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MARINE & FRESHWATER RESEARCH

Urban billabong restoration benefits from Traditional Owner involvement and regular flooding

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ABSTRACT

Context. Floodplain wetlands (e.g. billabongs) in urban environments have significant ecological and cultural value, yet are often highly degraded. Impacts such as reduced flooding and weed invasion continue to threaten these critical ecosystems. Both ecological and Indigenous people's knowledge are important for urban billabong restoration. **Aims.** Our project aimed to (1) assess the response of billabong vegetation to flooding, and (2) increase the role of local Traditional Owners in billabong management. **Methods.** Over 3 years, a team of wetland ecologists and local Wurundjeri Woi Wurrung Narrap ('Country') Rangers surveyed responses of understorey vegetation and the condition and flowering of remnant river red gums (*Eucalyptus camaldulensis*) to flooding across seven degraded billabongs adjacent to the Birrarung (Yarra River) in Melbourne, Australia. Knowledge sharing during 'On Country' days guided restoration targets and management direction. **Key results.** Regular (at least 2 in 3 years) and longer-duration (up to 8 months) flooding promoted native wetland plants, supressed weeds, and improved the condition and reproductive output of river red gums. Monitoring by Indigenous Rangers facilitated the cultural practice of caring for Country. **Conclusions.** Regular flooding and Traditional Owner involvement promotes billabong health. **Implications.** Collaborative research and knowledge sharing with Traditional Owners advances wetland restoration practice and improves care of Country.

Keywords: billabongs, Birrarung, cultural water, environmental water, Indigenous Rangers, traditional ecological knowledge, wetland restoration, Wurundjeri Woi Wurrung, Yarra River.

Introduction

Rivers and their wetlands are some of the most human-affected ecosystems globally (Grill *et al.* 2019). Over half of the world's wetlands have been lost as a result of draining and conversion for agriculture or urban development in the past two centuries (Davidson 2014). Remaining wetlands are often under threat from impacts such as changes to water regimes, urbanisation, and spread of invasive plants and animals (Davis and Froend 1999). Floodplain wetlands in urban environments are often particularly affected. Approaches that combine both ecological and Indigenous peoples' knowledge are needed to restore the ecological and cultural values of these critical ecosystems.

Floodplain wetlands (also known as billabongs in Australia) rely on connectivity with their parent river, with flooding by overbank flows driving their ecology (Junk *et al.* 1989; Poff *et al.* 1997). However, many of the world's floodplain wetlands have become disconnected from their rivers by channel modification and flow regulation. Reduced flooding of wetlands encourages invasion by exotic and terrestrial plant species (Catford *et al.* 2011; Greet *et al.* 2011). Conversely, natural floods or environmental watering can supress such weeds and promote native wetland vegetation (Greet *et al.* 2015; Duong *et al.* 2019). The condition and reproductive output of floodplain trees such as river red gums (*Eucalyptus camaldulensis*) are also dependent on regular flooding, whereas drought-stressed floodplain trees flower less and are at higher risk of dieback and mortality (Jensen *et al.* 2008; Moxham *et al.* 2018).

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Indigenous people's knowledge of wetland ecosystems stem from living and identifying with their land and waterscapes for millennia (Goodall 2008). The value of including Indigenous people and their knowledge in research and management of wetland ecosystems has increasingly been promoted in recent decades, for example, at the Rio 'Earth Summit' (United Nations Conference on Environment and Development, 'Agenda 21', 1992) and in calls for the rights of wetlands to be recognised (O'Donnell *et al.* 2020; Finlayson *et al.* 2022). However, in Australia, the inclusion of Traditional Owners in the scientific investigation and management of freshwater environments remains limited (Jackson and Nias 2019; Moggridge *et al.* 2022). Traditional Owners do not perceive the land, water or biodiversity within a landscape as isolated elements. Rather, these elements are understood holistically as 'Country', to be managed and cared for to provide both sustenance and spiritual fulfilment (Kingsley *et al.* 2013). For Traditional Owners, the need to manage for healthy native vegetation communities stems from their cultural responsibility to care for Country.

Many billabongs within urban areas of Australia have been lost since colonisation (the past *c.* 200 years) and associated land-use change and displacement of Indigenous people and their land-care practices. The few remaining billabongs along the lower Birrarung (Yarra River, Melbourne) retain important ecological, social, and Indigenous cultural values (Leahy *et al.* 2005). The local waterway manager, Melbourne Water, is increasingly looking to restore these billabongs, and recognise the important role that local Traditional Owners should have in their management. Following recent legislative developments such as the *Yarra River Protection (Willip-gin Birrarung Murron) Act* 2017, which recognises the Traditional Owners of the Yarra River as its custodians, and State Government's Water is Life strategy (2022), involvement of Traditional Owners in water management is now also a legal requirement in the State of Victoria. Billabong management often involves revegetation and weed control. More recently this has expanded to include monitoring of water quality, frogs and vegetation to inform environmental watering.

