Evaluating vegetation change at Lake Bitterang following environmental watering

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Front cover photo: Lake Bitterang (Sally Kenny) and undertaking botanical surveys at Lake Bitterang (Claire Moxham)

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Summary

Background

Hattah Lakes is one of the six 'Icon Sites' in The Living Murray (TLM) initiative; a river restoration program designed to improve the health of Murray River ecosystems through targeted environmental watering events. Evaluation of the effectiveness of environmental watering is essential to guide management, and to enable reporting on management outcomes and program effectiveness for investors and stakeholders.

Objective

This project aims to evaluate the effect of an environmental watering event, over a three year period, on the vegetation composition of Lake Bitterang, a long dry lake (5-15 years) that is part of the Hattah Lakes Icon site. A second long dry lake near Chalka Creek that did not receive environmental water was also examined as a 'control'. Wetland vegetation was surveyed prior and twice following the watering event.

Key results

Key findings of vegetation changes after environmental watering included:

- An increase in native plant species richness and abundance.
- A replacement of the terrestrial dry water plant function group with terrestrial damp functional group.
- Compositional changes were driven by two species (*Enchylaena tomentosa* Ruby Saltbush and *Glycyrrhiza acanthocarpa* Southern Liquorice), highlighting the importance of species level analysis.
- A decrease in litter.
- Environmental watering explained 61% of the variation in vegetation community composition, between the Chalka Creek (control) and Lake Bitterang (treatment).
- 99 plant species were recorded (80 native and 19 exotic), and six of these species are listed on DELWP's Advisory List of Rare or Threatened Plant Species.

Recommendations

This study provided valuable insights into the short-term effects of environmental watering on wetland vegetation in long dry lakes, it is recommended that:

- The study design be reviewed to address statistical limitations that have been identified through this analysis.
- Monitoring should be extended over time to allow examination of medium and long-term effects of environmental watering.
- Data from the TLM Condition Monitoring sites should be incorporated into any future analyses examining inundation effects on wetland vegetation.

Conclusion

This study highlights the importance and effectiveness of environmental watering in maintaining the wet/dry floodplain vegetation cycle on a long dry lake system and the integrity of Lake Bitterang. The study findings could reasonably be expected to occur at other dry lakes within the Hattah Lakes system that sit within and outside of the environmental watering infrastructure. In addition, the study provides essential data on which to base management decisions in an environmental watering context.

1 Introduction

1.1 Project context

The Living Murray (TLM) initiative is a river restoration program designed to improve the health of Murray River ecosystems through targeted environmental watering events (MDBA 2013). The program is co-ordinated by the Murray-Darling Basin Authority (MDBA) in partnership with national and state governments. The program has the long-term goal of achieving a healthy working Murray River system for the benefit of the environment and all Australians (MDBA 2011).

Hattah Lakes is one of six 'Icon Sites' located along the Murray River, it was selected to be part of the TLM program for its significant ecological, cultural, recreational, heritage and economic values (MDBA 2009). The Hattah Lakes Icon Site is a semi-arid environment encompassing a 13 000 ha complex of lake systems and floodplains, in north-west Victoria (MDBA 2012). The area is defined by the extent of the 1956 flood event which was the largest known for the region (MDBA 2012). The Icon Site forms part of the Hattah-Kulkyne National Park and Murray-Kulkyne Park (MDBA 2012), it contains important habitat for threatened terrestrial and aquatic flora and fauna.

The lack of connectivity between Hattah Lakes and the Murray River, together with the extraction of water for agriculture, industry and urban use, and severe lake drying conditions over the last decade, has had a negative impact on the ability of the Hattah Lakes ecosystem to maintain healthy vegetation (MDBA 2012). This has resulted in a decline in the environmental health of the system and habitat value for fauna (Cunningham *et al*. 2009). Floodplain health is critical for maintaining ecological functions in the broader riverine ecosystem and in supporting Australia's Ramsar Convention commitments at Hattah's internationally important wetlands (MDBA 2012). Since 2005, environmental watering has been implemented to mitigate the effects of the reduced frequency of natural flooding, by inundating the Hattah Lakes Icon Site (MDBA 2009).

Predicting and demonstrating the effectiveness environmental watering to maintain ecosystem health is becoming increasingly important, particularly in drying climates where there is insufficient rainfall to maintain semi-arid floodplain ecosystems (Colloff and Baldwin 2010, McGinness *et al.* 2013). Monitoring is a key component of this process because it provides feedback on system responses to competing management actions. This feedback allows managers to learn about the effectiveness of different management actions, thereby, refining management strategies to be more effective and efficient.

The main objective of this project is to evaluate the wetland vegetation response to environmental watering at Lake Bitterang, a long-dry wetland at Hattah Lakes (MDFRC 2014). A second long dry lake near Chalka Creek (hereafter, Chalka Creek) was also examined as a 'control'. The project was designed and established in 2013 (MDFRC 2014), before environmental watering began in 2013.

1.2 Target lakes

Lake Bitterang

Lake Bitterang (73 ha, Figure 1) is a Ramsar listed wetland (DSE 2003) and is defined as a persistent temporary wetland (remaining wet 49% of the time) meaning it is intermittently flooded. It may retain water for several months or years at a time dependent on the level of flooding (SKM 2004, MDBA 2012). Flood history of the lake can be determined from information compiled from satellite imagery (> 1972; Andrew Greenfield pers. comm.) which indicates that there was water in Lake Bitterang in the mid- and late-1970s, early 1980s, early and mid-1990s, during a natural flood event in 2011, and from December 2013 to the current day. The earlier flooding events (1970s, 1980s, 1990s) were natural floods and water remained in the lake for two years on average (SKM 2004), with a range of one month to 3.5 years. During the 2011 natural flood event, water was present in the middle of the lake at the lowest point. The current presence of water is due to environmental watering which occurred in late 2013 and again in mid-2014.

Figure 1. Water receding at Lake Bitterang**.**

Chalka Creek dry lake

The Chalka Creek dry lake (Figure 2) can be considered an episodic lake/wetland which rarely floods and retains water for short periods of time (several months to a year; SKM 2004). The Chalka Creek lake is excluded from the Icon site and does not receive environmental watering, only natural flood events. It is not explicitly covered by the flood history information, but GIS flood history layers (MCMA 2014a, 2014b) suggest it was flooded the 1956 natural flood event, again in the mid-1970s and partially flooded during the summer 2011 natural flood event.

Figure 2. Vegetation surveys at the long dry Chalka Creek lake.

Thus, prior to the TLM initiative, both lakes would have last received water during the 2011 flood. Before this flood event, Chalka Creek lake has been dry since the 1970s and Lake Bitterang since the 1990s.

Vegetation and ecological characteristics of long dry lakes

In many floodplain ecosystems, vegetation community dynamics are predominantly driven by the hydrological regime (Junk *et al.* 1989, Ralph and Rogers 2011). This is often regular, occurring annually and in the same season (Puckridge *et al.* 1998). However, semi-arid floodplains have sporadic hydrology where the variable flood pulses alternate between prolonged periods of drought (the 'dry') and flood events (the 'wet'; Walker *et al.* 1995; Puckridge *et al.* 1998; Colloff and Baldwin 2010; Baldwin *et al.* 2013; Bino *et al.* 2015; Thapa *et al.* 2015); where plants and plant communities respond to resource availability and associated variable productivity (Thapa *et al*. 2015). Plant communities in these semi-arid floodplain systems often have three main vegetation 'states' that relate to water availability (Figure 3):

1) 'wet' - where the wetland is inundated and aquatic species are often present.
2) 'drying' where the lake is drying – this vegetation state is dominated by water respondent species (e.g. terrestrial damp species).
3) 'dry' where the lake is dry (often for long periods) – this vegetation state is often dominated by dry terrestrial floodplain species such as grasses and saltbushes.

In semi-arid systems the length of these states may last over long time periods (e.g. decades). Long dry lakes are ecologically interesting as the dry state lake beds are inhabited by terrestrial dry species (e.g. saltbushes) rather than the aquatic and wetland fringing vegetation ordinarily expected in seasonally intermittent lakes/wetlands. Following inundation (wet state), it is expected that these terrestrial dry species will die as a result of their inability to survive flooding (Casanova and Brock 2000; Capon 2003; Nishihiro *et al.* 2004; Raulings *et al.* 2010). As the water starts to recede (drying state), the littoral zone will be vegetated by species that can tolerate the damp soil on the edge of the lake (e.g. terrestrial damp species). Over time these species may die and be replaced by terrestrial species more capable of surviving the dry conditions. However, the suite of species able to return following inundation is affected by propagule viability in the lake bed. This may relate to the availability of a soil seed bank or seed being carried into the lake. Many floodplain species have sizeable persistent soil seed banks that respond to inundation (Brock and Rogers 1998; Capon 2003), however, these seed banks do have temporal limits.

