REPORT TYPE: Final

Hattah Lakes TLM Intervention Monitoring – Waterbird Food Resources

Influence of food resources on waterbird communities at the Hattah Lakes

Mallee CMA

August 2023

Artwork by Melissa Barton. This piece was commissioned by Alluvium and tells our story of caring for Country, through different forms of waterbodies, from creeklines to coastlines. The artwork depicts people linked by journey lines, sharing stories, understanding and learning to care for country and the waterways within.

Alluvium recognises and acknowledges the unique relationship and deep connection to Country shared by Aboriginal and Torres Strait Islander people, as First Peoples and Traditional Owners of Australia. We pay our respects to their Cultures, Country and Elders past and present.

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

This report has been prepared by EcoFutures Consulting Australia Pty Ltd for the Mallee CMA, in collaboration with Centre for Applied Water Science, University of Canberra under the contract titled CONTRACT 003072 – 2022/23 TLM INTERVENTION MONITORING – HATTAH LAKES WATERBIRD.

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Review:	Lacey Hofweber
Version:	2 – final
Date issued:	30 June 2023
Issued to:	Emma Collins, Mallee CMA
Cover image:	Top: Lake Kramen in February 2023. Photo courtesy of Mallee CMA Bottom: Eucalypt fence on Lake Hattah, March 2023. Ben Gawne

Acknowledgments

We would like to take this opportunity to acknowledge the contribution of a large number of people who contributed to this project including Clive Curson, Anthony Rizzuto, Gus Macdonald and Liam Tha who all assisted with field work. Heather McGinness, Ross Thompson, Alex Holmes and Dan Eyles who contributed to the planning. Aksheyta Gupta and Ying Quek who assisted with remote sensing. Finally, Emma Collins, David Wood and Greg Cranston from the Mallee CMA for their support and contributions.

Executive Summary

Hattah Lakes is one of six icons sites within The Living Murray initiative and has been listed as a significant wetland by Ramsar due to the range of environmental values that it supports. Among these values, Hattah Lakes supports 225 species of native birds (including 47 waterbirds). In recognition of Hattah Lake's importance to waterbirds, the Hattah Lakes Environmental Watering Plan includes the following overarching objectives for waterbirds:

- HL6 Create refugia for waterbirds in dry periods
- HL7 Create vital habitat – feeding habitat for waterbirds
- HL8 Colonial waterbird breeding

This study seeks to improve our understanding of the relationship between flow regime, food and waterbirds use of the Lakes. The study coincided with a large flood (2022-23) that provided a rare opportunity to document the outcomes of a large unregulated flow. The flood favoured fish production; a resource exploited by large numbers of piscivorous birds.

The flood provided a vast organic matter and nutrient subsidy, fuelling a food web that supported thousands of waterbirds. This highlights the importance of considering the Hattah Lakes as part of a larger system. It also provides important perspective for the management of the lakes and achievement of management objectives.

While the 2022-23 flood was a large, rare unregulated event, the outcomes provide an important contrast to the outcomes of managed delivery of environmental flows. In addition to the large organic carbon and nutrient subsidy, the flood created a floodplain mosaic comprised of a range of smaller wetlands that provided additional habitats for various waterbird species. The configuration of Hattah Lakes presents challenges in manipulating flow regimes within individual lakes, but finding ways to emulate the effects of the flood may increase and diversify waterbird foraging habitats.

The study also identified significant variation in food webs and productivity among the lakes, which may be influenced by factors such as lake depth, connectivity, and vegetation. The most productive lake was Lake Cantala which may have been due to its depth, the presence of inundated trees or the lake's proximity to the river.

The study sought to examine the influence of aquatic vegetation within the lakes; however, this vegetation did not develop even though there were strong responses from riparian and floodplain vegetation. Various factors, including water depth, water quality, and the presence of carp, may contribute to the lack of aquatic vegetation. The drying of the lakes between 2019 and 2021 did not appear to affect productivity or food webs. Connectivity between the lakes and the river was influenced by the 2022-23 flood, but its importance is considered secondary to productivity and habitat.

Carp are both an ongoing threat and a food source for waterbirds. Carp may contribute to the lack of aquatic vegetation; however, relationship remains uncertain. Developing a multi-pronged approach to carp management that includes optimising bird access, drying and connectivity management may help reduce carp numbers.

Figure 1. Native hens on patrol in Hattah Lakes NP, March 2023

Figure 2. Hoary-headed grebe at Lake Bulla, March 2023

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1 Introduction

The Living Murray (TLM) and Basin Plan are collaborative programs to protect and restore Australia's most significant rivers. At the core of these programs is the allocation of environmental flows to redress major changes in Basin river's flow regimes. 12 of the Hattah Lakes are listed as one of 16 Ramsar listed wetlands within the Murray-Darling Basin and Australia has committed to its protection through the Ramsar treaty, but also through migratory bird agreements (e.g. JAMBA (1981), ROKAMBA) (2007) and the Convention on Biological Diversity (1992). The Hattah Lakes have been subjected to reductions in the frequency, magnitude and duration of high flows that historically supported the extensive complex of lakes and floodplain ecosystems.

The reductions in inundation have been associated with reductions in the health of River red gum (*Eucalyptus camaldulensis) and* Black box (*Eucalyptus largiflorens*) communities and wetland habitat essential for waterbirds, fish, frogs, and turtles. Waterbird responses to delivery of environmental flows have been variable both among events and between lakes. Within the context of adaptive management, the Mallee CMA and Parks Victoria both recognise that this variability is associated with considerable uncertainty about the best way to manage the lakes and deliver environmental flows to meet waterbird requirements. In response the Mallee CMA seeks to improve understanding of waterbird food resources within the Hattah Lakes with the objective of improving waterbird responses to environmental flows.

1.1 Project Background and Objectives

Hattah Lakes is one of six icons sites within The Living Murray initiative which is one of Australia's most significant river restoration programs and has become key to achievement of Basin Plan objectives. The Hattah Lakes have been listed as a significant wetland by Ramsar due to the range of environmental values that it supports. Among these values, Hattah Lakes supports 225 species of native birds (including 47 waterbirds). In recognition of Hattah Lakes importance to waterbirds, the Hattah Lakes Environmental Water Management Plan has established a Vision for the Lakes:

Improve biodiversity values of Hattah Lakes, maintaining wetland and floodplain communities representative of those which would be expected under natural flow conditions. (Mallee CMA 2021).

And a supporting objective hierarchy, that includes:

- HL6 Create refugia for waterbirds in dry periods
- HL7 Create vital habitat – feeding habitat for waterbirds
- HL8 Colonial waterbird breeding

Several of the remaining six objectives are also relevant to this project (Table 1). Food availability is believed to be one of the key drivers of waterbird dynamics, and changes in the productivity and availability of food resources during different phases of the wetlands wet-dry cycle are important to sustaining diverse community of waterbirds at the lakes. The range of different species of bird found at the lakes suggest that plants, invertebrates, and fish may all represent important food resources at different times and understanding the ways that flow influences their abundance will be important to supporting waterbirds. Improving our understanding of the relationship between flow and food resources may improve environmental flow management and its outcomes.

It is noted that waterbird populations respond at a variety of scales to habitat and food availability. Understanding the ways that flows influence food availability at the lakes will also help managers manage flow during periods of flood and drought to ensure that Hattah Lakes provides the resources they need to complete their life cycles.

1.2 Hattah Lakes

The Hattah Lakes wetland system provides vital habitat for a wide array of waterbirds in a hydrologically connected mosaic of permanent and intermittent floodplain lakes (Butcher and Hale 2011). The lakes are considered internationally important under the Ramsar Convention, protecting this representative near-natural wetland system. This conservation status safeguards various threatened avian species, including Australian painted snipe (*Rostratula australis*), Australian bittern (*Botaurus poiciloptilus*), plants such as Winged peppercress (*Lepidium monoplocoides*) and fish such as Murray cod (*Maccullochella peelii*) and Flat-headed galaxias (*Galaxias rostratus*) (Butcher and Hale 2011). The Hattah Lake system provides habitat for 70 species of wetland birds, of which 34 have been recorded breeding within the site. In addition, the site supports several migratory species, notably waterbirds and fish, with 12 waterbirds listed as migratory under the EPBC Act as well as under international migratory species treaties. The site is also considered important for fish breeding.

The Ecological Character Descriptions (EDCs) for the Hattah Lakes wetland system identifies and describes the components, processes and services, benchmarked to the time of listing. Limits of Acceptable Change (LACs) developed for the critical components of the ecological character of the site include hydrology, lake-bed herbland vegetation, fish, and waterbirds (Butcher and Hale 2011). These ECDs describe the lakes as being dominated by one vegetation type: lake-bed herbland. The lakes traditionally progressed from wet to dry with composition changes of plant communities going from aquatic amphibious species to some terrestrial species on the edges in the wet phase, to being dominated by terrestrial species in the dry phase. The relative length of each inundation event and subsequent dry phase typically drives the vegetation community structure. Butcher and Hale (2011) describe the dominant functional feeding groups as ducks and herbivores, which is thought to reflect the dominant habitat of open water with submergent herbland vegetation.

The critical services provided by the Hattah Lakes system is the suite of near-natural permanent and intermittent freshwater floodplain lakes which provide a range of physical habitats in a variety of climatic conditions. The lakes are considered a drought refuge, especially deep, semi-permanent lakes such as Hattah and Mournpall which can provide critical feeding and breeding habitats for waterbirds in dryer years.

In 2013, the trigger point for flows into the Hattah Lakes system was lowered to capture flows of about 23,000 ml/d at Lock 15, however, in recent years, aside from 2016 and the 2022-23, flows have rarely made it into the lakes. At times water has entered the system but wasn't enough to make it to the lakes. At other times, flows were greater than 23,000 ml/day but pumping still occurred as the river flow was not enough to achieve target inundation level.

Environmental water is delivered to the Hattah Lakes wetland system to maintain a suite of environmental objectives (Table 1). Most of these objectives are ecologically linked to the maintenance of a diversity of freshwater ecosystem types (HL1).

Table 1: Environmental Water Management Plan Objectives for the Hattah Lakes Icon Site (MCMA 2021)

Objectives for the Hattah Lakes Icon Site	
HL1 Diversity of ecosystem type	Maintain a diversity of freshwater ecosystem types within the Hattah Lakes Icon Site, including semi-permanent lakes, persistent temporary wetlands, floodplain woodlands, shrublands, and episodic wetlands (Lake Kramen) by 2030.
HL2 Maintain ecological character of the Ramsar site	Maintain the ecological character of the Hattah-Kulkyne Lakes Ramsar site by 2030
HL3 Species richness and abundance of aquatic vegetation	Improve species richness and abundance of native water-dependent floodplain and wetland aquatic vegetation at the Hattah Lakes Icon Site by 2030.
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 the Hattah Lakes Icon Site by 2030.
HL5 Support threatened species	By 2030, improve biodiversity at Hattah Lakes by supporting the life-cycle of the EPBC-listed regent parrot (*Polytelis anthopeplus monarchoides*).
HL6 Create refugia for waterbirds in dry periods	Provide refugia to support the long-term survival and resilience of water-dependent populations of waterbirds, including during drought, to allow for subsequent re-colonisation beyond Hattah Lakes by 2030.
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.
HL8 Colonial waterbird breeding	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 times every 10 years.
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.

1.3 Purpose of this Report

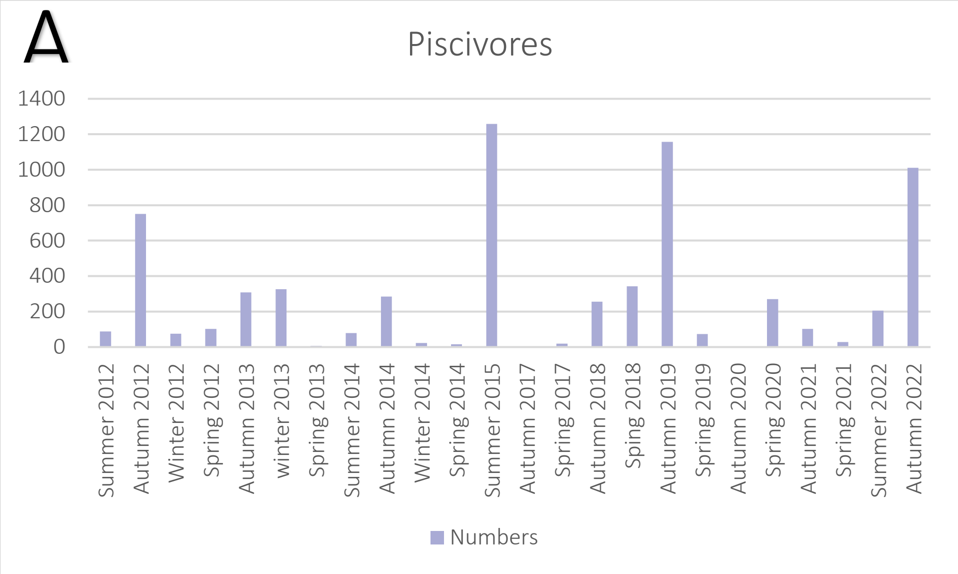
Our aim was to investigate the resources available to waterbirds across semi-permanent (Hattah, Mournpall), persistent temporary (Bitterang, Cantala) and episodic wetlands (Kramen) using a conceptual model to understand the critical factors in order to help manage the protection of ecosystems supporting feeding habitat for waterbirds (most notably waterfowl, herbivores and piscivores) at the Hattah Lakes icon site.

This report presents the results from field surveys in February and April 2023 and provides interpretation of their meaning and implications for future management of Hattah Lakes.

2 Context

2.1.1 Summary of previous data

The TLM Condition Monitoring program has collected data at Hattah Lakes going back to 2012 on waterbird numbers. The following graphs provide an overview of the waterbird community at the Lakes. Peaks in piscivorous waterbirds were observed in Autumn of 2012, 2019 and 2022 and Summer of 2015. Peaks of waders were observed in winter of 2013 and spring 2019 (Figure 3). Across all lakes at all times, the most common waterbird guilds are grebes (34%) and dabbling ducks (26%), followed by piscivores (14%) and coots and rails (12%) (Figure 4). Both of the most commonly observed species are piscivores, being Darters and Pelicans (Figure 5). Among the five lakes sampled in this study, proportions of feeding guilds have varied between being dominated by piscivores (Lake Cantala) to having a mix of ducks, waders, grebes and piscivores (Lake Bitterang) (Figure 6).



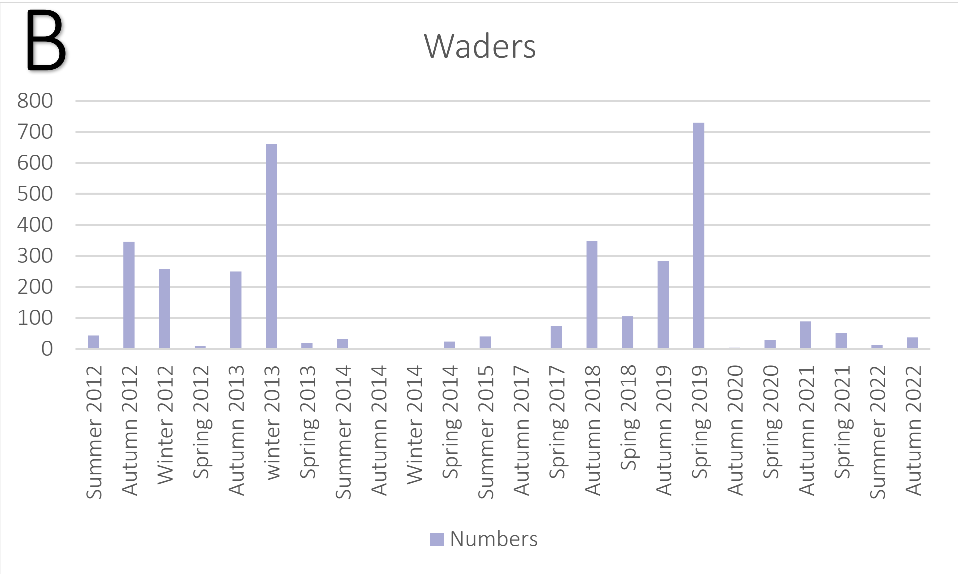


Figure 3. Bar graphs of observations of numbers of piscivorous (A) and wading (B) waterbirds across all Lakes. As expected, bird numbers fluctuate widely through time and it is unusual to get peaks in waders and piscivorous birds at the same time. Data sourced from Hattah Lakes TLM condition monitoring of, provided by the Mallee CMA and supported by the TLM program.

