river red gum population status index of 0.93 (pooling indices between WRCs) 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 and population structure index but failed to meet 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 partially met in 2021–22.

Black box

The mean percentage of trees with a Tree Condition Index (TCI) score of 10 or more increased for black box (from 39.5% in 2020–21 to 56.4% 2021–22). Despite an increase, this represents the ninth consecutive year in which the 70% target has not been met for black box. In contrast, the annual mortality target of <1% of trees sampled was met (0.3%). 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 2021–22 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 increased from the previous monitoring period. Across the Icon Site, seven transects were compliant with the native water-responsive species richness index, while seven were compliant with native water-responsive species abundance. This represents an overall increase in compliance from 2020–21 surveys.

All wetlands with the exception of Lake Kramen were inundated during the current surveys. As a result, the proportion of drought tolerant species occurring in semi-permanent and persistent temporary wetlands decreased greatly in 2021–22 compared to 2020–21. This was associated with an increase in the proportion of woody amphibious fluctuation tolerator and terrestrial damp species. In contrast, Lake Kramen saw an increase in the proportional abundance of terrestrial dry functional species and a decrease in the abundance of aquatic species.

Icon Site scores for species richness and abundance increased for the 2021–22 survey period. Wetland vegetation is highly dynamic, responding to wetting and drying cycles with changes in species richness and abundance. NMDS ordination indicated this, with the only site not inundated – Lake Kramen – containing a substantially different floristic composition to other wetland sites and being strongly associated with species more likely to be found where conditions are drier. Compliant transects were recorded at persistent temporary and episodic wetlands, while none were recorded at semi-permanent sites. 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 be considered partially met for 2021–22.

Floodplain vegetation communities

Whole-of-icon-site scores show there has been a marked increase in species richness since the last survey, while Icon Site species abundance also increased but this change was not as substantial as that for species richness. This suggests that high rainfall and environmental watering that occurred in 2021 has facilitated the establishment of a number of species across the Icon site.

The proportional abundance of drought-tolerant species at the often- and sometimes-flooded sites followed a similar pattern to the previous two surveys. This was accompanied by gains in the abundance of terrestrial damp and aquatic species. NMDS ordination revealed some distinction between the FRFs in terms of species composition, with rarely-flooded sites exhibiting a more distinct species composition than often- or sometimes-flooded sites. This distinction was mostly driven by an association with terrestrial dry species. However, there was significant overlap between the often- and sometimes-flooded sites.

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 system in a wetting and drying cycle.

Icon Site scores for 2021–22 represent an increase in both species richness and abundance. However, no clear trajectory towards 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’ can be observed. Results suggest partial attainment of the ecological objective for 2021–22.

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 2021–22 this target was met across the whole Icon Site, as well as within all individual WRCs (Lignum Shrubland, Lignum Swamp and Lignum Woodland). Following widespread inundation at Hattah Lakes in 2021–22 due to the delivery of environmental water as well as high rainfall in November 2021, lignum condition scores increased on average across all WRCs. At an Icon Site level, 86.7% of lignum plants recorded an LCI score of ≥4, while a score of 77.6% was recorded in Lignum Shrubland, 92.1% in Lignum Swamp, and 89.7% in Lignum Woodlands. 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, all 11 common waterbirds set out to be recorded annually over the 2020–30 period, under the Hattah Lakes objectives, were recorded.

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

The overall 10-year objectives to provide feeding habitat for waterbirds and to stimulate successful breeding by colonial waterbirds are on track to be met by 2030 at the Hattah Lakes Icon Site. The addition of summer surveys proved valuable in detecting nesting and successful breeding by a range of waterbirds.

As a noteworthy observation, a juvenile white-bellied sea-eagle, listed as endangered in Victoria, was seen being fed by an adult near a nest at Lake Bitterang in autumn.

Fish communities

After a prolonged period of drawdown and complete drying over 2019–2021, the fish community of the Hattah Lakes Icon Site in 2022 has been reset and re-established by the autumn and spring 2021 watering events. The rewetting of the Icon Site has seen the successful re-colonisation of the entire fish community. The 2022 fish community shows some similarity in species presence and structure to that observed post previous environmental watering and flooding events in 2011, 2014, and 2017, highlighting the ability of these species to quickly re-establish given the appropriate conditions.

Of particular note in 2022 was the substantial increase in golden perch abundance, particularly at most Wetland sites. The majority of golden perch collected were YOY and juveniles (90%), suggesting that eggs and larvae of this species were able to move into the Lakes system through the pumps and survive to this point. It is likely that the spring 2021 pumping event (rather than the autumn 2021 event) into the Icon Site enabled many native and introduced fish species to recolonise, as they would have been more active and also present at young life stages that could survive through the pumping. Total abundance was reduced compared to previous years; however, this was driven by the substantial decline in carp gudgeon abundance, which are known to be low flow or generalist species, and will no doubt increase in numbers in future years in the wetlands.

The amenable environmental and watering conditions at Hattah Lakes Icon Site also led to the recolonisation of most introduced species, particularly carp and eastern gambusia, which were both sampled in considerable numbers. The spring watering event is likely to have substantially improved native fish response (compared to autumn) but at the cost of native fish entrainment (particularly golden perch) and benefit to introduced fish species (particularly carp recruitment). Further consideration should be given to other management interventions or strategies that would enable the exit of native fish into permanent waterways, or whether some wetlands in the system could have water levels retained for a longer period. In the absence of the provision of permanent refuge habitat in the Lakes system, or appropriate exit pathways/strategies, localised fish kills may periodically occur. Additionally, periodic system 'resets' preclude progress being made towards long-term Anabranch and Wetland fish ecological objectives and targets.

1 Introduction

Ecology Australia was commissioned by the Mallee Catchment Management Authority (MCMA) to undertake the 2021–22 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 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 2021–22 survey period, all vegetation condition monitoring sites (across the five different components) were assessed at Hattah Lakes. This was despite widespread inundation from environmental watering which impeded access to a large proportion of vegetation and bird monitoring sites for much of the survey season. Vegetation condition monitoring in 2021–22 followed the same methods as during the 2020–21 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.

Reporting for the 2021–22 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.

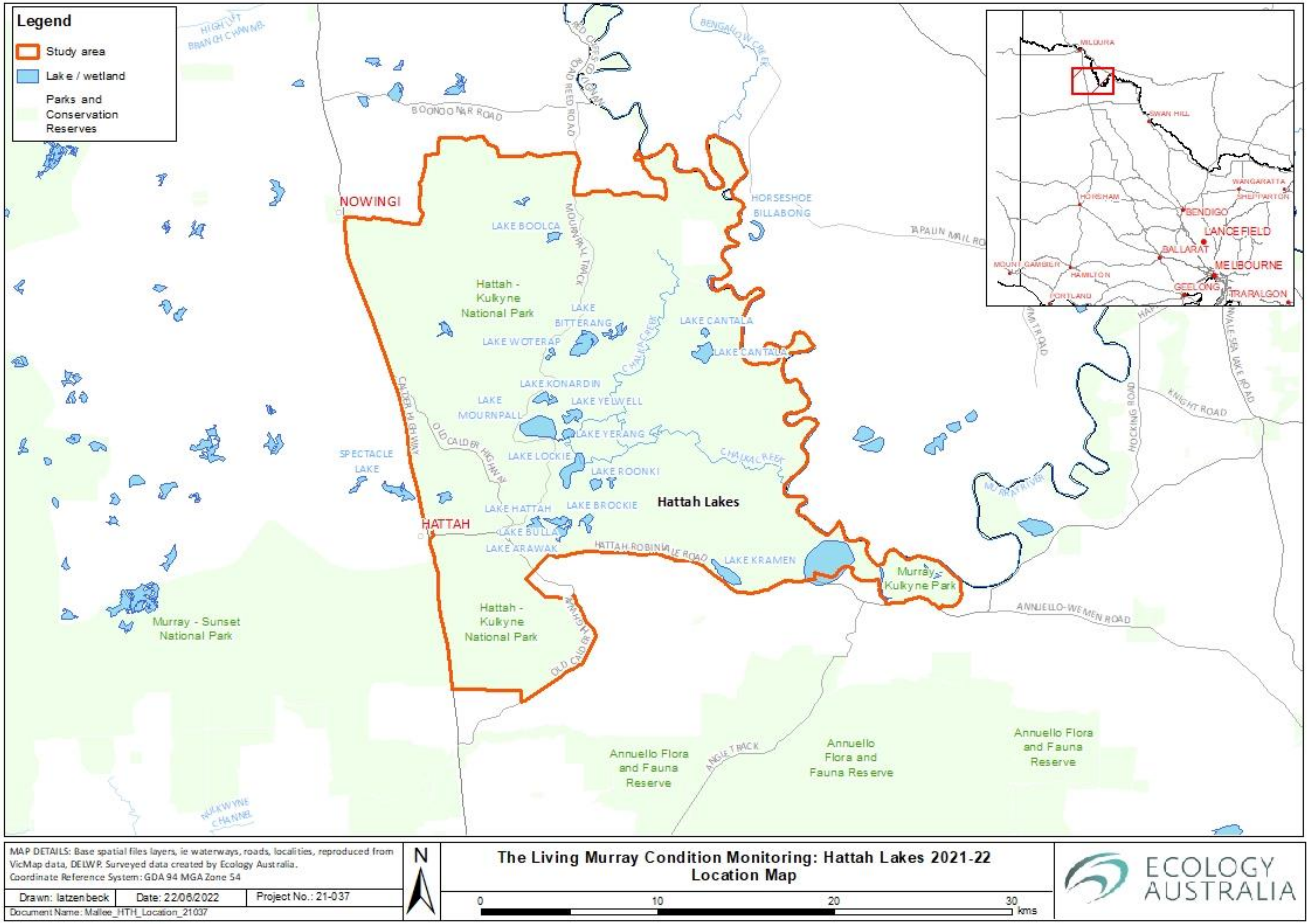


Figure 1 **Boundary of Hattah Lakes Icon Site.**

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 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 38,000 ML/d flow at Euston. 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 Living Murray program (TLM), the still height was lowered in 2013 so that flows of about 23,000 ML/d could enter the lakes. In August 2021, flows reached 23,000 ML/d at Lock 15, going on to reach a maximum of 36,125 ML/d in late November. However, due to delivery of environmental water in autumn and spring 2021, the water levels in all lakes except Lake Kramen were higher than the Murray River. Regulators were therefore kept shut to prevent loss of water throughout this period.

Chalka Creek is the main channel that delivers water through the Hattah Lakes system from the Murray River. As part of the Hattah Lakes Works and Measures Program under TLM, the sill level at the inlet to Chalka Creek was lowered. Chalka Creek now receives water in ‘natural’ flows when flow in the main channel reaches about 23,000 ML/d at Lock 15. This means that apart from the 2016 and 2021 flood events, all water delivered to the lakes has been through pumps.

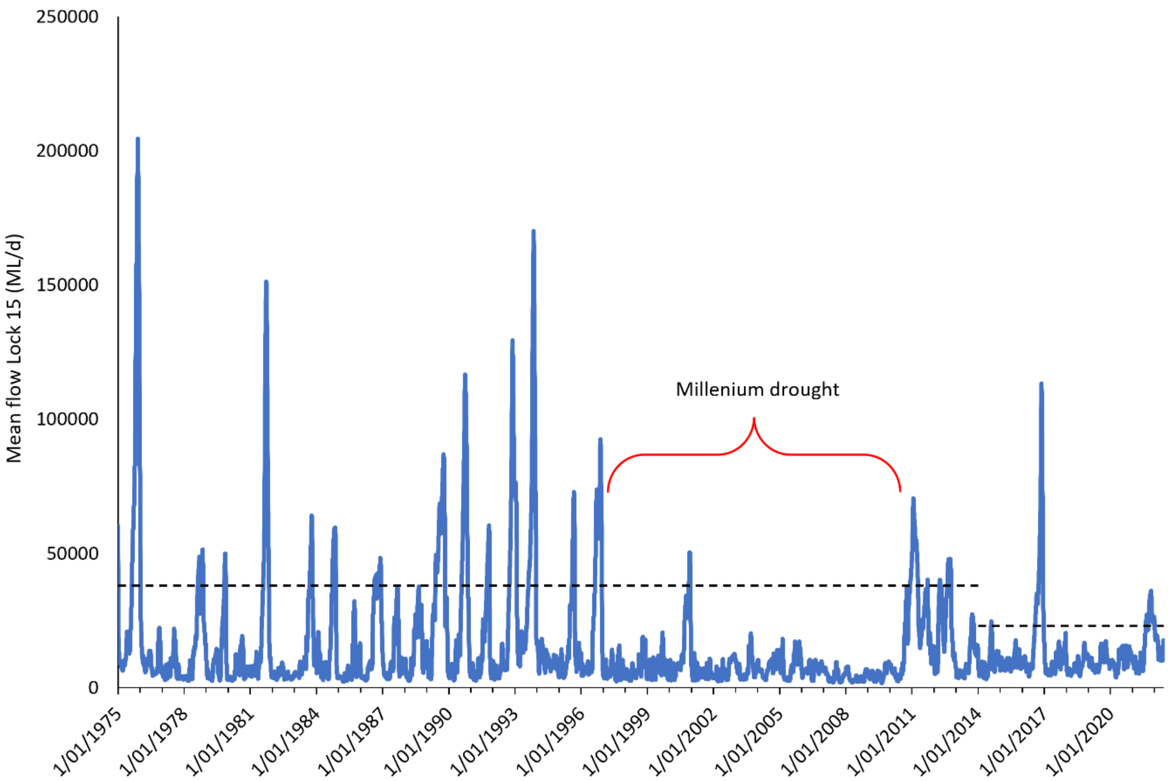


Figure 2 Mean daily discharge (ML/day) hydrograph for the Murray River downstream of the Euston Weir, 1975–2022 (source: https://livedata.mdba.gov.au/euston-weir-downstream). The Millennium Drought is outlined in red and the dashed lines represent significant flooding trigger points.

2.1.2 Wetland watering history

The first environmental water delivery took place in 2005–06, with water delivered to Lake Hattah 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 with more of the semi-permanent lakes receiving water and further water in 2009–10. The drought was eventually broken by the flood event of 2010–11, but even this did not provide large scale inundation through the lake system.

A significant change took place following the completion of TLM water delivery infrastructure. This 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. Over the last eight years, there have been four large inundation events across the floodplain, one targeting river red gum communities and three targeting black box communities on the higher terraces of the floodplain.

Environmental water was delivered prior to the 2021–22 monitoring season, in autumn 2021 (13 lakes) and spring 2021 (18 lakes) to all lakes apart from Lake Kramen. Prior to this, the last time environmental water was delivered was in November 2017, after which the lakes were left to dry.

Table 2 **The inundation history of the Hattah Lakes from 2001 to 2022 (source: MCMA). The table reflects conditions at the time of sampling (spring to autumn). 2013–14 marks the start of water delivery using the TLM water delivery infrastructure.**

Key: D =Dry, W-D = lake in drawdown (no new water delivery), W = Wet (received water), E = Environmental water used, U = Unregulated flows (‘natural’ inflows)

Site	Flow component achievement over time																				
	2001-02	2002-03	2003-04	2004-05	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
Lake Bulla	D	D	D	D	D	D	D	D	W E	W U	W-D	D	W E	W E	W-D E	W E/U	W E	W-D	W-D	D	W E
Lake Hattah	D	D	D	D	W E	W-D	D	W-D	W E	W U	W-D	D	W E	W E	W-D E	W E/U	W E	W-D	W-D	D	W E
Lake Mournpall	D	D	D	D	D	W E	D	D	W E	W U	W-D	W-D	W E	W E	W-D E	W E/U	W E	W-D	W-D	D	W E
Lake Arawak	D	D	D	D	D	W E	W-D	D	D	D	D	D	W E	W E	W-D E	W E/U	W E	W-D	D	D	W E
Lake Bitterang	D	D	D	D	D	D	D	D	D	D	D	D	W E	W E	W-D E	W E/U	W E	W-D	W-D	D	W E
Lake Brockie	D	D	D	D	D	D	D	D	D	D	D	D	W E	W E	W-D E	W E/U	W E	W-D	D	D	W E
Lake Cantala	D	D	D	D	D	D	D	D	D	D	D	D	D	W E	W-D E	W E/U	W E	W-D	W-D	D	W E
Lake Konardin	D	D	D	D	D	D	D	D	D	D	D	D	W E	W E	W-D E	W E/U	W E	W-D	D	D	W E
Lake Little Hattah	D	D	D	D	W E	W-D	D	W-D	W E	W U	W-D	D	W E	W E	W-D E	W E/U	W E	W-D	D	D	W E
Lake Nip Nip	D	D	D	D	D	D	D	D	D	D	D	D	W E	W E	W-D E	W E/U	W E	W-D	D	D	W E
Lake Tullamook	D	D	D	D	D	D	D	D	W E	W-D	D	D	W E	W E	W-D E	W E/U	W E	W-D	D	D	W E

Site	Flow component achievement over time																				
	2001-02	2002-03	2003-04	2004-05	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
Lake Yerang	D	D	D	D	D	D	D	D	D	W U	W-D	D	W E	W E	W-D E	W E/U	W E	W-D	D	D	W E
Lake Yelwell	D	D	D	D	D	D	D	D	W E	W U	W-D	D	W E	W E	W-D E	W E/U	W E	W-D	D	D	W E
Lake Boich	D	D	D	D	D	D	D	D	W E	W-D	D	D	W E	W E	W-D E	W E/U	W E	W-D	D	D	W E
Lake Lockie	D	D	D	D	W E	W E	D	W	W E	W U	W-D	D	W E	W E	W-D E	W E/U	W E	D	D	D	W E
Lake Marramook	D	D	D	D	D	W E	W-D	D	W E	W-D	D	D	W E	W E	W-D E	W E/U	W E	W-D	D	D	W E
Lake Roonki	D	D	D	D	D	D	D	D	W E	W-D	D	D	W E	W E	W-D E	W E/U	W E	W-D	D	D	W E
Lake Kramen	D	D	D	D	D	D	D	D	D	W E	W-D	W-D	D	W E	W E	W-D E	D	D	W E	W-D	D

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, duration of flood events) and antecedent conditions (e.g. time since last flood event [Nilsson and Svedmark 2002; Brock et al. 2006]). Changes to flooding regimes as a result of river regulation have substantially affected vegetation condition along the lower Murray River. In addition, the effects of river regulation have been compounded by recent drought (MCMA 2021a).

River red gums are large native trees growing to 40 m high (VicFlora 2022). 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 2022). This species is common on the floodplains of the Murray River, forming Black Box Woodland where infrequent flooding plays a major role in the recruitment of this species (MCMA 2021a). Black box provides important habitat for both arid 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 Living Murray program across the majority of The Living Murray 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 Plain (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 assess the crown extent and density of river red gum and black box populations against established targets to estimate tree condition.

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, on the basis of a determination of the condition of a representative 30 trees 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 33 transects distributed across the Icon Site (with six of these transects newly established during 2020–21 surveys). For black box, tree condition was assessed at 22 transects across Hattah, including four transects established during the 2020–21 surveys. Transects 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 transect comprised of a minimum of 30 tagged trees (individual tree waypoints can be provided). 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).

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 with a 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 'recently 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 possible) and can be replaced with a new tree.

At each transect, 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 assessing the crown of the tree for crown extent and crown density. Each measure was recorded as a percent (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 black box tree at breast height (1.3 m above the ground) (DBH) was measured to determine growth of target trees (in alternate years with river red gum condition assessments). At each site, two photos were taken from established photo points. Assessments were undertaken between November 2021 and April 2022.

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. Data is presented as the mean proportion of trees at each site within Hattah Lakes with a TCI ≥ 10. 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.

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

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 2021–22 season by the total number of live trees at the end of the previous year's sampling.

3.3 Results

3.3.1 Tree condition index

The proportion of trees with a TCI of 10 or more was calculated for each of the 22 black box and 33 river red gum Tree Condition sites within the Hattah Lakes study area. The target of 70% for black box was not met, with 56.4% of sampled trees having a TCI of 10 or more (Figure 3). This was despite an increase in the percentage of trees with a TCI score ≥10 compared with 2020–21. The target of 70% for river red gums was also not met, with 55.1% of sampled trees having a TCI of 10 or more (Figure 4). This represents the eighth consecutive year of monitoring in which the target for black box has not been met. For river red gums, this year's survey represents a marginal decline from the previous survey, when 57.1% of trees recorded a TCI greater than 10. This is the second year running that the TCI target for river red gums has not been met at Hattah Lakes.

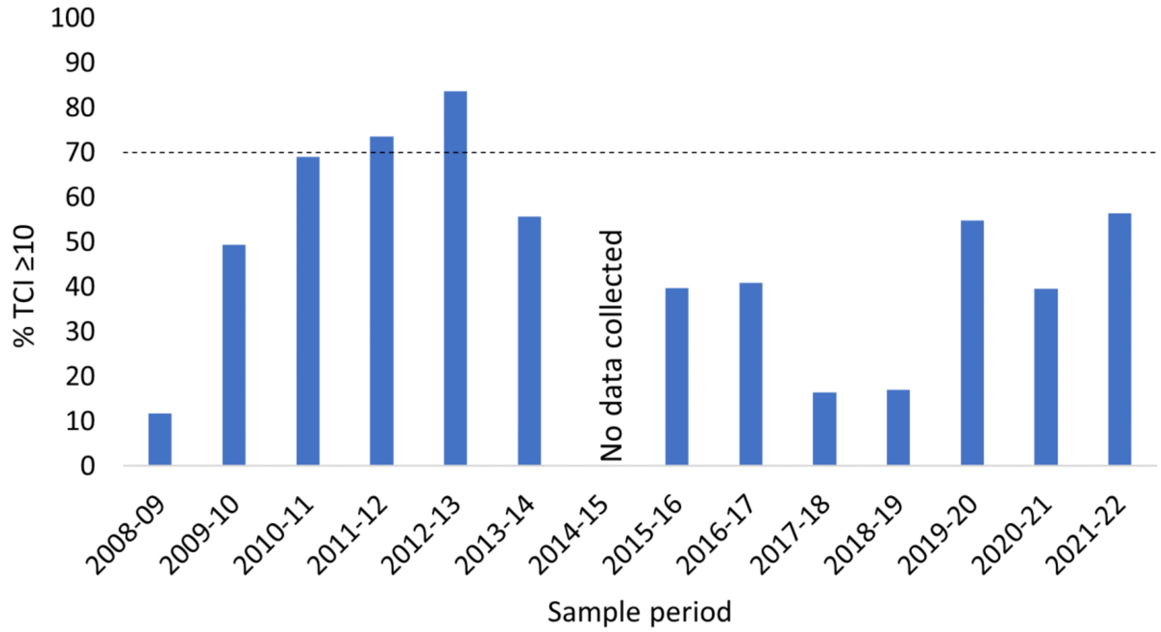


Figure 3 **Mean percentage of black box trees with TCI ≥ 10 for each survey period across the black box Tree Condition sites at Hattah Lakes. An overall target of 70% was used to determine if the Hattah Lakes black box tree population was healthy and sustainable.**

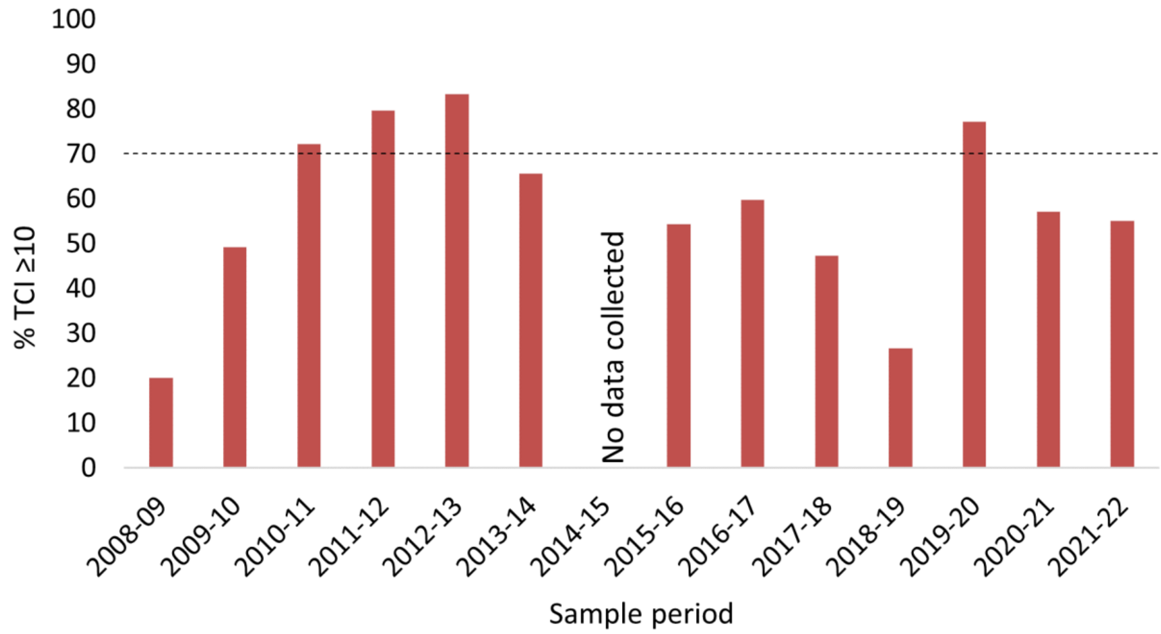


Figure 4 **Mean percentage of river red gum trees with TCI≥ 10 for each survey period across the river red gum Tree Condition sites at Hattah Lakes. An overall target of 70% was used to determine if the Hattah Lakes river red gum tree population was healthy and sustainable.**

Across both black box and river red gum sites, significant variation was present in the percent of trees with a TCI ≥10 (Table 4; Table 5; Figures 2–5, 7–9 Part B Report Palmer et al. 2022a). Across black box sites the lowest percentage of trees at a site with a TCI ≥10 was 13%, recorded at B5 H and B6 H. Conversely, 100% of trees exceeded the target at B11 H and B18 H. Scores were marginally lower for river red gum sites at Hattah Lakes, with a minimum percent TCI ≥10 of 3% at R9 H, and a maximum of only 93% at R10 H. Detailed results relating to each site are shown in the Part B report in Figures 3–6 and 9–11 (Palmer et al. 2022a).

Table 4 Percentage of live trees at each black box site with a Tree Condition Index (TCI) score ≥10, Hattah Lakes, 2021–22.

Site	% TCI ≥10
B1 H	47
B2 H	43
B3 H	73
B4 H	40
B5 H	13
B6 H	13
B7 H	60
B8 H	30
B9 H	47
B10 H	70
B11 H	100
B12 H	77
B13 H	19
B14 H	83
B15 H	87
B16 H	47
B17 H	80
B18 H	100
B19 H	33
B20 H	57
B21H	93
B22 H	27
Average across all sites:	**56**

Table 5 Percentage of live trees at each river red gum site with a Tree Condition Index (TCI) score. ≥10, Hattah Lakes, 2021–22.

Site	% TCI ≥10	Site	% TCI ≥10
R1 H	33	R18 H	29
R2 H	59	R19 H	60
R3 H	77	R20 H	87
R4 H	27	R21 H	70
R5 H	70	R22 H	27
R6 H	32	R23 H	67
R7 H	73	R24 H	43
R8 H	9	R25 H	17
R9 H	3	R26 H	90
R10 H	93	R27 H	53
R11 H	63	R28 H	63
R12 H	87	R29 H	60
R13 H	60	R30 H	60
R14 H	37	R31 H	23
R15 H	40	R32 H	90
R16 H	55	R33 H	83
R17 H	83	**Average across all sites:**	**55**

3.3.2 Tree mortality rate

In 2021–22 there were four newly dead trees across black box and river red gum condition monitoring sites at Hattah Lakes. This translates to an overall mortality rate of 0.2% across the Icon Site. A mortality rate of 0.2% was recorded for river red gums, and a mortality rate of 0.3% for black box, both well below the established target of <1% annual mortality. It should be noted, however, that these values do count trees whose mortality status was unclear as dead (i.e. trees which had recently lost all leaves and could not conclusively be called alive or dead, and thus were left in the 30 tree data set but scored with zeros for extent and density). In 2021–22 at Hattah Lakes, an example of these inconclusively dead trees was only noted from one black box transect. If these trees were presumed to be dead and included in the calculations as such, the mortality rate for black box is still maintained below the <1% target, at 0.5%.

3.4 Discussion

Tree condition increased to 56.4% of sampled black box trees with a TCI of 10 or more at Hattah Lakes in 2021-22. While this represents an increase on the previous year's results, it represents the eighth consecutive year for which the target of 70% of black box with a TCI greater than or equal to 10 has not been met. Sampled river red gums decreased marginally, from 57.1% with a score of 10 or more, to 55.1%. This is down from a large peak in 2019–20 where 77.2% achieved the target (which placed it above the ecological target for the first time since 2012–13).

Variability in tree condition from year to year can be due to a number of factors, including long- and short-term inundation histories as well as antecedent environmental conditions. However, a paucity of fine-resolution inundation data (showing changes within and between seasons) 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 Millenium 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 mean score. Access to inundation data for analysis alongside the annual tree condition monitoring results would enable further investigation to draw apart the causes of these fluctuations. This would 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, resulting in increased capacity to access water, whereas black box sites tend to occur at higher elevations and experience less frequent inundation. An exception to this was the current survey period, where black box sites recorded a higher percentage of trees with a TCI equal to or over 10 than river red gum sites. This followed an increase in black box scores compared with the previous monitoring period whilst river red gum sites recorded a marginal decrease. This may reflect the widespread environmental watering inundation as well as high rainfall in spring 2021, which may have led to a recharge of groundwater reserves at some black box sites.

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 not met, while the annual mortality target of <1% was met. As with black box, 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' is only being partially 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 2021–22

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

Persistently lower black box TCI scores, coupled with higher levels of mortality than river red gums, suggest that this species is likely not receiving the necessary flooding frequency and/or duration and depth required to flourish and sustain healthy populations at Hattah Lakes.

Across the floodplains of the Murray River, tree health is intimately associated with the timing, frequency and duration of flow events (Roberts and Marston 2011; Rogers 2011). The provision of flood history mapping across all tree condition sites 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. Furthermore, analysis of tree condition in relation to flood history would provide valuable insight into how environmental flows are influencing the long-term survival of black box and river red gum populations. 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 targeted delivery of environmental flows to address declining health of eucalypt communities.

Previous research has shown that flower production in black box is linked to improvement in canopy health (Moxham et al. 2019). Thus, consideration of indicators associated with reproductive effort (i.e. buds, flowers and fruits) in any assessment of tree condition is recommended to provide greater insight into tree condition assessments and the ability of populations to persist over time.

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 possible) and can be replaced with a new tree.

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 Living Murray 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 1 sites, including 24 river red gum transects and 9 black box transects. Population status/structure data was mostly collected in November 2021, however difficult access due to flooding meant several sites were assessed in January 2022.

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)

In 2021–22, Ecology Australia identified an error in previous analysis and presentation of data. From at least the 2018–19 report, only the 2006–07 and 2007–08 monitoring periods were lumped together, putting the subsequent three-year monitoring periods one year out of sync. This has been resolved in the current report.

Additional to this, it was identified that several sites had been assessed twice in the same three-year period, and this duplication of sites was apparently not removed from the previous analysis of these data. Duplicated sites included:

- HB-S18 in 2019–20 and 2020–21
- HR-S24 in 2009–10 and 2010–11

A decision was made to remove HB-S18 2019–20 and HR-S24 2009–10 from the analysis.

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 (2021–22) is round 1 of the 2021–24 three-year sampling period and therefore represents only approximately a third 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).

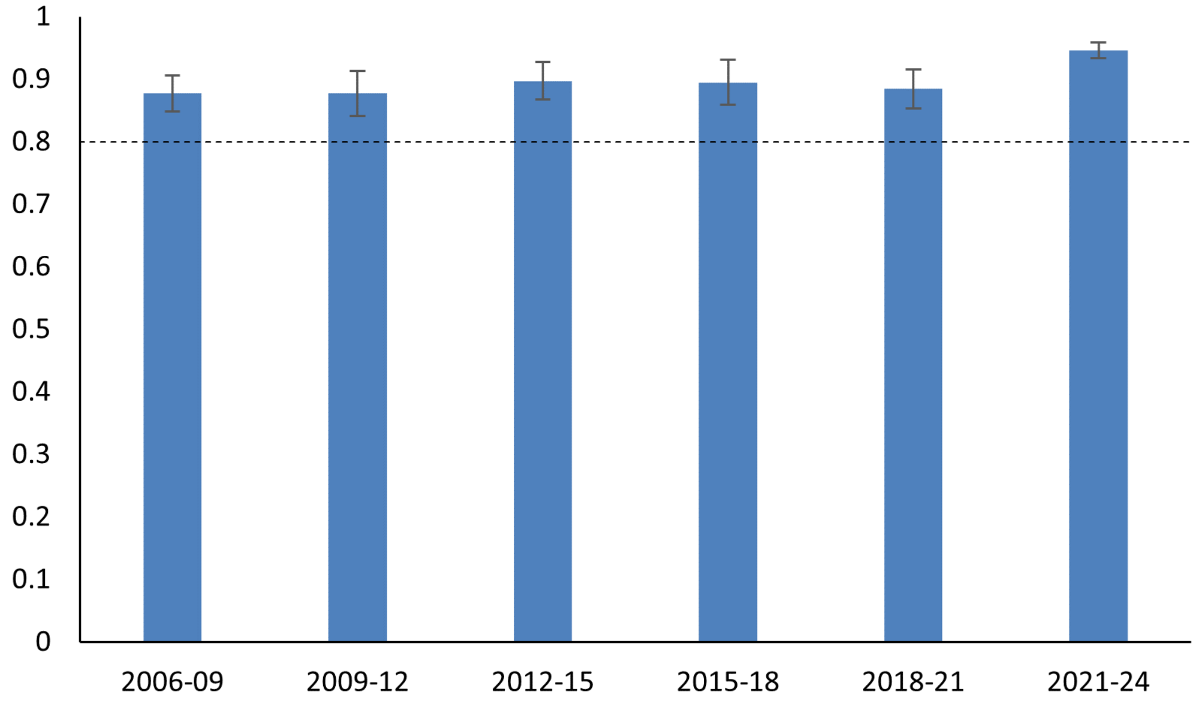


Figure 5 Mean population status index (± 95% CI) for black box at the Hattah Lakes Icon Site, based on correlation with an ideal population structure, the 'inverse J-curve'. A minimum threshold of 0.80 is set for black box at Hattah Lakes. Population status indices are pooled between WRCs in each survey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

A linear mixed effect model did not detect a significant effect of survey period on black box population status index across any three-year period ($P = 0.07$), with relatively wide confidence intervals for the amount of variation within periods (Table 7). However, the period 2021–24 has so far recorded a slightly higher standard error than all other periods, in additional to the highest index mean and upper confidence interval of all survey periods. 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	0.8502	0.03773	0.7729	0.9274
RCW	0.9114	0.03457	0.8406	0.9823
2006-09	0.837	0.03173	0.7737	0.9002
2009-12	0.8606	0.03109	0.7986	0.9226
2012-15	0.8833	0.03109	0.8213	0.9453
2015-18	0.867	0.03119	0.8048	0.9292
2018-21	0.8865	0.03068	0.8253	0.9476
2021-24	0.9505	0.0514	0.848	1.053

The total number of live black box individuals is lower than previous three-monitoring periods in all size classes (except for the 75–90 cm and 165–180 cm size classes). However, this cannot be interpreted as a decline in the total number of trees, as this monitoring period is Round 1 of the current three-year monitoring period and only a third of total sites have been assessed. Previous monitoring periods do, however, show a declining trend in the juvenile population (0–15 cm) since the 2012–15 monitoring period (Figure 6). This is mostly explained by the steep reduction in seedlings ≤1 cm DBH and more moderate decline in the 1–2 cm DBH since 2012–15 (Figure 7). The current monitoring period has shown an increase in seedlings ≤1 cm compared to the 2018–21 monitoring despite only a third of sites having been monitored.

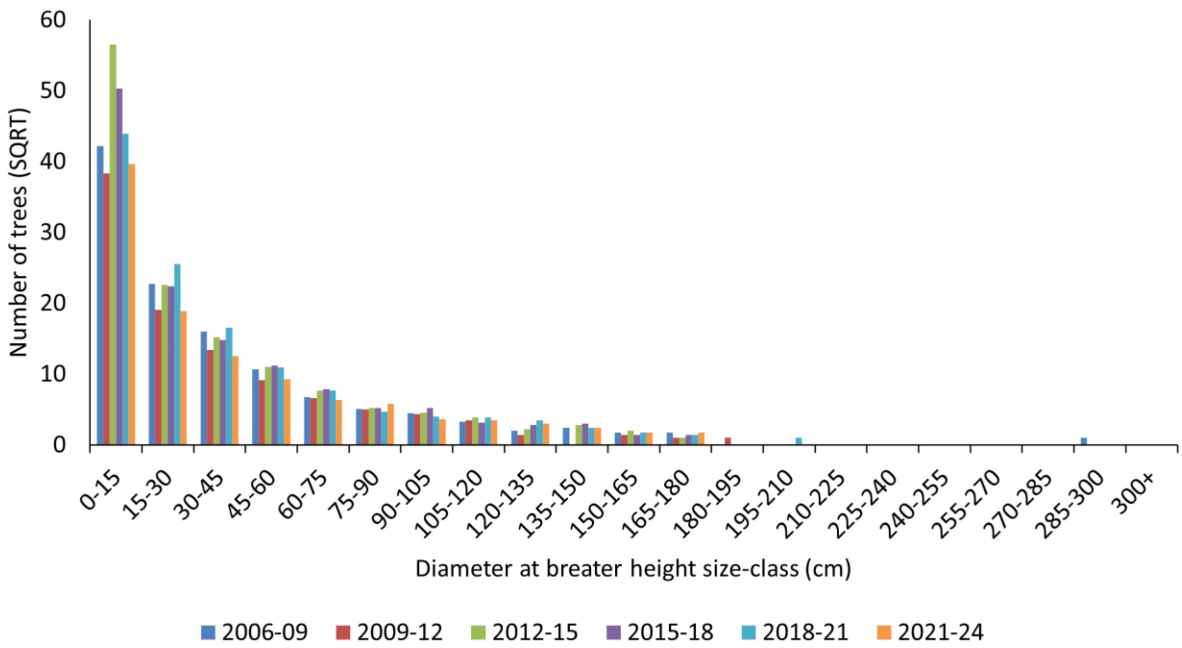


Figure 6 Frequency of black box trees (square-root transformed) for each DBH size-class (0–300+ cm) for each three-year period, pooled within the Hattah Lakes Icon Site.

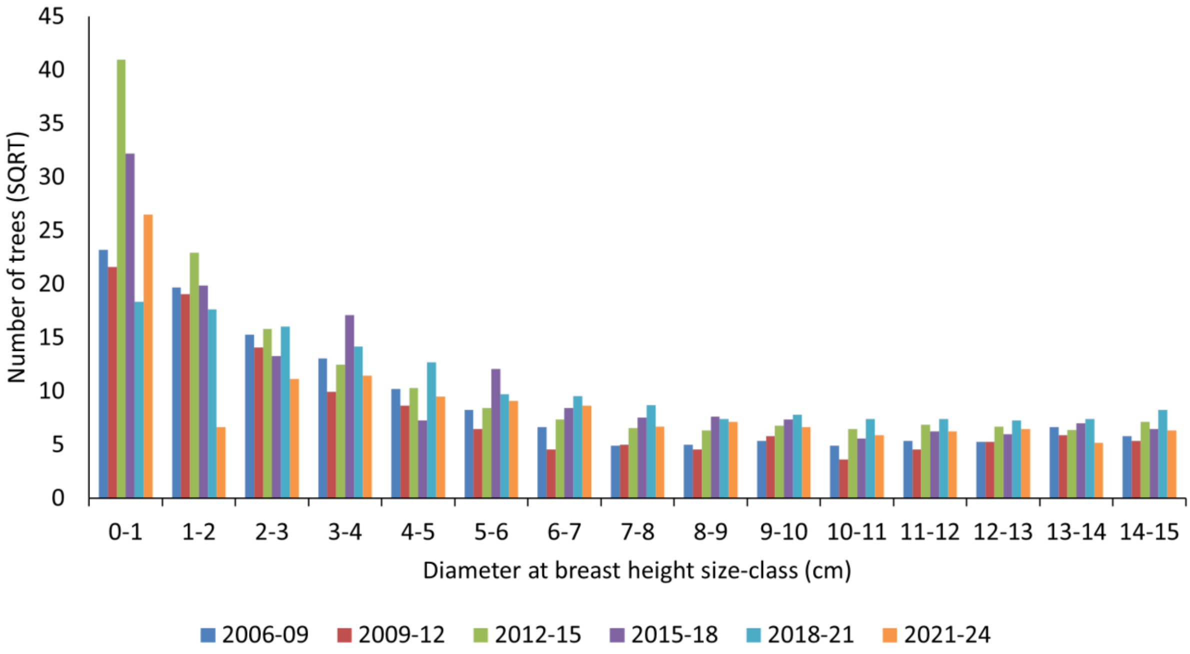


Figure 7 Frequency of black box trees (square-root transformed) for each DBH size-class (0–15 cm) for each three-year period, pooled within the Hattah Lakes Icon Site.

4.3.2 River red gum

A mean river red gum population status index of 0.93 (pooling indices between WRCs) was recorded for the current three-year period at Hattah Lakes, exceeding the minimum threshold of 0.80 (Figure 8).

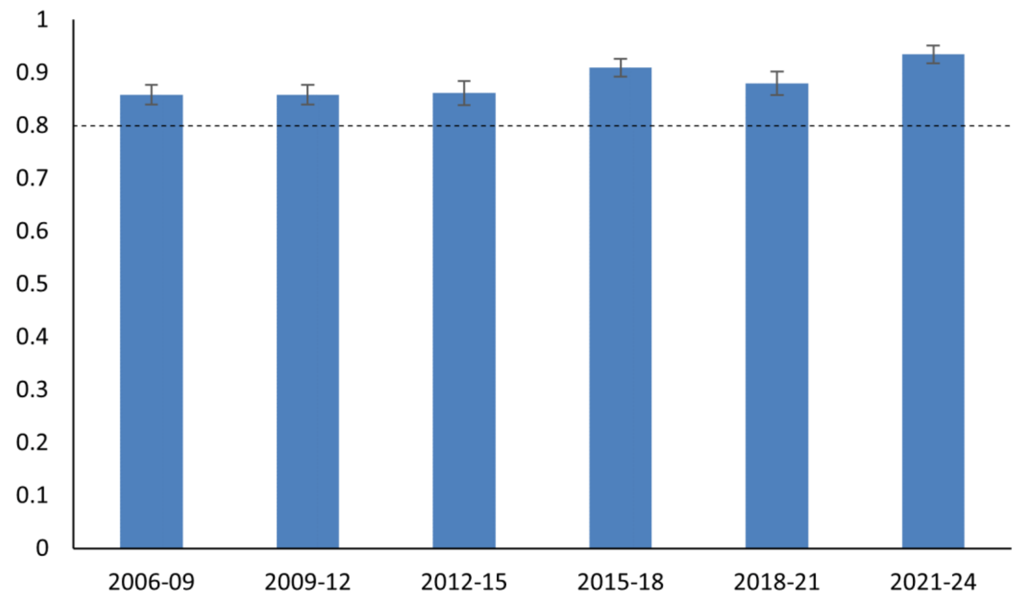


Figure 8 Mean population status index (± 95% CI) for river red gum at the Hattah Lakes Icon Site, based on correlation with an ideal population structure, the 'inverse J-curve'. A minimum threshold of 0.80 is set for black box at Hattah Lakes. Population status indices are pooled between WRCs in each 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 = 0.2), 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 (RFG) 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	0.8762	0.0195	0.8371	0.9153
RGF	0.9519	0.03153	0.8886	1.0151
RGFT	0.8386	0.02409	0.7903	0.8869
2006-09	0.8734	0.02039	0.8332	0.9137
2009-12	0.8672	0.02039	0.8269	0.9074
2012-15	0.8779	0.0203	0.8378	0.918
2015-18	0.915	0.0217	0.8721	0.9578
2018-21	0.8815	0.02006	0.8419	0.9212
2021-24	0.9183	0.0258	0.8673	0.9692

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 (Figure 9). This is almost entirely driven by a decline in the ≤1 cm seedlings (Figure 10). The majority of the juvenile size classes showed an increase in the number of individuals in the 2018–21 monitoring season compared to the previous years, while the numbers from the current period are also relatively high.

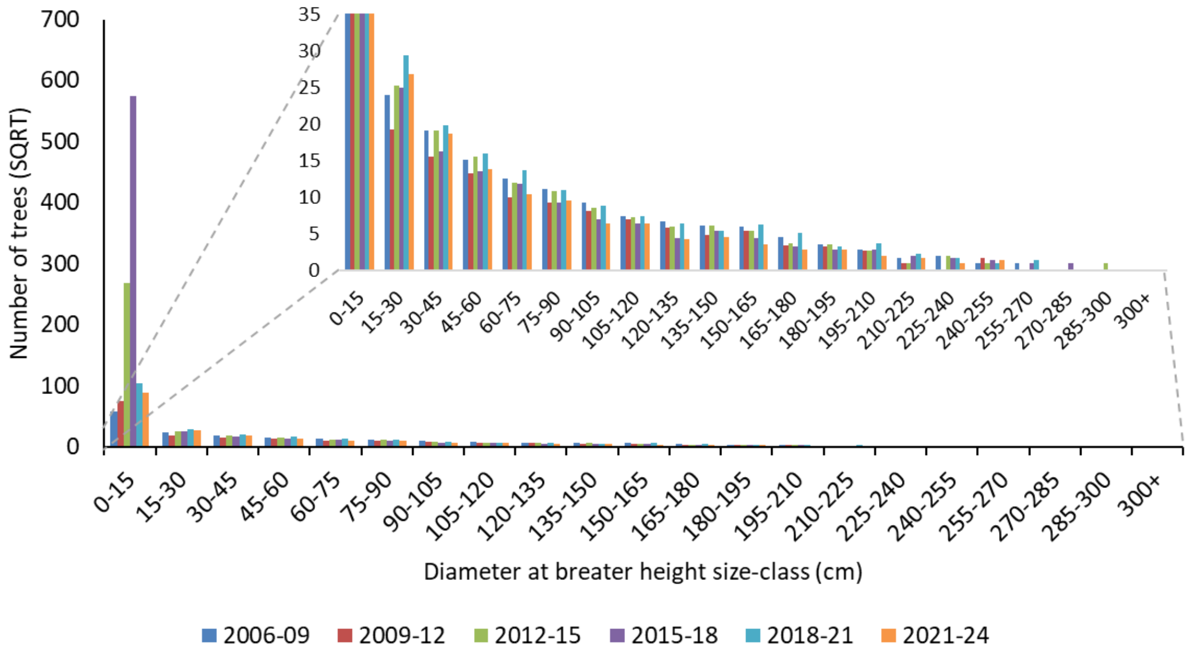


Figure 9 Frequency of river red gum trees (square-root transformed) for each DBH size-class (0–300+ cm) for each three-year period, pooled within the Hattah Lakes Icon Site.

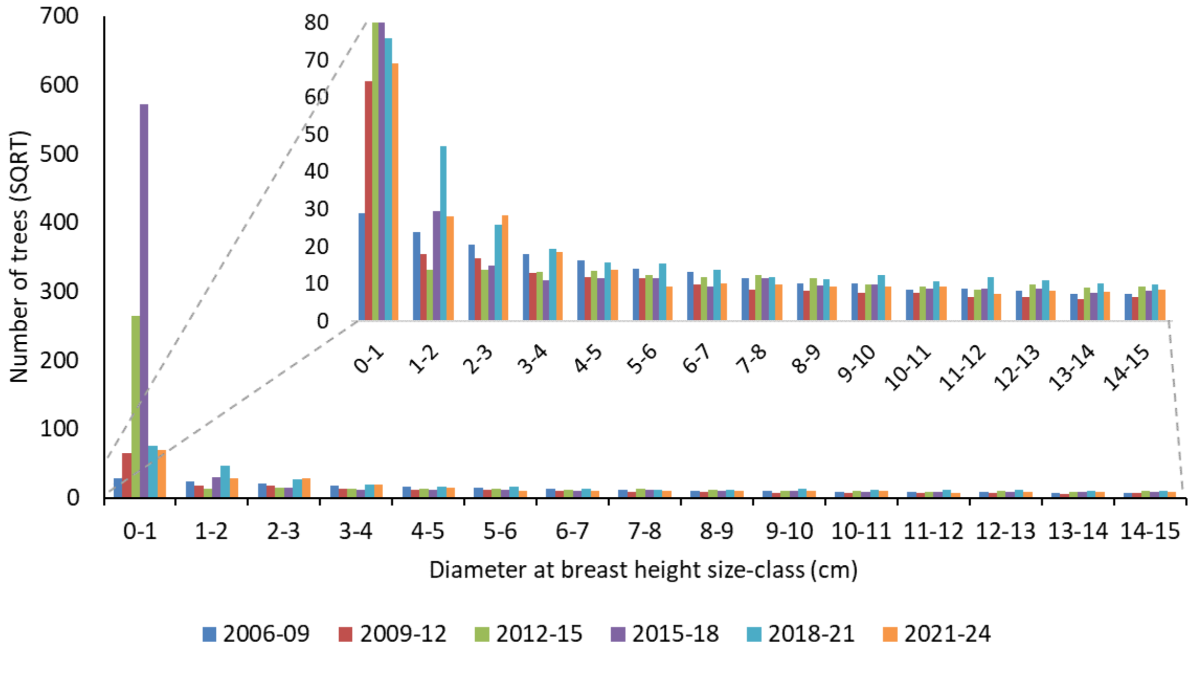


Figure 10 Frequency of river red gum trees (square-root transformed) for each DBH size-class (0–15 cm) for each three-year period, pooled within the Hattah Lakes Icon Site.

4.4 Discussion

A black box population status index of 0.95 was recorded for 2021–22, well above the minimum threshold of 0.80. 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, 48,138 GL of environmental water were delivered to Hattah Lakes between October and November 2021, and it is possible delivery of this water resulted in inundation of certain areas of black box woodland.

For red gums, a population status index of 0.93 was recorded which was also well above the minimum threshold of 0.80. Substantial red gum recruitment during the 2015–18 period was followed by a marked decline in recruitment in 2018–21. Despite only one year 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. 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 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 one year of data has 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 0.93, 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 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 2021–22.

Objective H3	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 and rainfall over the last 12 months has aided in river red gum recruitment. Inundation mapping provided by the MCMA for the 2021 spring water delivery suggests that over of 50% of river red gum structure sites may have experienced some level of inundation during the 2021-22 season.

Minimum thresholds for the whole-of-site scale indices are currently being achieved for black box and river red gums. However, for both species, considerable variability was found in population structure between survey years. This variability is likely due to a number of factors, including inundation history, past land use and current environmental conditions. Further analysis utilising inundation mapping and data on more recent environmental changes would assist in interpreting these results.

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 as a result 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 Living Murray 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 finding 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
- 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).

Data collection for this round of monitoring was undertaken in January–April 2022. 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

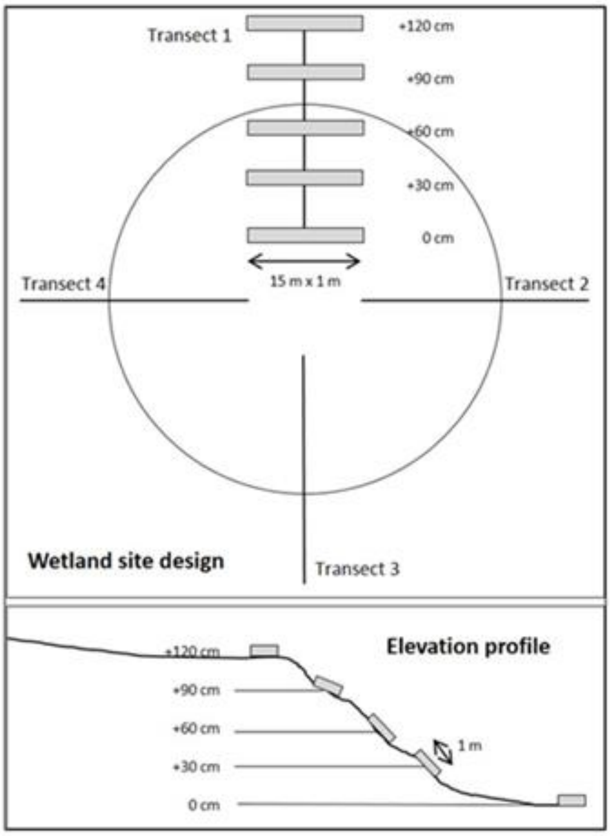


Figure 11 Schematic of the survey design used to assess wetland vegetation communities under The Living Murray program at the Hattah Lakes Icon Site (adapted from Wallace [2009] in MCMA 2022b).

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 in summer when the surveys were conducted or have been identified to genus level only due to the absence of fertile material. 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 2022). 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.

FG	Description
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.

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 13). 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 RStudio (R Core Team 2019) 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. These values 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.

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 3) 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.

Both indigenous and introduced species were included in the analysis, as both groups will respond to changes in hydrology across the wetlands.

Species composition in wetlands

The average abundance of each species at each site was calculated by finding the average abundance across all elevations within each transect and then finding the average of all transects. Species composition (species richness and abundance) was then analysed through an ordination using non-metric multidimensional scaling (NMDS) with the WRC as the factor. Vectors were fitted for the abundance of each functional group at each site. The model was estimated in R (R Core Team 2019) using the package Vegan (Oksanen 2019).

For the current survey, species richness and abundance were also presented in bar chart form for each wetland site at Hattah Lakes. In addition, the mean depth of inundation for each site (for the current survey only) was also calculated by finding the mean inundation depth across all elevations within each transect (including those where the inundation depth was 0 cms), then averaging across all transects in the wetland. This was displayed alongside the species richness and abundance values for each wetland.

5.3 Results

5.3.1 Data summary

A total of 68 vascular plant taxa were recorded from the twelve Hattah wetland sites during the 2021–22 monitoring. Of these, 59 (87%) were indigenous and nine (13%) were exotic. This represents a decrease in the number of taxa identified from the 2020–21 survey period, however an increase in the percentage of native taxa, with 77% recorded in 2020–21. Eight species listed under the *Flora and Fauna Guarantee Act 1988* (FFG Act) were recorded, which represents no change from the previous survey period. All eight species are classified as endangered under the Act. For further details on plant species recorded please refer to the 2021–2022 Part B report (Palmer et al. 2022a).

5.3.2 Point of reference assessment

Water-responsive species richness

For the second year in a row, no transects within the Semi-permanent WRC (SPW) were compliant with the native water responsive species richness index (Table 13; Figure 12). Compliance rates within the Episodic WRC (EPW) remained steady with 2020–21 levels at 50% compliant. Meanwhile, the Persistent Temporary WRC (PTW) saw an increase from no compliant transects in 2020–21 to 17% compliant in

2021–22. Across the Icon Site, compliance increased from 4% of transects (2 transects) in 2020–21, to 15% compliant in 2021–22 (7 transects). This increase is attributable to the rise in compliant transects within the PTW category (with these transects occurring within Chalka Creek and Chalka Creek North wetlands). In the previous two years transects not containing any species had not been included in analyses of proportion of transects compliant for richness and abundance, thus inflating icon site scores. This has been rectified in the current reporting and the previous two years results have been updated to reflect this.

Table 13 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 2021–22 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	5	3	0 of 12	0	0.158 (±0.074)	0 of 12	0	0.162 (±0.066)
Persistent temporary	13	8	5 of 30	0.167		4 of 30	0.133	
Episodic	2	1	2 of 4	0.5		3 of 4	0.75	

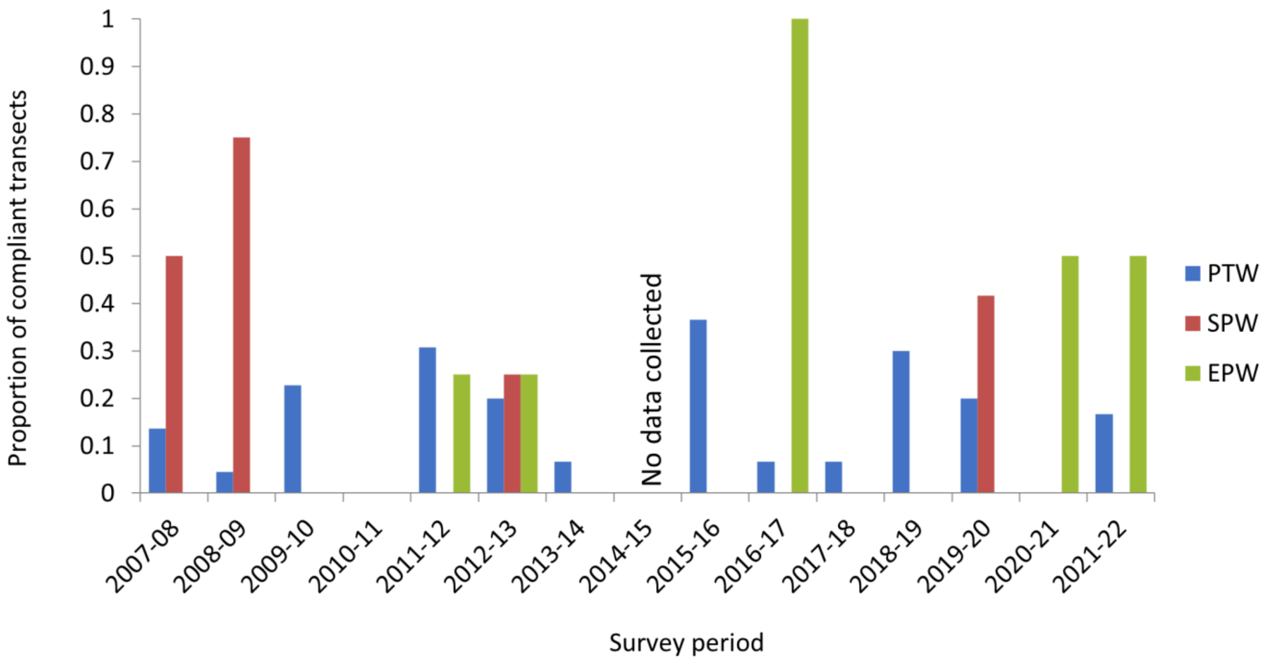


Figure 12 Proportion of transects from wetlands in WRCs at the Hattah Lakes Icon Site considered compliant with the native water-responsive species richness index (transects with a mean species richness score above the 80th percentile).

Water responsive species abundance

Trends in transect compliance rates for species abundance were similar to those found for species richness in 2021–22. As in 2020–21, no SPW sites were considered compliant in 2021–22 (Table 13; Figure 13). EPW transects compliant in terms of species abundance remained constant at 75% in 2021–22. However, PTW sites saw an increase in compliance from 7% compliant in 2020–21 to 13% compliant in 2021–22. Across the Icon Site, species abundance compliance increased from 11% (5 transects) in 2020–21 to 15% (7 transects) in 2021–22.

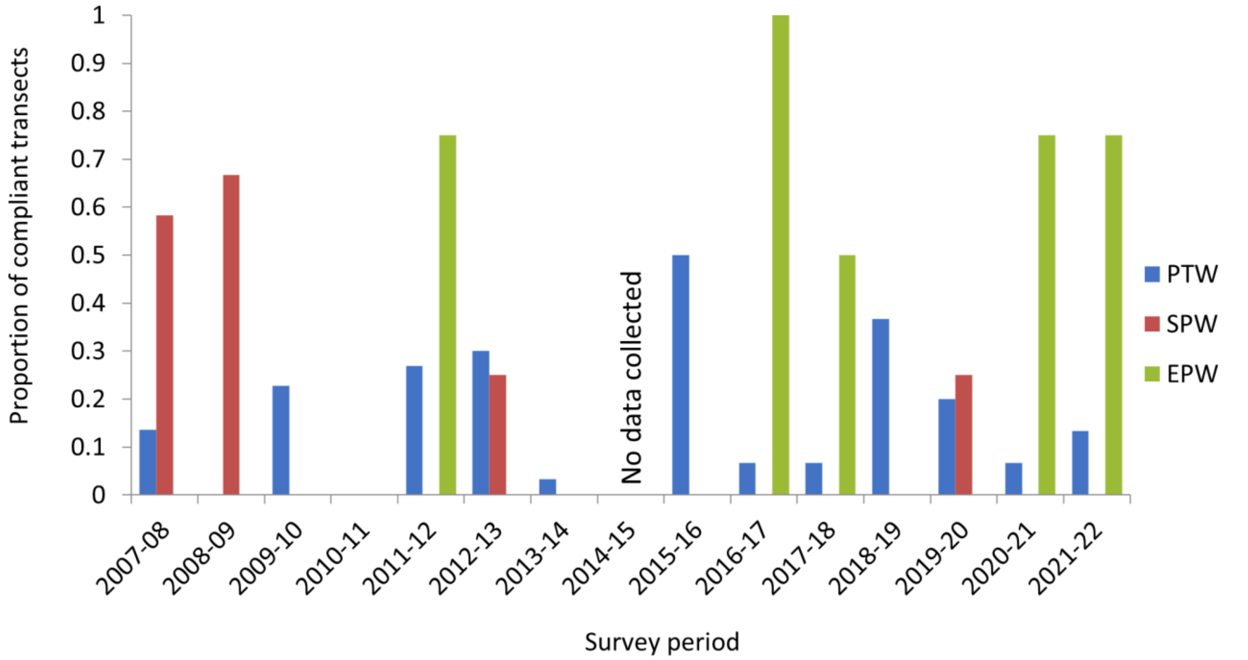


Figure 13 Proportion of transects from wetlands in WRCs at the Hattah Lakes Icon Site considered compliant with the native water-responsive species abundance index (transects with a mean species abundance score above the 80th percentile).

Whole-of-Icon site score

The proportion of transects compliant with native water-responsive species richness indices at Hattah Lakes differed across WRCs (Table 13). Transects were compliant in Persistent Temporary and Episodic WRCs, with no compliant transects in the Semi-permanent WRC. The Icon Site score for native species richness at wetlands during the current survey (0.158) was substantially higher than the score recorded in the previous survey period (0.051) (Figure 14).

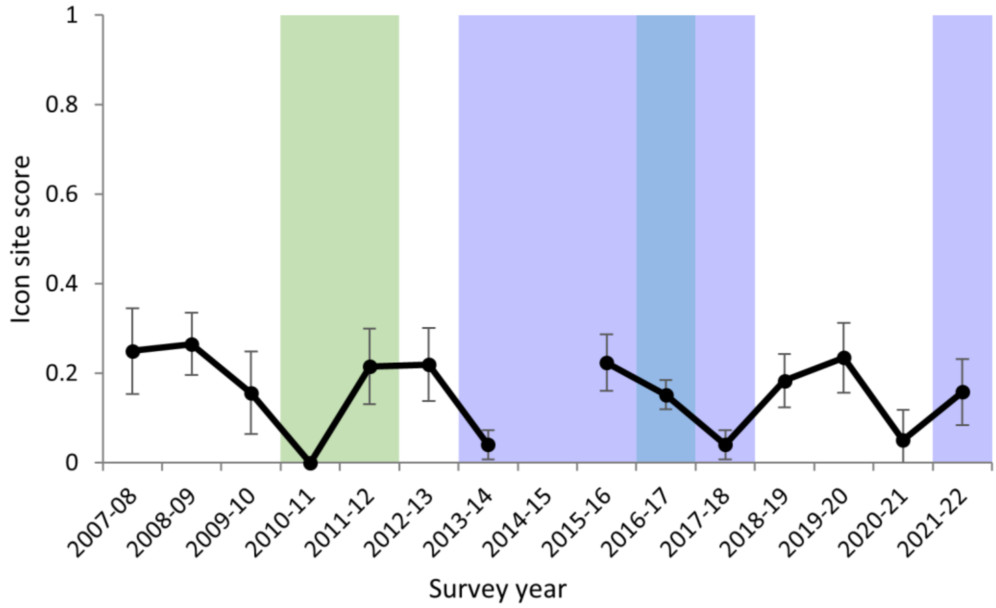


Figure 14 Icon Site scores for the Hattah Lakes Icon Site wetlands based upon native water-responsive species richness indices and weighted across each WRC (± 95% confidence intervals for two sampled comparisons with normally distributed error variance) across survey years. No data were collected in 2014–15. Water events are shaded (green: natural flooding; purple: e-water; teal: natural flooding and e-water).

Mean Icon Site species richness scores in wetlands are higher in seasons without flooding, compared to seasons with e-water events (Figure 15). Icon Site scores for wetland species richness in seasons with natural flooding and e-water were similar, with a slight increase evident in years which received both natural flooding and e-water.