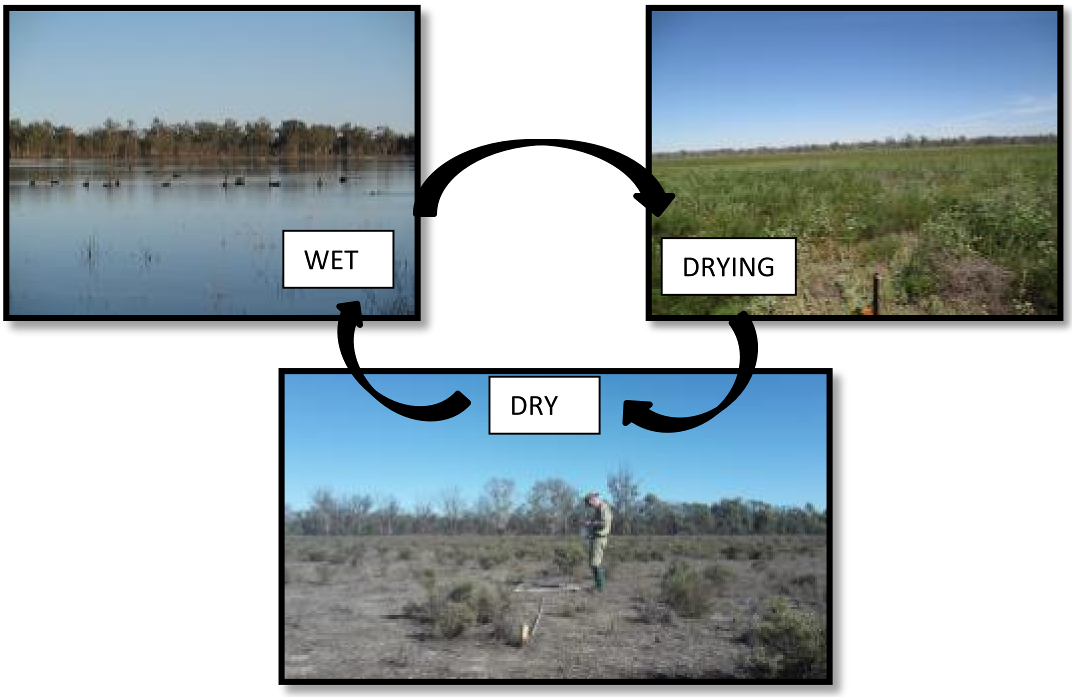


Figure 3. A simplified representation of the wet-dry cycle of floodplain vegetation.

This wet-dry cycle varies temporally, it may take months or years to complete the full cycle depending on external ecological drivers such as climate and flooding frequency. This temporal variation can be problematic for monitoring vegetation responses to environmental watering and reporting program outcomes.

This report provides insights into vegetation responses at Lake Bitterang to environmental watering over a three year period.

2 Methods

2.1 Project design

The project was designed and established in 2013, by the Murray-Darling Freshwater Research Centre (MDFRC). Two lakes that are infrequently flooded were selected to examine vegetation responses to environmental watering: Lake Bitterang and a dry lake within the Chalka Creek catchment (Figure 4). The Chalka Creek site is used as a 'control' site (MDFRC 2014) and is located beyond the range of environmental watering, thus is only flooded by natural events.

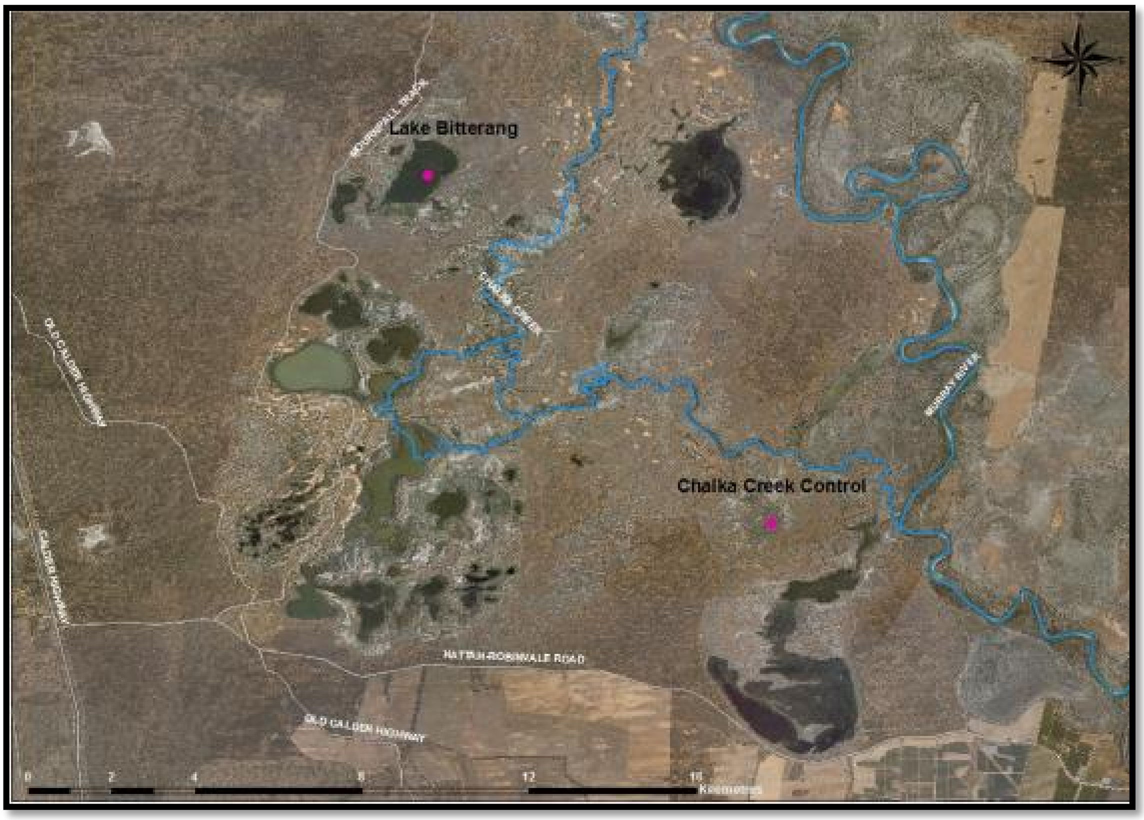
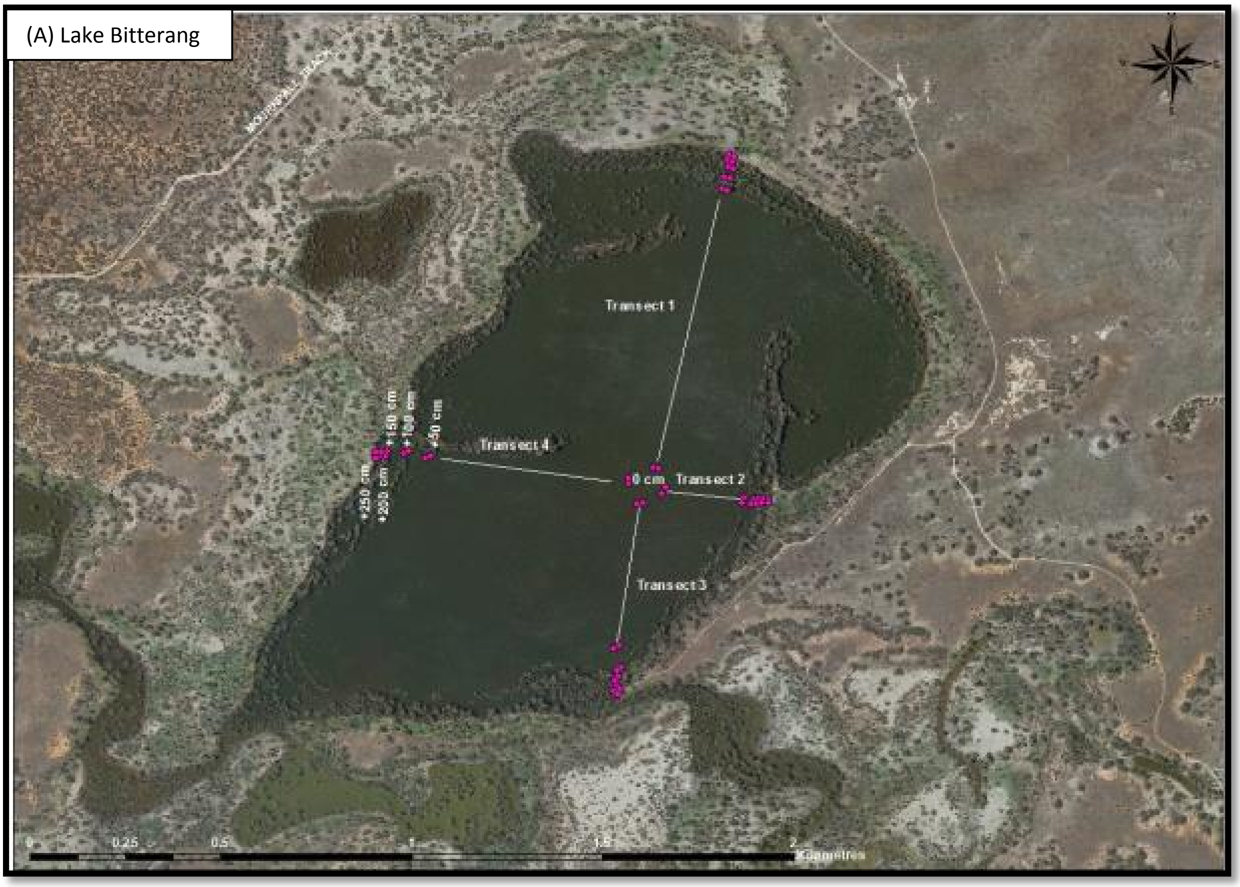


Figure 4. The location of Lake Bitterang and Chalka Creek study sites within Hattah-Kulkyne National Park.