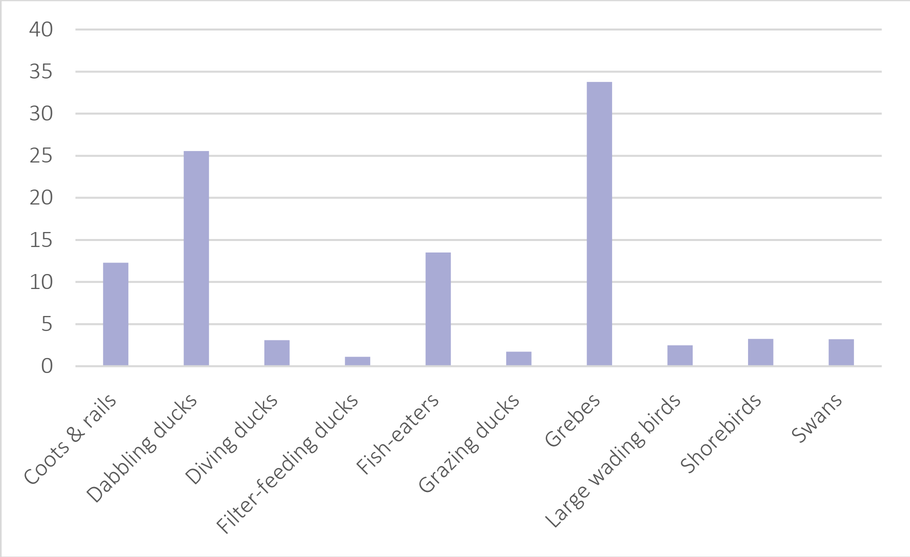


Figure 4. The proportion of different waterbird guilds across all the lakes since 2012. Data sourced from Hattah Lakes TLM condition monitoring of, provided by the Mallee CMA and supported by the TLM program.

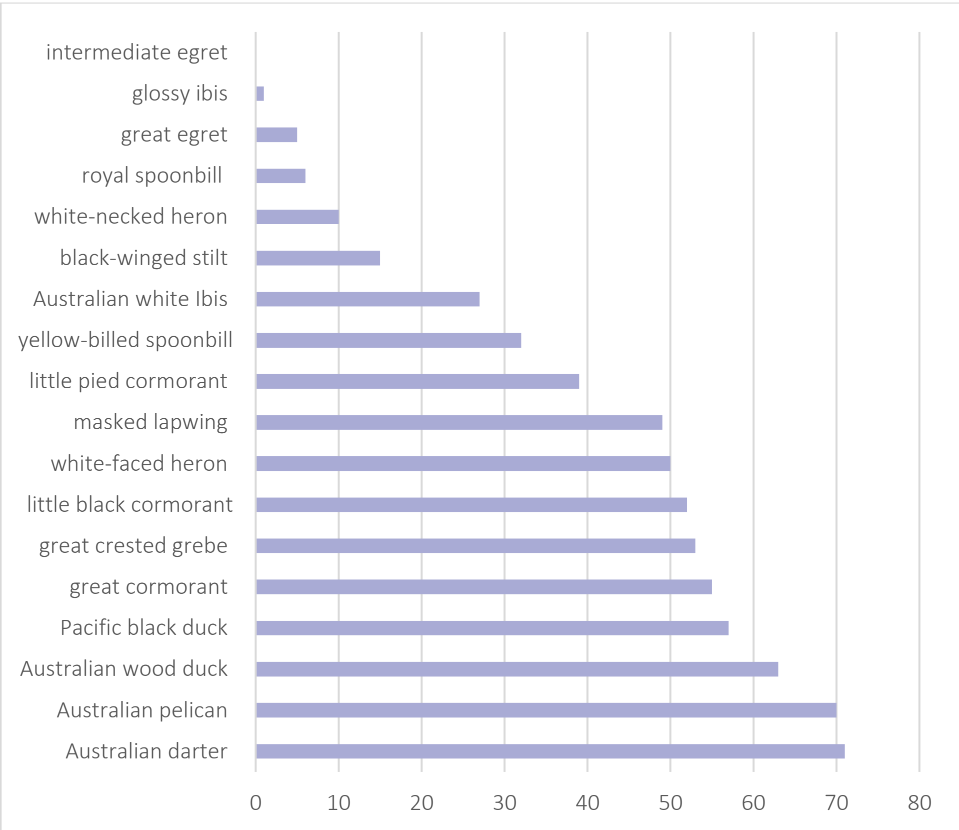


Figure 5. Number of observations of the most common species observed across all lakes since 2012, noting the mix of guilds. Data sourced from Hattah Lakes TLM condition monitoring of, provided by the Mallee CMA and supported by the TLM program.

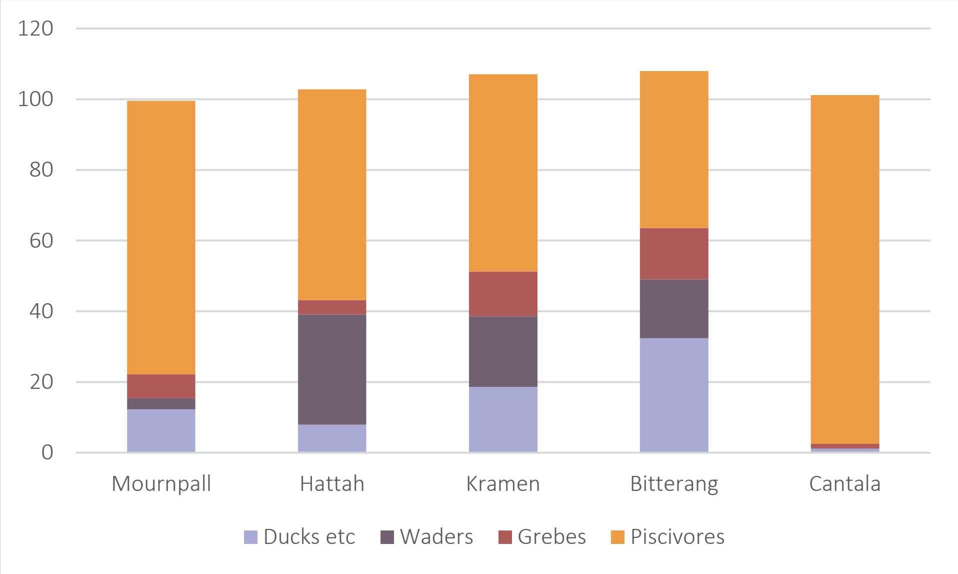


Figure 6. Stacked bar graph of the proportions of major guilds found at the five lakes sampled in this project since 2012. Data sourced from Hattah Lakes TLM condition monitoring of, provided by the Mallee CMA and supported by the TLM program.

2.1.2 Overview of waterbird ecology

Bird populations in inland wetlands in Australia are driven by continental and highly variable rainfall patterns, with wet and dry phases providing vastly different habitat availability for waterbirds (Wen et al. 2016). Waterbird distribution reflects dynamic resource availability across much of Australia's arid interior, responding rapidly both locally and over the broad scale to resources made available by variable flooding across the landscape (Kingsford et al. 2010). Patterns of resource availability for species and guilds is mostly pulsed, with historical flooding highly variable, differing in time and space across the continent (Kingsford et al. 2010). The reduction of available wetlands means that there is a risk of a bottleneck of resources, where no wetland or set of wetlands provides the resources required for certain species or guilds, and this is most likely when water availability overall is limited (Kingsford et al. 2010).

Each species of waterbird is defined by its resource requirements and its availability, although other, sometimes separate, life history requirements, such as breeding drive where waterbirds can be found across the available habitats. Waterbirds can be grouped by function (Table 2). Each waterbird species partitions its resources through its foraging strategy that is a combination of the bird's physical form (size, leg and bill length and shape, etc) and its behavioural adaptations (where it forages and what it prefers to eat).

Table 2: Functional (ecologically related) groups of the waterbird community based on broad resource use (habitat and feeding) adapted from Kingsford et al. 2010.

Waterbird Group	Food Resource	Movement behaviour	Habitat use	Breeding Strategy
Ducks (dabbling and diving ducks)	Generalist; plankton, small invertebrates, plant material	Nomadic	Shallow water, littoral zone	Solitary
Herbivores	Plant material	Nomadic or sedentary	Shallow water, littoral zone	Colonial or solitary
Piscivores	Fish	Nomadic or sedentary	Open and deeper (>1m) water	Colonial

Waterbird Group	Food Resource	Movement behaviour	Habitat use	Breeding Strategy
Large waders	Macroinvertebrates, fish, amphibians	Nomadic	Littoral zone	Colonial or solitary
Small waders	Small invertebrates, seeds	Migratory	Littoral zone and mudflats	Solitary

Wetlands across Australia dry and flood according to large-scale climatic drivers, and wetland birds exploit these conditions according to when food resource and foraging conditions are present, which coincides with different stages of flooding and drying. We have characterised the relationship between birds, their resources and the wetting and drying of lakes using conceptual models in 2.1.3.

Condition and Intervention Monitoring reports for the Hattah Lakes icon site provide background on the bird guilds presence and use of the lakes over the past few decades. The past few decades can be considered dry years overall, with only 2011, 2016 and 2022 providing insight into bird numbers during floods. Environmental watering was assessed over three years between 2014 – 2016 (Biosis 2016). Conditions at the lakes at the time involved a small watering event in November 2015, followed by declining water levels, including the drying out of many lakes. Over this period, the lakes provided habitat for a variety of waterbirds, including most of the functional groups. In drier years such as these, the lakes appear to have provided habitat for herbivores such as Australian wood duck (*Chenonetta jubata*), Pacific black duck (*Anas superciliosa*), Grey teal (*Anas gracilis*), and Black swan (*Cygnus atratus*). Conditions for (small) waders were provided as lakes dried out providing mudflats for species such as Sharp-tailed sandpiper (*Calidris acuminata*), Red-necked stint (*Calidris ruficollis*), Marsh sandpiper (T*ringa stagnatilis*), Red-kneed dotterel (*Erythrogonys cinctus),* and Red-capped plover (*Charadrius ruficapillus*). Conditions were present for some colonial nesting species, such as Great cormorants (*Phalacrocorax carbo),* and Australasian darters (*Anhinga novaehollandiae)* at Lakes Mournpall, Hattah, Arawak and Yellwell in June 2014 and Little pied cormorants (*Microcarbo melanoleucos)* were recorded nesting at Lake Yellwell in December 2015.

The 2021 TLM Hattah Lakes Condition Monitoring Report (Palmer et al. 2021) was only able to report on bird numbers at Lake Kramen, which was the only lake containing water during the spring and autumn waterbird surveys. All 11 common waterbirds set out to be recorded annually over the 2020-2030 period were recorded at Lake Kramen. A total of 2658 waterbirds, comprising 28 species, were recorded overall. The dabbling ducks were recorded in the highest numbers (34%) in spring and grebes represented 46.9% of birds in autumn, pointing to a change in resource availability across the seasons.

The 2022-23 spring and summer provided an opportunity to survey Hattah Lakes in a year of high water, providing insight into waterbird use in flood years. In particular, the opportunity to investigate environmental watering objectives such as vital feeding habitat for waterbirds (HL7), and colonial waterbird breeding (HL8). It is anticipated that as water draws down over the next year or two, the resources provided by Hattah Lakes will evolve, allowing the opportunity to investigate the environmental watering objective of the lakes providing refuge for waterbirds during dry years.

2.1.3 Conceptual models

There are several ways of thinking about the relationship between flow, food, and waterbirds. The Mallee CMA and project team focused on three conceptual models, each of which emphasises different ways of considering the ways in which flow may influence waterbirds and their food resources.

The Habitat model (Figure 7) acknowledges that flow directly influences all water dependent species through the provision of suitable hydraulic conditions (depth, current speed, hydroperiod), but then also has a range of indirect effects through flows influence on non-woody vegetation, living and dead trees all of which provide important habitat for other biota (fish, birds).

The Food-Web model (Figure 8) identifies the dietary relationships among different groups of wetland biota. The base of the food web is comprised of terrestrial and aquatic vegetation, algae that are processed via a range of different pathways to provide food for waterbirds and large predatory fish.

The Inundation model (Figure 9) illustrates a temporal sequence that seeks to illustrate the ways that wetlands change as they progress through inundation and drying. Different phases are associated with different habitat and food resources for different species.

Habitat model

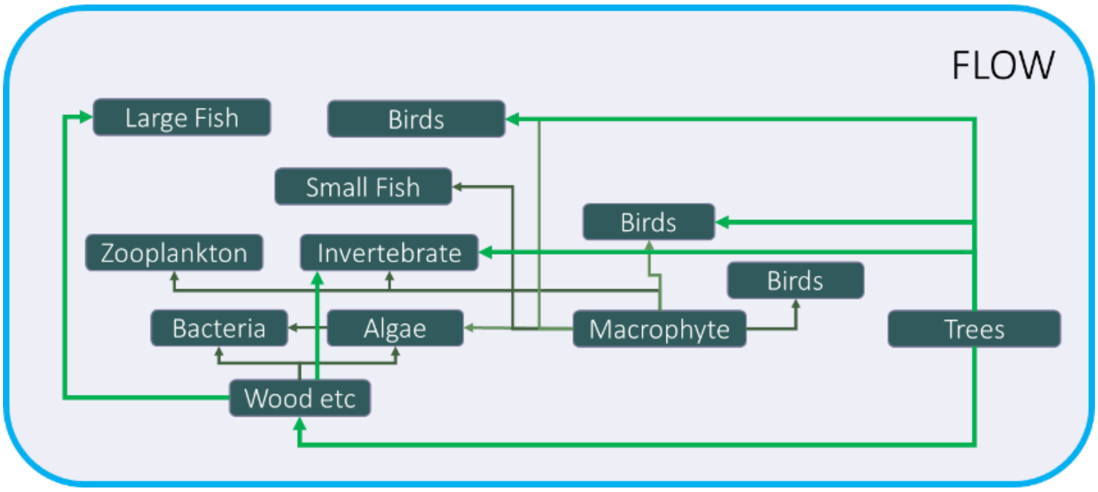


Figure 7. A representation of the influences on habitat availability with flow providing a foundation that influences vegetation (trees & macrophytes) that then contribute to habitat for zooplankton, invertebrates, fish and birds.

Food Web

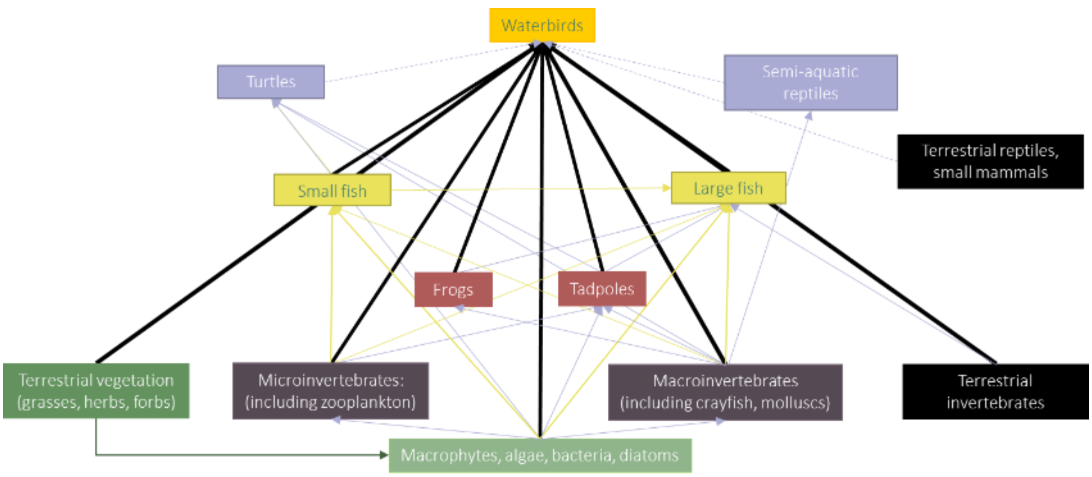


Figure 8: A wetland food-web model illustrating the major predator-prey relationships in a floodplain wetland. The food web identifies several endpoints for macrophyte, algal and bacterial organic matter, including fish, turtles, and birds. This food web based on that published in the supplementary material to: MCGINNESS, H. M., PATON, A., GAWNE, B., KING, A. J., KOPF, R. K., MAC NALLY, R. & MCINERNEY, P. J. 2020. Effects of fish kills on fish consumers and other water-dependent fauna: exploring the potential effect of mass mortality of carp in Australia. Marine and Freshwater Research, 71, 156-169.