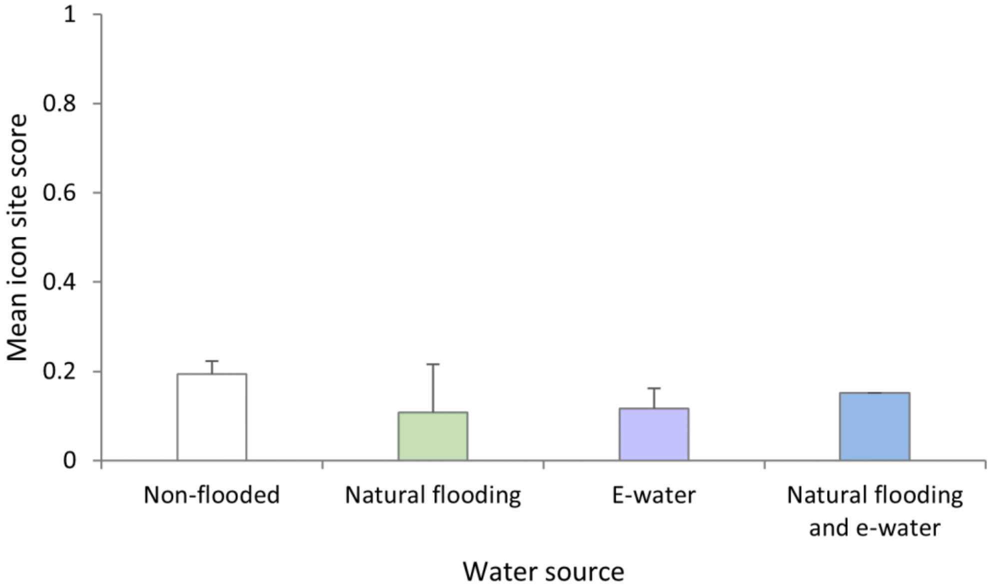


Figure 15 Mean Icon Site wetland scores based upon native water-responsive species richness indices, for the Hattah Lakes Icon Site (± standard error), for each water event type. Non-flooded years n = 7, natural flooding n = 2, e-water n = 3, natural flooding and e-water n = 2.

Similarly for native water-responsive species abundance indices, no transects were recorded as compliant at Semi-permanent Wetlands (Figure 13). Of the Persistent Temporary WRC transects, approximately 13% were recorded as compliant, an increase from 7% in the previous survey period. Consistent with the last survey period, 75% of Episodic wetland transects were compliant in the current period. The Icon Site score for native species abundance for the current survey (0.162) was higher than 2019-20 (0.120) (Figure 16).

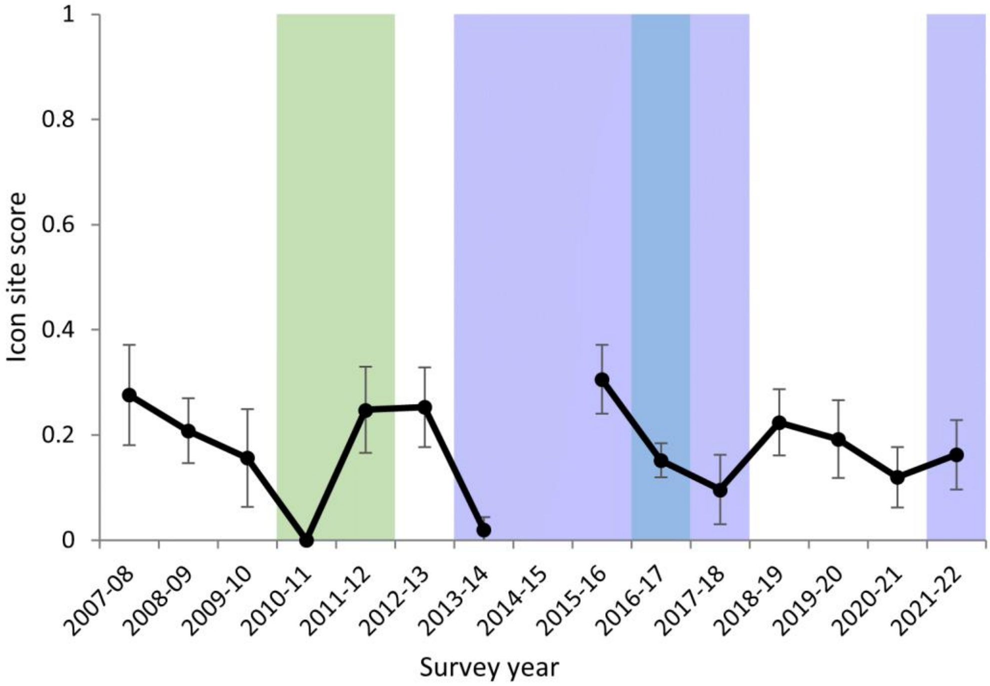


Figure 16 Icon Site scores for the Hattah Lakes Icon Site wetlands based upon native water-responsive species abundance indices and weighted across each WRC (± 95% confidence intervals for two sampled comparisons with normally distributed error variance) across survey years. No data were collected in 2014–15. Water events are shaded (green: natural flooding; purple: e-water; teal: natural flooding and e-water).

Results indicate native water-responsive species abundance Icon Site scores for wetlands at Hattah Lakes were higher in seasons without flooding, compared to seasons where wetlands received water, either naturally or through e-water events (Figure 17). The Icon Site score was similar across seasons where wetlands received water through natural flooding, e-water, or a combination of the two.

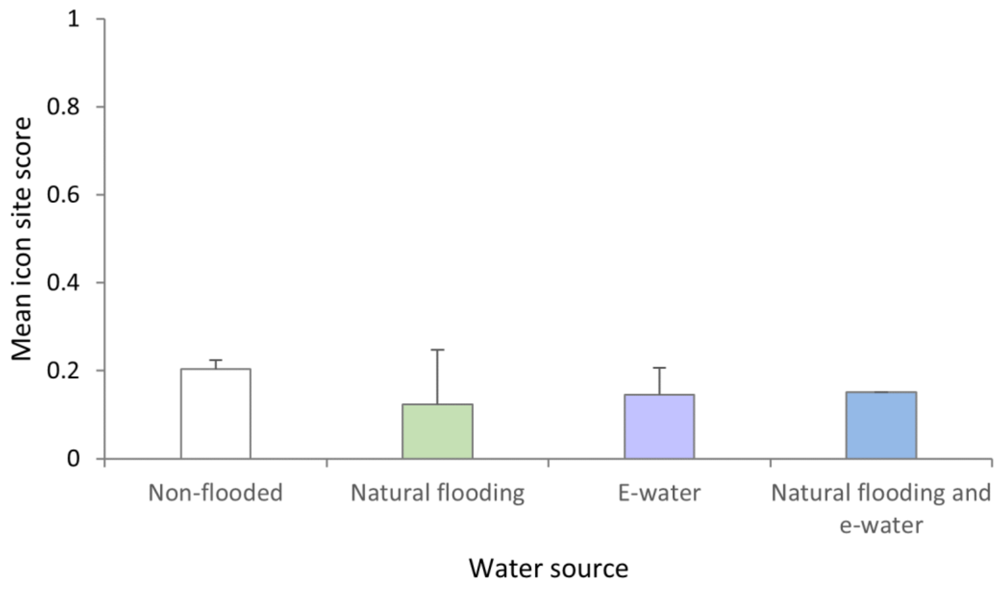


Figure 17 Mean Icon Site wetland scores based upon native water-responsive species abundance indices, for the Hattah Lakes Icon Site (± se), for each water event type. Non-flooded years n = 7, natural flooding n = 2, e-water n = 3, natural flooding and e-water n = 2.

Drought-tolerant vegetation in wetlands

The inundation of all wetlands within the SPW category has led to significant changes in functional group representation since 2020–21 (Figure 18). 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 represents a significant departure from the trend evident across the previous three years where the proportion of terrestrial dry species was increasing, alongside a concomitant decrease in the abundance of terrestrial damp species. The abundance of amphibious (A) species saw a slight decrease from the levels recorded in 2020–21, but overall this functional group has been increasing since 2018–19 levels. The lack of terrestrial species records for 2021–22 has led to a substantial increase in the proportional abundance of woody amphibious fluctuation tolerators (Atw) since 2020–21 levels, increasing from 12% to 76% (the highest abundance for this functional group within SPW wetlands since the inception of monitoring).

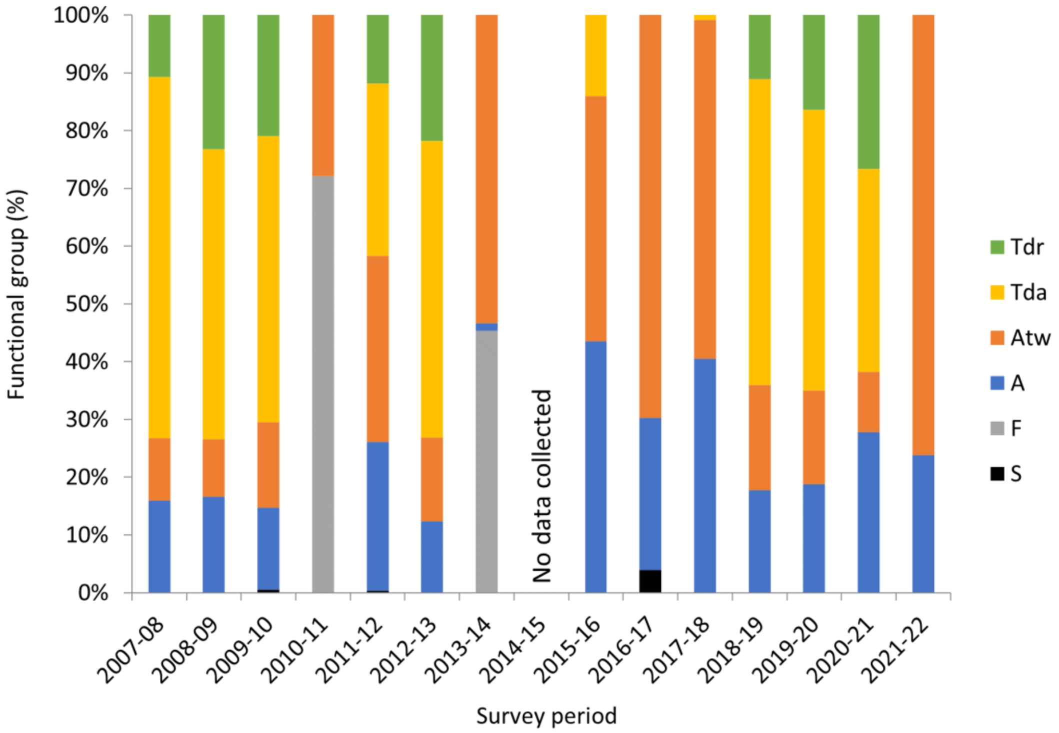


Figure 18 Semi-Permanent Wetland WRC (SPW), proportion of sum of abundance for each functional group at the Hattah Lakes Icon Sites for each survey period.

Complete or partial inundation of all wetlands across the PTW class has led to a reversal of trends towards a drought-tolerant flora which began in 2017–18 (Figure 19). The proportional abundance of terrestrial dry species decreased from 35% in 2020–21 to 15% in 2021–22. Furthermore, the abundance of amphibious species increased markedly from 6% to 27% in 2021–22. The abundance of terrestrial damp species saw a slight decrease compared with 2020–21 levels (48% down from 51% in 2020–21). Meanwhile, the abundance of woody amphibious fluctuation tolerators was maintained at 2020–21 levels at 11%.

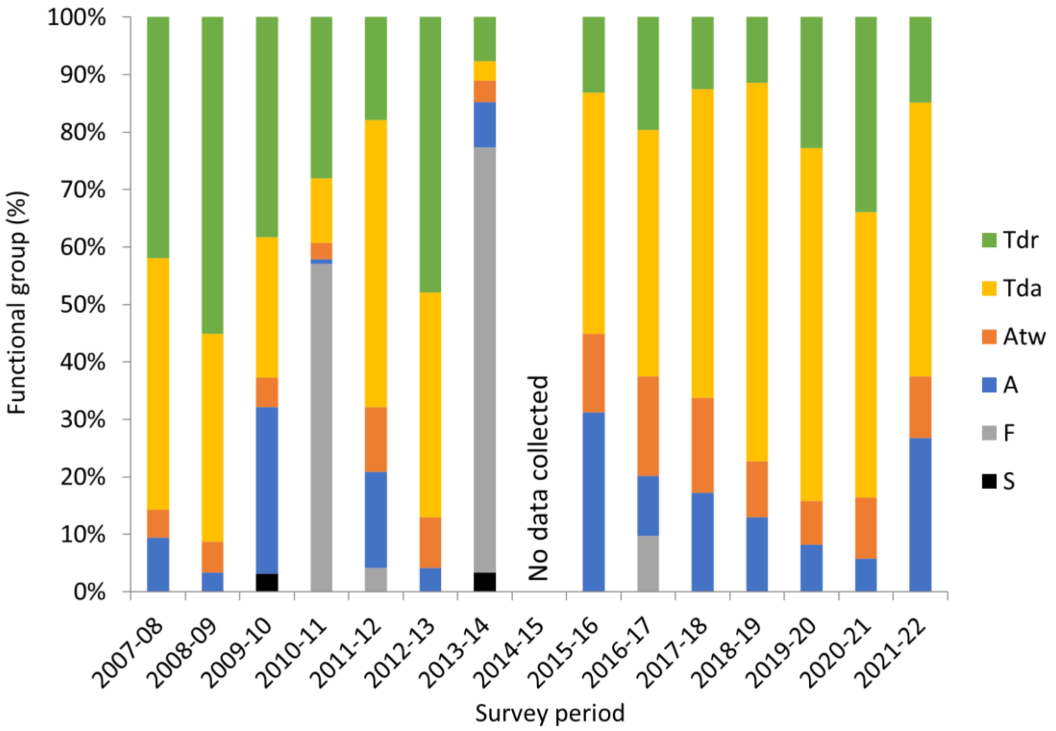


Figure 19 Persistent Temporary Wetland WRC (PTW), proportion of sum of abundance for each functional group at the Hattah Lakes Icon Sites for each survey period.

Following a drawdown of water from Lake Kramen (the only EPW site) in 2021, the proportion of terrestrial dry species saw an increase on 2020–21 levels (from 27% to 39%) (Figure 20). The proportional abundance of terrestrial damp species also increased from 46% to 52%. Meanwhile the abundance of amphibious species decreased markedly from 45% to 4%. The abundance of woody amphibious species remained constant at 5%.

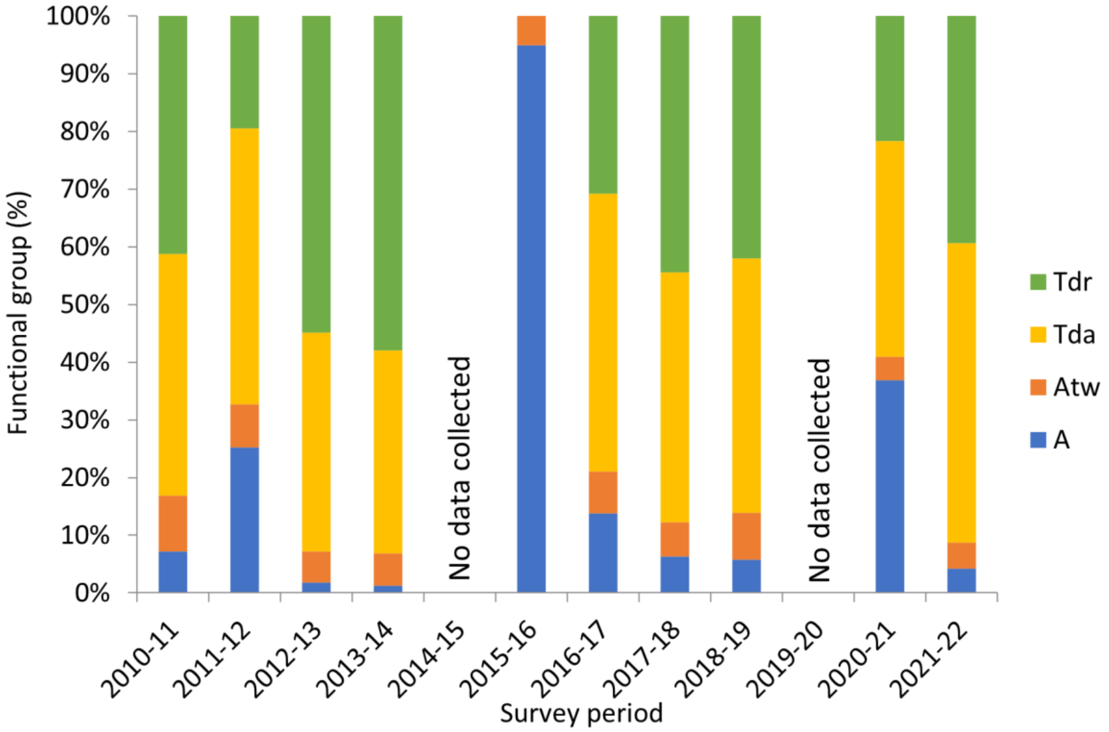


Figure 20 Episodic Wetland WRC (EPW), proportion of sum of abundance for each functional group at the Hattah Lakes Icon Sites for each survey period.

5.3.3 Species composition in wetlands

NMDS ordination revealed three highly distinct groupings of wetland sites at Hattah Lakes in 2021–22 (Figure 21). Lake Kramen exhibited a unique composition when compared with all other sites, being strongly associated with the terrestrial functional groups and a number of species therein including narrow-leaf dock *Rumex tenax*, common blown-grass *Lachnagrostis filiformis* s.s. and small knotweed *Polygonum plebium*. Due to the strong similarity of sites, total overlap occurred between Chalka Creek and Chalka Creek North, and between Lake Bitterang, Lake Bulla, Lake Brockie, Lake Hattah and Lake Mournpall. Chalka Creek and Chalka Creek North were both strongly associated with red water-milfoil *Myriophyllum verrucosum* and lesser joyweed *Alternanthera denticulata.*

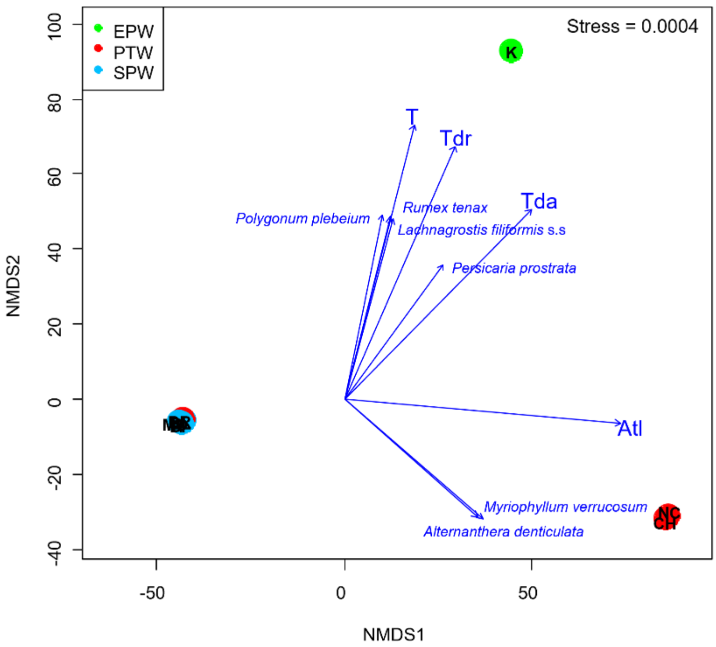


Figure 21 NMDS ordination of species composition across wetlands in Hattah Lakes for the 2021–22 season (grouped by WRC). Lines show statistically significant (P = 0.05) vectors indicating strength of association with each wetland.
WRCs: EPW; Persistent episodic wetland, PTW; Persistent temporary wetland, SPW; Semi-permanent wetland. Site Codes: BI; Lake Bitterang, BL; Lake Bulla, BR; Lake Brockie, CH; Chalka Creek, H; Lake Hattah, K; Lake Kramen, LH; Lake Little Hattah, MO; Lake Mournpall, NC; North Chalka Creek. Lake Boich, Lake Little Hattah, Lake Nip Nip and Lake Yerang have all been excluded from the ordination due to no species being recorded in 2021–22.

Lake Kramen and North Chalka Creek recorded the highest mean species richness for the 2021–22 survey season with an average of nine species per transect (Figure 22). In line with the findings from previous years, these sites were also experiencing the lowest levels of inundation of any wetlands at Hattah Lakes (with Lake Kramen completely dry and North Chalka Creek transects mostly dry). Increasing mean depth of inundation was associated with a decrease in species richness, with wetlands which were deeply inundated generally recording very low numbers of species.

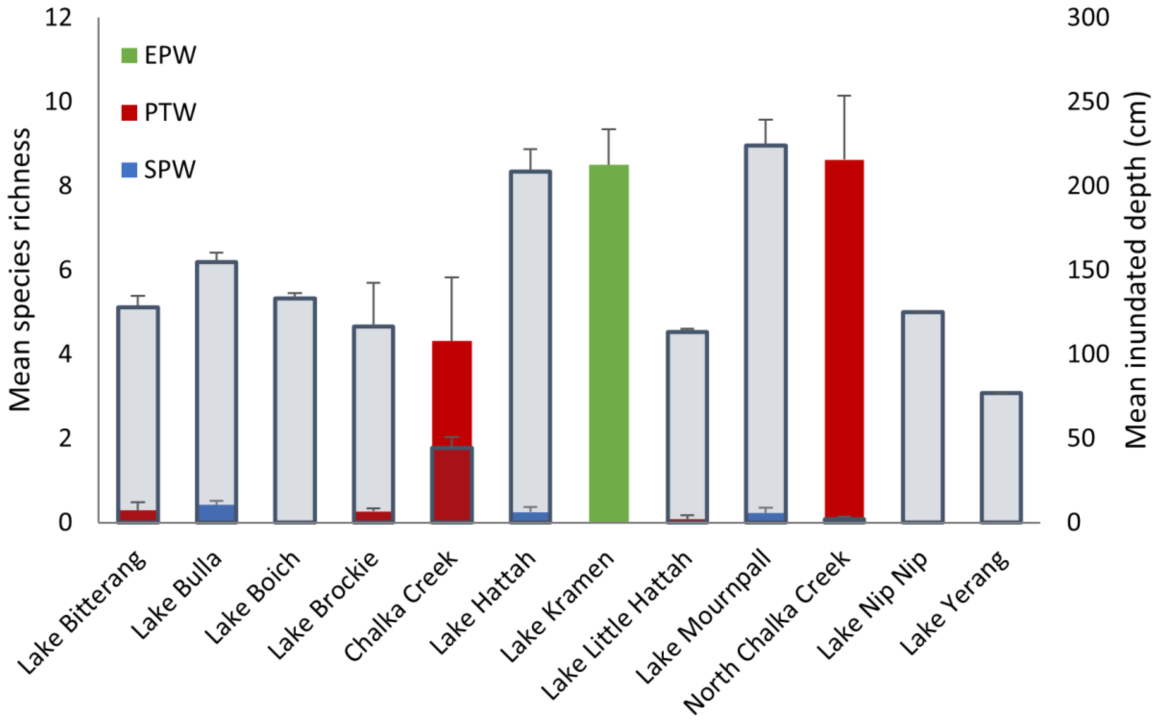


Figure 22 Mean transect species richness and mean depth of inundation (cm) (± standard error) at each wetland site in Hattah Lakes for the 2021–22 season. Mean inundation depth is shown in grey outlines. Sites are grouped by WRC: EPW; Persistent Episodic Wetland, PTW; Persistent Temporary Wetland and SPW; Semi-Permanent Wetland.

Mean species abundance followed similar trends to mean species richness, with the greatest species abundance recorded at the sites with the lowest levels of inundation (Figure 23). Species abundance was greatest at Lake Kramen, with an average of 59 records per transect. In contrast, deeply inundated sites recorded very low levels of abundance or no species at all.

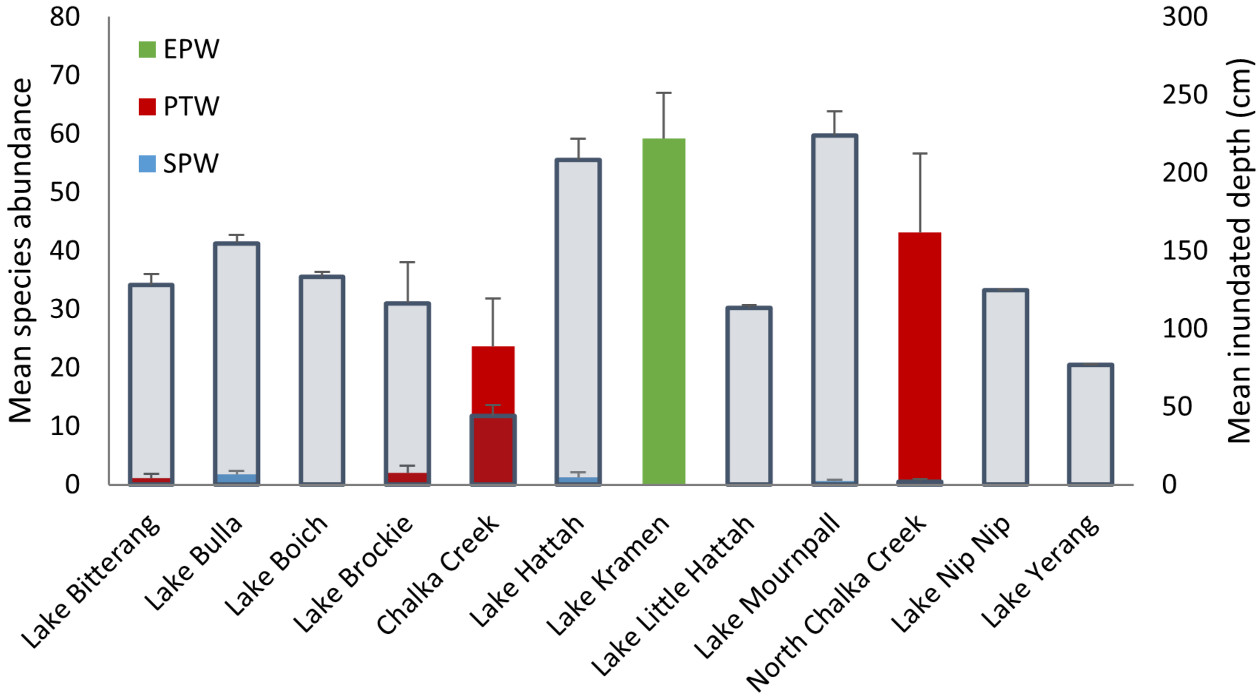


Figure 23 Mean transect species abundance and mean depth of inundation (cm) (± standard error) at each wetland site in Hattah Lakes for the 2021–22 season. Mean inundation depth is shown in grey outlines. Sites are grouped by WRC: EPW; Persistent Episodic Wetland, PTW; Persistent Temporary Wetland and SPW; Semi-Permanent Wetland.

5.4 Discussion

5.4.1 Persistent temporary wetlands

Out of the 30 transects surveyed across the Persistent Temporary Wetlands (PTW), five were compliant for water-responsive species richness. This represents a substantial increase from no compliant transects in the previous survey period, although this is a decrease since the two surveys prior to 2020–21 in 2019–20 (6) and 2018–19 (9). Similarly, a greater number of transects were compliant for species abundance in 2021–22 (4) compared to 2020–21 (2). Additionally, a proportional shift in functional groups occurred at PTW sites from a largely terrestrial dry flora dominated community to a greater number of amphibious species.

Higher water-responsive species richness and abundance at PTW sites in the current survey period, compared to 2020–21, is most likely attributed to the environmental watering received in 2021 and subsequent drawdown at some transects. This watering event facilitated the colonisation of amphibious species, with a concurrent decrease in the proportion of terrestrial dry species. Deep inundation levels at a number of PTW transects meant low numbers of species were recorded at these sites during this survey period. Higher species richness and abundance at PTW sites in 2018–19 and 2019–20 are likely a response to the natural flooding and e-water deliveries which occurred over the 2016–17 and 2017–18 seasons. The lower species richness and abundance at PTW sites in the last survey period (2020–21) is most likely a reflection of increasing time since the last significant inundation event, shifting the proportions of functional group abundances in favour of terrestrial dry genera, which can tolerate extended dry periods.

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

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 (Table 14). The three greatest inundation depths recorded during this survey period occurred at the three wetlands that comprise the SPW WRC, including Lake Hattah, Lake Mournpall and Lake Bulla. The last time any SPW sites were compliant 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 compositions occurred such that terrestrial dry species became more dominant, thus reducing water-responsive species richness and abundance.

5.4.3 Episodic wetlands

Lake Kramen is the only wetland within the Episodic Wetland group and is therefore limited in sample size. Equivalent to the last survey period, two of the four transects at Lake Kramen were found to be compliant for species richness, while three out of four were compliant for species abundance. Lake Kramen was in the drawdown phase in both this survey period and the last. The only other instances of compliance, over the duration of the monitoring program, occurred over survey periods which coincided with wetland drawdown.

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, with Lake Kramen undergoing drawdown this year while all other wetlands were inundated. Thus, a greater proportion of terrestrial dry species were 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).

Table 14 Hattah Lakes Icon Site – summary of compliant transects.

Wetland	No. of compliant transects		Potential Factors affecting compliance
	Richness	Abundance	
Persistent Temporary Wetlands			
Chalka Creek	2 of 4	2 of 4	High water-responsive species richness and abundance in non-inundated transects (+30 to +90 cm), including a high abundance of lesser joyweed.
Chalka Creek North	3 of 4	2 of 4	High water-responsive species richness and abundance in non-inundated transects (+100 to +150 cm), including a high abundance of lesser joyweed. Also a high abundance of the exotic species creeping heliotrope *Heliotropium supinum*.
Lake Bitterang	0 of 4	0 of 4	Only three emergent amphibious species present due to inundation depths, including river red gum, eumong *Acacia stenophylla* and spiny flat-sedge *Cyperus gymnocaulos* at higher elevations.
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

Wetland	No. of compliant transects		Potential Factors affecting compliance
	Richness	Abundance	
			inundation depths being too great to sustain aquatic flora at designated transects elevations.
Little Lake Hattah	0 of 4	0 of 4	No species recorded due to inundation depths being too great at designated transect elevations to sustain aquatic flora.
Lake Nip Nip	0 of 4	0 of 4	No species recorded 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 three emergent amphibious species present due to inundation depths, including river red gum, eumong and spiny flat-sedge at higher elevations.
Lake Mournpall	0 of 4	0 of 4	Only two emergent amphibious species present due to inundation depths, including river red gum and spiny flat-sedge at higher elevations.
Lake Bulla	0 of 4	0 of 4	Only two emergent amphibious species present due to inundation depths, including river red gum and eumong.
Episodic Wetlands			
Lake Kramen	2 of 4	3 of 4	High proportion of terrestrial damp and dry species compared to other sites due to the lake being the only wetland in a drying phase. Transects dominated by southern liquorice *Glycyrrhiza acanthocarpa*. Also, a high abundance of blue burr-daisy *Calotis cuneifolia* and Mallee love-grass *Eragrostis dielsii* (both terrestrial dry species) at higher elevations. A high cover of leaf litter was also recorded.

5.4.4 Whole of Icon Site

Across the whole Icon Site, 15% of transects were compliant for both water-responsive species richness and abundance. This represents an increase in compliance from the last survey period, from 9% species richness and 14% species abundance. This overall increase in species richness is likely attributed to the inundation and drawdown of wetlands during this survey period. The less pronounced increase in species abundance is likely owing to the volume of water in most wetlands surveyed in 2021–22, with recorded water levels at many transects too deep to sustain aquatic flora. Thus, opportunities for population growth are limited to higher elevation transects at inundated sites. 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 in the next round of monitoring.

5.5 Objectives and target attainment

The Icon Site score for native water-responsive species richness at wetlands during the current survey was substantially higher than the score recorded in the previous survey. The Icon Site score for native water-responsive species abundance was also higher in this survey period than the last. 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.

Increases were found in the percentage of compliant site for species richness and abundance at PTW sites while no decreases were recorded. This suggests 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'.

Table 15 Summary of Hattah Lakes wetland target attainment in 2021–22.

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			
• 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			
Species abundance			

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**
• 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			

5.6 Recommendations

Conclusively establishing whether or not ecological objectives have been met at a whole-of-site scale is problematic. Tracking changes in water-responsive species richness and abundance across regular yearly intervals allows the identification of how wetlands respond to fluctuations in wetting and drying cycles and helps to identify patterns and make inferences about when water-responsive species richness and abundance are likely to be maintained at the most productive levels. However, it does not accurately allow the comparison of more detailed changes in the state of vegetation communities across time, due to short-term fluctuations in climatic variables. In order to gauge these changes, spatial and temporal heterogeneity must be incorporated into the monitoring regime.

Wetland vegetation in arid and semi-arid regions such as Hattah is highly dynamic and tends to respond rapidly to watering and drying events across different temporal and spatial scales (Capon 2003). This often results in rapid shifts in species composition (richness and abundance) and structure. Static indices based on thresholds do not take into account these temporary responses to climatic events. One way to overcome this would be to assess changes in species richness and abundance during the same wetting/drying cycles.

In addition, individual wetlands within a particular area such as Hattah Lakes display a high level of spatial variability, consisting of flood-dependant vegetation that changes with the topography of the landscape. This spatial heterogeneity can contribute significantly to distinct differences in species composition between individual wetland sites, as well as between water regime classes.

To better understand and determine the trajectories of wetland vegetation and support complex adaptive management decisions, we recommend taking into consideration the spatial and temporal complexity inherent in wetlands when developing ecological objectives for wetlands, rather than relying on static indices of species richness and abundance. In addition, comparisons should be made between years for sites in the same stage of wetting and drying to aid in making inferences about the overall trajectory of species richness and abundance across years.

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 in order 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 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 2021–2022 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 Table 1. 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 16).

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 April 2021 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 16 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 24). 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.

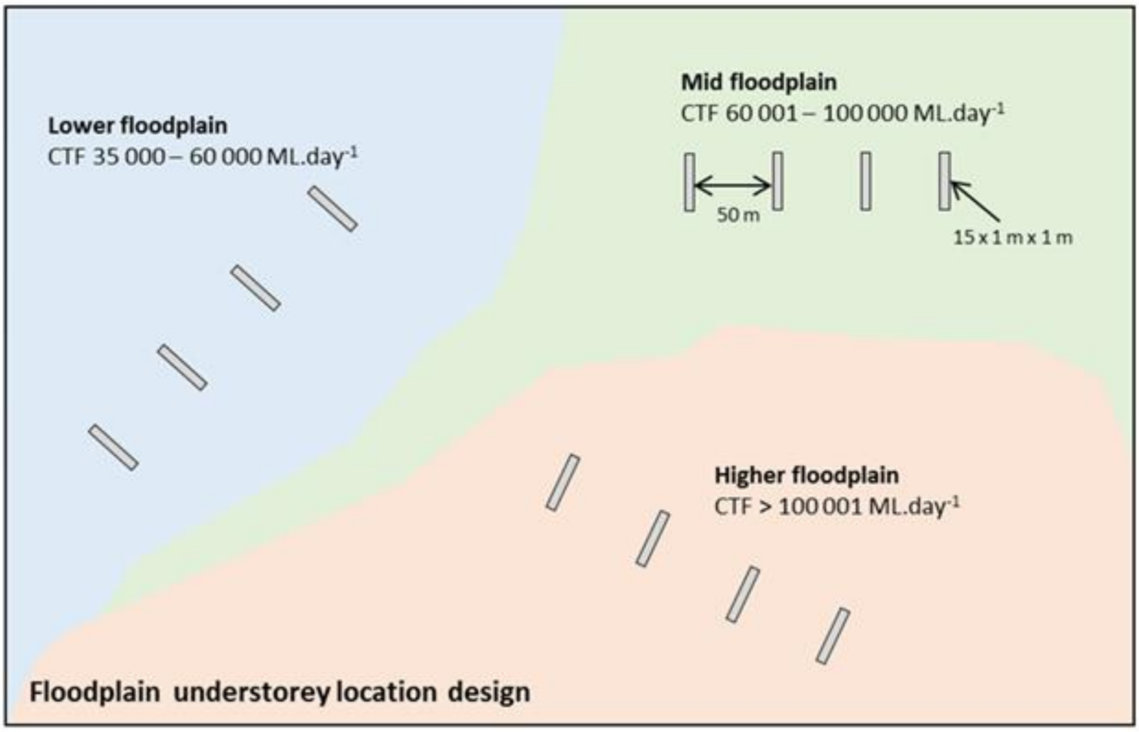


Figure 24 Schematic of the survey design used to assess floodplain understorey vegetation communities under The Living Murray program at the Hattah Lakes Icon Site (Huntley et al. 2016).

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 17). 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 17 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 (Index 1 in Table 4.2) 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.

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 RStudio (R Core Team 2019) 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). Scores were plotted as a time series to examine the effect watering events have had on the richness and abundance of water responsive species at an Icon Site scale. The source and categories of watering events at Hattah Lakes were taken from MDBA (2018).

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. 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.

Species composition on the floodplains

The average abundance of each species at each site was calculated by finding the average across all four transects within each FRF. Species composition (species richness and abundance) was then analysed through an ordination using non-metric multidimensional scaling (NMDS). Vectors were fitted for the abundance of each functional group at each site. Floodplain sites were grouped based on the FRF in which they occurred. The model was estimated in R (R Core Team 2019) using the package Vegan (Oksanen 2019). Species richness and abundance were also presented in bar chart form for each floodplain site at Hattah Lakes.

6.3 Results

6.3.1 Data summary

A total of 121 vascular plant taxa were recorded from the six Hattah floodplain sites during the 2021–22 monitoring. Of these, 108 (89%) were indigenous and 13 (11%) were exotic. This represents a substantial increase in the number of taxa identified during the 2021–21 survey period (77 taxa), however a slight decrease in the percentage of native taxa was recorded from the last survey period (92%). Thirteen species listed under the *Flora and Fauna Guarantee Act 1988* (FFG Act) were recorded, an increase from 11 in the previous survey period. Of the 13 species listed, 11 were classified as endangered and two were vulnerable. For further details on plant species recorded please refer to the 2021–2022 Part B report (Palmer et al. 2022a).

6.3.2 Point of reference assessment

Water-responsive species richness

Table 18 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 2021–22 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.

Water regime class (WRC)	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	2 of 6	0.333	0.542 (±0.529)	2 of 6	0.333	0.229 (±0.430)
Mid floodplain (sometimes)	3969.81	0.036	2 of 6	0.333		2 of 6	0.333	
Higher floodplain (rarely)	18870.03	0.03	3 of 5	0.6		1 of 5	0.2	

The proportion of compliant transects increased across all FRFs in 2021–22 (Table 18; Figure 25). The rarely-flooded sites saw the greatest increase in compliance rates, increasing from 20% in 2020–21 to 60% in 2021–22. The often and sometimes-flooded sites also saw 33% increases in compliance, up from no compliant sites in 2020–21. In the previous two years transects not containing any species had not been included in analyses of proportion of transects compliant for richness and abundance, thus inflating icon site scores. This has been rectified in the current reporting and the previous two years results have been updated to reflect this.

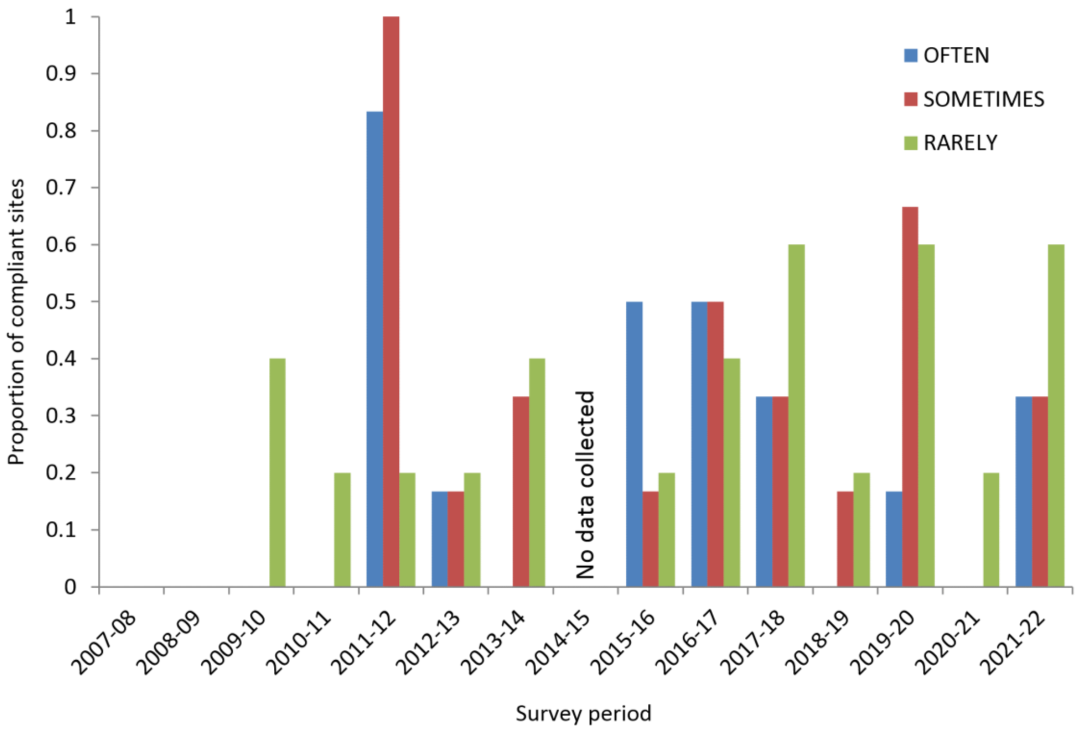


Figure 25 Proportion of compliant sites within each FRF at the Hattah Lakes Icon Site with native water-responsive species richness at or above the 80th percentile, across years.

Water-responsive species abundance

Despite large increases in species richness compliance rates across rarely-flooded sites, there was no change in the proportion of sites compliant in terms of species abundance when compared with 2020–21 (Figure 26). Compliance rates for species abundance at rarely-flooded sites has stayed constant at this level since 2018–19, despite larger fluctuations in compliance rates for the often and sometimes-flooded sites. The often and sometimes-flooded sites both saw 33% increases in the proportion of compliant sites when compared with 2020–21 where no sites were compliant.

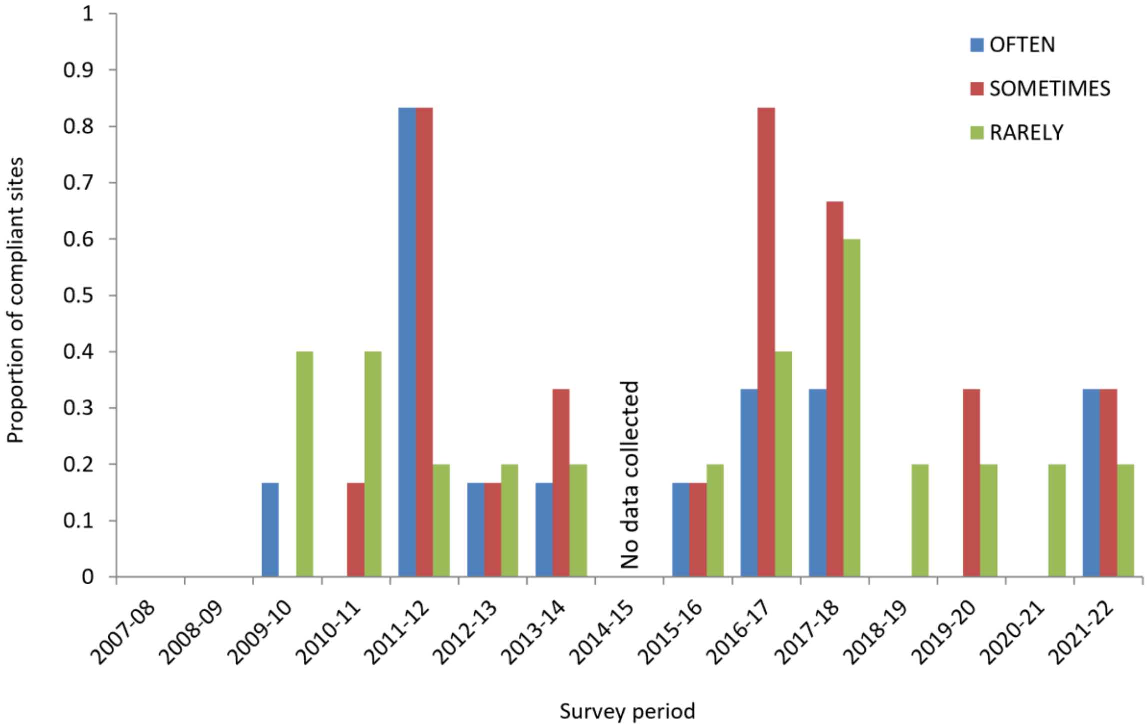


Figure 26 Proportion of compliant sites within each FRF at the Hattah Lakes Icon Site with native water-responsive species abundance at or above the 80th percentile, across years.

Whole-of-Icon Site score

Of the 17 floodplain sites surveyed across Hattah lakes, seven were compliant in terms of water-responsive species richness, a substantial increase from two in the previous survey period (Table 18). Correspondingly, the Icon Site score for native species richness on floodplains has increased markedly from 2020–21 (0.542 in 2021–22 and 0.157 in 2020–21) and is one of the highest scores recorded since the start of the monitoring program (Figure 27).

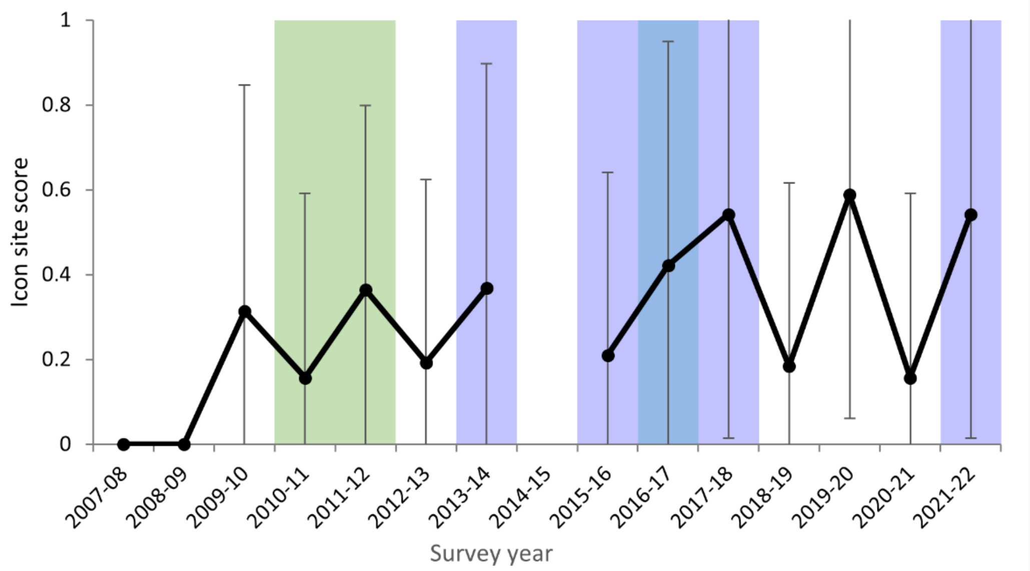


Figure 27 Icon Site scores for the Hattah Lakes Icon Site floodplains based on native water-responsive species richness indices and weighted across each FRF (± 95% confidence intervals for two sampled comparisons with normally distributed error variance) across survey years. No data were collected in 2014–15. Water events are shaded (green: natural flooding; purple: e-water; teal: natural flooding and e-water). NB: While e-watering occurred at Hattah lakes in 2014–15, this would not have reached the floodplain. Environmental water reached four of six sites in 2021-22.

Seasons that received natural flooding, e-water events, or a combination of the two, had a higher mean Icon Site score for water-responsive species richness than those that received no water. Survey periods that received either natural flooding and e-water or e-water events alone had the greatest mean Icon Site scores (Figure 28). Anomalous data collected in 2019–20, which resulted in a high Icon Site score during a non-flooded season, has skewed the data such that the mean Icon Site score for non-flooded years appears greater than it otherwise would.

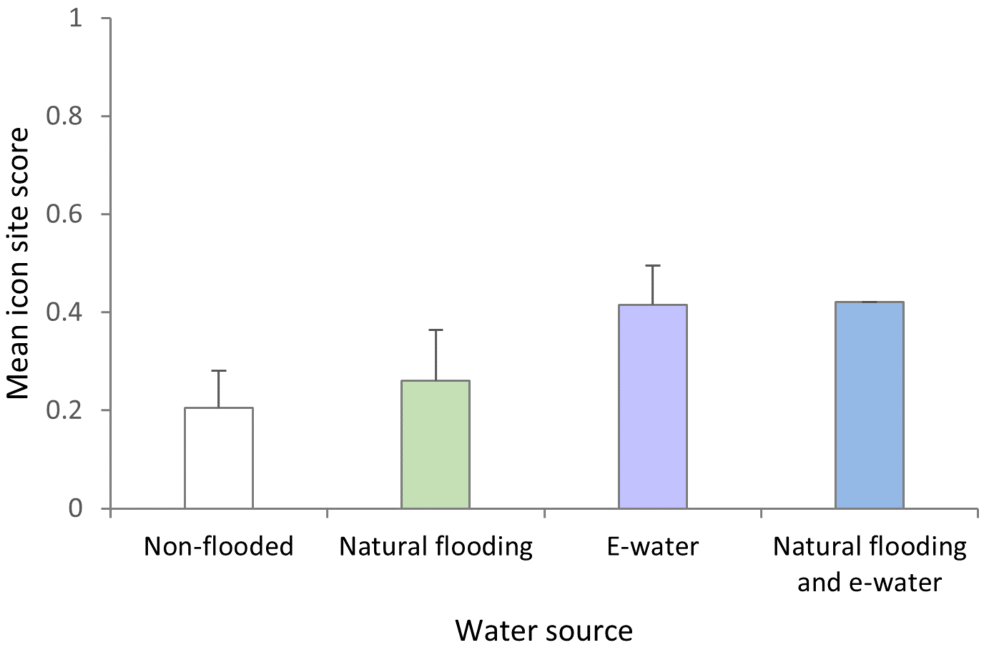


Figure 28 Mean Icon Site floodplain scores based upon native water-responsive species richness indices, for the Hattah Lakes Icon Site (± standard error), for each water event type. Non-flooded years n = 7, natural flooding n = 2, e-water n = 3, natural flooding and e-water n = 2.

Of the seventeen Hattah Lakes Icon Sites assessed in 2021–22, five were compliant in terms of water-responsive species abundance, an increase from one in 2020–21 (Table 18). Correspondingly, the Icon Site score has increased since the last survey period (0.229 in 2021–22 and 0.157 in 2020–21), however is still considerably lower than the survey period assessed during the last natural flooding and e-water event in 2016–17 (Figure 29).

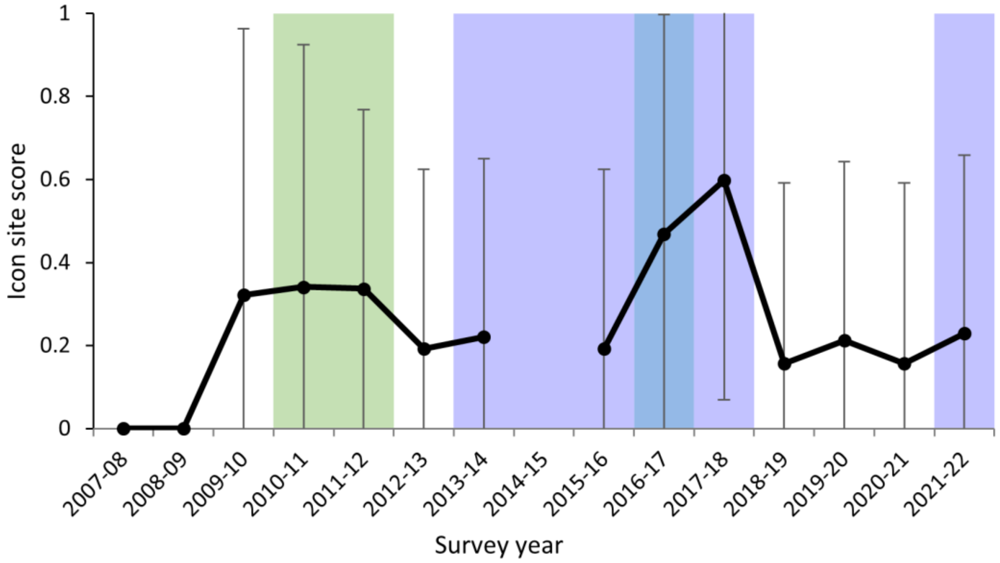


Figure 29 Icon Site scores for the Hattah Lakes Icon Site floodplains based on native water-responsive species abundance indices and weighted across each FRF (± 95% confidence intervals for two sampled comparisons with normally distributed error variance) across survey years. No data were collected in 2014–15. Water events are shaded (green: natural flooding; purple: e-water; teal: natural flooding and e-water). While e-watering occurred at Hattah lakes in 2014–15, this would not have reached the floodplain.

Mean Icon Site scores for water-responsive species abundance at the Hattah Lakes floodplain sites are greater across years that received water, either from natural flooding or e-water events (Figure 30). Survey periods which received both natural flooding and e-water had the greatest mean Icon Site score.

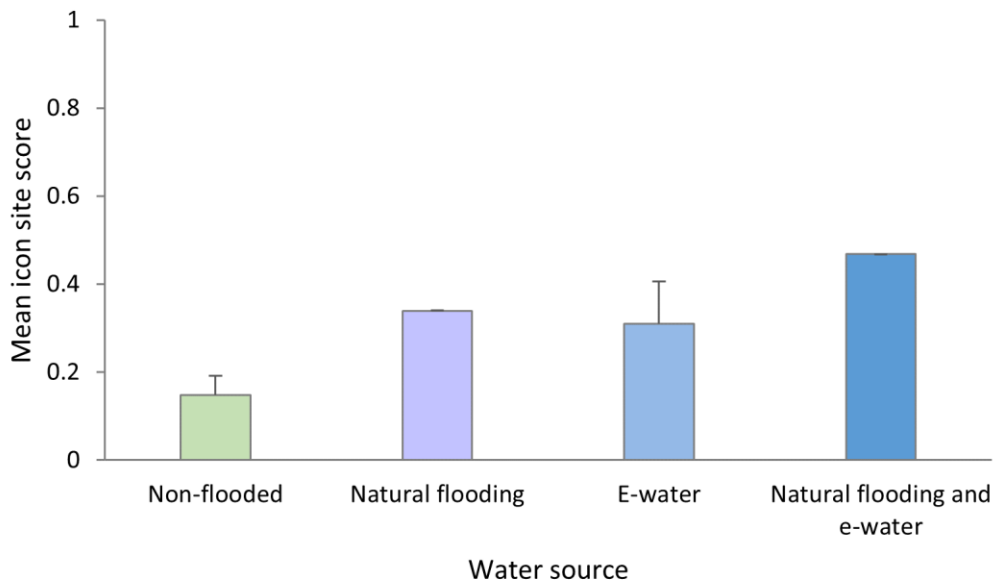


Figure 30 Mean Icon Site floodplain scores based upon native water-responsive species abundance indices, for the Hattah Lakes Icon Site (± standard error), for each water event type. Non-flooded years n = 7, natural flooding n = 2, e-water n = 3, natural flooding and e-water n = 2.

Plant functional groups

Often-flooded sites across Hattah Lakes saw a proportional decrease in the abundance of terrestrial dry (Tdr) species in 2021–22 (22% down from 31% in 2020–21) (Figure 31). This was accompanied by increases in the abundance of terrestrial damp (Tda) (48% up from 39%) and amphibious (A) (18% up from 9%) species. This represents a continuation of the decline in terrestrial dry species abundance and increases in terrestrial damp species which has been occurring since 2020–21.

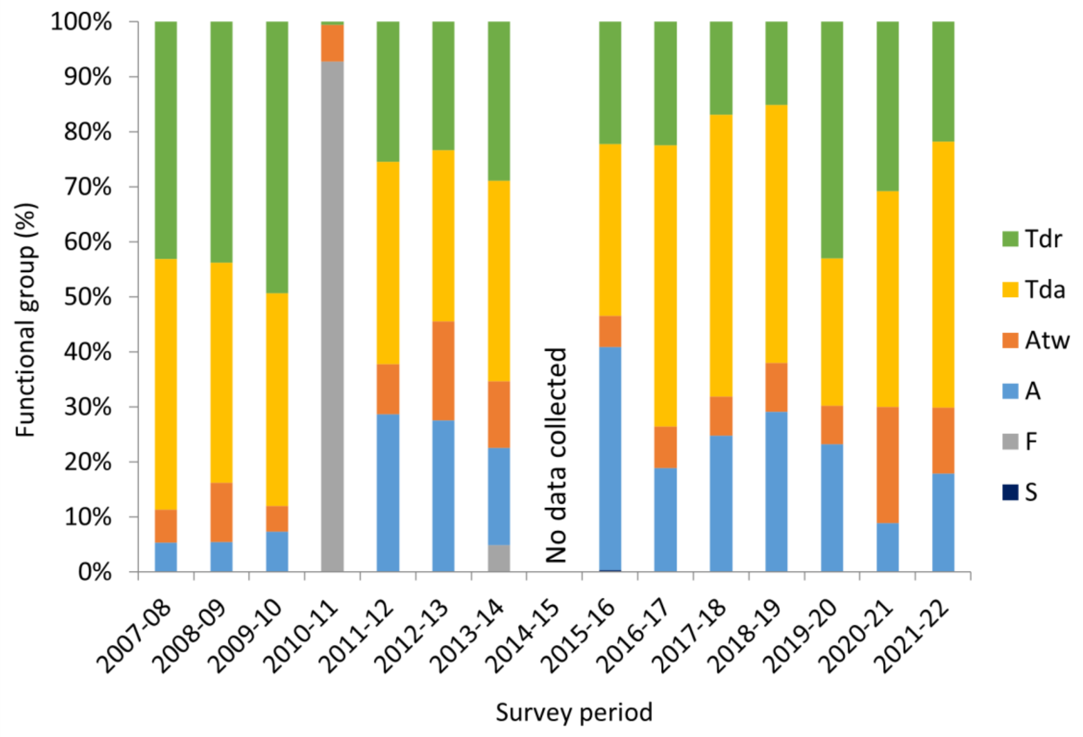


Figure 31 Proportion of the sum of abundance for each plant functional group in each survey period across all often-flooded FRF floodplain sites surveyed at the Hattah Lakes Icon Site.

As with the often-flooded sites, sometimes-flooded sites saw continuing declines in terrestrial dry species abundance (34% down from 48%) and increases in terrestrial damp species abundance (45% up from 21%) (Figure 32). The proportional abundance of amphibious species increased slightly, however, levels remain markedly lower than those recorded between 2011–12 and 2019–20. The proportional abundance of woody amphibious fluctuation tolerators remains relatively high compared with levels prior to 2019–20.

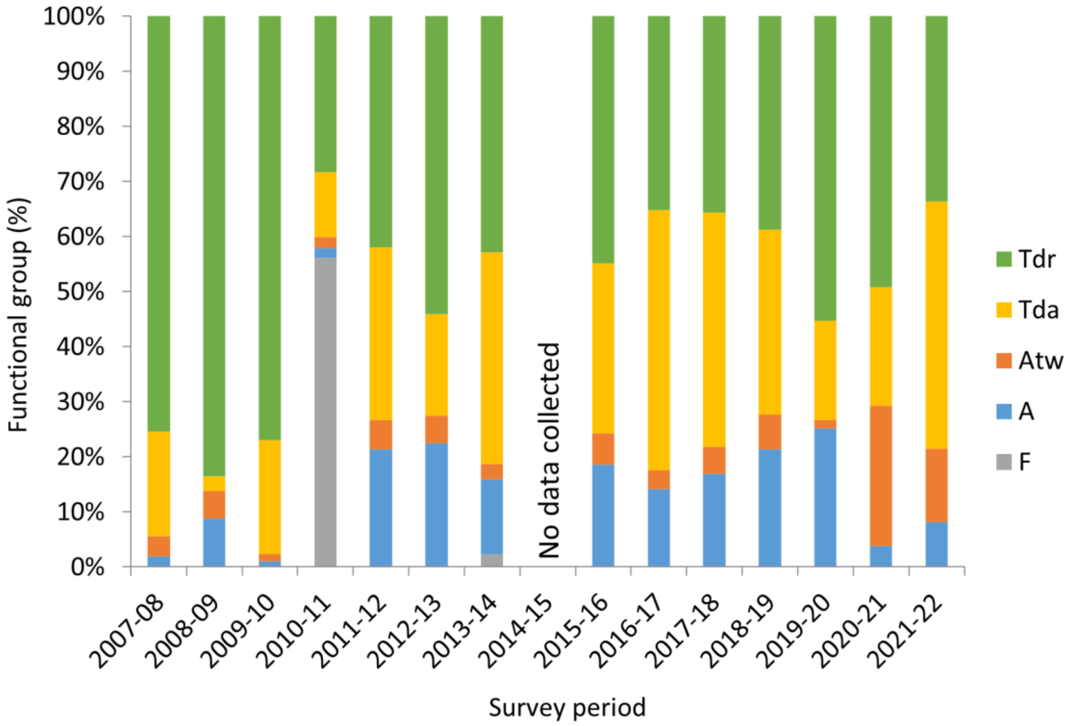


Figure 32 Proportion of the sum of abundance for each plant functional group in each survey period across all sometimes-flooded FRF floodplain sites surveyed at the Hattah Lakes Icon Site.

The rarely-flooded sites saw a marked decrease in the abundance of terrestrial dry species in 2021–22 (67% down from 86% in 2020–21) (Figure 33). Nonetheless, terrestrial dry species still accounted for the overwhelming majority of functional group representation at the rarely-flooded sites. The proportional abundance of terrestrial damp species increased markedly in 2021–22 (up to 20% from 8% in 2021–22). The abundance of woody amphibious fluctuation tolerators remained relatively constant compared with the previous monitoring period, whereas amphibious species recorded an increase from 0% to 4%.

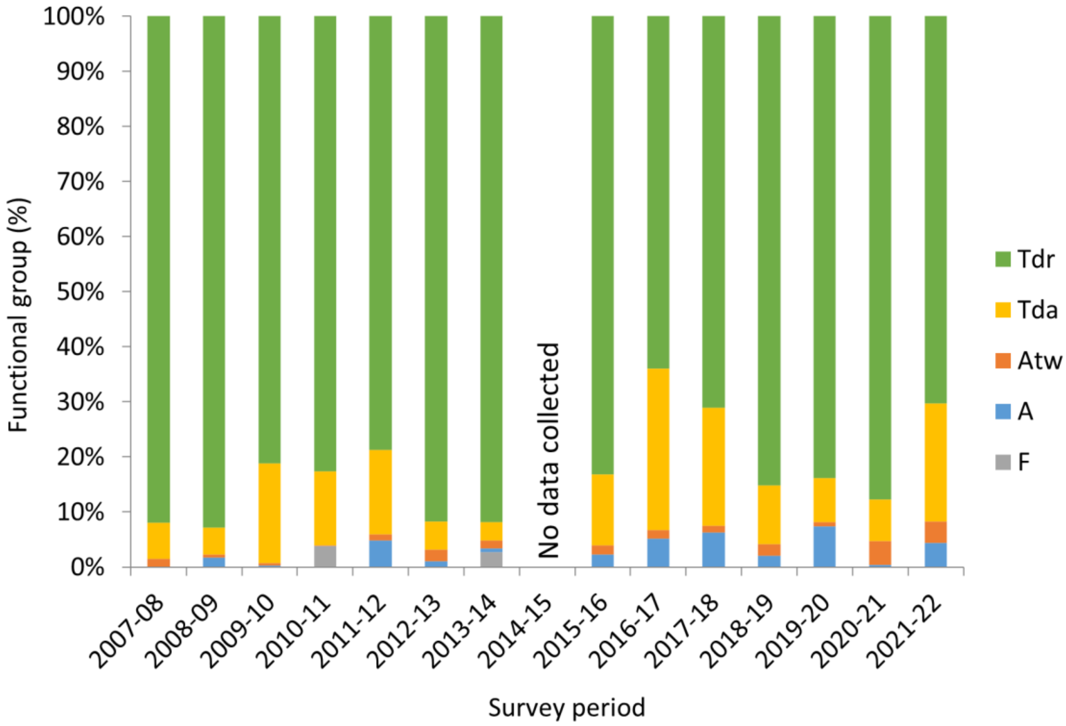


Figure 33 Proportion of the sum of abundance for each plant functional group in each survey period across all rarely-flooded FRF floodplain sites surveyed at the Hattah Lakes Icon Site.

6.3.3 Species composition on floodplains

NMDS ordination revealed that species composition of the rarely-flooded sites was markedly different from the often and sometimes-flooded sites (Figure 34). This was with the exception of HFP5RAR, which was more closely aligned with the often and sometimes-flooded sites. The often and sometimes-flooded sites were generally similar to one another in terms of their species composition, though they were more variable than the rarely-flooded sites. A similar result was obtained when NMDS ordination was undertaken in 2020–21. Unsurprisingly, the rarely-flooded sites were significantly associated (P<0.005) with the terrestrial dry functional group and several species therein including ruby saltbush *Enchylaena tomentosa* var. *tomentosa* and nodding saltbush *Einadia nutans*. By contrast, the often and sometimes-flooded sites were more strongly associated with the terrestrial damp and woody amphibious fluctuation tolerant functional groups.