The project reported on here represents a collaboration between Melbourne Water, Wurundjeri Woi Wurrung Cultural Heritage Aboriginal Corporation's Narrap ('Country') Unit and The University of Melbourne to restore Birarrung's billabongs. At the core of this project is the principle of Traditional Owner self-determination. From the inception of the project, the Wurundjeri Woi Wurrung Narrap Unit co-designed project activities and methods to ensure that project outcomes were beneficial to the Ranger team and broader Wurundjeri Woi Wurrung community. This project has two primary aims. First, to monitor and assess vegetation responses to natural and managed flooding (environmental watering) of urban billabongs along the lower Birrarung to inform environmental water management. A second but critical aim of this project is to further the role and leadership of the Traditional Owners, the Wurundjeri Woi Wurrung people, in the management of Country, including vegetation management, research, being part of decision-making processes and performing responsibilities to care for Country.

Materials and methods

Study area

Our study is centred along the lower Birrarung (Yarra River) within the traditional lands of the Wurundjeri Woi Wurrung people. To the Wurundjeri Woi Wurrung, the Birrarung, a river of mists and shadows, and its environs are a living entity that follows Wurundjeri willam traditional estates and forms a central part of their cultural beliefs and practice.

The Birarrung's catchment covers an area of 4046 km^2 and the river meanders 242 km from its source in the foothills of the Great Diving Range to its mouth at Port Phillip. Its lowland reaches formerly supported countless billabongs and broad swamps that were integral to Wurundjeri culture for millennia. These reaches are now largely encompassed within the metropolis of Melbourne (population 5 million), and since colonisation (*c.* 1840) many of its wetlands and billabongs have been destroyed or degraded irreversibly. Those remaining are degraded and threatened by human population pressures such as reduced flooding, weed invasion, and stormwater runoff (Leahy *et al.* 2005).

The completion of the Upper Yarra Dam in 1957 to provide flood protection and supply water to Melbourne substantially reduced flows to the lower Birrarung (by ~1/3) and, thus, overbank flows to its billabongs. Billabongs along the lower Birrarung flood much less frequently today than under natural flow regimes, e.g. Bolin Bolin is currently inundated ~3–4 years rather than annually (Boon 2010).

The billabongs

Seven billabongs along the lower Birrarung form the basis of this study: Annulus, Banyule, Bolin Bolin, Burke Road, Horseshoe, Montpellier and Willsmere (Table 1, Fig. 1). These sites are part of a cultural landscape which has been shaped by Wurundjeri Woi Wurrung occupation and land management for generations (Freedman 2020). These billabongs were previously identified as sites of ecological significance through a prioritisation process undertaken by Melbourne Water. The billabongs were also selected because they represent a gradient from more to less connected to the Birrarung. The estimated volumes and commence-to-fill flow levels based on LIDAR and gauged flows in the Birrarung at Banksia Street, Heidelberg (Melbourne Water streamflow gauge 229135A) are shown in Table 1. Many of these billabongs have received environmental watering (by pumping from the river) in recent years, including Banyule in 2019 and Annulus in 2020 and 2021 (Table 1).

For this study, understorey vegetation and large remnant river red gums were surveyed in spring and late

Table 1. Billabongs surveyed as part of this study and their hydrological attributes.

Billabong	Commence-to-fill flow (ML day^{-1})	Wetland volume (ML)	Primary water source	Environmental watering events
Montpellier	1900	4.2	Overbank flows	None
Horseshoe	5000	31.9	Overbank flows	None
Willsmere–Kew	7200	52.4	Stormwater	2018
Bolin Bolin	9000	91.0	Overbank flows	2017
Burke Road	10 700	31.4	Overbank flows	2018
Banyule	11 800	67.4	Overbank flows	2016, 2019
Annulus	14 000	51.8	Overbank flows	2020, 2021

Billabongs are listed in order from more to less connected on the basis of 'commence-to-fill' flow required in the Yarra River (adapted from Jacobs, unpubl. data, 2019). Commence to fill flow volumes are based on flows at Banksia Street, Heidelberg (MW gauge 229131A).