Inundation

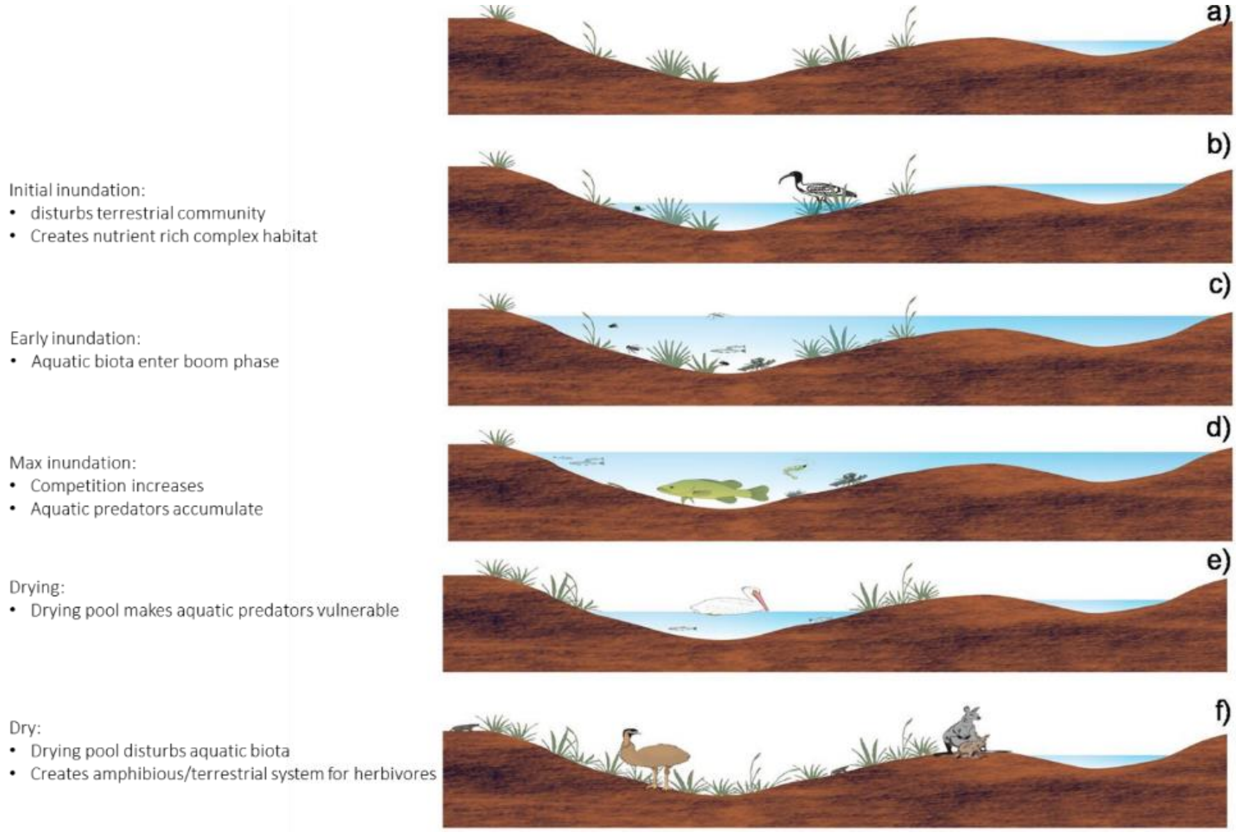


Figure 9: A temporal model of wetland inundation and drying, illustrating the changing relationships and food webs as the water levels increase and then decline.

Hypotheses

In considering the three conceptual models, the Mallee CMA and project team identified a range of hypotheses that were believed to explain some of the patterns of waterbird response at the Hattah Lakes.

1. Habitat availability
    - Lake Kramen appears to be an outlier with abundant aquatic vegetation. The only other lake with noticeable aquatic vegetation is Lake Wallawalla with all other lakes having mostly amphibious vegetation around the margins. Aquatic vegetation is important for waterbirds.
    - Vegetation also provides important habitat for animals which provide food for a range of species (e.g., egret, pelican).
2. Food web differences
    - Differences in the characteristics of the inundation in terms of time with deep water habitat and the overall duration the lake is inundated are expected to influence patterns of productivity and the movement of organic matter through the food web.
    - Vegetation is an important food source for some birds including swans, coots, and some ducks.
3. Effects of initial inundation
    - The characteristics of early inundation may influence subsequent habitat and food resources. Expect differences between wet, dry, and vegetated versus bare sediment.
4. Connectivity
    - May influence movement of some biota into and out of lakes, particularly large fish.

These hypotheses informed the design of the field sampling and the subsequent interpretation of the results.

2.2 Site descriptions

2.2.1 Overall

Five lakes were chosen to assess waterbird food resources at the Hattah Lakes, aiming to include the three wetland types common to this floodplain system (Semi-Permanent Wetland (Hattah and Mournpall), Persistent Temporary Wetland (Bitterang and Cantala) and Episodic wetland (Kramen)). The key lake attributes are summarised in Table 3.

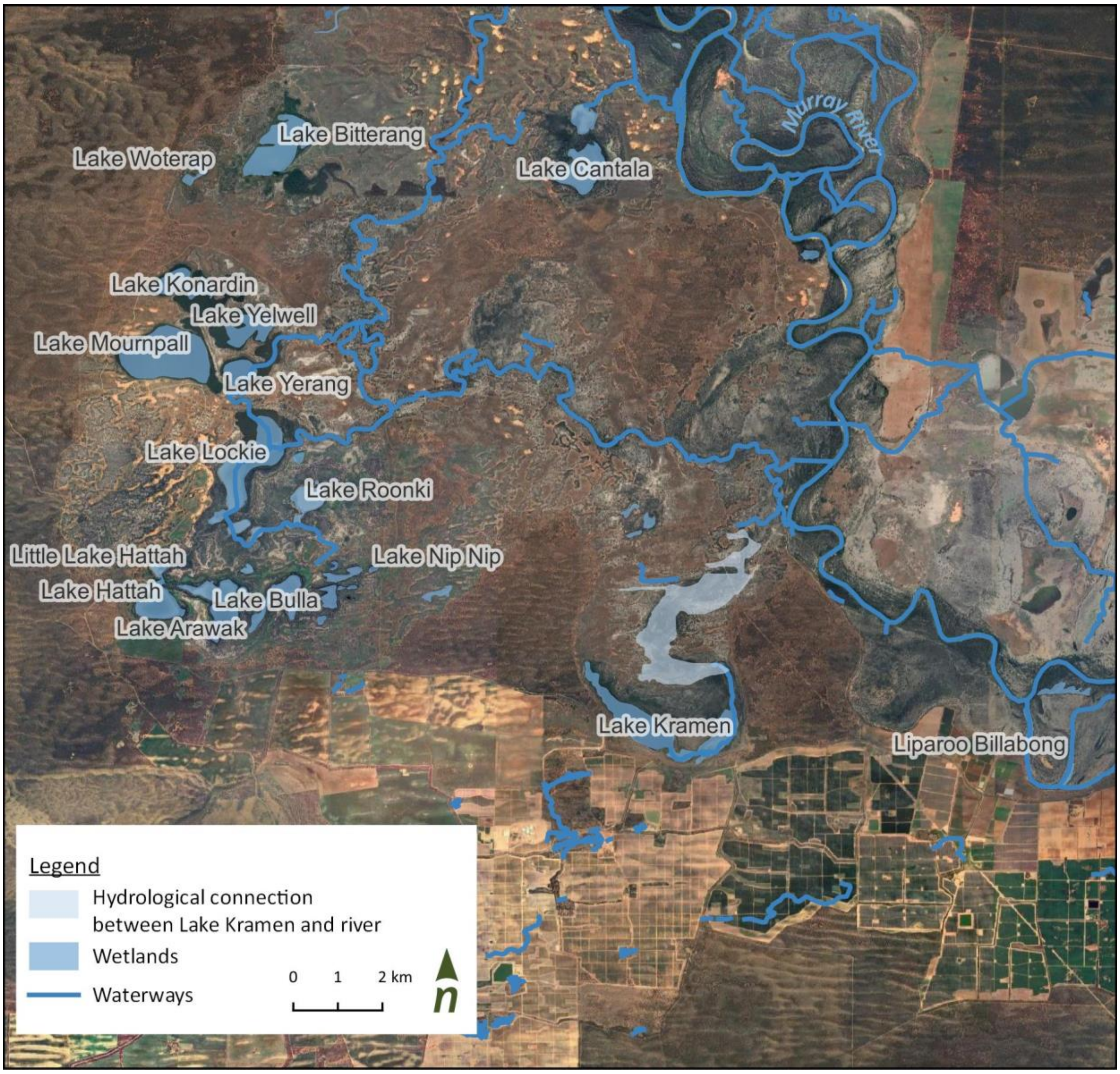


Figure 10. Map of Hattah Lakes and the connections between the lakes and the river.

Table 4, and in the following sections. All five lakes have lakebed herbland at the lowest elevations, and Riverine Chenopod Woodland at higher floodplain elevations, with either Intermittent Swampy Woodland or Riverine Grassy Woodlands and Forests fringing the lakebed.

Table 3 Lakes sampled in the study (Butcher and Hale 2011). A map of the lakes and their connections is provided in Figure 10.

Lake	Type	Depth (m)	Wet:Dry (y:y)	Area (Ha)	Connection
Hattah	SPW	3.1	16:1	61	Chalka Creek
Bitterang	PTW	2.4	8:8	73	Chalka Creek
Kramen	Episodic	2.9	8:8	124	Kramen Creek and riparian floodplain
Mournpall	SPW	3.2	15:2	195	Chalka Creek
Cantala	PTW	2.2	5:10	101	Cantala Creek

Table 4 Wetland EVC descriptions (DSE Benchmarks)

Wetland EVC number	Wetland EVC name	EVC description
EVC 107	Freshwater Wetland (Lake Bed Herbland)	Herbland or shrubland to 0.5 m tall dominated by species adapted to drying mud within lake beds. Some evade periods of prolonged inundation as seed, others as dormant tuber-like rootstocks. Occupies drying deep-cracking mud of lakes on floodplains. Floods are intermittent but water may be retained for several seasons leading to active growth at the 'drying mud stage'.
EVC 813	Intermittent Swampy Woodland	Eucalypt woodland to 15 m tall with a variously shrubby and rhizomatous sedgy - turf grass understorey, at best development dominated by flood stimulated species in association with flora tolerant of inundation. Flooding is unreliable but extensive when it happens. Occupies low elevation areas on river terraces (mostly at the rear of point-bar deposits or adjacent to major floodways) and lacustrine verges (where sometimes localised to narrow transitional bands). Soils often have a shallow sand layer over heavy and frequently slightly brackish soils.
EVC 295	Riverine Grassy Woodland or Forests	Occurs on the floodplain of major rivers, in a slightly elevated position where floods are rare, on deposited silts and sands, forming fertile alluvial soils. River Red Gum woodland to 20 m tall with a ground layer dominated by graminoids and sometimes lightly shrubby or with chenopod shrubs.

Wetland EVC number	Wetland EVC name	EVC description
EVC 103	Riverine Chenopod Woodland (syn. Black Box Chenopod Woodland)	Eucalypt woodland to 15 m tall with a diverse shrubby and grassy understorey occurring on most elevated riverine terraces. Confined to heavy clay soils on higher level terraces within or on the margins of riverine floodplains (or former floodplains), naturally subject to only extremely infrequent incidental shallow flooding from major events if at all flooded.

2.2.2 Bitterang

At Lake Bitterang, three wetland or floodplain EVCs are mapped (NatureKit) (from lower to higher elevation):

- Freshwater wetland (Lake-bed Herbland) – EVC 107
- Riverine Grassy Woodland or Forests – EVC 295
- Riverine Chenopod Woodland (syn. Black Box Chenopod Woodland) – EVC 103

2.2.3 Cantala

Lake Cantala has the following three main wetland/floodplain EVCs are mapped (NatureKit) (from lower to higher elevation):

- Freshwater wetland (Lake-bed Herbland) – EVC 107
- Riverine Grassy Woodland or Forests – EVC 295
- Riverine Chenopod Woodland (syn. Black Box Chenopod Woodland) – EVC 103

2.2.4 Hattah

Lake Hattah has the following three wetland or floodplain EVCs mapped (from lower to higher elevation):

- Freshwater wetland (Lake-bed Herbland) – EVC 107
- Intermittent Swampy Woodland – EVC 813
- Riverine Chenopod Woodland (syn. Black Box Chenopod Woodland) – EVC 103

2.2.5 Kramen

Lake Kramen has the following mapped wetland or floodplain EVCs from lower to higher elevation):

- Freshwater wetland (Lake-Bed Herbland) – EVC 107
- Intermittent Swampy Woodland – EVC 813
- Riverine Chenopod Woodland (syn. Black Box Chenopod Woodland) – EVC 103

2.2.6 Mournpall

Lake Mournpall has the following mapped wetland or floodplain EVCs (from lower to higher elevation):

- Freshwater wetland (Lake-Bed Herbland) – EVC 107
- Intermittent Swampy Woodland – EVC 813
- Riverine Chenopod Woodland (syn. Black Box Chenopod Woodland) – EVC 103

3 Methods

Two littoral sites were consistently assessed at each lake for food web and vegetation sampling, with subsequent visits targeting the same locations whenever feasible (Figure 9). Notably, at Lake Cantala, spring and autumn assessments involved different sites due to access limitations, resulting in a single site evaluation during summer and the assessment of sites (both different than the summer site) at the south-eastern corner of the lake in autumn, prompted by unsafe blue-green algae levels at the initial site.

We used a combination of survey methods including at least one point count (using a spotting scope and binoculars), perimeter walks and canoe searches, recording the time taken to survey the lakes and the number of people doing the surveying. Despite the thorough search effort of each lake, bird counts are likely to be underestimates in some cases, however, the method will have revealed most bird species and provided good estimates of their numbers (for further details of method see Section 3.6).

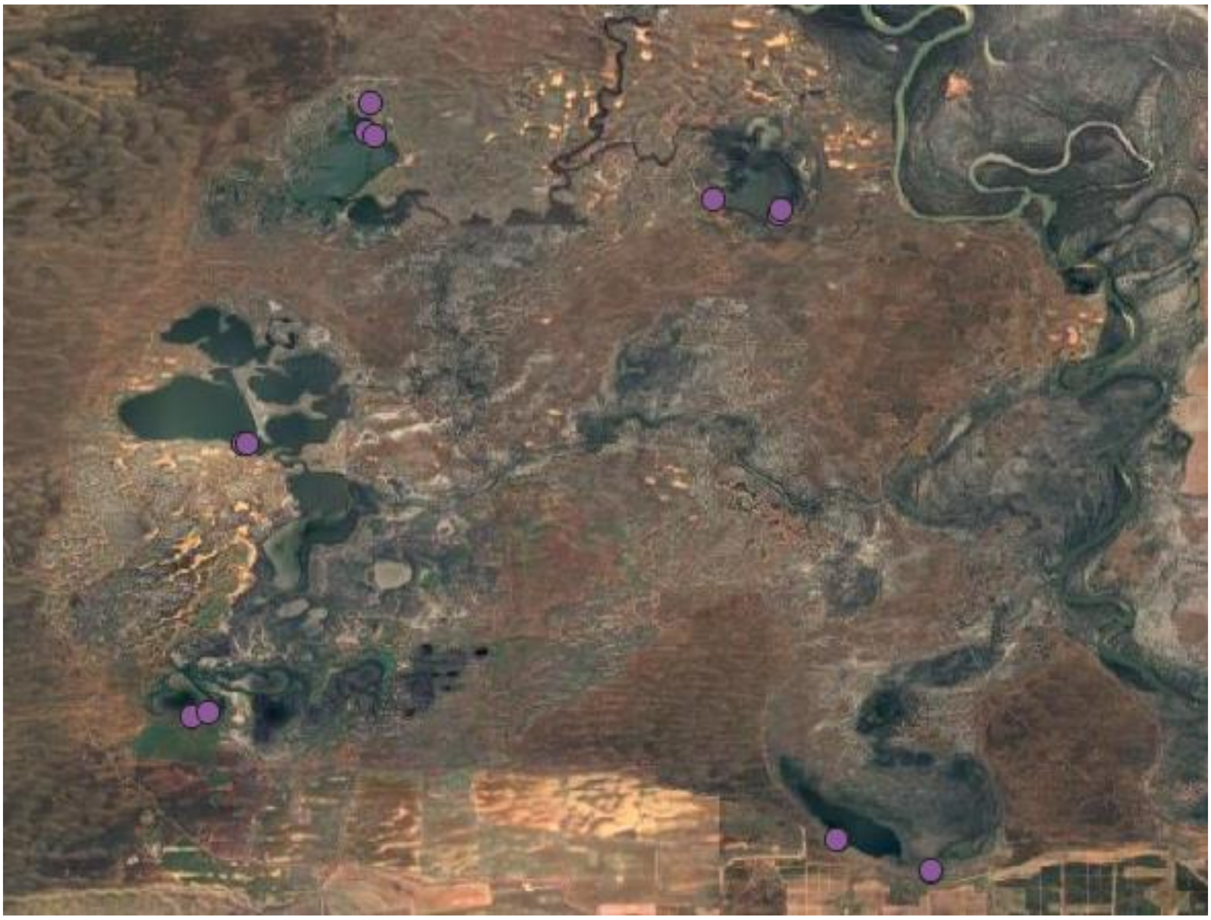


Figure 11: Littoral sampling sites (food-web and vegetation sampling), and the opportunistic floodplain depression site just north of Lake Bitterang.

3.1 Inundation

Images of flood extent for each of the lakes for sampling dates were reviewed using Sentinel 2A imagery for the two nearest available dates (20th Feb 2023, 25th April 2023) to run the Modified Normalized Difference Water Index (MNDWI) for all the five Lakes, using Sentinel 2 and AusMap data.