The sampling design and monitoring protocol follow that established by the TLM Condition Monitoring program (MDFRC 2011). Four transects, that span a range of elevations, were established at each site in January 2013 (Lake Bitterang; Figure 5A) and March 2013 (Chalka Creek; Figure 5B). Along each transect, floristic sampling quadrats were located at 50 cm elevation intervals (0 cm elevation (centre of the lake), +50 cm and + 100 cm elevations). Three additional elevations (+150 cm, +200 cm and +250 cm) were also established at Lake Bitterang (MDFRC 2014). In total, there were 24 floristic quadrats at Lake Bitterang and 12 at Chalka Creek.

This placement of the floristic quadrats at 50 cm elevation intervals often resulted in a lack of spatial independence between quadrats at the elevation intervals, particularly at the 0 cm elevation.

Understorey vegetation was assessed following the protocols outlined in MDFRC (2011, 2014) and Nicol and Weedon (2006). Briefly, the presence/absence of all plant species were recorded within each quadrat at each elevation point. Each quadrat was located roughly perpendicular to the lake edge and comprised 15 contiguous 1 m^2 cells to produce a frequency score for each species. The frequency score for each species was determined by recording a species as 'present' if it was rooted within any cell and alive. Thus, each plant species had a frequency score between zero and 15 for each quadrat at each elevation point. Dead plants were not recorded. Substrate type (bare ground, litter, biological soil crust, water) was also recorded within certain constraints (MDFRC 2014). For example, litter was only recorded if it covered at least 50% of each cell.



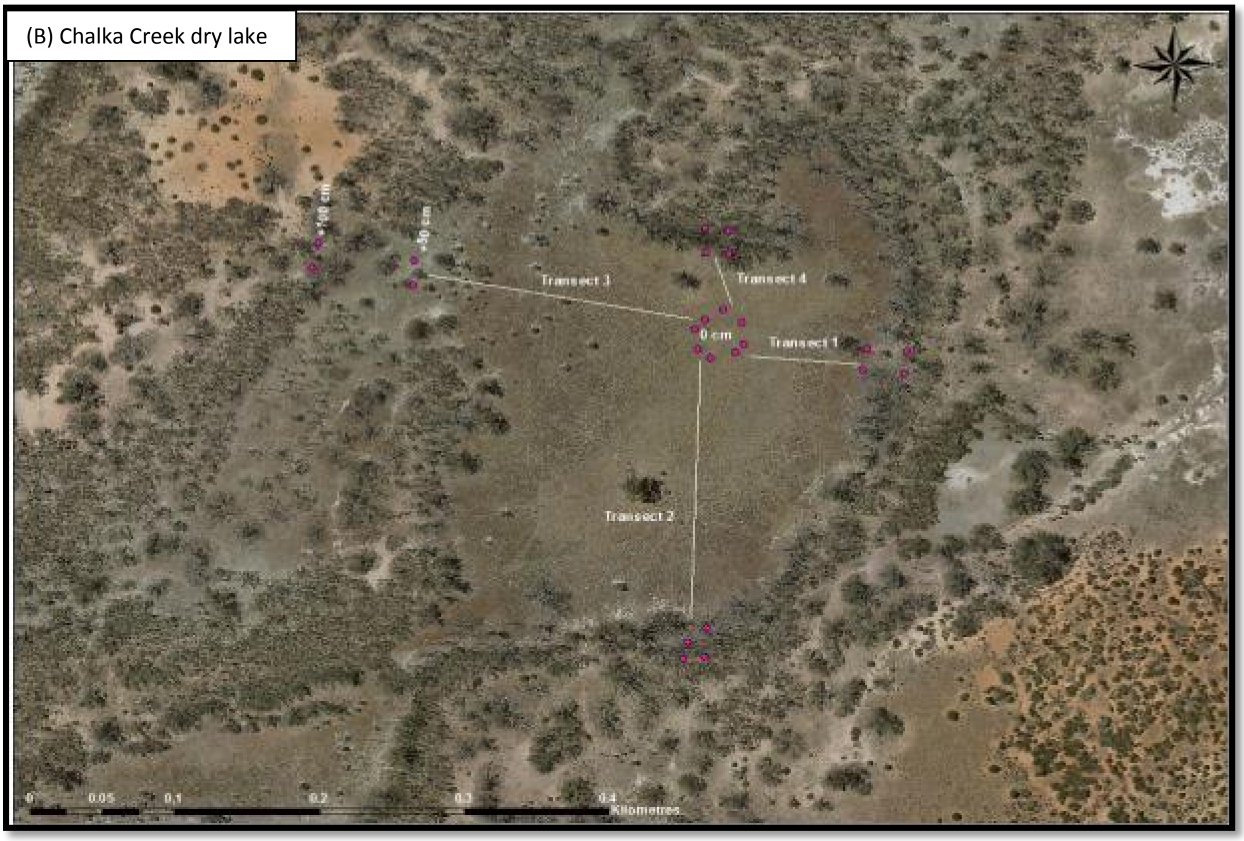


Figure 5. The location of (A) the four Lake Bitterang transects and (B) the four Chalka Creek transects (note: the elevation points are shown on one transect for clarity). Each pair of pink dots represents either end of a quadrat at each elevation point.

Plant species were identified using the Flora of Victoria (Walsh and Entwisle 1994, 1996, 1999) and nomenclature follows Walsh and Stajsic (2007) and the Victorian Biodiversity Atlas (DELWP 2016). Plants were identified to the greatest level possible, based on the availability of plant material. For example, some new emerged species could only be identified to family level (e.g. Poaceae spp.), while others could be identified to genus or species level.

Permanent photo points were established on transect one at each site and photos were repeated at each survey. The photo point at Lake Bitterang was at +50 cm and at +100 cm at Chalka Creek. GPS locations were recorded for each photo point and at both ends of each quadrat along the elevation gradient (Appendix 1).

Data was collected at Lake Bitterang in January 2013, January or March 2014 by MDFRC staff, and in May 2016 by Arthur Rylah Institute (ARI) staff. Data was collected at the Chalka Creek site in March 2013 and April 2014 by MDFRC staff and in May 2016 by ARI staff.

2.2 Water plant functional groups

Water plant functional groups are a useful measure to compare temporal vegetation responses to environmental watering. At broad spatial scales functional groups address the variation in the data, such as among plant communities, species identification, observer variation, and climatic variables (Merritt *et al.* 2010; Campbell *et al.* 2014). These functional groups are based on how species respond to flood events and species water requirements over their life time (Brock and Casanova 1997).

Each plant species recorded during this study were allocated to one of five established water plant functional groups (Table 1) following Brock and Casanova (1997), Casanova (2001) and Campbell *et al.* (2014), or using the key in Casanova (2011). A sixth functional group (T) was used to identify species which were terrestrial but could not be identified beyond family level (e.g. Poaceae spp.).

Table 1. Water plant functional groups and their descriptions (Casanova 2011).

Water plant functional group	Definition
ATe	Emergent amphibious fluctuation tolerating species which can survive in saturated soil or shallow water but most of the plant most be above water.
ATl	Low-growing amphibious fluctuation tolerating species which can germinate on either saturated soil or under water but must be above water to flower and set seed.
ATw	Woody amphibious fluctuation tolerating species which require water to be present in their root zone year round but will germinate in shallow water or on drying soil.
Tda	Terrestrial damp species which may germinate following flooding or high rainfall and require the soil to remain damp for approximately three months. They cannot tolerate flooding but exist in dry puddles, drainage lines and wetland edges.
Tdr	Terrestrial dry species which do not require flooding but which will germinate in damp soil following a flood event. They may invade riparian zones and wetland edges if these remain dry for an extended period of time (e.g. episodic lakes).
T	Terrestrial species identified to family or genus level only which cannot be reliably allocated to either Tda or Tdr.

2.3 Data analysis

Data analysis examined vegetation change over time, at the lake scale. Analysis focused on plant species richness, composition, frequency and water plant functional groups.

Average species richness and frequency (vegetation abundance) was calculated for each survey period at each site. Floristic attributes that were examined statistically included total, native and exotic species richness and abundance, dominant species abundance (*Enchylaena tomentosa* var. *tomentosa* and *Glycyrrhiza acanthocarpa*) and water plant functional group abundance (Tda and Tdr).

Generalized Linear Mixed Models (GLMMs) were used to construct a model for each response variable that included treatment (watered vs. unwatered control) and survey year (2013 [pre-watering] vs. 2016 [post-watering]) as fixed effects. A random effect related to the repeated nature of the quadrat sampling was included to account for possible correlation structures in the data. For each factor a single level was selected as the level to which all other comparisons were made (i.e. Treatment – 'unwatered', Survey year – '2013'). The GLMMs were constructed using the lme4 package in R v. 3.2.4 (R Core Team 2016). Additional explanation of model construction and evaluation procedure is presented in Appendix 2.