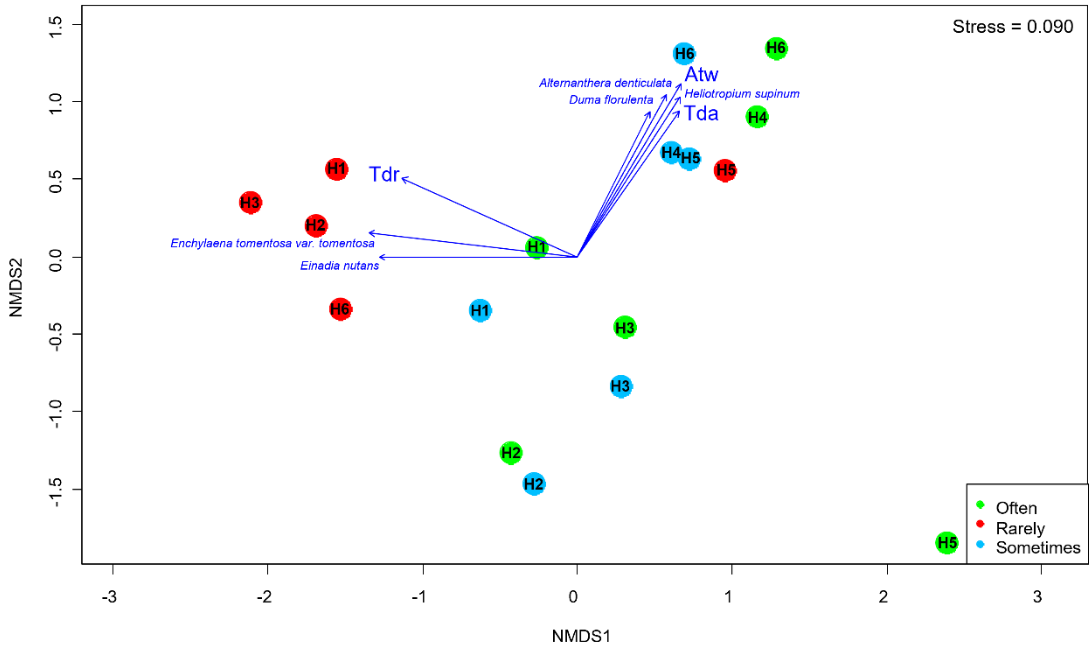


Figure 34 NMDS ordination of species composition across floodplain sites in Hattah Lakes for the 2021–22 season. Lines show statistically significant (P = 0.005) vectors indicating strength of association with each floodplain. Sites are categorised by the FRF in which they occur and are labelled with the floodplain site to which they belong.

Species richness was highly variable between FRFs and sites, with no FRF consistently recording the highest mean species richness within an overall floodplain site (Figure 35). Across all floodplain sites the highest mean species richness was recorded at HFP6OFT, with an average of 15 species per transect. In contrast, the lowest mean species richness was recorded at the often-flooded site HFP5OFT, which also was deeply inundated, with an average of 0.3 species per transect. HFP5OFT also recorded a marked decrease in mean species richness of nine species when compared with 2020–21 levels.

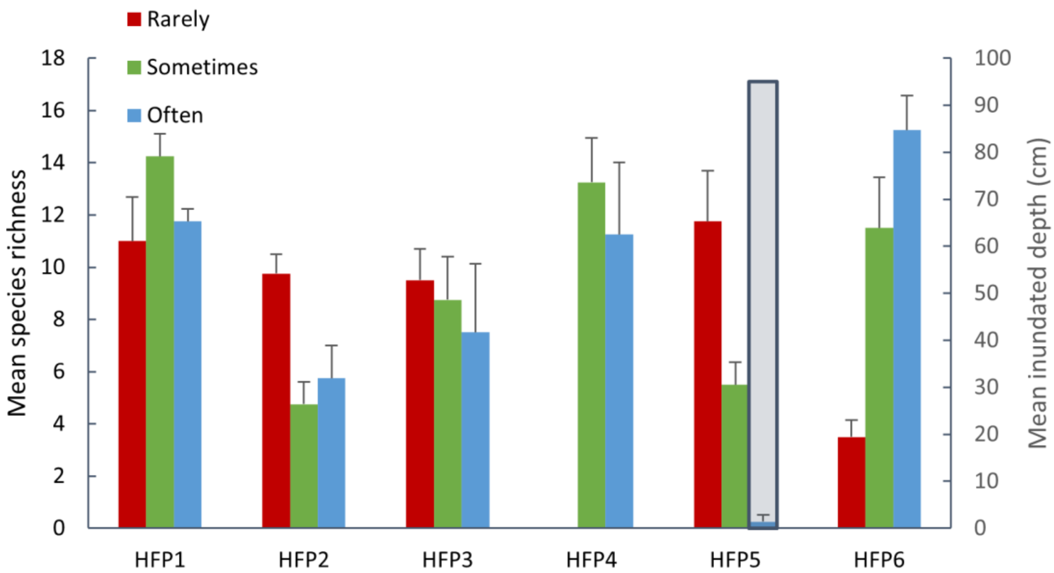


Figure 35 Mean transect species richness (± standard error) at each FRF across all floodplain sites in Hattah Lakes for the 2021–22 season. The rarely-flooded HFP4 site was excluded as it is situated on a sand dune and is therefore no longer being monitored.

As with species richness, species abundance was highly variable between sites and FRFs (Figure 36). This is in contrast to 2020–21 surveys where the rarely-flooded sites consistently recorded the highest mean species abundance. In general, species abundance increased across all FRFs compared with the previous surveys with the greatest increase evident across the sometimes-flooded sites (Palmer et al. 2021). In line with the results for species richness, the highest mean species abundance was recorded at HFP6OFT, with an average of 101 species records per transect. The lowest mean species richness was recorded at HFP5OFT, with an average of 0.3 species per transect.

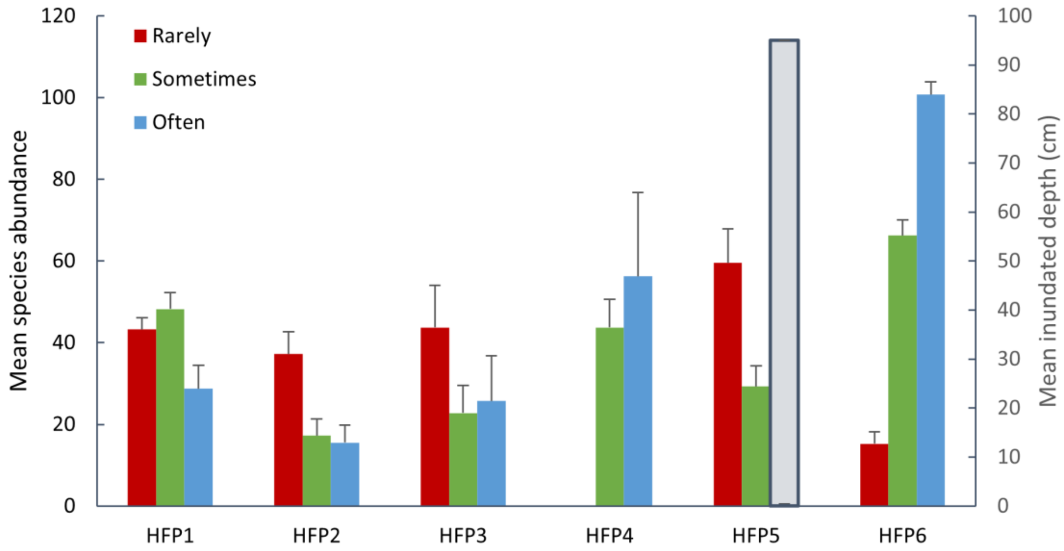


Figure 36 Mean transect species abundance (± standard error) at each FRF across all floodplain sites in Hattah Lakes for the 2021–22 season. The rarely-flooded HFP4 site was excluded as it is situated on a sand dune and is therefore no longer being monitored.

6.4 Discussion

6.4.1 Whole-of-Icon Site score

The Icon Site score for native water-responsive species richness at Hattah lakes floodplain sites increased markedly in this survey period from the last, while the Icon Site score for species abundance also increased, though to a lesser degree. This overall increase in species richness and abundance is likely attributed to the high rainfall and subsequent flooding that occurred in 2021, which has facilitated the proportional increase of terrestrial damp and amphibious functional groups from a largely terrestrial dry species dominated composition during the last survey period. Similar increases in richness and abundance can be seen following past high rainfall and/or natural flooding events.

6.4.2 Often-flooded

NMDS ordination revealed that the often-flooded sites are more similar in species composition to the sometimes-flooded sites than the rarely-flooded sites. This is most likely associated with greater similarities in proportions of functional groups between these FRFs across years, with greater proportions of terrestrial damp and amphibious species than rarely-flooded sites. Thus, it’s likely that the often- and sometimes-flooded sites experience a more similar water regime than the rarely-flooded sites. The exception to this was the rarely-flooded H5 site, most likely because this site was inundated. The greater variability in species composition in often- and sometimes-flooded sites compared with rarely-flooded sites is likely attributed to the potential for a greater variety of species across different functional groups to establish at these sites, whereas the rarely-flooded sites are dominated by terrestrial dry species. The distinct difference in species composition seen between the Hattah 5 often-flooded site and all other sites is due to the inundation levels recorded at the time of the survey at this site. The water levels at this site were likely too deep to allow species to remain established at the transect elevations surveyed. Consequently, just one amphibious emergent species was recorded, river red gum, which is capable of withstanding inundation.

Both water-responsive species richness and abundance at often-flooded sites increased markedly from the last survey period when no sites were considered compliant. A concurrent increase in the proportions of terrestrial damp and amphibious functional groups occurred during this survey period. These changes are likely attributed to environmental water delivery in 2021, allowing for the colonisation of a greater variety of water-dependent species, with increased availability of nutrients and moisture.

6.4.3 Sometimes-flooded

The current season saw a significant increase in water-responsive species richness and abundance since the last survey period, with two of six transects compliant in the current survey period, compared with zero in the last. A corresponding increase in the proportions of terrestrial damp species and a simultaneous proportional decrease in terrestrial dry species occurred in the current survey period. Although the higher Murray River flows that occurred in 2021 did not reach this floodplain, it is likely that the high rainfall event that occurred in November reached these sites, facilitating the establishment of terrestrial damp species, such as pale goodenia *Goodenia glauca*, lesser joyweed and Warrego summer-grass.

6.4.4 Rarely-flooded

As they are situated at higher elevations than the other two FRF categories, rarely-flooded sites have been dominated by drought tolerant species for the duration of the monitoring program. However, the occurrence of terrestrial damp, and to a lesser degree amphibious species, can be seen to increase 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, higher species richness was recorded during this survey period, with the appearance of species such as jerry-jerry (Atl), spreading nut heads (Tda) and lesser joyweed (Tda), which were not recorded at these sites in the last survey period. The NMDS ordination visualising species composition between sites further describes the unique species composition of the rarely-flooded sites in relation to the sometimes- and often-flooded sites. The rarely-flooded sites showed a strong association with the terrestrial dry functional group and related species therein such as nodding saltbush and ruby saltbush.

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, while the Icon Site score for species abundance also increased, to a lesser degree. 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.

Results from the current survey represent an increase in species richness and abundance. However, no clear trajectory towards the ecological objective to 'improve the species richness and abundance of native wetland and floodplain aquatic vegetation functional groups by 2030' can be seen across the duration of the monitoring program. Results highlight fluctuations in water-responsive species richness following inundation events and subsequent decreases with time since inundation.

A summary of target attainment relating to the objectives is provided below in Table 19.

Table 19 Summary of floodplain community target attainment in 2021–22.

Objective LMW2	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 (80th percentile is ≥6.15)		■	
Mid floodplain (80th percentile is ≥5.95)		■	
High floodplain (80th percentile is ≥1.6)		■	
Species abundance (water responsive species)			
Lower floodplain (80th percentile is ≥37.35)		■	
Mid floodplain (80th percentile is ≥22.9)		■	
High floodplain (80th percentile is ≥7.15)		■	

6.6 Recommendations

Conclusively establishing whether or not ecological objectives have been met at a whole of site scale is problematic. Tracking changes in water-responsive species richness and abundance across regular yearly intervals allows the identification of how floodplains respond to fluctuations in wetting and drying cycles and helps to identify patterns and make inferences about when water-responsive species richness and abundance are likely to be maintained at the most productive levels. However, it does not accurately allow the comparison of more detailed changes in the state of vegetation communities across time, due to short-term fluctuations in climatic variables. In order to gauge these changes, spatial and temporal heterogeneity must be incorporated into the monitoring regime.

Floodplain vegetation in arid and semi-arid regions such as Hattah is highly dynamic and tends to respond rapidly to watering and drying events across different temporal and spatial scales (Capon 2003). This often results in rapid shifts in species composition (richness and abundance) and structure. Static indices based on thresholds do not appropriately acknowledge these temporary responses to climatic events. One way to overcome this would be to assess changes in species richness and abundance during the same wetting/drying cycles, taking into account both rainfall events and natural flooding.

To better understand and determine the trajectories of floodplain vegetation and support complex adaptive management decisions, we recommend taking into consideration the spatial and temporal complexity inherent in floodplains when developing ecological objectives for floodplains, rather than relying on static indices of species richness and abundance.

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 assessment of 16 quadrats, with each quadrat measuring 20 x 20 m. 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 20)
- 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.

Data collection for 2021–22 was undertaken from November 2021 and March 2022.

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 20 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).

7.2.2 Lignum flowering and health

Exploratory analyses were undertaken to investigate the relationship between lignum flower abundance (absent, scarce, common or abundant) and health (quantified by LCI) to ascertain whether flower abundance provided a useful indicator of lignum condition.

A chi-square test of independence was undertaken to determine whether there was a significant relationship between LCI and flowering category across all years (2016–17 to 2021–22). Following this, the average LCI for each flower abundance category was calculated across all years, in addition the number of plants within each flower abundance category. The proportional distribution of each LCI category within each of the flower abundance categories was also calculated.

7.2.3 Lignum health and inundation

Using raster data of surface water extent produced by CSIRO Land and water (Ticehurst et al. 2022), surface water across Hattah lakes was mapped for the period from January 2005 to November 2020. Methods developed by Ticehurst et al. (2021) were then used to generate a dataset showing whether or not a site received any surface water in two-monthly intervals for all lignum sites across Hattah Lakes.

The relationship between average site LCI and several components of the water regime at Hattah Lakes (average length of inundation, average time between inundation and the number of time periods when inundated) was displayed graphically. Linear regression analyses were also undertaken to test for significant correlations between each of these water regime variables and average LCI. Data for average site LCI were calculated from 2020–21 surveys as surface water data could only be sourced up until November 2020.

To investigate short-term responses of lignum to water availability, analysis of the relationship between average LCI and inundation was undertaken at a smaller time scale, focussed on a widespread flood event during November 2016. Average LCI (±SE) both one year before, during, and one- and two-years post-inundation was calculated for sites that received water in 2016 and sites that did not.

7.3 Results

7.3.1 Ecological objectives and targets

The 2021–22 monitoring results indicate an increase in lignum condition from 2020–21, with 12% more plants obtaining an LCI score ≥4, on average across all sites (75% in 2020–21 compared to 87% in 2021–22; 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.

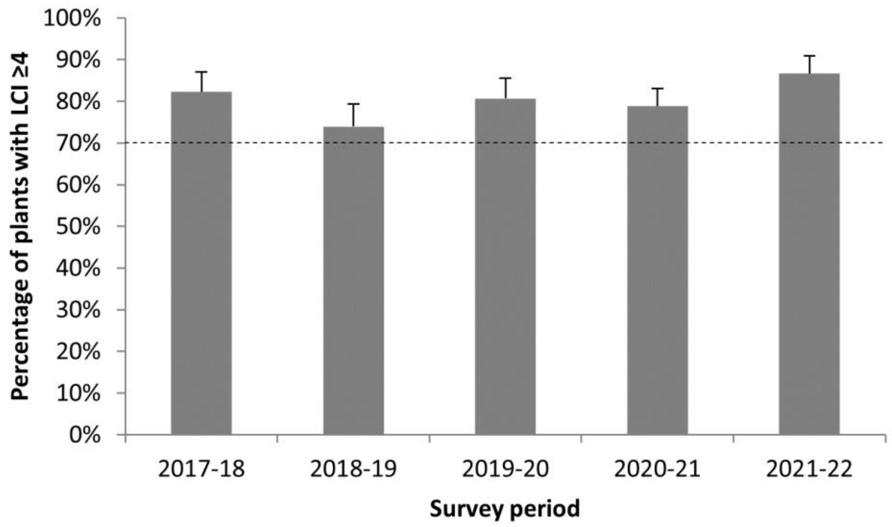


Figure 37 Mean percentage of lignum plants (± SE) that have a Lignum Condition Index (LCI) score ≥4 across the whole Hattah Lakes Icon Site. The Icon Site target of 70% is shown for comparison.

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 12% increase of plants with a LCI ≥4, the proportion of plants with a higher condition score of 8 and 9 has increased substantially compared to the 2020–21 period from 6.4% to 25.75% and 3.96% to 22.06% respectively (Figure 38).

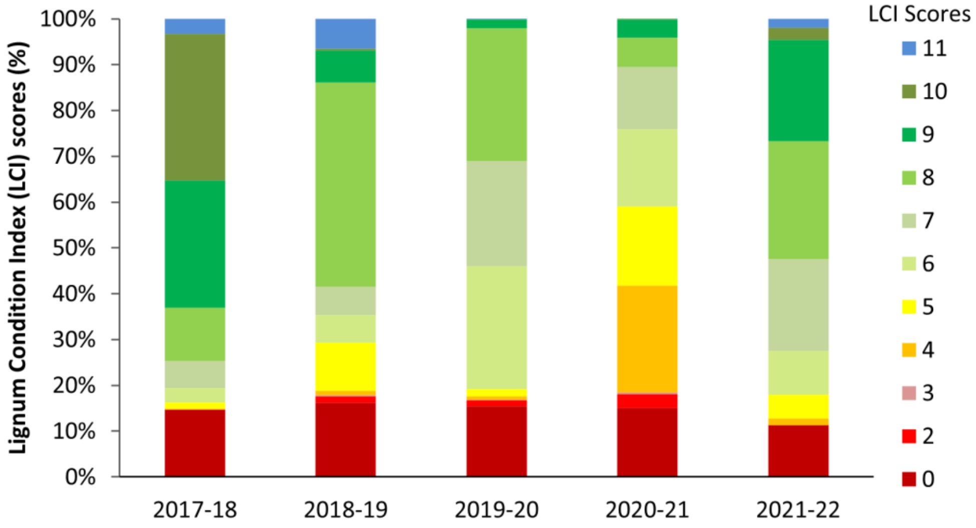


Figure 38 Proportion of sum of count for each Lignum Condition Index (LCI) recorded across all Lignum Icon sites, for each survey period.

The results of Lignum Shrubland, Lignum Swamp and Lignum Woodlands Water Regime Classes (WRCs) all displayed an increase in average percentage of plants with an LCI ≥4, increasing by 8.05 %, 6.34 % and 8.34 % 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. Although the Lignum Woodland WRC has increased in condition compared to the 2020–21 survey period, no overall trend in condition since 2017–18 is apparent.

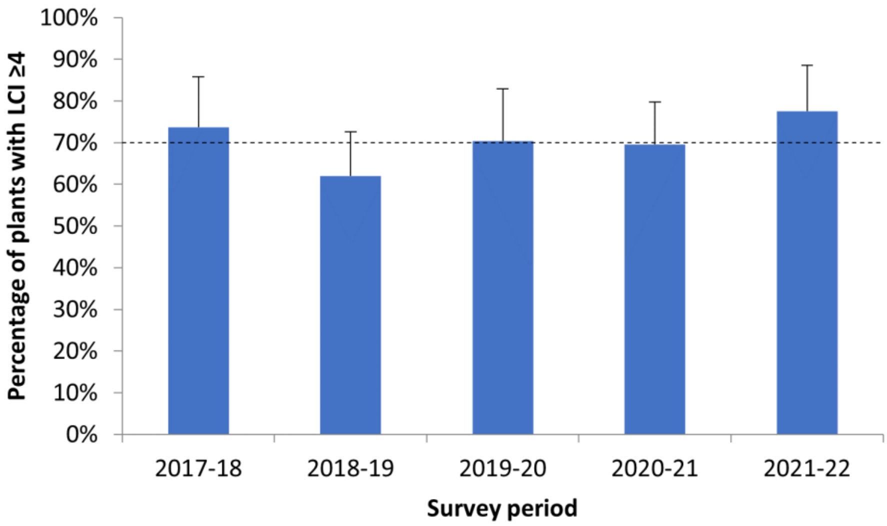


Figure 39 Mean percentage of lignum plants (± SE) within Lignum Shrubland at Hattah Lakes with a LCI score ≥4. The Icon Site target of 70% is shown for comparison.

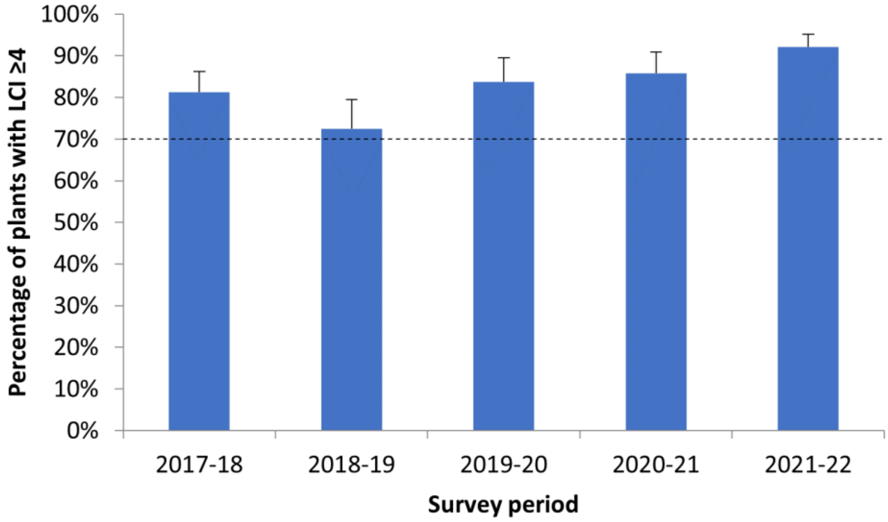


Figure 40 Mean percentage of lignum plants (± SE) within Lignum Swamp at Hattah Lakes with a LCI score ≥4. The Icon Site target of 70% is shown for comparison.

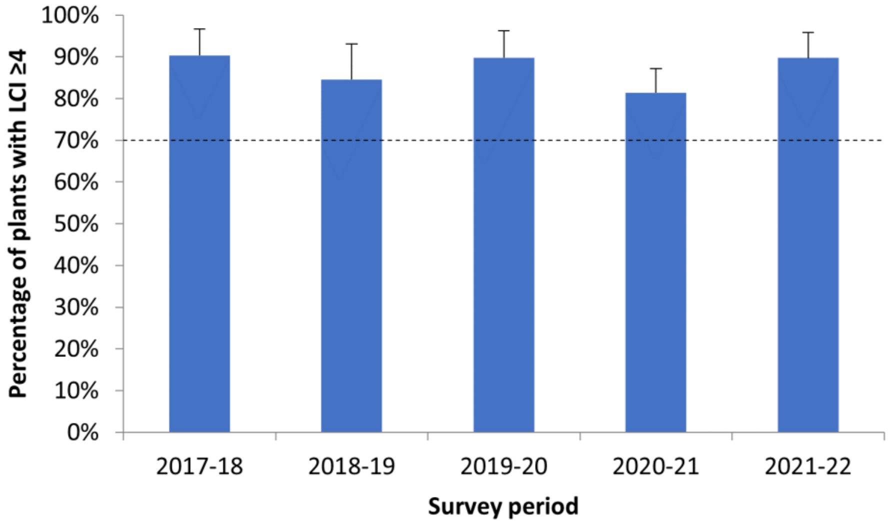


Figure 41 Mean percentage of lignum plants (± SE) within Lignum Woodland at Hattah Lakes with a LCI score ≥4. The Icon Site target of 70% is shown for comparison.

The average cover of lignum across all Hattah Lakes sites has increased from 24% in 2020–21 to 30% in 2021–22 (Figure 42).

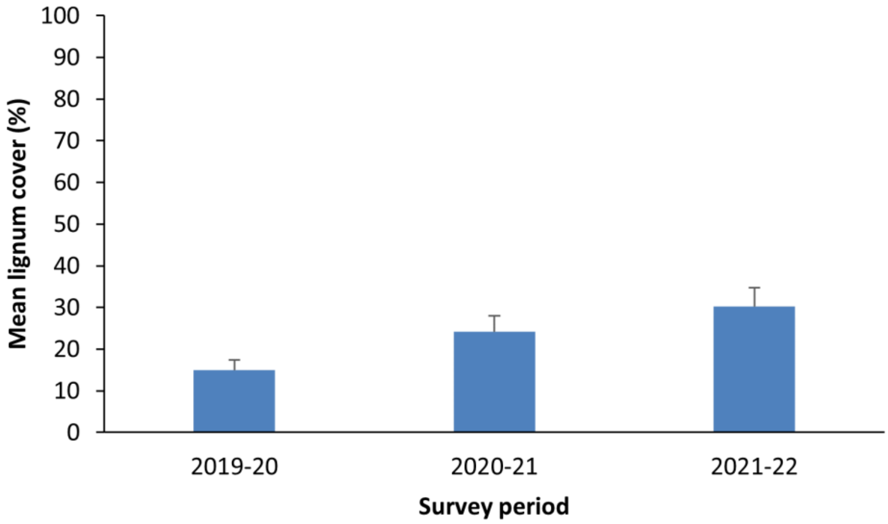


Figure 42 Mean percentage cover of lignum plants across all sites at Hattah Lakes. Recording of lignum cover began in the 2019–20 season.

At an individual site scale, the Icon Site Index (the proportion of sites that exceed the target of 70 % plants with an LCI ≥4) has increased from 13 of 16 compliant sites (0.81) in 2020–21 to 14 of 16 sites compliant (0.87) in 2021–22.

Table 21 Proportion of compliant Lignum sites across the Hattah Lakes Icon Site.

Survey period	2017–18	2018–19	2019–20	2020–21	2021–22
No. compliant sites	12	9	12	13	14
Proportion compliant	0.75	0.5625	0.75	0.8125	0.875

7.3.2 Lignum health and flowering

Lignum plants with no flowers were the most abundant category by a large margin, with 7294 individuals recorded. Abundance decreased progressively for scarcely flowering individuals (850), commonly flowering individuals (173) and abundantly flowering individuals (66). At lignum sites across Hattah Lakes between 2016–17 and 2021–22 the average LCI was lowest for lignum plants with no flowers (6.4), and increased for scarcely flowering (7), commonly flowering (7.7) and abundantly flowering individuals (8.2) (Figure 43). A chi-square test of independence found a significant relationship between LCI and flowering category across all years (2016–17 to 2021–22) ($\chi 2$ = 787.04, df = NA, P < 0.0001).

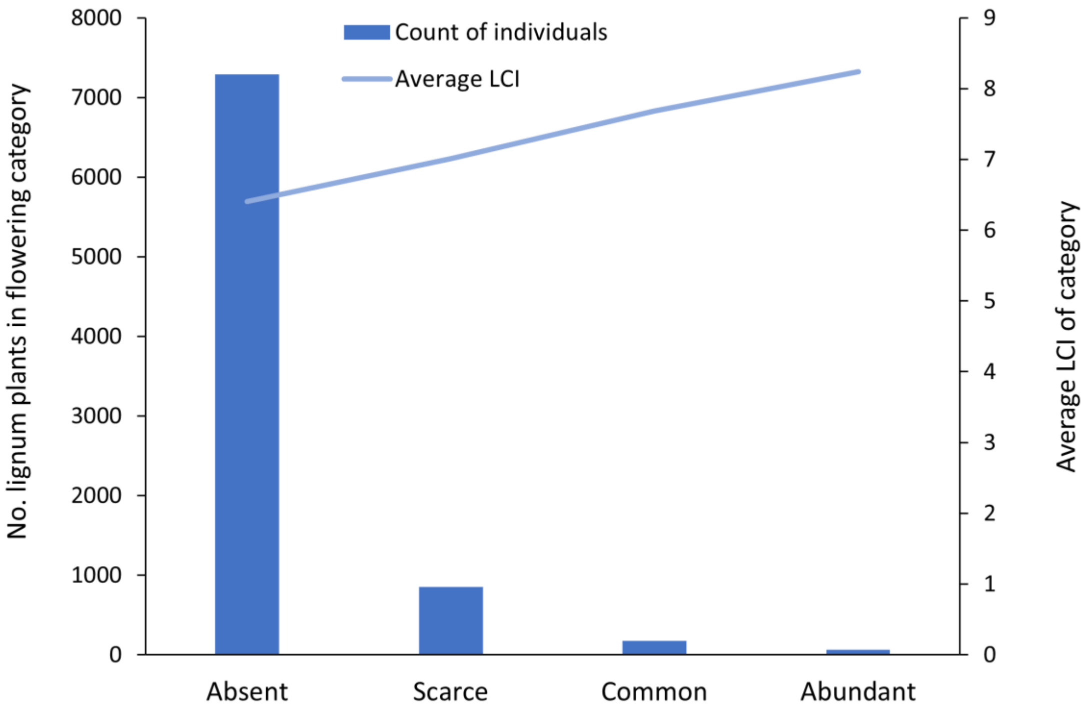


Figure 43 Total number of live lignum plants within each flowering category (absent, scarce, common and abundant) versus the average Lignum Condition Index (LCI) for each flowering category, Hattah Lakes 2016–17 to 2021–22.

The distribution of individuals based on LCI scores varied between flower abundance categories at Hattah (Figure 44). LCIs for individuals with no flowers followed a normal distribution curve, with the majority of individuals recording an LCI of 8. However, individuals without flowers also occurred at both extremes, with some recording the lowest and highest scores (2 and 11). A similar pattern was found for scarcely flowering individuals, with the majority of individuals exhibiting scores of 7 and 8, although no individuals were recorded with an LCI of 2. Commonly flowering individuals did not exhibit lower scores between 2 and 5, with a majority scoring an LCI of 7. Abundantly flowering individuals also did not exhibit scores between 2 and 4, while most individuals were found with an LCI of 8 with the next most-abundant category being 9.

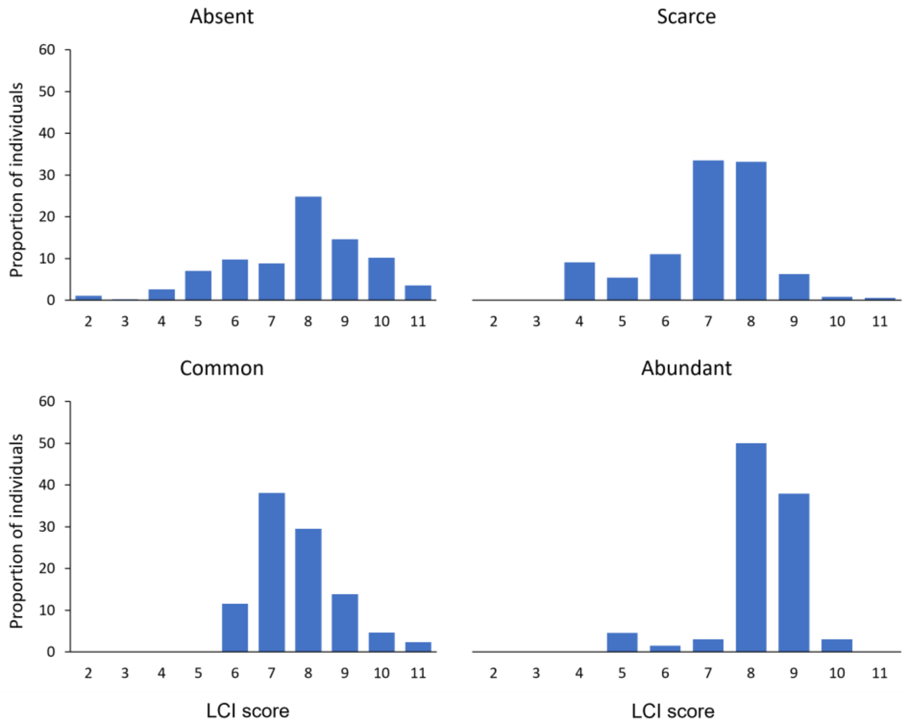


Figure 44 Proportional abundance of each Lignum Condition Index (LCI) category (2-11; live plants only) within each flower abundance category (absent, scarce, common and abundant), Hattah Lakes 2016–17 to 2021–22.

7.3.3 Lignum health and long-term inundation trends

Between January 2005 and November 2020, 25% of lignum sites across Hattah Lakes received no surface water. Lignum sites across Hattah Lakes also recorded a number of extended periods between inundation events (though the length of these was highly variable and was generally less than at LMW).

Lignum health (quantified by LCI) in 2020–21 at Hattah Lakes was significantly correlated with average time between inundation ($P < 0.05$), length of inundation ($P < 0.05$) and the number of inundation events ($P < 0.05$) at each site since January 2005 (Figure 45). Average time between inundation and average site LCI showed a negative linear relationship, with LCIs decreasing on average with increasing intervals between inundation events. The average time between inundation events varied considerably, ranging from 9.75 two-monthly intervals to 96 two-monthly intervals (these sites recorded no inundation events, therefore scoring the maximum possible number of intervals).

Average lengths of inundation across sites ranged from 4.8 to one (indicating a brief pulse of inundation which was only recorded at one time-point), which was recorded across several sites. Average LCI also increased with frequency of inundation events recorded across each site (i.e. how many inundated intervals were recorded for each site).

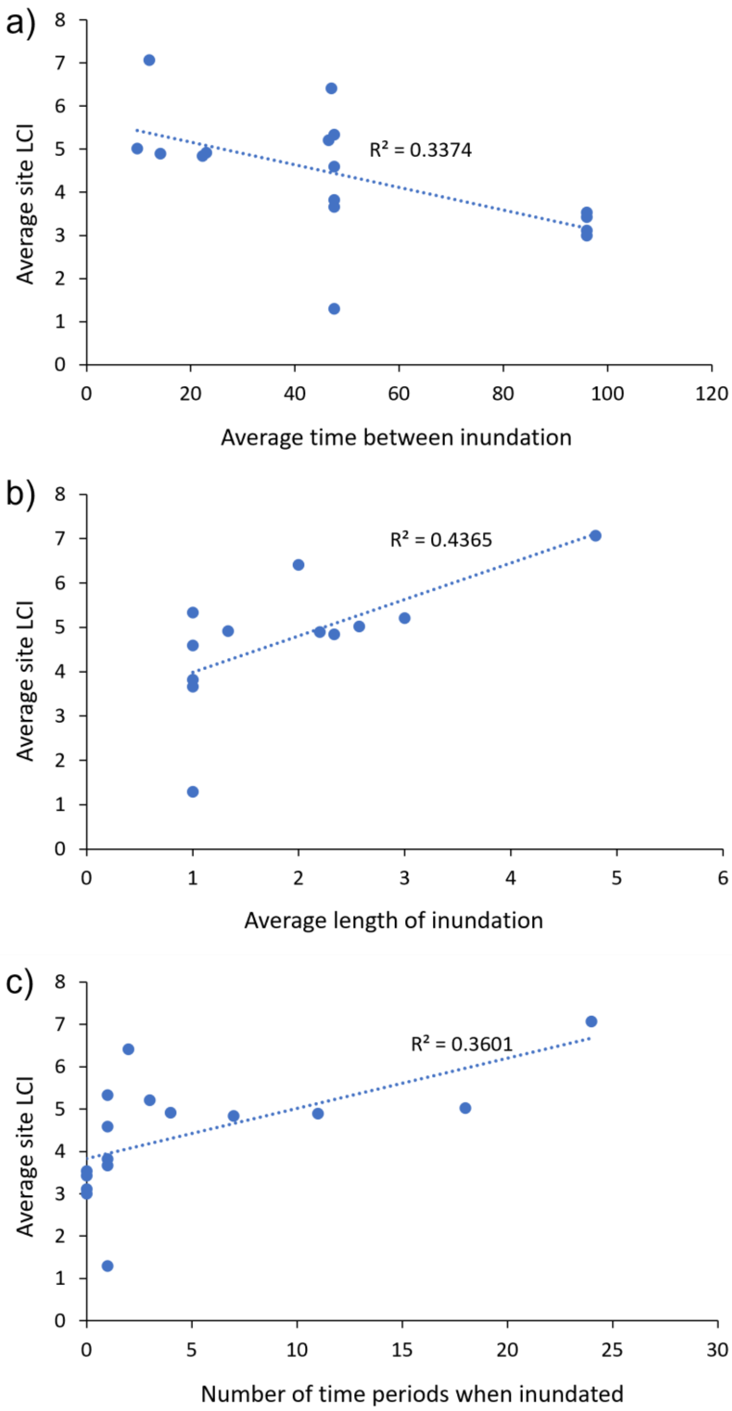


Figure 45 Average site LCI (Lignum Condition Index) recorded in 2020–21 versus a) average time between inundation events, b) average length of inundation, and c) number of time periods when inundated for lignum sites dating from January 2005 – November 2020 at Hattah Lakes.

The percent cover of lignum at each site as of 2020–21 (measured as described in MCMA (2021b)) was negatively correlated with increasing average time between inundation, though this association was not significant (P = 0.06). Lignum percent cover was positively correlated with increasing average length of inundation, though this was also not a significant association (P = 0.2). However, cover was significantly positively correlated with the number of inundation events recorded across Hattah lakes since January 2005 (P < 0.05) (Figure 46).

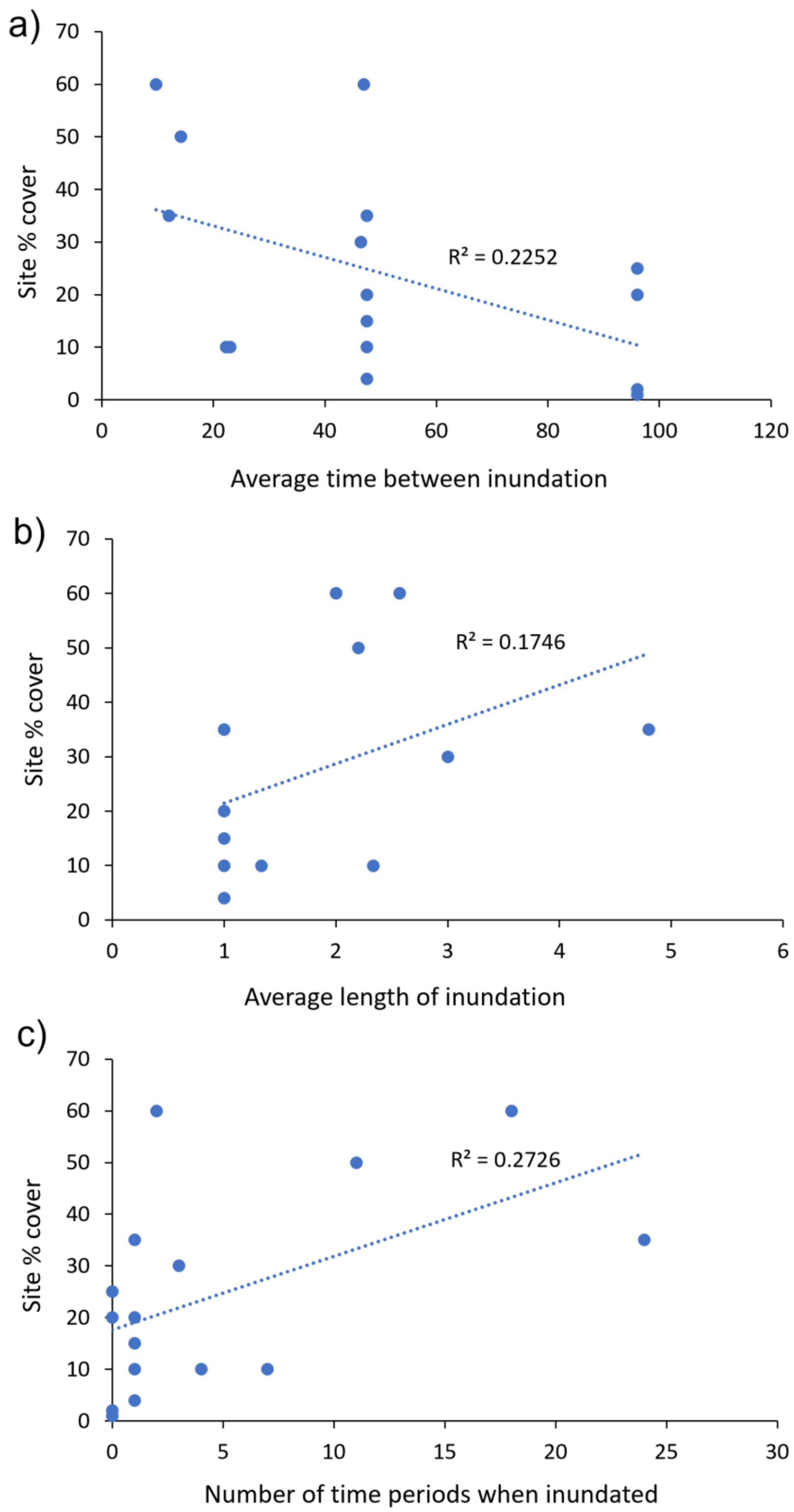


Figure 46 Site percent cover of lignum recorded in 2020-21 versus a) average time between inundation events b) average length of inundation and c) number of time periods when inundated for lignum sites dating from January 2005 – November 2020 at Hattah Lakes.

Analysis of lignum health (LCI) at sites which did and did not receive water before, during and after a large-scale flooding event at Hattah Lakes in November 2016 revealed that average LCIs were lower during the inundation event of November 2016 (Figure 47). This was noted across both inundated and non-inundated sites. Average LCI fluctuated between years, with higher levels in the years immediately before and after flooding in 2016. Little difference was evident in average LCIs between the sites which received water in 2016 and those which did not, though on average the dry sites recorded higher mean LCIs.

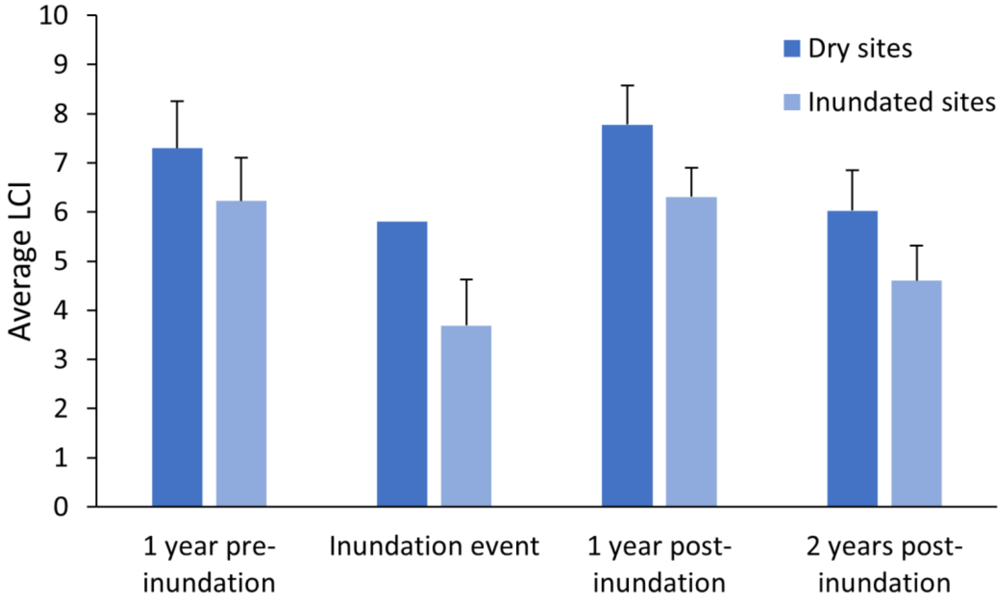


Figure 47 Average LCI (Lignum Condition Index) (±SE) of sites which did not receive any inundation over a four-year period (dry sites) versus those which did receive inundation during November 2016 (inundated sites). Hattah Lakes 2015–16 to 2018–19.

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 new method where the full complement of sites were assessed (only three of 16 sites were assessed in 2016–17). When considering lignum condition at the whole-of-Icon Site level, condition has improved compared with previous years, reaching the highest level since the new data collection method began in 2017–18 (87% 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, this season may be a reflection of environmental watering inundation and a large rainfall event just prior to monitoring. Hattah Lakes experienced inundation in 2021–22, with 27,207 GL of environmental water delivered in autumn 2021 and 48,138 GL delivered in spring 2021, which was enough to inundate some sections of the floodplains across the Icon Site. Lignum can respond rapidly to flooding and rainfall, producing new shoots, flowers and leaves (Capon et al. 2009). Given the naturally rapid response of lignum to wetting and drying cycles, such a substantial increase in lignum condition in 2021–22 is possible in response to this inundation. Prior to 2021–22, Icon Site-wide lignum condition at Hattah Lakes had been relatively steady since 2017–18, with the lowest levels recorded in 2018–19 still meeting the ecological target.

When comparing data across the three WRCs, all three showed an increase in condition since 2020–21 (with all three also meeting the ecological target of 70% of plants with an LCI score ≥4). 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. These relatively high scores across all WRCs and the wider Icon Site likely reflects the frequency of adequate watering events at Hattah Lakes. Widespread flooding was seen at Hattah in 2016–17 and environmental water delivered in 2017–18 and 2021–22. Additionally, a significant rainfall event occurred just prior to the commencement of this monitoring season. These events appeared to have maintained lignum condition at a desirable level, with ecological targets met nearly all survey periods since 2017–18 (with the exception being Lignum Shrubland in 2018–19 and 2020–21).

7.4.2 Lignum health and flowering

Analysis of lignum flowering and health (LCI) revealed a significant positive relationship between the two variables. Average LCIs were lowest for the absent flowers category and increased progressively with increasing flower abundance. However, visualisation of the distribution of individuals based on LCI scores for each flowering category revealed that lignum plants with no flowers were recorded in good health. No individuals from common or abundant flower categories were recorded with LCIs below 5. In addition, an increase in the proportion of individuals in common and abundant categories with higher LCIs is apparent. Results indicate common or abundant flowering is associated with better health; however, it is likely not a useful stand-alone indicator of health. Rather, reproductive effort needs to be taken into account with other indicators (i.e. viability, colour, cover) to provide a clear understanding of overall lignum health.

7.4.3 Lignum health and inundation

Across all sites, lignum health and cover deteriorated with increasing time between inundation events and tended to increase with both the length and number of inundation events. Results are consistent with previous research highlighting the importance of increased frequency of flows on lignum health (Chong and Walker 2005).

Surprisingly, lignum exhibited no significant short-term responses to widespread flooding that occurred in November 2016. Sites which received inundation and those which did not had similar average LCIs to one another both before, during and after flooding. Lignum can respond rapidly in response to soil moisture, whether from rainfall or flooding (Roberts and Marston 2011). Hattah received heavy rainfall throughout September (124.8 mm) and October (40 mm) 2016, substantially higher than monthly averages for the region (Bureau of Meteorology 2022). It is possible lignum across Hattah may have exhibited an increase in health in response to this rainfall, which may have muted its response to further water availability in November.

Analysis of the response of lignum to inundation events is limited by the data available. Surface water data used here does not provide information on the depth of inundation or high-resolution information on the timing and duration of inundation. Furthermore, arid floodplain vegetation is influenced by interacting effects of flooding events and environmental conditions such as rainfall and temperature.

Lignum persists in dry conditions by maintaining vegetative growth and not producing leaves or flowers (Chong and Walker 2005). Meanwhile, lignum cover, vitality, flowering and leaf production can all occur rapidly in response to flooding or significant rainfall (Siebentritt 2003). Our results show lignum flowering is related to health across Hattah Lakes, however the absence of flowers does not necessarily indicate poor health. Reproductive effort is a key component of overall health. The lignum condition index as currently used to measure ecological objectives in relation to The Living Murray program is not taking into account the ability of lignum to produce reproductive material and therefore is not providing the most accurate measurement of lignum health given the data that is collected.

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 2021–22. 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 22). 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 2021–22.

Table 22 Summary of Lignum target attainment in 2021–22

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

The use of a compliance score and Icon Site index for determining lignum 'health' may not always be accurate. Given the natural response of lignum to wetting and drying cycles, year-to-year fluctuations in the LCI score are to be expected. For example, lignum produces leaves, flowers and shoots rapidly in response to rainfall and flooding. However, green stems dry out with increasing time since rainfall or inundation (Capon et al. 2009). In addition, frequently flooded areas tend to be dominated by large (>3 m tall), dense clumps of lignum whilst considerably smaller (<1 m tall), stunted individuals are scattered sparsely in drier conditions. Thus, a site containing a high percentage of lignum below the stated target of ≥4 may not necessarily be in poor condition; rather, it may be in a dryer period of a variable climate that cycles through wet and dry phases. Current water availability and flooding history across all lignum sites therefore needs to be considered when assessing the compliance of a site based on the percent of plants with a LCI ≥4.

Nonetheless, too long between inundation or significant rainfall events inevitably leads to declines in lignum condition, as was exemplified by analyses relating LCI to long-term inundation variables at each site. 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, declining lignum condition scores may require the application of e-water with the aim of targeting certain WRCs or sites. Although lignum condition scores generally appear to be within desirable ranges at Hattah Lakes, the Lignum Shrubland WRC may require further targeted delivery of e-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. 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).

The provision of fine-scale inundation extent data would 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).

While the absence of flowers does not necessarily indicate poor health, results show lignum flowering is related to health across Hattah Lakes. Thus, we recommend including data on both flowering and leaf abundance in assessments of lignum condition in relation to ecological objectives.

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. These surveys are part of The Living Murray condition monitoring program. For the 2021-22 season, monitoring at the Hattah Lakes Icon site was increased from biannual surveys in spring and autumn to include a third survey round in summer to allow for better monitoring of waterbird breeding success throughout the year. This chapter presents the findings of the three waterbird surveys carried out over the 2021-22 season.

8.2 Ecological objectives

As stated in the Hattah Lakes Condition Monitoring Plan (MCMA 2021b), the two 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 >1m) and shallow feeding areas (<0.5m 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 three 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*, great egret *Ardea alba*, intermediate egret *Ardea intermedia*, Australasian darter *Anhinga novaehollandiae*, great cormorant *Phalacrocorax carbo*, little black cormorant *Phalacrocorax sulcirostris*, little pied cormorant *Microcarbo melanoleucos*, white-necked heron *Ardea pacifica*, yellow-billed spoonbill *Platalea flavipes*, and royal spoonbill *Platalea regia*.

8.3 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) and follows the Birdlife Australia suggested method (Birdlife Australia 2016). All waterbirds visible from a fixed point on the edge of each wetland (or two 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 two 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, were recorded where observed and 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 2022) taken in the months surveys were conducted.

The following 15 wetlands were surveyed in spring 2021 and in summer and autumn 2022:

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

8.4 Results

The 15 wetlands surveyed at the Hattah Lakes Icon Site were visited between 15 and 18 November 2021 (spring), between 31 January and 3 February 2022 (summer) and between 2 and 4 May 2022 (autumn). Hattah Lakes had received environmental watering in early spring 2021 and all surveyed wetlands contained water, with the exception of Lake Kramen, which only held minimal water during spring and was dry during the summer and autumn surveys (Table 23).

Table 23 Extent of water surface of the Hattah Lakes during the 2021-2022 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	120	60.0	0.22
		Summer	100	50.0	0.98
		Autumn	80	40.0	0.10
Lake Bitterang	156	Spring	120	187.2	0.08
		Summer	100	156.0	0.67
		Autumn	90	140.4	0.17
Lake Brockie	42	Summer	90	37.8	1.51
		Autumn	75	31.5	0.89
Lake Bulla	46	Spring	120	55.2	0.60
		Summer	100	46.0	0.65
		Autumn	80	36.8	0.19
Lake Cantala	108	Spring	120	129.6	0.42
		Summer	90	97.2	1.59
		Autumn	80	86.4	8.32
Lake Hattah	65	Spring	100	65.0	0.28
		Summer	90	58.5	1.33
		Autumn	80	52.0	0.71
Lake Konardin	85	Spring	120	102.0	0.06
		Summer	100	85.0	0.36
		Autumn	85	72.3	0.29
Lake Kramen	74	Spring	20	14.8	22.36
		Summer	0	0.0	n/a
		Autumn	0	0.0	n/a
Lake Little Hattah	12	Spring	100	12.0	1.42
		Summer	90	10.8	6.94
		Autumn	80	9.6	1.67
Lake Lockie	176	Spring	150	264.0	0.05
		Summer	100	176.0	0.10
		Autumn	85	149.6	0.41
Lake Mournpall	181	Spring	130	235.3	0.02
		Summer	100	181.0	0.58
		Autumn	85	153.9	1.31
Lake Nip Nip	2	Spring	110	2.2	16.82
		Summer	90	1.8	37.78
		Autumn	70	1.4	57.86

Wetland	Total area (ha)	Survey	% Full	Surface water area (ha)	Waterbird density (birds/ha surface water)
Lake Woterap	33	Spring	140	46.2	0.28
		Summer	100	33.0	1.48
		Autumn	70	23.1	0.56
Lake Yelwell	59	Spring	180	106.2	0.09
		Summer	120	70.8	0.86
		Autumn	100	59.0	1.03
Lake Yerang	39	Spring	180	70.2	0.40
		Summer	100	39.0	0.62
		Autumn	80	31.2	2.08

Waterbirds were recorded at all wetlands, except for Lake Kramen in summer and autumn, when it had completely dried out. 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 the 2021-22 Part B report (Palmer et al. 2022).

8.4.1 Waterbird numbers and diversity

In total 2836 waterbirds, comprising 29 species, were recorded (Table 24; Table 25). Waterbird numbers showed an opposite trend to the previous two monitoring seasons, with numbers and species richness increasing from the spring to autumn surveys (see Part B report [Palmer et al. 2022]). Numbers increased from 593 individuals counted in spring, to 904 in summer and 1339 in autumn, while diversity increased more moderately from 20 species in spring to 23 species in summer and autumn.

Four species listed as vulnerable under the Victorian Flora and Fauna Guarantee Act (FFG Act), 1988 were recorded: hardhead *Aythya australis*, musk duck *Biziura lobata*, blue-billed duck *Oxyura australis*, and Australasian shoveler *Anas rhynchotis*. As during the previous monitoring season, the guild with the highest number of individuals recorded in spring (358, 60% of waterbirds recorded in spring, Table 24; Figure 48) were the dabbling ducks, with grey teal *Anas gracilis* being the most common species (355 individuals, see Part B report [Palmer et al. 2022]). The least common were the diving ducks, with only one blue-billed duck and four hardhead observed (0.8% of waterbirds). In summer, fish-eaters were the most abundant guild (323, 35.7% of waterbirds recorded in summer, Table 24; Figure 48), due to large numbers of great cormorants *Phalacrocorax carbo* (226 individuals, see Part B report [Palmer et al. 2022]) mostly concentrated at Lakes Cantala and Mournpall. As in spring, grey teal was the most abundant species overall in summer and present at every wetland holding water, with 253 individuals recorded. The least abundant guild in summer was the shorebird guild, representing only 0.2% of all waterbirds observed (two masked lapwings at Lake Yelwell). Fish-eaters were by far the most abundant guild in autumn, with 1011 individuals observed (75.5% of all waterbirds, Table 24; Figure 48), again represented by increased numbers of great cormorants at Lakes Cantala and Mournpall (701 and 183 individuals, respectively, Part B report [Palmer et al. 2022]). Least abundant during the autumn surveys were the diving ducks, swans, and filter feeding ducks with 2 (0.1%), 3 (0.2%), and 5 (0.4%) individuals recorded, respectively (Table 24).

On average, waterbird density increased slightly from spring to autumn with 3.1, 4, and 5.4 waterbirds per hectare surface water in spring, summer and autumn, respectively. The highest density was recorded at the smallest wetland surveyed, Lake Nip Nip (37.5 birds/ha on average, with the highest, 57.9 birds/ha in autumn) and at Lake Kramen in spring, when it still contained some water (22.4 birds/ha, Table 23; Part B report [Palmer et al. 2022]). Density was lowest on average at Lakes Konardin and Lockie (0.2 birds/ha). The lowest density recorded during any of the surveys was in spring at Lake Mournpall, with only four waterbirds observed: two Eurasian coots *Fulica atra*, one grey teal and one great crested grebe *Podiceps cristatus* (0.02 birds/ha, Table 23; Part B report [Palmer et al. 2022]).

Table 24 Number of waterbirds observed during spring 2021 and summer and autumn 2022 surveys by guild and guild representations as proportion of all waterbirds seen

Waterbird feeding guild	Spring	Summer	Autumn	Total	Proportion of all waterbirds Spring	Summer	Autumn
Coots & rails	17	83	17	**117**	2.9	9.2	1.3
Dabbling ducks	358	275	102	**735**	60.4	30.4	7.6
Diving ducks	5	9	2	**16**	0.8	1.0	0.1
Filter-feeding ducks	8	16	5	**29**	1.3	1.8	0.4
Fish-eaters	29	323	1011	**1363**	4.9	35.7	75.5
Grazing ducks	36	52	27	**115**	6.1	5.8	2.0
Grebes	27	126	119	**272**	4.6	13.9	8.9
Large wading birds	8	10	31	**49**	1.3	1.1	2.3
Shorebirds	45	2	22	**69**	7.6	0.2	1.6
Swans	60	8	3	**71**	10.1	0.9	0.2
Total abundance	**593**	**904**	**1339**	**2836**	**100**	**100**	**100**
Species richness	**20**	**23**	**23**	**29**			

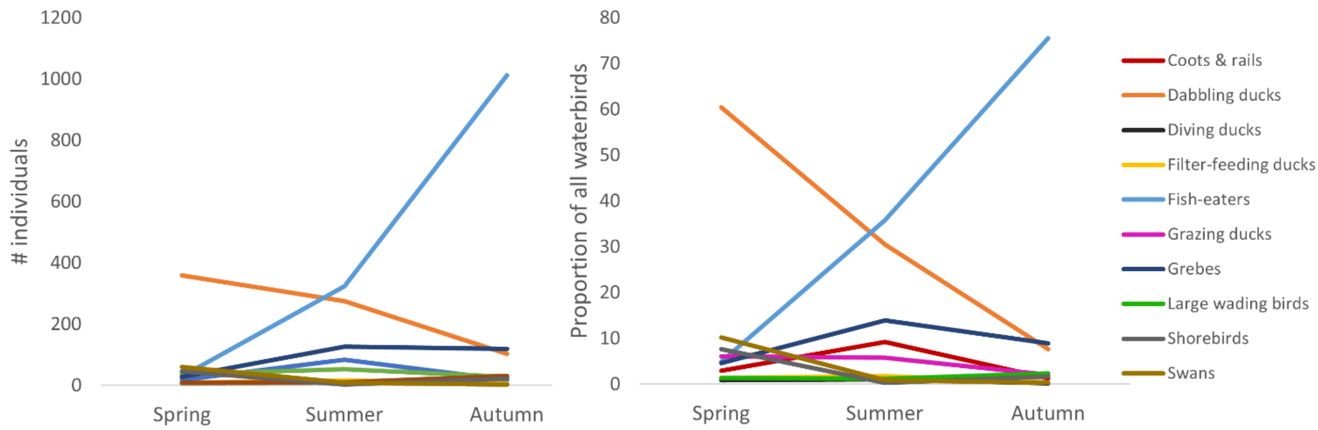


Figure 48 Changes in number of individuals (A) and proportion of all waterbirds recorded (B) over the three survey rounds for each waterbird guild at the Hattah Lakes icon site

Table 25 Total counts of waterbirds by species, guild, and wetland for the 2021-22 monitoring season.

Species		Arawak	Bitterang	Brockie	Bulla	Cantala	Hattah	Konardin	Kramen	Little Hattah	Lockie	Mournpall	Nip Nip	Woterap	Yelwell	Yerang	Total
Coots & rails		**19**	**6**	**15**	**7**	**6**	**16**	**3**		**14**	**6**	**4**	**3**		**14**	**4**	**117**
Eurasian Coot	*Fulica atra*	19	6	15	7	6	16	3		14	6	4	3		14	4	117
Dabbling ducks		**6**	**61**	**30**	**22**	**73**	**26**	**14**	**210**	**26**	**22**	**22**	**140**	**48**	**15**	**20**	**735**
Chestnut Teal	*Anas castanea*									1							1
Grey Teal	*Anas gracilis*	5	61	27	20	71	24	14	210	17	21	20	136	45	12	20	703
Pacific Black Duck	*Anas superciliosa*	1		3	2	2	2			8	1	2	4	3	3		31
Diving ducks					**2**					**6**	**2**	**6**					**16**
Blue-billed Duck	*Oxyura australis*									1							1
Hardhead	*Aythya australis*				2					5		6					13
Musk Duck	*Biziura lobata*										2						2
Filter-feeding ducks			**2**								**1**		**13**	**11**		**2**	**29**
Australasian Shoveler	*Anas rhynchotis*													2			2
Pink-eared Duck	*Malacorhyncus membranaceus*		2								1		13	9		2	27
Fish-eaters		**22**	**52**	**9**	**20**	**819**	**13**	**3**		**17**	**12**	**245**	**4**	**9**	**66**	**72**	**1363**
Australasian Darter	*Anhinga novaehollandiae*	14	3	4	3	1	3				1	3		5	12	1	50
Australian Pelican	*Pelecanus conspicillatus*		9								7				26	60	102
Great Cormorant	*Phalacrocorax carbo*	4	34	4	3	818	2	3			2	233	1		17	5	1126
Little Black Cormorant	*Phalacrocorax sulcirostris*	1	6		2		6			13	1	7		4	11	5	56

Species		Arawak	Bitterang	Brockie	Bulla	Cantala	Hattah	Konardin	Kramen	Little Hattah	Lockie	Mournpall	Nip Nip	Woterap	Yelwell	Yerang	Total
Little Pied Cormorant	*Microcarbo melanoleucos*	3		1	12		2			4	1	2	3			1	29
Grazing ducks		**12**	**4**	**20**	**6**	**5**	**28**	**2**	**13**	**7**			**4**		**12**	**2**	**115**
Australian Wood Duck	*Chenonetta jubata*	12	4	20	6	5	28	2	13	7			4		12	2	115
Grebes		**7**	**16**	**8**	**10**	**24**	**46**	**34**		**34**	**10**	**32**	**20**	**7**	**12**	**12**	**272**
Australasian Grebe	*Tachybaptus novaehollandiae*					8	13			3	1	3	16	5			49
Great Crested Grebe	*Podiceps cristatus*	5	5	5	6		13	2		11	3	17			3	12	82
Grebe sp.		2					6										8
Hoary-headed Grebe	*Poliocephalus poliocephalus*		11	3	4	16	14	32		20	6	12	4	2	9		133
Large wading birds			**1**	**3**	**1**	**1**	**1**	**2**	**4**	**4**	**16**				**11**	**5**	**49**
Australian White Ibis	*Threskiornis molucca*									2	4				1	1	8
Great Egret	*Ardea alba*						1		3								4
Nankeen Night-heron	*Nycticorax caledonicus*				1												1
Straw-necked Ibis	*Threskiornis spinicollis*															1	1
White-faced Heron	*Egretta novaehollandiae*		1	3		1		2	1	1	3				4	3	19
Yellow-billed Spoonbill	*Platalea flavipes*									1	9				6		16
Shorebirds							**3**		**44**		**20**				**2**		**69**
Black-fronted Dotterel	*Elseyornis melanops*										16						16
Masked Lapwing	*Vanellus miles*						3		23		4				2		32
Pied Stilt	*Himantopus leucocephalus*								21								21
Swans			**2**		**2**				**60**		**3**	**2**	**2**				**71**
Black Swan	*Cygnus atratus*		2		2				60		3	2	2				71
	Total number of waterbirds	**66**	**144**	**85**	**70**	**928**	**133**	**58**	**331**	**108**	**92**	**311**	**186**	**75**	**132**	**117**	**2836**
	Species richness	**10**	**12**	**10**	**13**	**9**	**14**	**7**	**7**	**15**	**19**	**12**	**10**	**8**	**14**	**13**	**29**

Overall, guilds were quite skewed during each survey, with dabbling ducks dominating in spring, dabbling ducks and fish-eaters most represented in summer (with an increase in the number of grebes compared to spring) and fish-eaters being by far the most abundant guild in autumn and grebes just overtaking dabbling ducks as the second-most abundant guild (Table 24).

With regard to species diversity, the large wading birds and fish species were best represented, with six and five species recorded across all surveys respectively. Dabbling ducks, diving ducks, grebes and shorebirds were each represented by three species, filter-feeding ducks by two species and the least diverse guilds with one species recorded for each were the coots and rails (Eurasian coot), grazing ducks (Australian wood duck *Chenonetta jubata*), and swans (black swan *Cygnus atratus*, Table 25).

Species only recorded for one of the three surveys were blue-billed duck and pied stilt *Himantopus leucocephalus* in spring, chestnut teal *Anas castanea*, Australasian shoveler *Anas rhynchotis*, and nankeen night-heron *Nycticorax caledonicus* in summer, and musk duck *Biziura lobata*, straw-necked ibis *Threskiornis spinicollis*, and black-fronted dotterel *Elseyornis melanops* in autumn. Fifteen of the 29 species were present during every survey round (Part B report [Palmer et al. 2022]).