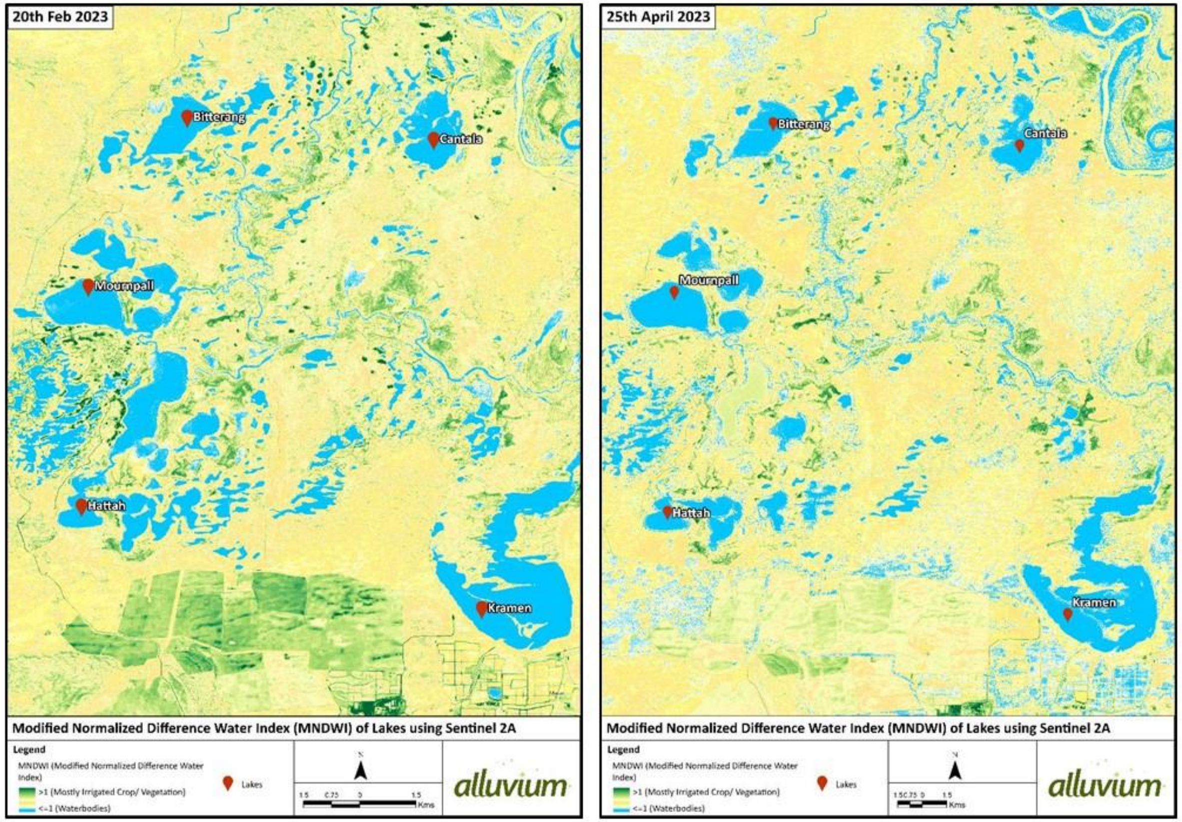


Figure 12. Inundation of the Hattah Lakes in summer (February) and autumn (April) using Modified Normalized Difference Water Index (MNDWI)

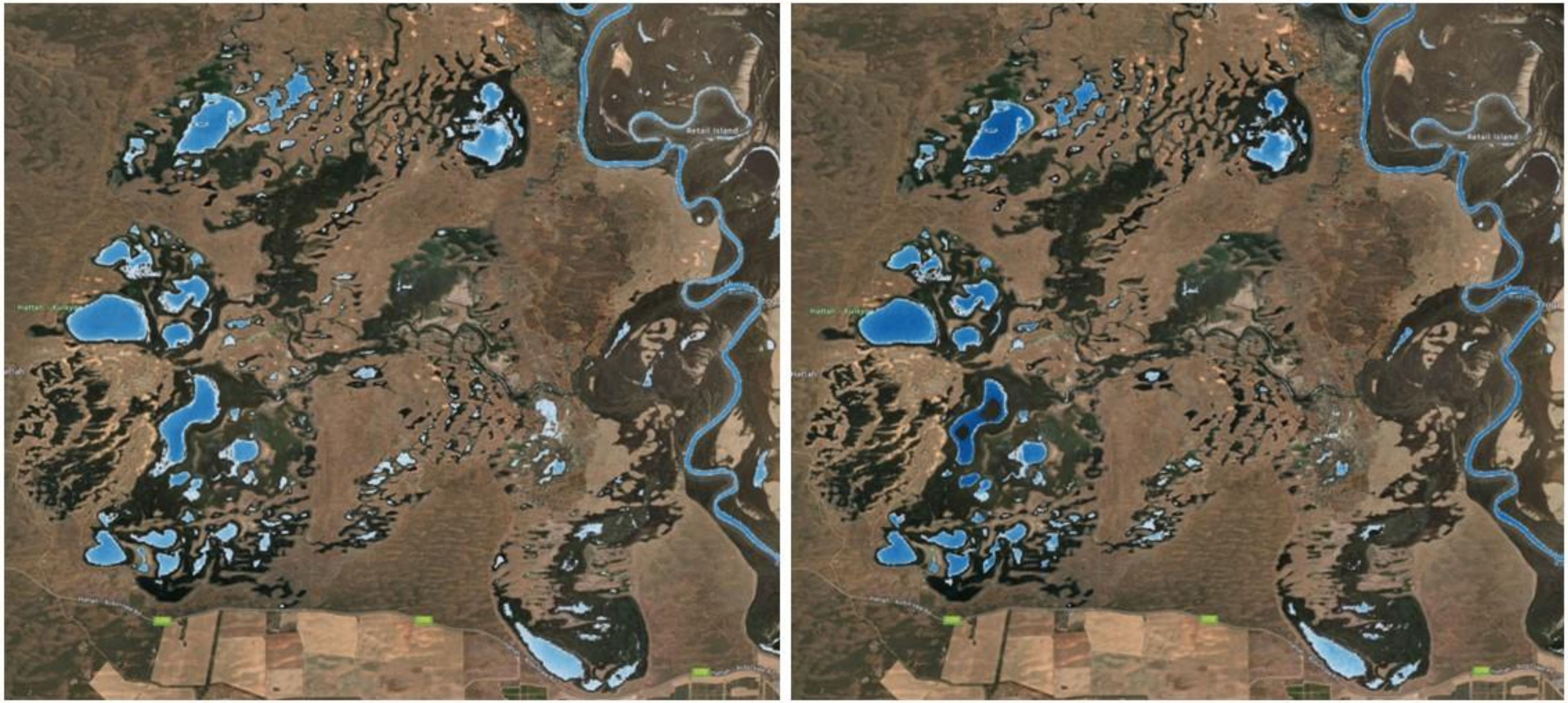


Figure 13: Hattah Lakes MNDWI from National Map for 22 Feb 2023 (left) and 23 April 2023 (right)

3.2 Water quality and algae

Basal energy sources are fundamental to the functioning of a food web, providing the initial energy input that sustains the entire ecosystem. The two major sources in aquatic ecosystem are from algal and water plants growing within water, and terrestrial organic matter, derived from decaying leaves or the inundation of vegetation and sediment. The amount of production that an ecosystem can sustain at higher trophic levels (birds and fish) is generally dependent on the quantity and quality of these basal resources (Hitchcock et. al. 2016; Johnston et. al. 2023). Samples for dissolved organic carbon (DOC) were collected in 200 ml prerinsed PET bottles, filtered to 0.45 µm using PES syringe filters and immediately frozen for transport to laboratory. Duplicate samples were analysed in the laboratory by the High Temperature Combustion Method (APHA 2005). Samples for chlorophyll *a* were taken as a proxy for algal biomass. Duplicate samples for planktonic chlorophyll a were determined by filtering 100 to 200 ml of water onto GF/C filters. Filters were frozen until subsequent determination by Standard Methods (APHA 2005) using the grinding technique and acetone as a solute with correction for phaeophytin. Benthic chlorophyll *a* was measured using the BenthoTorch™ fluorescence probe (bbe Moldaenke, Schwentinental, Germany) and taking 20 measurements on tree or rock surfaces 10-30 cm under the water surface. Chlorophyll *a* values were converted to carbon, where the ratio of carbon and chlorophyll *a* was 40:1 and subsequently converted to wet weight where carbon at 1:10 (Dewi et. al. 2018).

3.3 Vegetation and habitat characteristics

Vegetation assessment aimed to inform understanding of waterbird food resources and complement aquatic food web assessment, with particular focus on the littoral zone. Although the original intention was to take 1x1 m area biomass samples of aquatic vegetation for food web assessment, this proved impractical due to the lack of aquatic vegetation in the littoral zone. Vegetation assessment was therefore primarily qualitative and used to characterise the sites.

Quadrats were used to capture sufficient descriptive floristic and structural information to characterise the aquatic littoral zone habitat (100 m2, usually 10x10 m quadrats), with a high-level description of adjacent riparian vegetation also recorded (in an approximate 20x20 m plot). Quadrats were located adjacent to the waterline to represent the vegetation at each site on the two field visits. This resulted in the exact location of quadrats shifting slightly between the two field visits at most lakes as water levels had lowered somewhat. The location of the quadrats was determined by where sampling of littoral invertebrates, fish and zooplankton were being sampled, which meant that they were in similar but not necessarily the same location in summer and autumn.

The following information was recorded at each vegetation site:

- GPS coordinates at a quadrat corner; left and right bearings (degrees); quadrat dimensions (usually 10x10 m)
- Photographs of littoral quadrat and adjacent riparian
- Approximate % cover of vegetation in overstorey, midstory and ground-layer
- Plant species observed.
- Approximate water depth
- Notes on substrate where visible, and any disturbance e.g., presence of carp
- High level description of riparian vegetation including characteristic species.

High level, qualitative habitat characterisation of each of the lakes was completed using field observations.

3.4 Invertebrates

Invertebrates play critical roles in energy flow and ecosystem dynamics in aquatic food webs. Zooplankton, consisting of tiny organisms like copepods and rotifers, act as primary consumers, feeding on basal resources such as algae and transferring energy to higher trophic levels. Macroinvertebrates, which include aquatic insects and their larvae, have varied diets including organic matter, algae, and smaller invertebrates, and may be consumed by a range of birds and fish. Decapods are typically larger invertebrates such as shrimps and prawn and often form a crucial part of higher trophic animal diets. Zooplankton samples were taken by filtering 100 L of water through a 35 µm plankton net. Samples were preserved in preserved 50% ethanol. Zooplankton density (individuals m^3) was estimated by counting consecutive aliquots until 100 specimens of each taxon were counted or until 50% of the homogenized sample was counted. Zooplankton were grouped in microzooplankton (< 250 µm) and mesozooplankton (> 250 µm). Zooplankton abundance was converted to biomass using conversion factors from previous work (Hitchcock unpub.) for major groups; nauplii (0.0075 µg/ind.), ciliates (0.003 µg/ind.), rotifers (0.0055 µg/ind.), ostracods (3 µg/ind.), small Cladocera (< 500 um) (1.9 µg/ind.), large Cladocera (>500 um) (4.2 µg/ind.), calanoid copepods (33 µg/ind.), cyclopoid copepods (8.8 µg/ind.) , harpacticoida copepods (6 µg/ind.) , and tartigrades (3 µg/ind.). Samples for macroinvertebrates and decapods were taken using duplicate sweep samples of 1 m2 with a 250 µm dip net. All macroinvertebrate samples were removed and preserved in ethanol for identification in the laboratory. Macroinvertebrate abundance was converted to biomass using the following conversion factors: Corixidae (15 mg/ind.), Chironomid (0. 1 mg/ind.), small bivalves (< 1 cm) (0.25 mg/ind.), Culucidae (0.1 mg/ind.). All decapods were picked and weighed alive in the field.

3.5 Fish

Small-bodied and juvenile fish are key components of aquatic food webs, contributing to the overall functioning and biodiversity of aquatic ecosystems. They serve as important prey items for larger predators including piscivore birds. Their abundance and availability as a food source support the growth and survival of higher trophic level organisms. Fish were sampled via seine net hauls. At each lake, three separate locations, 500 m apart, were selected, and at each at least five separate hauls of 5 m were completed (minimum of 75 m in total at each lake). Due to the in-lake debris, a 3 m long seine net (1.5 m high) was used with a mesh size of 3 mm. Fish were placed in a holding bucket, identified, and enumerated and the first 20 individuals of each species at a lake were weighed and length measured, and returned to the water.

3.6 Waterbirds

Our aim for this investigation was to survey birds at selected lakes in the Hattah system at the same time as sampling the resources available to them. We designed the bird survey method to record a census of all waterbirds using the lakes at the time of resource sampling. We used a combination of survey methods including at least one point count (using a spotting scope and binoculars), perimeter walks and canoe searches, recording the time taken to survey the lakes and the number of people doing the surveying. Despite the thorough search effort of each lake, bird counts are likely to be underestimates in some cases, however, the method will have revealed most bird species and provided good estimates of their numbers.

Recorded at each site:

1. Start Time/End Time
2. Weather Observations (sky, wind, rain, temperature estimation)
3. Other relevant info (e.g., disturbance by members of the public, etc)
4. Observers
5. GPS Waypoint of spotting scope site(s), Start and End times for observing from fixed point.
6. List of Bird Species Observed, number of each species.
7. Any breeding evidence (nests, recently fledged young, etc)
8. Any relevant behavioural observations (feeding, habitat use, etc)

We have used Kingsford et al. (2010) resource guilds to categorise the waterbirds. We have also discussed the bird resource guild habitat use in the context of what was available to the birds at Hattah in February and April 2023.

4 Results

4.1 Indicators

4.1.1 Inundation

Results of the MNDWI for all the five Lakes are shown below in (Figure 11 and Figure 13). This corresponds with field observations, that water levels dropped between the two time points, with the most apparent difference being in a contraction of inundated floodplain areas surrounding the lakes.

4.1.2 Water quality and algae

Dissolved organic carbon (DOC) biomass was higher in summer than autumn at all lakes and did not vary greatly between lakes. Phytoplankton biomass varied between lakes and seasons. Overall phytoplankton biomass was very high and can be considered highly eutrophic. The highest biomass was recorded at Lake Hattah in summer and Lake Cantala in both summer and autumn. We did not enumerate phytoplankton biomass directly, but from microscopy performed for zooplankton analysis it was clear that the phytoplankton in Lakes Hattah, Mournpall, Bitterang and Cantala was overwhelmingly dominated by the cyanobacteria *Microcyctis* sp. In contrast, Lake Kramen had lower phytoplankton biomass than the other lakes and the community observed appeared more dominated by the diatom *Cyclotella* sp. Benthic algal biomass was also high, with higher biomass recorded in autumn for Lakes Hattah, Cantala and Kramen compared to summer, whilst biomass at Lakes Mournpall and Bitterang remained consistent between seasons. Benthic algal biomass appeared to be inversely related to phytoplankton biomass, suggesting changes in available light due to shading by higher densities of phytoplankton may be a potential influencing factor. The benthic algal biomass presented here is that recorded surfaces; the amount at a particular site will also depend on the available surfaces (for example trees, debris etc.) for growth.

Figure 14. Blue-green algae at (Left) Lake Cantala and (Right) Hattah Lake, April 2023.

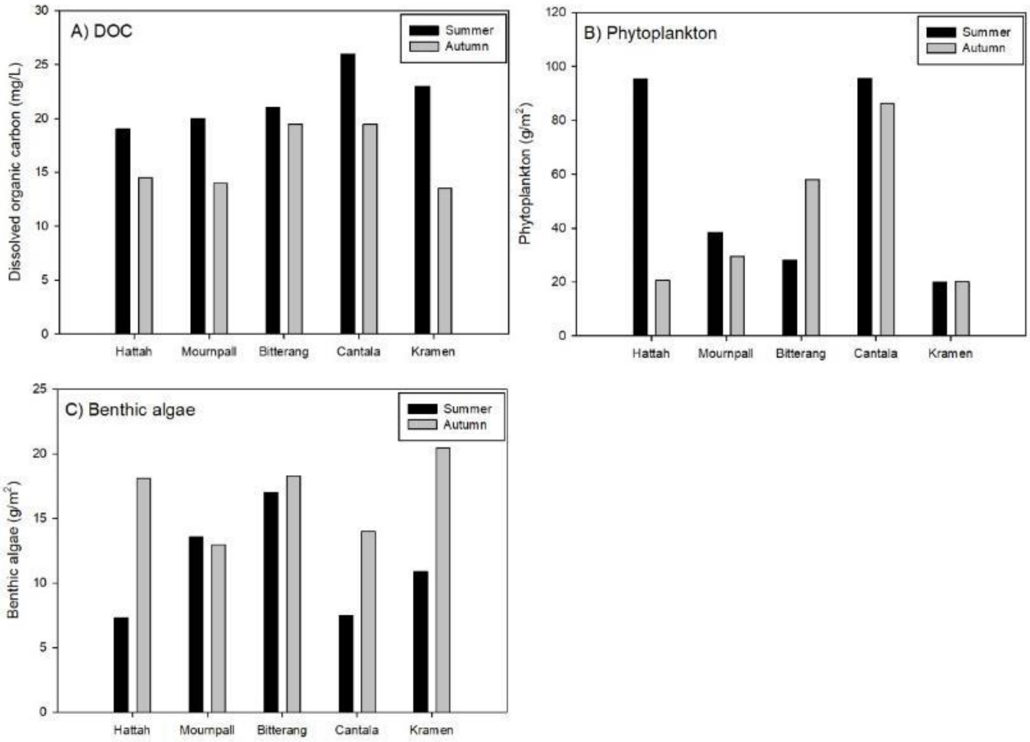


Figure 15: Organic carbon and algal results for Hattah Lakes Summer and Autumn 2023. A) Dissolved organic carbon, B) Phytoplankton, and C) Benthic algae

4.1.3 Vegetation and habitat characteristics

Vegetation at the sites responded to flooding, with the recent maximum flooding extent clearly visible in the riparian vegetation in the lush ground layer vegetation in the fringing woodland and dead terrestrial shrubs (e.g., Slender hop-bush (*Dodonaea viscosa ssp. angustissima))* (Figure 16). Key observations from the vegetation and habitat characterisation include:

- At the time of assessment, mature fringing woodland was partly inundated at Lakes Kramen, Bitterang, Cantala but not Lakes Hattah and Mournpall.
- Dense young Eucalypt 'fences' were generally inundated on both occasions.
- Water levels dropped from Feb-April by ~0.5-1m.
- Aquatic vegetation was very limited (e.g.) (usually only amphibious fringing species, e.g. Spiny flat-sedge (*Cyperus gymnocaulos)* recovering after drawdown), although some aquatic vegetation appeared to be developing at Lake Kramen further from shore as shown by grazing Black swans (i.e. not at near-shore littoral sampling sites).
- Adjacent riparian vegetation included Eucalypt seedlings and diverse understorey herbs across all sites, mudflats observed at some locations.