To examine overall vegetation composition changes, non-metric multidimensional scaling ordination (nMDS) was used to visualise the separation of quadrats across the two sites based on species composition and frequency (Kent and Coker 1992, Clarke 1993). Average species frequency was calculated within each elevation irrespective of transect number at each site. Three separate ordinations were run: (1) both sites combined, (2) Lake Bitterang only and (3) Chalka Creek only with stress values of 0.13, 0.07 and 0.09 respectively. Stress values < 0.1 indicates a good ordination with little change of misinterpretation and stress values of < 0.2 indicate a useful ordination but other methods should be used to cross-check conclusions (Clarke 1993). The association between floristic composition and environment variables (e.g. elevation and inundation) were explored by fitting directional vectors through the ordination space using the envfit procedure to highlight separators between groups of quadrats (Kantvilas and Minchin 1989). These were year, elevation and inundation level. Inundation level was a simple presence/absence categorical variable with '1' representing quadrats not inundated and '2' representing inundated quadrats. The envfit procedure allows for the determination of statistical significance of key variables with respect to species composition at these sites. In addition, the adonis (permutational multivariate analysis of variance) procedure was also used to determine if there were: (1) between year differences in species composition within sites and (2) between site differences in species composition across the survey years. The ordination, envfit and adonis were carried out using the Vegan 2.3-4 package in R v. 3.2.4 (R Core Team 2016).

3 Results

3.1 Species richness and abundance

Ninety-nine plant species were recorded during this study, of which 19 species were exotic and 80 were native. The number of species recorded in each year fluctuated; however the number of native species was always substantially greater than the number of exotic species (Figure 6). Six species are listed on DELWP's Advisory List of Rare or Threatened Plant Species (DELWP 2015). Five of these species, *Alternanthera* sp. 1 (Plains), *Lepidium pseudohyssopifolium, Sclerolaena patenticuspis, Swainsona microphylla* and *Verbena officinalis* var. *africana,* were recorded in only one of the survey periods. *Calotis cuneifolia* was recorded in two survey periods (2013 and 2016). Three threatened species, *L. pseudohyssopifolium, S. patenticuspis* and *S. microphylla* were recorded once only; while *Alternanthera* sp. 1 (Plains) was recorded in two quadrats, *C. cuneifolia* in six quadrats and *V. officinalis* var. *africana* in three quadrats.

A detailed species list is presented in Appendix 3.

3.1.1 Species richness

At Lake Bitterang, 66 plant species were recorded across all three survey periods. Native species (58) far outweighed the number of exotic species (eight). Four threatened species were recorded at Lake Bitterang: *C. cuneifolia, L. pseudohyssopifolium, S. patenticuspis* and *V. officinalis* var. *africana*. *Verbena officinalis* var. *africana* was only recorded in 2016 post-flooding. Average species richness was lowest in the second survey period in 2014 when the lake was flooded, and was highest in the second survey period in 2016 (Figure 6A).

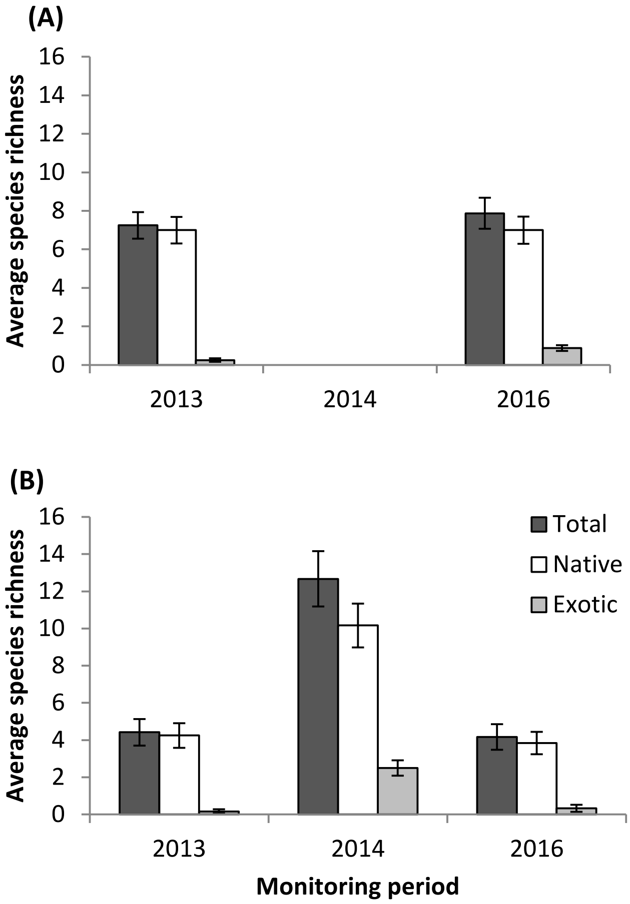


Figure 6. Average species richness (+/- standard error) at (A) Lake Bitterang and (B) Chalka Creek across the three survey periods. Note Lake Bitterang flooded in 2014.

Sixty plant species were recorded across all three survey years at Chalka Creek. Again the number of native species (45) exceeded the number of exotic species (15). Two threatened species were recorded at Chalka Creek: *Alternanthera* sp. 1 (Plains) and *S. microphylla*. Average species richness was lowest in the third survey periods in 2016 and highest in the second survey period in 2014 (Figure 6B), following a year of above average rainfall.

The environmental watering at Lake Bitterang was associated with a significant increase in both total and native species richness (Table 2). However, this flooding event also increased exotic species richness in the longer term.

Table 2. Modelling results for total, native and exotic species richness. Significant results are in bold.

Variable	Parameter	Estimate	SE	z value	P value
Total species richness	Intercept	1.414	0.127	11.100	<0.001
	Watered	**0.562**	**0.136**	**4.117**	**<0.001**
	2016	0.036	0.102	0.348	0.728
Native species richness	Intercept	1.397	0.126	11.114	<0.001
	Watered	**0.544**	**0.134**	**4.062**	**<0.001**
	2016	-0.035	0.106	-0.331	0.741
Exotic species richness	Intercept	-2.102	0.520	-4.043	**<0.001**
	Watered	0.801	0.467	1.716	0.086
	2016	**1.129**	**0.426**	**2.649**	**0.008**

NOTE: For all models a single level (e.g. Control or 2013) within each factor (e.g. Treatment or Year) is used as the reference level. Hence, where the level reported on above is 'Watered' this means that the estimates/errors/P-value refer to the that level as compared to the reference level (i.e. Control). The nature of the estimate (+ means 'higher', - means 'lower') in combination with the P-value (≤ 0.05 'levels different', >0.05 'levels similar') will indicate if a level differs from the reference level, and the direction of change.

3.1.2 Floristic abundance

The results show an increase in the average frequency of native and exotic species over time at Lake Bitterang (Figure 7A). The greatest frequency of both was recorded in the third survey period in 2016. In comparison, at Chalka Creek the frequency of native and exotic species fluctuated over time and peaked in the second survey period in 2014 (Figure 7B). The frequency of exotic species was low at both sites. The environmental watering at Lake Bitterang was not associated with a change in floristic abundance, but there was a significant increase in total, native and exotic abundance between the first and third survey periods (Table 3).

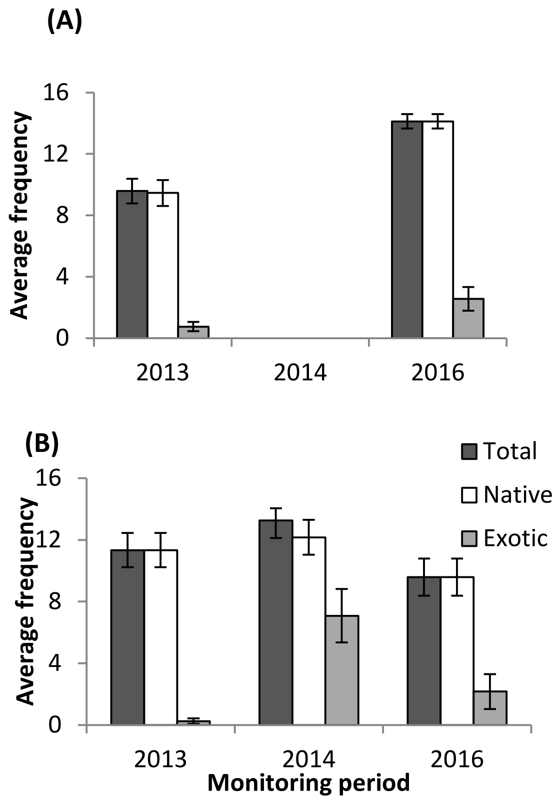


Figure 7. Average total, native and exotic plant frequency (+/- standard error) at (A) Lake Bitterang and (B) Chalka Creek. Note: Lake Bitterang flooded in 2014.

Table 3. Modelling results for total, native and exotic abundance. Significant results are in bold.

Variable	Model	Estimate	SE	z value	P value
Total abundance	Intercept	0.6835	0.342	1.999	0.0457
	Watered	0.3844	0.4118	0.933	0.3506
	2016	**0.8339**	**0.1732**	**4.814**	**<0.001**
Native abundance	Intercept	0.6708	0.3476	1.93	0.0536
	Watered	0.3693	0.4189	0.882	0.378
	2016	**0.8743**	**0.1736**	**5.038**	**<0.001**
Exotic abundance	Intercept	-5.4479	0.8946	-6.09	<0.001
	Watered	1.1241	0.906	1.241	0.215
	2016	**1.9336**	**0.3128**	**6.181**	**<0.001**

NOTE: For all models a single level (e.g. Control or 2013) within each factor (e.g. Treatment or Year) is used as the reference level. Hence, where the level reported on above is 'Watered' this means that the estimates/errors/P-value refer to the that level as compared to the reference level (i.e. Control). The nature of the estimate (+ means 'higher', - means 'lower') in combination with the P-value (≤ 0.05 'levels different', >0.05 'levels similar') will indicate if a level differs from the reference level, and the direction of change.