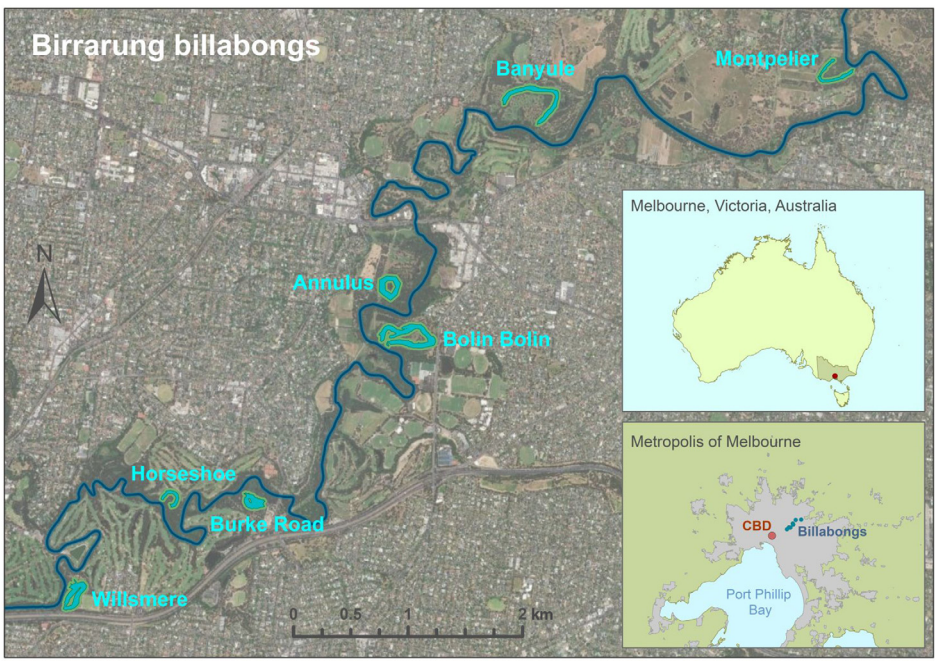

Fig. 1. Map of seven billabongs along the lower Birrarung (Yarra River) that were the focus of this study.

summer–autumn (hereafter spring and autumn surveys) across 3 years (2019–20, 2020–21 and 2021–22) at all billabongs except for trees at Annulus, which has been historically *entirely* cleared. During these surveys, incidences of other wetland and terrestrial biota were noted, with water samples collected for environmental DNA analyses during 2021–22 spring and autumn surveys to be analysed for vertebrate fauna and aquatic vegetation (data not presented). All field-based activities were conducted jointly by University of Melbourne researchers and Narrap Rangers.

Natural and managed flooding 2020–22

There are many contributing factors to streamflow variation along the Birrarung, including environmental-flow releases, rainfall, and stormwater run-off, with the billabongs all connecting (by overbank flows) to the Birrarung at different flow levels (Table 1). In general, 2019 was a relatively dry year, 2020 an average to wet year, and 2021 a particularly wet year (Fig. 2). In 2019, only two billabongs flooded, namely, Montpellier (naturally by overbank flows) and Banyule (environmental watering). In 2020, two billabongs, namely, Burke Road and Banyule, remained dry, with the others flooding by overbank flows, except Annulus, which received environmental watering. In contrast, in 2021 all billabongs flooded naturally by overbank flows, many on several occasions (Fig. 2), except Annulus, which received environmental watering in September, with flooding lasting for 3 months. All of the billabongs were deeply flooded (to >1 m deep) at the time of the spring surveys in November 2021, and all billabongs except Annulus remained partially flooded in March 2022 (i.e. were flooded for up to 8 months).

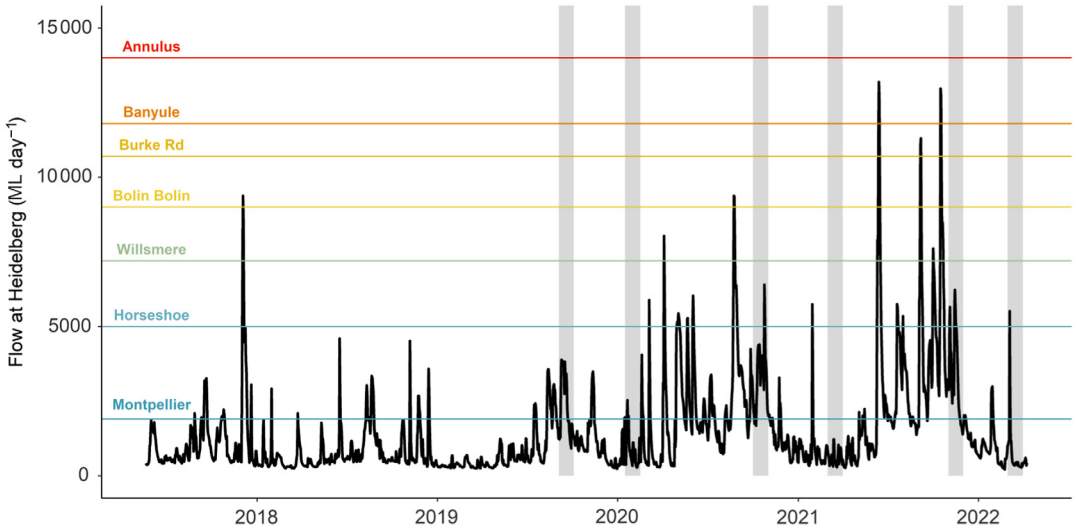

Fig. 2. River levels in the Birrarung (Yarra River) at Banksia Street, Heidelberg, between 01/01/2016 and 1/04/2022 (black line) with the commence-to-fill flow levels indicated for the seven billabongs (CTF levels determined by Jacobs by using LIDAR; Jacobs, unpubl. data, 2019). When river flows in the Birrarung reach the respective CTF levels, the corresponding billabong is flooded by overbank flows; e.g. there were two significant flood events in 2021 when all billabongs except Annulus flooded by overbank flows. Timing of the spring and autumn vegetation surveys are indicated by grey vertical bars.