Habitat features and vegetation characteristics at each of the five lakes is summarised in (Table 5). Photo points and location of each of the sampling sites for the two field visits is provided in Appendix A.

Figure 16: Floodplain vegetation showing the clear demarcation of flood extent at Lake Cantala

Figure 17: An example of a littoral sampling site (Lake Bitterang) with a typical lack of truly aquatic vegetation

Table 5 Lake vegetation and habitat characteristics

Lake	Inundated fringing woodland (dominant species)	Aquatic macrophytes	Mudflats	Shallow water habitat	Open water habitat	Inundated large dead trees	Inundated Eucalypt "fence"	Other
Hattah	River red Gum (RRG)	No	Minimal	Some	Extensive	Scattered	Yes	Little Hattah and channel between lakes
Mournpall	RRG	Minimal (Swamp ludwigia)	Minimal	Some	Extensive	Extensive	Yes	Lignum (inundated)
Kramen	Black box (BB)	Starting to develop (Black swans grazing in deeper water, April)	Some	Substantial	Extensive	Scattered	Yes	Inundated Blackbox flats
Bitterang	RRG	No	Minimal	Some	Extensive	Scattered	Yes	Ephemeral flooded areas, e.g., opportunistic sampling site
Cantala	RRG	No	Minimal	Extensive	Extensive	Extensive	Yes	N sections substantially different from S

4.1.4 Invertebrates

Zooplankton biomass varied between lakes and seasons. Microzooplankton included ciliates, rotifers and copepod nauplii. The highest microzooplankton biomass was at Lake Cantala. Mesozooplankton abundance was also extremely high at Lake Cantala in autumn. High biomass also occurred in Lake Hattah in autumn and Lake Kramen in summer. Most common taxa include Calanoid copepod (*Boekella spp.*), small cladocera (*Bosmina spp.*) and larger cladocera (*Daphnia spp*.). Macroinvertebrates varied between lakes and seasons with the highest biomass at Lake Kramen. There were also relatively high numbers at Lake Mournpall in summer and Lake Cantala in autumn. Macroinvertebrate biomass was dominated by Corixidae (water boatman) at all lakes. Other taxa included Chironomid, Culucidae, Oligochaeta and Mollusca. Decapod biomass varied between lakes and season, with biomass the highest at Lake Hattah in summer. Biomass was lowest at Lakes Cantala and Kramen. Decapod biomass was dominated by Freshwater Shrimp (*Paratya australiensis*)), with smaller numbers of Freshwater prawn (*acrobrachium australiense*) also present.

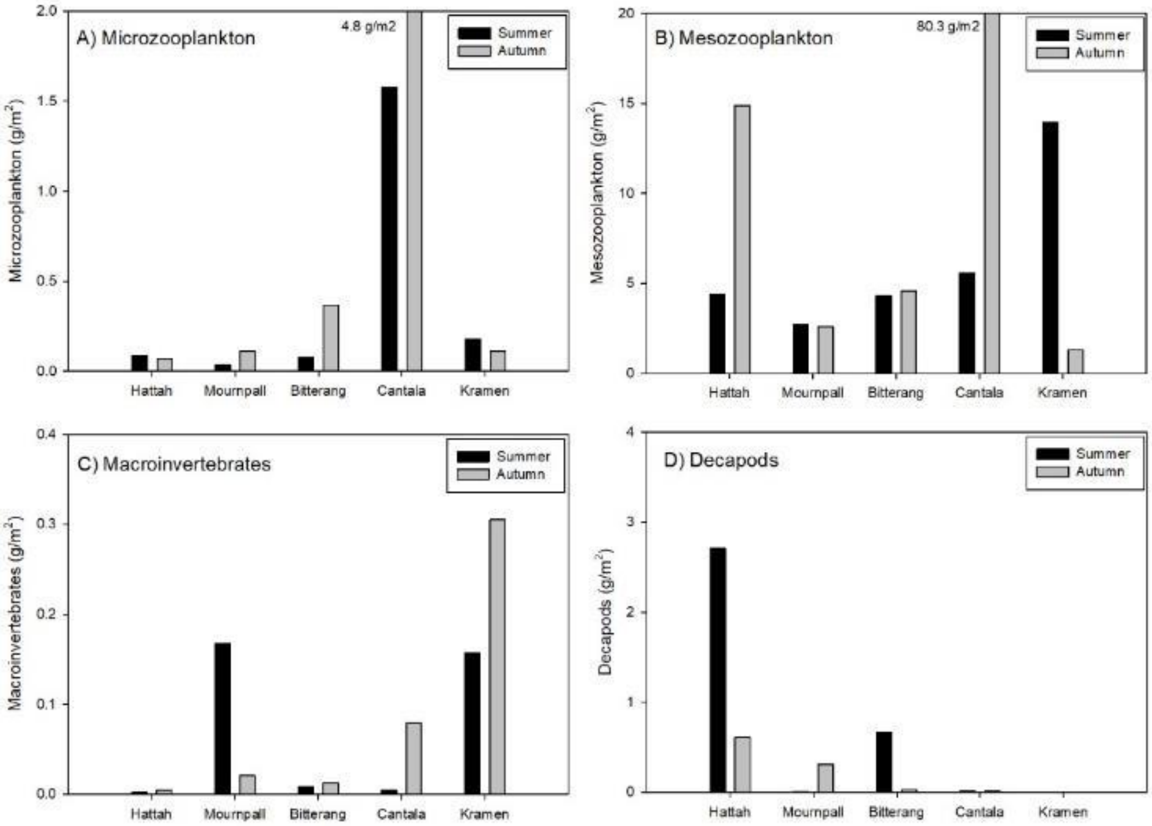


Figure 18: Invertebrate biomass at Hattah Lakes, Summer and Autumn 2023. A) Microzooplankton, B) Mesozooplankton, C) Macroinvertebrates, D) Decapods

Figure 19:Freshwater Shrimp (left) and Calanoid copepod (right)

4.1.5 Fish

Fish biomass varied significantly between lakes and seasons. Fish biomass was very high in summer at Lakes Hattah, Mournpall and Cantala compared to other lakes and times and was overwhelmingly dominated by Carp gudgeon (*Hypseleotris* sp.). Carp gudgeon wererarelyy present in autumn and Australian smelt (*Retropinna semoni*) was the dominant small-bodied fish in most lakes. Other species present included Flatheaded gudgeon (*Philypnodon grandiceps*), Eastern mosquitofish (*Gambusia holbrooki*), and Un-speckled hardyhead (*Craterocephalus stercusmuscarum fulvus*). Lake Kramen had the lowest fish biomass of the five lakes studied across both seasons. No juveniles of large-bodied fish were caught. Adult Common carp (Cyprinus carpio) were seen in most of the lakes in summer and autumn, and carcasses of adult Common carp and Bony herring (*Nematalosa erebi*) were found under trees at Lake Bitterang.

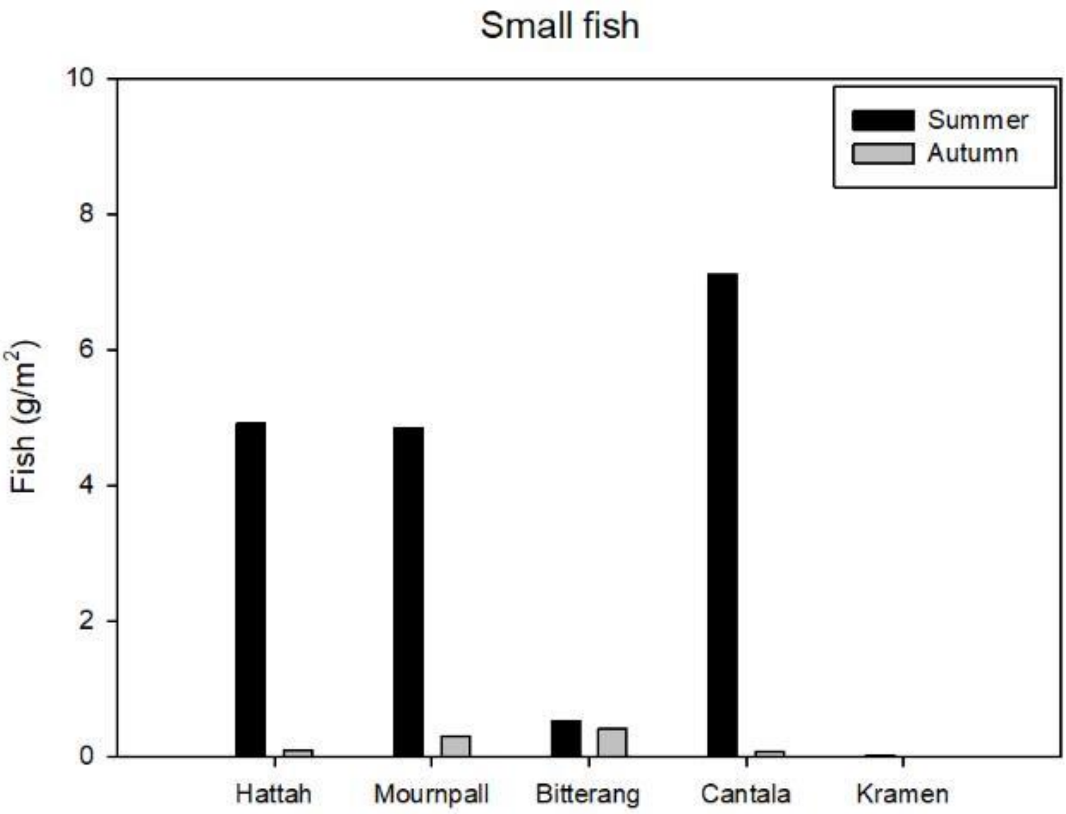


Figure 20:Small-bodied fish biomass, Hattah Lakes, summer and autumn 2023

Figure 21:Common fish sampled at Hattah Lakes. Left Australian smelt and right Flat-headed gudegon

4.1.6 Waterbirds

Overall patterns between lakes and sampling trips

Results of waterbird surveys conducted at all lakes in the February and April sampling sessions showed a similar number of total birds recorded in summer and autumn, except Lake Kramen, which had half the number of birds in autumn compared to summer. There was 5000+ birds recorded at Cantala in both sampling sessions which was primarily a Great cormorant nesting colony on both occasions. Very few other waterbirds (e.g., Australasian darters, Little pied cormorants) were found to be nesting at Cantala during either visit. The Great cormorant nesting colony appeared to be operating at the same intensity during both visits.

In most cases, the species of bird present were similar in both sampling sessions, but in some cases, there was a small change in bird species making up the total numbers.

Total Bird Numbers

Table 6: Total bird numbers recorded in February and April

Hattah		Mournpall		Kramen		Bitterang		Cantala	
Feb	Apr	Feb	Apr	Feb	Apr	Feb	Apr	Feb	Apr
644	516	880	778	607	300	302	301	5080	5142

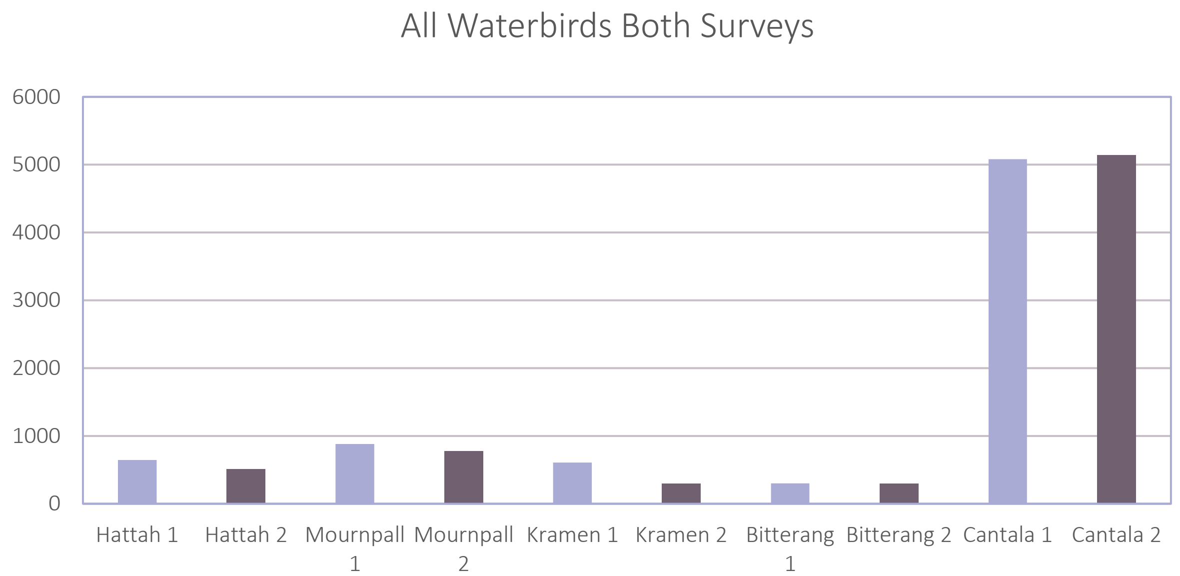


Figure 22: Total bird numbers recorded in February (1) and April (2) at all lakes surveyed on this project.

Birds by Feeding Guild

Piscivores were the main feeding guild recorded at all lakes. Large Waders were the second most numerous guild – many Large Waders also eat fish. Lake Cantala had the most piscivores by far, certainly there were enough fish to support a significant breeding event. Lake Mournpall also had a significant Great cormorant breeding event (~600 birds in ~200 nests).