3.2 Water plant functional groups

The abundance of water plant functional groups varied across the three survey periods at both sites (Figure 8, Table 4). At Lake Bitterang, the dominant functional group significantly changed between the first and last survey periods, with the abundance of the terrestrial dry group decreasing and the terrestrial damp group increasing in 2016 post-watering (Figure 8A, Table 4). At the first survey period, the two most common species were *Enchylaena tomentosa* (terrestrial dry) and *Glycyrrhiza acanthocarpa* (terrestrial damp). *Glycyrrhiza acanthocarpa* was still very common in the third survey period in 2016; however, *Eucalyptus camaldulensis* (Atw - woody amphibious fluctuation tolerator) was the most commonly recorded species, generally as seedlings or saplings.

The terrestrial dry group was the dominant functional group at Chalka Creek across all three survey periods, and this group was in higher abundance (abet marginally) at this site than at Lake Bitterang in the initial monitoring period (Figure 8B, Table 4). In the first survey period in 2013, the two most commonly recorded species were again *E. tomentosa* and *G. acanthocarpa* and while these were also common in subsequent survey periods, they were not the most abundant species. *Erodium* spp. and the exotic *Brassica tournefortii,* both terrestrial dry species, were the most commonly recorded species in the second (2014) and third (2016) survey periods, *Maireana brevifolia* (terrestrial dry) was the most common species recorded.

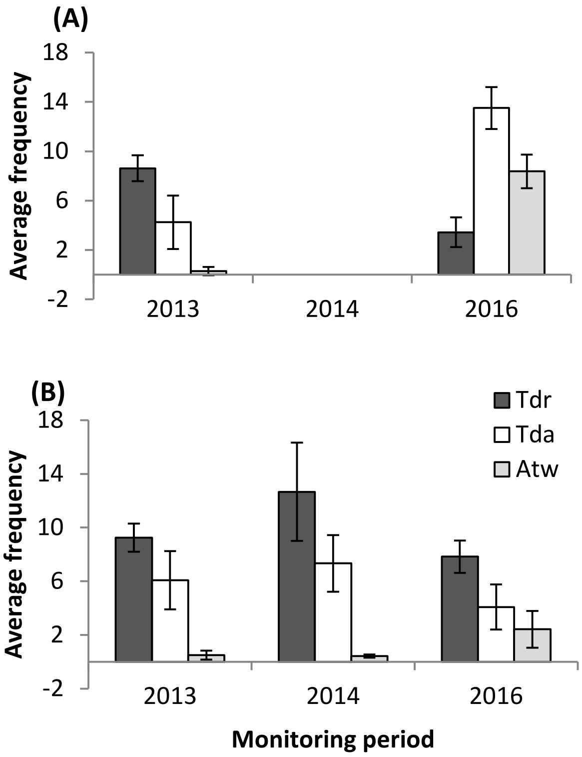


Figure 8. Average frequency (+/- standard error) of water plant functional groups at (A) Lake Bitterang and (B) Chalka Creek over the three survey periods. Note: Lake Bitterang flooded in 2014; Tdr = terrestrial dry, Tda = terrestrial damp, ATw = woody amphibious fluctuation tolerator WPFGs.

Table 4. Modelling results for the terrestrial dry (Tdr) and terrestrial damp (Tda) WPFG abundance. Significant results are in bold.

Variable	Model	Estimate	SE	z value	P value
Tdr (terrestrial dry)	Intercept	0.9429	0.3309	2.85	0.0043
	Watered	-0.7551	0.3957	-1.908	0.0563
	2016	**-1.2489**	**0.1573**	**-7.938**	**<0.001**
Tda (terrestrial damp)	Intercept	-3.8551	0.9058	-4.256	<0.001
	Watered	**3.0431**	**1.0408**	**2.924**	**0.003**
	2016	**2.8429**	**0.2425**	**11.725**	**<0.001**

*NOTE: For all models a single level (e.g. Control or 2013) within each factor (e.g. Treatment or Year) is used as the reference level. Hence, where the level reported on above is 'Watered' this means that the estimates/errors/P-value refer to the that level as compared to the reference level (i.e. Control). The nature of the estimate (+ means 'higher', - means 'lower') in combination with the P-value (≤ 0.05 'levels different', >0.05 'levels similar') will indicate if a level differs from the reference level, and the direction of change.

3.3 Species compositional change over time

Species composition at the two sites changed over time, although this change was more obvious at the Lake Bitterang site (Figure 9). At Chalka Creek, the different elevation quadrats largely clustered together irrespective of survey period, indicating strong similarity in species composition and average frequency over time. In contrast, species composition and average frequency at Lake Bitterang was more variable due to the environmental watering events in late 2013 and 2014. All Lake Bitterang quadrats (all elevations) in the first survey period (2013) and some in the third (2016, 100 – 250 cm) were more similar to the Chalka Creek quadrats than to the Lake Bitterang quadrats in the second survey period in 2014 (all elevations) and the lower elevations (0 – 50 cm) in the third survey period (Figure 9). The inundation vector explained 60.65% ($p < 0.0001$) of the variation in species composition across the different elevations, two sites and three survey periods. Pairwise tests (adonis) indicated there was a significant difference between the two sites and along an inundation gradient (Table 5). At Lake Bitterang, there was a significant difference between quadrats in each survey period, along the elevation gradient and along an inundation gradient (Table 5). Whereas, at Chalka Creek there was a significant difference between quadrats along the elevation gradient, but not between survey periods (Table 5).

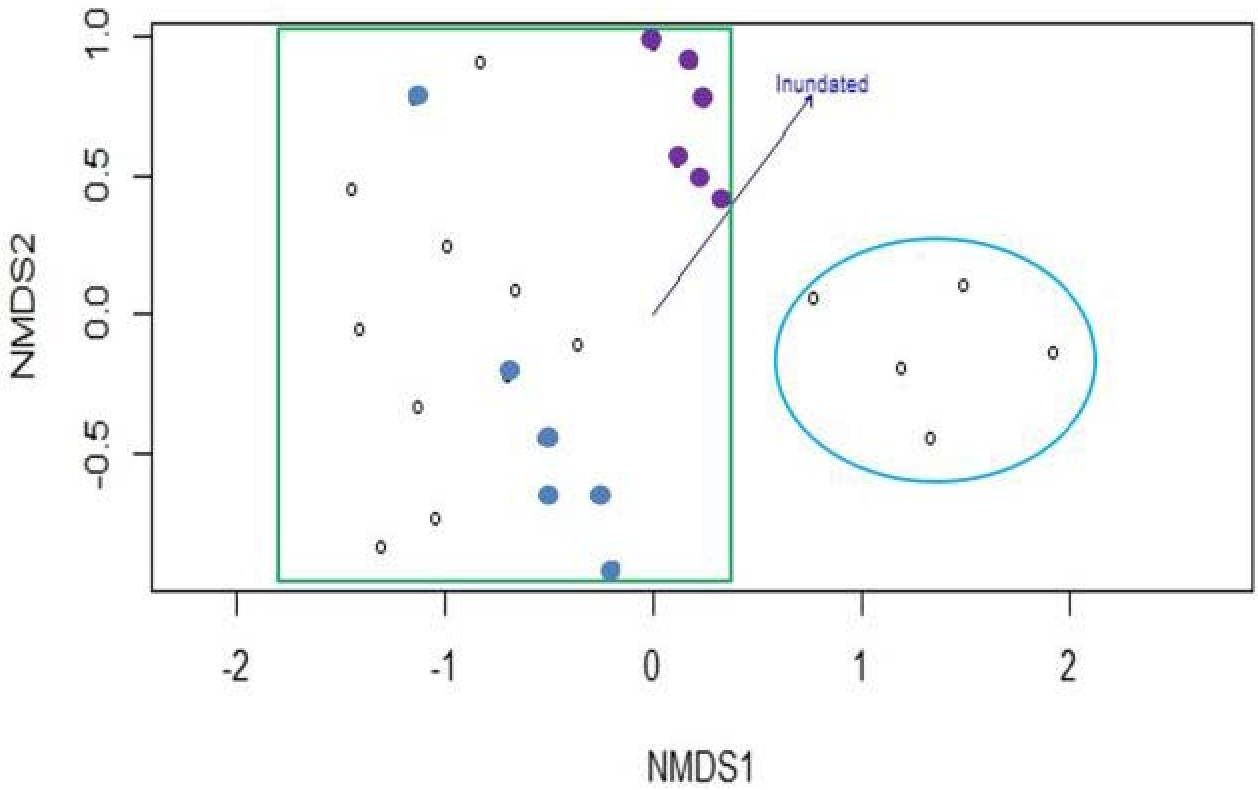


Figure 9. nMDS ordination based on species composition of different elevation quadrats at Lake Bitterang and Chalka Creek. Note: the green rectangle encompasses all Chalka Creek quadrats, and the Lake Bitterang quadrats in the first survey period in 2013 at all elevations (blue circles), and the third survey period in 2016 at 100 – 250 cm elevations only (purple circles). The large blue circle encompasses the second survey period quadrats at Lake Bitterang at all elevations, and the third survey period quadrats at 0 – 50 cm elevations. Also there is some overlap of quadrats within the large blue circle.