Understorey vegetation surveys

At each billabong, permanent 10- × 10-m quadrats were established to monitor understorey vegetation. Five quadrats were set up at each of the larger billabongs (Banyule, Bolin Bolin and Montpellier) and three at the smaller billabongs (Annulus, Burke Road, Horseshoe and Willsmere). Quadrats were established in low-elevation areas with the greatest potential to be inundated by natural or managed flooding events, and thus for vegetation change in response to flooding.

Quadrats were aligned along the cardinal compass bearings (i.e. N, E, S, W), marked with a permanent star picket in the north-eastern corner and a photo was taken from the star picket looking south-west each survey. The GPS coordinates of the north-eastern corner of each quadrat were recorded and their locations are presented in Appendix 1 in the Supplementary material.

Quadrats were surveyed by Narrap Rangers and University of Melbourne researchers in spring and autumn each year, with timing being dependent on water levels and accessibility and on any intended watering event. For each survey, all plant species within each quadrat were identified and their cover was visually estimated to the nearest 5% or given 1% where cover was estimated to be <2.5%. Cover estimates were also given for bare ground, leaf litter and surface water where present. When present, water depths were recorded at each corner and at the centre of the quadrat.

A field manual outlining the protocol for the understorey vegetation surveys was produced and provided to all surveyors (and is provided in Appendix 2 in the Supplementary material). This survey manual also includes a plant identification guide for plants commonly observed at the billabongs.

River red gum surveys

At each billabong, between 20 and 30 large old river red gums were identified and mapped (Appendix 1). Older trees were identified on the basis of their girth, growth habit, and presence of features such as a rough bark 'skirt' and hollows. Aerial photos from *c.* 1945 were inspected prior to tree selection, to identify areas that were treed then and thus potentially supporting trees at least 75 years old today (see https://1945.melbourne/). These areas were walked, and all appropriate trees were identified up to a maximum of 30 trees per billabong (n = 157 trees in total). The GPS coordinates of each tree location were recorded, and a photo taken of each tree. From these, annotated maps were produced to help locate the trees each year (Appendix 3 in the Supplementary material).

A field manual outlining the protocol for tree surveys is provided in Appendix 4 in the Supplementary material. In short, for each tree, its diameter at breast height (DBH) was initially recorded. In autumn of 2020, 2021 and 2022, the condition (tree-crown extent: proportion of the existing crown with live foliage, estimated to the nearest 5%) and extent of sexual reproduction (abundance of buds, flowers and cones scored on a scale from 0 to 3; Table 2) of each tree were visually assessed using The Living Murray Method (Souter *et al.* 2010). Important cultural and ecological values of the trees, where apparent, were noted.

Table 2. Ordinal scale used to score the extent of sexual reproduction of river red gums (Souter *et al.* 2010).

Score	Description	Definition
0	Absent	Buds, flowers, cones not visible
1	Scarce	Buds, flowers, cones present but not readily apparent
2	Common	Buds, flowers, cones readily apparent
3	Abundant	Buds, flowers, cones dominate appearance of tree

'On Country' days

As a fundamental part of the project, we hold annual 'On Country' workshops. Oral exchange of knowledge is an integral part of Indigenous Australian traditional culture (Goodall 2008). These workshops were held at one or more of the study billabongs and attended by the Wurundjeri Woi Wurrung's Narrap Unit (including all Narrap Rangers), University of Melbourne researchers, Melbourne Water staff and other water and land managers. At these all-day workshops we shared recent findings from the project, knowledge about the history of the place and its cultural and ecological significance and discussed broader concerns regarding billabong health and management. These days were planned collaboratively, consisting of two or more presentations on themes of interest to Narrap, with plenty of time given to unstructured discussion. From these discussions, notes were recorded, which were later transcribed collaboratively into jointly produced reports on the learnings and ideas generated from the day. Ultimately, these On Country days aimed to identify further research needs, and to strengthen Traditional Owner participation and leadership in collaborative research-project development and management of Country.

Data analysis

For the understorey vegetation survey data, plant species were grouped by origin (native or exotic) and wetland affinity (wetland or terrestrial). For analyses, we considered the following two plant groupings: native wetland plants, which are plants that we would expect to find in these systems naturally; and exotic terrestrial species, which are typically considered 'weeds' by land and water managers and are often the target of control by environmental watering.