8.4.2 Waterbird breeding

Evidence of waterbird breeding at Hattah Lakes was observed at each survey (Table 26). The most relevant evidence of breeding related to Ecological Objective HL8 (Waterbird breeding), is the presence of large numbers of adult great cormorants on nests at Lakes Cantala and Mournpall (85 and 19, respectively in summer, and 300+ and 80+, respectively in Autumn, Table 26). Further breeding activity by colonial waterbirds was observed at Lake Arawak (Australasian darters), Lake Bitterang and Lake Yelwell (Australasian darter and great cormorant), and Lake Woterap (Australasian darter). Breeding evidence for most species was recorded during the summer survey.

Table 26 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 is shown in bold.

Wetland	Breeding evidence	Species	Spring	Summer	Autumn
Lake Arawak	Adults on nest	**Australasian darter**		**1**	
	Juveniles	**Australasian darter**		**3**	
		Great crested grebe		1	
Lake Bitterang	Juveniles	Eurasian coot		1	
		Great cormorant		**1**	
		Great crested grebe		2	
		Grey teal		15	
Lake Brockie	Juveniles	**Australasian darter**		**4**	
		Eurasian coot		8	
		Great crested grebe		2	
Lake Bulla	Juveniles	Black swan		1	
		Eurasian coot		3	

Wetland	Breeding evidence	Species	Spring	Summer	Autumn
		Great crested grebe		1	
Lake Cantala	Adults on nest	**Great cormorant**		**85**	**300+**
	Juveniles	**Great cormorant**		**9**	
		Grey teal	2		
		Hoary-headed grebe		9	
Lake Hattah	Juveniles	Australian wood duck		2	
		Eurasian coot		8	
		Great crested grebe		5	
		Grey teal		2	
Lake Konardin	Juveniles	Eurasian coot		1	
		Great crested grebe		1	
Lake Kramen	Adults on nest	Pied stilt	4		
	Juveniles	Black swan	5		
Lake Little Hattah	Juveniles	Australian wood duck		2	
		Eurasian coot		8	
		Great crested grebe		3	
		Hoary-headed grebe		8	
		Pacific black duck		3	
Lake Lockie	Juveniles	Eurasian coot		2	
Lake Mournpall	Adults on nest	**Australasian darter**		**1**	
	Juveniles	**Great cormorant**		**19**	**80+**
		Australasian darter		**2**	
		Eurasian coot		2	
		Great crested grebe		3	
		Hardhead		4	
Lake Nip Nip	Juveniles	Australasian grebe		4	
Lake Woterap	Juveniles	**Australasian darter**			**1**
		Grey teal		3	
Lake Yelwell	Adults on nest	**Great cormorant**		**2**	
	Juveniles	**Australasian darter**		**2**	
		Eurasian coot		6	
		Great crested grebe		1	
		Grey teal		4	
Lake Yerang	Juveniles	Great crested grebe		3	

8.5 Discussion

The Hattah Lakes received environmental water in spring 2021 and combined with relatively high rainfall in the Murray-Darling basin, this meant that all wetlands except for Lake Kramen contained copious amounts of water during all three survey rounds, especially in spring. This is in stark contrast to conditions during the previous surveys in 2020-21, when all wetlands except for Lake Kramen were dry (Palmer et al. 2021). The implications of these differences and what they may mean in terms of working towards the Ecological Objectives developed for the Hattah Lakes in relation to waterbirds will be discussed here.

8.5.1 Wetland status, bird abundance and species richness

Waterbird species richness across all three 2021-22 survey rounds was nearly identical to that observed during the 2020-21 surveys (28 species then, 29 species now) and very close to the numbers recorded during the 2019-20 surveys (32 species). This similarity in species richness across years is especially interesting considering the differences in water present at Hattah Lakes. Where about half of the surveyed wetlands contained water in 2019-2020, most wetlands were dry during the 2020-21 surveys and overflowing after environmental watering during the current survey period. Over the previous dry period, when only Lake Kramen held water, this wetland could have been a local waterbird refuge and therefore attracted 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, this meant that surface water was present throughout the wider region. This provided waterbirds the opportunity to spread out over a large area, leading to relatively low waterbird numbers and a moderate species count at the Hattah Lakes Icon Site, despite the abundance of water.

The high amount of water throughout the wetland system was especially favouring species with a preference for open, deeper water such as dabbling ducks, grebes and fish-eaters, guilds that dominated in numbers throughout the year. Most notable was the strong increase in number of fish-eaters, mostly great cormorants, from spring to autumn. In spring, the fresh inflow of water would have mainly brought smaller fish, eggs, and larvae into the wetlands. As the year progressed, fish in the system would have bred and grown, making the wetlands more attractive for fish-eaters that hunt for larger-bodied fish. The number of cormorants was especially high at two of the larger wetlands, Lakes Cantala and Mournpall, which likely offer the best foraging habitat. As the water receded somewhat over summer and autumn, the number of large wading birds increased, likely due to increased availability of shallow water along the wetland margins.

Overall waterbird abundance increased between spring and autumn, which was mostly due to the high influx of great cormorants in summer and especially in autumn. Some guilds, like dabbling ducks and swans showed a decline in numbers over the 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 number of food plants for these species too strongly causing them to move elsewhere to forage. Finally, Eurasian coots showed a marked peak in numbers during the summer surveys. This reflects a high number of juveniles observed at the time, probably following a breeding period in late spring.

Waterbird density peaked either in summer or in autumn at each wetland, which is due to the increasing number of individuals present and reduced extent of surface water available from spring to autumn. Overall, waterbird density increased from 3.1 birds per hectare surface water in spring, to 4 in summer and 5.4 in autumn.

8.5.2 Progress toward ecological objectives

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 >1m) and shallow feeding areas (<0.5m 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, received environmental water in spring 2021 and therefore provided feeding habitat for waterbirds as defined in objective HL7 over the 2021-22 season. This also included the flooding of lignum habitat. Lake Kramen contained a small amount of water in spring and therefore still provided some waterbird habitat, while in summer and autumn this wetland was dry and did not provide any waterbird habitat.

An additional aim of this objective is to record the presence of 11 common waterbird species on an annual basis. Over the 2021-22 season, all 11 selected species have been recorded at the Hattah Lakes Icon Site, ten during each of the three survey rounds (Table 27).

At this stage of the 2020-30 ten-year period, objective HL7 is still on track to be met at the Hattah Lakes Icon Site (Table Y).

Table 27 Waterbird species to be recorded annually at Hattah Lakes to attain objective HL7, and whether these species have been recorded during the spring 2021, summer and/or autumn 2022 surveys

Target species	2021-22		
	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	●	●	●

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 8.2 for a full list of species). Evidence of successful breeding was observed for Australasian darters in both summer and autumn (fledged juveniles and active breeding), and for great cormorants in summer, with active breeding observed in autumn (no fledged juveniles) (Table 28). Objective HL8 is therefore still on track to be reached successfully by 2030 (Table 29).

Table 28 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 2021-22 survey period. Black dots indicate successful breeding (fledged juveniles observed) and white dots indicate active breeding observed without presence of fledged juveniles.

Target species	2021-22		
	Spr	Sum	Aut
Australasian darter		●	●
Australian white ibis			
Glossy ibis			
Great cormorant		●	○
Great egret			
Intermediate egret			
Little black cormorant			
Little pied cormorant			
Royal spoonbill			
White-necked heron			
Yellow-billed spoonbill			

Table 29 Summary of waterbird target attainment in 2021–22

Objective	Progress	
	On target	Off target
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	✓	

8.5.3 Implications for management

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.

9 Non-waterbirds

9.1 Introduction

In addition to waterbird counts, the 2021-22 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 can provide valuable insights 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 within which each non-waterbird species identified by sight or sound was recorded. Evidence of breeding and recruitment (i.e. nests and juveniles) were recorded opportunistically.

9.3 Results

Fifteen wetlands in the Hattah Lakes Icon Site were surveyed for non-waterbird species between 15 and 18 November 2021 (spring), 31 January and 3 February 2022 (summer) and 2 and 4 May 2022 (autumn). The list of surveyed wetlands can be found in the Waterbirds chapter of this report. In total 1850 non-waterbirds comprising 46 species were observed; 516 (31 species) in spring, 542 (34 species) in summer, and 792 (34 species) in autumn (see Part B report [Palmer et al. 2022]).

9.3.1 Number and species richness of non-waterbirds

The highest number and diversity of non-waterbirds (798) was observed at Lake Kramen, with consistently relatively high numbers observed during each survey. Lake Hattah had the second-highest non-waterbird abundance (231 individuals), mainly due to a high number of little corellas *Cacatua sanguinea* counted in autumn (163). The lowest number and diversity of non-waterbirds was observed at Lake Woterap (17 individuals of six species). Numbers were also relatively low at Lakes Yerang and Brockie with 25 and 28 individuals counted, respectively. These lakes consequently also showed low species diversity with 11 and eight species observed, respectively.

As during the 2020-21 surveys, little corellas were the most abundant species (588), largely due to large flocks observed at Lake Kramen in spring (222 individuals) and Lake Hattah in autumn (163 individuals). The next most abundant non-waterbird species, each with over 100 individuals counted, were regent parrots *Polytelis anthopeplus* (197 individuals, mostly at Lake Kramen), noisy miners *Manorina melanocephala* (173 individuals, spread across all wetlands), tree martins *Petrochelidon nigricans* (147 individuals, mostly at Lake Mournpall), and galahs *Eolophus roseicapillus* (109 individuals, also mostly at Lake Kramen) (Part B report [Palmer et al. 2022]). The least encountered species (only one individual) were brown treecreeper *Climacteris picumnus*, crested pigeon *Ocyphaps lophotes*, little grassbird

Poodytes gramineus, peaceful dove *Geopelia striata*, peregrine falcon *Falco peregrinus*, and restless flycatcher *Myiagra inquieta*.

Some vulnerable and near-threatened species were also recorded. Small to medium-sized flocks of Regent Parrots, nationally listed as vulnerable were observed at eight of the surveyed wetlands. Most were seen in autumn, but at Lakes Cantala, Kramen, and Little Hattah regent parrots were observed at each of the three surveys. Also noteworthy was the presence of white-bellied sea-eagles *Haliaeetus leucogaster*, listed as endangered under the FFG Act, at Lakes Bitterang, Cantala and Yelwell. At Lake Bitterang an adult was observed feeding a juvenile near a nest in autumn, which indicates this species has successfully bred at this wetland over summer. Apostlebirds *Struthidea cinerea*, listed as vulnerable under the FFG Act, were observed in spring at Lake Nip Nip and in autumn at Lake Little Hattah.

The Part B report accompanying this Part A report (Palmer et al. 2022) 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 2021 surveys two juvenile white-winged choughs *Corcorax melanorhamphos* were seen at Lake Hattah, tree martins *Petrochelidon nigricans* were seen flying in and out of tree hollows at Lake Little Hattah, and at least two juvenile nankeen kestrels *Falco cenchroides* were counted in a tree hollow over Lake Nip Nip. In summer, two juvenile galahs were seen being fed by adults at Lake Little Hattah, one juvenile Australian magpie *Gymnorhina tibicen* at Lake Nip Nip, a juvenile sacred kingfisher *Todirhamphus sanctus* at Lake Mournpall, a juvenile magpie-lark *Grallina* cyanoleuca at Lake Yelwell, and a juvenile pied butcherbird *Cracticus* nigrogularis at Lake Kramen. In autumn, as mentioned above, a juvenile white-bellied sea-eagle was seen being fed by an adult near a nest at Lake Bitterang, and galahs were observed inspecting tree hollows at Lake Kramen. This is an increase in the number of species for which breeding activity was observed in the 2020-21 survey season (nine species during the current surveys against three for the 2020-21 surveys).

9.3.3 Lakebed use by non-waterbirds

Non-waterbirds were observed using the lakebed at 10 out of the 15 surveyed wetlands. Of all 1850 non-waterbirds observed during the 2021-22 season, 219 (11.8%) individuals, comprising 14 species (30.4% of species recorded) were observed using lakebeds.

At Lake Kramen, which was largely or completely dry during each survey, some non-waterbird species were observed foraging anywhere on the dry lakebed or perched in single trees growing out of the lakebed. All other wetlands held water during each survey and consequently 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 hunters such as welcome swallows *Hirundo neoxena*, tree martins and whistling kites *Haliastur sphenurus*, which were observed flying over the water.

Species exclusively observed on lakebeds included emu *Dromaius novaehollandiae*, welcome swallow, and little grassbird. Other species recorded using lakebeds were apostlebird, Australian magpie, Australian raven *Corvus coronoides*, grey fantail *Rhipidura albiscapa*, little corella, magpie-lark, rufous whistler *Pachycephala rufiventris*, spiny-cheeked honeyeater *Acanthagenys rufogularis*, tree martin, white-plumed honeyeater *Ptilotula penicillatus*, and willie wagtail *Rhipidura leucophrys*.

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 2020-21 surveys, Lake Kramen had by far the highest count of non-waterbirds of the surveyed Hattah Lakes wetlands, over three times as many individuals as the wetland with next-highest non-waterbird count, Lake Hattah. This suggests Lake Kramen, whether dry or containing water, is an important non-waterbird site within the Hattah Lakes area. It is possible that its location at the edge of the Hattah-Kulkyne National Park with nearby almond plantations and other agricultural areas means that higher numbers of non-waterbirds frequent this area, compared to other wetlands in the system.

Non-waterbird counts were not directly related to species richness at the surveyed wetlands. While Lake Kramen recorded the highest species diversity (24 species), wetlands with significantly lower numbers of individuals still harboured a relatively high number of species. For example, 118 individuals of 22 species were recorded at Lake Cantala, and at Lake Nip Nip 43 individuals of 19 species. Wetland size and inundation status are therefore not direct predictors of the number of species they support. This is likely more affected by 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. These are important determinants of food availability, shelter, and nesting opportunities for many non-waterbird species. 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

The variety of non-waterbird species observed at the Hattah Lakes and the range of habitats they prefer is a good indication of the importance of the wetlands in supporting biodiversity. At low water levels, such as at Lake Kramen for the current survey period, they provide foraging habitat for species such as Australian magpies, Australian ravens, and emus. At high water levels, aerial insect hunters such as tree martins and welcome swallows are attracted to the insects associated with open water. Indirectly, by supporting a variety of vegetation types around the margins such as river red gums, tangled lignum, and patches of herbaceous plants, many other species are able to find food and shelter here, as well as places to perch in the form of dead and fallen trees.

Nationally vulnerable Regent Parrots were also observed at eight of the 15 wetlands, with most seen at Lake Kramen, as was the case during the 2020-21 surveys (Palmer et al. 2021). Hollow-bearing trees throughout the Hattah Lakes 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 containing hollows along many of the wetland margins, and therefore for the long-term survival of threatened species such as regent parrots and white-bellied sea-eagles for which they provide important breeding habitat.

9.4.3 Implications for management

Non-waterbirds rely on vegetation that provides them with food, shelter and breeding opportunities and the current surveys show that the Hattah Lakes wetlands currently provide habitat to a substantial number of species, including some of national and state significance. Vegetation quality and therefore bird diversity depends on water management that allows such vegetation to thrive across the wetlands.

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 and 2015 when no sampling occurred. The background and methods used is described in the most recent program design report (Mallee CMA 2021b).

Several refinements have been made over the duration of the monitoring program:

- Switching the timing of sampling from spring (2005–2008) to autumn (2010 onwards)
- 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) compared to two netters previously
- The removal of bait traps as a sampling technique (2021 onwards)
- The requirement to PIT tag native large-bodied fish (2021 onwards).

10.2 Ecological objectives

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 23).

Table 30 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).

10.3 Methods

10.3.1 Sampling design

As outlined in the program design (Mallee CMA 2021b), the monitoring program 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 24).

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 31 TLM Condition Monitoring fish sites in 2022.

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

Not all sites have been sampled on an annual basis and not all gear types or sampling effort has been used each year (see Table 32). Wetland and Anabranch sites are typically dry in the absence of environmental watering, with all Wetland and Anabranch sites dry for the previous two years of monitoring (2020–2021). The current year (2022) is the first year since 2018 that all sites spanning all macrohabitats have been sampled, and only one of five monitoring years (2006–2022) that this has occurred (2006, 2014, 2017, 2018 and now 2022).

The main differences in gear use and effort were in the early years of the monitoring program due to backpack electrofishing not being used in addition to the netting effort in Wetland and Anabranch sites until 2010, and sampling occurring in spring rather than autumn from 2006–2008.

Table 32 Summary of sampling data continuity over time. * = years where spring sampling occurred instead of autumn (note in 2008 the electrofishing occurred in spring and the netting primarily in autumn). See key below for colour interpretation.

Macrohabitat (bold) & site	Year														
	2006*	2007*	2008*	2010	2011	2012	2013	2014	2016	2017	2018	2019	2020	2021	2022
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)

10.3.2 Sampling method

Fish sampling was undertaken between 28 February and 12 April 2022. Sampling was undertaken at all sites, and the location of sites was consistent with previous years.

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

- Overnight deployment of a pair of small-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 rigid plastic 50 x 50 mm rigid plastic meshed exclusion grid to stop entrapment of non-target fauna (e.g. turtles, rakali) and larger bodied fish.
- Seine netting consisted of a single haul at each site, comprising 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 protocols (e.g 8 x 150 second shots). 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 was undertaken using Sustainable Rivers Audit protocols (i.e. 12 x 90 second shots) (MDBC 2007). 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. GPS coordinates, settings and outputs were logged at one second intervals, resulting in a sampling 'track' for future reference.

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 reduce 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.

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) 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 (120–300/350 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 recaptures between years). The dart tag also facilitates reporting of capture information from recreational fishermen, 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.

10.3.3 Data analyses

Data preparation

Fish community data preparation included grouping species into four 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 analysis here, we used the following decisions to improve uniformity of treatment of fish community data across sites:

- Use small-bodied fish catches (both introduced and native species) from small fykes and seine net operations.
- Use small-bodied fish catches from electrofishing (boat and backpack).
- Use large-bodied fish catches from electrofishing (boat and backpack) and coarse-meshed fykes.

This effectively meant that 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 'Electro-fishing' (including both boat and backpack data) and 'Net Methods' (including coarse and small/larval fyke nets) for further analysis.

Fish community data from Hattah Icon Site sampling locations were only considered from 2010 onwards, as all sampling pre 2009 was conducted in spring, and post 2009 was conducted in autumn. Sampling did not occur in 2009 and 2015, so 12 sampling events have been analysed in this report. Due to variable formats being used for some aspects of the effort data, total catch of all gear replicates was summed to a site total for comparison between sites within reaches (there are three sites per reach) or macrohabitats (i.e. rather than calculate Catch Per Unit Effort [CPUE]). The reaches are assigned to flow-based macrohabitats of interest within the TLM program (i.e. Anabranch, Riverine and Wetland).

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 both the non-transformed abundance data of species in the community and the presence absence data. PERMANOVA was run on site totals across 2010–2022 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 while Jaccard distances were used for the analysis of presence/absence 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.

10.3.4 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.

10.4 Results

10.4.1 Raw abundance overview

An overview of the 2022 fish monitoring results, based on total raw abundances across the entire Icon Site (compared with previous years), is provided in Table 33. This data should be interpreted with caution for several reasons, including that the total number of sites sampled per year and the sampling effort at some sites have changed over time. However, the following points are made regarding the overview results:

- There has been a substantial increase in the total numbers of golden perch *Macquaria ambigua* detected in 2022, the highest since monitoring began, far exceeding the previous record set in 2011.
- Silver perch *Bidyanus bidyanus* continue to be detected in low abundance despite the highest total numbers recoded since 2010.
- Carp *Cyprinus carpio* total numbers increased drastically in 2022 to the highest since 2014, including the survey years where all sites were sampled (2016–19).
- All previous detected fish species were detected during the 2022 monitoring surveys, apart from spangled perch *Leiopotherapon unicolor,* a species last recorded in 2012.

Table 33 Summary of the 2010–2022 Hattah fish monitoring results by flow guild designations (Baumgartner et al. 2014) and large-bodied fish in bold.

		Year											
		2010	2011	2012	2013	2014	2016	2017	2018	2019	2020	2021	2022
		# of sites sampled											
Common name	Scientific name	21	21	27	9	27	21	27	27	15	3	3	27
Long-lived apex predators													
Murray Cod	***Maccullochella peelii***	5		1	7	30	52		8	38	49	62	31
Flow dependent specialists													
Silver Perch	***Bidyanus bidyanus***	11	1	1	1	3	2		5	1	4	1	9
Golden Perch	***Macquaria ambigua***	32	78	41	12	35	31	41	34	44	21	40	229
Foraging generalists													
Bony Herring	***Nematalosa erebi***	672	126	337	270	1190	494	449	513	418	252	177	299
Unspecked Hardyhead	*Craterocephalus fulvus*	214	1263	97	19	81	198	25	9	28	187	114	100
Carp Gudgeon complex	*Hypseleotris sp*	213	46029	14700	323	641	11026	34765	24393	8628	64	68	6881
Murray-Darling Rainbowfish	*Melanotaenia fluviatilis*	23	39	10	11	32	98	77	4	31	84	74	69
Flat-headed Gudgeon	*Philypnodon grandiceps*	8	191	170	1	1	666	1404	1312	451	17	8	751
Dwarf flat-headed Gudgeon	*Philypnodon macrostomus*		1				12	41	35	12			8
Australian Smelt	*Retropinna semoni*	401	203	37	27	133	1969	4838	7276	262	124	100	573
Unassigned native fish													
Spangled Perch	***Leiopotherapon unicolor***		1	1									
Unassigned introduced fish													
Carp	***Cyprinus carpio***	39	1126	604	81	6950	46	988	104	144	41	45	1564
Goldfish	***Carassius auratus***	32	36	151	1	56	8	5	19		1	6	55
Goldfish x Carp	***Carassius auratus X Cyprinus carpio***												1
Eastern Gambusia	*Gambusia holbrooki*	170	4960	1283	444	2346	12437	6823	25375	404	148	23	20509
Oriental Weatherloach	*Misgurnus anguillicaudatus*		49	8		54	8		5				1
Total		**1820**	**54103**	**17441**	**1197**	**11552**	**27047**	**49456**	**59092**	**10461**	**992**	**718**	**31081**
Average number of fish per site		*87*	*2576*	*646*	*133*	*428*	*1288*	*1832*	*2189*	*697*	*330*	*239*	*1151*

10.4.2 Species detection over time

Native species

The detection of native species over the course of the 2010–2022 monitoring period for each macrohabitat is illustrated in Figure 49 and Figure 50 for large-bodied and small-bodied species respectively.

Bony herring *Nematalosa erebi* and golden perch are the most frequently detected large bodied native fish, being detected every year in all macrohabitats, when the Anabranch and Wetland macrohabitats contain water.

Murray cod *Maccullochella peelii* and silver perch have been more frequently detected across sampling years at Riverine sites, with a small number of occurrences at Wetland sites of Murray cod in 2010, 2014 and 2019 and silver perch in 2010, 2011, 2014 and 2022. At Anabranch sites there is only one detection each of Murray cod and silver perch, in 2014 and 2010 respectively.

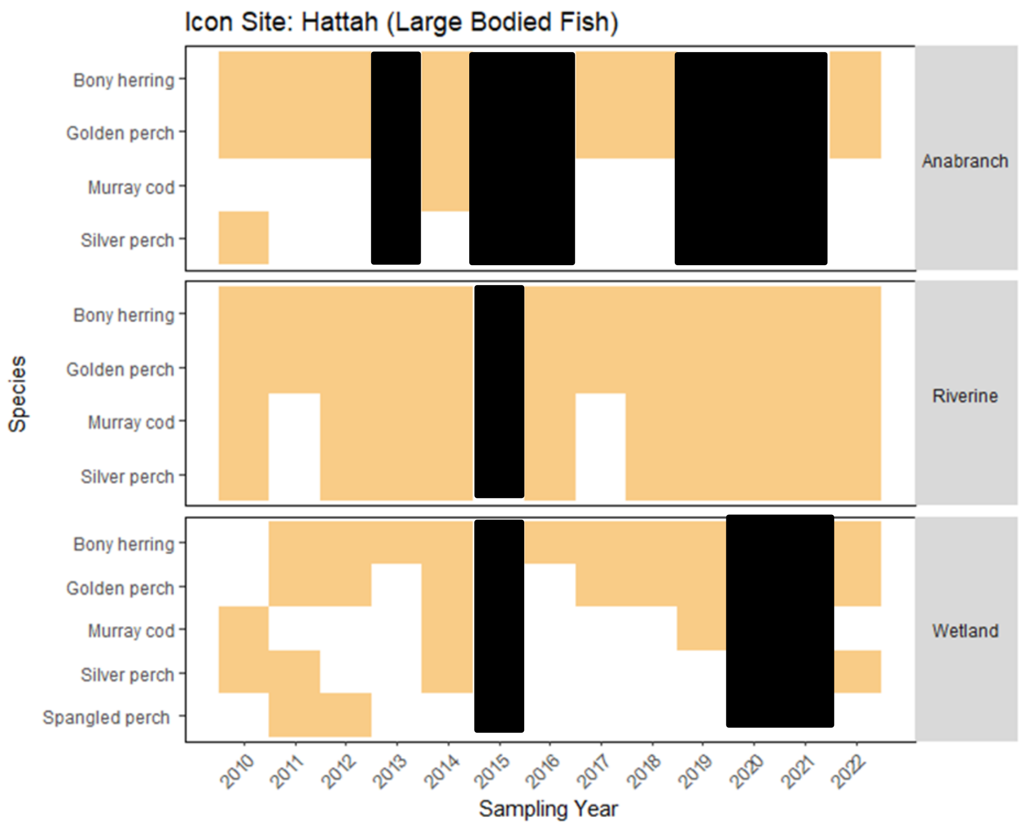


Figure 49 Detection of large-bodied native fish species over the 2010–2022 monitoring period for each macrohabitat. Black bars indicate no sampling occurred (see Table 32).

For the first time since during the 2010–2022 monitoring period, all small-bodied native species that have previously been recorded were detected at all macrohabitats (Figure 50).

The most commonly detected native small-bodied fish are carp gudgeon, unspecked hardyhead, Murray-Darling rainbowfish, flat-headed gudgeon and Australian smelt. Aside from carp gudgeon, (which has been consistently detected across years in all macrohabitats), the other small-bodied species have only been detected in some years or macrohabitats. However, three of these species, Australian smelt, Murray-Darling rainbowfish and unspecked hardyhead, have always been detected from the Riverine macrohabitat.

Dwarf flat-headed gudgeon is the least commonly detected small-bodied native species, mostly being recorded from Wetland sites. In 2022 dwarf flat-headed gudgeon were recorded for only the second time from the Riverine macrohabitat, and for the first time from the Anabranch macrohabitat.

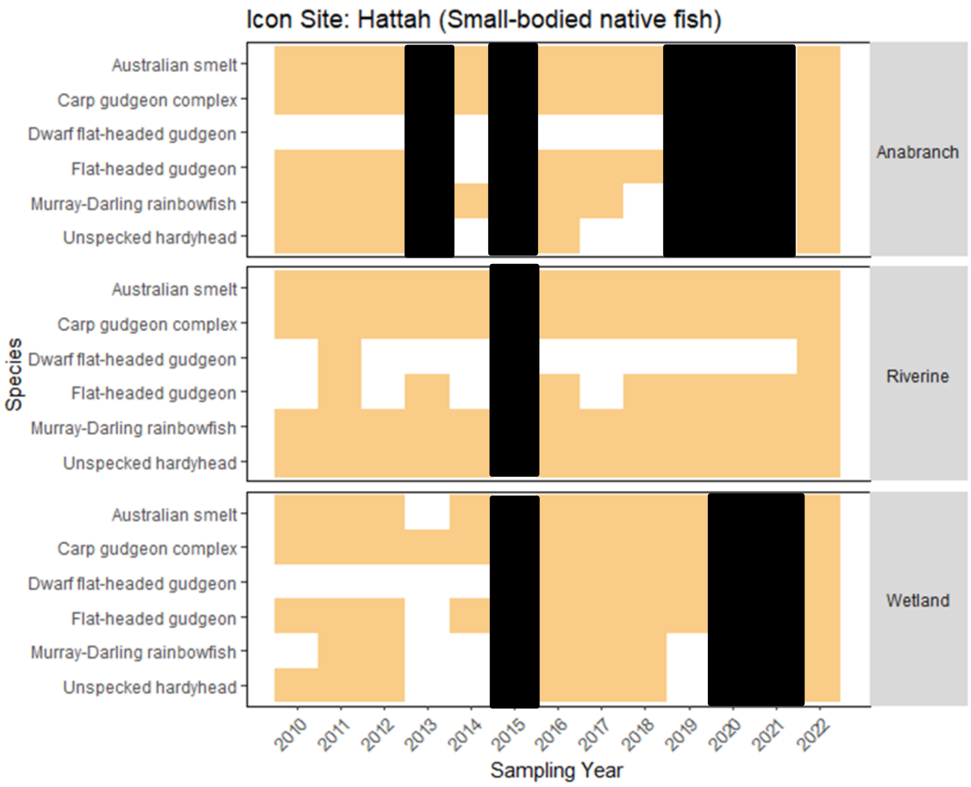


Figure 50 Detection of small-bodied native fish species over the 2010–2022 monitoring period for each macrohabitat. Black bars indicate no sampling occurred (see Table 32).

Introduced species

Carp and eastern gambusia have been detected in every sampling event since 2010 (Figure 51). Carp have always been detected at all three macrohabitats. Eastern gambusia has almost always been detected from all three macrohabitats. Goldfish has been recorded from all three macrohabitats on five occasions including 2022. Oriental weatherloach is the most infrequently detected introduced species, being more typically detected at Wetland and Anabranch sites, with 2022 being only the second time over the 2010–2022 monitoring period that the species has been detected from the Riverine macrohabitat.

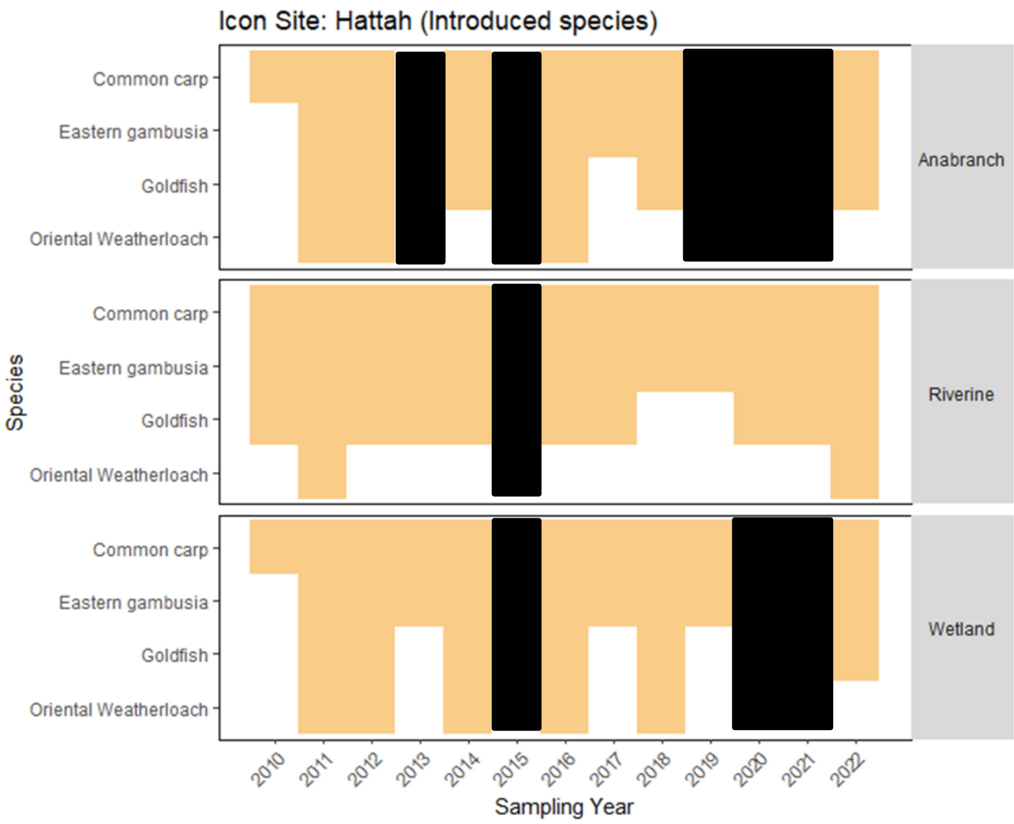


Figure 51 Detection of introduced fish species over the 2010–2022 monitoring period for each macrohabitat. Black bars indicate no sampling occurred (see Table 32).

10.4.3 Abundance

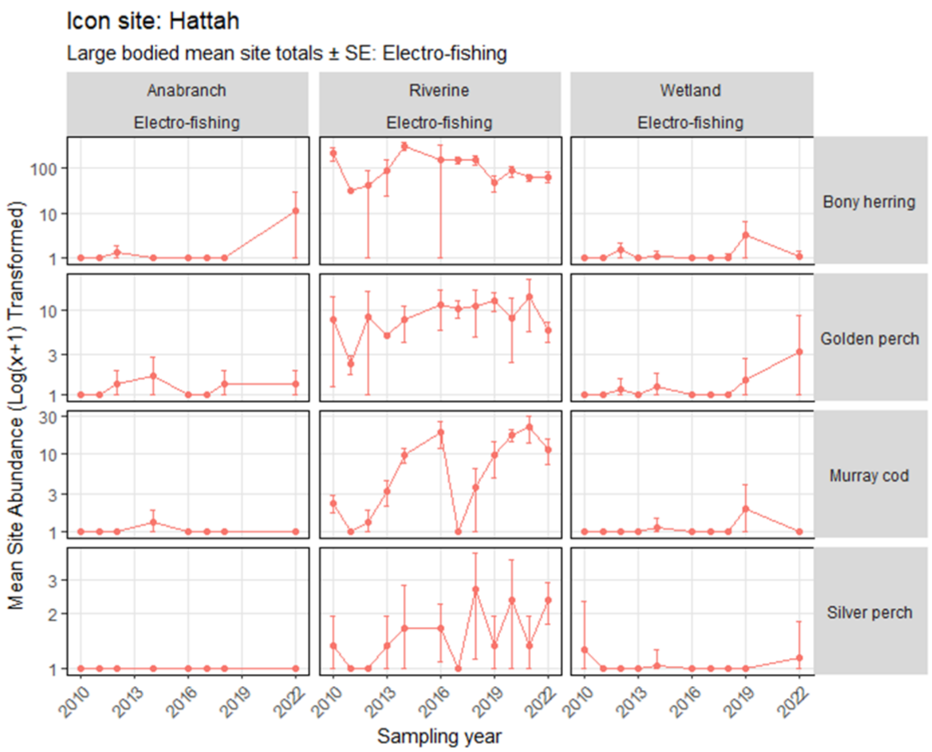
Large-bodied native fish

Large-bodied native fish are typically in higher abundance at Riverine sites than either Anabranch or Wetland sites (Figure 52), although a truly valid comparison cannot be made due to the different sampling gears being applied in the macrohabitats.

Throughout the monitoring period, golden perch are occasionally sampled in reasonable abundance in Anabranch (2010–2011) and Wetland habitats (2011 and 2022). However, in 2022 golden perch abundance at Wetland sites was the highest recorded over the monitoring period (based on both electrofishing and netting data), although catches were highly variable between sites. Bony herring abundance at Anabranch sites in 2022 was the highest recorded based on electrofishing data and third highest recorded based on netting data but was again highly variable between sites.

Murray cod are predominantly captured in Riverine macrohabitat only and have rarely been detected at Anabranch or Wetland sites (2010, 2014, 2019). The abundance of Murray cod has been highly variable within Riverine sites across years, with 2022 being comparable to 2019, and therefore a slight decline from the record abundance of 2021. Murray cod abundance has increased over two distinct periods (2012–2016 and 2018–21), following dramatic declines that coincided with flooding/blackwater events in 2011 and 2016.

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. Silver perch abundance at Wetland sites in 2022 was the highest recorded since 2010, the first time the species has been recorded at the Wetland sites since 2014 (excluding salvage from Lake Mournpall in 2020) and the first time they have been detected at Lakes Arawak, Bulla and Lockie during the monitoring program.



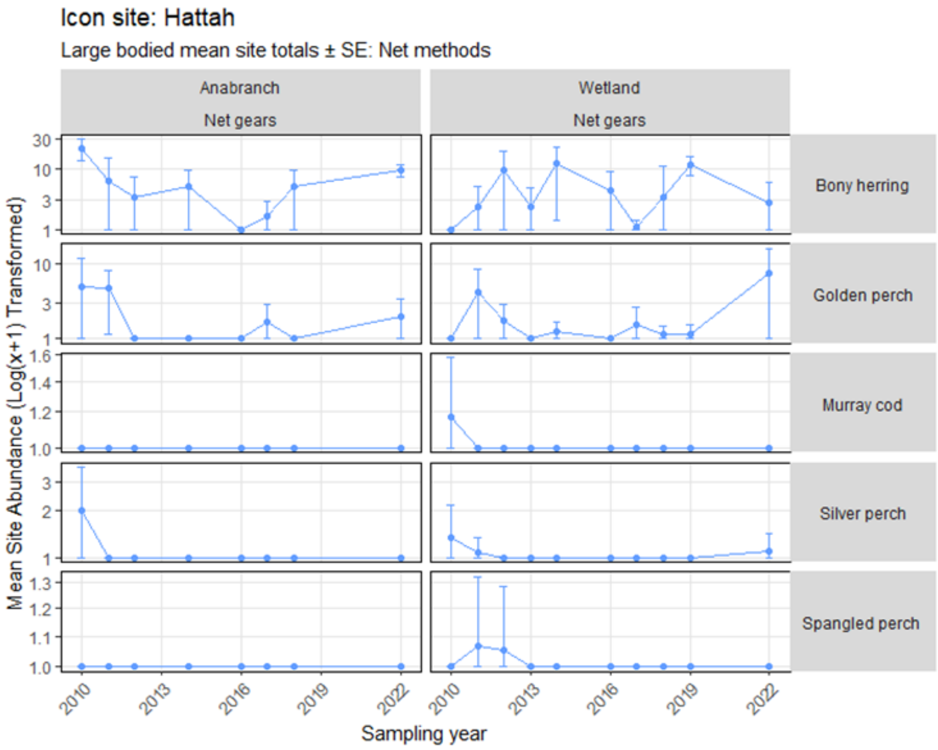


Figure 52 Annual mean total site abundance of large-bodied native species at each macrohabitat, separated boat and backpack electrofishing (top) and nets (coarse-meshed fyke nets and seine) (bottom).

Small-bodied native fish

Carp gudgeon are typically the most abundant fish species throughout the monitoring program and are more abundant at Anabranch and Wetland sites than Riverine sites, particularly over the 2016–2019 and 2011–2012 periods. Other abundant species include Australian smelt and unspecked hardyhead. Australian smelt abundance generally peaked over the 2016–2018 period before declining substantially in 2019 (during the later stages of drawdown) at the Wetland sites. In 2022, the species was again detected in relatively high abundance at Riverine and Anabranch sites and very low abundance at Wetland sites.

Unspecked hardyhead and Murray-Darling rainbowfish abundances are highly variable at Riverine sites but are generally in much lower abundance at Anabranch and Wetland sites, aside from a peak in 2011 (unspecked hardyhead). While the abundance of Murray-Darling rainbowfish was low and highly variable between Wetland sites in 2022, the abundance was the highest recorded for this species from this macrohabitat over the 2010–2022 monitoring period.

Flat-headed gudgeon has been notably more abundant at Wetland sites than both Riverine or Anabranch sites over the 2016–2019 period and again in 2022. The abundance of this species has increased considerably over these years compared with the earlier years of the program (2010–2014) at all macrohabitats based on the electrofishing data.

Dwarf flat-headed gudgeon have been present sporadically and in low abundance throughout the monitoring program, however they are typically more abundant at Wetland sites, particularly over the 2016–2019 period. The 2022 electrofishing abundances of dwarf flat-headed gudgeon were the highest recorded over the 2010–2022 monitoring period at all three macrohabitats.

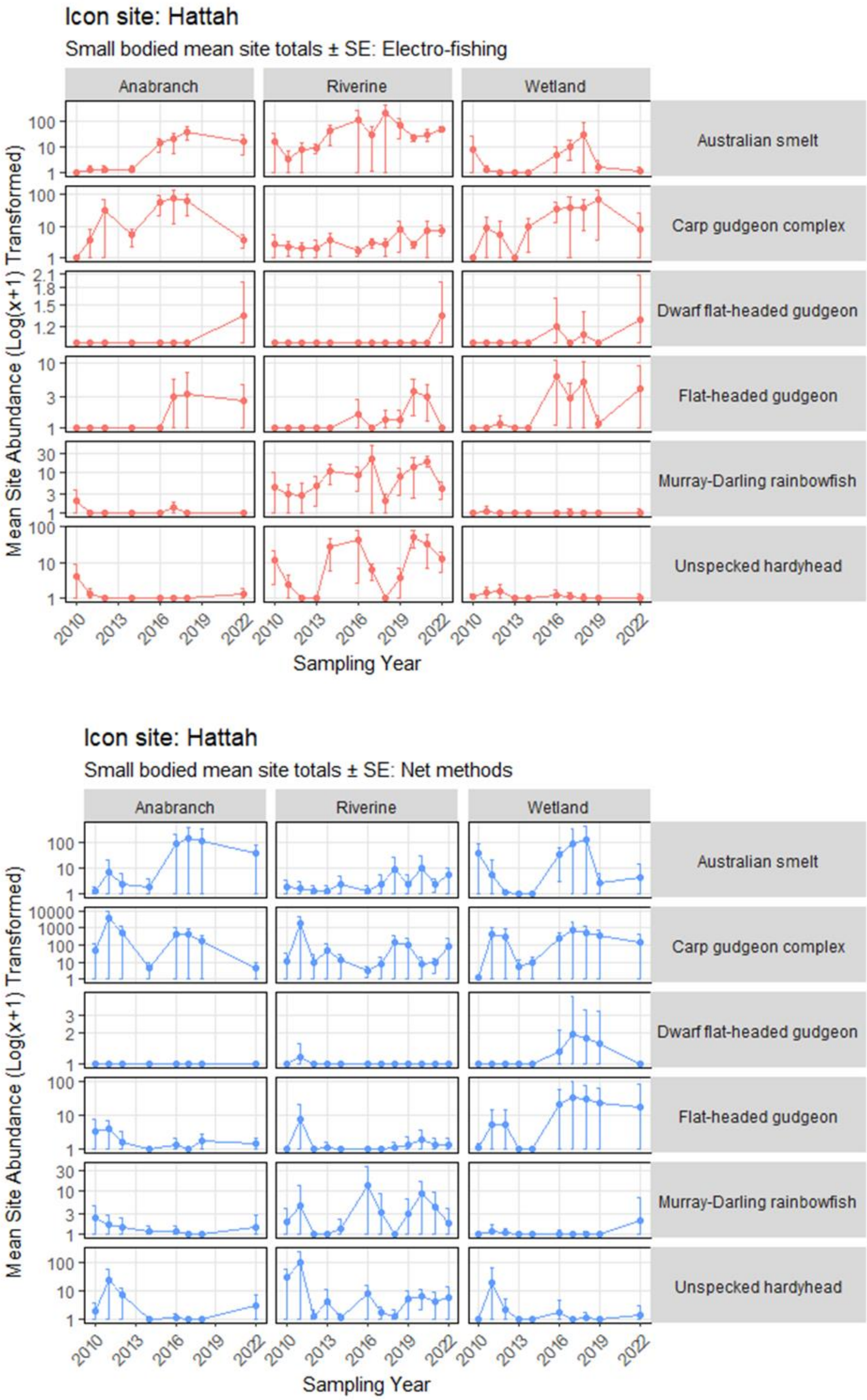


Figure 53 Annual mean total site abundance of small-bodied native species, separated by boat and backpack electrofishing (top) and nets (fyke and seine) (bottom).

Introduced fish

Carp abundance has fluctuated considerably throughout the monitoring program. At the Riverine sites, a large peak is evident in 2017 following the November 2016 flooding event, and a much smaller increase occurred in 2022 following a period of relative stability over 2018–2021 (Figure 54). However, the 2022 carp abundance at Anabranch sites was the highest recorded over the 2010–2022 monitoring period based on electrofishing and third highest recorded based on netting (behind 2011 and 2012). At Wetland sites, carp abundance was the second highest recorded based on electrofishing (behind 2014) and third highest recorded based on netting (behind 2011 and 2014).

Eastern gambusia abundance was the highest recorded from all three macrohabitats over the 2010–2022 monitoring period, based on electrofishing data, and the highest abundances recorded from Anabranch sites and third highest recorded from Wetland sites based on netting data. High levels of variability were evident between sites for both the electrofishing and netting data.

Goldfish have been recorded sporadically in variable low numbers throughout all macrohabitats across all years. In 2022 goldfish abundance at Wetland sites was the highest recorded over the 2010–2022 monitoring period based on electrofishing data, but only the fourth highest based on netting data, with a high level of between site variability with either method.

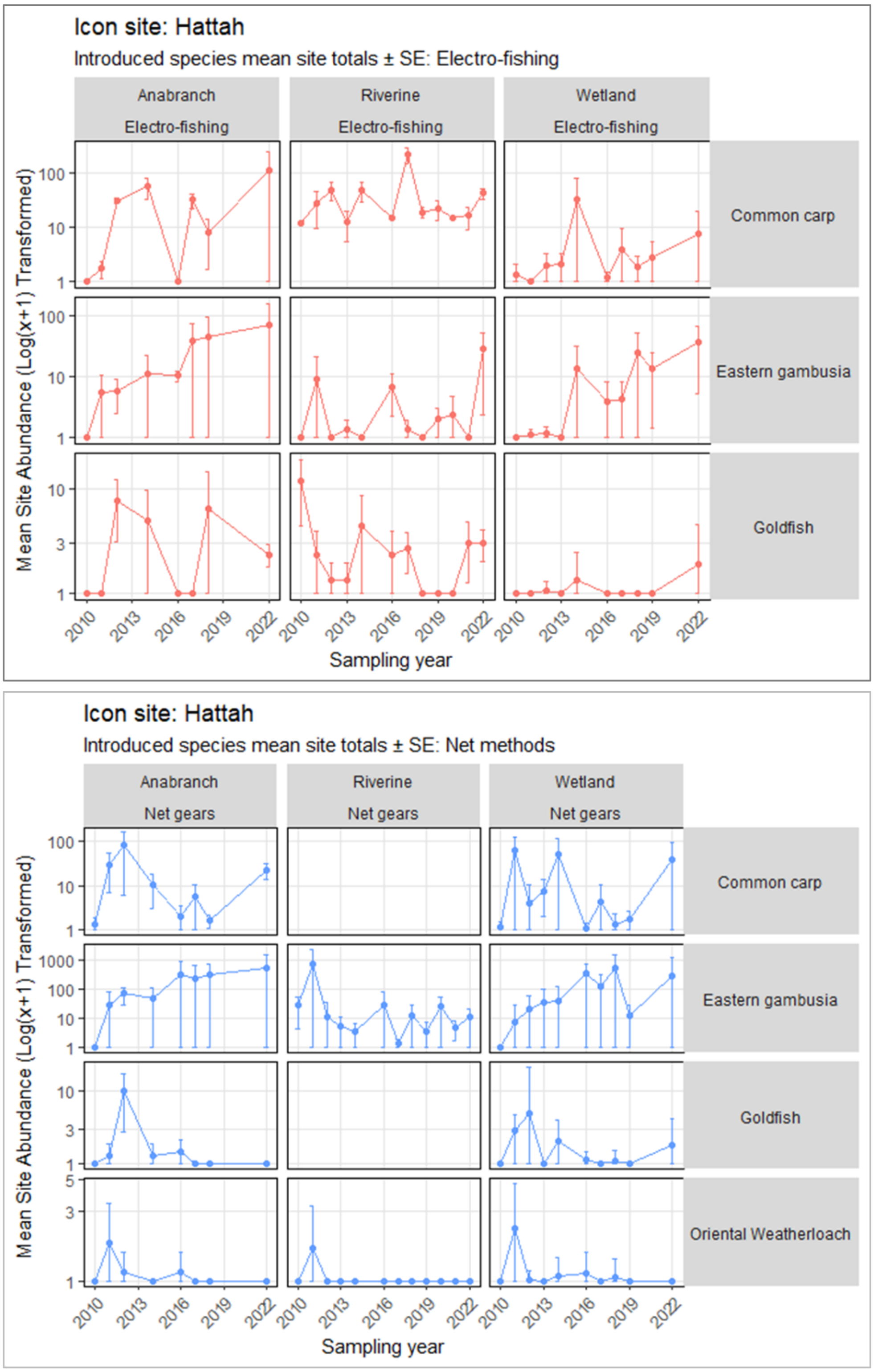


Figure 54 Annual mean total site abundance of introduced species, separated by boat and backpack electrofishing (top) and nets (coarse or fine-meshed fykes depending on whether large- or small-bodied species, and seine) (bottom).

10.4.4 Community structure

The fish community structure at the Hattah Lakes Icon Site differed significantly between years and among macrohabitats (PERMANOVA results P < 0.05 for all factors; Table 34 and Table 35). This can also be seen in the nMDS plots, where some gradients and clusters occurred, irrespective of whether abundance or presence data is analysed (Figure 55 and Figure 56). The interaction between macrohabitat and year was significant when using either abundance or presence data for analysis (P = 0.001; Table 34 and Table 35), indicating that the fish community changed among years inconsistently across the macrohabitats. 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 (P = 0.001; Table 34 and Table 35).

The significant differences in fish community structure between year and macrohabitat are evident in the nMDS plots, with 2022 being a fairly unique year overall based on abundance data (Figure 55b), but not based on presence data (Figure 56b). Based on abundance, the 2022 Riverine fish community is most similar to the 2011 Riverine fish community and to a lesser extent that of 2016–17 and 2020–21; however, based on presence data, the Riverine fish community is most similar to 2020 and 2021. The 2022 Anabranch fish community is most similar to 2014, and to a lesser extent 2011, based on abundance data but is distinct based on presence data, whilst the 2022 Wetland fish community is most similar to 2014 based on abundance data but is distinct based on presence data. The Riverine macrohabitats group together in most years. There are tighter groups by macrohabitat in most years when examining presence data rather than absence data, with Anabranch macrohabitat grouping together closely in most years except 2010, and Riverine macrohabitat grouping closely together in most years except 2022.

When the electrofishing and netting data are separated, it is clear that the majority of the dispersion in the site data points (using either abundance or presence data) is in the electrofishing data (see Figure 55d and Figure 56d), indicating higher levels of detection and abundance variability in the electrofishing data compared with the netting data. This is probably to be expected, given boat electrofishing (used for Riverine sites) and backpack electrofishing (used for Wetland and Anabranch) are not directly comparable. The fish community structure at Riverine macrohabitats group closely together by year when using either abundance data or presence data, so most of the dispersion between years is in the backpack electrofishing data at Anabranch and Wetland macrohabitats. The 2010 Wetland fish community is particularly distinct based on both abundance and presence electrofishing and netting data. The 2013 Wetland fish community and the 2010 Anabranch fish communities are also particularly distinct based on both abundance and presence electrofishing data.

Based on the SIMPER results, the species that are most influential for the differences between years and macrohabitats differ considerably depending on whether abundance or presence data is used for analyses (see Part B Report, Palmer et al. 2022). Carp gudgeon and eastern gambusia are the most influential for most between-year differences based on abundance data, with bony herring and carp being slightly more influential for some year comparisons. When exploring the between-year differences based on presence data, the most influential species are highly variable.

When exploring the fish community structure differences between macrohabitats based on abundance data, carp gudgeon are the most influential species for each of the three comparisons, followed by eastern gambusia (Part B Report, Palmer et al. 2022). When the presence data is used (Part B Report, Palmer et al. 2022), 6–8 species are influential for each of the comparisons, with Murray cod marginally being the most influential for differences between Anabranch and Riverine macrohabitats, Murray-Darling rainbowfish marginally being the most influential between Wetland and Riverine macrohabitats, and flat-headed gudgeon marginally being the most influential between Anabranch and Wetland macrohabitats.

Table 34 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 highlighted.

Abundance	Df	SumsOfSqs	F.Model	R2	Pr(>F)
Macrohabitat	2	6.755	21.3886	0.10081	0.001
Year	11	21.371	12.3039	0.31896	0.001
Macrohabitat:Year	16	9.033	3.5754	0.13482	0.001
Residuals	189	29.844		0.44541	
Total	218	67.004		1	
Abundance with Reach Strata	Df	SumsOfSqs	F.Model	R2	Pr(>F)
Macrohabitat	2	6.755	21.3886	0.10081	0.001
Year	11	21.371	12.3039	0.31896	0.001
Macrohabitat:Year	16	9.033	3.5754	0.13482	0.001
Residuals	189	29.844		0.44541	
Total	218	67.004		1	

Table 35 PERMANOVA partitioning and analysis of fish assemblage presence data between macrohabitats and years (using Jaccard distances), including a test for the effect of 'reach' strata. Significant p-values highlighted.

Presence	Df	SumsOfSqs	F.Model	R2	Pr(>F)
Macrohabitat	2	3.931	27.4609	0.11742	0.001
Year	11	11.946	15.1719	0.35681	0.001
Macrohabitat:Year	16	4.704	3.5576	0.12170	0.001
Residuals	189	13.528		0.40408	
Total	218	33.479		1	
Presence with Reach Strata	Df	SumsOfSqs	F.Model	R2	Pr(>F)
Macrohabitat	2	3.931	27.4609	0.11742	0.001
Year	11	11.946	15.1719	0.35681	0.001
Macrohabitat:Year	16	4.704	3.5576	0.12170	0.001
Residuals	189	13.528		0.40408	
Total	218	33.479		1	

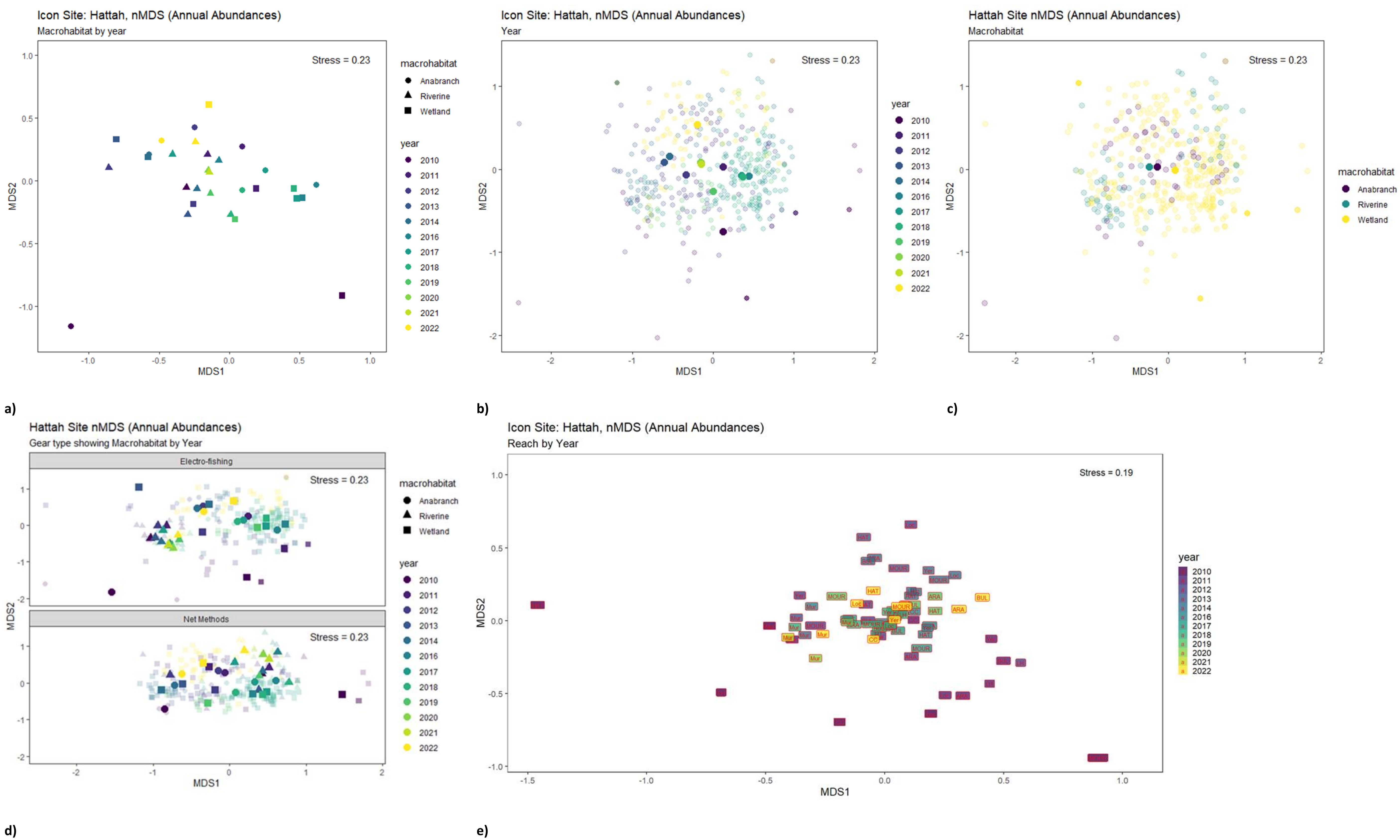


Figure 55 nMDS plot of community composition for annual site abundance by a) macrohabitat and year (centroids only), b) year only (centroids in bold), c) macrohabitat only (centroids in bold), d) macrohabitat and year separated by gear type (top – electrofishing and bottom – fyke nets/seine hauls), and e) reach and year (centroids only). Note high stress levels in nMDS plots (i.e. Stress = >0.20) means these plots should be used only as a guide.

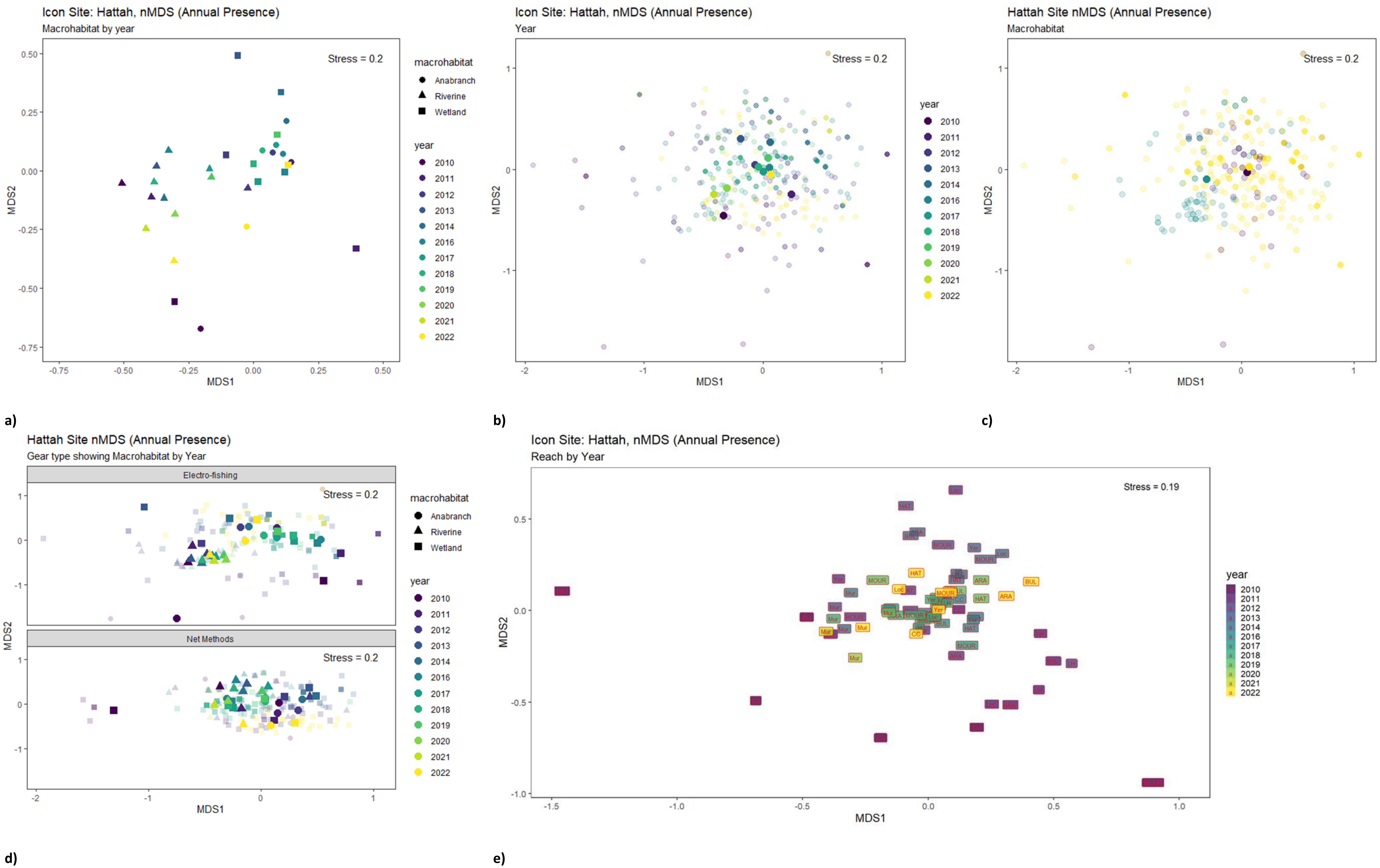


Figure 56 nMDS plot of community composition for annual site presence by a) macrohabitat and year (centroids only), b) year only (centroids in bold), c) macrohabitat only (centroids in bold), d) macrohabitat and year separated by gear type (top – electrofishing and bottom – fyke nets/seine hauls), and e) reach and year (centroids only).

10.4.5 Iconic species summaries

Murray cod

As outlined in the abundance results (10.4.3), Murray cod have rarely been recorded from Anabranch and Wetland sites, and their abundance at Riverine sites has increased over two distinct periods (2012–2016 and 2018–21) following dramatic declines that coincided with flooding/blackwater events in 2011 and 2016. In 2022 their abundance was comparable to 2019, a slight decline from the record abundance of 2021.

Since the 2016 blackwater event, there have been very few adult (550+ mm) Murray cod sampled compared with the 2014 and 2016 and young-of-year, juvenile and sub-adult fish have been the dominant size classes sampled since 2018. In the last two years (2021–22), young-of-year (YOY) have comprised a smaller proportion of the fish sampled than captured than in the previous three years (2018–2020).

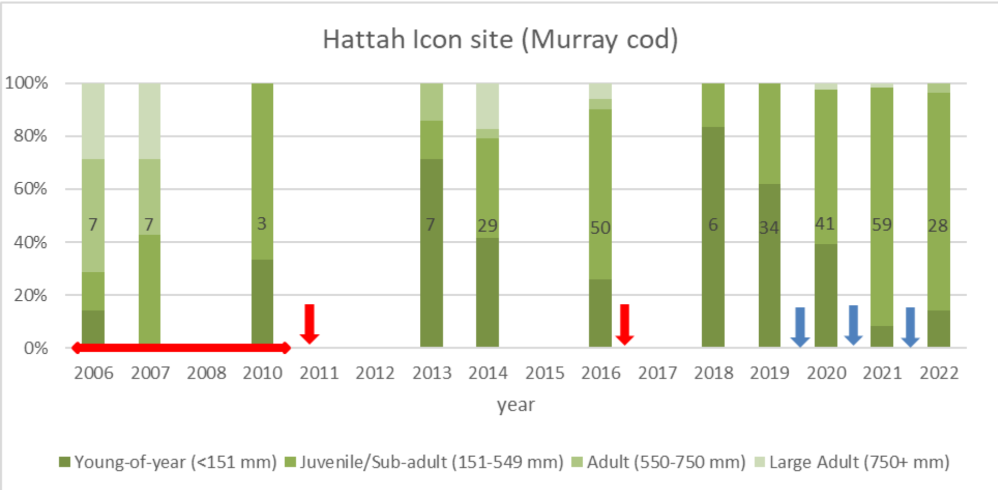


Figure 57 Murray cod size-class summaries for whole of Icon Site, with the number of fish measured (n) shown on columns. Horizontal red arrow depicts the Millennium Drought. Vertical red arrows depict flood/blackwater events and blue arrows depicts Murray River Southern Spring Flow releases. Note that sampling in 2006–2008 was conducted in spring rather than autumn and is included only for broad comparative purposes.

Murray cod (and golden perch) 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) (https://www.dpi.nsw.gov.au/fishing/recreational/resources/stocking).

Murray cod length-frequency histograms over the 2010–2022 monitoring period are presented in the Part B Report (Palmer et al. 2022) and those for the 2019–2022 are presented below in Figure 58. Although the sample size was not large (29), there is an apparent absence of Murray cod in the 175–225 size range, likely to represent 1+ age fish, that is the 2021 YOY size class.