Table 7. Table of major feeding guilds across the 5 Lakes and the floodplain depression in February and April

	Hattah		Mournpall		Kramen		Bitterang		Cantala		
Feeding Guild	Feb	Apr	Feb	Apr	Feb	Apr	Feb	Apr	Feb	Apr	Big Depression
Dabbling Ducks	5	0	24	0	19	10	8	0	0	0	16
Diving Ducks	0	0	1	0	3	0	4	2	0	0	0
Filter feeding Duck	0	0	0	0	6	0	2	0	0	0	15
Herbivores	20	20	23	0	8	70	40	0	0	0	0
Large Wader	195	68	27	10	110	3	50	2	4	2	34
Piscivore	410	420	787	762	417	196	183	296	5075	5130	2
Small Wader	6	1	0	0	15	0	7	0	1	0	2
Eurasian Coots	8	5	18	6	29	20	8	1	0	10	0

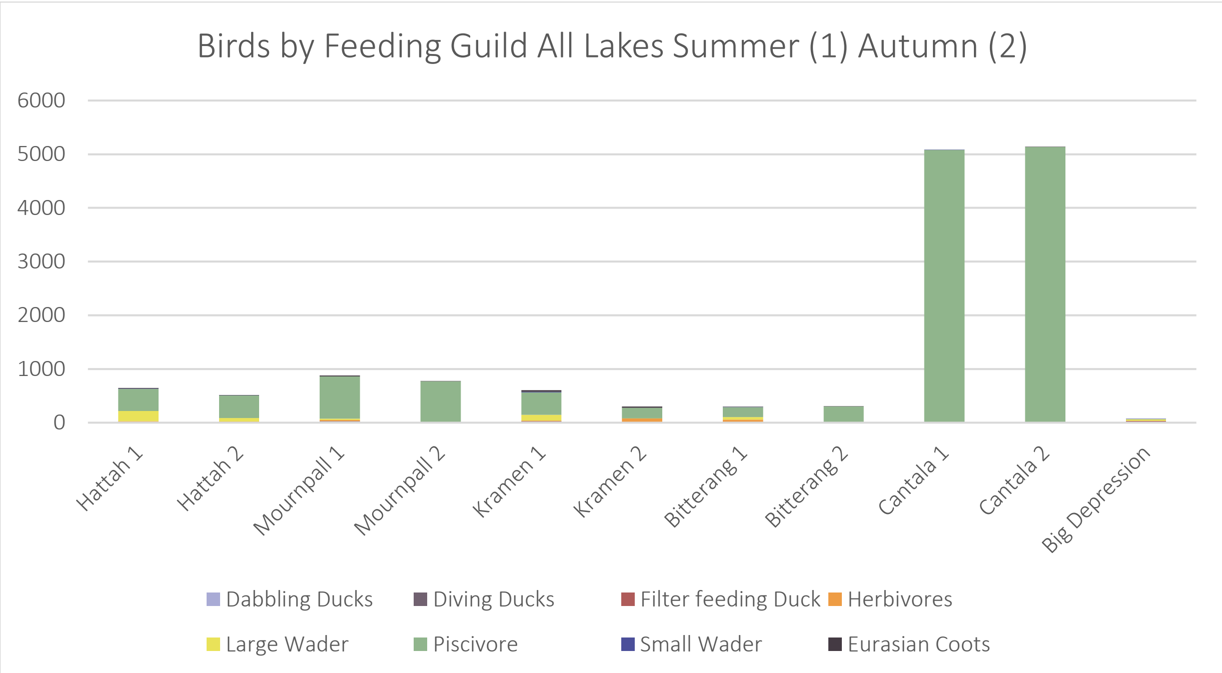


Figure 23: Waterbirds by Feeding Guild, All Lakes, Summer and Autumn survey sessions

Piscivores

Great cormorant colony nesting dominates the overall numbers of piscivores, with 600+ at Lake Mournpall and 5000+ at Lake Cantala. Both Great cormorant colonies appeared to be operating at the same intensity during both visits. Lake Kramen had half the piscivores in autumn as it did in summer. Lake Bitterang had 1/3 more piscivores in autumn than summer (the autumn numbers were bolstered by a flock of hoary headed grebes, a mix of adults and juveniles, which may have moved onto the main lake from a surrounding breeding/foraging area or were not detected in summer). Little black cormorants (*Phalacrocorax sulcirostris)* dominated the bird species at Hattah, with 200+ in both summer and autumn, although there was also a colony of breeding Nankeen night herons (*Nycticorax caledonicus*) in Summer.

In both Great cormorant breeding colonies (Cantala and Mournpall), the majority of nests were found in inundated, large dead trees found in deeper water inside the living eucalypt tree 'fence' (see Table 5). Great cormorants appear to favour these conditions for nesting. Occasionally, a single nest or few nests were found at other lakes, but almost always in large, dead trees in deeper water.

Although many grebes with dependent young were observed at all lakes, no nests were observed. It is possible that they were hidden amongst the living eucalypt tree fence, or that the nests were made on adjacent inundated floodplain depressions or smaller lakes adjacent to the larger lakes.

Australasian darter nests were found at most lakes, usually close to or inside the living eucalypt tree fence, or in large, old, inundated floodplain eucalypts. It is possible that inundated, large eucalypts and the living tree fence provide important habitat structure for Australasian darter nests.

Table 8: Piscivore numbers recorded at all lakes in February (1) and April (2)

Hattah		Mournpall		Kramen		Bitterang		Cantala	
Feb	Apr	Feb	Apr	Feb	Apr	Feb	Apr	Feb	Apr
410	420	787	762	417	196	183	296	5075	5130

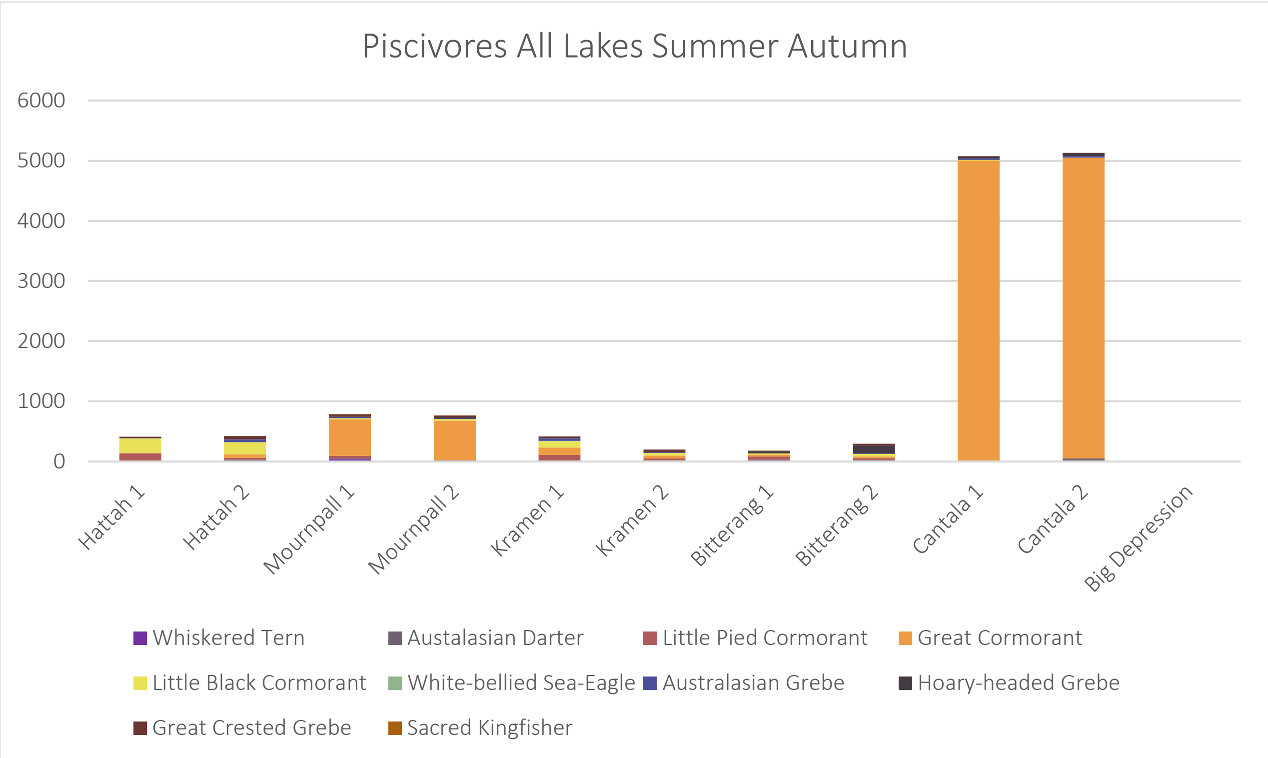


Figure 24: Piscivores at all lakes in both survey sessions (February = 1, April = 2)

Large Waders

Lake Hattah had 1/3 as many Large Waders in autumn as in summer – due to reductions in Nankeen night herons and Australian white ibis (*Threskiornis molucca*). Lake Kramen had only a few large waders in autumn compared with over 100 in summer. Lake Bitterang had almost no large waders in autumn. The 'Big Depression' was an ephemeral floodplain wetland that had reduced to the point where birds were literally scooping the food up as if from a bucket in summer. This depression was dry by April. Piscivores, large waders, filter feeders and dabbling ducks were all present at the Big Depression in February.

All observed Nankeen night heron nests at Lake Hattah were found in the living, eucalypt tree fence. Fledged juveniles also favoured this dense habitat to retreat to when flushed. Many other large waders (and other waterbirds) were also found roosting in the living eucalypt tree fence.

Table 9: Large Wader totals for all lakes in February (1) and April (2)

Hattah		Mournpall		Kramen		Bitterang		Cantala	
Feb	Apr	Feb	Apr	Feb	Apr	Feb	Apr	Feb	Apr
195	70	27	10	110	3	50	2	4	2

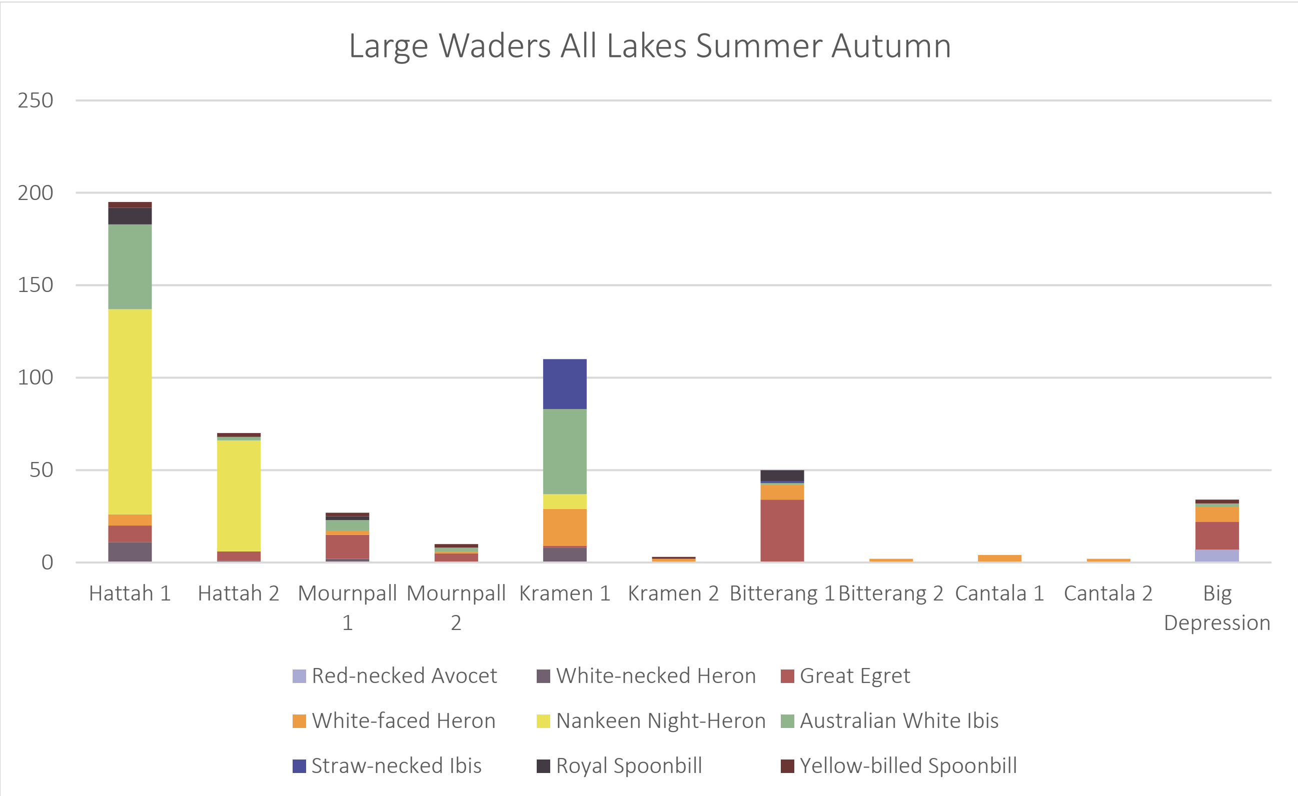


Figure 25: Large Waders at all lakes in February (1) and April (2)

Herbivores and Filter Feeders

There was a notably low abundance of herbivores and filter feeders across all the sampled lakes. Wood ducks (*Aix sponsa)* are primarily terrestrial foragers but also take insects from the surface of water and require water close to foraging areas (Birds of the World, 2022). Black swans, Wood ducks, and Pink-eared ducks (*Malacorhynchus membranaceus)* were recorded at Lake Bitterang in summer. Given the absence of aquatic vegetation in Lake Bitterang, it is possible these birds were foraging in floodplain areas or small ephemeral ponds such as the Big Depression but returned to the main lake. Wood duck and Black swan numbers had increased at Lake Kramen by the autumn surveys, hinting at the development of aquatic vegetation.

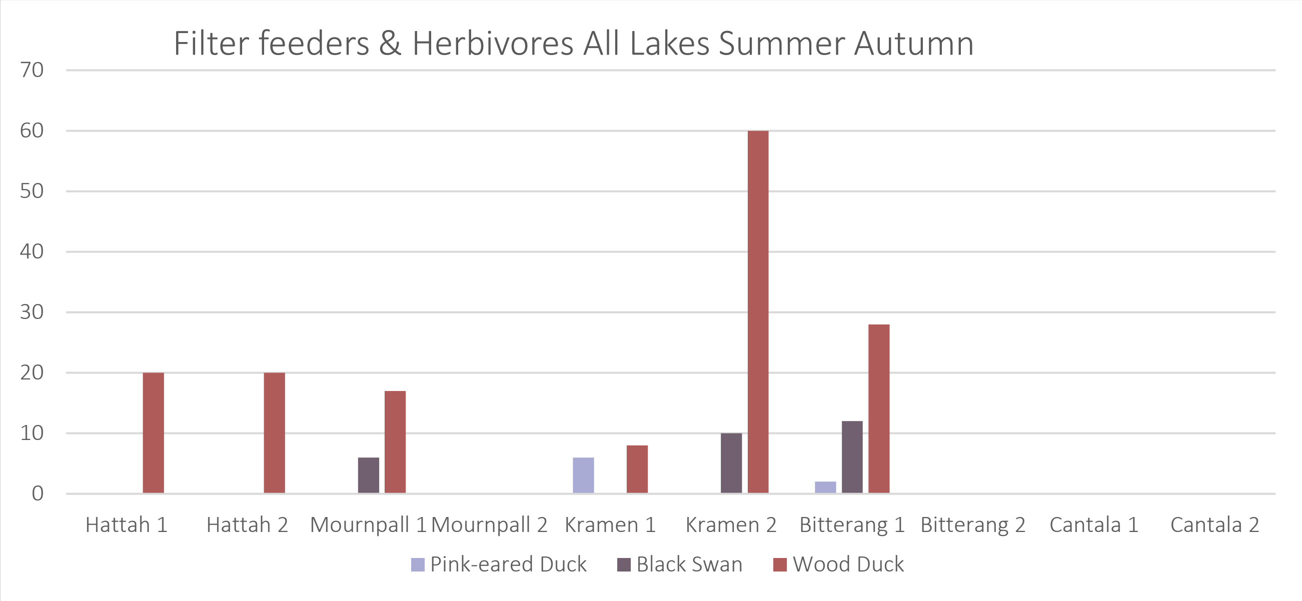


Figure 26: Filter Feeders and Herbivores recorded at all lakes in February (1) and April (2)

Dabbling Ducks and Eurasian Coot

These guilds have been grouped together, as they occurred in low numbers, suggesting that their resources were not widely available at the time of sampling. Dabbling ducks were generally in low numbers, their foraging resources were largely not present, at least in the main lakes. Eurasian coot (*Fulica atra)* were observed in small numbers at the majority of the lakes. As generalist foragers, they employ diverse array of foraging methods to consume a broad spectrum of tropic resources from vegetation to insects, molluscs, fish, fish eggs, frogs, and their eggs and even small mammals and reptiles (Birds of the World, 2022).

A few Australasian teal were observed foraging in very shallow water, by wading along the margin of some of the lakes. It is possible that a small number of teal (and other dabbling ducks) can use these small pockets of habitat, but that the larger, deeper lakes sampled in this study did not provide extensive resources for filter feeders or herbivores.