To determine understorey-vegetation and tree-condition responses to flooding, we considered only the autumn survey data (because water depths were sometimes prohibitive to surveys in spring). Using linear models, we tested the effects of the following flooding variables on vegetation responses: *flooding*, i.e. whether or not a site flooded in the previous year, and if so, the *duration* and *frequency* of flooding in the previous year; the *number of years a site had been flooded in the previous three*; and the *number of years since a site had flooded*. Flooding, whether natural or by environmental watering, was considered similarly.

For plant cover and tree crown extent we used beta regression models, which included all flooding variables (with *flooding* considered only when neither *frequency* or *duration* were important), a random variable for site (and tree for the crown extent model) and the response variable (cover or crown extent) expressed as a proportion (between 0 and 1; Ferrari and Cribari-Neto 2004). For reproduction, we used ordinal regression with a similar model structure. Flooding variables were considered important when $P \leq 0.05$.

Given the lack of detailed hydrological data for most sites, flooding variables were inferred from flow data for the Yarra River and commence-to-fill levels of the respective billabongs (Fig. 2), and were checked against our survey notes on water depth and detailed anecdotal accounts provided by Sarah Gaskill (Melbourne Water). All analyses were conducted in R (ver. 4.1.0 (2021-05-18), R Foundation for Statistical Computing, Vienna, Austria, see https://www.r-project.org/).

Results

Understorey vegetation

For all surveys (2019–22, spring and autumn), we identified 86 plant species across the seven billabongs, including 32 native and 54 exotic plant species; it is fair to say that these urban billabongs are quite 'weedy'. In total, 30 (18 native, 12 exotic) of these species are wetland plants and 56 (14 native, 42 exotic) are terrestrial plants (see Appendix 2). Thus, terrestrial plants tended to be exotic species.

In general, billabongs least connected with the river (i.e. receiving the least flooding), for example, Burke Road and Banyule, tended to have higher proportions of exotic than native species, but these patterns were not clear (Fig. S1). At only one site, i.e. Willsmere, were higher numbers of native species (17) than exotic species (9) recorded.

The cover of native wetland plants was, on average, higher in 2022 than in previous years (64%, on average, cf. ~50% in previous years), particularly for sites that had been dry the previous year, for example, Banyule (Fig. S2). In contrast, the cover of exotic terrestrial plants was much reduced in 2022, namely, 17% cf. ~30% in previous years, on average, across all billabongs (Fig. S3). Benefits from flooding were seemingly comparable whether natural or by environmental watering. For example, native wetland cover increased from ~5 to ~28% following successive waterings at Annulus.

Considering only autumn surveys, the number of years a billabong was flooded in the past 3 years was important ($P = 0.05$) in determining native wetland plant cover, with sites flooded in two or three of the past 3 years having >50% native wetland plant cover (Fig. 3*a*).

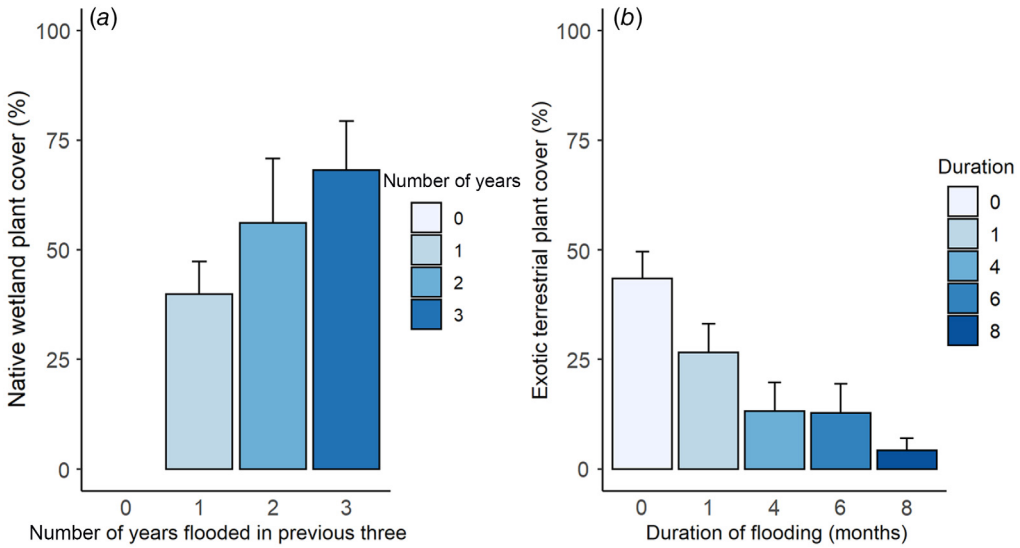

Fig. 3. Relationships between native wetland plant cover and exotic terrestrial plant cover and flooding: (*a*) native wetland plant cover increased with the number of times a billabong was flooded in previous 3 years; (*b*) exotic terrestrial plant cover reduced with longer duration of flooding (months prior to survey).