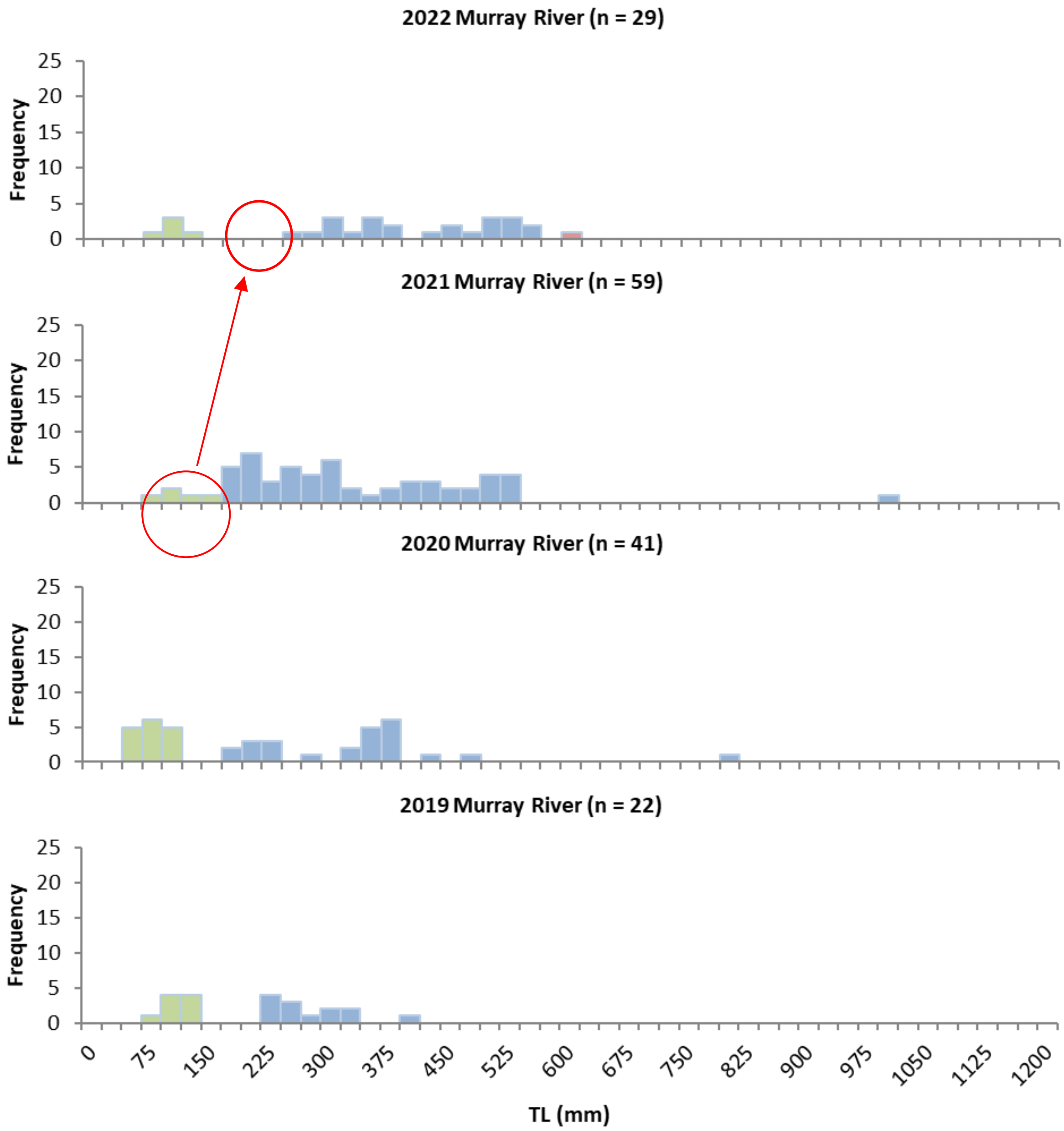


Figure 58 Unweighted length frequency histograms for Murray cod captured during 2019–2022 TLM monitoring. Green shading indicates young-of-year (YOY). Red shading indicates fish of 'legal size' 550–750 mm under current Victorian and NSW recreational fishing regulations. Missing size class in 2022 circled in red. Note that these unweighted histograms are provided to show the range of sizes captured across the icon site and are not intended to provide an accurate representation of population(s) structure.

Golden perch

As outlined in section 10.4.3, record high abundances of golden perch were sampled in 2022 at Wetland sites, particularly at Lakes Bulla (70) and Yerang (58) (see Part B Report, Palmer et al. 2022).

In 2022, over 90% of golden perch sampled across the Icon Site, and 99.5% from Wetlands were juvenile fish measuring (100–175 mm TL), with individuals in the 125–150 mm size range being particularly abundant. It is likely that these represent a young-of-year cohort exhibiting strong growth, despite being above the 0–75 mm length range normally used TLM indices calculation purposes (Figure 59). This is the highest proportion of juveniles sampled over the monitoring program and follows four years (2018–2021) where these size classes (juveniles and YOY) comprised less than 5% of the golden perch sampled.

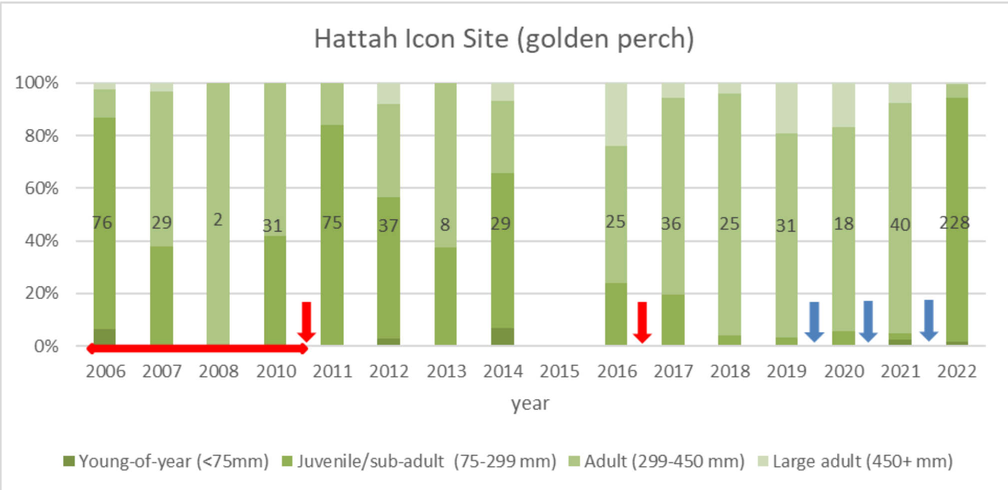


Figure 59 Golden perch size-class summaries for whole-of-Icon Site, with the number of fish measured (n) shown on columns. Horizontal red arrow depicts the Millennium Drought. Vertical red arrows depict flood/blackwater events and blue arrows depicts Murray River Southern Spring Flow releases. Note that sampling in 2006–2008 was conducted in spring rather than autumn and is included only for broad comparative purposes.

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) (https://www.dpi.nsw.gov.au/fishing/recreational/resources/stocking).

Golden perch length-frequency histograms over the 2010–2022 monitoring period are presented below in Figure 60. The 2022 dominance of the juvenile 75–175 mm size class at the Wetland macrohabitat and the larger magnitude of this recruitment event compared to previous recruitment events detected in 2014 and 2011 is clear. As outlined above, despite the use of <75 mm in this report as an approximate size-based cut-off indicative of young-of-year (YOY) fish, there is a possibility that growth rates are significantly higher and that the 75–175 mm cohort are in fact YOY.

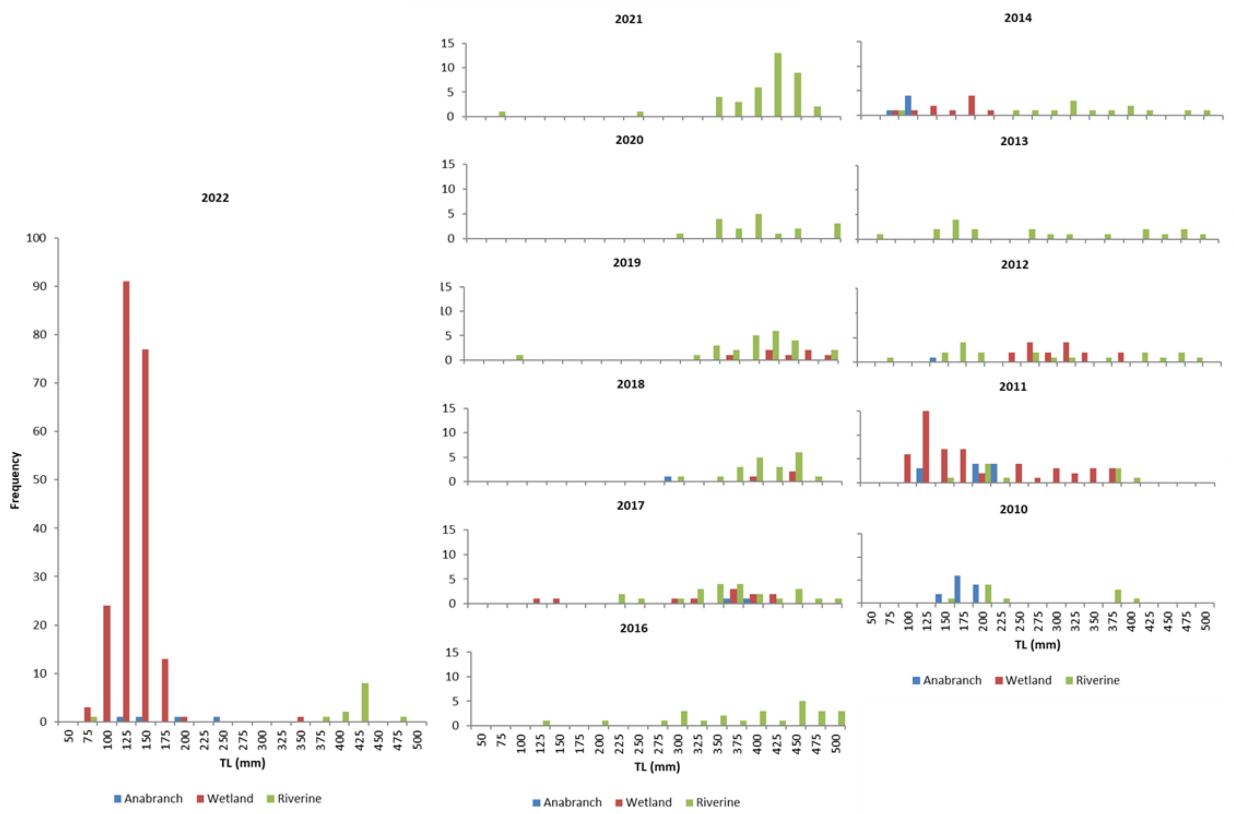


Figure 60 Unweighted length frequency histograms for golden perch across macrohabitats sampled during 2010–2022 TLM monitoring. Note that these unweighted histograms are provided to show the range of sizes captured across the icon site and are not intended to provide an accurate representation of population(s) structure.

10.4.6 Carp

As outlined in section 10.4.3, carp abundance at the Anabranch and Wetland sites was among the highest recorded over the monitoring program, comparable with 2011 following a natural flooding event and 2014, following a large-scale spring 2013 watering event of dry/almost dry lakes. As shown in Figure 61 below, the population is dominated by young-of-year and sub-adult fish, both at the Icon Site scale (~65%) and at the Wetland scale (~55%), although much higher proportions of these size classes were detected in 2011 (~80%), 2014 (~95%) and 2017 (~94%).

Figure 61 Golden perch size-class summaries for whole-of-Icon Site (top) and Wetland macrohabitat (bottom), with the number of fish measured (n) shown on columns. Horizontal red arrow depicts the Millennium Drought. Vertical red arrows depict flood/blackwater events, blue arrows depict Murray River Southern Spring Flow releases, and green arrows depict major spring watering events of the previously dry or almost dry wetlands. Note that sampling in 2006–2008 was conducted in spring rather than autumn and is included only for broad comparative purposes.

10.4.8 Indices results

Diversity Index: P expected

The 2022 P expected index scores (i.e. the number of native indigenous species collected in each site compared to the number expected) are identical for the Riverine macrohabitat to those recorded over most of the monitoring program (with the exception of 2012) (Figure 62). The Anabranch P expected score in 2022 was the highest recorded over the monitoring program, while the Wetland score was high and comparable to 2016 and 2018. No Wetland or Anabranch macrohabitats were sampled in 2020–2021, and no Anabranch habitats were sampled in 2013 and 2019; therefore, the Icon Site scale scores in those years should be interpreted with caution.

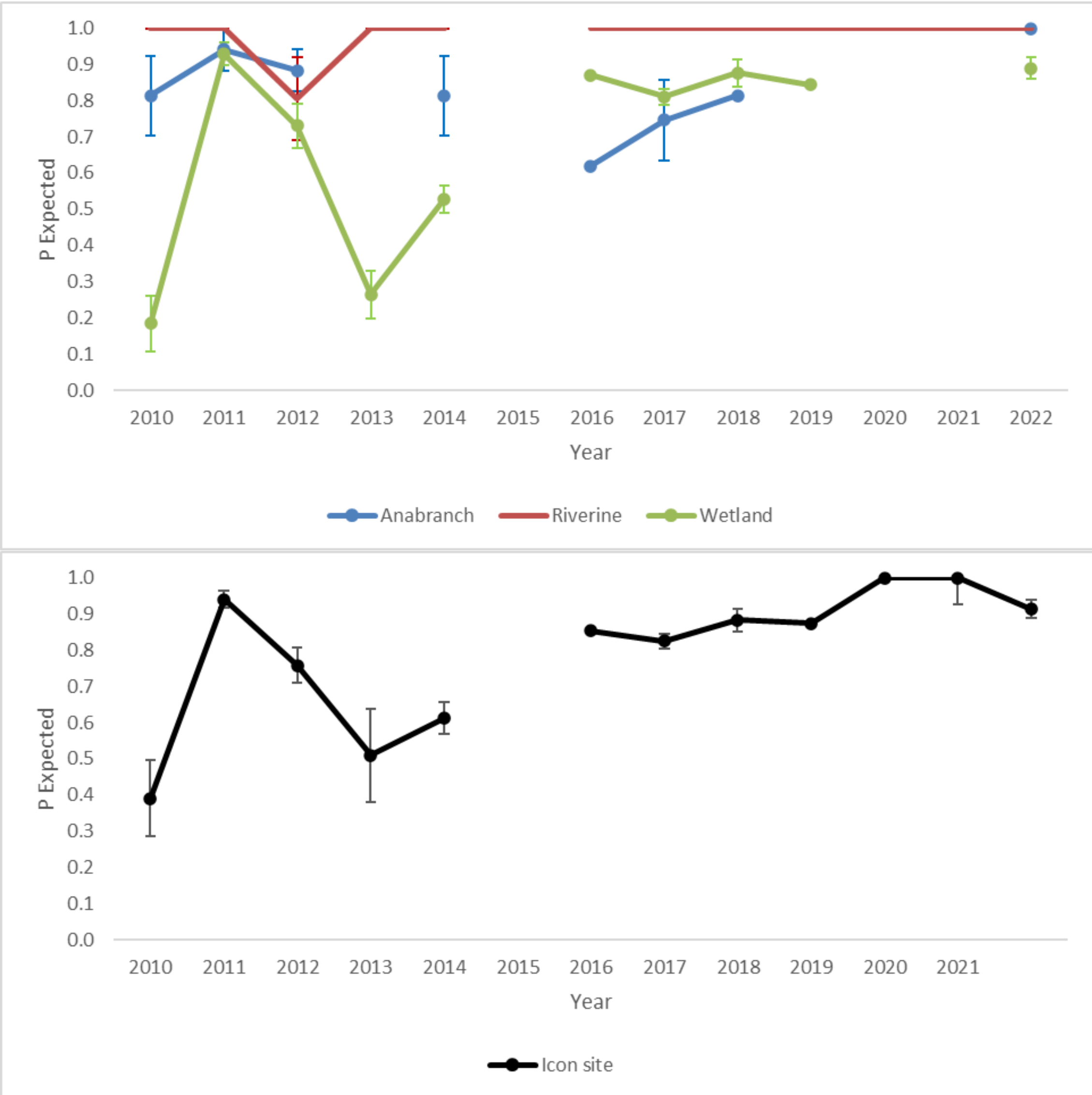


Figure 62 Diversity Index (P expected) scores at the macrohabitat scale (top) and Icon Site scale (bottom).

Biomass Index: P native

The 2022 P native scores (previously known as P nativeness, i.e. the proportion of fish biomass within each site that is from native fish species) has been relatively high at Riverine sites for the past three years (Figure 63). The 2022 P native scores for Anabranch sites are among the lowest recorded over the monitoring program but are marginally higher than the lowest scores from 2014 (following spring 2013 re-filling of the lakes) and 2017 (following spring 2016 natural flooding). The 2022 Wetland P native scores are also low and comparable to 2011 (following summer 2011 natural flooding) and 2013–14 (following spring 2013 re-filling of the lakes). The Icon Site P native scores are the lowest recorded since 2014. However, no Wetland or Anabranch macrohabitats were sampled in 2020–2021 and no Anabranch habitats were sampled in 2013 and 2019, and therefore the Icon Site scale scores in those four years should be interpreted with caution.

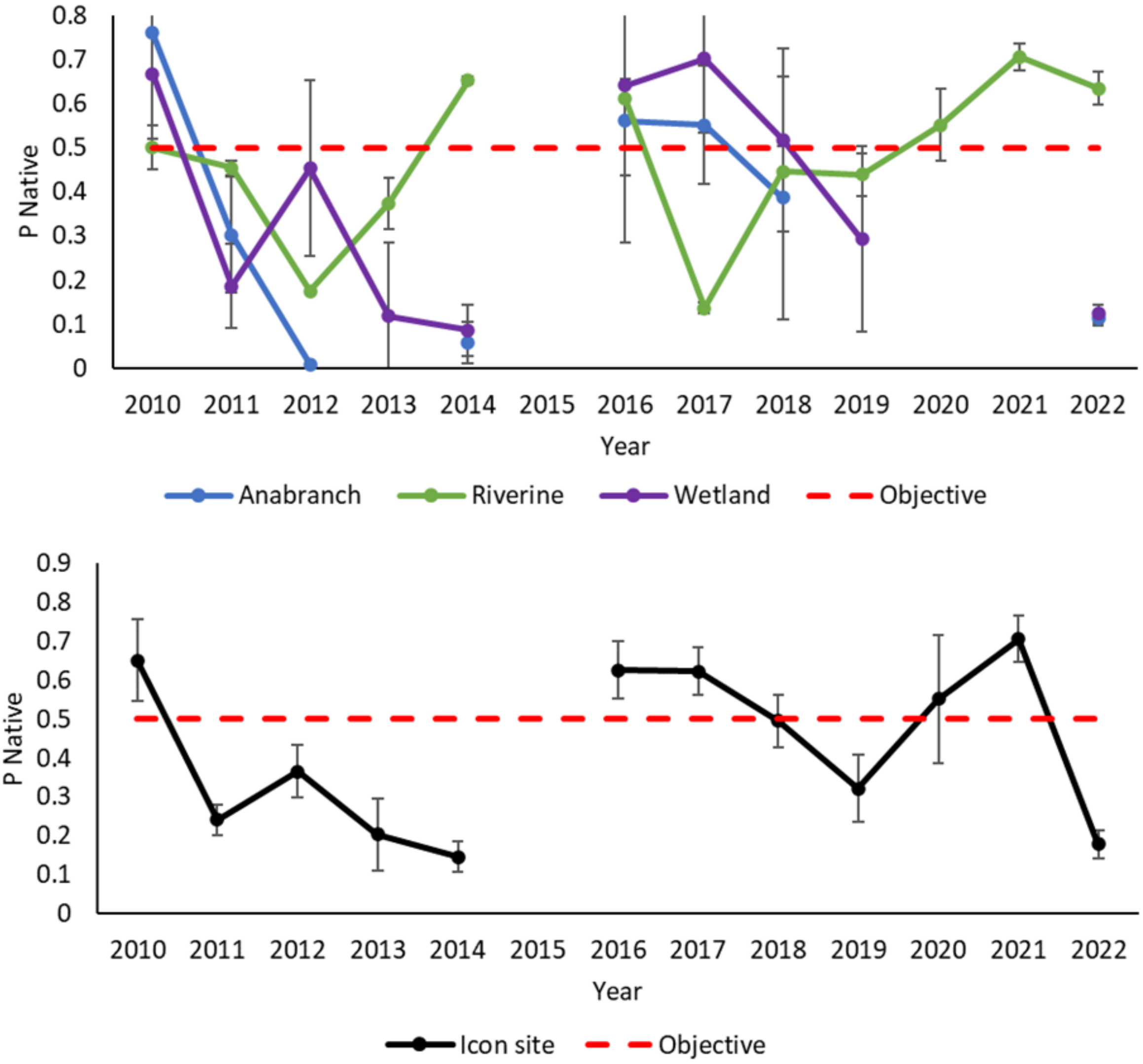


Figure 63 Biomass Index (P native) scores at the macrohabitat scale (top) and Icon Site scale (bottom). Red line indicates compliance target for objective (refer to section 10.3.3).

Recruitment Index: P recruits

The 2022 Recruitment Index (P recruits) scores (i.e. the proportion of indigenous native fish in each site that are recruits) were the lowest recorded for the Anabranch macrohabitat. The 2022 P recruits scores for Riverine macrohabitat were mid-range and comparable to scores from 2020–2021. For Wetland macrohabitat, the P recruits scores were again mid-range, and comparable to those from 2011 and 2017. At the Icon Site scale, the P recruits scores were comparable to 2016 and 2014. However, no Wetland or Anabranch macrohabitats were sampled in 2020–2021 and no Anabranch habitats were sampled in 2013 and 2019; therefore, the Icon Site scale scores in those four years should be interpreted with caution.

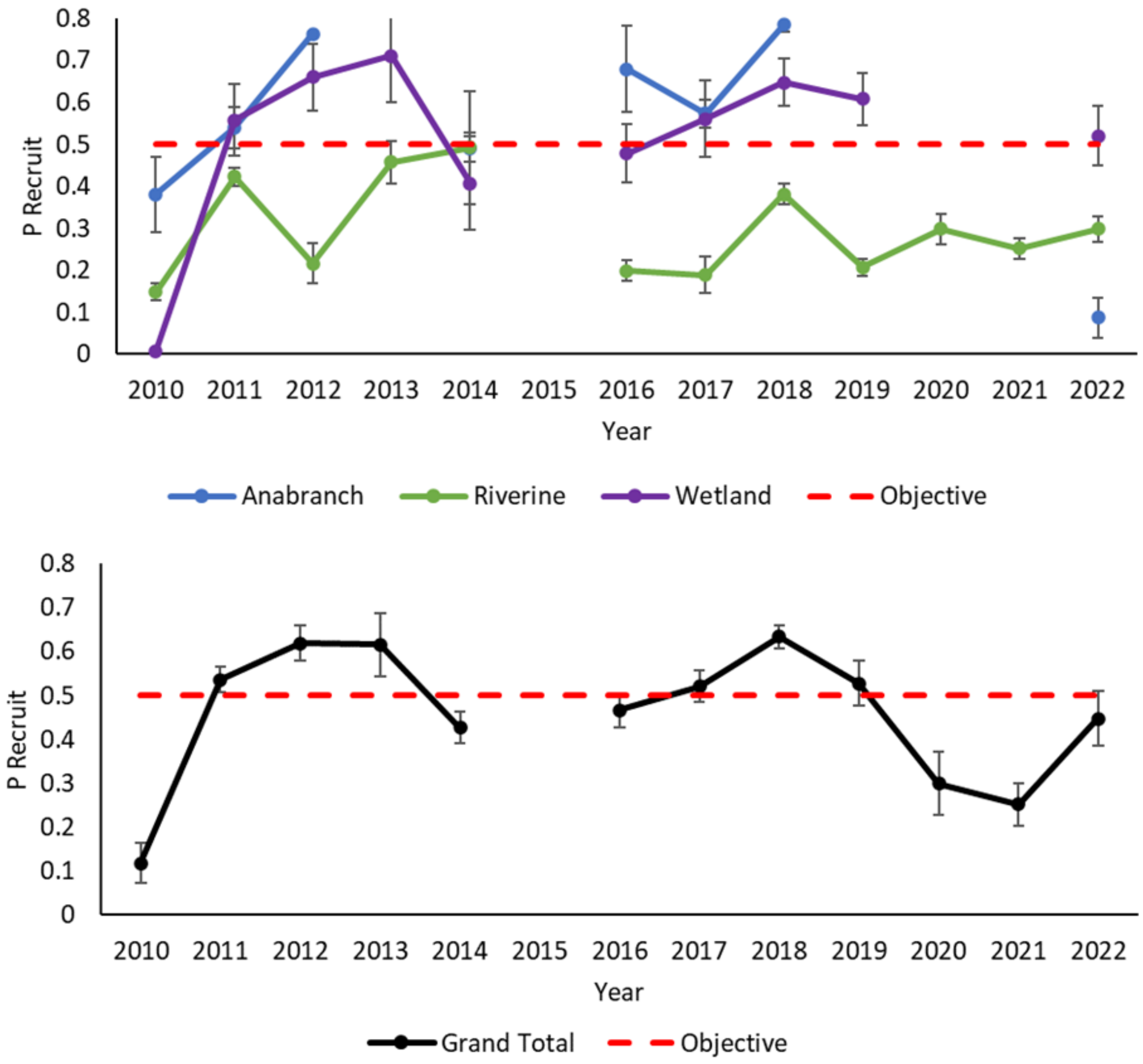


Figure 64 Recruitment Index (P recruits) scores at the macrohabitat scale (top) and Icon Site scale (bottom). Red line indicates compliance target for objective (refer to section 10.3.3).

10.4.9 Objective and target attainment

A summary of the relevant targets is provided below in Table 36. The P recruit scores for all macrohabitats and the Icon Site, met the target in 2022. However, the P native scores (a biomass index) did not, with low very low scores for Anabranch and Wetland macrohabitats in 2022 being comparable to scores for those macrohabitats in 2014, the last time the lakes were re-filled (from dry) with environmental water. Progress is not being made towards the long-term target for P native at the Anabranch and Wetland macrohabitats because Hattah Lakes are periodically drawn down to completely dry (i.e. system reset) as occurred in 2020–2021.

Table 36 Summary of target attainment in 2022. 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**	**Progress towards long term target**	**Not attained**
By 2030, evidence of recruitment of small bodied native fish species at enough sites for P recruits (a recruitment index - see section 10.3.4) and P native (a biomass index – see section 10.3.4) to attain targets below in 80% of years between 2020–2030. Species include: Australian smelt (*Retropinna semoni*), carp gudgeon (*Hypseleotris* spp.), flyspecked 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			

10.5 Discussion

After a prolonged period of drawdown and complete drying over 2019–2021, the fish community of the Hattah Lakes Icon Site in 2022 has been reset and re-established by the autumn and spring 2021 watering events. The rewetting of the Icon Site has seen the successful re-colonisation of the entire fish community (except Murray cod), with all species detected throughout all macrohabitats (excluding Murray cod and silver perch, which have been only sporadically detected in Anabranch and Wetland habitats through the monitoring program). Although not detected from Anabranch in 2022, silver perch were recorded at Wetland sites for the first time since 2014, in the highest abundance since 2010, and at several Wetlands where they have not previously been recorded over the monitoring program (Lakes Arawak, Bulla and Lockie).

Due to the variation in sampling coverage due to dry Wetlands and Anabranch sites in some years, it is difficult to compare the fish community composition between years. By abundance measures, 2022 is quite distinct, yet presence data suggests that the community in 2022 most closely resembles that of 2016, 2017 and 2018, which are recent years that have had most if not all sites sampled. The 2022 fish community also shows some similarity in species presence and structure to post previous environmental watering and flooding events in 2011 (2011 flooding) 2014 (2013 watering) and 2017 (2016 flooding), highlighting the ability of these species to quickly re-establish given the appropriate conditions.

Of particular note in 2022 was the substantial increase in golden perch abundance, particularly at most Wetland sites. The majority of golden perch collected were YOY and juveniles (90%), suggesting that eggs and larvae of this species were able to move into the Lakes system through the pumps and survive to this point. Golden perch are known to spawn in the southern MDB at water temperature >17 °C and in response to variable high flow conditions (Zampatti and Leigh 2013; King et al. 2016; Koster et al. 2017). These conditions are likely to have occurred in October–November 2021 when environmental watering via pumping was occurring. While the entrainment of young golden perch into the Hattah Lakes system would normally be a positive outcome for the species (fast growth due to abundant food and warm temperatures), some individuals collected at some of the wetland sites (particularly Lake Yerang) were in very poor physical condition, with lesions and extensive fungal infections, and some needed to be euthanised rather than released. This may suggest that water quality (a blue green algal bloom was evident at Lake Yerang), habitat or food resources were inadequate to sustain the biomass of fish present. Furthermore, under normal non-regulated conditions, early life stages of golden perch could move into these off-channel wetlands during flooding to grow and then return as juveniles to the more permanent main channel environment (see for example model proposed by Stuart and Sharpe 2020). However, in the case of the managed Hattah Lakes, this exit pathway to permanent waters is largely not possible unless natural flooding or flow-through watering occurs.

As already noted, the re-wetting event of the Hattah Lakes has enabled the fish community to rejuvenate after a prolonged dry period. In particular, it is likely that the spring 2021 pumping event (rather than the autumn 2021 event) into the Icon Site enabled many native and introduced fish species to recolonise, as they would have been more active and also present at young life stages that could survive through the pumping. Total catch was reduced compared to previous years; however, this was driven by the substantial declines in carp gudgeon catch, which are known to be low flow or generalist species, and will no doubt increase in numbers in future years in the wetlands. Most other small-bodied native species were present in comparable numbers to other wet years, with the exception of Australian smelt, which were sampled in lower abundances compared to recent comparable wetting years (2016–

2018). The fish community in 2022 was quite distinct from other years, mostly driven by differences in small-bodied fishes such as carp gudgeon and eastern gambusia abundances, with bony herring and carp being more influential for some yearly comparisons.

The amenable environmental and watering conditions at Hattah Lakes Icon Site also led to the recolonisation and proliferation of all introduced species, particularly carp and eastern gambusia, which were both sampled in considerable numbers. Carp were recorded in their highest abundance since 2014, and a large proportion (65%) were obvious YOY or juveniles, indicating a successful recruitment event. It is worth noting the somewhat arbitrary cut-off length used for YOY designation (<200 mm) and highlighting that if carp growth rates have been high, then the proportion of YOY carp in 2022 is likely to be substantially higher. Carp are well known to breed and recruit successfully on flood and inundation events that occur during spring and summer (e.g. Stuart and Jones 2006; King et al. 2016), so this outcome is not unexpected. However, this does pose an interesting management question for trade-off and environmental watering targets, as the spring watering event is likely to have substantially improved native fish response (compared to autumn) but at the cost of native fish entrainment (particularly golden perch) and benefit to introduced fish species. Further consideration should be given to other management interventions or strategies that would enable exit of some native fish into permanent waterways, or whether some Wetlands (e.g. Lakes Mournpall and Hattah) in the system could have water levels retained for a longer period. In the absence of the provision of permanent refuge habitat in the Lakes system, or appropriate exit pathways/strategies, localised fish kills may periodically occur. Additionally, periodic system ‘resets’ preclude long-term progress towards Anabranch and Wetland fish ecological objectives and targets.

Finally, Murray cod abundance in 2022 at the Riverine sites was similar to recent years, showing recovery after the blackwater events of 2011 and 2016. Murray cod continue to be present in most size classes, although larger adult size classes are still completely absent. Additionally in 2022, the 1+ cohort was missing in the sampled fish population. This lack of 1+ fish could indicate either recruitment failure of the 2021 YOY, or that juveniles/subadults have emigrated on the higher flow conditions away from this area of the Murray River. Currently, little is known about juvenile Murray cod movement patterns, but we suspect the latter mechanism is more likely. Future monitoring and comparison with other longer term monitoring data from any nearby sampled sites from other monitoring programs may help to elucidate this.

The Hattah Icon Site TLM dataset, 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. To date, these data have been presented as an annual mean catch of fish species to report on any indicative population trends across the period that sampling has taken place. Other than PERMANOVA analyses in this report and the previous (Palmer et al. 2021), the reports to date have had minimal statistical analyses regarding 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 is currently underway 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, the results of which can be found in McPhan et al (2022).

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The Living Murray Condition Monitoring 2021–22 Hattah Lakes Part B (supplementary report)

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Cover photo: Lake Lockie waterbirds monitoring site, May 2022.

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Plates

1 Introduction

This report provides supplementary information for The Living Murray Condition Monitoring, Hattah Lakes 2021–22, Part A (Main Report). Information contained in this report includes mapping, data tables and photo-point imagery that would otherwise be provided as appendices in the main report. As a means of reducing the size of this document, and in keeping with the preceding condition monitoring reports (Brown et al. 2018, Bloink et al. 2019, 2020; Palmer et al. 2021), only a selection of photo-point images are provided for the River Red Gum, Black Box, wetland vegetation communities, floodplain vegetation communities and Lignum components; the full suite of images will be submitted to Mallee CMA separately.

2 River Red gum

2.1 River Red Gum tree condition site details

Table 1 River Red Gum tree condition site details, Hattah Lakes.

Site	Easting	Northing
R1 H	638130.1	6156828
R2 H	636317	6153947
R3 H	631538	6160633
R4 H	629054.9	6157714
R5 H	624523.4	6155819
R6 H	625943.2	6158711
R7 H	627075.6	6162714
R8 H	630941.9	6169594
R9 H	631482.7	6171481
R10 H	634821.1	6156958
R11 H	627688.8	6160767
R12 H	623978.1	6156542
R13 H	628107	6158837
R14 H	629275	6162049
R15 H	631664.7	6162960
R16 H	630064.7	6168345
R17 H	625826.5	6164605
R18 H	630975.9	6170874
R19 H	632987.2	6156713
R20 H	636807.8	6155982
R21 H	629739	6173166
R22 H	632345.8	6172489
R23 H	632944.3	6171396
R24 H	633968.6	6167534
R25 H	634035.2	6166219
R26 H	638386.4	6158668
R27 H	638053.6	6154622
R28 H	630832.2	6158192
R29 H	624383.5	6152750
R30 H	623841.9	6162843
R31 H	633243	6162253
R32 H	630199.5	6166109
R33 H	633492.3	6150891

Photo-point	Easting	Northing	Bearing (degrees)
RRG_P001_H	638149	6156828	265
RRG_P002_H	636317.9	6153921	5
RRG_P003_H	631539.4	6160622	250
RRG_P004_H	629075.8	6157740	270
RRG_P005_H	624527.1	6155788	30
RRG_P006_H	625943	6158711	290
RRG_P007_H	627061.4	6162690	46
RRG_P008_H	630976.8	6169583	280
RRG_P009_H	631490.4	6171484	250
RRG_P010_H	634848.3	6156939	265
RRG_P011_H	627694	6160762	0
RRG_P012_H	623927.3	6156553	110
RRG_P013_H	628150.4	6158794	280
RRG_P014_H	629279.8	6162051	290
RRG_P015_H	631625	6162928	10
RRG_P016_H	630070.4	6168335	360
RRG_P017_H	625800.3	6164614	130
RRG_P018_H	630965.3	6170874	40
RRG_P019_H	632980.3	6156732	325
RRG_P020_H	636802	6156018	20
RRG_P021_H	629798.2	6173143	215
RRG_P022_H	632356.9	6172484	270
RRG_P023_H	632976.7	6171383	230
RRG_P024_H	633961.8	6167530	70
RRG_P025_H	634031.6	6166214	60
RRG_P026_H	638405.6	6158695	215
RRG_P027_H	638054.2	6154623	280
RRG_P028_1_H	630836	6158197	66
RRG_P028_2_H	631021	6158274	244
RRG_P029_1_H	624374	6152735	350
RRG_P029_2_H	624347	6152824	131
RRG_P030_1_H	623925	6162829	310
RRG_P030_2_H	623848	6162885	74
RRG_P031_1_H	633219	6162230	248
RRG_P031_2_H	632619	6162163	105
RRG_P032_1_H	630187	6166113	143
RRG_P032_2_H	630198	6166006	6
RRG_P033_1_H	633485	6150898	130
RRG_P033_2_H	633510	6150877	326

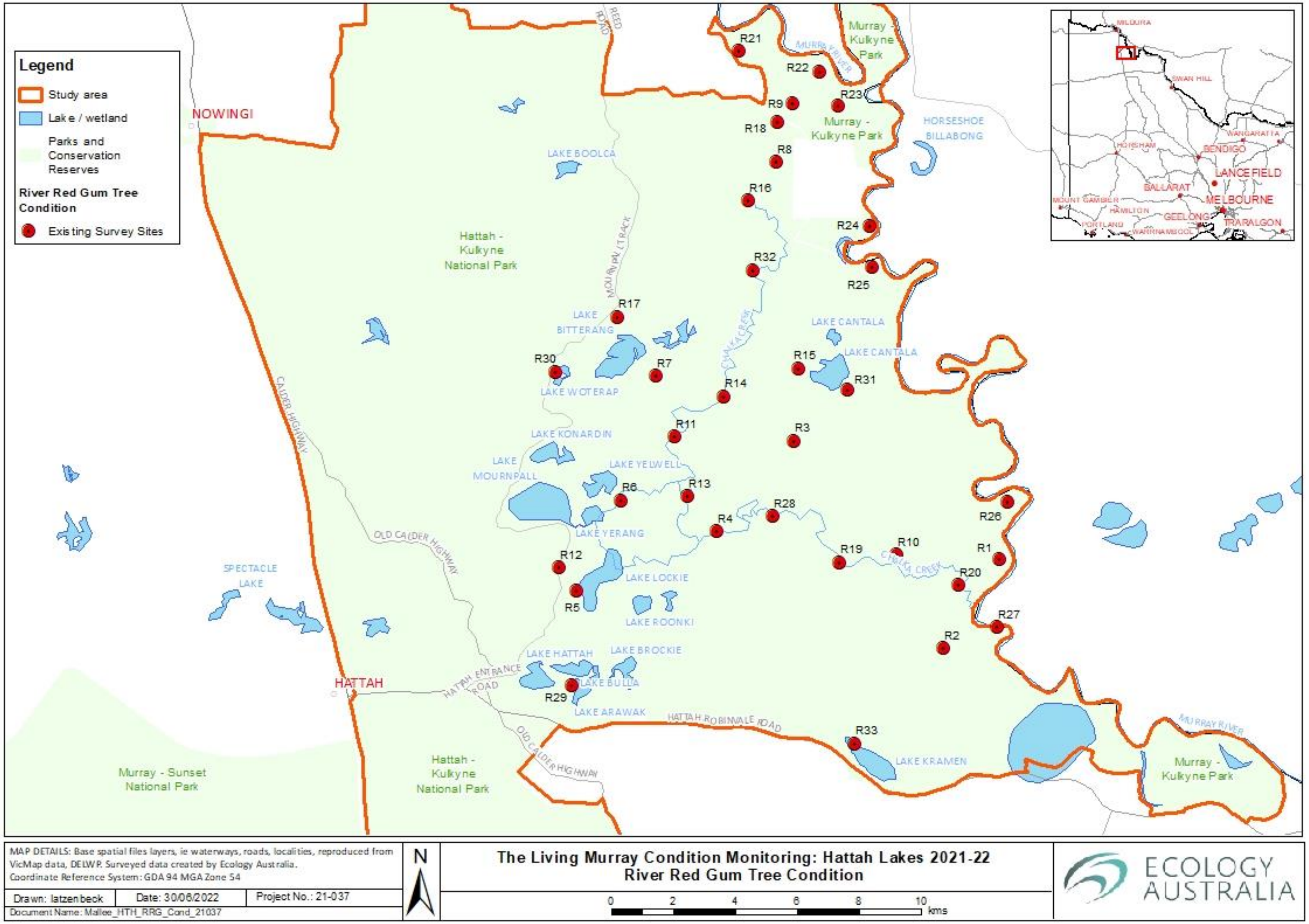

Figure 1 Map of River Red Gum Tree Condition sites, Hattah Lakes study area (2021-22).

2.2 River Red Gum tree condition photo-point image comparisons (selected sites)

2008-09

2011-12

2015-16

2018-19

2020-21

2021-22

Plate 1 Photo-point image comparison, tree condition site R1, Hattah Lakes, 2008-09 to 2021-22.

2007-08

2010-11

2015-16

2018-19

2020-21

2021-22

Plate 2 Photo-point image comparison, tree condition site R6, Hattah Lakes, 2007-08 to 2021-22


2008-09


2011-12


2015-16


2018-19


2019-20


2021-22

Plate 3 Photo-point image comparison, tree condition site R18, Hattah Lakes, 2008-09 to 2021-22.


2007-08


2010-11


2015-16


2017-18


2020-21


2021-22

Plate 4 Photo-point image comparison, tree condition site R22, Hattah Lakes, 2007-08 to 2021-22.

2.3 River Red Gum Tree Condition Index (TCI) score comparisons between sites

For the purposes of these figures only live trees and those which had no leaves but could not be conclusively deemed as dead have been included (i.e. those which make up the current ~30 trees per site). In 2021-22 trees with no leaves which were not deemed conclusively as dead were given a score of zero.

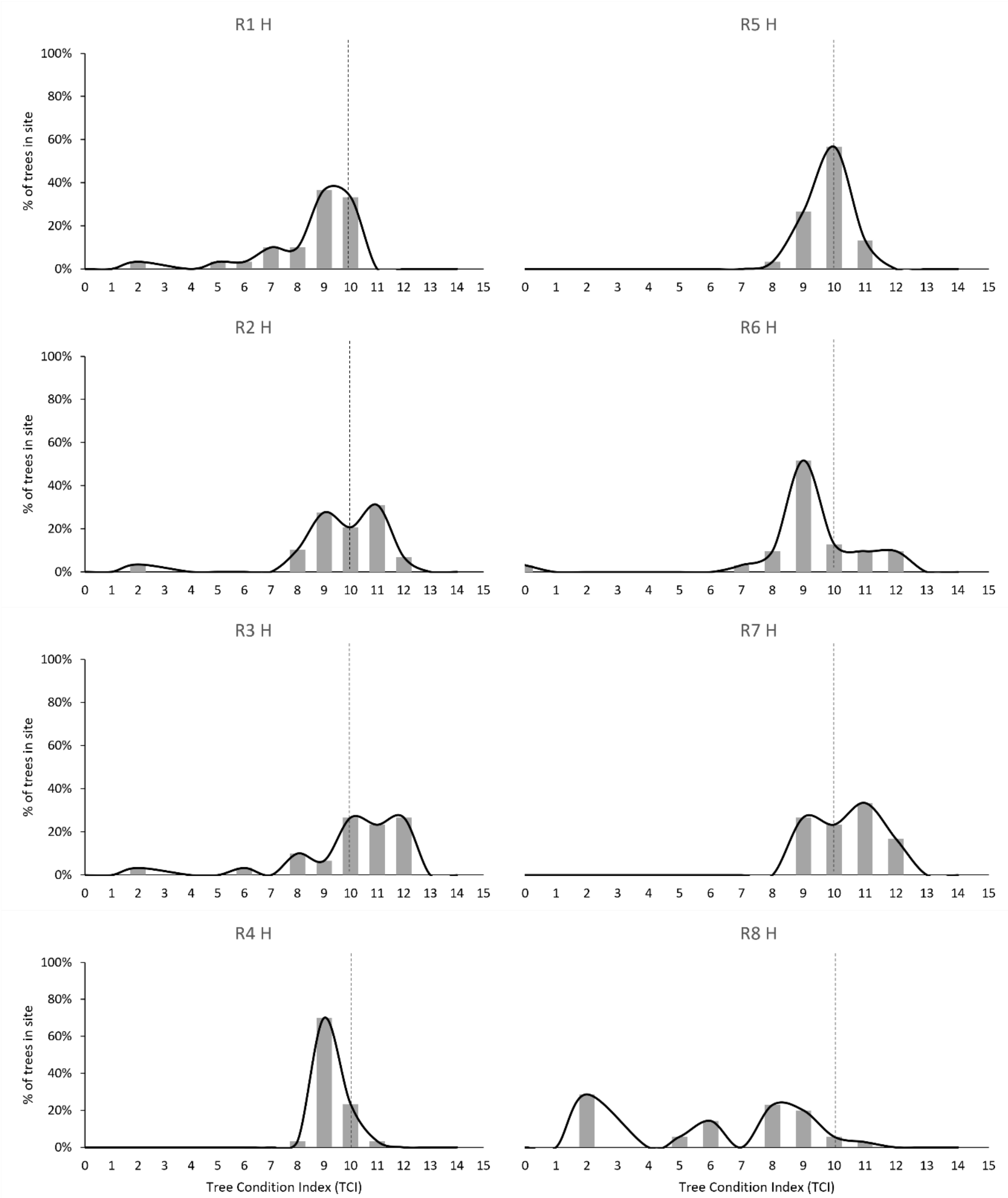

Figure 2 **Percentage of trees in each TCI category across River Red Gum sites R1 H-R8 H, Hattah Lakes, 2021-22. The vertical dotted line indicates the ecological target for tree condition of ≥10.**

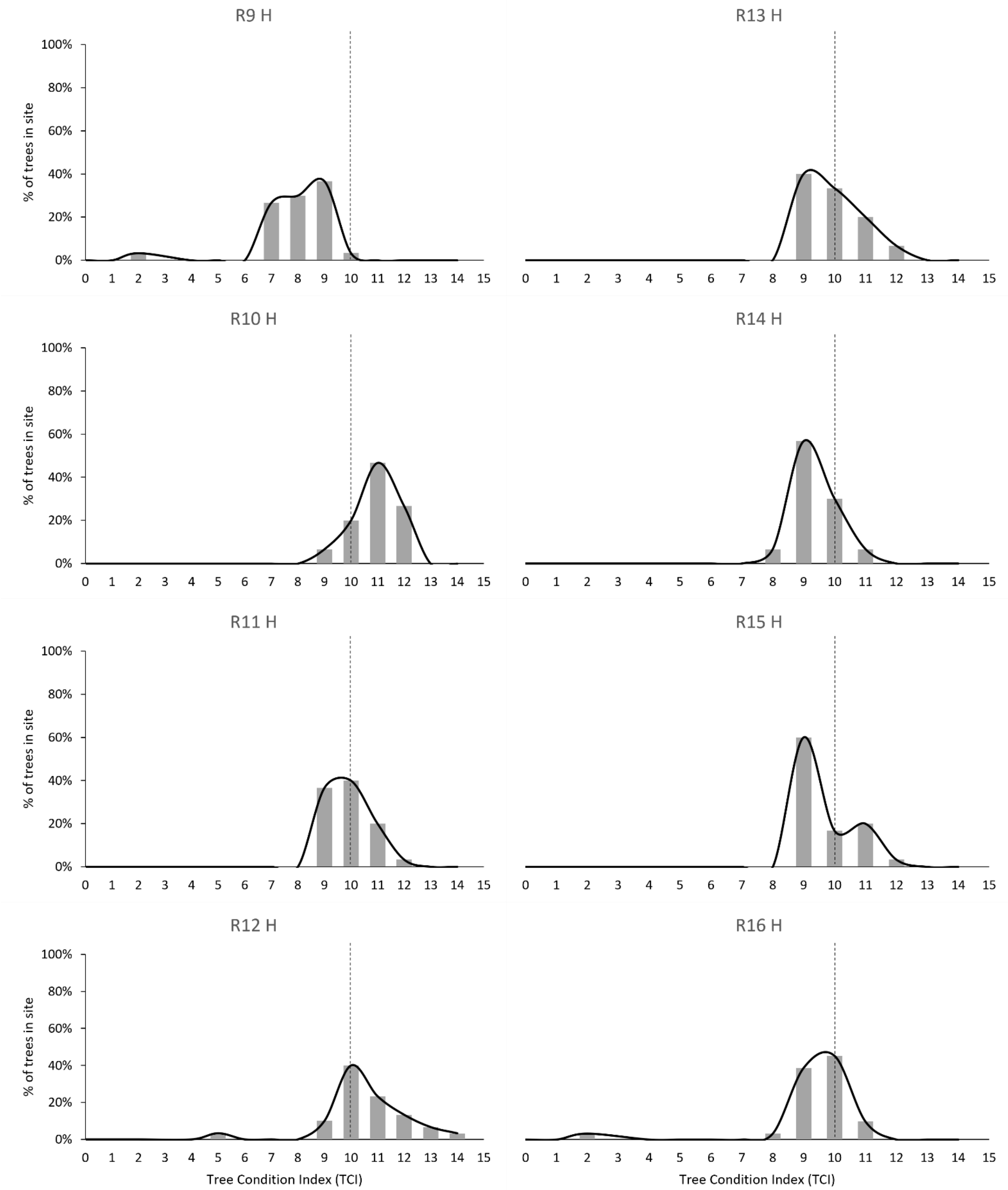

Figure 3 Percentage of trees in each TCI category across River Red Gum sites R9 H-R16 H, Hattah Lakes, 2021-22. The vertical dotted line indicates the ecological target for tree condition of ≥10.

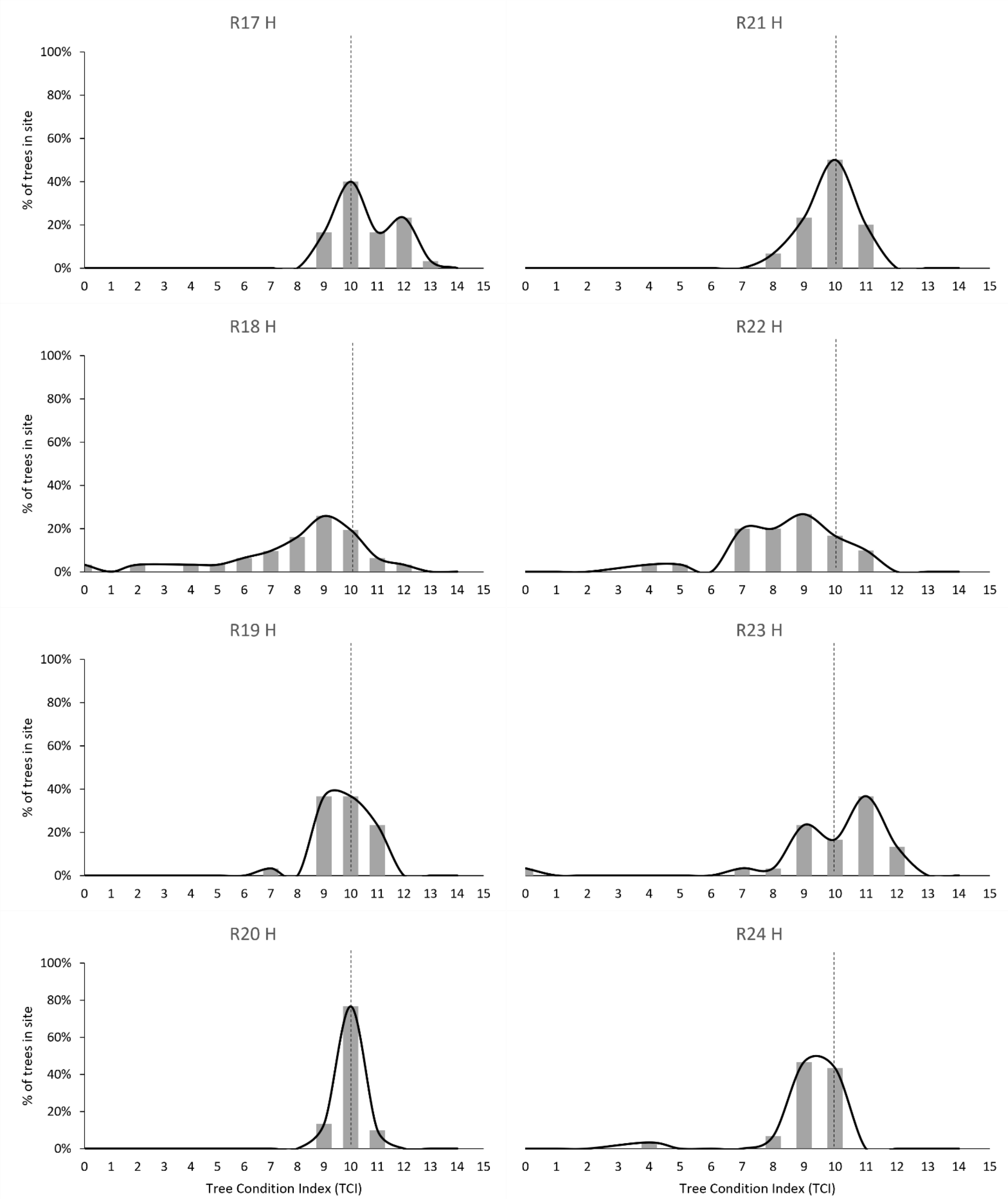

Figure 4 Percentage of trees in each TCI category across River Red Gum sites R17 H-R24 H, Hattah Lakes, 2021-22. The vertical dotted line indicates the ecological target for tree condition of ≥10.

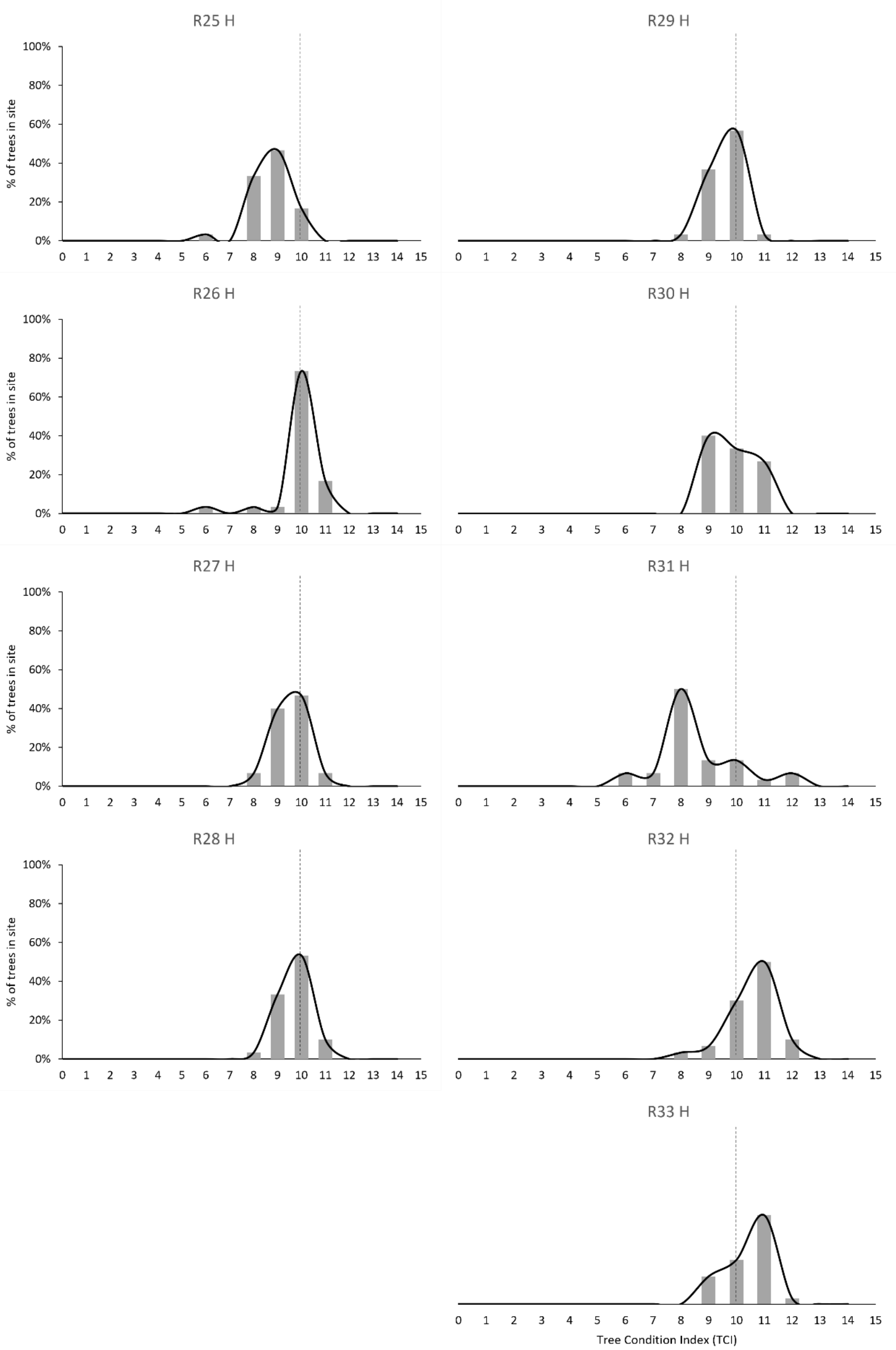

Figure 5 Percentage of trees in each TCI category across River Red Gum sites R25 H-R33 H, Hattah Lakes, 2021-22. The vertical dotted line indicates the ecological target for tree condition of ≥10.

Table 2 Total number of trees in each TCI category across all River Red Gum tree condition sites, Hattah Lakes, 2021-22. Trees with a TCI score of zero represent dead trees which have died across any season.

Site	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
R1 H			1			1	1	3	3	11	10				
R2 H			1						3	8	6	9	2		
R3 H			1				1		3	2	8	7	8		
R4 H									1	21	7	1			
R5 H									1	8	17	4			
R6 H	1							1	3	16	4	3	3		
R7 H										8	7	10	5		
R8 H			10			2	5		8	7	2	1			
R9 H			1					8	9	11	1				
R10 H										2	6	14	8		
R11 H										11	12	6	1		
R12 H						1				3	12	7	4	2	1
R13 H										12	10	6	2		
R14 H									2	17	9	2			
R15 H										18	5	6	1		
R16 H			1						1	12	14	3			
R17 H										5	12	5	7	1	
R18 H	1		1		1	1	2	3	5	8	6	2	1		
R19 H								1		11	11	7			
R20 H										4	23	3			
R21 H									2	7	15	6			
R22 H					1	1		6	6	8	5	3			
R23 H	1							1	1	7	5	11	4		
R24 H					1				2	14	13				
R25 H							1		10	14	5				
R26 H							1		1	1	22	5			
R27 H									2	12	14	2			
R28 H									1	10	16	3			
R29 H									1	11	17	1			
R30 H										12	10	8			
R31 H							2	2	15	4	4	1	2		
R32 H									1	2	9	15	3		
R33 H										5	8	16	1		
Total:	**3**	**0**	**16**	**0**	**3**	**6**	**13**	**25**	**81**	**302**	**325**	**167**	**52**	**3**	**1**

2.4 River Red Gum population structure site details

Table 3 River Red Gum population structure sites monitored in round 1 (2021-22) at Hattah Lakes

Site	Easting	Northing
HR-S1	632115	6172963
HR-S2	632306	6172996
HR-S3	635634	6166092
HR-S4	632125	6162457
HR-S5	632224	6163067
HR-S6	627812	6161303
HR-S7	627660	6160077
HR-S8	627719	6159836
HR-S9	625327	6158436
HR-S10	624755	6158494
HR-S11	624635	6158221
HR-S12	625027	6158054
HR-S13	625453	6157376
HR-S14	625720	6157265
HR-S15	626191	6156847
HR-S16	627789	6156918
HR-S17	627955	6156991
HR-S18	638113	6158790
HR-S19	638789	6153021
HR-S20	638734	6153087
HR-S21	635573	6149911
HR-S22	635428	6149801
HR-S23	633677	6150209
HR-S24	638068	6154447

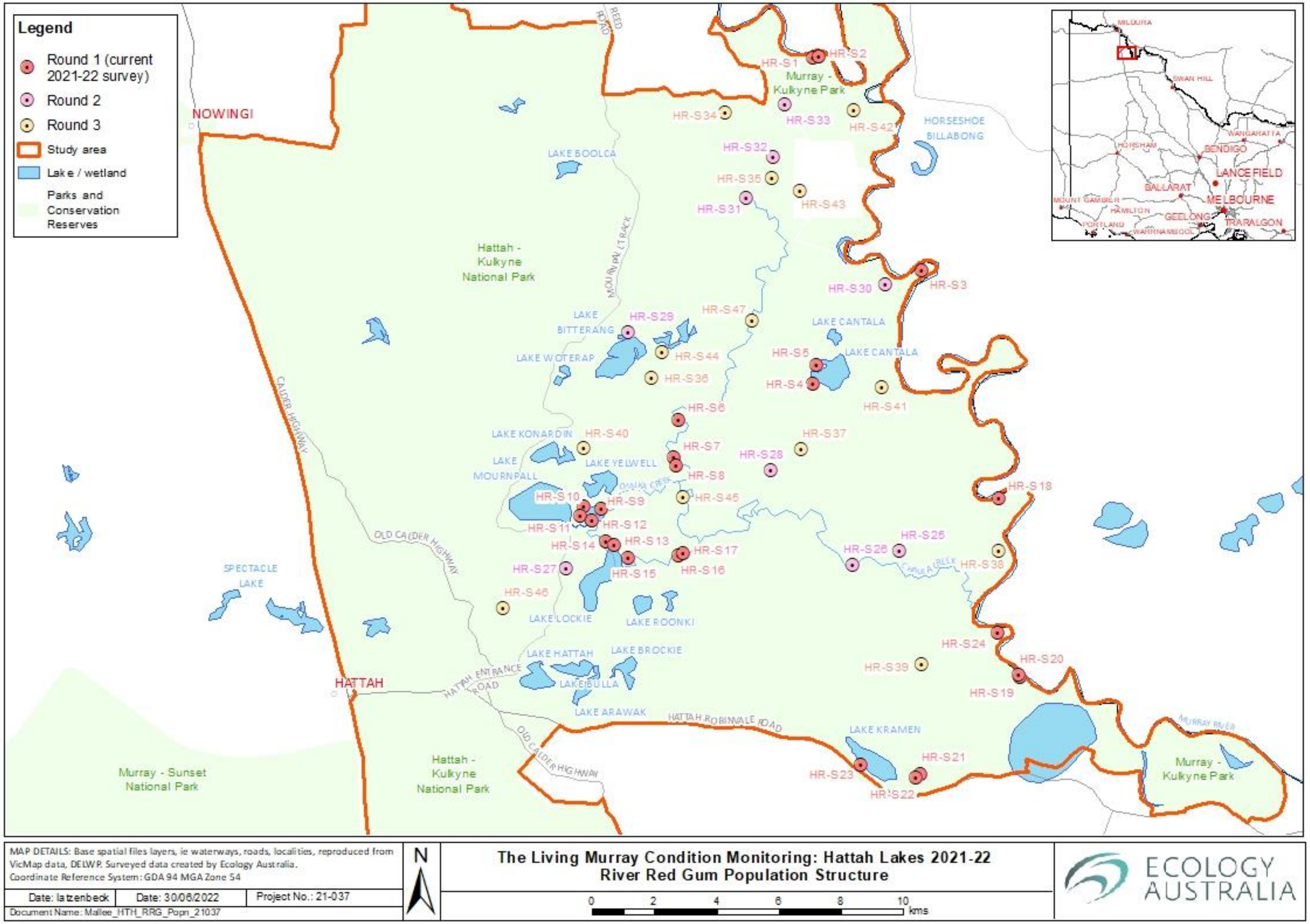

Figure 6 Map of River Red Gum Population Structure sites, Hattah Lakes study area (2021-22). The current survey assessed the Round 1 sites.

3 Black Box

3.1 Black Box tree condition site details

Table 4 Black Box tree condition site details, Hattah Lakes.