Table 5. Results of the pairwise tests (adonis) for both sites combined (see Figure 9), for Lake Bitterang and Chalka Creek. Note: Pr (> F) in bold are significant. Inundation was not tested for Chalka Creek as it did not receive environmental watering or natural flood events during the study.

Site(s)	Variable	F	R^2	P value
Both	Year	1.32	15.83	0.24
	Location	**4.44**	**15.1**	**0.004**
	Inundation	**6.59**	**20.85**	**<0.0001**
Lake Bitterang	Year	**3.1**	**15.87**	**0.005**
	Elevation	**2.85**	**15.1**	**0.005**
	Inundation	**3.08**	**16.14**	**0.003**
Chalka Creek	Year	1.32	15.83	0.24
	Elevation	**3.61**	**34.04**	**0.005**

3.4 Dominant species responses

The vegetation composition and WPFG changes detected in the above results are largely driven by two plant species that dominated the vegetation: *E. tomentosa* (Ruby Saltbush) in the terrestrial dry WPFG and *G. acanthocarpa* (Southern Liquorice) in the terrestrial damp WPFG. Analysis of the abundance of these species reflects the above results with a significant decrease in *E. tomentosa* and an increase in *G. acanthocarpa* after the environmental watering event (Figure 10, Table 6). In addition, *G. acanthocarpa* occurrence was initially higher at Lake Bitterang.

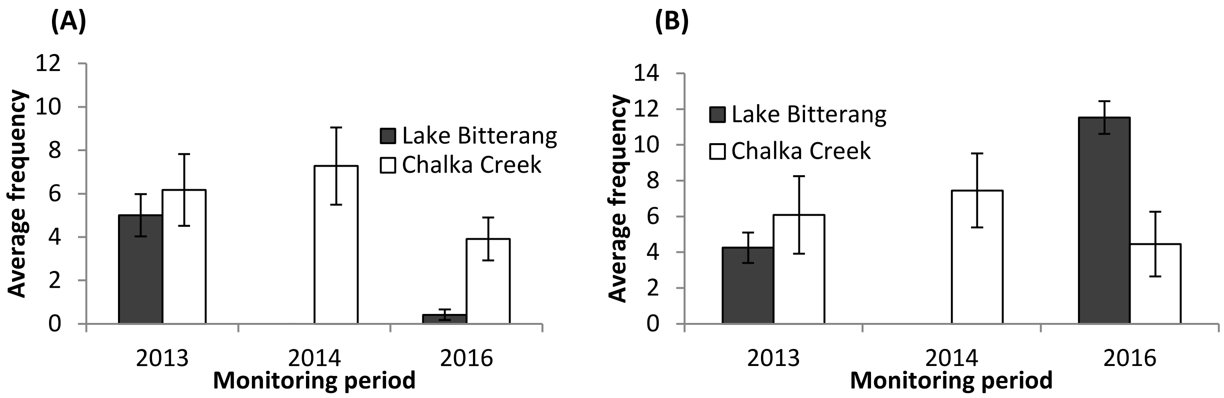


Figure 10. Average frequency (+/- standard error) of (A) *E. tomentosa* and (B) *G. acanthocarpa* at Lake Bitterang and Chalka Creek over the three survey periods. Note: Lake Bitterang flooded in 2014.

Table 6. Modelling results for Ruby Saltbush (*Enchylaena tomentosa*) and Southern Liquorice (*Glycyrrhiza acanthocarpa*) abundance. Significant results are in bold.

Variable	Model	Estimate	SE	z value	P value
E. tomentosa Ruby Saltbush	Intercept	-0.2863	0.5732	-0.499	0.617
	Watered	-1.0548	0.6963	-1.515	0.130
	2016	**-2.4555**	**0.2257**	**-10.879**	**<0.001**
G. acanthocarpa Southern Liquorice	Intercept	**-2.4199**	**0.7454**	**-3.247**	**0.001**
	Watered	1.527	0.8588	1.778	0.0754
	2016	**0.771**	**0.1595**	**4.833**	**<0.001**

NOTE: For all models a single level (e.g. Control or 2013) within each factor (e.g. Treatment or Year) is used as the reference level. Hence, where the level reported on above is 'Watered' this means that the estimates/errors/P-value refer to the that level as compared to the reference level (i.e. Control). The nature of the estimate (+ means 'higher', - means 'lower') in combination with the P-value (≤ 0.05 'levels different', >0.05 'levels similar') will indicate if a level differs from the reference level, and the direction of change.

3.5 Substrate abundance

The average abundance of litter fluctuated between survey periods, increasing overall at Chalka Creek and decreasing over time at Lake Bitterang (Figure 11). Low litter abundance was recorded at Lake Bitterang in the second survey period in 2014 as the lake was flooded and all quadrats were inundated. In contrast, by the third survey period in 2016 the water had begun to recede and less quadrats were inundated. However, at this time, all quadrats at 0 cm elevation were still inundated, while at 50 cm elevation two quadrats were still inundated, and one was partially inundated.

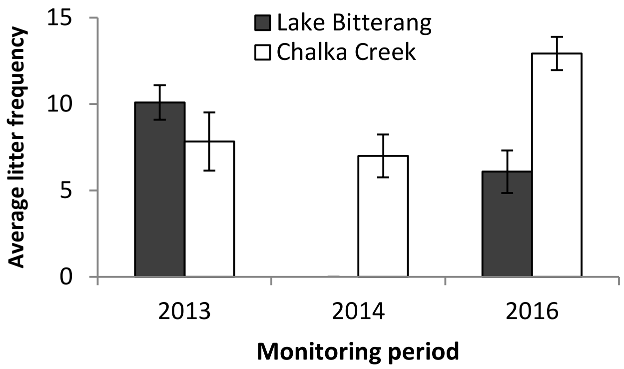


Figure 11. Average frequency of litter (+/- standard error) at Chalka Creek and Lake Bitterang across the three survey periods. Note: Lake Bitterang flooded in 2014.

3.6 Permanent photo points

Photo points were established on transect one at both sites in the first survey period in 2013. Visually the sites appear quite different over the three survey periods, highlighting the differences in species richness and abundance seen above. For example, Lake Bitterang is full of water in 2014 (Figure 12) explaining the low species richness recorded at this survey period. In comparison, Chalka Creek was not inundated in any year, but the effects of above average rainfall in the year prior to the second survey period in 2014 can be seen in the increased cover of the vegetation (Figure 12).

Lake Bitterang | Chalka Creek

Figure 12. Photo points for Lake Bitterang and Chalka Creek from top to bottom in the first (2013), second (2014) and third (2016) survey periods.

4 Discussion

The vegetation response to environmental watering at the long dry Lake Bitterang showed changes in community composition, species and plant functional group abundance across the three year monitoring period. These changes did not occur at the Chalka Creek reference site, thus may be attributed to environmental watering. Positive changes associated with environmental watering at Lake Bitterang included an increase in native species richness, a replacement of the terrestrial dry water plant functional group with the terrestrial damp group, and a decrease in litter. Whereas, at the long dry lake at Chalka Creek vegetation composition remained relatively stable throughout the study. The above average rainfall in 2014 produced a flush of growth at Chalk Creek in the second survey period, however, by the third survey period overall vegetation composition had returned to the starting condition. Two species (*E. tomentosa* and *G. acanthocarpa*) were the main drivers of this vegetation change at Lake Bitterang. The results from this study highlight the importance and effectiveness of environmental watering in maintaining the wet-dry floodplain vegetation cycle and the integrity of Lake Bitterang.

4.1 Findings

Lake Bitterang vegetation responses

The vegetation response to environmental watering at Lake Bitterang showed a significant difference in plant community composition. Native species richness increased; likely due to the prolonged inundation. This is attributed to the increase in available habitat (e.g. bare ground) and resources (e.g. soil moisture) once the water receded for plant species colonisation (Casanova and Brock 2000; Capon 2003; Raulings *et al.* 2010). However, this also highlights the greatest potential for weed invasion, although in this case exotic species richness and abundance was low and did not increase post-flooding. Unsurprisingly, all species richness measures were significantly different between all survey periods, which is attributed to the limited number of plant records in 2014 when the lake was flooded.

Terrestrial species (e.g. *E. tomentosa*) were most common across all survey periods regardless of environmental watering. The terrestrial dry water plant functional group was dominant in 2013 (pre-flooding), then replaced by the terrestrial damp water plant function group (e.g. *G. acanthocarpa*) in 2016 (post-flooding). This reflects the increased abundance of flood respondent species.

Vegetation community composition was significantly different over the survey periods, however, this was largely driven by the second survey data in 2014 when the lake was flooded. This was highlighted by the floristic quadrats still inundated in 2016 clustering more closely with the 2014 quadrats than the 2016 non-inundated quadrats. Indeed, those quadrats at the 100 – 250 cm elevation in 2016 which were vegetated not only more strongly clustered together, but also clustered with the quadrats from the first survey period in 2013. Again this highlights the importance of environmental watering and the subsequent effect it had on community composition and abundance in following years.