For exotic terrestrial plant cover, the duration of flooding in the previous year was most important ($P < 0.001$), with exotic terrestrial plant cover decreasing from ~50% in the absence of flooding to <5% after 8 months of flooding prior to the survey (Fig. 3*b*).

River red gum tree condition

The condition (tree crown extent) of the river red gum trees was noticeably better in 2022 than in previous years, across all sites. On average, tree crown extent was 86% in 2022, compared with 80% in both 2020 and 2021 (Fig. S3).

Considering all three surveys, trees were in better condition when billabongs were flooded more regularly ($P = 0.002$) and for longer ($P < 0.001$; Fig. 4*a*, *b*). Trees were generally in best condition (86%) when billabongs had been flooded for two of the previous 3 years, and worst (74%) at billabongs that had not been flooded in the previous 3 years. The mean condition of river red gum trees was almost 10% better when flooded for 8 months in the preceding year than not at all (86% cf. 78%).

River red gum flowering

Reproduction scores (abundance of buds, flowers and cones) recorded for surveyed trees were considerably higher in 2022 than in previous years. In 2022, almost half (45%) of all trees surveyed had abundant buds, flowers or cones compared with less than 20% of trees in 2020 and 2021 (Fig. 5*a*, 6). Across all years, reproduction scores were higher at billabongs that had been flooded in the previous year than at those that had not been flooded (Fig. 5*b*). One-third (34%) of all river red gums at billabongs that recently flooded had abundant buds, flowers and cones, compared with 9% for those at billabongs that had not been flooded.

On Country days

On Country days typically saw robust discussion among the Narrap Rangers, researchers and land and waterway managers on broader concerns regarding billabong health and management. In these discussions, the potential reintroduction of Wurundjeri fire-management practices to promote billabong health was a frequent theme of discussion (Fig. 7). The vegetation around the billabongs was typically described by Traditional Owners as 'messy', with the vegetation too thick and dominated by weeds. Knowledge shared from sediment core analyses at Bolin Bolin (Fletcher 2022) and cultural investigations (Freedman 2020) both indicate that, prior to colonisation, the landscape was regularly burnt by the Wurundjeri Woi Wurrung people and was much more open and thinly wooded. The potential interaction between fire and flooding on billabong vegetation was also raised; blackwater events are common at these sites following flooding. Hence, the (new research) question arose whether fire (i.e. controlled burning) could potentially reduce plant biomass and lead to better outcomes from subsequent flooding.

Many Narrap Rangers expressed a keenness to be involved with further monitoring at the billabongs, because of the learning opportunities it provided, and for the wellbeing benefits of working on Country and performing cultural responsibilities to care for Country. Some suggested a

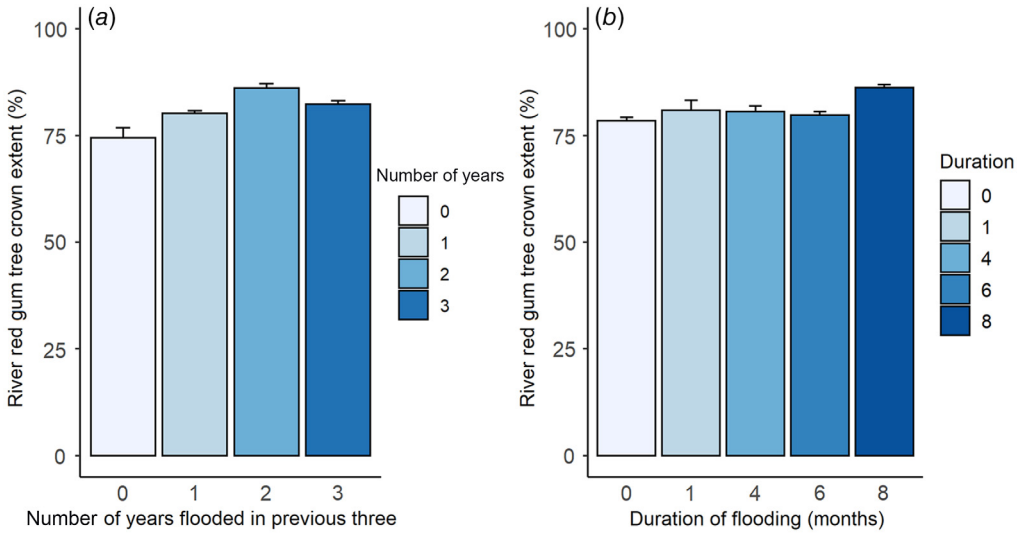

Fig. 4. Relationships between mean tree condition (crown extent, %) of river red gums at six billabongs and flooding. Tree condition increased with (*a*) the number of times a billabong was flooded in previous 3 years, and (*b*) duration of flooding (months prior to survey).