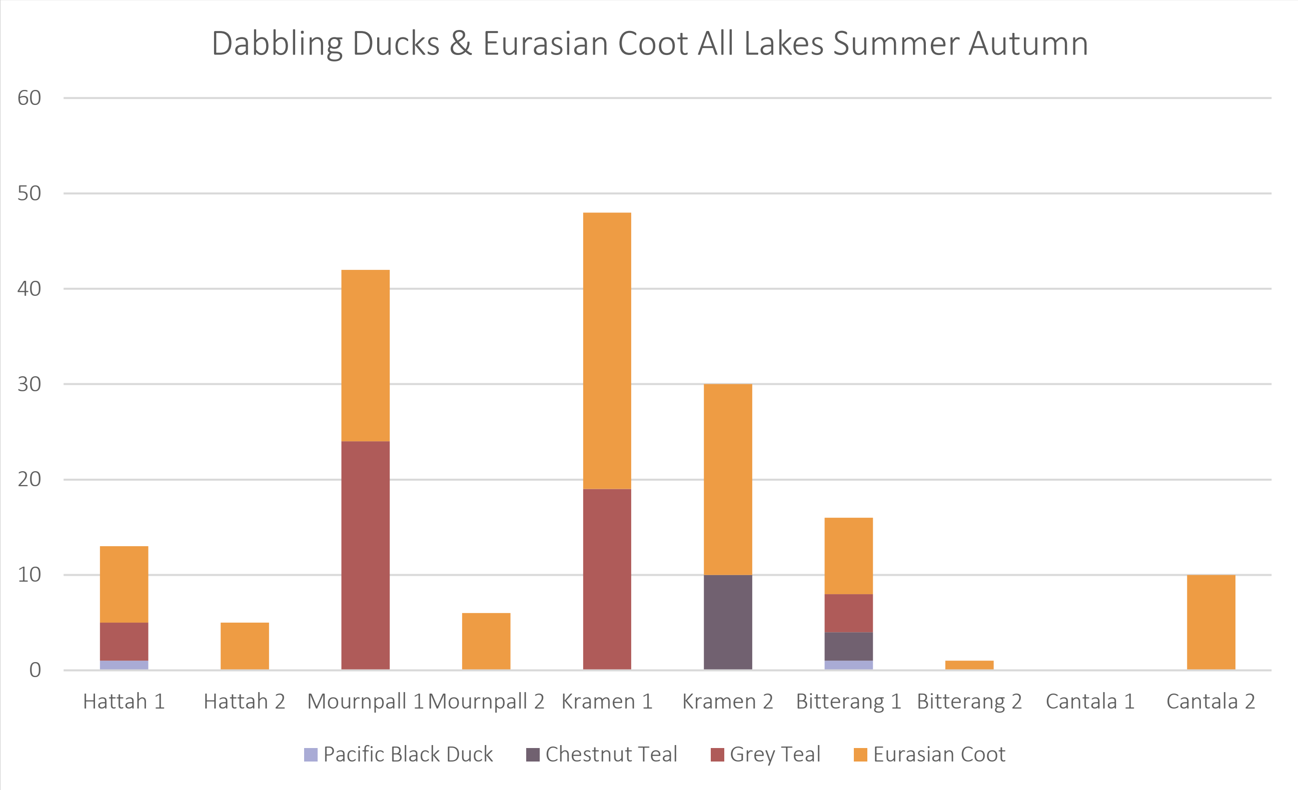


Figure 27: Dabbling Ducks and Eurasian Coot recorded at all lakes in February (1) and April (2)

4.1.7 Incidental observations

Floodplain ephemeral wetlands

We observed several examples of ephemeral floodplain ponds containing a wide array of different birds feeding 'shoulder to shoulder' in these shallow and receding depressions. We suspect that the diminishing volume and depth of the water provides easy and efficient foraging opportunities as the prey becomes concentrated. Table 10 shows the bird species, counts and feeding guilds of the birds present at the depression near Lake Bitterang that we opportunistically sampled (see Figure 28) for a photograph of this location). Feeding guilds not present or present in very low numbers on the main lakes were present and feeding at the depression, implying that these depressions are an important habitat component for birds at Hattah and the watering conditions which promote these should be considered in management plans.

Sampling of the depression revealed high numbers of potentially prey. Small-bodied fish biomass, dominated by Carp gudgeon was 13.07 g/m2, whilst macroinvertebrate biomass was 0.95 g/m^2. Concentrations of prey significantly higher than observed in of the major lakes.

Table 10: Birds counted at the floodplain depression (aka 'Great Depression') near Lake Bitterang in February

Waterbirds	Count	Feeding Guild
Wood Duck	4	Herbivore
Grey Teal	12	Dabbling Duck
Pink-eared Duck	15	Filter Feeder
Red-necked Avocet	7	Large Wader
Masked Lapwing	2	Small Wader

Waterbirds	Count	Feeding Guild
Great Cormorant	2	Piscivore
Great Egret	15	Large Wader
White-faced Heron	8	Large Wader
Australian White Ibis	2	Large Wader
Yellow-billed Spoonbill	2	Large Wader

Figure 28 ephemeral floodplain depression near Lake Bitterang (opportunistic bird count/food-web sampling Feb 2023)

Regent Parrots

One of the objectives of the Hattah Lakes Icon Site Condition monitoring is to improve biodiversity at Hattah Lakes by supporting the life-cycle of the EPBC-listed Regent parrot (*Polytelis anthopeplus monarchoides*) by 2030.

Regent parrots were recorded throughout the park (they were recorded at every lake on every visit); however, they were in highest numbers at Lake Kramen. More than 100 were sighted leaving the lake in flocks of 5 to 20 or more, presumably to forage, on the morning of February 21st. More than 100 were recorded at Lake Kramen during April surveys. Many of the inundated, living eucalypts contained roosting flocks of Regent parrots during both visits. Lake Kramen is likely an important roost site at Hattah, possibly providing protection from land-based predators in the inundated trees and drinking water upon return to the roost site after foraging.

5 Discussion

Discussion of findings at each of the lakes, hypotheses for important factors affecting waterbird food resources at the lakes, environmental significance and management implications and recommendations is provided below.

5.1 Lakes

The sampled lakes were deep, open water bodies with plenty of fish which provided fishing opportunities for deep water fishing birds such as cormorants and grebes.

5.1.1 Bitterang

Lake Bitterang is a relatively small, open water lake with inundated trees predominantly around the north and east shores. Lake Bitterang appeared to be one of the least productive lakes, having relatively high algal biomass, but low numbers of macroinvertebrates fish and waterbirds. There were some decapod crustaceans in summer, which suggests that biota were able to move into the lake with the flood. However, there were very few macroinvertebrates and medium levels of zooplankton to support fish production, which was subsequently reflected in the numbers of waterbirds.

5.1.2 Cantala

Lake Cantala is the shallowest of the lakes and third largest of the five sampled. It has some of the characteristics of a swamp with mature trees scattered across the lakebed. For a number of measures, Lake Cantala was the most productive, including phytoplankton, zooplankton fish and piscivorous waterbirds. The number of small fish dropped between February and March, a pattern also observed in Lakes Hattah and Mournpall.

Great cormorants will eat a wide size range of fish, typically ranging from 5 – 30 cm length. They are highly generalist and their preference for particular taxa and size varies between seasons and locations depending on the fish population present (Čech and Vejřík 2011). The size of a Great cormorants population is positively related to the productivity of nearby waters and abundance of fish populations (Klimaszyk and Rzymski, 2016).

5.1.3 Hattah

Lake Hattah, one of the comparatively smaller and deeper lakes, exhibits a distinct characteristic of having experienced a lower frequency of dry periods compared to the other lakes surveyed. In summer, Lake Hattah had moderate levels of phytoplankton and high numbers of small fish and medium levels of waterbirds. The numbers of small fish would suggest the lake could support greater numbers of piscivorous birds, but it is possible that the deep water means fish density is less or they are more difficult to catch, making Lake Cantala a better foraging option. In Summer the lake had very high concentrations of decapods.

5.1.4 Kramen

Previous inundation of Lake Kramen led to development of extensive beds of aquatic plants, however, this did not appear to be the case on the dates sampled. Lake Kramen did, however, respond differently to the flood than the other lakes sampled. It supported similar levels of benthic algae but low levels of phytoplankton. The Lake also supported amongst the most abundant macroinvertebrate communities but very few small fish. It is also of note that there were very few decapod crustaceans suggesting that connectivity may have played a role. It would be useful to compare the projects surveys with surveys of the large fish community to see if there is a similar pattern.

5.1.5 Mournpall

Lake Mournpall is the deepest and largest lake sampled, and during the flood, it would have had connections to Lakes Yelwell and Konardin. While Lakes Yelwell and Konardin have areas of swamp, Lake Mourpall is largely open water with fringing River red gum. Lake Mournpall had low levels of macroinvertebrates, small fish and waterbirds; although moderate levels of zooplankton.

5.2 Hypotheses

5.2.1 Food web differences

There is clear evidence that the five different lakes supported different food webs with the largest differences being in the relative abundance of different groups, but also differences in relative abundances of groups including planktonic versus benthic organisms and micro versus meso-zooplankton. The drivers of these differences are not clear but may reflect differences in habitat, connectivity, or resources, or may simply be an artifact of taking a snapshot of what are very dynamic systems.

The data also supports the idea that food web differences influence the waterbird community, most notably with Lake Cantala being the most productive lake that also supported the highest numbers of piscivorous waterbirds. There is also evidence that food resources likely influenced the relatively large Nankeen Night Herron population at Lake Hattah. Whilst the exact energetic requirements of the Night Herron are unknown, food consumption in birds is directly linked to their body size and feeding behaviour. Similar sized birds such as Ibis and Royal Spoonbill require approximately 1800 kj a day for an adult and between 0 to 1800 kj a day for the chicks during the first 50 days of their life (O'Brien and McGinness, 2019). This translates to approximately 360 grams of a food a day per adult bird. Lake Hattah in summer had 2.7 g/m2 of decapods alone, which means a Night Herron would only have to forage in a small area to meet their food requirements. At the other lakes they would need to forage 10-50 fold greater area to encounter the same number of decapods.

5.2.2 Habitat

Large floods are associated with the homogenisation of the areas they inundate, and this appeared to be the case at Hattah Lakes where the sampled lakes all supported deep water that was largely devoid of aquatic vegetation. The one exception to this was Lake Cantala which supported living trees across much of its bed. It is not clear to what extent these trees influenced habitat or the observed food web within Lake Cantala.

The other habitat characteristic that may contribute was flooding depth. Water depth is known to influence the vegetation community, patterns of productivity and waterbird foraging (Lantz et al. 2010). Flooding depth may have influenced food web and waterbird responses at Lake Cantala and may also have contributed to the lack of vegetation observed at Lake Kramen. It will be interesting to observe what happens at each of the Lakes as they dry down; whether each has a period of increased piscivore activity and whether Lake Kramen develops an aquatic plant community.

Our interpretation of what is important about lake habitat is, in part, influenced by sampling on the five large lakes. The observations in the floodplain depression and examination of the satellite imagery reveal that there was a mosaic of different habitat types across Hattah Lakes NP. For each of the large lakes, the waterbird community was dominated by piscivores, while for the depression there was a far more even mix of ducks and waders. Given the large number of these floodplain depressions that filled around the peak of the flood, it is possible that these provided important habitat for waterbirds.

5.2.3 Connectivity

It is possible that connectivity has played a role in influencing outcomes within each lake. The low numbers of fish and decapod shrimp in Lake Kramen may reflect its connection via floodplain inundation rather than via a feeder creek. It is also possible that the relatively short connection linking Lake Cantala to floodwaters may have extended the period that animals could move between the river and the lake when compared to the longer and shorter duration connection of the Lakes Hattah, Bitterang and Mournpall.

One of the key elements of connectivity is the movement of large fish into and out of the lakes. We do not have any data on large fish, but it will be interesting to review data from surveys during the flood and subsequent sampling.

5.2.4 Initial inundation

Of the lakes sampled, only Lake Kramen was dry prior to the flood. It appears unlikely that its response to inundation was strongly influenced by being dry, given the other lakes all contained water, and the magnitude of the flood may have overwhelmed within lake effects. There are also no comparisons to be made between the other lakes for this flood.

5.3 Environmental significance

5.3.1 Impacts of large floods

Floods can play three broad roles: (1) a resource or habitat for biota; (2) a vector for connectivity and exchange of energy, materials, and organisms; and (3) as an agent of geomorphic change and disturbance. The 2022-23 flood will have disturbed some vegetation and animals while simultaneously providing resources for others including suitable habitat to germinate or food. In addition to closing roads within Hattah-Kulkyne National Park, it is also likely that the flood will have led to other geomorphic changes that may influence future responses to floods.

The 2022-23 flood was associated with a strong response from piscivorous waterbirds, in particular Great cormorants. Large floods lead to widespread inundation of floodplains, providing temporary resources to bird populations. These temporary resource pulses are important to many highly mobile water bird populations (Roshier et al. 2001), they are important in supporting breeding and subsequent chick recruitment.

5.3.2 Landscape Mosaic

One of the clearest outcomes from a comparison of Hattah Lakes in December for the last four years is the difference water makes. In 2019, it was a dry year with only two lakes containing water (Figure 29). In 2020, only Lake Kramen held water, but the legacy of previous inundation was evident as dark green patches on the Sentinel images. In 2021, again there was a clear legacy of water in the landscape, constrained to low lying areas around the lakes (Figure 29). In contrast, December 2022 showed many wetlands and floodplain depressions scattered across the landscape. The importance of landscape patterns is widely recognised and has developed into an ecological discipline. Observations from other floodplains have found that habitat heterogeneity or complexity is associated with increased diversity and changes in food webs. The other observation is that while there were many inundated floodplain depressions, only a few were associated with high numbers of birds. This aligns with our understanding of floodplains as dynamic mosaics in which resource availability varies through space and time, but that this dynamism contributes to sustained feeding opportunities at the landscape scale. This conception of the outcomes of the flood suggest that consideration needs to be given to the habitats created at the landscape scale and how these vary through time. We did not consider landscape scale drivers when we planned the project (Sections 2.1.3 and 5.2), however, the results of this work suggest that it will need to be considered in future investigations.

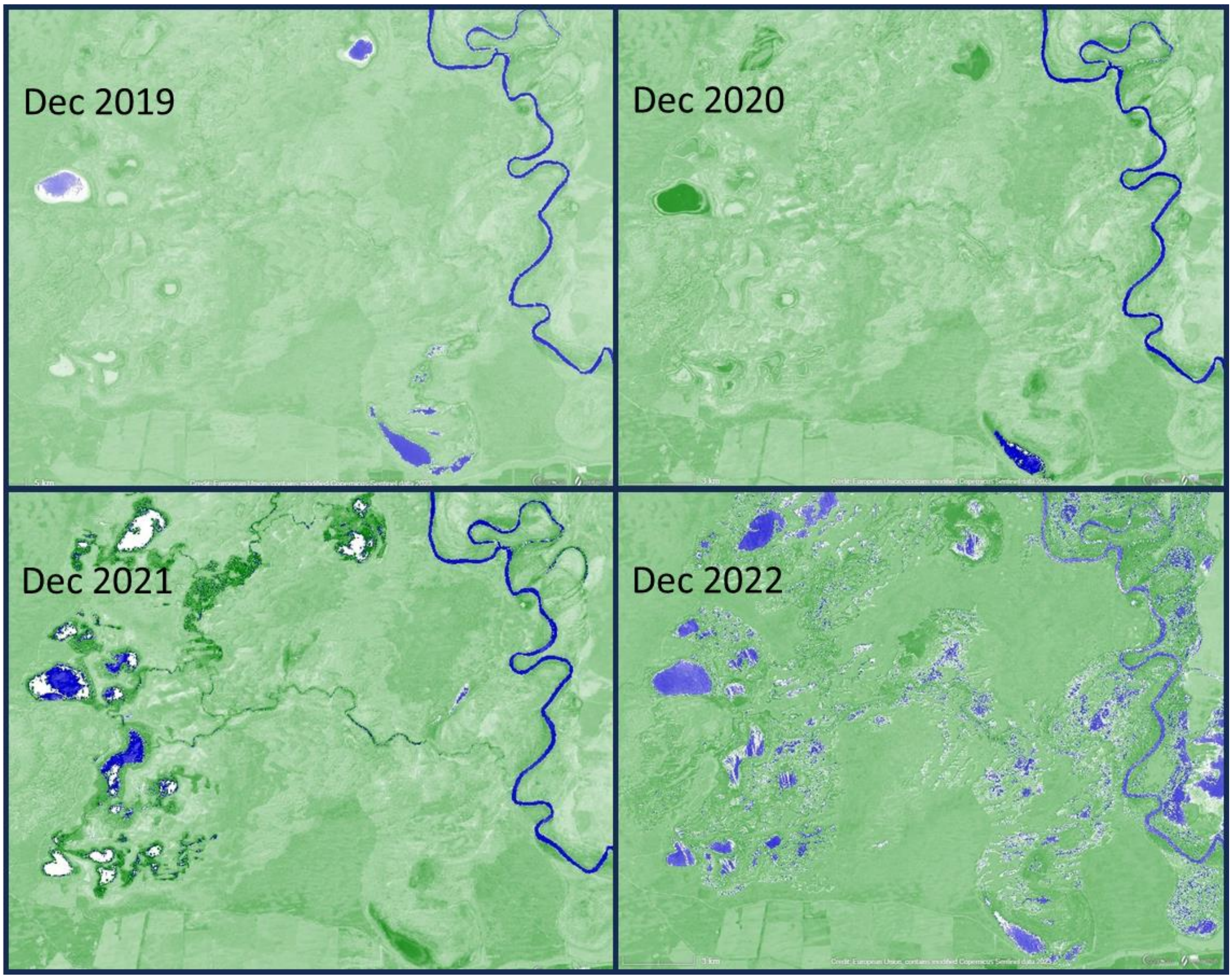


Figure 29. Sentinel 2 images of Hattah Lakes in December 2019 – 2022.

5.3.3 Environmental flows and floodplain areas

The 2022-23 flood has initiated a multi-year successional process during which the lakes will go through a gradual drying phase with a shift in habitat zones and biotic communities. The challenge will be to identify ways in which environmental flows can improve environmental outcomes as the lakes dry and ensure they translate into enduring improvements in condition.

One of the considerations will be to manage the draw-down and drying in a way that favours waterbird foraging without impacting the character of the lakes.

In planning for using environmental water for future inundation of the lakes, consideration should be given to whether there is the capacity to create a variety of habitat types even if these are marginal areas around the larger lakes that will contract and dry in isolation of the large lake (Figure 28).