Site	Easting	Northing
B1 H	636602.609	6153594.594
B2 H	637120.713	6158900.888
B3 H	631495.697	6157908.936
B4 H	624226.075	6152499.561
B5 H	625774.426	6160132.565
B6 H	626480.707	6165335.466
B7 H	632265.479	6167726.670
B8 H	625643.132	6172468.566
B9 H	631611.976	6172689.454
B10 H	640987.253	6151883.025
B11 H	639181.659	6151880.384
B12 H	633715.592	6165900.616
B13 H	634350.875	6165472.419
B14 H	633972.185	6156788.721
B15 H	634173.121	6156496.852
B16 H	639334.416	6152551.742
B17 H	640165.022	6152251.342
B18 H	639069.517	6151204.089
B19 H	624580.495	6169621.661
B20 H	631149.451	6163352.214
B21 H	625869.098	6157508.509
B22 H	621969.397	6158375.396

Photo-point	Easting	Northing	Bearing (degrees)
BB_P001_H	636595.101	6153598.607	25
BB_P002_H	637124.700	6158901.822	155
BB_P003_H	631494.030	6157887.272	350
BB-P004_H	624226.323	6152494.469	40
BB_P005_H	625783.613	6160123.363	260
BB_P006_H	626481.310	6165334.944	60
BB_P007_H	632264.439	6167716.910	275
BB_P008_H	625652.104	6172484.535	250
BB_P009_H	631603.993	6172662.982	30
BB_P010_H	640975.963	6151876.717	105
BB_P011_H	639173.913	6151857.307	30
BB_P012_H	633733.779	6165910.465	235
BB_P013_H	634348.420	6165481.646	100
BB_P014_H	633971.415	6156788.643	260
BB_P015_H	634190.281	6156491.702	220
BB_P016_H	639328.328	6152589.888	160
BB_P017_H	640150.555	6152283.525	180
BB_P018_H	639068.649	6151218.525	230
BB_P019_1_H	624582	6169600	260
BB_P019_2_H	624464	6169641	155
BB_P020_1_H	631145	6163344	35
BB_P020_2_H	631324	6163615	208
BB_P021_1_H	625892	6157523	230
BB_P021_2_H	625893	6157442	252
BB_P022_1_H	621990	6158371	325
BB_P022_2_H	621952	6158373	153

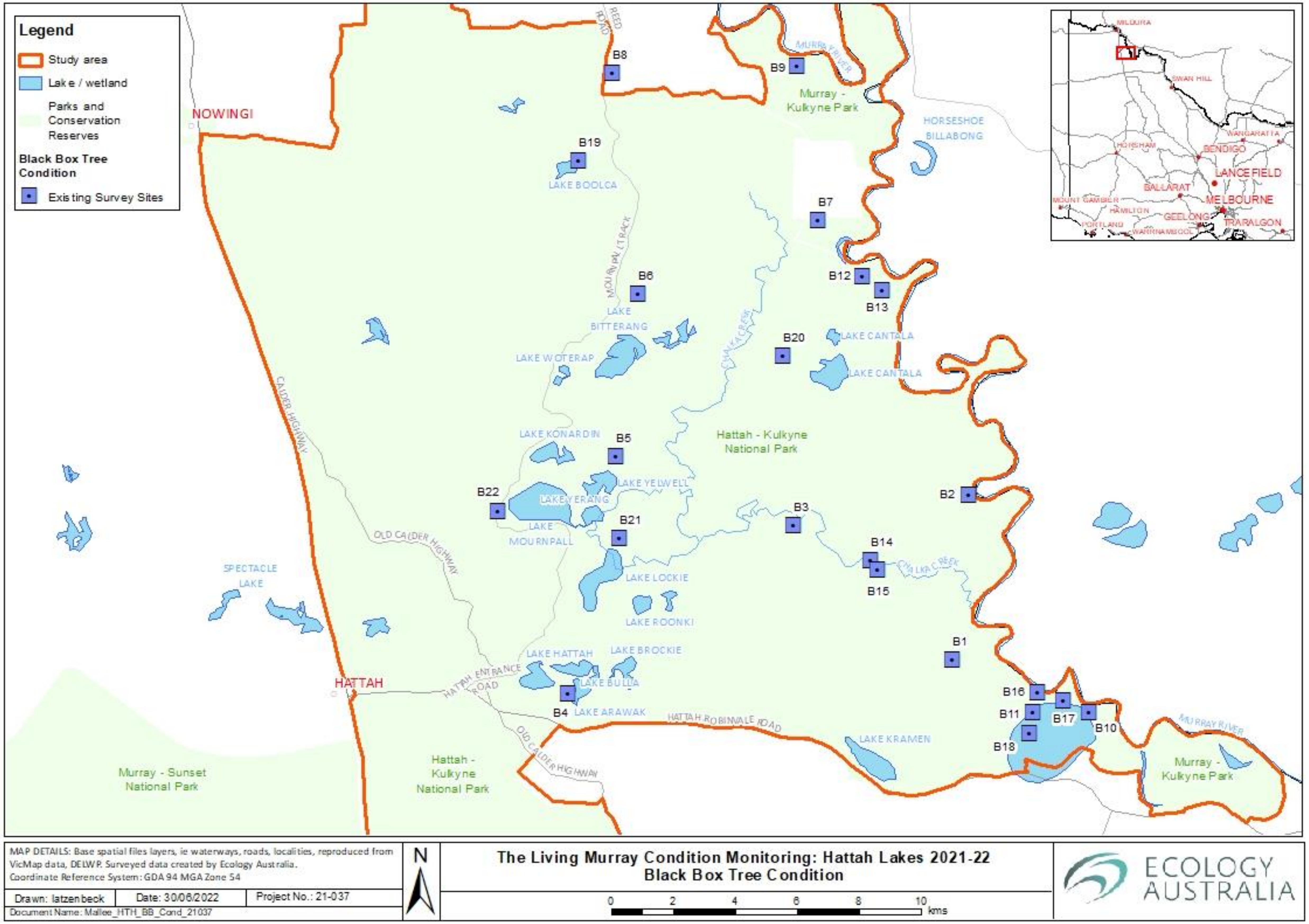

Figure 7 Map of Black Box Tree Condition sites, Hattah Lakes study area (2021-22).

3.2 Black Box photo-point image comparisons (selected sites)

2007-08

2010-11

2013-14

2015-16

2019-20

2021-22

Plate 5 Photo-point image comparison, tree condition site B1, Hattah Lakes, 2007-08 to 2021-22.

2008-09

2010-11

2013-14

2016-17

2018-19

2021-22

Plate 6 Photo-point image comparison, tree condition site B4, Hattah Lakes, 2008-09 to 2020-21.

2007-08

2010-11

2013-14

2016-17

2018-19

2021-22

Plate 7 Photo-point image comparison, tree condition site B11, Hattah Lakes, 2007-08 to 2021-22.

2007-08

2010-11

2013-14

2016-17

2018-19

2021-22

Plate 8 Photo-point image comparison, tree condition site B13, Hattah Lakes, 2007-08 to 2021-22.

2007-08

2010-11

2013-14

2016-17

2018-19

2021-22

Plate 9 Photo-point image comparison, tree condition site B18, Hattah Lakes, 2007-08 to 2021-22.

3.3 Black Box Tree Condition Index (TCI) score comparisons between sites

For the purposes of these figures only live trees and those which had no leaves but could not be conclusively deemed as dead have been included (i.e. those which make up the current ~30 trees per site). In 2021-22 trees with no leaves which were not deemed conclusively as dead were given a score of zero.

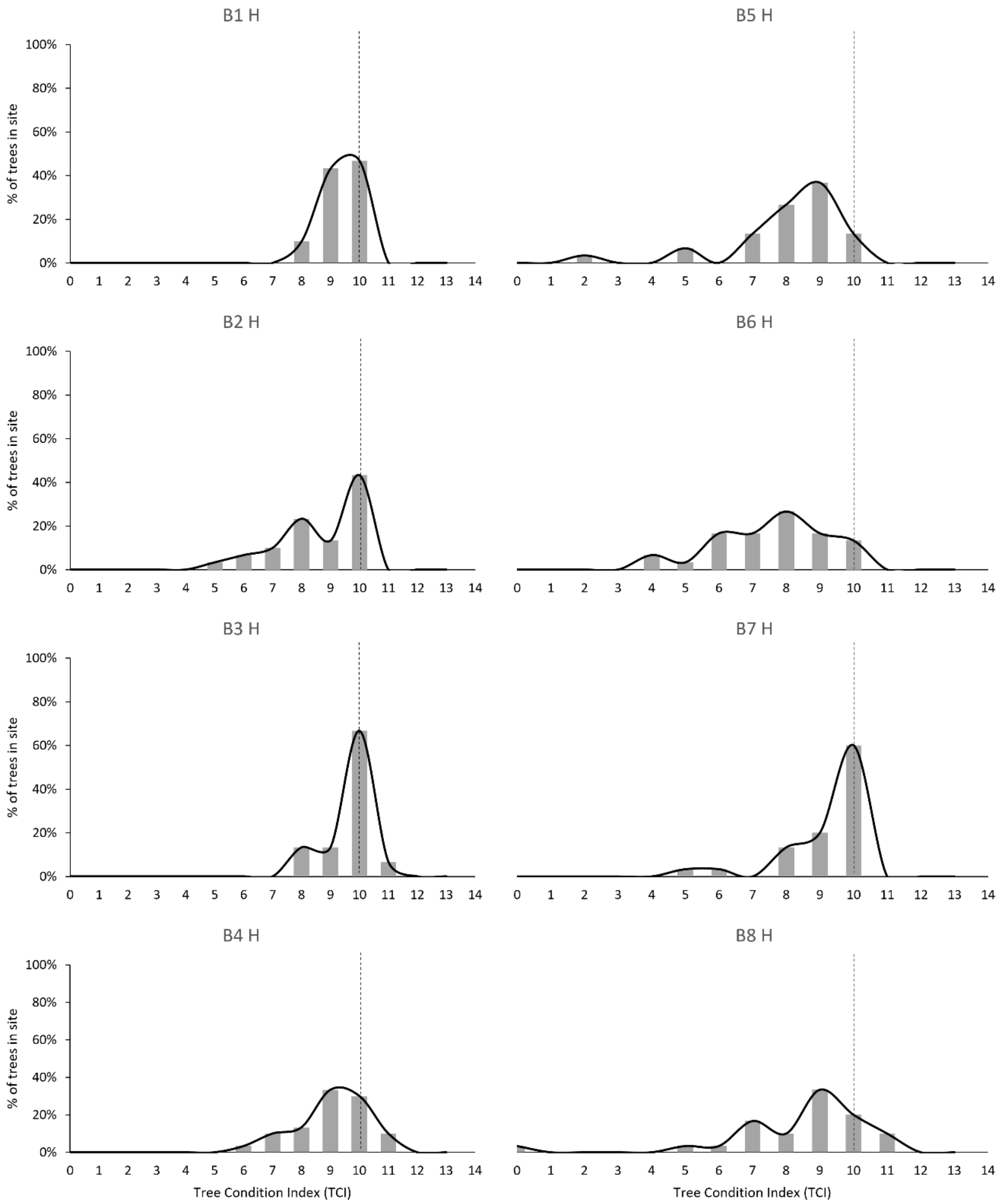

Figure 7 Percentage of trees in each TCI category across Black Box sites B1 H-B8 H, Hattah Lakes, 2021-22. The vertical dotted line indicates the ecological target for tree condition of ≥10.

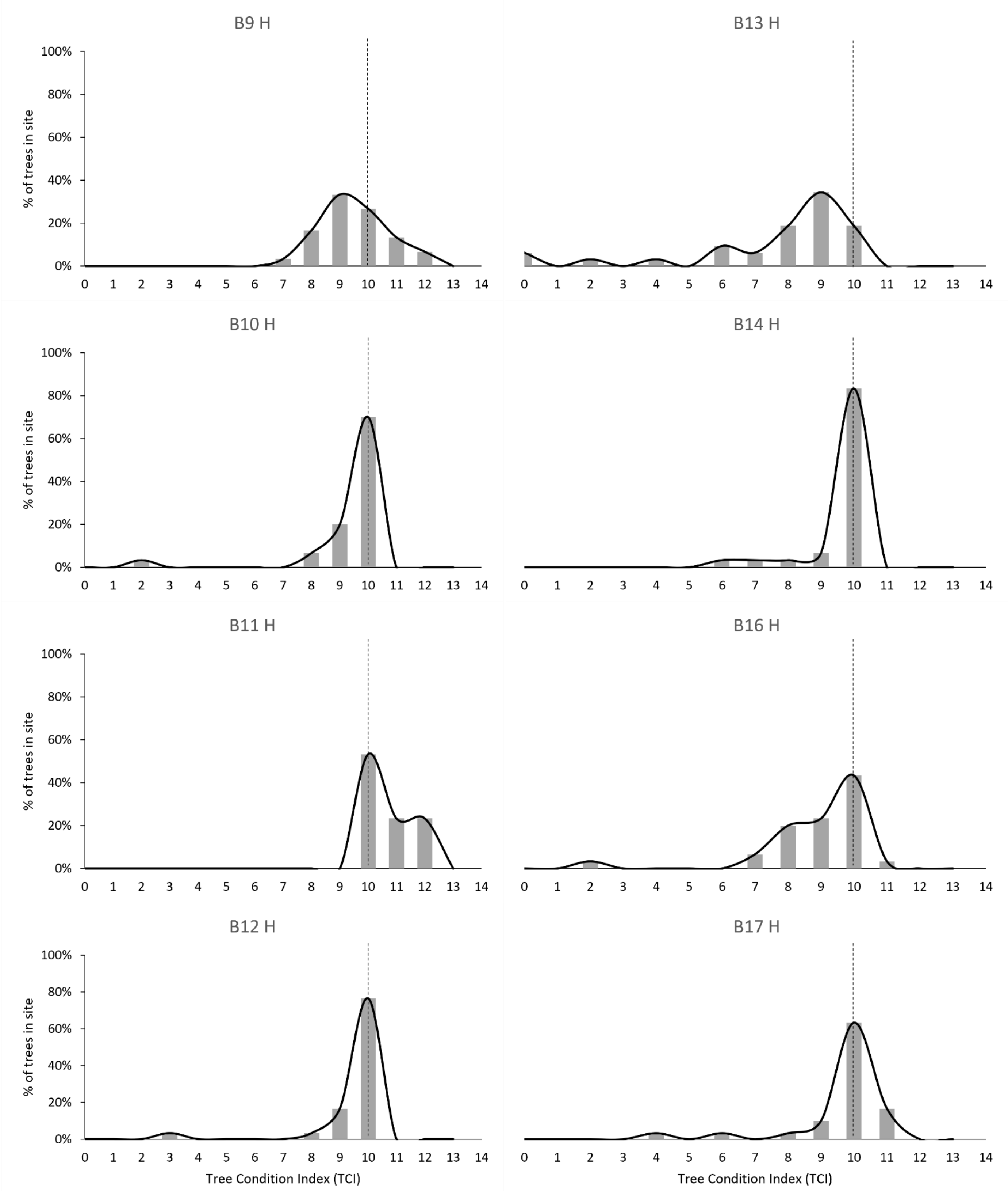

Figure 8 **Percentage of trees in each TCI category across Black Box sites B9 H-B17 H, Hattah Lakes, 2021-22. The vertical dotted line indicates the ecological target for tree condition of ≥10.**

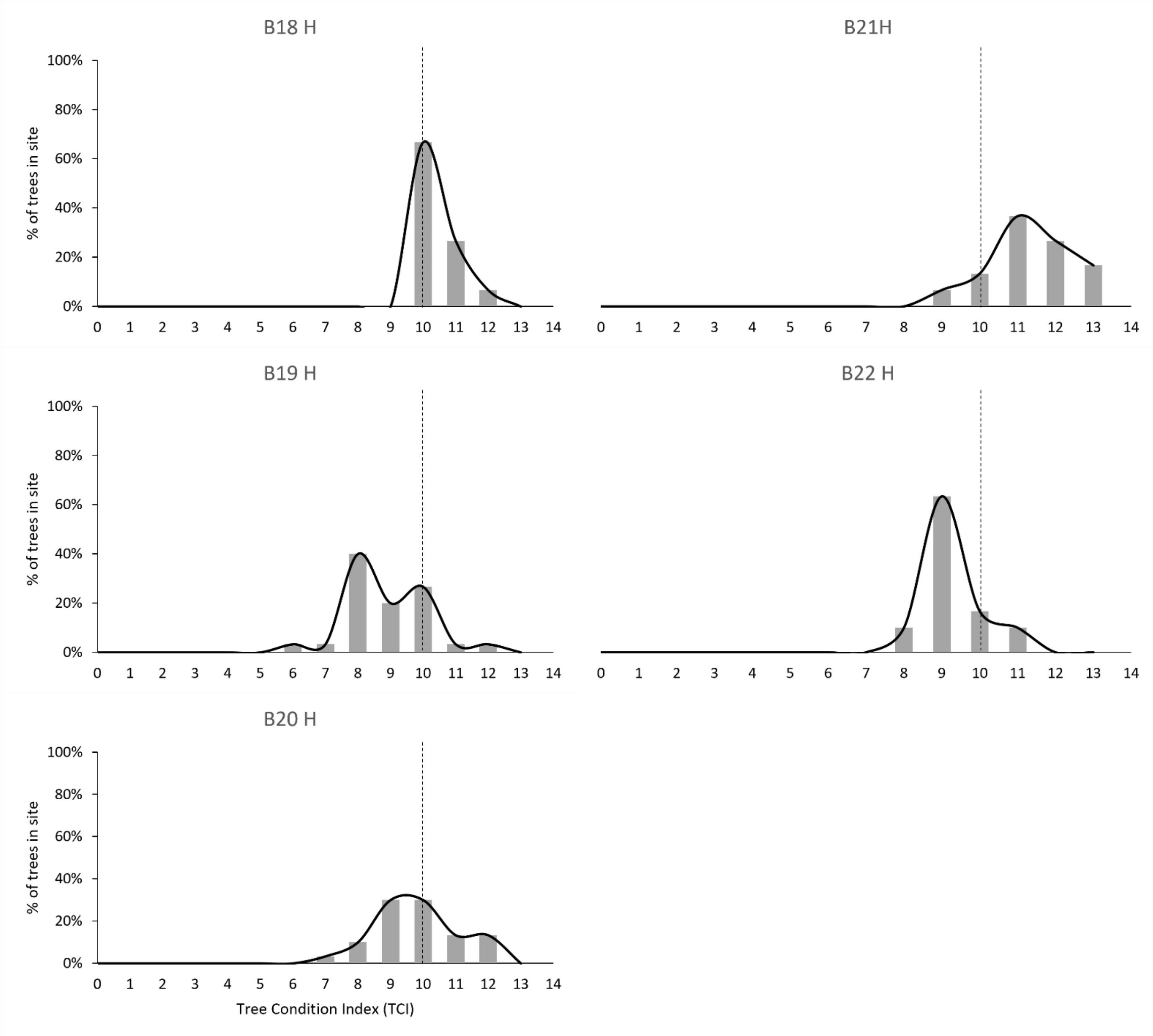

Figure 9 **Percentage of trees in each TCI category across Black Box sites B18 H-B22 H, Hattah Lakes, 2021-22. The vertical dotted line indicates the ecological target for tree condition of ≥10.**

Table 5 Total number of trees in each TCI category across all Black Box tree condition sites, Hattah Lakes, 2021-22. Trees with a TCI score of zero represent dead trees which have died across any seasons.

Site	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
B1 H									3	13	14				
B2 H						1	2	3	7	4	13				
B3 H									4	4	20	2			
B4 H							1	3	4	10	9	3			
B5 H			1			2		4	8	11	4				
B6 H					2	1	5	5	8	5	4				
B7 H						1	1		4	6	18				
B8 H	1					1	1	5	3	10	6	3			
B9 H								1	5	10	8	4	2		
B10 H			1						2	6	21				
B11 H											16	7	7		
B12 H				1					1	5	23				
B13 H	2		1		1		3	2	6	11	6				
B14 H							1	1	1	2	25				
B15 H										4	23	3			
B16 H			1					2	6	7	13	1			
B17 H					1		1		1	3	19	5			
B18 H											20	8	2		
B19 H							1	1	12	6	8	1	1		
B20 H								1	3	9	9	4	4		
B21H										2	4	11	8	5	
B22 H									3	19	5	3			
Total:	**3**	**0**	**4**	**1**	**4**	**6**	**16**	**28**	**81**	**147**	**288**	**55**	**24**	**5**	**0**

3.4 Black Box population structure site details

Table 6 Black Box population structure sites monitored in Round 1 (2021-22) at Hattah Lakes.

Site	Easting	Northing
HB-S1	633825	6165780
HB-S2	637998	6159948
HB-S3	637604	6156463
HB-S4	633980	6156441
HB-S5	636127	6153572
HB-S6	636050	6150796
HB-S7	639143	6152521
HB-S8	645845	6148885
HB-S9	645852	6148977

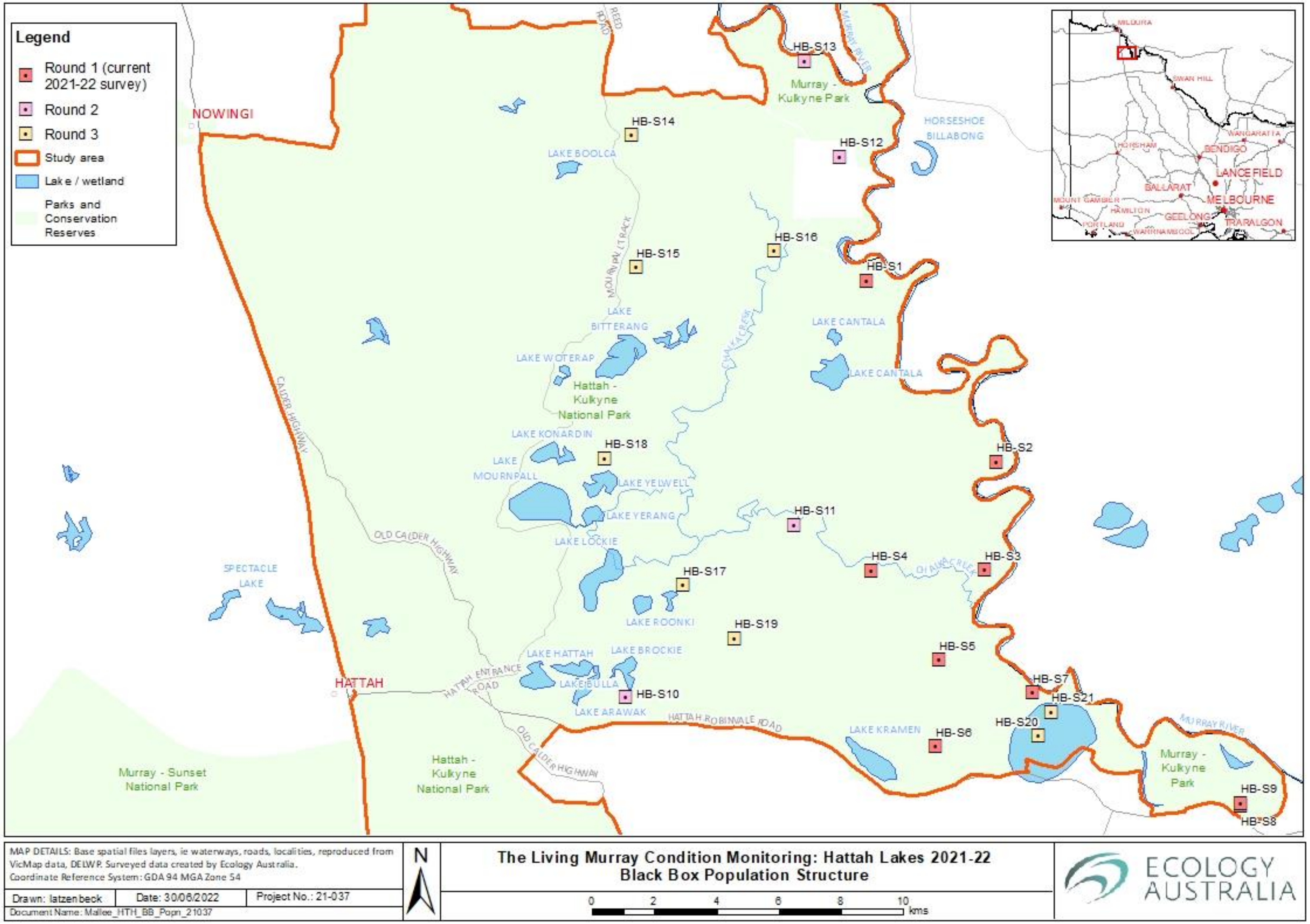

Figure 10 Map of Black Box Population Structure sites, Hattah Lakes study area (2021-22). The current survey assessed the Round 1 sites.

4 Wetland Vegetation Communities

4.1 Wetland site details

Table 7 Wetland site locations, Hattah Lakes.

Transect	Easting	Northing	Transect	Easting	Northing	Transect	Easting	Northing
NCT1+0A	627529	6162393	LHT1+60B	623218	6153868	BRT3+120A	625827	6153469
NCT1+0B	627536	6162380	LHT2+0A	623171	6153793	BRT3+120B	625843	6153470
NCT1+30A	627537	6162402	LHT2+0B	623160	6153781	BRPHOTO A	626370	6153388
NCT1+30B	627547	6162388	LHT2+30A	623256	6153722	BRPHOTO B	626388	6153377
NCT1+60A	627540	6162405	LHT2+30B	623245	6153712	BOT1+0A	627053	6153223
NCT1+60B	627549	6162391	LHT2+60A	623274	6153707	BOT1+0B	627066	6153232
NCT1+90A	627542	6162407	LHT2+60B	623265	6153696	BOT1+30A	627020	6153266
NCT1+90B	627553	6162393	LHT3+0A	623134	6153779	BOT1+30B	627029	6153278
NCT2+0A	627549	6162348	LHT3+0B	623124	6153789	BOT1+60A	627011	6153280
NCT2+0B	627555	6162334	LHT3+30A	623097	6153739	BOT1+60B	627019	6153292
NCT2+30A	627540	6162345	LHT3+30B	623082	6153746	BOT2+0A	627115	6153223
NCT2+30B	627546	6162330	LHT3+60A	623088	6153728	BOT2+0B	627113	6153208
NCT2+60A	627536	6162343	LHT3+60B	623076	6153737	BOT2+30A	627154	6153260
NCT2+60B	627541	6162328	LHT4+0B	623131	6153824	BOT2+30B	627155	6153245
NCT2+90A	627533	6162341	LHT4+0A	623116	6153819	BOT2+60A	627168	6153274
NCT2+90B	627538	6162327	LHT4+30A	623066	6153923	BOT2+60B	627171	6153259
NCT3+0A	627568	6162300	LHT4+30B	623081	6153924	BOT3+0A	627087	6153165
NCT3+0B	627575	6162287	LHT4+60A	623039	6153968	BOT3+0B	627073	6153170
NCT3+30A	627588	6162311	LHT4+60B	623052	6153976	BOT3+30A	627067	6152970
NCT3+30B	627593	6162297	LHPHOTO	623218	6153586	BOT3+30B	627052	6152971
NCT3+60A	627591	6162312	HT1-100	623255	6153010	BOT3+60A	627066	6152954
NCT3+60B	627597	6162298	HT1-50A	623285	6153313	BOT3+60B	627051	6152953
NCT3+90A	627593	6162314	HT1-50B	623298	6153306	BOPHOTO	627011	6153280
NCT3+90B	627599	6162298	HT1+0A	623287	6153355	NN1+0A	628067	6153850
NCT4+0A	627594	6162257	HT1+0B	623298	6153344	NN1+0B	628075	6153838
NCT4+1B	627600	6162244	HT1+50A	623286	6153373	NN1+50A	628100	6153863
NCT4+30A	627584	6162251	HT1+50B	623298	6153361	NN1+50B	628104	6153848
NCT4+30B	627590	6162238	HT1+100A	623287	6153390	NN1+100A	628118	6153871
NCT4+60A	627581	6162251	HT1+100B	623298	6153379	NN1+100B	628116	6153854
NCT4+60B	627588	6162237	HT1+150A	623288	6153409	NN2+0A	628069	6153831
NCT4+90A	627578	6162250	HT1+150B	623296	6153395	NN2+0B	628052	6153829
NCT4+90B	627586	6162235	HT2-100	623282	6152986	NN2+50A	628078	6153800
NCTPHOTO	627593	6162314	HT2-50A	623545	6152950	NN2+50B	628065	6153794
MOT1-100	623306	6158691	HT2-50B	623546	6152934	NN2+100A	628085	6153790
MOT1-50A*	623989	6158850	HT2+0A	623598	6152952	NN2+100B	628072	6153782
MOT1-50B*	623997	6158837	HT2+0B	623605	6152938	NN3+0A	628048	6153827
MOT1+0A*	624045	6158899	HT2+50A	623610	6152953	NN3+0B	628046	6153842
MOT1+0B*	624033	6158912	HT2+50B	623619	6152938	NN3+50A	627972	6153810
MOT1+50A	624068	6158952	HT2+100A	623623	6152961	NN3+50B	627967	6153824
MOT1+50B	624080	6158944	HT2+100B	623633	6152948	NN3+100A	627940	6153805
MOT1+100A	624110	6159002	HT2+150A	623638	6152961	NN3+100B	627927	6153825
MOT1+100B	624125	6158997	HT2+150B	623647	6152949	NN4+0A	628048	6153845
MOT2-100	623245	6158708	HT2+200A	623651	6152962	NN4+0B	628063	6153850
MOT2-50	623567	6158246	HT2+200B	623662	6152951	NN4+50A	628038	6153873

Transect	Easting	Northing	Transect	Easting	Northing	Transect	Easting	Northing
MOT2+0A	623591	6158177	HT3-100	623266	6152973	NN4+50B	628052	6153877
MOT2+0B	623576	6158177	HT3-50A	623261	6152739	NN4+100A	628029	6153889
MOT2+50A	623609	6158138	HT3-50B	623246	6152738	NN4+100B	628044	6153894
MOT2+50B	623594	6158138	HT3+0A	623261	6152706	NNPHOTO	628125	6153834
MOT2+100A	623618	6158117	HT3+0B	623246	6152705	KT1+50A	633594	6150527
MOT2+100B	623603	6158120	HT3+50A	623261	6152697	KT1+50B	633604	6150538
MOT2+150A	623626	6158099	HT3+50B	623246	6152697	KT1+100A	633471	6150761
MOT2+150B	623610	6158101	HT3+100A	623259	6152688	KT1+100B	633484	6150754
MOT2+200A	623634	6158083	HT3+100B	623244	6152688	KT1+150A	633365	6150954
MOT2+200B	623618	6158084	HT3+150A	623259	6152680	KT1+150B	633375	6150944
MOT3-100	623286	6158686	HT3+150B	623244	6152679	KT1+200A	633318	6151042
MOT3-50	622566	6158340	HT3+200A	623260	6152674	KT1+200B	633328	6151031
MOT3+0A	622494	6158305	HT3+200B	623245	6152672	KT1+250A	633279	6151105
MOT3+0B	622484	6158316	HT4-100	623247	6152994	KT1+250B	633290	6151094
MOT3+50A	622467	6158293	HT4-50A	622799	6152989	KT2+50A	633665	6150518
MOT3+50B	622457	6158303	HT4-50B	622807	6153002	KT2+50B	633676	6150508
MOT3+100A	622450	6158286	HT4+0A	622717	6152992	KT2+100A	633869	6150613
MOT3+100B	622440	6158296	HT4+0B	622723	6153005	KT2+100B	633881	6150605
MOT3+150A	622436	6158282	HT4+50A	622692	6152999	KT2+150A	633916	6150642
MOT3+150B	622426	6158293	HT4+50B	622696	6153015	KT2+150B	633927	6150632
MOT3+200A	622426	6158278	HT4+100A	622678	6153001	KT2+200A	633933	6150652
MOT3+200B	622416	6158289	HT4+100B	622683	6153016	KT2+200B	633946	6150642
MOT4-100	623174	6158807	HT4+150A	622669	6153005	KT2+250A	633947	6150661
MOT4-50	623099	6159087	HT4+150B	622675	6153020	KT2+250B	633959	6150650
MOT4+0A	623093	6159124	HT4+200A	622664	6153005	KT3 +50A	633657	6150418
MOT4+0B	623104	6159133	HT4+200B	622669	6153020	KT3+50B	633643	6150424
MOT4+50A	623081	6159138	HPHOTO A	623193	6152674	KT3+100A	633844	6150057
MOT4+50B	623094	6159148	HPHOTO B	623196	6152696	KT3+100B	633830	6150069
MOT4+100A	623076	6159151	BLT1-100	624641	6153328	KT3+150A	633894	6149975
MOT4+100B	623085	6159160	BLT1-50	624680	6153467	KT3+150B	633882	6149983
MOT4+150A	623069	6159157	BLT1+0A	624688	6153528	KT3+200A	633908	6149946
MOT4+150B	623080	6159167	BLT1+0B	624703	6153530	KT3+200B	633897	6149955
MOT4+200A	623061	6159163	BLT1+50A	624688	6153544	KT3+250A	633921	6149925
MOT4+200B	623072	6159174	BLT1+50B	624703	6153545	KT3+250B	633909	6149932
MOPHOTOA	622431	6158272	BLT1+100A	624691	6153557	KT4+50A	633590	6150467
MOPHOTOB	622495	6158301	BLT1+100B	624706	6153559	KT4+50B	633583	6150481
YT1+0A	625003	6158254	BLT1+150A	624691	6153568	KT4+100A	633509	6150422
YT1+0B	624990	6158263	BLT1+150B	624707	6153568	KT4+100B	633500	6150434
YT1+50A	624789	6158015	BLT2-100	624643	6153323	KT4+150A	633497	6150414
YT1+50B	624779	6158027	BLT2-50	624796	6153214	KT4+150B	633488	6150426
YT1+100A	624779	6157999	BLT2+0A	624850	6153189	KT4+200A	633487	6150409
YT1+100B	624772	6158012	BLT2+0B	624842	6153177	KT4+200B	633477	6150420
YT2+0A	624995	6158333	BLT2+50A	624859	6153183	KT4+250A	633479	6150406
YT2+0B	625006	6158343	BLT2+50B	624852	6153170	KT4+250B	633469	6150417
YT2+50A	624890	6158504	BLT2+100A	624869	6153177	KPHOTO A	633318	6151042
YT2+50B	624905	6158507	BLT2+100B	624861	6153165	KPHOTO B	633971	6149884
YT2+100A	624886	6158511	BLT2+150A	624873	6153174	KPHOTO C	633996	6149874
YT2+100B	624901	6158513	BLT2+150B	624866	6153161	BIT1+0A	626035	6163295
YT3+0A	625060	6158338	BLT3-100	624635	6153314	BIT1+0B	626048	6163290
YT3+0B	625070	6158327	BLT3-50	624558	6153178	BIT1+50A	626216	6164025
YT3+50A	625215	6158490	BLT3+0A	624516	6153083	BIT1+50B	626229	6164019
YT3+50B	625225	6158480	BLT3+0B	624501	6153084	BIT1+100A	626222	6164054
YT3+100A	625233	6158503	BLT3+50A	624510	6153071	BIT1+100B	626238	6164051

Transect	Easting	Northing	Transect	Easting	Northing	Transect	Easting	Northing
YT3+100B	625243	6158494	BLT3+50B	624495	6153074	BIT1+150A	626233	6164081
YT4+0A	625052	6158250	BLT3+100A	624507	6153063	BIT1+150B	626246	6164075
YT4+0B	625038	6158247	BLT3+100B	624491	6153064	BIT1+200A	626230	6164102
YT4+50A	625098	6158099	BLT3+150A	624503	6153054	BIT1+200B	626242	6164095
YT4+50B	625084	6158095	BLT3+150B	624488	6153056	BIT1+250A	626236	6164115
YT4+100A	625109	6158063	BLT4-100	624611	6153323	BIT1+250B	626249	6164108
YT4+100B	625095	6158057	BLT4-50	624252	6153383	BIT2+0A	626069	6163241
YPHOTO	624888	6157920	BLT4+0A	624202	6153398	BIT2+0B	626058	6163226
CHT1+0A	629209	6157750	BLT4+0B	624212	6153410	BIT2+50A	626272	6163214
CHT1+0B	629220	6157739	BLT4+50A	624193	6153408	BIT2+50B	626269	6163200
CHT1S+50A	629206	6157746	BLT4+50B	624205	6153418	BIT2+100A	626298	6163210
CHT1S+50B	629217	6157736	BLT4+100A	624185	6153418	BIT2+100B	626292	6163197
CHT1S+100A	629204	6157745	BLT4+100B	624198	6153426	BIT2+150A	626311	6163211
CHT1S+100B	629216	6157734	BLT4+150A	624179	6153425	BIT2+150B	626305	6163198
CHT1S+150A	629203	6157744	BLT4+150B	624190	6153435	BIT2+200A	626324	6163211
CHT1S+150B	629214	6157732	BLPHOTO A	624400	6153077	BIT2+200B	626319	6163200
CHT2+0A	629252	6157706	BLPHOTO B	624407	6153102	BIT2+250A	626338	6163209
CHT2+0B	629267	6157702	BRT1+0A	626263	6153544	BIT2+250B	626338	6163200
CHT2N+50A	629254	6157712	BRT1+0B	626277	6153540	BIT3+0A	626008	6163200
CHT2N+50B	629269	6157707	BRT1+30A	626294	6153628	BIT3+0B	625993	6163197
CHT2N+100A	629255	6157714	BRT1+30B	626306	6153620	BIT3+50A	625946	6162828
CHT2N+100B	629270	6157709	BRT1+60A	626304	6153656	BIT3+50B	625933	6162820
CHT2N+150A	629256	6157717	BRT1+60B	626315	6153647	BIT3+100A	625952	6162771
CHT2N+150B	629270	6157713	BRT1+90A	626308	6153670	BIT3+100B	625941	6162761
CHT3+0A	629312	6157701	BRT1+90B	626322	6153664	BIT3+150A	625944	6162745
CHT3+0B	629327	6157701	BRT1+120A	626314	6153685	BIT3+150B	625934	6162735
CHT3S+50A	629312	6157694	BRT1+120B	626328	6153679	BIT3+200A	625944	6162720
CHT3S+50B	629328	6157692	BRT2+0A	626296	6153386	BIT3+200B	625933	6162708
CHT3S+100A	629312	6157688	BRT2+0B	626282	6153379	BIT3+250A	625948	6162713
CHT3S+100B	629328	6157687	BRT2+30A	626326	6153341	BIT3+250B	625942	6162699
CHT3S+150A	629313	6157684	BRT2+30B	626316	6153331	BIT4+0A	625971	6163252
CHT3S+150B	629328	6157683	BRT2+60A	626335	6153327	BIT4+0B	625971	6163267
CHT4+0A	629373	6157711	BRT2+60B	626324	6153318	BIT4+50A	625440	6163319
CHT4+0B	629389	6157708	BRT2+90A	626340	6153319	BIT4+50B	625453	6163325
CHT4N+50A	629373	6157724	BRT2+90B	626328	6153310	BIT4+100A	625382	6163331
CHT4N+50B	629388	6157728	BRT2+120A	626345	6153315	BIT4+100B	625396	6163336
CHTN4+100A	629373	6157729	BRT2+120B	626333	6153305	BIT4+150A	625336	6163323
CHTN4+100B	629387	6157734	BRT3+0A	626048	6153461	BIT4+150B	625339	6163336
CHTN4+150	629382	6157739	BRT3+0B	626058	6153472	BIT4+200A	625317	6163321
CHPHOTO	629230	6157708	BRT3+30A	625944	6153464	BIT4+200B	625321	6163336
LHT1+0A	623174	6153822	BRT3+30B	625958	6153470	BIT4+250A	625307	6163319
LHT1+0B	623184	6153810	BRT3+60A	625909	6153463	BIT4+250B	625309	6163335
LHT1+30A	623191	6153859	BRT3+60B	625924	6153467	BIPHOTO	626216	6164025
LHT1+30B	623204	6153854	BRT3+90A	625868	6153463			
LHT1+60A	623205	6153876	BRT3+90B	625882	6153467			

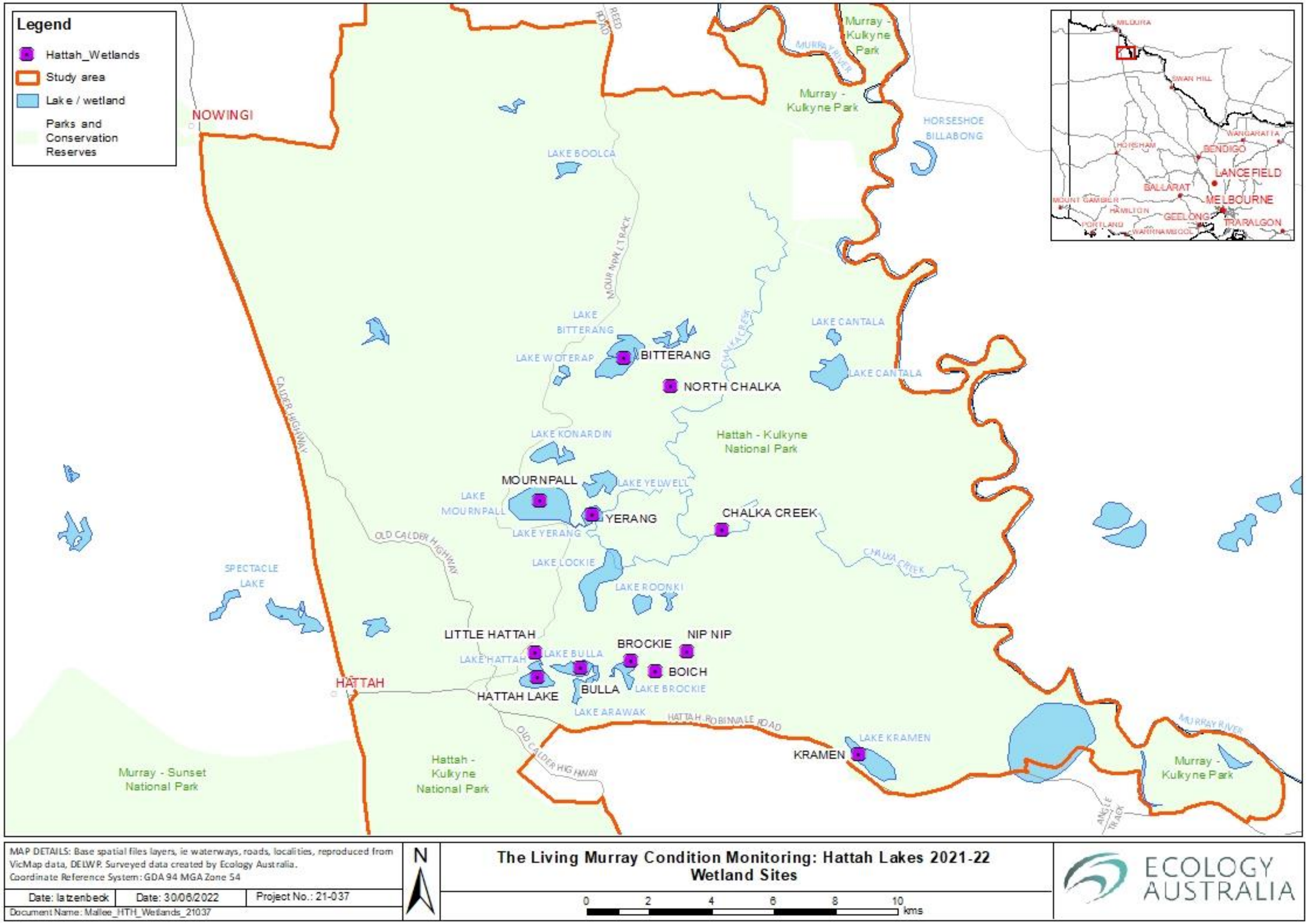

Figure 11 Map of Wetland sites, Hattah Lakes study area (2021-22).

4.2 Wetland species lists

Table 8 Vascular plant species recorded within each of the twelve wetland monitoring locations, Hattah Lakes Icon Site, January – April 2022. The number of transects which a species was recorded in at each site for 2021-22 is also shown.

Key:

- CS — Conservation Status: Victorian Flora and Fauna Guarantee Act 1988 (P = Protected flora species under the FFG Act, e = Listed as endangered under the FFG Act, cr = Listed as critically endangered under the FFG Act).
- FG — Functional group: A = amphibious species, Arf = amphibious floating plants also found in damp habitats, Arp = amphibious floating plants, Ate = amphibious monocotyledons, Atl = amphibious herbs, Atw = amphibious woody plants, F = floating plants, S = submerged plants, T = terrestrial plants that do not tolerate flooding, Tda = terrestrial species preferring damp habitats, Tdr = drought-tolerant species.
- # — Species native to Victoria though not indigenous within study area
- * — Exotic plant species.
- C — Species listed as Regionally Controlled under the CaLP Act
- Sites — CH = Chalka Creek, NC = North Chalka Creek, BI = Lake Bitterang, BO = Lake Boich, BR = Lake Brockie, BL = Lake Bulla, HT = Lake Hattah, K = Lake Kramen, LH = Lake Little Hattah, MO = Lake Mournpall, NN = Lake Nip Nip, Y = Lake Yerang

Note that many wetlands were flooded in 2021-22 hence the low number of species.

CS	Scientific name	Common name	FG	CH	NC	BI	BO	BR	BL	HT	K	LH	MO	NN	Y
P	*Acacia stenophylla*	eumong	Atw	1	3	1			1	2					
	Alternanthera denticulata	lesser joyweed	Tda	5	9						1				
	Alternanthera sp.	joyweed	T		1										
	Alternanthera sp. *1* (Plains)	plains joyweed	Tda	1	8										
en P	*Ammannia multiflora*	jerry-jerry	Atl	1	5										
	Asteraceae sp.	composite	T	1											
	Atriplex suberecta	sprawling saltbush	Tdr								12				
en P	*Austrobryonia micrantha*	Mallee cucumber	Tda		1										
P	*Azolla rubra*	pacific azolla	Arf	1											
en P	*Bergia trimera*	small water-fire	Tda		3										

CS	Scientific name	Common name	FG	CH	NC	BI	BO	BR	BL	HT	K	LH	MO	NN	Y
	Brassicaceae sp.	crucifer			2										
en P	*Calotis cuneifolia*	blue burr-daisy	Tdr								13				
*	*Centaurium tenuiflorum*	slender centaury	Tdr								2				
P	*Centipeda cunninghamii*	common sneezeweed	Atl		8						3				
P	*Centipeda minima* subsp. *minima*	spreading sneezeweed	Atl	3											
	Chenopodiaceae sp.	chenopod			1										
*	*Cucumis myriocarpus* subsp. *myriocarpus*	paddy melon	Tdr		1										
	Cyperus gymnocaulos	spiny flat-sedge	Ate			2				2			2		
* P	*Datura innoxia*	recurved thorn-apple	Tdr	1											
	Duma florulenta	tangled lignum	Atw		2										
	Dysphania glomulifera subsp. *glomulifera*	globular pigweed	Tdr		4										
	Dysphania pumilio	clammy goosefoot	Tdr	1	8						3				
P	*Eclipta platyglossa* subsp. *platyglossa*	yellow twin-heads	Tda		3										
	Elatine gratioloides	waterwort	Atl	1	3										
	Eleocharis sp.	spike sedge	A	4											
	Enchylaena tomentosa var. *tomentosa*	ruby saltbush	Tdr								2				
	Epilobium billardiereanum	variable willow-herb	Tda								1				
	Eragrostis dielsii	Mallee love-grass	Tdr								8				
*	*Erigeron bonariensis*	flaxleaf fleabane	Tdr								11				
	Eucalyptus camaldulensis	river red-gum	Atw		1	1		4	6	3	3		3		
	Eucalyptus largiflorens	black box	Atw		1										
	Euphorbia dallachyana	flat spurge	Tdr	4	8										
	Glinus lotoides	hairy carpet-weed	Tda	3							1				

CS	Scientific name	Common name	FG	CH	NC	BI	BO	BR	BL	HT	K	LH	MO	NN	Y
	Glinus oppositifolius	slender carpet-weed	Tda		4						1				
en P	*Glossostigma diandrum*	spoon-leaf mud-mat	Atl		1										
	Glycyrrhiza acanthocarpa	southern liquorice	Tda								20				
	Goodenia glauca	pale goodenia	Tda		3										
en P	*Gratiola pumilo*	dwarf brooklime	Tda	5											
	Haloragis glauca f. *glauca*	bluish raspwort	Tda		1										
*	*Heliotropium supinum*	creeping heliotrope	Tda	4	11										
	Juncus subsecundus	finger rush	Tda								4				
	Lachnagrostis filiformis	common blown-grass	Tda	1							6				
*	*Lactuca serriola*	prickly lettuce	Tdr								2				
P	*Laphangium luteoalbum*	jersey cudweed	Tdr								7				
	Lotus cruentus	red bird's-foot trefoil	Tdr								2				
	Malva weinmanniana	Australian hollyhock	Tdr								2				
P	*Marsilea costulifera*	narrow-leaf nardoo	Arp	2	7										
	Myriophyllum verrucosum	red water-milfoil	Arp	2	1										
	Paspalidium jubiflorum	warrego summer-grass	Tda		2										
	Persicaria prostrata	creeping knotweed	Atl	3	2						10				
en P	*Phyllanthus lacunarius*	lagoon spurge	Tda		3										
	Poaceae sp.	grass	T		1										
	Polygonum plebeium	small knotweed	Tda		1						8				
	Potamogeton sulcatus	furrowed pondweed	Arp	5											
	Pseudoraphis spinescens	spiny mud-grass	Arp	5											
	Rumex tenax	narrow-leaf dock	Tda		1						4				
*	*Solanum nigrum*	black nightshade	Tdr		1						1				

CS	Scientific name	Common name	FG	CH	NC	BI	BO	BR	BL	HT	K	LH	MO	NN	Y
	Solanum simile	oondoroo	Tda								1				
*	*Sonchus asper* subsp. *asper*	rough sow-thistle	Tdr								1				
P	*Sphaeromorphaea littoralis*	spreading nut-heads	Tda	2	9						3				
	Sporobolus mitchellii	rat-tail couch	Tda		7										
	Stemodia florulenta	blue rod	Tda								4				
en P	*Trigonella suavissima*	sweet fenugreek	Tda								5				
	Vallisneria australis	eel grass	S	1											
	Verbena officinalis var. *gaudichaudii*	native verbena	Tdr								1				
	Verbena sp.	verbena	T								12				
	Wahlenbergia fluminalis	river bluebell	Tda								6				
*	*Xanthium occidentale*	noogoora burr	Tda	1											

Table 9 Vascular plant species recorded within wetland quadrats, Hattah Lakes Icon Site, 2007–08 to 2021-22.

Key: CS Conservation status: Victorian Flora and Fauna Guarantee Act 1988 (P = Protected flora species under the FFG Act, v = Listed as vulnerable under the FFG Act, e = Listed as endangered under the FFG Act, cr = Listed as critically endangered under the FFG Act).

FG Functional group: A = amphibious species, Arf = amphibious floating plants also found in damp habitats, Arp = amphibious floating plants, Ate = amphibious monocotyledons, Atl = amphibious herbs, Atw = amphibious woody plants, F = floating plants, S = submerged plants, T = terrestrial plants that do not tolerate flooding, Tda = terrestrial species preferring damp habitats, Tdr = drought-tolerant species.

* Exotic plant species.

C Species listed as Regionally Controlled under the CaLP Act

Sites CH = Chalka Creek, NC = North Chalka Creek, BI = Lake Bitterang, BO = Lake Boich, BR = Lake Brockie, BL = Lake Bulla, HT = Lake Hattah, K = Lake Kramen, LH = Lake Little Hattah, MO = Lake Mournpall, NN = Lake Nip Nip, Y = Lake Yerang

Note that new species recorded for the first time in 2021-22 include oondoroo *Solanum simile,* spoon-lead mud-mat *Glossostigma diandrum* and recurved thorn-apple *Datura innoxia* and these species have been highlighted in the following table.

CS	Scientific name	Common name	FG	CH	NC	BI	BO	BR	BL	HT	K	LH	MO	NN	Y
*	*Abutilon theophrasti*	chingma lantern	Tda					x							
P	*Acacia brachybotrya*	grey mulga	Tdr			x									
P	*Acacia ligulata*	small cooba	Atw			x									
P	*Acacia* spp.	wattle	T						x	x		x			
P	*Acacia stenophylla*	eumong	Atw	x	x	x		x	x	x			x		
P	*Actinobole uliginosum*	flannel cudweed	Tdr			x									
*	*Aira cupaniana*	quicksilver grass	Tdr								x				
	Aizoaceae spp.	ice plant	T		x										
	Ajuga australis	austral bugle	Tdr			x	x				x			x	
	Alternanthera denticulata	lesser joyweed	Tda	x	x	x	x	x	x	x	x	x	x	x	x
	Alternanthera nodiflora	common joyweed	Tda	x								x			x
	Alternanthera spp.	joyweed	T		x					x			x	x	x
	Alternanthera sp. *1 (Plains)*	plains joyweed	Tda	x	x										

CS	Scientific name	Common name	FG	CH	NC	BI	BO	BR	BL	HT	K	LH	MO	NN	Y
en P	*Ammannia multiflora*	jerry-jerry	Arp	x	x	x								x	x
	Aristida calycina var. *calycina*	dark wire-grass	Tda								x				
en P	*Asperula gemella*	twin-leaf bedstraw	Tda		x					x					
	Asteraceae spp.	composite	T	x		x	x	x	x	x	x	x	x	x	
	Atriplex eardleyae	small saltbush	Tdr				x							x	
	Atriplex leptocarpa	slender-fruit saltbush	Tdr		x		x				x	x		x	
	Atriplex lindleyi	flat-top saltbush	Tdr								x				
	Atriplex lindleyi subsp. *inflata*	corky saltbush	Tdr	x	x	x									
	Atriplex pumilio	mat saltbush	Tdr		x	x	x							x	
	Atriplex semibaccata	berry saltbush	Tdr	x	x	x	x	x						x	
	Atriplex spp.	saltbush	Tdr	x	x	x	x	x	x	x	x		x	x	x
	Atriplex stipitata	kidney saltbush	Tdr	x		x	x	x	x	x				x	
	Atriplex stipitata subsp. *Stipitata*	kidney saltbush	Tdr		x	x	x	x	x	x				x	
	Atriplex suberecta	sprawling saltbush	Tdr		x		x	x	x	x	x		x	x	x
en P	*Austrobryonia micrantha*	Mallee cucumber	Tda	x	x	x	x	x	x	x	x		x	x	x
	Austrostipa drummondii	cottony spear-grass	Tdr		x										
	Austrostipa scabra subsp. *scabra*	rough spear-grass	Tdr				x	x		x				x	
	Austrostipa scabra subsp. *falcata*	rough spear-grass	Tdr		x	x			x		x				
	Austrostipa spp.	spear grass	T	x	x	x	x		x	x	x	x	x	x	x
P	*Azolla rubra*	Pacific azolla	Arf	x											x
P	*Azolla* spp.	azolla	F		x										x
en P	*Bergia trimera*	small water-fire	Tda		x					x			x		
	Boerhavia dominii	tah-vine	Tdr				x							x	
P	*Brachyscome ciliaris*	variable daisy	Tdr			x	x	x	x						

CS	Scientific name	Common name	FG	CH	NC	BI	BO	BR	BL	HT	K	LH	MO	NN	Y
P	*Brachyscome ciliaris* var. *ciliaris*	variable daisy	Tdr		x										
P	*Brachyscome cuneifolia*	wedge-leaf daisy	Tda			x									
P	*Brachyscome lineariloba*	hard-head daisy	Tdr		x	x		x		x					
en P	*Brachyscome gracilis* subsp. *gracilis*	Dookie daisy	T		x		x	x							
*	*Brassica* spp.	turnip	Tdr				x						x	x	
*	*Brassica tournefortii*	Mediterranean turnip	Tdr								x				
*	*Brassica ×juncea*	Indian mustard	Tdr											x	
	Brassicaceae spp.	crucifer	T		x					x			x		
*	*Bromus rubens*	red brome	Tdr	x		x			x	x	x		x		x
	Amphibromus spp.	swamp wallaby-grass	Tdr										x	x	
	Bulbine semibarbata	leek lily	Tdr		x										
	Bulbine sp.	leek lily	Tda											x	
	Calandrinia eremaea	small purslane	Tdr		x										
	Calandrinia spp.	purslane	T								x				
	Callitriche spp.	water starwort	Arp								x			x	
en P	*Calotis cuneifolia*	blue burr-daisy	Tdr			x					x				x
P	*Calotis erinacea*	tangled burr-daisy	Tdr			x			x						
P	*Calotis hispidula*	hairy burr-daisy	Tdr		x						x				
*	*Centaurea* spp.	knapweed	Tdr								x				
*	*Centaurium* spp.	centaury	T					x	x		x			x	
*	*Centaurium tenuiflorum*	slender centaury	Tdr						x		x		x		
P	*Centipeda cunninghamii*	common sneezeweed	Atl	x	x	x	x	x	x	x	x	x	x	x	x
P	*Centipeda minima subsp. minima*	spreading sneezeweed	Atl	x	x	x		x	x	x	x	x	x	x	x
en P	*Centipeda crateriformis* subsp. *compacta*	compact sneezeweed	Atl	x	x		x	x	x	x	x	x	x	x	x

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	Chenopodiaceae spp.	chenopod	T		x	x									
en P	*Chenopodium desertorum* subsp. *desertorum*	frosted goosefoot	Tdr				x							x	
en P	*Chenopodium desertorum* subsp. *rectum*	frosted goosefoot	Tdr											x	
	Chenopodium melanocarpum (NSW only)		Tdr				x	x							
	Chenopodium spp.	goosefoot	Tdr							x	x		x	x	x
	Chloris truncata	windmill grass	Tdr			x									
* P	*Chondrilla juncea*	skeleton weed	Tdr		x			x	x	x	x	x	x	x	
en P	*Convolvulus clementii*	desert bindweed	Tdr		x	x			x	x			x		
	Convolvulus remotus	grassy bindweed	Tdr			x	x		x			x			
	Convolvulus spp.	bindweed	Tdr			x	x				x		x		
*	*Cotula bipinnata*	ferny cotula	Tda				x							x	
	Crassula colorata	dense crassula	Atl	x	x										
	Crassula colligata subsp. *colligata*	slender stonecrop	T								x				
*	*Cucumis myriocarpus* subsp. *myriocarpus*	paddy melon	Tdr		x										
	Cucurbitaceae spp.		T											x	
	Cynodon dactylon	couch	Tdr	x	x	x				x		x			
	Cynodon dactylon var. *pulchellus*	native couch	Tdr	x	x	x									
	Cyperaceae spp.	sedge	Ate	x					x	x			x		x
	Cyperus difformis	variable flat-sedge	Ate		x										
	Cyperus gymnocaulos	spiny flat-sedge	Ate			x		x	x	x			x		
en P	*Cyperus pygmaeus*	dwarf flat-sedge	Ate		x										
	Cyperus gunnii subsp. *gunnii*	flecked flat-sedge	Ate										x		
*	*Datura innoxia*	recurved thorn-apple	Tdr	x											
	Dissocarpus paradoxus	hard-head saltbush	Tdr		x										

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* C	*Dittrichia graveolens*	stinkwort	Tda	x		x	x			x			x	x	
	Dodonaea viscosa subsp. *angustissima*	slender hop-bush	Tdr	x	x	x	x	x	x	x	x	x	x	x	x
	Duma florulenta	tangled lignum	Ate		x										x
	Dysphania cristata	crested goosefoot	Tdr				x							x	
	Dysphania glomulifera subsp. *glomulifera*	globular pigweed	Tdr		x			x	x	x	x		x	x	
	Dysphania pumilio	clammy goosefoot	Tdr	x	x	x	x	x	x	x	x	x	x	x	x
	Dysphania spp.	pigweed	Tdr							x					
P	*Eclipta platyglossa* subsp. *platyglossa*	yellow twin-heads	Tda	x	x	x	x	x		x				x	x
	Einadia nutans subsp. *Nutans*	nodding saltbush	Tdr	x	x	x	x	x	x	x	x	x		x	
	Elatine gratioloides	waterwort	Arp	x	x			x	x	x		x			x
	Eleocharis pallens	pale spike-sedge	Ate										x		
	Eleocharis pusilla	small spike-sedge	Ate	x											
	Eleocharis spp.	spike sedge	A	x						x					
	Enchylaena tomentosa var. *tomentosa*	ruby saltbush	Tdr	x	x	x	x	x	x	x	x	x	x	x	x
	Enneapogon nigricans	dark bottle-washers	Tdr			x									
	Epilobium billardiereanum	variable willow-herb	Tda								x				
	Epilobium billardiereanum subsp. *cinereum*	grey willow-herb	Tda								x				
cr P	*Eragrostis australasica*	cane grass	Tda						x		x				
	Eragrostis dielsii	Mallee love-grass	Tdr	x	x	x	x	x	x	x	x	x	x	x	x
en P	*Eragrostis lacunaria*	purple love-grass	Tdr				x	x					x		
	Eragrostis spp.	love grass	T				x		x		x			x	
*	*Erigeron bonariensis*	flaxleaf fleabane	Tdr	x		x			x	x	x	x	x		x
*	*Erigeron* spp.	fleabane	Tdr	x	x	x	x	x	x	x	x	x	x	x	x
*	*Erigeron sumatrensis*	tall fleabane	Tdr	x	x	x	x		x	x			x		x

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*	*Erodium cicutarium*	common heron's-bill	Tdr								x		x		
	Erodium crinitum	blue heron's-bill	Tdr								x				
	Eucalyptus camaldulensis	river red-gum	Atw	x	x	x	x	x	x	x	x	x	x	x	x
	Eucalyptus largiflorens	black box	Atw		x	x		x		x	x		x		
	Euphorbia dallachyana	flat spurge	Tdr	x	x	x	x	x	x	x	x	x		x	x
	Fabaceae spp.	legumes	T										x		
	Geococcus pusillus	earth cress	Tda										x		
	Glinus lotoides	hairy carpet-weed	Tda	x		x	x	x	x	x	x	x	x	x	x
	Glinus oppositifolius	slender carpet-weed	Tda	x	x			x		x	x			x	
en P	*Glossostigma diandrum*	spoon-leaf mud-mat	Atl		x										
	Glossostigma elatinoides	small mud-mat	Arp	x											
	Glossostigma spp.	mud mat	Arp									x			
	Glycyrrhiza acanthocarpa	southern liquorice	Tda		x	x	x	x	x	x	x	x	x	x	x
	Goodenia glauca	pale goodenia	Tda		x								x		
	Gratiola pubescens	glandular brooklime	Tda	x											
en P	*Gratiola pumilo*	dwarf brooklime	Tda	x							x				
	Haloragis glauca f. *glauca*	bluish raspwort	Tda		x										
	Haloragis spp.	raspwort	T											x	
	Heliotropium curassavicum	smooth heliotrope	Tda					x	x	x	x		x	x	
*	*Heliotropium europaeum*	common heliotrope	Tda	x		x	x	x	x				x	x	
en P	*Heliotropium asperrimum*	rough heliotrope	T									x			
*	*Heliotropium supinum*	creeping heliotrope	Tda	x	x	x	x		x					x	x
*	*Hordeum leporinum*	barley-grass	Tdr	x	x			x		x	x			x	x
	Hydrocotyle spp.	pennywort									x				

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	Hypericum gramineum	small st john's wort	Tdr			x				x			x		
*	*Hypochaeris glabra*	smooth cat's-ear	Tdr	x						x	x				
*	*Hypochaeris radicata*	flatweed	Tdr				x								
	Isolepis australiensis	inland club-sedge	Ate			x	x						x		
	Isolepis platycarpa	broad-fruit club-sedge	Ate			x				x					
	Isolepis hookeriana	grassy club-sedge	Ate										x		
	Isolepis spp.	club sedge	A			x			x	x	x		x	x	
	Juncus bufonius	toad rush	Ate			x			x	x			x		
	Juncus spp.	rush	Ate							x	x		x		
	Juncus subsecundus	finger rush	Ate			x					x				
	Lachnagrostis filiformis	common blown-grass	Tda	x	x	x		x	x	x	x	x	x	x	x
	Lachnagrostis spp.	blown grass	Tda			x								x	
*	*Lactuca serriola*	prickly lettuce	Tdr	x		x	x	x		x	x	x	x	x	x
P	*Laphangium luteoalbum*	jersey cudweed	Tda	x	x	x	x	x	x	x	x	x	x	x	x
	Lemna disperma	common duckweed	F	x			x	x	x			x		x	x
	Lemna spp.	duckweed	F		x		x	x	x			x		x	x
*	*Leontodon saxatilis* subsp. *saxatilis*	hairy hawkbit	Tdr							x					
	Lepidium fasciculatum	bundled peppercress	Tdr								x				
	Lepidium pseudohyssopifolium	native peppercress	Tdr			x					x				
	Limosella australis	austral mudwort	Arp								x		x	x	
	Limosella spp.	mudwort	Arp					x							
	Lobelia concolor	poison pratia	Atl			x		x	x	x			x	x	
	Lotus cruentus	red bird's-foot trefoil	Tdr			x			x	x	x		x		
	Ludwigia peploides subsp. *montevidensis*	clove-strip	Arp										x		x

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	Lythrum hyssopifolia	small loosestrife	Tda						x	x	x		x		
	Maireana brevifolia	short-leaf bluebush	Tdr		x	x	x	x	x	x	x			x	x
	Maireana decalvans	black cotton-bush	Tdr	x	x	x	x			x	x		x	x	
	Maireana pentagona	hairy bluebush	Tdr		x										
	Maireana spp.	bluebush	Tdr		x	x					x			x	
*	*Malva parviflora*	small-flower mallow	Tdr		x						x			x	
	Malva spp.	mallow	Tdr			x	x	x	x		x		x	x	
	Malva weinmanniana	Australian hollyhock	Tdr				x	x	x	x	x		x	x	
* C	*Marrubium vulgare*	horehound	Tdr		x	x				x					
P	*Marsilea costulifera*	narrow-leaf nardoo	Arp	x	x				x				x		
P	*Marsilea drummondii*	common nardoo	Arp	x	x										x
P	*Marsilea* spp.	nardoo	Arp		x										
*	*Medicago minima*	little medic	Tda	x	x	x	x	x	x	x	x	x	x	x	x
*	*Medicago polymorpha*	burr medic	Tdr			x				x	x		x	x	
*	*Medicago* spp.	medic	Tdr			x	x		x	x	x			x	
	Melaleuca lanceolata	moonah	Ate			x									
*	*Melilotus indicus*	sweet melilot	Atl						x						
	Myosurus australis	mousetail	Atl	x	x	x									x
	Myriophyllum spp.	water milfoil	Arp						x			x		x	
	Myriophyllum verrucosum	red water-milfoil	Arp	x	x	x	x	x	x	x	x	x		x	
P	*Olearia pimeleoides*	pimelea daisy-bush	Tdr			x	x	x							
	Osteocarpum acropterum var. *deminutum*	babbagia	Tdr		x										
	Osteocarpum salsuginosum	bonefruit	Tdr		x										
	Osteocarpum spp.	bonefruit	Tdr		x										

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	Ottelia ovalifolia subsp. *ovalifolia*	swamp lily	Arf	x								x			
	Oxalis spp.	wood sorrel	T		x										
	Paspalidium jubiflorum	warrego summer-grass	Tda		x	x									
*	*Paspalum distichum*	water couch	Ate	x	x							x			
*	*Pentameris airoides* subsp. *airoides*	false hair-grass	Tdr	x	x	x									x
	Persicaria decipiens	slender knotweed	Ate		x	x				x	x		x		
	Persicaria lapathifolia	pale knotweed	Ate							x			x		x
	Persicaria prostrata	creeping knotweed	Atl	x	x	x		x	x	x	x	x	x	x	x
	Persicaria spp.	knotweed	A		x				x	x	x	x	x	x	x
*	*Phyla nodiflora* var. *minor*		Atl		x										
en P	*Phyllanthus lacunarius*	lagoon spurge	Tda		x	x	x								
	Poa sp.	tussock grass	Tdr		x	x									
	Poaceae spp.	grass	T	x	x	x	x	x	x	x	x	x	x	x	x
P	*Podolepis capillaris*	wiry podolepis	Tdr		x			x	x	x					
P	*Polycalymma stuartii*	poached-eggs daisy	Tdr			x									
	Polygonaceae spp.												x		
*	*Polygonum arenastrum*	wireweed	Tda										x		
*	*Polygonum aviculare*	prostrate knotweed	Tdr						x		x				
	Polygonum plebeium	small knotweed	Tda	x	x	x	x	x	x	x	x	x	x	x	x
	Polygonum spp.	hogweed	Tda										x		
	Portulaca oleracea	common purslane	Tdr											x	
	Potamogeton sulcatus	furrowed pondweed	Arf	x						x		x			
	Pseudoraphis spinescens	spiny mud-grass	Arp	x	x							x			
*	*Mesembryanthemum granulicaule*	wiry noon-flower	Tdr			x								x	

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	Ranunculus pentandrus var. *platycarpus*	inland buttercup	Tda								x				
*	*Reichardia tingitana*	false sow-thistle	Tdr			x				x	x				
	Rhagodia sp.	saltbush	T				x								
	Rhagodia spinescens	hedge saltbush	Tdr		x	x	x	x	x	x			x	x	
P	*Rhodanthe corymbiflora*	paper sunray	Tdr												
P	*Rhodanthe pygmaea*	pygmy sunray	Tdr												x
P	*Rhodanthe* sp.	sunray	T										x		
	Roepera spp.	twin-leaf	T	x			x				x				
*	*Rorippa palustris*	marsh yellow-cress	Tda										x		
	Rorippa spp.	bitter cress	Tda							x	x		x		
	Rumex brownii	slender dock	Tda								x		x		
	Rumex crystallinus	glistening dock	Tda		x	x								x	
	Rumex sp.	dock	Tda		x					x	x	x	x		
	Rumex tenax	narrow-leaf dock	Tda	x	x	x			x	x	x		x		
	Rytidosperma sp.	wallaby grass	Tdr		x	x		x	x						
	Salsola tragus subsp. *tragus*	prickly saltwort	Tdr		x	x	x			x	x		x	x	
*	*Salvia verbenaca*	wild sage	Tdr			x		x						x	
	Schenkia australis	spiked centaury	Tdr			x	x	x	x	x	x		x	x	
*	*Schismus barbatus*	arabian grass	Tdr							x	x			x	x
	Sclerochlamys brachyptera	short-wing saltbush	Tdr		x			x							
	Sclerolaena diacantha	grey copperburr	Tdr		x	x					x			x	
	Sclerolaena divaricata	tangled copperburr	Tdr											x	
	Sclerolaena muricata var. *villosa*	grey roly-poly	Tdr	x		x									
	Sclerolaena obliquicuspis	limestone copperburr	Tdr											x	

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vu P	*Sclerolaena patenticuspis*	spear-fruit copperburr	Tdr			x									
	Sclerolaena spp.	copperburr	Tdr											x	
	Sclerolaena stelligera	star bluebush	Tdr		x										
P	*Senecio glossanthus*	slender groundsel	Tdr											x	x
P	*Senecio pinnatifolius*	variable groundsel	Tda	x											
P	*Senecio quadridentatus*	cotton fireweed	Tdr			x	x	x	x		x			x	
P	*Senecio runcinifolius*	tall fireweed	Tdr			x					x		x		
P	*Senecio* spp.	groundsel	T						x			x	x	x	
	Sida spp.	sida	Tdr				x				x			x	
	Sida trichopoda	narrow-leaf sida	Tdr									x			
*	*Silene apetala* var. *apetala*	mallee catchfly	Tdr	x		x									
*	*Sisymbrium erysimoides*	smooth mustard	Tdr								x				
	Solanum esuriale	quena	Tdr								x				
*	*Solanum nigrum*	black nightshade	Tdr		x	x	x	x		x	x		x	x	
	Solanum simile	oondoroo	Tda								x				
*	*Sonchus asper* subsp. *asper*	rough sow-thistle	Tdr	x							x				x
*	*Sonchus oleraceus*	common sow-thistle	Tdr	x	x	x		x	x	x	x	x	x		
P	*Sonchus* spp.	sow thistle	Tdr	x	x	x		x	x	x	x	x	x	x	
	Spergularia brevifolia	salt sea-spurrey	Tdr		x										
*	*Spergularia rubra*	red sand-spurrey	Tdr		x										
	Spergularia spp.	sand spurrey	T		x						x				
P	*Sphaeromorphaea littoralis*	spreading nut-heads	Tda	x	x	x	x	x	x	x	x	x	x	x	x
	Sporobolus mitchellii	rat-tail couch	Tda	x	x		x								
*	*Stellaria media*	chickweed	Tda								x				

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*	*Stellaria pallida*	lesser chickweed	Tda		x						x				
	Stemodia florulenta	blue rod	Tda	x	x	x	x	x	x	x	x	x	x	x	x
en P	*Swainsona microphylla*	small-leaf swainson-pea	Tdr			x					x				
*	*Symphyotrichum subulatum*	aster-weed	Tda			x									
	Tetragonia moorei	annual spinach	Tdr					x							
	Teucrium racemosum	grey germander	Tdr		x						x				
*	*Trifolium tomentosum* var. *tomentosum*	woolly clover	Tdr	x					x						
en P	*Trigonella suavissima*	sweet fenugreek	Tda								x		x		
	Vallisneria australis	eel grass	S	x						x					x
*	*Verbena bonariensis*	purple-top verbena	Tdr					x							
*	*Verbena officinalis* var. *officinalis*	verbena	Tdr			x	x	x	x	x	x			x	
	Verbena officinalis var. *gaudichaudii*	native verbena	Tdr			x		x	x	x	x				
	Verbena spp.	verbena	T								x			x	
*	*Verbena supina*	trailing verbena	Tda					x		x	x			x	
*	*Veronica peregrina* subsp. *xalapensis*	wandering speedwell	Tda		x										
P	*Vittadinia cervicularis*	annual new holland daisy	Tdr							x			x		
en P	*Vittadinia condyloides*	club-hair new holland daisy	Tdr							x					
P	*Vittadinia cuneata*	fuzzy new holland daisy	Tdr						x				x		
P	*Vittadinia dissecta* var. *dissecta*	dissected new holland daisy	Tdr			x			x	x	x				
P	*Vittadinia dissecta* var. *hirta*	dissected new holland daisy	Tdr	x	x	x	x	x	x	x	x		x	x	
P	*Vittadinia gracilis*	woolly new holland daisy	Tdr			x					x		x		x
en P	*Vittadinia pterochaeta*	winged new holland daisy	Tdr				x								
P	*Vittadinia* spp.	new holland daisy	Tdr		x	x	x	x	x	x		x	x	x	
P	*Vittadinia sulcata*	furrowed new holland daisy	Tdr											x	

CS	Scientific name	Common name	FG	CH	NC	BI	BO	BR	BL	HT	K	LH	MO	NN	Y
*	*Vulpia myuros* f. *myuros*	rat's-tail fescue	Tdr	x	x	x		x	x	x		x	x		x
	Wahlenbergia fluminalis	river bluebell	Tda	x	x	x	x		x	x	x	x	x		
	Wahlenbergia spp.	bluebell	T	x	x					x	x		x		
*	*Xanthium occidentale*	noogoora burr	Tda	x										x	
*	*Xanthium orientale*	Californian burr	Tdr	x											
* C	*Xanthium spinosum*	Bathurst burr	Tdr											x	

4.3 Wetland photo-point image comparison (selected sites)


2008-09


2010-11


2013-14


2018-19


2020-21


2021-22

Plate 10 Photo-point image comparison, wetland site Lake Brockie, Hattah Lakes, 2008-09 to 2021-22.