Chalka Creek dry lake vegetation responses

In contrast, despite this lack of environmental watering at Chalka Creek there were some significant differences in all measures of species richness due to the above average rainfall received in the year preceding the second survey period in 2014 and the subsequent flush of plant growth. In fact the drier years preceding the first (2013) and third (2016) surveys are highlighted by the lack of significant differences in all measures of species richness between these two sampling periods.

Again, terrestrial species dominated the vegetation at Chalka Creek with the terrestrial dry water plant functional group (e.g. *E. tomentosa, Maireana brevifolia*) dominant in all survey periods. Contrary to this was the high abundance of the terrestrial damp species *G. acanthocarpa* across all survey periods.

Vegetation community composition was not significantly different between the survey periods, but was significantly different along the elevation gradient, with quadrats of the same elevation largely clustering together, irrespective of survey year. Indicating that a soil moisture/elevation gradient may be a contributing driver of vegetation community composition.

Lake comparisons

At the water plant functional group scale vegetation at the Lake Bitterang and Chalk Creek sites were both initially dominated by the terrestrial dry group. Post-flooding the terrestrial damp group become dominant at Lake Bitterang. Thus, this change may be attributed to the environmental watering. However, when the influence of flooding is removed there is a strong overlap of vegetation composition and species at both sites. That is, vegetation community composition at Lake Bitterang pre-flooding and post-flooding at higher elevation (100 – 250 cm) quadrats, were similar to Chalka Creek vegetation community composition, irrespective of survey period. This similarity between the two sites is expected at the first survey period (starting condition) and might be attributed to the environmental watering not impacting on the higher elevation quadrats at Lake Bitterang. In addition, the higher elevation vegetation composition is largely driven by the dominance of terrestrial dry species (e.g. *E. tomentosa, M. brevifolia, Einadia nutans*) and the abundance of the terrestrial damp species *G. acanthocarpa*. As was expected at both sites, terrestrial damp species decreased as elevation and soil dryness increased with distance from the lake edge.

4.2 Study limitations

Although this study has highlighted significant differences in vegetation community composition in relation to environmental watering at Lake Bitterang and important insights have been gained, the study does have several limitations.

Firstly, Lake Bitterang is a single lake within a larger lake system and these findings may not be readily applicable to other lakes within the system. Indeed, while Chalka Creek was chosen as a control site as it was thought to have a similar flooding history to Lake Bitterang (MDFRC 2014), analysis of satellite imagery (> 1972) and GIS layers (MCMA 2014a, 2014b) indicates this is not the case. Chalka Creek can be considered a dry lake while Lake Bitterang is a persistent temporary lake (SKM 2004). Thus, within this project the findings from Lake Bitterang may not be readily applicable to the dry lake at Chalka Creek should it be inundated in the future. However, it must be acknowledged that control sites can be hard to find.

Secondly, the study design is unreplicated, with only one treatment site and one control site. Thus this study should be considered a pilot study to gain insights into the effects of flooding at Lake Bitterang and a lack of inundation at Chalka Creek. The inclusion of additional flooded and dry lakes within the Hattah Lakes system would allow the findings from this study to be more reliably applied across similar lakes both within Hattah-Kulkyne National Park and similar lake systems within the Murray-Darling Basin or other comparable river basins across Australia. Further, it would strengthen our understanding of how wetland vegetation not only responds to flooding, but also how community composition changes over time.

Thirdly, the study design and monitoring protocol has two key limitations: spatial autocorrelation and replication (at the site, transect and quadrat scale). At the site level the number of quadrats available for analysis are unbalanced and the design would be more statistically rigorous if they were balanced. At the transect scale, four transects were used at each lake with a varying number of quadrats at different elevations. At Chalka Creek, these transects cannot be considered independent samples due to their close proximity to each other (spatial autocorrelation). In contrast, at Lake Bitterang transects are sufficiently geographically separated to be considered independent samples; however, the size of the lake suggests that additional transects would improve replication within the lake and increase our understanding of how wetland vegetation responds to inundation in the short and longer term. In addition, at the quadrat scale, the placement of quadrats at predetermined elevations also resulted in spatial autocorrelation (and an unbalanced number of quadrats) and if vegetation changes at elevation intervals is an objective of the study, further replication and placement rules are required.

It appears from the study design that multiple objectives were incorporated, examining not only the overall vegetation change at each site, but also the influence of elevation. However, the study design constraints render the study statistically limited, and unable to achieve either of these objectives in a scientifically robust framework. Nevertheless, this study does provide valuable insights in the effect of environmental watering on a long dry lake system and contributes to our knowledge base.

4.3 Recommendations

While this study provided valuable insights into the short-term effects of environmental watering on wetland vegetation in long dry lakes, it is recommended that:

- The study design be reviewed to address statistical limitations.
- The study be extended to capture the medium and long-term effects of environmental watering. Results to date are based on a single watering event and longer term data is required to fully evaluate the effects of environmental watering on vegetation.

4.4 Conclusion

This project has provided valuable insights into the short-term effects of environmental watering on wetland vegetation at Lake Bitterang and the lack of flooding at a Chalka Creek dry lake. In particular, vegetation changes at Lake Bitterang after flooding included an increase in native species richness, a replacement of the terrestrial dry water plant function group with the terrestrial damp group, and a decrease in litter. Whereas, vegetation composition remained relatively stable at the Chalka Creek long dry lake reference site. Thus vegetation changes at Lake Bitterang may be attributed to environmental watering.

The majority of compositional changes were driven by two species (*E. tomentosa* and *G. acanthocarpa*), highlighting the importance of species level analysis of data at the individual lake scale. Nevertheless, the study findings could reasonably be expected to occur at other persistent temporary lakes within the Hattah Lakes system. Additional data collection in future years will further improve our understanding of the effects of environmental watering on wetland vegetation at Lake Bitterang and potentially across the Hattah Lakes system.

This study highlights the importance and effectiveness of environmental watering in maintaining the wet/dry floodplain vegetation cycle on a long dry lake system and the integrity of Lake Bitterang. In addition, the study provides essential data on which to base management decisions in an environmental watering context.

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Appendix 1. GPS locations

Table S1. GPS locations for quadrats at Lake Bitterang and Chalka Creek Control. Note: 'BIT1_0' indicates the site is at Lake Bitterang (BIT), transect 1 and at 0 cm elevation. 'CC' refers to Chalka Creek and site naming is the same as for Lake Bitterang. 'A' refers to one end of the quadrat (first cell) and 'B' refers to the other end. Fifteen contiguous 1 m^2 cells comprised each quadrat between A and B.

Site	A_Easting	A_Northing	B_Easting	B_Northing	Datum	Zone
BIT1_0	626035	6163295	626048	6163290	D_GDA1994	54
BIT1_50	626216	6164025	626229	6164019	D_GDA1994	54
BIT1_100	626222	6164054	626238	6164051	D_GDA1994	54
BIT1_150	626233	6164081	626246	6164075	D_GDA1994	54
BIT1_200	626230	6164102	626242	6164095	D_GDA1994	54
BIT1_250	626236	6164115	626249	6164108	D_GDA1994	54
BIT2_0	626069	6163241	626058	6163226	D_GDA1994	54
BIT2_50	626272	6163214	626269	6163200	D_GDA1994	54
BIT2_100	626298	6163210	626292	6163197	D_GDA1994	54
BIT2_150	626311	6163211	626305	6163198	D_GDA1994	54
BIT2_200	626324	6163211	626319	6163200	D_GDA1994	54
BIT2_250	626338	6163209	626338	6163200	D_GDA1994	54
BIT3_0	626008	6163200	625993	6163197	D_GDA1994	54
BIT3_50	625946	6162828	625933	6162820	D_GDA1994	54
BIT3_100	625952	6162771	625941	6162761	D_GDA1994	54
BIT3_150	625944	6162745	625934	6162735	D_GDA1994	54
BIT3_200	625944	6162720	625933	6162708	D_GDA1994	54
BIT3_250	625948	6162713	625942	6162699	D_GDA1994	54
BIT4_0	625971	6163252	625971	6163267	D_GDA1994	54
BIT4_50	625440	6163319	625453	6163325	D_GDA1994	54
BIT4_100	625382	6163331	625396	6163336	D_GDA1994	54
BIT4_150	625336	6163323	625339	6163336	D_GDA1994	54
BIT4_200	625317	6163321	625321	6163336	D_GDA1994	54
BIT4_250	625307	6163319	625309	6163335	D_GDA1994	54
CCT1_0	634291	6154947	634293	6154931	D_GDA1994	54
CCT1_50	634378	6154927	634375	6154912	D_GDA1994	54
CCT1_100	634405	6154926	634404	6154909	D_GDA1994	54
CCT2_0	634287	6154925	634270	6154921	D_GDA1994	54
CCT2_50	634267	6154723	634254	6154713	D_GDA1994	54
CCT2_100	634265	6154702	634251	6154701	D_GDA1994	54
CCT3_0	634261	6154927	634259	6154942	D_GDA1994	54
CCT3_50	634064	6154974	634065	6154992	D_GDA1994	54
CCT3_100	633994	6154987	633998	6155005	D_GDA1994	54
CCT4_0	634266	6154949	634278	6154956	D_GDA1994	54
CCT4_50	634267	6154998	634283	6154997	D_GDA1994	54
CCT4_100	634266	6155016	634282	6155014	D_GDA1994	54

Appendix 2. Data analysis

Species richness is true count data and therefore a Poisson distribution was specified within a GLMM framework (i.e. no random effects). A log link between the mean of the response variable and the systematic components of the model was used (Zuur *et* al. 2009). All other variables related to frequency data were modelled as proportions and were modelled using a Binomial distribution, with data being modelled as the number of successes and failures within a fixed number of Bernoulli trials (i.e. 15 trials for frequency data; Crawley 2007). A logit link between the mean of the response variable and the systematic components of the model was used (Zuur *et al*. 2009).