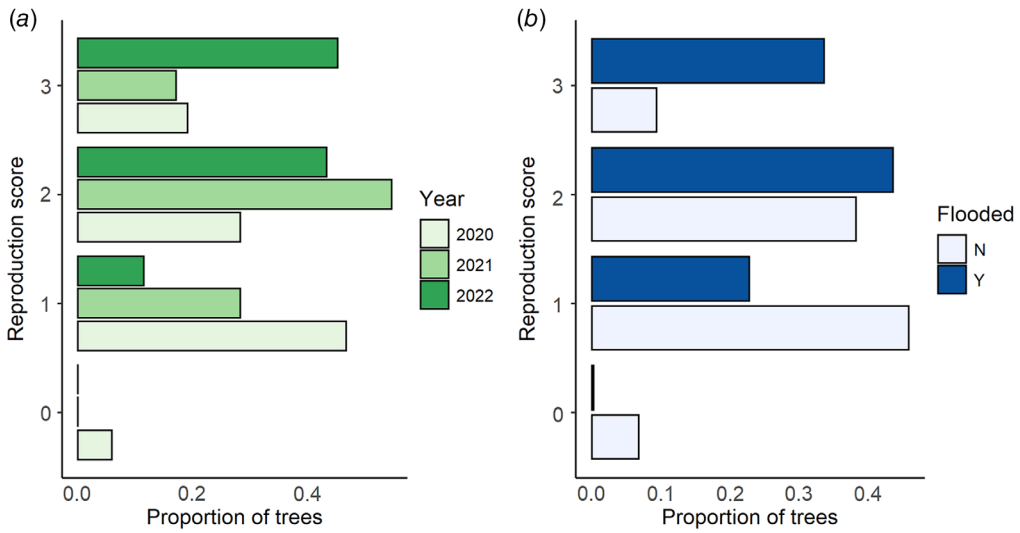

Fig. 5. Extent of sexual reproduction (abundance of buds, flowers and cones) of river red gums surveyed at six billabongs in years 2020–22 and (*a*) year of survey, (*b*) whether or not the billabong had been flooded in the previous year.

broadening of the current monitoring to include a range of other biota, including insects, frogs, fish and terrestrial fauna (this is already occurring by environmental DNA sampling), especially important totemic species such as eels and the pied currawong.

Some Narrap team members emphasised the importance of billabongs in traditional cultural practices and economies and highlighted the potential to re-invigorate such cultural practices (e.g. tree scaring, food or medicinal plant production). It was generally acknowledged that the cultural importance of the billabongs needed to be better recognised and that Wurundjeri Woi Wurrung people should have a greater role in their management.

Discussion

Our observations from vegetation surveys over 3 years clearly demonstrated that flooding promotes native wetland plants and increases the condition and reproductive output of river red gums. Our results suggest that billabong managers aim to achieve flooding of these billabongs in at least 2 in 3 years to promote healthy native wetland vegetation. Importantly, our study illustrated that monitoring by Indigenous Rangers in collaboration with researchers and land and waterway managers can help inform the protection and restoration of freshwater ecosystems and further Traditional Owner involvement and leadership in the management of Country.

Fig. 6. River red gums in good condition following recent flooding at Banyule (left) and Montpellier (right) billabongs, photographed during autumn surveys in 2022.

Fig. 7. Word cloud generated from notes taken during discussions on future billabong research and management at one of the On Country days. Relative size of each word represents how frequently the respective word was voiced.

Ecological benefits from flooding

There were clear benefits from flooding for the native wetland vegetation that inhabits the investigated billabongs. Native wetland plants typically flourished, and exotic terrestrial species (predominantly weeds) were suppressed, in areas that flooded. Similar outcomes from environmental watering and natural flooding have been reported previously, with native wetland plants benefitting from flooding and terrestrial species that lack mechanisms to tolerate flooding senescing from floods (Siebentritt *et al.* 2004; Greet *et al.* 2015; Duong *et al.* 2019).

Following flooding, the remnant river red gums at the billabongs were verdant, with many flowering profusely. Likewise, enhanced floodplain tree condition and elevated levels of reproductive output have been observed for river red gums and black box (*Eucalyputs largiflorens*) in response to flooding along the River Murray (Jensen *et al.* 2008; Moxham *et al.* 2018). In contrast, in the absence of flooding, the condition and reproductive output of these trees is reduced, and the cover of exotic terrestrial plants often high.

From our investigations, joint recommendations were made directly to Melbourne Water. Specifically, we recommended that regular flooding (at least 2 in 3 years) is important for promoting the native wetland vegetation and the condition of river red gums of Birrarung's billabongs. Longer flood durations are preferable, with the condition of river red gums increasing, and the cover of weeds further supressed, as flood duration increases (up to 8 months). Nonetheless, monitoring should be conducted over the longer term within an adaptive management framework to refine and strengthen confidence in these recommendations.