2007-08


2011-12


2015-16


2018-19


2020-21


2021-22

Plate 11 Photo-point image comparison, wetland site Lake Hattah, Hattah Lakes, 2007-08 to 2021-22.

2008-09

2009-10

2013-14

2015-16

2017-18

2021-22

Plate 12 Photo-point image comparison, wetland site Lake Nip Nip, Hattah Lakes, 2008-09 to 2021-22.


2008-09


2009-10


2015-16


2017-18


2019-20


2021-22

Plate 13 Photo-point image comparison, wetland site Chalka Creek North, Hattah Lakes, 2008-09 to 2021-22.

5 Floodplain Vegetation Communities

5.1 Floodplain Site Details

Table 10 Floodplain site locations, Hattah Lakes.

Transect	Easting	Northing
Hattah 1		
TR1OFT1A	630174	6169674
TR1OFT1B	630159	6169677
TR1OFT2A	630178	6169721
TR1OFT2B	630163	6169723
TR1OFT3A	630180	6169769
TR1OFT3B	630165	6169768
TR1OFT4A	630181	6169817
TR1OFT4B	630167	6169810
TR1SOT1A	629836	6169166
TR1SOT1B	629841	6169180
TR1SOT2A	629878	6169153
TR1SOT2B	629880	6169168
TR1SOT3A	629920	6169141
TR1SOT3B	629924	6169157
TR1SOT4A	629970	6169129
TR1SOT4B	629972	6169144
TR1RAT1A	629769	6169458
TR1RAT1B	629753	6169455
TR1RAT2A	629761	6169507
TR1RAT2B	629746	6169506
TR1RAT3A	629771	6169549
TR1RAT3B	629755	6169554
TR1RAT4A	629779	6169596
TR1RAT4B	629763	6169601
Hattah 2		
TR2OFT1A	633767	6167619
TR2OFT1B	633768	6167635
TR2OFT2A	633810	6167614
TR2OFT2B	633812	6167630
TR2OFT3A	633853	6167605
TR2OFT3B	633857	6167621
TR2OFT4A	633913	6167596
TR2OFT4B	633912	6167613
TR2SOT1A	633681	6167375
TR2SOT1B	633675	6167360
TR2SOT2A	633721	6167362
TR2SOT2B	633716	6167348
TR2SOT3A	633769	6167364
TR2SOT3B	633764	6167350
TR2SOT4A	633816	6167358
TR2SOT4B	633813	6167344
TR2RAT1A	633681	6167672
TR2RAT1B	633685	6167687
TR2RAT2A	633634	6167669
TR2RAT2B	633641	6167682
TR2RAT3A	633588	6167696

Transect	Easting	Northing
Hattah 3		
TR3OFT1A	638442	6153193
TR3OFT1B	638444	6153209
TR3OFT2A	638470	6153156
TR3OFT2B	638481	6153165
TR3OFT3A	638512	6153133
TR3OFT3B	638523	6153148
TR3OFT4A	638534	6153101
TR3OFT4B	638545	6153111
TR3SOT1A	638585	6153232
TR3SOT1B	638578	6153222
TR3SOT2A	638602	6153190
TR3SOT2B	638597	6153176
TR3SOT3A	638624	6153154
TR3SOT3B	638620	6153140
TR3SOT4A	638666	6153127
TR3SOT4B	638661	6153112
TR3RAT1A	638435	6153055
TR3RAT1B	638419	6153050
TR3RAT2A	638455	6153017
TR3RAT2B	638441	6153011
TR3RAT3A	638479	6152981
TR3RAT3B	638464	6152976
TR3RAT4A	638497	6152954
TR3RAT4B	638483	6152950
Hattah 4		
TR4OFT1A	634776	6157167
TR4OFT1B	634778	6157153
TR4OFT2A	634817	6157193
TR4OFT2B	634822	6157179
TR4OFT3A	634864	6157211
TR4OFT3B	634867	6157197
TR4OFT4A	634907	6157225
TR4OFT4B	634914	6157211
TR4SOT1A	635255	6157273
TR4SOT1B	635246	6157286
TR4SOT2A	635297	6157295
TR4SOT2B	635289	6157308
TR4SOT3A	635338	6157314
TR4SOT3B	635336	6157329
TR4SOT4A	635379	6157336
TR4SOT4B	635374	6157350
TR4RAT1A	635003	6156849
TR4RAT1B	634994	6156861
TR4RAT2A	635037	6156864
TR4RAT2B	635034	6156878
TR4RAT3A	635072	6156886

Transect	Easting	Northing
Hattah 5		
TR5OFT1A	624486	6152147
TR5OFT1B	624498	6152158
TR5OFT2A	624457	6152180
TR5OFT2B	624463	6152194
TR5OFT3A	624423	6152216
TR5OFT3B	624432	6152229
TR5OFT4A	624383	6152246
TR5OFT4B	624393	6152257
TR5SOT1A	624345	6152048
TR5SOT1B	624352	6152060
TR5SOT2A	624392	6152031
TR5SOT2B	624396	6152046
TR5SOT3A	624434	6152016
TR5SOT3B	624439	6152030
TR5SOT4A	624480	6152010
TR5SOT4B	624479	6152024
TR5RAT1A	624289	6152177
TR5RAT1B	624293	6152192
TR5RAT2A	624245	6152187
TR5RAT2B	624247	6152201
TR5RAT3A	624195	6152187
TR5RAT3B	624201	6152201
TR5RAT4A	624148	6152188
TR5RAT4B	624152	6152203
Hattah 6		
TR6OFT1A	625332	6157185
TR6OFT1B	625347	6157182
TR6OFT2A	625327	6157134
TR6OFT2B	625340	6157137
TR6OFT3A	625335	6157088
TR6OFT3B	625352	6157088
TR6OFT4A	625304	6157041
TR6OFT4B	625319	6157038
TR6SOT1A	624970	6157248
TR6SOT1B	624953	6157252
TR6SOT2A	624960	6157203
TR6SOT2B	624945	6157207
TR6SOT3A	624960	6157156
TR6SOT3B	624943	6157153
TR6SOT4A	624953	6157109
TR6SOT4B	624937	6157111
TR6RAT1A	625114	6157398
TR6RAT1B	625115	6157383
TR6RAT2A	625079	6157399
TR6RAT2B	625075	6157384
TR6RAT3A	625036	6157400

Transect	Easting	Northing
TR2RAT3B	633597	6167708
TR2RAT4A	633546	6167690
TR2RAT4B	633551	6167704

Transect	Easting	Northing
TR4RAT3B	635065	6156901
TR4RAT4A	635106	6156914
TR4RAT4B	635099	6156928

Transect	Easting	Northing
TR6RAT3B	625032	6157385
TR6RAT4A	624994	6157406
TR6RAT4B	624987	6157392

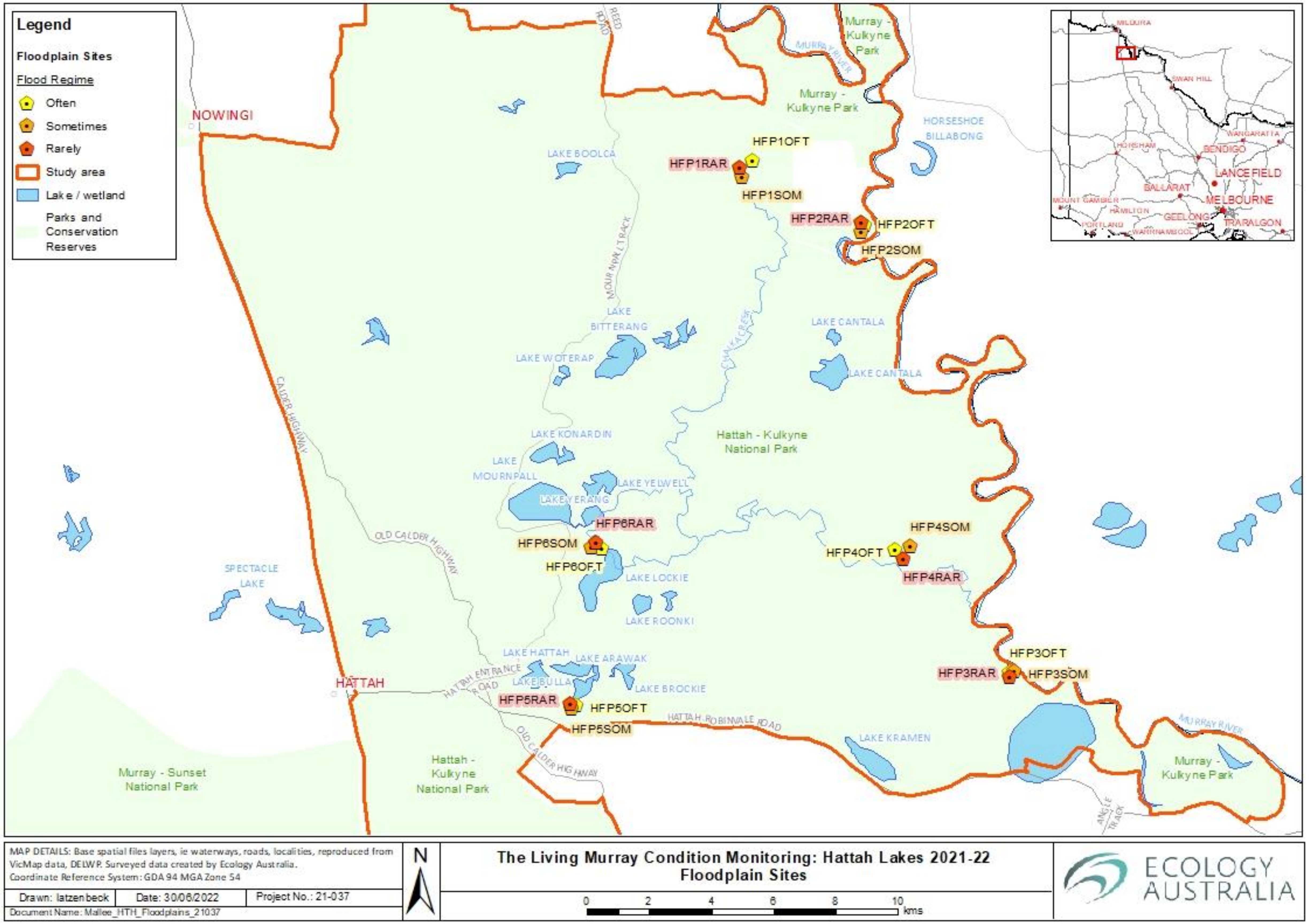


Figure 12 Map of Floodplain sites, Hattah Lakes study area (2021-22).

5.2 Floodplain species lists

Table 11 Vascular plant species recorded within each of the 6 floodplain monitoring locations, Hattah Icon Site, January-March 2022. The number of transects which a species was recorded in at each site for 2021-22 is also shown.

Key:
CS Conservation Status: Victorian Flora and Fauna Guarantee Act 1988 (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).
FG Functional group: A = amphibious species, Arf = amphibious floating plants also found in damp habitats, Arp = amphibious floating plants, Ate = amphibious monocotyledons, Atl = amphibious herbs, Atw = amphibious woody plants, F = floating plants, S = submerged plants, T = terrestrial plants that do not tolerate flooding, Tda = terrestrial species preferring damp habitats, Tdr = drought-tolerant species.
\# Species native to Victoria though not indigenous within study area
* Exotic plant species.
C Species listed as Regionally Controlled under the CaLP Act 1995

Note no new species were recorded in 2021-22.

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
P	*Acacia stenophylla*	eumong	1			5	2	
	Alternanthera denticulata s.l.	lesser joyweed	3		2	6	6	6
	Alternanthera nodiflora	common joyweed				4		8
	Alternanthera sp. *1* (Plains)	plains joyweed	6	3				
en P	*Ammannia multiflora*	jerry-jerry				1	2	3
	Amphibromus nervosus	common swamp wallaby-grass				1		
en P	*Aristida holathera* var. *holathera*	tall kerosene grass				2		
en P	*Asperula wimmerana*	Wimmera woodruff	4			1		
	Asteraceae spp.	composite						4
	Atriplex eardleyae	small saltbush			1			
	Atriplex leptocarpa	slender-fruit saltbush	2	2				

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
	Atriplex lindleyi subsp. *inflata*	corky saltbush	4	2				
	Atriplex semibaccata	berry saltbush	10	2				
	Atriplex spp.	saltbush						2
	Atriplex stipitata subsp. *miscella*	kidney saltbush	2					
	Atriplex stipitata subsp. *stipitata*				2			
en P	*Austrobryonia micrantha*	Mallee cucumber				2	1	3
	Austrostipa scabra subsp. *falcata*	rough spear-grass	3	1		1		1
	Austrostipa spp.	spear grass						1
en P	*Bergia ammannioides*	jerry water-fire						1
en P	*Bergia trimera*	small water-fire				1	2	1
	Boerhavia dominii	tah-vine	5		1			
	Brassicaceae spp.	crucifer						1
*	*Bromus rubens*	red brome	1					
P	*Centipeda cunninghamii*	common sneezeweed	2		3	6	1	6
	Chenopodiaceae spp.	chenopod	1			1		
en P	*Chenopodium desertorum* subsp. *rectum*	frosted goosefoot			2			
	Chenopodium nitrariaceum	nitre goosefoot	8	2	1			
	Chloris truncata	windmill grass				2		
* P	*Chondrilla juncea*	skeleton weed				2		
	Cressa australis	rosinweed					4	1
en P	*Cullen pallidum*	woolly scurf-pea				2		
	Cynodon dactylon var. *pulchellus*	native couch	6	2	3	2	2	1
	Cyperaceae spp.	sedge		1				
	Dodonaea viscosa subsp. *angustissima*	slender hop-bush	3			4		1

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
	Duma florulenta	tangled lignum	1			7	7	8
	Dysphania cristata	crested goosefoot				3	5	3
	Dysphania pumilio	clammy goosefoot						4
P	*Eclipta platyglossa* subsp. *platyglossa*	yellow twin-heads	1		2	2		
	Einadia nutans	nodding saltbush	3	7	5	3		2
	Elatine gratioloides	waterwort				3		
	Eleocharis pusilla	small spike-sedge				4		
	Enchylaena tomentosa var. *tomentosa*	ruby saltbush	9	5	7	2		6
	Eragrostis dielsii	Mallee love-grass					2	1
vu P	*Eremophila divaricata* subsp. *divaricata*	spreading emu-bush		1				
*	*Erigeron* sp.	fleabane		1	4			
	Eriochiton sclerolaenoides	woolly-fruit bluebush					1	
	Eucalyptus camaldulensis	river red-gum	10	1	7	2	5	7
	Eucalyptus largiflorens	black box		1		1	1	2
	Euphorbia dallachyana	flat spurge	8	4	4	6	6	3
	Glinus lotoides	hairy carpet-weed				3		6
	Glycyrrhiza acanthocarpa	southern liquorice					2	4
	Goodenia glauca	pale goodenia	8		1	4	7	1
	Goodenia sp.	goodenia				1		
	Haloragis glauca f. *glauca*	bluish raspwort	3	1				
*	*Heliotropium supinum*	creeping heliotrope	1			6	7	7
	Juncus subsecundus	finger rush				2		
	Lachnagrostis filiformis	common blown-grass				2		
*	*Lactuca serriola*	prickly lettuce	1	2				

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
P	*Laphangium luteoalbum*	jersey cudweed			1			1
*	*Lepidium africanum*	common peppercress			1	1		
	Limosella australis	austral mudwort						1
	Maireana brevifolia	short-leaf bluebush		1				
	Maireana decalvans	black cotton-bush		1			2	1
	Maireana pentagona	hairy bluebush					3	
	Maireana sp.	bluebush	2	1	1			
* C	*Marrubium vulgare*	horehound			1			
P	*Marsilea costulifera*	narrow-leaf nardoo				4	1	4
P	*Marsilea drummondii*	common nardoo	1				1	1
*	*Medicago* sp.	medic						1
*	*Mesembryanthemum nodiflorum*	small ice-plant	3	3	2			
en P	*Minuria denticulata*	woolly minuria	2					
	Myoporum parvifolium	creeping myoporum	2					
	Myriophyllum verrucosum	red water-milfoil				1		3
	Osteocarpum acropterum var. *deminutum*	babbagia		1	1			
	Oxalis perennans	grassland wood-sorrel	3	2	8			
	Paspalidium jubiflorum	warrego summer-grass		8	2		1	
	Persicaria prostrata	creeping knotweed	2		6			
	Persicaria sp.	knotweed						1
*	*Phyla nodiflora* var. *minor*					2		
en P	*Phyllanthus lacunarius*	lagoon spurge	1			5		1
	Pimelea trichostachya	annual rice-flower				1		
	Poaceae spp.	grass	3					2

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
	Polygonum plebeium	small knotweed						5
	Potamogeton sp.	pondweed				1		
	Rhagodia spinescens	hedge saltbush	5	5				
	Roepera glauca	pale twin-leaf			1			
en P	*Rorippa eustylis*	dwarf bitter-cress						4
	Rumex brownii	slender dock		3				
	Rumex sp.	dock				1		
	Rumex tenax	narrow-leaf dock			6			
	Rytidosperma setaceum	bristly wallaby-grass		1		2		
	Salsola tragus subsp. *tragus*	prickly saltwort			2			1
*	*Schismus barbatus*	Arabian grass			1			2
	Sclerochlamys brachyptera	short-wing saltbush	1	2	2	1		
	Sclerolaena diacantha	grey copperburr	7	2	3			
	Sclerolaena muricata var. *muricata*	black roly-poly	3					
	Sclerolaena muricata var. *villosa*	grey roly-poly	2			1		
	Sclerolaena obliquicuspis	limestone copperburr			1			
vu P	*Sclerolaena patenticuspis*	spear-fruit copperburr	1					
	Sclerolaena tricuspis	streaked copperburr			2			
P	*Senecio pinnatifolius*	variable groundsel	1					
P	*Senecio quadridentatus*	cotton fireweed		5	2			
P	*Senecio runcinifolius*	tall fireweed	1					
P	*Senecio* sp.	groundsel						1
	Sida corrugata	variable sida	1	1		1		
	Sida sp.	sida			3			

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
	Sida trichopoda	narrow-leaf sida	6	2			1	
	Solanum esuriale	quena			2			
*	*Solanum nigrum*	black nightshade		1	8			1
*	*Sonchus oleraceus*	common sow-thistle	1	2	5	1		
P	*Sonchus* sp.	sow thistle					1	1
	Spergularia sp.	sand spurrey				1	3	1
P	*Sphaeromorphaea littoralis*	spreading nut-heads					1	2
	Stemodia florulenta	blue rod	1				1	
	Teucrium racemosum	grey germander	1		1			
	Verbena sp.	verbena				1	1	
P	*Vittadinia dissecta* var. *hirta*	dissected New Holland daisy				2		
P	*Vittadinia gracilis*	woolly New Holland daisy	5					
P	*Vittadinia* sp.	New Holland daisy		1				1
	Wahlenbergia fluminalis	river bluebell	2					

Table 12 Vascular plant species recorded within each of the 6 floodplain monitoring locations, Hattah Icon Site, 2007-22.

Key: CS Conservation Status: Victorian Flora and Fauna Guarantee Act 1988 (P = Protected flora species under the FFG Act, v = Listed as vulnerable under the FFG Act, e = Listed as endangered under the FFG Act, cr = Listed as critically endangered under the FFG Act).

FG Functional group: A = amphibious species, Arf = amphibious floating plants also found in damp habitats, Arp = amphibious floating plants, Ate = amphibious monocotyledons, Atl = amphibious herbs, Atw = amphibious woody plants, F = floating plants, S = submerged plants, T = terrestrial plants that do not tolerate flooding, Tda = terrestrial species preferring damp habitats, Tdr = drought-tolerant species.

Species native to Victoria though not indigenous within study area

* Exotic plant species.

C Species listed as Regionally Controlled under the CaLP Act

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
P	*Acacia* spp.	wattle			x	x		
P	*Acacia stenophylla*	eumong	x	x	x	x	x	x
P	*Actinobole uliginosum*	flannel cudweed	x			x		x
*	*Aira cupaniana*	quicksilver grass	x					
	Ajuga australis	austral bugle	x			x		x
	Alternanthera denticulata	lesser joyweed	x	x	x	x	x	x
	Alternanthera nodiflora	common joyweed				x		x
	Alternanthera spp.	joyweed	x	x	x	x	x	x
	Alternanthera sp. *1* (Plains)	plains joyweed	x	x	x		x	x
en P	*Ammannia multiflora*	jerry-jerry	x			x	x	x
	Amphibromus nervosus	common swamp wallaby-grass				x		
en P	*Aristida holathera* var. *holathera*	tall kerosene grass				x		
	Asperula conferta	common woodruff	x	x		x		
en P	*Asperula gemella*	twin-leaf bedstraw	x		x			
en P	*Asperula wimmerana*	Wimmera woodruff	x			x		

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
	Asteraceae spp.	composite	x	x	x	x	x	x
	Atriplex eardleyae	small saltbush			x			x
	Atriplex leptocarpa	slender-fruit saltbush	x	x	x	x	x	x
	Atriplex lindleyi	flat-top saltbush		x				
	Atriplex lindleyi subsp. *inflata*	corky saltbush	x	x	x		x	
	Atriplex pseudocampanulata	mealy saltbush			x			
	Atriplex pumilio	mat saltbush	x		x		x	
	Atriplex semibaccata	berry saltbush	x	x	x	x	x	x
	Atriplex spp.	saltbush	x	x	x	x	x	x
	Atriplex stipitata	kidney saltbush	x		x	x	x	x
	Atriplex stipitata subsp. *miscella*	kidney saltbush	x		x			
	Atriplex stipitata subsp. *stipitata*	kidney saltbush	x	x	x	x	x	
	Atriplex suberecta	sprawling saltbush	x	x			x	
en P	*Austrobryonia micrantha*	mallee cucumber				x	x	x
	Austrostipa drummondii	cottony spear-grass	x					
	Austrostipa elegantissima	feather spear-grass						x
	Austrostipa nitida	Balcarra spear-grass				x	x	x
	Austrostipa scabra	rough spear-grass	x				x	x
	Austrostipa scabra subsp. *scabra*	rough spear-grass			x		x	x
	Austrostipa scabra subsp. *falcata*	rough spear-grass	x	x		x	x	x
	Austrostipa spp.	spear grass	x	x		x	x	x
en P	*Austrostipa trichophylla*	spear-grass				x		
P	*Azolla* spp.	azolla	x		x			x
en P	*Bergia ammannioides*	jerry water-fire						x

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
en P	*Bergia trimera*	small water-fire				x	x	x
cr P	*Boerhavia coccinea*	scarlet spiderling	x	x	x			x
	Boerhavia dominii	tah-vine	x		x	x		x
	Boerhavia spp.	tah-vine		x		x		x
P	*Brachyscome ciliaris*	variable daisy	x			x	x	
P	*Brachyscome ciliaris* var. *ciliaris*	variable daisy	x	x		x	x	x
P	*Brachyscome ciliaris* var. *lanuginosa*	variable daisy					x	
P	*Brachyscome lineariloba*	hard-head daisy	x	x	x	x	x	x
P	*Brachyscome paludicola*	woodland swamp-daisy			x			
en P	*Brachyscome gracilis* subsp. *gracilis*	dookie daisy	x			x		
*	*Brassica tournefortii*	Mediterranean turnip	x			x		x
*	*Brassica X juncea*	Indian mustard						x
	Brassicaceae spp.	crucifer	x	x	x	x	x	x
*	*Bromus diandrus*	great brome				x		
*	*Bromus rubens*	red brome	x	x	x	x	x	x
	Bulbine semibarbata	leek lily	x			x	x	x
	Bulbine spp.	bulbine lily	x				x	
	Calandrinia eremaea	small purslane	x		x	x	x	x
en P	*Calotis cuneifolia*	blue burr-daisy	x	x	x	x	x	x
P	*Calotis erinacea*	tangled burr-daisy				x		
P	*Calotis hispidula*	hairy burr-daisy	x	x	x	x	x	x
P	*Calotis* spp.	burr daisy			x		x	
	Caryophyllaceae spp.	carnation				x		
*	*Centaurea melitensis*	Malta thistle	x		x			

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
* P	*Centaurea solstitialis*	St Barnaby's thistle	x					
P	*Centipeda cunninghamii*	common sneezeweed	x	x	x	x	x	x
P	*Centipeda minima* subsp. *minima s.s.*	spreading sneezeweed	x	x	x	x	x	x
P	*Centipeda* spp.	sneezeweed	x	x	x	x	x	x
	Chenopodiaceae spp.	chenopod	x			x	x	x
en P	*Chenopodium desertorum* subsp. *desertorum*	frosted goosefoot			x		x	x
en P	*Chenopodium desertorum* subsp. *rectum*	frosted goosefoot		x	x			
	Chenopodium nitrariaceum	nitre goosefoot	x	x	x	x	x	
	Chenopodium spp.	goosefoot		x				
	Chloris truncata	windmill grass			x	x	x	
* P	*Chondrilla juncea*	skeleton weed	x		x	x		x
P	*Chthonocephalus pseudevax*	groundheads				x		
* C	*Cirsium vulgare*	spear thistle		x	x	x		
*	*Citrullus* spp.	wild melon	x					
	Clematis microphylla	small-leaved clematis	x		x			
*	*Cotula bipinnata*	ferny cotula			x			
	Crassula colorata	dense crassula	x	x	x	x	x	x
	Crassula sieberiana	sieber crassula	x	x	x	x	x	x
	Crassula spp.	crassula	x				x	
	Cressa australis	rosinweed					x	x
*	*Cucumis myriocarpus* subsp. *myriocarpus*	paddy melon	x		x		x	x
en P	*Cullen pallidum*	woolly scurf-pea				x		
	Cullen spp.	scurf pea				x		
* C	*Cuscuta campestris*	field dodder			x			

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
	Cynodon dactylon	couch	x	x	x	x	x	x
	Cynodon dactylon var. *pulchellus*	native couch	x	x	x	x	x	x
	Cyperaceae spp.	sedge		x				
	Cyperus difformis	variable flat-sedge				x		
	Cyperus gilesii (NSW)							x
	Cyperus gymnocaulos	spiny flat-sedge			x		x	
	Cyperus gunnii subsp. *gunnii*	flecked flat-sedge	x					
	Daucus glochidiatus	australian carrot	x		x		x	
	Disphyma crassifolium subsp. *clavellatum*	rounded noon-flower					x	
* C	*Dittrichia graveolens*	stinkwort	x	x		x	x	x
	Dodonaea viscosa subsp. *angustissima*	slender hop-bush	x	x	x	x		x
	Duma florulenta	tangled lignum	x	x	x	x	x	x
	Dysphania cristata	crested goosefoot			x	x	x	x
	Dysphania glomulifera subsp. *glomulifera*	globular pigweed	x	x	x			x
	Dysphania pumilio	clammy goosefoot	x	x	x	x	x	x
P	*Eclipta platyglossa* subsp. *platyglossa*	yellow twin-heads	x	x	x	x	x	x
	Einadia nutans subsp. *nutans (s.s.)*	nodding saltbush	x	x	x	x	x	x
	Elatine gratioloides	waterwort				x	x	x
	Eleocharis pusilla	small spike-sedge				x		
	Eleocharis spp.	spike sedge	x	x				
	Enchylaena tomentosa var. *tomentosa*	ruby saltbush	x	x	x	x	x	x
	Enneapogon avenaceus	common bottle-washers	x					
	Enteropogon acicularis	spider grass	x			x		
	Enteropogon ramosus (NSW only)					x		

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
cr P	*Eragrostis australasica*	cane grass	x				x	x
	Eragrostis dielsii	mallee love-grass	x	x			x	x
en P	*Eragrostis lacunaria*	purple love-grass	x					
vu P	*Eremophila divaricata* subsp. *divaricata*	spreading emu-bush		x	x		x	
*	*Erigeron bonariensis*	flaxleaf fleabane	x	x	x	x	x	x
*	*Erigeron* spp.	fleabane	x	x	x	x	x	x
*	*Erigeron sumatrensis*	tall fleabane		x	x		x	
	Eriochiton sclerolaenoides	woolly-fruit bluebush					x	
	Eucalyptus camaldulensis	river red-gum	x	x	x	x	x	x
	Eucalyptus largiflorens	black box	x	x	x	x	x	x
P	*Euchiton sphaericus*	annual cudweed	x	x		x		x
	Euphorbia dallachyana	flat spurge	x	x	x	x	x	x
*	*Fumaria* sp.	fumitory		x				
*	*Galium aparine*	cleavers		x	x			
	Geraniaceae sp.		x	x			x	
	Glinus lotoides	hairy carpet-weed	x	x	x	x	x	x
	Glinus oppositifolius	slender carpet-weed			x			
	Glycyrrhiza acanthocarpa	southern liquorice					x	x
	Glycyrrhiza spp.	liquorice					x	
P	*Gnaphalium* spp.	cudweed	x	x				
	Goodenia glauca	pale goodenia	x	x	x	x	x	x
	Goodenia heteromera	spreading goodenia	x					
	Goodenia spp.	goodenia	x			x		
	Gunniopsis septifraga (NSW)							x

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
	Haloragis aspera	rough raspwort	x		x			
	Haloragis glauca f. *glauca*	bluish raspwort	x	x				
	Haloragis spp.	raspwort	x	x				
*	*Heliotropium amplexicaule*	blue heliotrope				x		
*	*Heliotropium europaeum*	common heliotrope	x	x			x	
	Heliotropium spp.	heliotrope				x	x	x
*	*Heliotropium supinum*	creeping heliotrope	x		x	x	x	x
*	*Hordeum leporinum*	barley-grass	x			x	x	x
*	*Hypochaeris glabra*	smooth cat's-ear				x		x
*	*Hypochaeris radicata*	flatweed	x	x	x		x	x
P	*Isoetopsis graminifolia*	grass cushion					x	
	Juncus spp.	rush		x				
	Juncus subsecundus	finger rush			x	x		
	Lachnagrostis filiformis s.l.	common blown-grass	x	x	x	x	x	x
P	*Laphangium luteoalbum*	jersey cudweed	x	x	x		x	x
	Lemna disperma	common duckweed	x		x	x	x	x
	Lemna spp.	duckweed					x	
*	*Leontodon saxatilis* subsp. *saxatilis*	hairy hawkbit		x	x		x	
*	*Lepidium africanum*	common peppercress			x	x		
	Lepidium pseudohyssopifolium	native peppercress		x	x	x		
	Lepidium spp.	peppercress		x		x		
	Limosella australis	austral mudwort					x	x
	Lobelia concolor	poison pratia			x			
	Lotus cruentus	red bird's-foot trefoil				x		

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
	Ludwigia peploides subsp. *montevidensis*	clove-strip			x			
*	*Lysimachia arvensis*	pimpernel	x	x				
	Maireana brevifolia	short-leaf bluebush	x	x	x	x	x	x
	Maireana decalvans s.l.	black cotton-bush	x	x	x	x	x	x
	Maireana humillima	dwarf bluebush					x	
	Maireana pentagona	hairy bluebush	x				x	x
	Maireana spp.	bluebush	x	x	x	x	x	x
	Malva weinmanniana	australian hollyhock	x				x	
* C	*Marrubium vulgare*	horehound			x	x	x	
P	*Marsilea costulifera*	narrow-leaf nardoo	x	x		x	x	x
P	*Marsilea drummondii*	common nardoo	x	x			x	x
P	*Marsilea* spp.	nardoo	x			x	x	x
*	*Medicago minima*	little medic	x	x	x	x	x	x
*	*Medicago polymorpha*	burr medic					x	
*	*Medicago* spp.	medic	x		x	x	x	x
	Mentha australis	river mint			x			
*	*Mesembryanthemum crystallinum s.l.*	common ice-plant			x			
*	*Mesembryanthemum nodiflorum*	small ice-plant	x	x	x		x	
*	*Mesembryanthemum* spp.	ice plant		x				
P	*Millotia perpusilla*	tiny bow-flower						x
en P	*Minuria denticulata*	woolly minuria	x			x	x	
*	*Monoculus monstrosus*	tripteris	x					
	Myoporum parvifolium	creeping myoporum	x			x		
	Myosurus australis	mousetail	x			x	x	x

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
P	*Myriocephalus rhizocephalus*	woolly-heads					x	
	Myriophyllum verrucosum	red water-milfoil				x	x	x
*	*Nicotiana glauca*	tree tobacco						x
	Nicotiana occidentalis (NSW only)		x					
	Nicotiana velutina	velvet tobacco						x
P	*Ophioglossum lusitanicum*	austral adder's-tongue				x		
	Osteocarpum acropterum var. *deminutum*	babbagia		x	x		x	
	Osteocarpum spp.	bonefruit		x	x		x	
	Oxalis perennans	grassland wood-sorrel	x	x	x	x		
	Oxalis spp.	wood sorrel	x	x	x	x	x	x
	Paspalidium jubiflorum	warrego summer-grass	x	x	x	x	x	x
	Paspalidium spp.	panic grass	x	x	x		x	
*	*Paspalum distichum*	water couch	x	x	x	x		x
*	*Pentameris airoides* subsp. *airoides*	false hair-grass	x		x	x	x	x
	Persicaria lapathifolia	pale knotweed		x	x			
	Persicaria prostrata	creeping knotweed	x	x	x		x	
	Persicaria spp.	knotweed		x	x			x
*	*Phyla nodiflora* var. *minor*					x		
en P	*Phyllanthus lacunarius*	lagoon spurge	x	x	x	x		x
	Phyllanthus spp.	spurge				x		
P	*Picris* spp.	picris		x				
	Pimelea trichostachya	annual rice-flower	x			x		
	Pittosporum angustifolium	weeping pittosporum		x				
	Plantago cunninghamii	clay plantain					x	

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
	Plantago drummondii	dark plantain	x					
	Plantago spp.	plantain	x					
	Plantago turrifera	crowned plantain	x	x		x	x	x
	Poa spp.	tussock grass						x
	Poaceae spp.	grass	x	x	x	x	x	x
P	*Podolepis capillaris*	wiry podolepis					x	
P	*Podotheca angustifolia*	sticky long-heads				x		
P	*Pogonolepis muelleriana*	stiff cup-flower		x		x		x
P	*Polycalymma stuartii*	poached-eggs daisy				x		x
P	*Polycalymma stuartii*	poached-eggs daisy						x
	Polygonaceae sp.				x			
	Polygonum plebeium	small knotweed	x	x	x	x	x	x
	Portulaca oleracea	common purslane		x				
	Potamogeton spp.	pondweed				x		
	Pterorhagia nanteuilii (NSW only)		x					
	Ranunculus pentandrus var. *platycarpus*	inland buttercup				x	x	x
*	*Rapistrum rugosum*	giant mustard						x
	Rhagodia spp.	saltbush	x	x				
	Rhagodia spinescens	hedge saltbush	x	x	x		x	x
P	*Rhodanthe pygmaea*	pygmy sunray	x					
	Roepera similis	white twin-leaf			x			
	Roepera spp.	twin-leaf		x	x		x	
	Roepera glauca	pale twin-leaf			x			
en P	*Rorippa eustylis*	dwarf bitter-cress	x	x	x		x	x

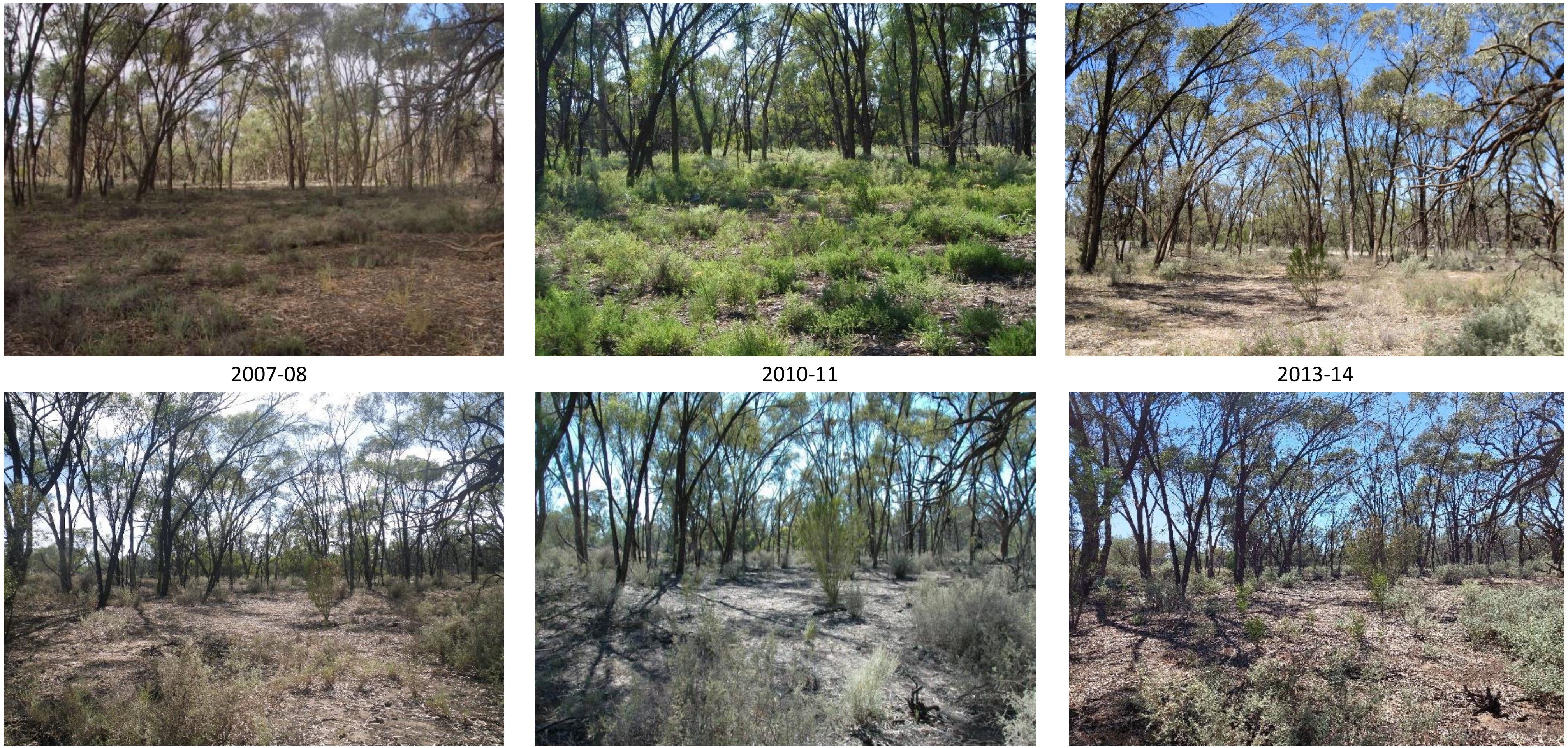
CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
	Rorippa laciniata	jagged bitter-cress	x					
	Rorippa spp.	bitter cress				x		
	Rumex brownii	slender dock		x	x	x	x	
	Rumex crystallinus s.l.	glistening dock			x			
	Rumex spp.	dock	x	x	x	x		x
	Rumex tenax	narrow-leaf dock	x	x	x		x	
	Rytidosperma caespitosum	common wallaby-grass	x	x		x		
	Rytidosperma setaceum	bristly wallaby-grass	x	x	x	x	x	x
	Rytidosperma spp.	wallaby grass				x		
	Salsola tragus subsp. *tragus*	prickly saltwort	x		x	x	x	x
	Santalum acuminatum	sweet quandong	x					
*	*Schismus barbatus*	arabian grass	x		x	x	x	x
	Scleranthus minusculus	cushion knawel	x			x		
	Scleroblitum atriplicinum	starry goosefoot	x				x	
	Sclerochlamys brachyptera	short-wing saltbush	x	x	x	x	x	x
	Sclerolaena diacantha	grey copperburr	x	x	x		x	x
	Sclerolaena divaricata	tangled copperburr	x			x	x	x
	Sclerolaena muricata	black roly-poly	x			x		
	Sclerolaena muricata var. *semiglabra*	dark roly-poly	x			x	x	x
	Sclerolaena muricata var. *muricata*	black roly-poly	x			x	x	x
	Sclerolaena muricata var. *villosa*	grey roly-poly	x		x	x	x	x
	Sclerolaena obliquicuspis	limestone copperburr	x	x	x			
vu P	*Sclerolaena patenticuspis*	spear-fruit copperburr	x	x	x		x	
	Sclerolaena spp.	copperburr	x	x		x	x	x

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
	Sclerolaena stelligera	star bluebush			x	x	x	
	Sclerolaena tricuspis	streaked copperburr	x		x	x	x	
P	*Senecio glossanthus s.s.*	slender groundsel	x	x	x	x	x	x
P	*Senecio pinnatifolius*	variable groundsel	x					
P	*Senecio quadridentatus*	cotton fireweed	x	x	x	x		
P	*Senecio runcinifolius*	tall fireweed	x	x	x	x	x	
P	*Senecio* spp.	groundsel		x				x
en P	*Sida ammophila*	sand sida	x	x	x			x
	Sida corrugata	variable sida	x	x	x	x		
en P	*Sida fibulifera*	pin sida	x	x	x		x	
en P	*Sida intricata*	twiggy sida					x	
	Sida petrophila							x
	Sida spp.	sida	x	x	x	x	x	x
	Sida trichopoda	narrow-leaf sida	x	x	x		x	
*	*Silene apetala* var. *apetala*	mallee catchfly	x		x	x		x
*	*Silene nocturna*	mediterranean catchfly				x		
*	*Sisymbrium erysimoides*	smooth mustard	x	x	x	x	x	x
	Solanum esuriale	quena	x	x	x		x	x
*	*Solanum nigrum s.l.*	black nightshade	x	x	x			x
*	*Sonchus asper s.l.*	rough sow-thistle					x	
*	*Sonchus oleraceus*	common sow-thistle	x	x	x	x	x	x
P	*Sonchus* spp.	sow thistle	x	x	x	x	x	x
*	*Spergularia diandra*	lesser sand-spurrey		x				
	Spergularia marina s.l.	salt sand-spurrey			x	x		

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
*	*Spergularia rubra s.l.*	red sand-spurrey	x			x	x	x
	Spergularia spp.	sand spurrey	x			x	x	x
P	*Sphaeromorphaea littoralis*	spreading nut-heads	x	x	x	x	x	x
	Sporobolus mitchellii	rat-tail couch	x	x	x		x	x
*	*Stellaria pallida*	lesser chickweed		x	x			
	Stemodia florulenta	blue rod	x	x	x		x	x
en P	*Swainsona microphylla*	small-leaf swainson-pea	x			x	x	x
	Tetragonia tetragonioides	New Zealand spinach	x					x
	Teucrium racemosum s.l.	grey germander	x		x			
*	*Trifolium campestre* var. *campestre*	hop clover			x			
*	*Trifolium* spp.	clover			x			
*	*Trifolium tomentosum* var. *tomentosum*	woolly clover	x		x		x	
	Triodia scariosa	porcupine grass				x		
	Vallisneria australis	eel grass					x	
*	*Verbena officinalis* var. *officinalis*	verbena	x	x	x	x		
	Verbena officinalis var. *gaudichaudii*	native verbena		x				
	Verbena spp.	verbena				x	x	
*	*Verbena supina*	trailing verbena	x	x	x	x	x	
*	*Veronica peregrina* subsp. *xalapensis*	wandering speedwell					x	
P	*Vittadinia cervicularis*	annual new holland daisy	x		x	x		x
en P	*Vittadinia condyloides*	club-hair new holland daisy	x					
P	*Vittadinia cuneata*	fuzzy new holland daisy	x					x
P	*Vittadinia dissecta* var. *dissecta*	dissected new holland daisy	x			x	x	x
P	*Vittadinia dissecta* var. *hirta*	dissected new holland daisy	x	x	x	x	x	x

CS	Scientific name	Common name	Hattah 1	Hattah 2	Hattah 3	Hattah 4	Hattah 5	Hattah 6
	Vittadinia eremaea (NSW only)		x					x
P	*Vittadinia gracilis*	woolly new holland daisy	x			x	x	x
en P	*Vittadinia pterochaeta*	winged new holland daisy					x	
P	*Vittadinia* spp.	new holland daisy	x	x		x	x	x
P	*Vittadinia sulcata*	furrowed new holland daisy						x
*	*Vulpia myuros* f. *myuros*	rat's-tail fescue	x		x	x	x	x
*	*Vulpia myuros*	rat's-tail fescue				x		
	Wahlenbergia fluminalis	river bluebell	x	x	x	x	x	x
	Wahlenbergia gracilis	sprawling bluebell				x		
	Wahlenbergia spp.	bluebell				x		
	Wurmbea dioica	common early nancy	x					
*	*Xanthium occidentale*	noogoora burr	x					
*	*Xanthium orientale*	californian burr		x	x			
* C	*Xanthium spinosum*	bathurst burr						

5.3 Floodplain photo-point image comparison (selected sites)



2007-08 2010-11 2013-14

2015-16 2018-19 2021-22

Plate 14 Photo-point image comparison, floodplain site 1 'Rarely', Hattah Lakes, 2007-08 to 2021-22.

2007-08

2011-12

2013-14

2016-17

2018-19

2021-22

Plate 15 Photo-point image comparison, floodplain site 2 'Sometimes', Hattah Lakes, 2007-08 to 2021-22.


2007-08


2010-11


2012-13


2015-16


2018-19


2021-22

Plate 16 Photo-point image comparison, floodplain site 4 'Often', Hattah Lakes, 2007-08 to 2021-22.

2007-08

2010-11

2013-14

2016-17

2018-19

2021-22

Plate 17 Photo-point image comparison, floodplain site 6 ‘Rarely’, Hattah Lakes, 2007-08 to 2021-22

6 Lignum

6.1 Lignum Site Details

Table 13 Lignum site locations, Hattah Lakes.

Site	Northing	Easting
H1_1	6155579	624483.5
H1_2	6155558	624480
H1_3	6155562	624503
H1_4	6155581	624503
H3_1	6150573	642230.1
H3_2	6150579	642249.3
H3_3	6150560	642254.5
H3_4	6150555	642235.9
H4_1	6152270	640092.3
H4_2	6152277	640074.2
H4_3	6152251	640084.5
H4_4	6152258	640066.3
H7_1	6159932	630497.9
H7_2	6159933	630480
H7_3	6159911	630481
H7_4	6159912	630503
H9_1	6157983	625540.7
H9_2	6157987	625545
H9_3	6157957	625558
H9_4	6157963	625535
H11_1	6165129	634307.7
H11_2	6165107	634312.2
H11_3	6165114	634331.6
H11_4	6165133	634325
H12_1	6164770	634759
H12_2	6164753	634775
H12_3	6164774	634775
H12_4	6164785	634769
H13_1	6164607	634467.4
H13_2	6164628	634466.6
H13_3	6164609	634448.6
H13_4	6164629	634445.2

Site	Northing	Easting
H14_1	6150218	642443.3
H14_2	6150234	642431.6
H14_3	6150222	642416.1
H14_4	6150203	642426.9
H15_1	6155842	634115
H15_2	6155860	634109.4
H15_3	6155857	634089.3
H15_4	6155838	634095.5
H16_1	6160198	631487
H16_2	6160191	631464
H16_3	6160209	631458
H16_4	6160215	631479
H17_1	6162352	627564
H17_2	6162365	627557
H17_3	6162356	627538
H17_4	6162341	627538
H18_1	6150859	640661
H18_2	6150857	640639.5
H18_3	6150875	640634.5
H18_4	6150877	640655.9
H19_1	6150879	640113.9
H19_2	6150876	640093.7
H19_3	6150897	640090.6
H19_4	6150900	640110.4
H20_1	6150787	640567.6
H20_2	6150805	640563.1
H20_3	6150796	640544.7
H20_4	6150778	640553.8
H21_1	6157969	635649
H21_2	6157980	635629
H21_3	6157962	635618
H21_4	6157946	635636

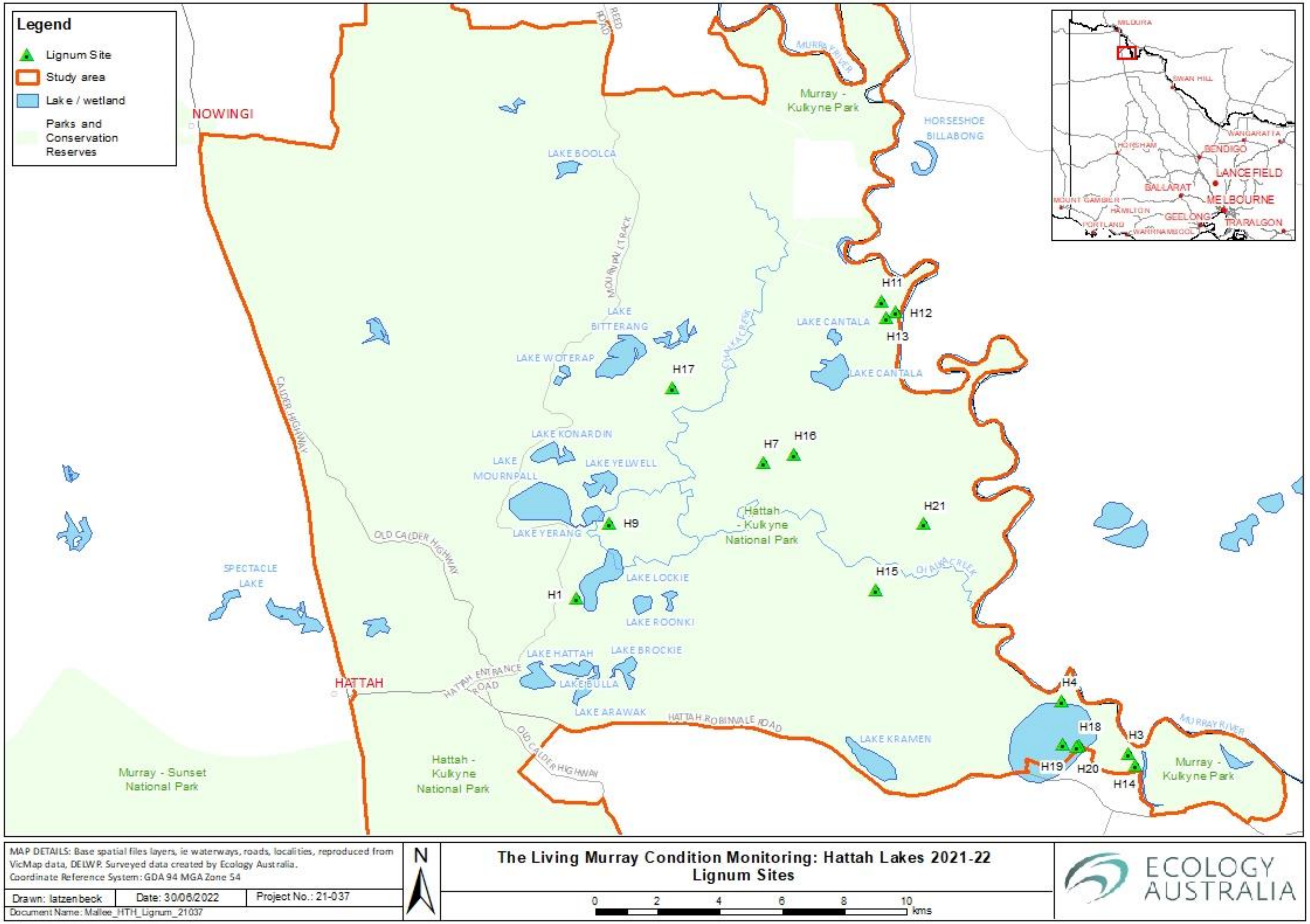


Figure 13 Map of Lignum sites, Hattah Lakes study area (2021-22).

6.2 Lignum photo-point image comparisons

2010-11

2011-12

2015-16

2017-18

2019-20

2021-22

Plate 18 Photo-point image comparison, Hattah Lignum Site 1, 2010-11 to 2021-22.


2009-10


2011-12

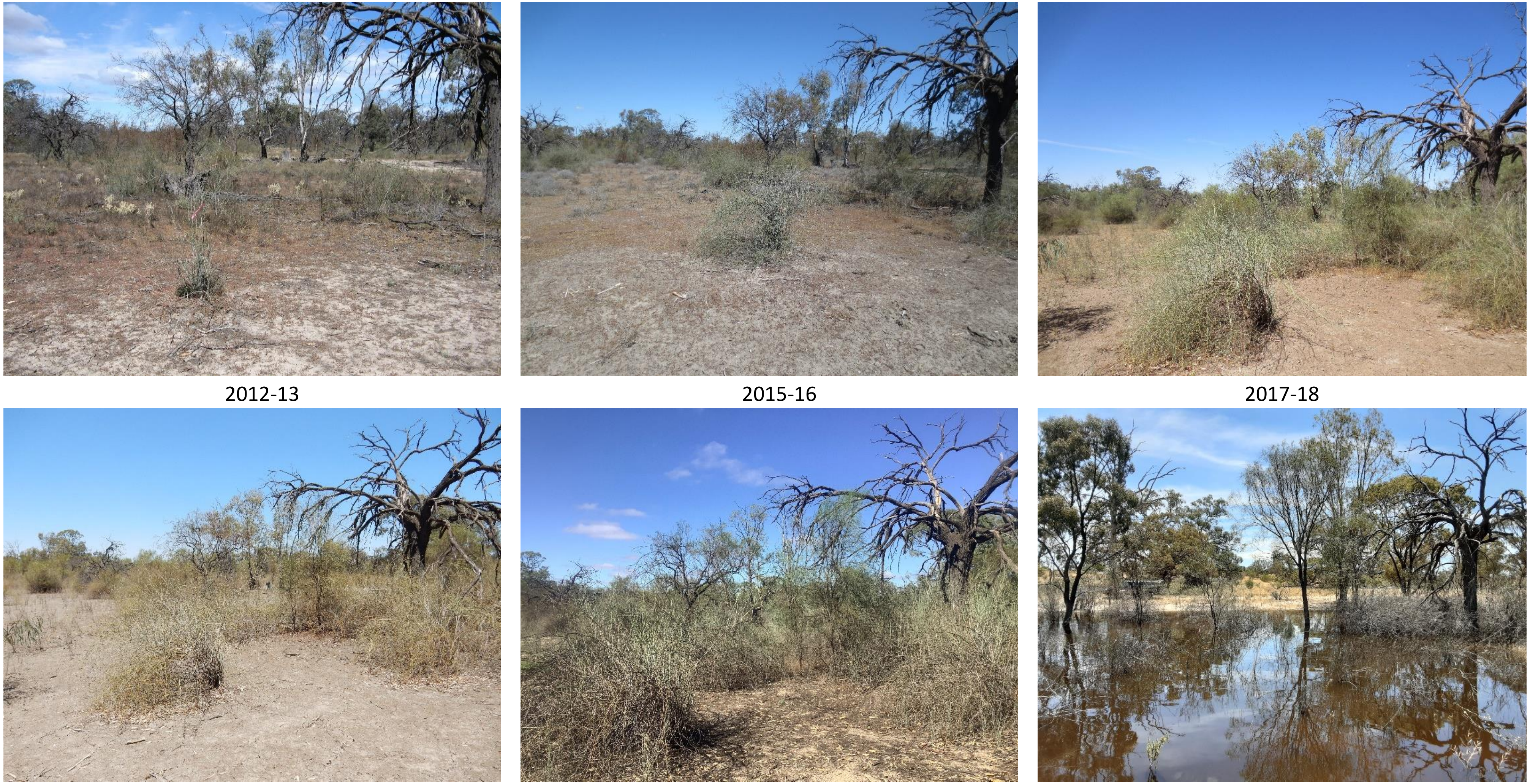

2015-16


2017-18


2019-20


2021-22

Plate 19 Photo-point image comparison, Hattah Lignum Site 4, 2009-10 to 2021-22.



2012-13 | 2015-16 | 2017-18

2018-19 | 2020-21 | 2021-22

Plate 20 Photo-point image comparison, Hattah Lignum Site 7, 2012-13 to 2021-22.


2013-14


2015-16


2017-18


2018-19


2019-20


2021-22

Plate 21 Photo-point image comparison, Hattah Lignum Site 9, 2013-14 to 2021-22.

7 Birds

Table 14 Bird survey site locations, Hattah lakes.