Figure 30. Margins of Lake Lockie, February 2023a va. Image courtesy of Mallee CMA

5.4 Management implications and recommendations

The current study is important as it documents the outcomes of a rare, large flood and provides important insights into the way the Hattah Lakes may have functioned in the past. To simplify the assessment, the Murray River delivered a landscape worth of organic matter and nutrients, and the lakes converted it into waterbirds. This observation underscores the importance of considering the Hattah Lakes as part of a larger system. It also provides important perspective for the management of the lakes and achievement of management objectives.

The results indicate that the long, large flood provided ideal conditions for fish and the waterbirds that prey on them in deep water. The proportion of piscivorous waterbirds was consistently high across the lakes, which exceeds the long-term proportion of piscivorous waterbirds (~20%). The response at Lake Cantala was more consistent with historical observations, with 99% piscivores compared to a long-term average of 79%. There was no similar increase in numbers of ducks which may be due to either dispersion of birds across the large area of inundated floodplain or their use of the many smaller wetlands rather than the surveyed lakes.

The flood did not lead to the extensive development of aquatic vegetation in the beds of the lakes at the time of survey. It had been expected that at least Lake Kramen would support abundant aquatic plants and while there was some evidence that aquatic plants had started to emerge in April, their absence certainly affected the waterbird community. The lack of aquatic vegetation was not constrained to the lakes sampled but was also evident in smaller floodplain depressions. Abundant vegetation was observed in riparian areas and some wetland areas that had dried, suggesting that there remains a viable seed bank of herbaceous terrestrial and amphibious species that emerge following drawdown. There may be a few causes for the lack of aquatic vegetation, including water depth (perhaps still too deep), water quality or the effects of Carp. It is also possible that extensive aquatic vegetation may not naturally be characteristic of most of the lakes, with extensive aquatic vegetation apparently observed only at Lake Kramen, which is distinct in terms of landscape position, bathymetry and hydrology.

The survey also found that food webs and productivity vary significantly among the Hattah Lakes. The causes of this variation remain uncertain, however, the lake depth, connectivity and vegetation may all influence outcomes. The combination of less depth, being closer to the river and the presence of inundated trees may all have contributed to the high productivity in Lake Cantala. This presents a conundrum for managers as the location of the lakes are fixed and depth of Lakes Hattah, Mournpall and Bitterang needs to be managed carefully to prevent further River red gum invasion of the lake beds.

5.4.1 Productivity

Organic Matter and Algae

The 2022-23 flood was associated with a large subsidy of organic matter and nutrients into the lakes which, as expected, was associated with a boom in productivity that cascaded up the food chain to fish and birds. There have been concerns raised about the effects of regulation on the flux of organic matter from floodplains into rivers (Baldwin et al 2016, Bond et al 2014), however, very little consideration has been given to the potential impacts of the movement of organic matter and nutrients back out of the river and into wetlands.

Levels of phytoplankton and benthic algae in the lakes were high, highlighted by the occurrence of blue-green algal blooms. Dissolved organic carbon (DOC) levels were also high across all lakes suggesting it was primarily imported by the flood.

The occurrence of cyanobacteria blooms can have major influence over the broader food web in aquatic ecosystems. Cyanobacteria are typically considered a poor food compared to other genera of algae which are often reduced in numbers during blooms (Facey et al. 2022). This has cascading impacts with potentially lower numbers of herbivorous zooplankton, a key food for many small and juvenile fish, and planktivorous birds. As the blooms recede, the biomass is rapidly decomposed, potentially leading anoxic conditions and fish kills (Watson et al. 2016). Additionally, cyanotoxins produced by any cyanobacteria can have range of deleterious impacts on animals, including birds (Ferrão-Filho and Kozlowsky-Suzuki, 2011).

Levels of dissolved organic carbon were similar or higher than those recorded in the Murray River downstream of Barmah during the 2010 flood (Cook et al. 2015), the 2011 flood in the Murray River (Whitworth et al. 2013) and the Murray River at Murray Bridge during the 2011 and 2016 floods. These flood levels of DOC in the river are up to an order of magnitude greater than median values (Silvester et al. 2023). In addition to this, there has been a long-term decline (1980 – 2021) in the amount of DOC recorded in river water.

For the Hattah Lakes receiving regulated environmental flows, overall productivity will be reduced, and the proportion of production generated by processes within the lakes will be much greater. Conceptualising the flow of material through the lakes, every time the lakes are inundated with low DOC and nutrient water, then the internal productivity of the lakes may decrease as birds and fish harvest organic matter which is then exported from the system as they disperse back to the river or other wetlands. It will therefore be important to consider ways in which productivity within the lakes can be sustained or enhanced.

Aquatic vegetation

The other key issue is aquatic vegetation which has been absent from all the lakes except Lake Kramen. Lake aquatic vegetation is important as habitat and as a food source for some waterbirds (e.g., swans). Aquatic vegetation is also important to the food web in other ways. First, it supports biofilm growth which acts as a high-quality food for invertebrates. It also generates plant tissue using nutrients from within the sediments. The plant tissue then acts as an additional source of organic matter for the food web. Improving the aquatic plant community would potentially improve productivity within the lakes.

The reasons for the lack of aquatic vegetation in Hattah Lakes and in many other wetlands remain uncertain. There are several potential threats; depauperate seed bank, water quality, water depth and Carp. Clearly these threats may interact, for example carp influences water quality and poor water quality interacts with depth to reduce light penetration. It appears unlikely that the issue lies with the seed bank as previous surveys of aquatic vegetation at Hattah Lakes have also noted that riparian and floodplain vegetation respond to inundation (EPA 2007). The EPA has undertaken germination experiments to assess the health of the seed bank and found high potential for diverse native macrophyte communities to develop at most lakes.

Water quality has the capacity to affect aquatic vegetation through changes in salinity or light penetration due to increases in turbidity due to either sediments or algae (Gell and Reid 2014, Porter et al 2017). Water quality within the Hattah Lakes is not known to represent a threat to aquatic vegetation and abundant growth in Lake Kramen on at least one occasion suggests that water quality on its own does not prevent development of aquatic vegetation in the Lakes.

The third threat is Carp which are known to influence both water quality and aquatic vegetation (Vilizzi et al 2015). Once again, Carp do not fully explain the absence of aquatic vegetation as there have been instances when Carp abundance has been low. Monitoring of the early pumped environmental flows (2005-2011) during the millennium drought found mainly small-bodied native species and very low numbers of non-native species (Vilizzi et al 2013). This contrasted with the results of two-way flooding by natural inundation which resulted in a more diverse fish assemblage, including large-bodied non-native species (Vilizzi et al 2013). Similarly, the installation of carp screens on Little Lake Hattah in 2013 appeared to be effective in excluding Carp (Koehn et al 2016). Operation of the carp screens has become a hazard and so they are no longer deployed. If adult Carp are a major impediment to development of aquatic vegetation, then it would be expected that inundation and low Carp numbers would be associated with a positive vegetation response which was not observed. Experiments undertaken in Brenda Park wetland in South Australia found that Carp impacted aquatic vegetation but that the effect varied through time and with depth (Vilizzi et al 2013).

This leaves the issue of aquatic vegetation uncertain. It is possible that different threats are acting at different times of which water depth, water quality or adult Carp numbers may all contribute. It is also possible that extensive aquatic vegetation may not naturally be characteristic of many of the lakes, with exception of Lake Kramen. It will be important to understand historical patterns of aquatic vegetation across the lakes and floodplains at times with varying flood levels and associated patterns of waterbird abundance – e.g. evaluating any aquatic vegetation data for years with higher and lower numbers of species reliant on aquatic vegetation. Monitoring changes in Lake Kramen's aquatic vegetation and fish community over the next couple of years would also help to understand the influence of the 2022-23 flood and the potential influence of threats. This project identified relatively few fish and if, over time, this translates into a lake with low carp numbers, then it might be expected that aquatic vegetation will develop as the lake dries and/or water quality changes.

With the Little Hattah Lake carp screen inoperable, we would recommend investigating other opportunities to limit large Carp access to some portion of the lakes. It would be good if this could be complemented by management of water depth but recognise that this is a challenge. One opportunity may be associated with the inundation of small wetlands or depressions where there will be increased capacity to control fish access, water depth and potentially some other water quality parameters. There are a range of carp screens installed on NSW and SA wetlands and both Victoria and SA have undertaken experiments excluding Carp. These studies provide a shoulder on which Mallee CMA could stand.

Source Water

As the organic matter and nutrients inundating the lakes are an important influence on productivity, it will be important to harvest water that has higher concentrations of organic matter and nutrients. This is one of the reasons that relaxing constraints will be important. Allowing environmental flows to interact with over bank habitats on its journey downstream will entrain organic matter and nutrients which can then be diverted into the Hattah Lakes. It will also be important to target unregulated flows or piggy-backed environmental flows as they are more likely to carry with them higher levels of organic matter and nutrients.

Water Levels

A third way in which internal productivity in the lakes may be enhanced is through manipulation of water levels. In the past, lakes have been surcharged (Brown et al., 2015) which means that organic matter and nutrients cycling through the margins of the system can be entrained and concentrated in the lake. The Inundation conceptual model includes consideration of the release of nutrients from sediments and lakebed vegetation. Inundation of a bare lakebed or one with minimal vegetation will be associated with a smaller productivity boost than a well vegetated area. Management of inundation to ensure that vegetated areas are inundated will help improve productivity. There are several areas through the park where lakes are connected to woodland areas including Lakes Cantala and Hattah where this may be possible. The leaching and nutrient releases occur over a period of days and so water levels would not need to be held at higher levels for extended periods.

5.4.2 Habitat

Waterbirds require foraging, roosting and breeding habitat and the 2022-23 flood has provided some useful insights into the way the Hattah Lakes provides these habitats. The habitat conceptual model identifies some of the key relationships that influence habitat, while the inundation model describes how habitats vary over the inundation-drying cycle. The opportunity to observe the outcomes of the 2022-23 flood revealed that habitat was important at two scales.

Landscape scale

The observations made during the 2022-23 flood have identified the development of a heterogenous floodplain mosaic. This study was focussed on the deep open wetlands that supported fish production and its subsequent consumption by piscivorous waterbirds. Complementary observations identified that the array of small wetlands and depressions also provided important habitats for a range of waterbirds including ducks and waders. This strongly suggests that developing a mosaic of wetlands is likely to both increase and diversify the areas of waterbird foraging habitat. The current configuration of Hattah Lakes means there are challenges in manipulating flow regimes within individual lakes which would enable manipulation of depths in different Lakes or scheduling of inundation to provide a diversity of habitats and food resources if constrained to the main lakes.

Given these limitations, we would recommend that consideration be given to delivering environmental flows to inundate small floodplain wetlands and depressions to increase habitat diversity, which, based on this year's observations would benefit ducks and waders. The Sentinel images during the 2022 flood suggest that there are areas south-east of Lake Bitterang on Chalka Creek that supported a high density of floodplain depressions. There were also areas near Lake Cantala and Lake Kramen that may provide opportunities.

Lake scale

Shallow water is known to be critical foraging habitat for a range of wading waterbirds such as egrets and herons. During the 2022-23 flood, this habitat was most common in small wetlands and depressions. It is of note in Figure 3 that peaks in piscivorous, and wading birds have been at different times. This suggests that the main lakes offer either good piscivore or wader habitat, but seldom at the same time.

In terms of achieving the EWMP objectives, consideration needs to be given to whether guilds of waterbirds will be provided with refuge or foraging habitat, or alternatively that the Lakes seek to provide these habitats to a diversity of waterbirds. Part of the solution may lie on allocating water to smaller wetlands and depressions, as suggested in the previous section.

An alternative will be careful management of the drying phase to ensure that there is suitable habitat for both piscivorous and wading birds. Management of the drying phase will also be important in improving waterbird access to carp. Important information about the transition in the waterbird community should be a priority for the next iteration of the intervention monitoring.

The other key element will be management of lake drying. The inundation model suggests that drying is important from a food-web and productivity perspective and that drying provides a short boon for waterbird foraging. This appeared to be confirmed by observations of waterbirds in drying floodplain depressions. The next iteration of the intervention monitoring may get an opportunity to examine Lake drying. Alternatively, observations of waterbird habitat use may provide insights into the ways that changes in habitat availability in drying lakes influence waterbird communities.

Drying will also remain an important tool in controlling carp and would also be expected to be associated with improvements in aquatic vegetation (see Section 5.4.4).

5.4.3 Connectivity

Flooding plays three key roles, 1) a resource or habitat for biota 2) a vector for connectivity and 3) as an agent of geomorphic change and disturbance (Sponseller et al 2013). Connectivity has been an issue of interest for the Hattah Lakes since the installation of the Messengers Pumps Station (Vilizzi et al., 2013, Brown et al., 2014). Previous monitoring has found that fish can pass through the pumps and return via the creek to the river (Brown et al., 2014). Clearly the 2022-23 flood dictated patterns of connectivity. The DOC data suggested that all lakes were receiving similar subsidies from the river however, the data from Lake Kramen suggested that fish and decapods may have had less access when compared to the other lakes. The high numbers of fish in Lake Cantala may also be related to its proximity to the river.

Floods have been associated with cycles of homogenisation during inundation followed by diversification as the system dries (Schofield et al 2018). It is possible that the differences in connectivity will influence subsequent changes in each of the Lakes creating some measure of habitat heterogeneity at the landscape scale. Observations of Lake Kramen through the subsequent intervention and condition monitoring will provide useful information about the extent to which the community that established during the flood influences subsequent conditions in Lake Kramen and to a lesser extent in Lake Cantala. Over the long-term understanding the way that differences in connectivity influence biota during the dry phase may be important in sustaining a variety of bird and fish species.

5.4.4 Carp

Carp were abundant in the Lakes, often seen close to shore feeding from the sediments (

Figure 31). Carp are known to impact wetlands but also provide a food source for waterbirds. Carp may also be implicated in the lack of submerged aquatic vegetation, although this remains uncertain. The proliferation of Carp during the 2022-23 flood was inevitable, however, at times when managers have greater control, there may be options for limiting the proliferation of carp within the Lakes through a combination of reductions in colonisation and increases in mortality. The importance of reducing carp numbers will depend on the impact they have on the Lakes which was discussed in the Aquatic vegetation section.

Regardless of their impact, from a waterbird perspective, the best option for carp is that they end up inside birds. Managers capacity to influence this will depend on the size distribution of the carp but would require consideration of the best predator for the different size carp and providing the appropriate foraging habitat. Once carp exceed optimal size for pelicans, then there are limited options except for drying. Clearly there is uncertainty around which species of waterbirds would be the most effective predators and whether they would be attracted to the lakes, however, there may be opportunities to compare outcomes across TLM sites.

For planning of environmental watering of the Lakes, consideration could be given to levels of inundation and timing of inflows to try and maximise carp vulnerability to waterbirds the following autumn and winter. Shallow water is clearly important to wading birds but may also favour some piscivorous waterbirds such as Pelicans. The second implication is that adding additional water to the lakes as they dry may reduce predator pressure on carp, enabling them to grow beyond the size where they are vulnerable to predation. The inundation model also suggests that elimination of the dry phase will reduce productivity within the lake. There is a potential trade-off here in that drying the lakes may impact on native fish (while benefiting waterbirds) and so these decisions should be based on the condition of the fish community within the lakes and the availability of waterbird foraging habitat in the region.

Figure 31. Adult carp feeding near the shore of Lake Hattah, March 2023.

5.5 Recap of Recommendations

Management

Monitoring of the 2022-23 flood has confirmed manager's hypotheses that productivity and food webs within the lakes are an important influence on the waterbird community. The results also reinforce the complexity of these responses with productivity, habitat and carp all potentially influencing outcomes. A summary of management recommendations are provided in Table 11.

Table 11. Key management recommendations based on the outputs of this 2023 TLM intervention monitoring.

Category	Subject	Recommendation
Productivity	Source Water	Prioritise delivering river water with high levels of organic matter and nutrients to the Lakes
	Aquatic vegetation	Investigate aquatic vegetation responses to carp exclusion and depth management
	Water Levels	Consider surcharging lakes to improve productivity
Habitat	Landscape scale	Identify opportunities to provide a greater diversity of habitats (e.g. small wetlands and floodplain depressions) through delivery of environmental water
Carp		In planning delivery of environmental water, consider the timing and extent of the drying phase to optimise waterbird access to young carp.

Monitoring

Monitoring the ongoing changes in waterbird community responses to the lakes to the 2022-23 flood will provide important insights into the key influences on waterbird abundance and diversity. While the 2022-23 flood was an unregulated event, the comparison between flood responses and regulated inundation help identify some of the key processes influencing the lakes. A summary of the key points for next year's TLM intervention monitoring are listed in Table 12.

Table 12. Summary of key lessons from this year's intervention monitoring.

Category	Subject	Monitoring
Productivity	Aquatic vegetation	Track changes in vegetation in Lake Kramen
Habitat	Landscape	Consideration of landscape habitat availability in sampling design
	Landscape	Consider rapid sampling of small wetlands and depressions if they contain water
	Lake	Improve characterisation of habitat availability within lakes, including areas of different depth water.
	Lake	Changes in food, habitat and waterbird distributions as Lakes dry
Drying	Lake	Relate changes in community composition to both changes in habitat and the communities that first occupied the lakes during the flood.

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