Tests for overdispersion were undertaken to assess whether there was additional variance in the data than assumed by the Poisson or Binomial distribution (Crawley 2007). Plots of residuals against fitted values, residual frequency histograms and residual variation box plots were examined to verify homogeneity and normality of residuals where appropriate (Zuur *et* al. 2009).

Appendix 3. Species List

Table S3. Species list for Lake Bitterang and Chalka Creek. Note: Threat status refers to the DELWP (2014) advisory list of rare and threatened plants, k = poorly known, r = rare and v = vulnerable. WPFG refers to the water plant functional groups of Brock and Casanova (1997), Casanova (2001) and Campbell *et al.* (2014). ATw = woody amphibious fluctuation tolerator, ATe = emergent amphibious fluctuation tolerator, ATl = low-growing amphibious fluctuation tolerator, Tda = terrestrial damp, Tdr = terrestrial dry and T = terrestrial.

Scientific name	Common name	Threat status	Origin	WPFG	Lake Bitterang	Chalka Creek
Acacia brachybotrya	Grey Mulga		native	Tdr	✓	
Acacia stenophylla	Eumong		native	ATw	✓	
Alternanthera sp. 1 (Plains)	Plains Joyweed	k	native	Tda		✓
Asperula conferta	Common Woodruff		native	Tda		✓
Asphodelus fistulosus	Onion Weed		exotic	Tdr		✓
Asteraceae spp.	Composite		native	T	✓	✓
Atriplex leptocarpa	Slender-fruit Saltbush		native	Tdr		✓
Atriplex lindleyi subsp. *inflata*	Corky Saltbush		native	Tdr	✓	
Atriplex pumilio	Mat Saltbush		native	Tdr	✓	
Atriplex semibaccata	Berry Saltbush		native	Tdr	✓	✓
Atriplex spp.	Saltbush		native	Tdr	✓	✓
Atriplex stipitata	Kidney Saltbush		native	Tdr	✓	✓
Atriplex suberecta	Sprawling Saltbush		native	Tdr		✓
Austrobryonia micrantha	Mallee Cucumber	r	native	Tda	✓	
Austrostipa scabra	Rough Spear-grass		native	Tdr		✓
Austrostipa spp.	Spear Grass		native	Tdr	✓	✓
Brachyscome ciliaris	Variable Daisy		native	Tdr	✓	
Brassica tournefortii	Mediterranean Turnip		exotic	Tdr		✓
Bromus spp.	Brome		native	Tdr		✓
Calotis cuneifolia	Blue Burr-daisy	r	native	Tdr	✓	
Calotis hispidula	Hairy Burr-daisy		native	Tdr		✓

Calotis spp.	Burr Daisy	native	Tdr		✓
Centipeda cunninghamii	Common Sneezeweed	native	ATl	✓	
Chenopodiaceae spp.	Chenopod	native	Tdr	✓	
Chloris truncata	Windmill Grass	native	Tdr	✓	✓
Convolvulus remotus	Grass Bindweed	native	Tdr	✓	
Convolvulus spp.	Bindweed	native	Tdr		✓
Conyza bonariensis	Flaxleaf Fleabane	exotic	Tdr	✓	
Conyza spp.	Fleabane	exotic	Tdr	✓	✓
Cucumis myriocarpus subsp. *leptodermis*	Paddy Melon	exotic	Tdr		✓
Cynodon dactylon	Couch	native	Tdr		✓
Cynodon dactylon var. *dactylon*	Couch	exotic	Tdr	✓	
Cyperus gymnocaulos	Spiny Flat-sedge	native	ATe	✓	
Dodonaea viscosa subsp. *angustissima*	Slender Hop-bush	native	Tdr	✓	
Dysphania pumilio	Clammy Goosefoot	native	Tdr	✓	✓
Einadia nutans	Nodding Saltbush	native	Tdr	✓	✓
Enchylaena tomentosa var. *tomentosa*	Ruby Saltbush	native	Tdr	✓	✓
Enneapogon nigricans	Dark Bottle-washers	native	Tda	✓	
Eragrostis dielsii	Mallee Love-grass	native	Tdr	✓	
Eragrostis spp.	Love Grass	native	Tdr	✓	
Erodium spp.	Heron's Bill	native	Tdr		✓
Eucalyptus camaldulensis	River Red-gum	native	ATw	✓	✓
Eucalyptus largiflorens	Black Box	native	ATw	✓	✓
Eucalyptus spp.	Eucalypt	native	ATw	✓	✓
Euphorbia drummondii	Flat Spurge	native	Tdr	✓	✓
Fabaceae spp.	Legume	native	T	✓	
Glycyrrhiza acanthocarpa	Southern Liquorice	native	Tda	✓	✓
Gnaphalium polycaulon	Indian Cudweed	native	Tda	✓	
Helichrysum luteoalbum	Jersey Cudweed	native	Tda	✓	
Heliotropium europaeum	Common Heliotrope	exotic	Tda	✓	
Hordeum glaucum	Northern Barley-grass	exotic	Tdr		✓
Hordeum murinum s.l.	Barley-grass	exotic	Tdr		✓

Hypericum gramineum spp. agg.	Small St John's Wort		native	Tdr	✓	
Juncus subsecundus	Finger Rush		native	ATe	✓	
Lachnagrostis filiformis s.l	Common Blown-grass		native	Tda	✓	
Lepidium pseudohyssopifolium	Native Peppercress	k	native	Tdr	✓	
Lotus cruentus	Red Bird's-foot Trefoil		native	Tdr	✓	
Maireana brevifolia	Short-leaf Bluebush		native	Tdr	✓	✓
Maireana spp.	Bluebush		native	Tdr	✓	✓
Malva spp.	Mallow		native	Tdr	✓	✓
Marrubium vulgare	Horehound		exotic	Tdr		✓
Medicago polymorpha	Burr Medic		exotic	Tdr		✓
Medicago spp.	Medic		exotic	Tdr	✓	✓
Olearia pimeleoides	Pimelea Daisy-bush		native	Tdr	✓	
Oxalis spp.	Wood Sorrel		native	Tdr		✓
Pentameris airoides subsp. *airoides*	False Hair-grass		exotic	Tdr	✓	✓
Persicaria prostrata	Creeping Knotweed		native	ATl		✓
Persicaria spp.	Knotweed		native	ATe		✓
Poaceae spp.	Grass		native	T	✓	✓
Polygonum plebeium	Small Knotweed		native	Tda	✓	
Rhagodia spinescens	Hedge Saltbush		native	Tdr	✓	✓
Rumex spp.	Dock		native	Tda		✓
Rumex tenax	Narrow-leaf Dock		native	Tda	✓	
Rytidosperma spp.	Wallaby Grass		native	Tdr	✓	✓
Salsola tragus	Prickly Saltwort		native	Tdr	✓	✓
Salvia verbenaca	Wild Sage		exotic	Tdr	✓	
Sclerolaena diacantha	Grey Copperburr		native	Tdr	✓	✓
Sclerolaena muricata var. *villosa*	Grey Roly-poly		native	Tdr	✓	
Sclerolaena patenticuspis	Spear-fruit Copperburr	v	native	Tdr	✓	
Senecio spp.	Groundsel		native	Tdr		✓
Sisymbrium erysimoides	Smooth Mustard		exotic	Tdr		✓
Solanum nigrum s.l.	Black Nightshade		exotic	Tdr	✓	✓
Soliva anthemifolia	Dwarf Jo-jo		exotic	Tda		✓

Sonchus spp.	Sow Thistle		exotic	Tdr		✓
Sphaeromorphaea australis	Spreading Nut-heads		native	Tda	✓	
Stelligera endecaspinis	Star Bluebush		native	Tdr		✓
Stemodia florulenta	Blue Rod		native	Tda		✓
Stemodia spp.	Blue Rod		native	Tda	✓	
Swainsona microphylla	Small-leaf Swainson-pea	r	native	Tdr		✓
Teucrium racemosum s.l.	Grey Germander		native	Tdr		✓
Verbena officinalis s.l.	Common Verbena		native	Tdr	✓	
Verbena officinalis var. *africana*	Inland Verbena	k	native	Tdr	✓	
Verbena supina	Trailing Verbena		exotic	Tda		✓
Vittadinia cervicularis	Annual New Holland Daisy		native	Tdr		✓
Vittadinia dissecta var. *hirta*	Dissected New Holland Daisy		native	Tdr	✓	
Vittadinia gracilis	Woolly New Holland Daisy		native	Tdr	✓	✓
Vittadinia spp.	New Holland Daisy		native	Tdr	✓	
Wahlenbergia fluminalis	River Bluebell		native	Tda	✓	✓

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