Wetland	Easting	Northing
Lake Arawak	624365	6152972
Lake Bitterang 1	626679	6163392
Lake Bitterang 2	625979	6162727
Lake Brockie	626343	6153303
Lake Bulla	624351	6153112
Lake Cantala	631927	6162688
Lake Hattah	622995	6153173
Lake Konardin	622922	6160085
Lake Kramen 1	634054	6149805
Lake Kramen 2	633309	6150667
Lake Little Hattah	623076	6153664
Lake Lockie 1	625555	6157250
Lake Lockie 2	624655	6155307
Lake Mournpall 1	622498	6158913
Lake Mournpall 2	624119	6158165
Lake Nip Nip	628084	6153750
Woterap	623828	6162977
Yelwell	625805	6159256
Yerang	624768	6157935

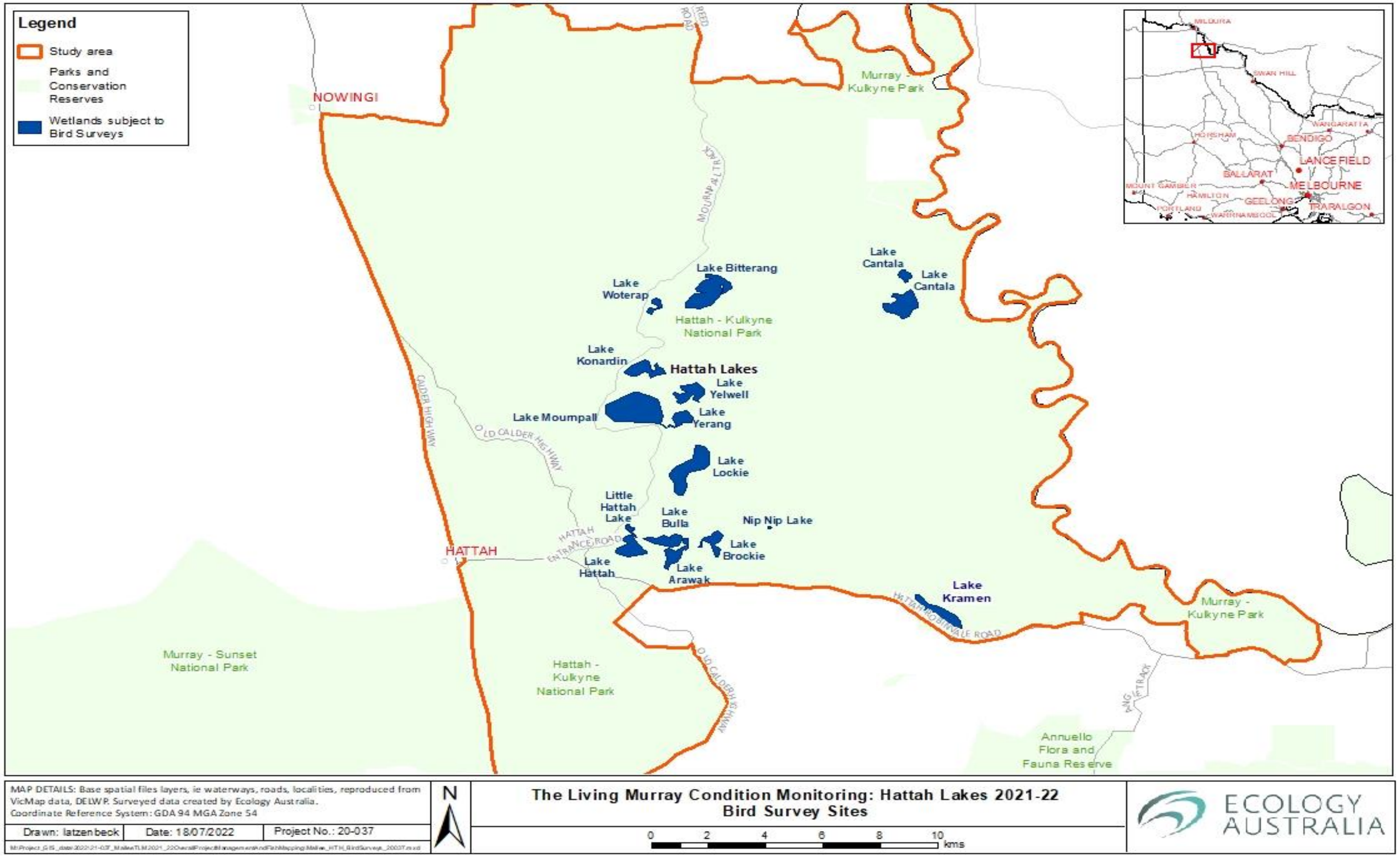


Figure 14 Map of wetlands at which birds were surveyed, Hattah Lakes (spring 2021 and summer and autumn 2022).

Table 15 Counts of waterbirds by species and feeding guild observed during spring, summer and autumn surveys at the Hattah Lakes wetland sites, 2021–22. Approximate water levels, wetland area and approximate area of surface water are provided (using full area measurements supplied by Mallee CMA). The table also includes species richness, total waterbird counts and waterbird density, measured as the total number of observed waterbirds per area of surface water (waterbirds ha^{-1}).

Site	Lake Arawak				Lake Bitterang				Lake Brockie*			Lake Bulla				Lake Cantala				Lake Hattah				Lake Konardin				Lake Kramen				Lake Little Hattah			
Survey	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total
Full area (ha)	**50**				**156**				**42**			**46**				**108**				**65**				**85**				**74**				**12**			
Water level (%full)	**120**	**100**	**80**	**100**	**120**	**100**	**90**	**103**	**90**	**75**	**83**	**120**	**100**	**80**	**100**	**120**	**90**	**80**	**97**	**120**	**90**	**80**	**97**	**120**	**100**	**85**	**102**	**20**	**0**	**0**	**6.7**	**100**	**90**	**80**	**90**
Area of surface water (ha)	**60**	**50**	**40**	**50**	**187**	**156**	**140**	**161**	**38**	**32**	**35**	**55**	**46**	**37**	**46**	**130**	**97**	**86**	**104**	**78**	**59**	**52**	**63**	**102**	**85**	**72**	**86**	**15**	**0**	**0**	**5**	**12**	**11**	**10**	**11**
Coots & rails	**2**	**13**	**4**	**19**		**2**	**4**	**6**	**14**	**1**	**15**	**2**	**5**		**7**		**1**	**5**	**6**	**3**	**13**		**16**	**2**	**1**		**3**						**14**		**14**
Eurasian Coot	2	13	4	19		2	4	6	14	1	15	2	5		7		1	5	6	3	13		16	2	1		3						14		14
Dabbling ducks		**6**		**6**	**9**	**42**	**10**	**61**	**29**	**1**	**30**	**14**	**8**		**22**	**52**	**19**	**2**	**73**	**6**	**18**	**2**	**26**	**4**	**6**	**4**	**14**	**210**			**210**	**1**	**22**	**3**	**26**
Chestnut Teal																																	1		1
Grey Teal		5		5	9	42	10	61	27		27	14	6		20	50	19	2	71	6	18		24	4	6	4	14	210			210		14	3	17
Pacific Black Duck		1		1					2	1	3		2		2	2			2			2	2									1	7		8
Diving ducks													**2**		**2**																	**5**	**1**		**6**
Blue-billed Duck																																1			1
Hardhead													2		2																	4	1		5
Musk Duck																																			
Filter-feeding ducks						**2**		**2**																											
Australasian Shoveler																																			
Pink-eared Duck						2		2																											
Fish-eaters	**6**	**16**		**22**	**2**	**48**	**2**	**52**	**8**	**1**	**9**	**13**	**5**	**2**	**20**		**117**	**702**	**819**		**12**	**1**	**13**		**3**		**3**						**15**	**2**	**17**
Australasian Darter	2	12		14		2	1	3	4		4		1	2	3			1	1		3		3												
Australian Pelican						9		9																											
Great Cormorant		4		4	2	32		34	3	1	4	2	1		3		117	701	818		2		2		3		3								
Little Black Cormorant	1			1		5	1	6				1	1		2						6		6										13		13
Little Pied Cormorant	3			3					1		1	10	2		12						1	1	2										2	2	4
Grazing ducks	**2**	**10**		**12**	**4**			**4**	**2**	**18**	**20**		**5**	**1**	**6**	**2**	**3**		**5**	**6**	**20**	**2**	**28**			**2**	**2**	**13**			**13**	**3**	**4**		**7**
Australian Wood Duck	2	10		12	4			4	2	18	20		5	1	6	2	3		5	6	20	2	28			2	2	13			13	3	4		7
Grebes	**3**	**4**		**7**		**9**	**7**	**16**	**4**	**4**	**8**	**4**	**2**	**4**	**10**		**14**	**10**	**24**	**2**	**15**	**29**	**46**		**21**	**13**	**34**					**8**	**19**	**7**	**34**
Australasian Grebe																		8	8	1	3	9	13									3			3
Great Crested Grebe	3	2		5		4	1	5	4	1	5	4	2		6					1	12		13		2		2					5	6		11
Grebe sp.		2		2																		6	6												
Hoary-headed Grebe						5	6	11		3	3			4	4		14	2	16			14	14		19	13	32						13	7	20
Large wading birds							**1**	**1**		**3**	**3**		**1**		**1**		**1**		**1**			**1**	**1**			**2**	**2**	**4**			**4**			**4**	**4**
Australian White Ibis																																		2	2
Great Egret																						1	1					3			3				
Nankeen Night-heron													1		1																				
Straw-necked Ibis																																			
White-faced Heron							1	1		3	3						1		1							2	2	1			1			1	1

Site	Lake Arawak				Lake Bitterang				Lake Brockie*			Lake Bulla				Lake Cantala				Lake Hattah				Lake Konardin				Lake Kramen				Lake Little Hattah			
Survey	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total
Yellow-billed Spoonbill																																		1	1
Shorebirds																				**1**		**2**	**3**					**44**			**44**				
Black-fronted Dotterel																																			
Masked Lapwing																				1		2	3					23			23				
Pied Stilt																												21			21				
Swans						**2**		**2**					**2**		**2**													**60**			**60**				
Black Swan						2		2					2		2													60			60				
Total abundance	**13**	**49**	**4**	**66**	**15**	**105**	**24**	**144**	**57**	**28**	**85**	**33**	**30**	**7**	**70**	**54**	**155**	**719**	**928**	**18**	**78**	**37**	**133**	**6**	**31**	**21**	**58**	**331**	**0**	**0**	**331**	**17**	**75**	**16**	**108**
Waterbird density	**0.2**	**1.0**	**0.1**	**0.4**	**0.1**	**0.7**	**0.2**	**0.3**	**1.5**	**0.9**	**1.2**	**0.6**	**0.7**	**0.2**	**0.5**	**0.4**	**1.6**	**8.3**	**3.4**	**0.3**	**1.3**	**0.7**	**0.8**	**0.1**	**0.4**	**0.3**	**0.2**	**22.4**	**n/a**	**n/a**	**n/a**	**1.4**	**6.9**	**1.7**	**3.3**
Species richness	**6**	**8**	**1**	**10**	**3**	**10**	**7**	**12**	**8**	**7**	**10**	**6**	**12**	**3**	**13**	**3**	**6**	**6**	**9**	**6**	**9**	**8**	**14**	**2**	**5**	**4**	**7**	**7**	**0**	**0**	**7**	**6**	**10**	**6**	**15**

Table 15 continued

Site	Lake Lockie*				Lake Mournpall*				Nip Nip				Woterap				Yelwell				Yerang				Spring total	Summer total	Autumn total	Total
Survey	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total				
Full area (ha)	176				181				2				33				59				39							
Water level (%full)	150	100	85	112	130	100	85	105	110	90	70	90	140	100	70	103	180	120	100	133	180	100	80	120				
Area of surface water (ha)	264	176	150	197	235	181	154	190	2	2	1	2	46	33	23	34	106	71	59	79	70	39	31	47				
Coots & rails	**3**	**3**		**6**	**2**	**2**		**4**		**1**	**2**	**3**					**1**	**12**	**1**	**14**	**2**	**2**		**4**	**17**	**83**	**17**	**117**
Eurasian Coot	3	3		6	2	2		4		1	2	3					1	12	1	14	2	2		4	17	83	17	117
Dabbling ducks	**9**	**7**	**6**	**22**	**1**	**21**		**22**	**32**	**40**	**68**	**140**	**7**	**35**	**6**	**48**	**3**	**12**		**15**	**10**	**10**		**20**	**358**	**275**	**102**	**735**
Chestnut Teal																										1		1
Grey Teal	9	6	6	21	1	19		20	32	40	64	136	7	32	6	45	3	9		12	10	10		20	355	253	95	703
Pacific Black Duck		1		1		2		2			4	4		3		3		3		3					3	21	7	31
Diving ducks			**2**	**2**		**6**		**6**																	**5**	**9**	**2**	**16**
Blue-billed Duck																									1			1
Hardhead						6		6																	4	9		13
Musk Duck			2	2																							2	2
Filter-feeding ducks			**1**	**1**					**4**	**7**	**2**	**13**	**4**	**7**		**11**							**2**	**2**	**8**	**16**	**5**	**29**
Australasian Shoveler														2		2										2		2
Pink-eared Duck			1	1					4	7	2	13	4	5		9							2	2	8	14	5	27
Fish-eaters	**2**	**3**	**7**	**12**		**62**	**183**	**245**		**1**	**3**	**4**	**2**	**5**	**2**	**9**		**21**	**45**	**66**	**4**	**7**	**61**	**72**	**29**	**323**	**1011**	**1363**
Australasian Darter	1			1		3		3						3	2	5		5	7	12		1		1	3	34	13	50
Australian Pelican		2	5	7															26	26			60	60		11	91	102
Great Cormorant			2	2		50	183	233		1		1						9	8	17	1	4		5	5	226	895	1126
Little Black Cormorant		1		1		7		7					2	2		4		7	4	11	3	1	1	5	7	43	6	56
Little Pied Cormorant	1			1		2		2			3	3										1		1	14	9	6	29
Grazing ducks										**4**		**4**					**4**	**4**	**4**	**12**	**2**			**2**	**36**	**52**	**27**	**115**
Australian Wood Duck										4		4					4	4	4	12	2			2	36	52	27	115
Grebes		**2**	**8**	**10**	**1**	**12**	**19**	**32**	**1**	**13**	**6**	**20**		**2**	**5**	**7**	**1**	**4**	**7**	**12**	**7**	**5**		**12**	**27**	**126**	**119**	**272**
Australasian Grebe			1	1			3	3	1	11	4	16		1	4	5									5	15	29	49
Great Crested Grebe			3	3	1	12	4	17									1	2		3	7	5		12	22	51	9	82
Grebe sp.																										2	6	8
Hoary-headed Grebe		2	4	6			12	12		2	2	4		1	1	2		2	7	9						58	75	133
Large wading birds		**2**	**14**	**16**													**1**	**6**	**4**	**11**	**3**		**2**	**5**	**8**	**10**	**31**	**49**
Australian White Ibis			4	4														1		1	1			1	1	1	6	8
Great Egret																									3		1	4

Site	Lake Lockie*				Lake Mournpall*				Nip Nip				Woterap				Yelwell				Yerang				Spring total	Summer total	Autumn total	Total
Survey	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total				
Nankeen Night-heron																										1		1
Straw-necked Ibis																							1	1			1	1
White-faced Heron		1	2	3														3	1	4	2		1	3	3	5	11	19
Yellow-billed Spoonbill		1	8	9													1	2	3	6					1	3	12	16
Shorebirds			**20**	**20**														**2**		**2**					**45**	**2**	**22**	**69**
Black-fronted Dotterel			16	16																							16	16
Masked Lapwing			4	4														2		2					24	2	6	32
Pied Stilt																									21			21
Swans			**3**	**3**		**2**		**2**		**2**		**2**													**60**	**8**	**3**	**71**
Black Swan			3	3		2		2		2		2													60	8	3	71
Total abundance	**14**	**17**	**61**	**92**	**4**	**105**	**202**	**311**	**37**	**68**	**81**	**186**	**13**	**49**	**13**	**75**	**10**	**61**	**61**	**132**	**28**	**24**	**65**	**117**	**593**	**904**	**1339**	**2836**
Waterbird density	**0.1**	**0.1**	**0.4**	**0.2**	**0.0**	**0.6**	**1.3**	**0.6**	**16.8**	**37.8**	**57.9**	**37.5**	**0.3**	**1.5**	**0.6**	**0.8**	**0.1**	**0.9**	**1.0**	**0.7**	**0.4**	**0.6**	**2.1**	**1.0**	**3.1**	**4.0**	**5.4**	
Species richness	**4**	**8**	**14**	**19**	**3**	**10**	**4**	**12**	**3**	**8**	**7**	**10**	**3**	**8**	**4**	**8**	**5**	**13**	**9**	**14**	**8**	**7**	**5**	**13**	**20**	**23**	**23**	**29**

Table 16 Counts of non-waterbirds by species observed during spring, summer and autumn surveys at the Hattah Lakes wetland sites, 2021–22. The table also includes species richness and total counts.

Site	Lake Arawak				Lake Bitterang				Lake Brockie*			Lake Bulla				Lake Cantala				Lake Hattah				Lake Konardin				Lake Kramen				Lake Little Hattah			
Survey	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total
Parrots	**3**	**1**	**6**	**10**	**3**		**8**	**11**	**1**	**2**	**3**	**6**		**5**	**11**	**5**	**14**	**8**	**27**	**5**	**17**	**175**	**197**			**12**	**12**	**238**	**137**	**244**	**619**	**8**	**12**	**21**	**41**
Galah										2	2							2	2	1	7	7	15					3		71	74		5	3	8
Little Corella			2	2	2		8	10				4		4	8		10		10	4	8	163	175			6	6	222	100	41	363			8	8
Mallee Ringneck			4	4														1	1											7	7			4	4
Red-rumped Parrot												2			2																	2	2		4
Regent Parrot	3			3												1	2	3	6			2	2					12	37	111	160	4	2	6	12
Sulphur-crested Cockatoo		1		1	1			1	1		1			1	1			2	2		2	3	5			5	5	1		13	14	2	3		5
Yellow Rosella																4	2		6							1	1			1	1				
Pigeons and Doves																													**1**		**1**				
Crested Pigeon																													1		1				
Peaceful Dove																																			
Raptors	**1**	**1**		**2**		**1**	**3**	**4**	**1**	**1**	**2**			**1**	**1**			**3**	**3**			**1**	**1**	**1**	**1**		**2**	**1**	**4**	**3**	**8**	**1**		**1**	**2**
Nankeen Kestrel																								1			1			2	2			1	1
Peregrine Falcon																													1		1				
Wedge-tailed Eagle																													3	1	4				
Whistling Kite	1	1		2		1	1	2	1	1	2			1	1			2	2			1	1		1		1	1			1	1			1
White-bellied Sea-eagle							2	2										1	1																
Ratites																												**17**	**3**		**20**				
Emu																												17	3		20				
Songbirds	**8**	**16**	**7**	**31**	**7**	**12**	**22**	**41**	**16**	**7**	**23**	**21**	**11**	**10**	**42**	**10**	**15**	**58**	**83**	**13**	**8**	**12**	**33**	**4**	**41**	**23**	**68**	**45**	**74**	**31**	**150**	**13**	**12**	**12**	**37**
Apostlebird																																		3	3
Australian Magpie	2		1	3		1		1				2	1	3	6	2			2	1	1		2						3	2	5			2	2
Australian Raven						2	1	3		2	2	3			3		1		1					2			2	30			30				
Black-faced Cuckoo-shrike																																			
Blue-faced Honeyeater		1		1		1		1																											
Brown Treecreeper																																			
Chestnut-rumped Thornbill																	6		6																
Grey Butcherbird													2		2						1	2	3					1	1	3	5		1		1
Grey Fantail																										4	4								
Grey Shrike-thrush																										1	1								
Laughing Kookaburra		2		2	2			2																						1	1			2	2
Little Grassbird																																			
Little Raven							4	4										1	1										7	17	24				
Magpie-lark			2	2			2	2				2	4	3	9	1		3	4			4	4		1	1	2	11	1		12			1	1
Noisy Miner	4	3	4	11	5	8	13	26	4	4	8	4	4	2	10		2	4	6	4	6	4	14			1	1	3	2	8	13	4	10	4	18
Pied Butcherbird										1	1			1	1							2	2	1			1		3		3		1		1
Rainbow Bee-eater		10		10													2		2						28		28								

Site	Lake Arawak				Lake Bitterang				Lake Brockie*			Lake Bulla				Lake Cantala				Lake Hattah				Lake Konardin				Lake Kramen				Lake Little Hattah			
Survey	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total
Raven sp.																													10		10				
Restless Flycatcher																		1	1																
Rufous Whistler																										2	2								
Sacred Kingfisher																																			
Spiny-cheeked Honeyeater																										1	1								
Striated Pardalote	2			2												2			2					1		2	3					1			1
Tree Martin																2		24	26	4			4						4		4	6			6
Weebill																									2	5	7								
Welcome Swallow							2	2										22	22						5		5		43		43				
White-plumed Honeyeater																2	2	2	6						1	4	5								
White-winged Chough									12		12	10			10					4			4									2			2
Willie Wagtail														1	1	1	2	1	4						1	2	3								
Yellow-plumed Honeyeater																									3		3								
Total abundance	**12**	**18**	**13**	**43**	**10**	**13**	**33**	**56**	**18**	**10**	**28**	**27**	**11**	**16**	**54**	**15**	**29**	**69**	**113**	**18**	**25**	**188**	**231**	**5**	**42**	**35**	**82**	**301**	**219**	**278**	**798**	**22**	**24**	**34**	**80**
Species richness	**6**	**7**	**6**	**13**	**5**	**6**	**9**	**13**	**5**	**6**	**8**	**8**	**5**	**9**	**13**	**9**	**10**	**15**	**22**	**7**	**7**	**10**	**13**	**5**	**9**	**14**	**21**	**11**	**16**	**14**	**24**	**9**	**8**	**11**	**19**

Table 16 continued

Site	Lake Lockie*				Lake Mournpall*				Nip Nip				Woterap				Yelwell				Yerang				Spring total	Summer total	Autumn total	Total
Survey	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total				
Parrots	**4**	**6**	**18**	**28**	**4**			**4**		**5**	**2**	**7**					**2**		**9**	**11**			**5**	**5**	**278**	**193**	**515**	**986**
Galah			4	4	2			2											2	2					6	12	91	109
Little Corella	4			4															2	2					236	118	234	588
Mallee Ringneck										3		3					2			2					2	3	16	21
Red-rumped Parrot		6	6	12						2	2	4													4	10	8	22
Regent Parrot			7	7															3	3			4	4	20	41	136	197
Sulphur-crested Cockatoo			1	1	2			2											2	2			1	1	6	7	28	41
Yellow Rosella																									4	2	2	8
Pigeons and Doves		**1**		**1**																						**2**		**2**
Crested Pigeon																										1		1
Peaceful Dove		1		1																						1		1
Raptors			**1**	**1**			**1**	**1**	**3**			**3**		**1**	**1**	**2**		**1**	**2**	**3**		**1**		**1**	**7**	**11**	**18**	**36**
Nankeen Kestrel									3			3													4		3	7
Peregrine Falcon																										1		1
Wedge-tailed Eagle																										3	1	4
Whistling Kite			1	1			1	1						1	1	2		1	1	2		1		1	3	7	10	20
White-bellied Sea-eagle																			1	1							4	4
Ratites			**2**	**2**		**1**		**1**																	**17**	**4**	**2**	**23**
Emu			2	2		1		1																	17	4	2	23
Songbirds	**21**	**14**	**34**	**69**	**47**	**80**	**4**	**131**	**7**	**11**	**15**	**33**	**2**	**7**	**6**	**15**	**6**	**13**	**9**	**28**	**10**	**2**	**7**	**19**	**214**	**332**	**257**	**803**
Apostlebird									5			5													5		3	8
Australian Magpie										3		3													7	9	8	24
Australian Raven																									35	3	3	41
Black-faced Cuckoo-shrike									1			1											2	2	1		2	3
Blue-faced Honeyeater											1	1						2		2						4	1	5
Brown Treecreeper	1			1																					1			1
Chestnut-rumped Thornbill																										6		6
Grey Butcherbird						2		2			1	1		1		1			1	1			1	1	1	8	8	17
Grey Fantail											1	1															5	5
Grey Shrike-thrush										1	1	2									1			1	1	1	2	4
Laughing Kookaburra																							2	2	2	2	5	9
Little Grassbird	1			1																					1			1
Little Raven																			2	2						7	24	31
Magpie-lark			9	9	1	1		2	1	2		3			1	1	2	3		5	2			2	20	12	26	58
Noisy Miner	7		6	13	4	4	4	12		3	2	5	2	4	5	11	4	8	4	16	5	2	2	9	46	60	67	173
Pied Butcherbird			2	2																					1	4	6	11
Rainbow Bee-eater						20		20						2		2										62		62

Site	Lake Lockie*				Lake Mournpall*				Nip Nip				Woterap				Yelwell				Yerang				Spring total	Summer total	Autumn total	Total
Survey	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total	Spring	Summer	Autumn	Total				
Raven sp.																										10		10
Restless Flycatcher																											1	1
Rufous Whistler											1	1															3	3
Sacred Kingfisher		1		1		1		1																		2		2
Spiny-cheeked Honeyeater		3		3																						3	1	4
Striated Pardalote					2			2		1		1							2	2	2			2	10	1	4	15
Tree Martin	7	4	10	21	40	46		86																	59	54	34	147
Weebill											2	2														2	7	9
Welcome Swallow											1	1														48	25	73
White-plumed Honeyeater	5	6	3	14		5		5			3	3													7	14	12	33
White-winged Chough																									16	12		28
Willie Wagtail			4	4		1		1		1	2	3													1	5	10	16
Yellow-plumed Honeyeater																										3		3
Total abundance	**25**	**21**	**55**	**101**	**51**	**81**	**5**	**137**	**10**	**16**	**17**	**43**	**2**	**8**	**7**	**17**	**8**	**14**	**20**	**42**	**10**	**3**	**12**	**25**	**516**	**542**	**792**	**1850**
Species richness	**7**	**7**	**13**	**19**	**7**	**10**	**3**	**14**	**5**	**9**	**12**	**19**	**2**	**5**	**4**	**6**	**4**	**5**	**11**	**14**	**5**	**3**	**7**	**11**	**31**	**36**	**34**	**46**

Table 17 All bird species recorded during surveys at the Hattah Lakes wetland sites, 2021–22

Key: EPBC Listed as a threatened species under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*

FFG Listed as a threatened taxon under the *Flora and Fauna Guarantee Act 1988*

Threat status is indicated with the following categories:
EN Endangered
VU Vulnerable
NT Near Threatened

W/NW Waterbird (W) or Non-Waterbird (NW)

Common name	Scientific name	Guild	W/NW	Threat status	
				EPBC	FFG
Eurasian Coot	*Fulica atra*	Coots & rails	W		
Chestnut Teal	*Anas castanea*	Dabbling ducks	W		
Grey Teal	*Anas gracilis*	Dabbling ducks	W		
Pacific Black Duck	*Anas superciliosa*	Dabbling ducks	W		
Hardhead	*Aythya australis*	Diving ducks	W		vu
Musk Duck	*Biziura lobata*	Diving ducks	W		vu
Blue-billed Duck	*Oxyura australis*	Diving ducks	W		vu
Australasian Shoveler	*Anas rhynchotis*	Filter-feeding ducks	W		vu
Pink-eared Duck	*Malacorhyncus membranaceus*	Filter-feeding ducks	W		
Australasian Darter	*Anhinga novaehollandiae*	Fish-eaters	W		
Little Pied Cormorant	*Microcarbo melanoleucos*	Fish-eaters	W		
Australian Pelican	*Pelecanus conspicillatus*	Fish-eaters	W		
Great Cormorant	*Phalacrocorax carbo*	Fish-eaters	W		
Little Black Cormorant	*Phalacrocorax sulcirostris*	Fish-eaters	W		
Australian Wood Duck	*Chenonetta jubata*	Grazing ducks	W		
Great Crested Grebe	*Podiceps cristatus*	Grebes	W		
Hoary-headed Grebe	*Poliocephalus poliocephalus*	Grebes	W		
Australasian Grebe	*Tachybaptus novaehollandiae*	Grebes	W		
Great Egret	*Ardea alba*	Large wading birds	W		
White-faced Heron	*Egretta novaehollandiae*	Large wading birds	W		
Nankeen Night-heron	*Nycticorax caledonicus*	Large wading birds	W		
Yellow-billed Spoonbill	*Platalea flavipes*	Large wading birds	W		
Australian White Ibis	*Threskiornis molucca*	Large wading birds	W		
Straw-necked Ibis	*Threskiornis spinicollis*	Large wading birds	W		
Mallee Ringneck	*Barnardius zonarius barnardi*	Parrots	NW		
Sulphur-crested Cockatoo	*Cacatua galerita*	Parrots	NW		
Little Corella	*Cacatua sanguinea*	Parrots	NW		

Common name	Scientific name	Guild	W/NW	Threat status	
				EPBC	FFG
Galah	*Eolophus roseicapillus*	Parrots	NW		
Yellow Rosella	*Platycercus elegans flaveolus*	Parrots	NW		
Regent Parrot	*Polytelis anthopeplus*	Parrots	NW	VU	vu
Red-rumped Parrot	*Psephotus haematonotus*	Parrots	NW		
Peaceful Dove	*Geopelia striata*	Pigeons and Doves	NW		
Crested Pigeon	*Ocyphaps lophotes*	Pigeons and Doves	NW		
Wedge-tailed Eagle	*Aquila audax*	Raptors	NW		
Nankeen Kestrel	*Falco cenchroides*	Raptors	NW		
Peregrine Falcon	*Falco peregrinus*	Raptors	NW		
White-bellied Sea-eagle	*Haliaeetus leucogaster*	Raptors	NW		en
Whistling Kite	*Haliastur sphenurus*	Raptors	NW		
Emu	*Dromaius novaehollandiae*	Ratites	NW		
Black-fronted Dotterel	*Elseyornis melanops*	Shorebirds	W		
Pied Stilt	*Himantopus leucocephalus*	Shorebirds	W		
Masked Lapwing	*Vanellus miles*	Shorebirds	W		
Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*	Songbirds	NW		
Chestnut-rumped Thornbill	*Acanthiza uropygialis*	Songbirds	NW		
Brown Treecreeper	*Climacteris picumnus*	Songbirds	NW		
Grey Shrike-thrush	*Colluricincla harmonica*	Songbirds	NW		
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	Songbirds	NW		
White-winged Chough	*Corcorax melanorhamphos*	Songbirds	NW		
Australian Raven	*Corvus coronoides*	Songbirds	NW		
Little Raven	*Corvus mellori*	Songbirds	NW		
Pied Butcherbird	*Cracticus nigrogularis*	Songbirds	NW		
Australian Magpie	*Cracticus tibicen*	Songbirds	NW		
Grey Butcherbird	*Cracticus torquatus*	Songbirds	NW		
Laughing Kookaburra	*Dacelo novaeguineae*	Songbirds	NW		
Blue-faced Honeyeater	*Entomyzon cyanotis*	Songbirds	NW		
Magpie-lark	*Grallina cyanoleuca*	Songbirds	NW		
Welcome Swallow	*Hirundo neoxena*	Songbirds	NW		
Noisy Miner	*Manorina melanocephala*	Songbirds	NW		
Rainbow Bee-eater	*Merops ornatus*	Songbirds	NW		
Restless Flycatcher	*Myiagra inquieta*	Songbirds	NW		
Rufous Whistler	*Pachycephala rufiventris*	Songbirds	NW		
Striated Pardalote	*Pardalotus striatus*	Songbirds	NW		
Tree Martin	*Petrochelidon nigricans*	Songbirds	NW		
Little Grassbird	*Poodytes gramineus*	Songbirds	NW		
Yellow-plumed Honeyeater	*Ptilotula ornata*	Songbirds	NW		
White-plumed Honeyeater	*Ptilotula penicillatus*	Songbirds	NW		

Common name	Scientific name	Guild	W/NW	Threat status	
				EPBC	FFG
Grey Fantail	*Rhipidura albiscapa*	Songbirds	NW		
Willie Wagtail	*Rhipidura leucophrys*	Songbirds	NW		
Weebill	*Smicrornis brevirostris*	Songbirds	NW		
Apostlebird	*Struthidea cinerea*	Songbirds	NW		vu
Sacred Kingfisher	*Todirhamphus sanctus*	Songbirds	NW		
Black Swan	*Cygnus atratus*	Swans	W		

8 Fish Communities

8.1 Fish Site Details

Table 18 Downstream (start) and upstream (end) locations for electrofishing reaches surveyed, Hattah Lakes.

Site	Downstream Easting	Downstream Northing	Upstream Easting	Upstream Northing
Mur1	629416.325	6175333.697	629754.709	6173940.220
Mur2	637546.893	6155604.520	637533.252	6154691.773
Mur3	638820.876	6153244.762	639993.720	6152703.388

Table 19 Central locations for netting and backpack electrofishing sites surveyed, Hattah Lakes.

Site	Macrobaitat	Central Easting	Central Northing
Ara1	Wetland	624436.985	6152994.054
Ara2	Wetland	624350.032	6152853.027
Ara3	Wetland	624388.971	6152490.003
Bul1	Wetland	624342.026	6153290.061
Bul2	Wetland	624540.992	6153244.996
Bul3	Wetland	624707.986	6153238.962
Cha1	Anabranch	629473.011	6157721.051
Cha2	Anabranch	634564.021	6156671.032
Cha3	Anabranch	637055.023	6155413.959
Ha1	Wetland	623215.009	6153196.968
Ha2	Wetland	623333.024	6152952.022
Ha3	Wetland	622741.957	6152796.985
LH1	Wetland	623032.018	6153759.021
LH2	Wetland	623120.961	6153653.009
LH3	Wetland	623228.970	6153583.013
Loc1	Wetland	624487.029	6155739.051
Loc2	Wetland	624500.036	6155278.989
Loc3	Wetland	624429.013	6155146.066
Mour1	Wetland	623816.962	6158488.973
Mour2	Wetland	622949.000	6158382.021
Mour3	Wetland	622963.020	6158856.023
Yer1	Wetland	624381.016	6157937.968
Yer2	Wetland	624776.002	6158028.019
Yer3	Wetland	624828.020	6157952.996
Mur1	Riverine	629308.787	6173888.666
Mur2	Riverine	637381.001	6154890.060
Mur3	Riverine	639623.819	6152562.694

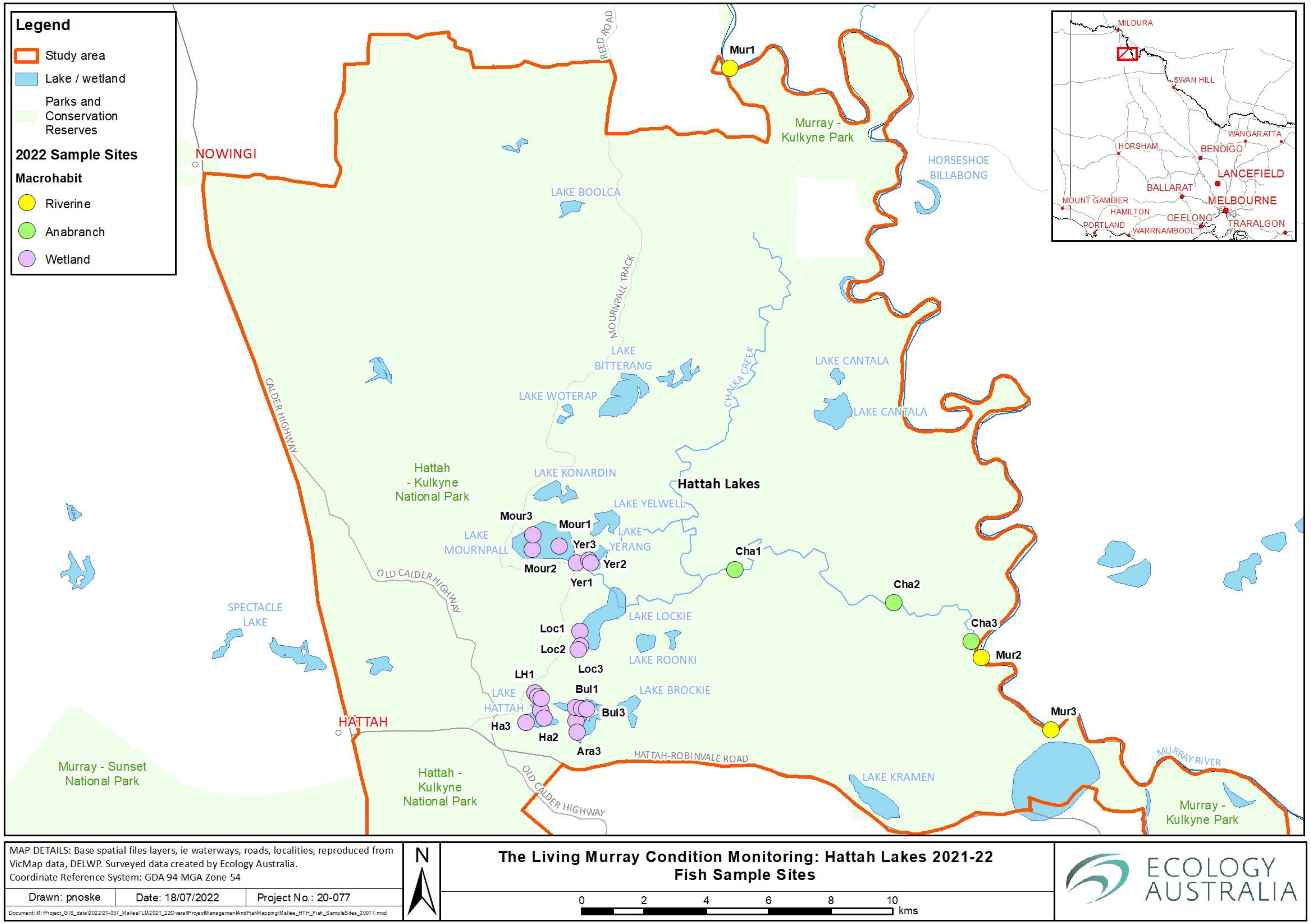


Figure 15 Map of fish sites, Hattah Lakes study area (2021-22).

8.2 Annual Abundance

Table 20 Fish recorded at each site within the Riverine macrohabitat, separated by method for the 2022 surveys.

Site/gear	Australian smelt	Bony herring	Carp gudgeon complex	Common carp	Dwarf flat-headed gudgeon	Eastern gambusia	Flat-headed gudgeon	Golden perch	Goldfish	Goldfish x Carp	Murray cod	Murray-Darling rainbowfish	Oriental Weatherloach	Silver perch	Unspecked hardyhead	Total
Mur1	**54**	**77**	**463**	**37**		**15**	**2**	**3**	**3**		**9**	**4**		**1**	**5**	**673**
EF (Boat)	38	77	5	30		1		3	3		9	4		1	5	176
FN (larval)	2		458			14	2									476
Seine net	14			7												21
Mur2	**65**	**64**	**9**	**47**	**1**	**79**		**5**	**2**	**1**	**15**	**1**		**2**	**33**	**324**
EF (Boat)	60	64	5	46	1	53		5	2	1	15	1		2	11	266
FN (larval)	2		2			2									1	7
Seine net	3		2	1		24									21	51
Mur3	**51**	**43**	**18**	**48**		**47**		**6**	**1**		**7**	**9**	**1**	**1**	**27**	**259**
EF (Boat)	44	43	10	47		28		6	1		7	4	1	1	20	212
FN (larval)						1						5			7	13
Seine net	7		8	1		18										34
Total	**170**	**184**	**490**	**132**	**1**	**141**	**2**	**14**	**6**	**1**	**31**	**14**	**1**	**4**	**65**	**1256**

Table 21 Fish recorded at each site within the Wetland macrohabitat, separated by method for the 2022 surveys

Site/gear	Australian smelt	Bony herring	Carp gudgeon complex	Common carp	Dwarf flat-headed gudgeon	Eastern gambusia	Flat-headed gudgeon	Golden perch	Goldfish	Murray-Darling rainbowfish	Silver perch	Unspecked hardyhead	Total
ARA1			**226**	**19**		**723**		**10**	**3**		**1**		**982**
EF (BP)			1			1							2
FN (coarse)				17				9	1		1		28
FN (larval)			225	2		663		1	2				893
Seine net						59							59
ARA2	**3**		**623**	**4**		**42**	**9**	**1**					**682**
EF (BP)			7			27	3						37
FN (coarse)				4				1					5
FN (larval)	1		597			15							613
Seine net	2		19				6						27
ARA3	**3**		**661**	**12**		**204**	**2**	**8**		**1**			**891**
EF (BP)			2	4		103	2						111
FN (coarse)				5				5					10
FN (larval)	3		434	3		101		3					544
Seine net			225							1			226
BUL1			**1199**	**106**		**103**	**1**	**12**	**1**				**1422**
EF (BP)			3			43	1						47
FN (coarse)				102				12	1				115
FN (larval)			1185	4		48							1237
Seine net			11			12							23
BUL2			**843**	**90**		**29**	**415**	**17**	**1**	**1**			**1396**
EF (BP)						5							5
FN (coarse)				87				17					104
FN (larval)			360	3		24	8		1	1			397
Seine net			483				407						890
BUL3	**1**		**1377**	**165**		**44**	**161**	**41**		**1**	**1**		**1791**
EF (BP)			2			41	2						45
FN (coarse)				161				35			1		197
FN (larval)	1		1262	4			7	6		1			1281
Seine net			113			3	152						268
HAT1		**9**	**20**	**45**		**4396**	**2**	**2**		**7**		**2**	**4483**

Site/gear	Australian smelt	Bony herring	Carp gudgeon complex	Common carp	Dwarf flat-headed gudgeon	Eastern gambusia	Flat-headed gudgeon	Golden perch	Goldfish	Murray-Darling rainbowfish	Silver perch	Unspecked hardyhead	Total
EF (BP)				3									3
FN (coarse)		9		40				2					51
FN (fine)			20	2		4395	2			7		2	4428
Seine net						1							1
HAT2	**1**	**1**	**432**	**17**		**3075**	**1**	**1**		**10**		**10**	**3548**
EF (BP)			1	4									5
FN (coarse)		1		13									14
FN (larval)	1		405			3072	1	1		9		10	3499
Seine net			26			3				1			30
HAT3			**385**	**9**		**5155**		**3**		**30**		**5**	**5587**
EF (BP)			1	1		30							32
FN (coarse)				4				3					7
FN (larval)			383	4		4888				30		5	5310
Seine net			1			237							238
LH1		**1**	**10**	**34**		**147**	**10**	**8**	**4**				**214**
EF (BP)				7		92	2	5	1				107
FN (coarse)		1		23				2	1				27
FN (larval)			10	4		13	8	1	2				38
Seine net						42							42
LH2			**42**	**11**	**3**	**183**	**4**	**2**	**2**				**247**
EF (BP)			6	2	3	57	4	1					73
FN (coarse)				4					1				5
FN (larval)			28	5		96		1	1				131
Seine net			8			30							38
LH3			**33**	**177**	**1**	**126**	**9**	**2**	**13**				**361**
EF (BP)			8	6	1	50	6	1	1				73
FN (coarse)				166				1	11				178
FN (larval)			19	5		66	3		1				94
Seine net			6			10							16
Loc1	**55**	**3**	**14**	**7**		**174**		**1**	**2**		**3**		**259**
EF (BP)	1	1	1	5		18			2		3		31
FN (coarse)		2		2				1					5
FN (larval)	53		5			81							139
Seine net	1		8			75							84
Loc2	**33**	**7**	**12**	**29**		**1052**	**15**		**1**			**1**	**1150**

Site/gear	Australian smelt	Bony herring	Carp gudgeon complex	Common carp	Dwarf flat-headed gudgeon	Eastern gambusia	Flat-headed gudgeon	Golden perch	Goldfish	Murray-Darling rainbowfish	Silver perch	Unspecked hardyhead	Total
EF (BP)				5		6						1	12
FN (coarse)		6		23					1				30
FN (larval)	31		11	1		967	15						1025
Seine net	2	1	1			79							83
Loc3	**30**	**2**	**18**	**11**		**342**	**26**	**1**					**430**
EF (BP)		1	10	7		7	5	1					31
FN (larval)	29	1	5	4		299	21						359
Seine net	1		3			36							40
MOUR1	**1**		**217**	**6**		**82**	**8**	**6**	**2**	**2**		**2**	**326**
EF (BP)				1		28		1	2	1			33
FN (coarse)				5				4					9
FN (larval)	1		217			33	8	1		1		1	262
Seine net						21						1	22
MOUR2	**3**	**1**	**90**	**4**		**153**	**4**	**4**				**1**	**260**
EF (BP)			1			22							23
FN (coarse)		1		4				4					9
FN (larval)	3		89			48	4					1	145
Seine net						83							83
MOUR3	**5**	**12**	**95**	**7**		**153**	**16**	**2**	**2**				**292**
EF (BP)			87			76	16		1				180
FN (coarse)		12		7				2					21
FN (larval)	5		8			73			1				87
Seine net						4							4
Yer1			**26**	**74**	**2**	**335**	**34**	**50**	**12**				**533**
EF (BP)			13	55	2	58	18	23	12				181
FN (coarse)				17				14					31
FN (larval)			8	2		189	14	13					226
Seine net			5			88	2						95
Yer2	**5**	**1**	**14**	**49**		**37**	**18**	**26**	**1**				**151**
EF (BP)	2		3	10		14	4	6					39
FN (coarse)		1		32				11					44
FN (larval)	3			7		2	14	9	1				36
Seine net			11			21							32
Yer3	**4**	**1**	**25**	**83**		**425**	**6**	**14**	**1**				**559**
EF (BP)			11	25		87	3	8					134

Site/gear	Australian smelt	Bony herring	Carp gudgeon complex	Common carp	Dwarf flat-headed gudgeon	Eastern gambusia	Flat-headed gudgeon	Golden perch	Goldfish	Murray-Darling rainbowfish	Silver perch	Unspecked hardyhead	Total
FN (coarse)		1		57				4	1				63
FN (larval)	4		7	1		231	3	2					248
Seine net			7			107							114
Grand Total	**144**	**38**	**6362**	**959**	**6**	**16980**	**741**	**211**	**45**	**52**	**5**	**21**	**25564**

Table 22 Fish recorded at each site within the Anabranch macrohabitat, separated by method for the 2022 surveys

Site/gear	Australian smelt	Bony herring	Carp gudgeon complex	Common carp	Dwarf flat-headed gudgeon	Eastern gambusia	Flat-headed gudgeon	Golden perch	Goldfish	Murray-Darling rainbowfish	Unspecked hardyhead	Total
CC1	**68**	**42**	**3**	**286**		**698**	**5**	**1**	**1**	**3**	**13**	**1120**
EF (BP)	29	30	1	267		175	4		1			507
FN (coarse)		7		15								22
FN (larval)	5	5				311		1		3	10	335
Seine net	34		2	4		212	1				3	256
CC2	**87**	**15**	**23**	**67**		**69**	**1**	**2**	**2**			**266**
EF (BP)	10		4	38		18			2			72
FN (coarse)		10		28				2				40
FN (larval)	8	5	10	1		47						71
Seine net	69		9			4	1					83
CC3	**104**	**20**	**3**	**120**	**1**	**2621**	**2**	**1**	**1**		**1**	**2874**
EF (BP)	8	1	3	23	1	25	1	1	1		1	65
FN (larval)		19		82		2556	1					2658
Seine net	96			15		40						151
Total	**259**	**77**	**29**	**473**	**1**	**3388**	**8**	**4**	**4**	**3**	**14**	**4260**

8.3 Community Structure

Table 23 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 for all methods (electro-fishing and net methods separation available upon request). greatest species contribution to dissimilarities highlighted in bold.

Year comparison	Australian smelt	Bony herring	Carp gudgeon complex	Common carp	Eastern gambusia	Murray-Darling rainbowfish	Unspecked hardyhead
2010_2011			**0.709**				
2010_2012			0.550		0.702		
2010_2013	0.848	**0.493**	0.689		0.272		
2010_2014		0.817		**0.539**	0.687		
2010_2016			0.774		**0.404**		
2010_2017			**0.580**		0.730		
2010_2018			**0.409**		0.797		
2010_2019			**0.707**				
2010_2020	0.718	**0.257**			0.580		0.433
2010_2021	0.406	**0.250**	0.650			0.742	0.546
2010_2022			0.668	0.767	**0.419**		
2011_2012			**0.739**				
2011_2013			**0.720**				
2011_2014			**0.620**	0.796			
2011_2016			**0.513**		0.835		
2011_2017			**0.617**		0.785		
2011_2018			**0.466**		0.816		
2011_2019			**0.725**				
2011_2020			**0.638**		0.728		
2011_2021			**0.673**		0.740		
2011_2022			**0.591**		0.862		

Year comparison	Australian smelt	Bony herring	Carp gudgeon complex	Common carp	Eastern gambusia	Murray-Darling rainbowfish	Unspecked hardyhead
2012_2013			**0.597**		0.784		
2012_2014			**0.425**	0.763			
2012_2016			**0.422**		0.803		
2012_2017			**0.592**		0.748		
2012_2018			**0.405**		0.796		
2012_2019			**0.728**				
2012_2020		0.581	**0.456**		0.776		0.687
2012_2021		0.579	**0.478**		0.671		0.743
2012_2022			**0.468**		0.807		
2013_2014				0.555	0.747		
2013_2016			0.785		**0.405**		
2013_2017			**0.591**		0.745		
2013_2018			**0.413**		0.799		
2013_2019			**0.722**				
2013_2020	0.710	**0.226**			0.589		0.418
2013_2021	0.608	**0.205**	0.722		0.347		0.486
2013_2022			0.723		**0.443**		
2014_2016			0.639	0.836	**0.325**		
2014_2017			**0.536**	0.679	0.817		
2014_2018			**0.360**	0.827	0.691		
2014_2019			**0.508**	0.785			
2014_2020		0.554		**0.396**	0.681		0.791
2014_2021		0.570		**0.435**	0.699		0.773
2014_2022			0.846	0.634	**0.352**		
2016_2017			**0.481**		0.764		
2016_2018			0.784		**0.414**		
2016_2019			0.803		**0.432**		

Year comparison	Australian smelt	Bony herring	Carp gudgeon complex	Common carp	Eastern gambusia	Murray-Darling rainbowfish	Unspecked hardyhead
2016_2020			0.738		**0.374**		
2016_2021			0.763		**0.401**		
2016_2022			0.783		**0.429**		
2017_2018			**0.440**		0.774		
2017_2019			**0.562**		0.729		
2017_2020	0.788		**0.559**		0.692		
2017_2021			**0.560**		0.705		
2017_2022			**0.521**		0.770		
2018_2019			0.792		**0.439**		
2018_2020			**0.393**		0.754		
2018_2021			**0.388**		0.767		
2018_2022			0.789		**0.411**		
2019_2020			**0.615**				0.704
2019_2021			**0.665**				0.725
2019_2022			**0.496**		0.808		
2020_2021	0.696	0.581	0.776		**0.241**		0.422
2020_2022		0.678	0.563		**0.338**		0.772
2021_2022		0.698	0.614	0.763	**0.389**		

Table 24 SIMPER analysis results showing the species most influential for a minimum of 70% of pairwise differences (and levels of their interaction) between macrohabitats based on abundance data for all sites, all methods (electro-fishing and net methods separation available upon request). greatest species contribution to dissimilarities highlighted in bold.

Maco habitat	Carp gudgeon Complex	Eastern gambusia
Anabranch_Riverine	**0.483**	0.774
Anabranch_Wetland	**0.495**	0.794
Wetland_Riverine	**0.489**	0.760

Table 25 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 presence data for all sites for all methods (electro-fishing and net methods separation available upon request). greatest species contribution to dissimilarities highlighted in bold

Year comparison	Australian smelt	Bony herring	Carp gudgeon complex	Common carp	Dwarf flat-headed gudgeon	Eastern gambusia	Flat-headed gudgeon	Golden perch	Goldfish	Murray cod	Murray-Darling rainbowfish	Oriental weatherloach	Silver perch	Unspecked hardyhead
2010_2011			0.402	0.747		0.493	**0.116**	0.664	0.580			0.213		0.309
2010_2012	**0.270**	0.474	0.379	0.656		0.145	0.731							0.569
2010_2013	0.320	0.660	0.562	0.442		**0.175**								0.725
2010_2014	**0.125**	0.360	0.469	0.569		0.246		0.717	0.643					
2010_2016		0.476	0.387	0.639		**0.152**	0.273				0.747	0.695		0.559
2010_2017		0.740	0.423	0.524	0.670	**0.157**	0.301							0.597
2010_2018		0.672	0.401	0.492	0.582	**0.150**	0.288							0.734
2010_2019		0.266	0.493	0.591		**0.150**	0.381	0.666		0.735				
2010_2020		0.619				0.223	**0.113**	0.433		0.535	0.331			0.703
2010_2021		0.523	0.695			**0.114**	0.774	0.331		0.436	0.225			0.610
2010_2022		0.697	0.533	0.620		**0.128**	0.349	0.245	0.442					0.761
2011_2012	**0.142**	0.705					0.495	0.603	0.385			0.272		
2011_2013	0.502						**0.281**	0.701	0.606			0.393		0.141

Year comparison	Australian smelt	Bony herring	Carp gudgeon complex	Common carp	Dwarf flat-headed gudgeon	Eastern gambusia	Flat-headed gudgeon	Golden perch	Goldfish	Murray cod	Murray-Darling rainbowfish	Oriental weatherloach	Silver perch	Unspecked hardyhead
2011_2014	0.435						0.314	0.618	0.708			0.528		**0.160**
2011_2016		0.663		**0.126**				0.243	0.355		0.749	0.462		0.567
2011_2017		0.630						0.527	0.416		0.719	0.290		**0.154**
2011_2018		0.696			0.603			0.506	0.399		0.776	0.286		**0.167**
2011_2019		0.592						0.502	0.406	0.740	0.673	0.287		**0.164**
2011_2020									0.701	**0.203**	0.590	0.338	0.471	
2011_2021		0.570					0.747		0.665	**0.208**	0.469	0.347		
2011_2022	0.670	0.386						0.748	0.581		0.487	0.281		**0.141**
2012_2013	0.704	0.408					0.291	0.524	0.619					**0.172**
2012_2014	0.692						0.518	0.288	0.406	0.754		0.621		**0.169**
2012_2016	**0.166**	0.589		0.282			0.388	0.675	0.757					0.493
2012_2017	**0.174**	0.313			0.740		0.558	0.656						0.444
2012_2018	**0.167**	0.616			0.522		0.416	0.708						0.306
2012_2019	0.314						0.435	0.547	0.713	0.633				**0.159**
2012_2020	0.460						0.770	0.676		**0.168**	0.318		0.575	
2012_2021	0.483						0.782	0.590	0.689	**0.177**	0.334			
2012_2022	0.372	0.702					0.603	**0.125**	0.491					0.249
2013_2014	0.709	0.393						**0.136**	0.270	0.615		0.511		
2013_2016	**0.151**	0.519		0.423			0.292				0.732	0.673		0.610
2013_2017	0.363	0.489			0.673		**0.185**	0.581						0.744
2013_2018	0.349	0.570		0.720	0.464		**0.182**	0.649						
2013_2019	0.351	0.692					**0.183**	0.471		0.582	0.761			
2013_2020	0.525						**0.144**	0.642		0.759	0.276			0.407
2013_2021	0.404							0.529	0.754	0.653	**0.140**			0.280
2013_2022	0.550	0.650					0.302	**0.153**	0.436		0.729			
2014_2016	**0.145**	0.720		0.393			0.276		0.476			0.558		0.639
2014_2017	0.306	0.455					**0.155**	0.543	0.628			0.702		

Year comparison	Australian smelt	Bony herring	Carp gudgeon complex	Common carp	Dwarf flat-headed gudgeon	Eastern gambusia	Flat-headed gudgeon	Golden perch	Goldfish	Murray cod	Murray-Darling rainbowfish	Oriental weatherloach	Silver perch	Unspecked hardyhead
2014_2018	0.322	0.682			0.422		**0.166**	0.512	0.601			0.763		
2014_2019	0.330						**0.170**	0.447	0.557	0.658		0.755		
2014_2020	0.542						**0.147**			0.658	0.419		0.756	0.285
2014_2021	0.438						0.671	0.763		0.566	0.301			**0.153**
2014_2022	0.270	0.575					**0.153**	0.382	0.487		0.734	0.658		
2016_2017		0.293		**0.155**	0.536			0.631				0.717		0.416
2016_2018		0.407		**0.145**	0.278		0.776	0.699				0.622		0.527
2016_2019		0.357		**0.144**	0.723		0.637	0.458		0.548				0.251
2016_2020				0.526				**0.145**		0.291	0.419		0.631	0.720
2016_2021				0.521				**0.144**	0.614	0.288	0.415			0.703
2016_2022	0.713	0.481		0.279				**0.158**	0.390		0.645			0.569
2017_2018		**0.176**		0.602	0.340			0.474			0.771			0.697
2017_2019		**0.219**			0.466		0.655	0.347		0.563				0.735
2017_2020		0.449						0.805		**0.171**	0.313		0.692	0.578
2017_2021		0.438						0.674	0.775	**0.167**	0.305			0.564
2017_2022	0.785	0.418			0.517			**0.148**	0.295		0.699			0.610
2018_2019		0.403		0.619	**0.148**		0.712	0.280		0.513				
2018_2020					0.777			0.581		0.304	**0.152**		0.689	0.454
2018_2021					0.745			0.563	0.660	0.294	**0.147**			0.440
2018_2022	0.584	0.505			0.400			**0.157**	0.291		0.663			0.741
2019_2020								0.753		0.633	0.363		0.500	**0.188**
2019_2021								0.727	0.482	0.611	0.352			**0.182**
2019_2022	0.477	0.380					0.738	0.283	**0.154**	0.653	0.566			
2020_2021									0.755				**0.383**	

Table 26 SIMPER analysis results showing the species most influential for a minimum of 70% of pairwise differences (and levels of their interaction) between macrohabitats based on presence data for all sites, all methods (electro-fishing and net methods separation available upon request). greatest species contribution to dissimilarities highlighted in bold.

Macrohabitat	Australian smelt	Bony herring	Common carp	Flat-headed gudgeon	Golden perch	Goldfish	Murray cod	Murray_Darling rainbowfish	Silver perch	Unspecked hardyhead
Anabranch_Riverine				0.667	0.370	0.570	**0.142**	0.259	0.744	0.473
Anabranch_Wetland	0.618504	0.215	0.773	**0.109**	0.522	0.420		0.696		0.318
Wetland_Riverine		0.705		0.544	0.351	0.629	0.245	**0.124**		0.455

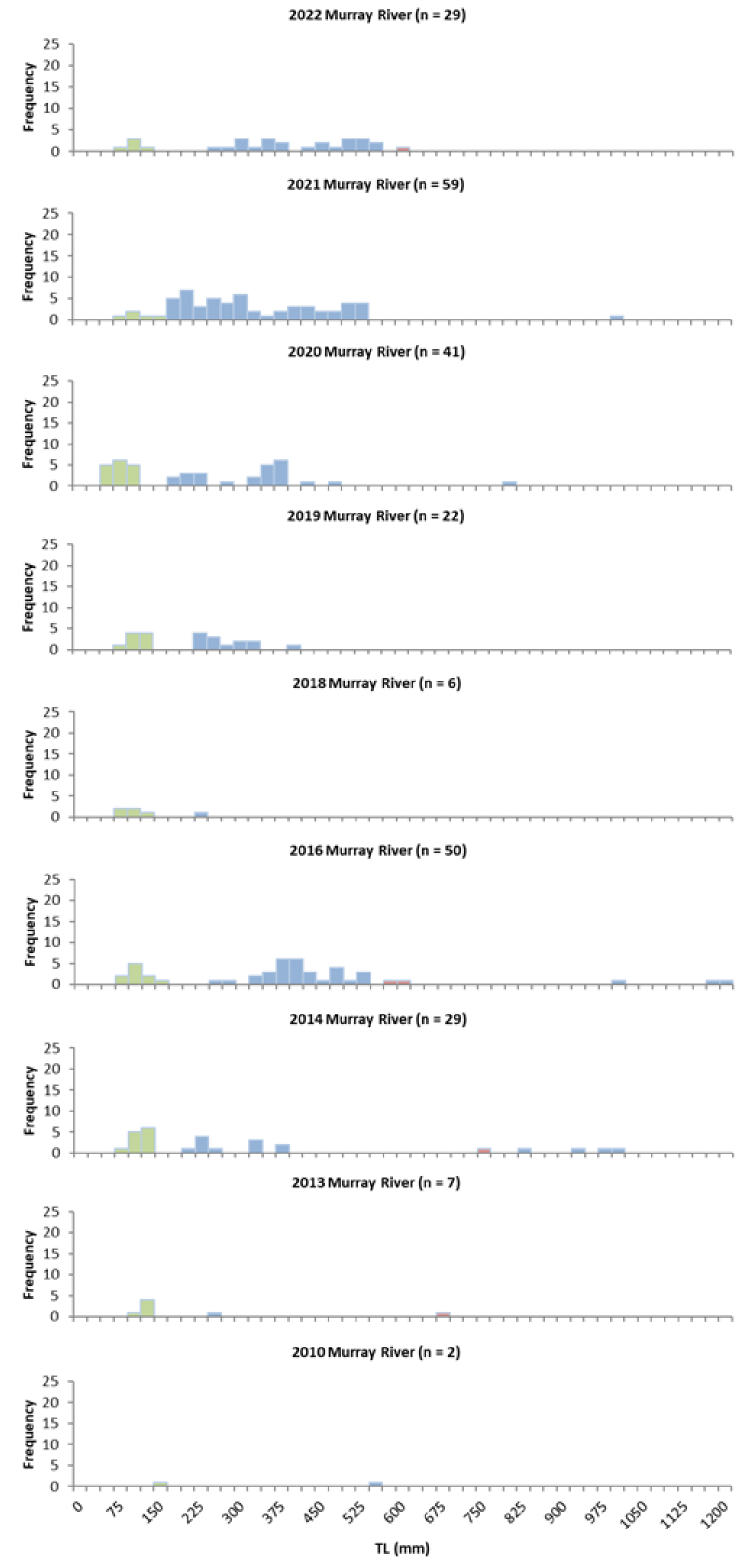


Figure 16 Unweighted length frequency histograms for Murray Cod captured during 2010–2022 TLM monitoring. Green shading indicates Young of Year (YOY). Red shading indicates fish of 'legal size' 550–750 mm under current Victorian and NSW recreational fishing regulations. Note that these unweighted histograms are provided to show the range of sizes captured across the icon site and not intended to provide an accurate representation of population(s) structure

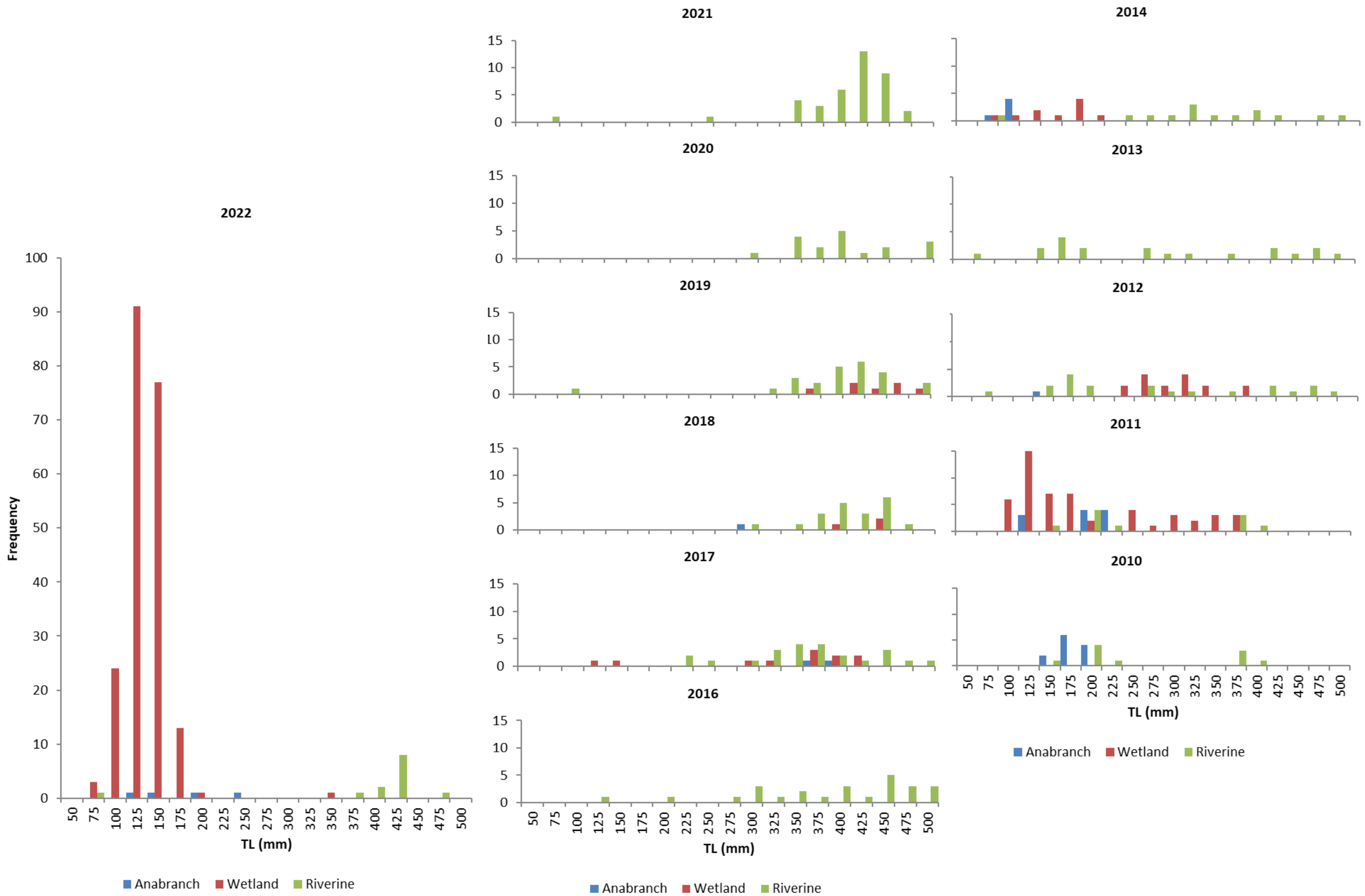


Figure 17 Unweighted length frequency histograms for Golden perch across Macrohabitats captured during 2010–2022 TLM monitoring. Note that these unweighted histograms are provided to show the range of sizes captured across the icon site and not intended to provide an accurate representation of population(s) structure.