Environmental watering had comparable benefits to natural flooding. Follow-up environmental watering at Annulus in 2021 furthered native vegetation cover gains observed after the first managed flooding event in 2020. Despite being dry for almost 10 years, native wetland plants became dominant where they were previously uncommon after the successive watering events. This included the flourishing of the previously unrecorded *Centipeda cunninghamii*, or 'old man weed', a plant noted by Narrap Rangers as an important traditional medical plant of the Wurundjeri. Indeed, *C. cunninghamii* is a culturally significant plant to many Traditional Owner groups of south-eastern Australia and has previously been demonstrated to benefit from environmental flows (Higgisson *et al.* 2021).

Benefits for wetland biota from flooding were, of course, not limited to the vegetation. During flood events, frogs were frequently heard calling and water birds were abundant, with spawning and breeding commonly observed, often nestled within wetland plants (e.g. sedges or rushes) emergent from the floodwaters.

Broader benefits from Traditional Owner involvement

Benefits of Traditional Owner involvement were multifaceted. Several Narrap Rangers undertook survey work for this study, helping to build capacity and knowledge of scientific survey methods within the group. The project undoubtedly benefited from the broader and historical perspectives on billabong health of the Wurundjeri Woi Wurrung. For example, On Country discussions highlighted the cultural significance of our sites and the important role of fire in the genesis and maintenance of billabong environments. Non-Indigenous project participants were also given opportunities to connect to Country through Indigenous peoples' cultural practices (e.g. smoking ceremonies), language and perspectives. Similar to cross-cultural assessments of billabong condition in northern Australia, our study illustrated how participatory approaches to research provide more holistic understandings for setting restoration targets and guiding freshwater ecosystem management (Russell *et al.* 2021).

Importantly, the joint undertaking of surveys by University of Melbourne researchers and Narrap Rangers helped to build trust. This was evident by the robust discussions during On Country gatherings that have led to the co-development of plans to further investigate past and enhance future Wurundjeri-led management of Birrarung's billabongs. These project developments include further paleoenvironmental investigations (of billabong sediments) to better understand pre-colonisation Wurundjeri land and water-management practices and vegetation communities; eDNA sampling (of billabong floodwaters) to better understand billabong use by fauna including important totemic species; and the reintroduction of cultural burning to manage these sites.

Implications for billabong management

Critically, this project is facilitating a greater role for the Wurundjeri Woi Wurrung people in the management of billabongs On Country. Knowledge borne from On Country workshops is directing project development and future billabong management, for example, the reintroduction of cultural burning. Findings from field surveys are already informing environmental watering planning by Melbourne Water (e.g. locations for watering and watering timing and frequency), as well as the development of broader landscape-scale environmental watering strategies for the lower Birrarung.

Environmental water management is often made to seem easy in wet years, with wetland biota flourishing and weeds being supressed in response to natural flooding. However, dry periods, which are likely to become more frequent with climate change (Barua *et al.* 2013), will continue to pose challenges to the maintenance and restoration of disconnected urban billabongs. Although regular flooding is clearly beneficial for promoting native wetland vegetation and suppressing weeds, other forms of weed control are likely to remain necessary to help dampen the recovery of terrestrial weeds between flooding events. The reintroduction of fire as a vegetation management tool at our sites is strongly recommended by Traditional Owners to help control weeds and for its broader ecological and cultural benefits (Weir *et al.* 2021). Trial cultural burns are now planned for 2023 at Bolin Bolin. Coupled with fire, more regular flooding (potentially by works to improve river–billabong connectivity or treated stormwater inputs) is likely to be a cost-effective approach to weed control and billabong rehabilitation longer term (Boon 2010).

Although this project has a relatively discrete focus, we recognise that it sits alongside and contributes to a broader body of academic and On Country work. Across Australia, Traditional Owners continue to assert cultural rights and responsibilities pertaining to Traditional Country management. The authors acknowledge this important work, including in the areas of Indigenous Water Justice (e.g. Robison *et al.* 2018), Cultural Flows (Moggridge and Thompson 2021) and Traditional Owner Cultural Burning (e.g. Weir *et al.* 2021). We hope to continue and expand this project in the future, and, in so doing, the project team will look to expand the project scope and draw on this broader academic and On Country work.

Our study clearly demonstrated the potential of flooding, natural or managed, to promote native wetland vegetation and restore the health of urban billabongs. In essence, we are sharing this study to provide a modest example of how Traditional Owners, researchers and land and water managers can work together to care for Country.

Supplementary material

Supplementary material is available online.

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Data availability. All data and code for analyses will be made available upon reasonable request to the authors.

Conflicts of interest. The authors declare that they have no conflicts of interest.

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