The Living Murray Hattah Lakes intervention monitoring – understorey vegetation program: annual report 2016

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Front cover photo: Lake Kramen site 16 lake edge (Sally Kenny).

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This project was coordinated by the Mallee Catchment Management Authority.

Executive Summary

Background

This annual report outlines The Living Murray Hattah Lakes Intervention Monitoring: Understorey Vegetation Program activities for the 2015-2016 financial year. The program seeks to determine the response of understorey vegetation to environmental watering events, with a specific focus on River Red Gum and Black Box plant communities and their associated network of permanent and semi-permanent wetlands within the Hattah Lakes Icon Site.

The Hattah Lakes system has been severely degraded due to regulation of the Murray River, drought and water extraction for agriculture, industry and urban use. The Living Murray (TLM) initiative is a river restoration program designed to improve the health of Murray River ecosystems through targeted environmental watering events. The Hattah Lakes Icon Site is one of six areas in the TLM program selected for its significant environmental values.

Activities and main findings

In the 2015-2016 financial year, three key activities were undertaken:

1. 2016 Annual monitoring

Twenty sites were monitored in April 2016. The data has been incorporated into a Microsoft Access database and the Victorian Biodiversity Atlas.

2. *Development and implementation of vegetation response models*

A multi-plant taxa Bayesian hierarchical model of occurrence was developed and is the first step in providing explicit information that addresses key knowledge gaps in relation to vegetation responses to environmental watering. The model provides a new tool to predict and evaluate the effectiveness of management interventions to inform environmental watering planning. The unique advantage of the multi-taxa model developed here is that inference can be drawn at the plant community level while maintaining species (taxa) identity for further inquiry when the management context necessitates. This enables the development of site specific management tools for use by on-ground managers.

3. Examination of key ecological monitoring questions to determine the effect of environmental watering on vegetation composition before and over the two years after the watering event

1. The effect of environmental watering on plant taxa and plant functional groups:
    - At the lake system scale, individual *taxa* models proved more useful response indicators than *plant functional group* metrics.
    - Of the 91 plant taxa evaluated 60 taxa displayed significant responses to the watering event.
    - Plant taxa fell into two main groups: species favouring either the lake edge or the floodplain.
    - Overall plant taxa favouring the lake edge had positive responses to the watering event, whereas plant taxa favouring the floodplain had a more even mix of both positive and negative responses.
    - Shrub (terrestrial dry taxa) occurrence decreased over the three year monitoring.
    - Native, perennial and forb (e.g. terrestrial damp taxa) richness increased one year post-watering, but then decreased by 2016, which is likely due to below average rainfall conditions.
    - Eucalypt seedling occurrence increased post-watering.
2. The effect of environmental watering on plant community structure:
    - Vegetation abundance and structural complexity decreased over the three years of monitoring.
3. The effect of environmental watering on tree canopy cover:
    - The canopy cover of River Red Gum and Black Box remained largely unchanged over the monitoring period. However, the modelling does indicate an increasing trend in canopy cover over time.

This monitoring program has demonstrated that the environmental watering event over a two year period has maintained, and in some instances improved, the lake edge water dependent plant communities of Hattah Lakes icon site. Tree cover (and thus health) has been maintained and recruitment increased in the short term. The higher elevation floodplain plant community has demonstrated the expected ecological response to the environmental watering event, where there is an initial decrease in plant community composition due to inundation, followed by an increase due to greater soil moisture. This has been slow to realise, likely due to the low rainfall in 2016; however, it is expected that over time this floodplain community will also increase in species richness and abundance.

Recommendations for 2016-2017

To date, the monitoring program has created a dataset that can be utilised for a range of analyses now and into the future to provide robust evidence-based decision making. In the 2016-2017 financial year, it is recommended that the following activities are undertaken:

1) Continue vegetation monitoring of all 20 permanent sites in April 2017, to provide a more comprehensive understanding of the vegetation responses to environmental watering.
2) Model the existing data to gain an understanding of the environmental and inundation characteristics influencing eucalypt recruitment and survival.
3) Further develop and utilise the new modelling tool to predict and demonstrate the effects of future environmental watering events and scenarios on plant assemblages.
4) The modelling tool could be further developed into an online management tool outlining generalised vegetation responses and environmental watering scenarios.
5) Communication activities.
6) Publish key results in peer-reviewed scientific papers to provide a strong evidence base for decision making.

1 Introduction

Background

The Living Murray (TLM) initiative is a river restoration program designed to improve the environmental health of the Murray River (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 and was selected to be part of TLM program for its significant ecological, cultural, recreational, heritage and economic values (MDBA 2009a). 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 the Murray-Kulkyne Park (48,000 ha, MDBC 2006, MDBA 2012) and contains important habitat for threatened plants and animals, both terrestrial and aquatic. Twelve of the lakes are listed under the Ramsar convention on wetlands of international significance, underpinning the role the Icon Site plays in the conservation of native waterbirds (DSE 2003, MDBA 2012).

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). As a result, the environmental health of the system and habitat value for fauna has declined (Cunningham *et al.* 2009). This has led to the implementation of environmental watering to mitigate the effects of the reduced frequency of natural flooding, by inundating the Hattah Lakes Icon Site (MDBA 2009a). Floodplain health is critical for maintaining ecological functions in the broader riverine ecosystem. Hence, the delivery of environmental water is seen as an important factor in the maintenance and improvement of ecosystem health.

Environmental watering regimes of the Hattah Lakes

The Hattah Lakes Icon Site system consists of waterways, floodplains and more than 20 lakes ranging in size from 10 to 200 ha (MDBA 2012). The targets for environmental watering are selected based on lake characteristics and associated biological and environmental attributes. To aid management of environmental watering, the target lakes have been classified into three water regime classes: persistent temporary, semi-permanent and episodic (MDBA 2012). Three primary watering scenarios (MDBA 2012) have been developed and implemented since 2005:

1) Inundation to 43.5 m (intermittently flooded) once every three years targeting lakes, waterways and fringing vegetation;
2) Inundation to 45 m (rarely flooded) once every eight years targeting the floodplain; and
3) Inundation to 45 m (rarely flooded) once every eight years targeting Lake Kramen and the floodplain.

Vegetation and ecological characteristics of floodplains

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 1):

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 floodplain systems the length of these states may last over long time periods (e.g. decades). Following inundation (wet state), it is expected that terrestrial dry plant 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 (Brock and Rogers 1998; Capon 2003).

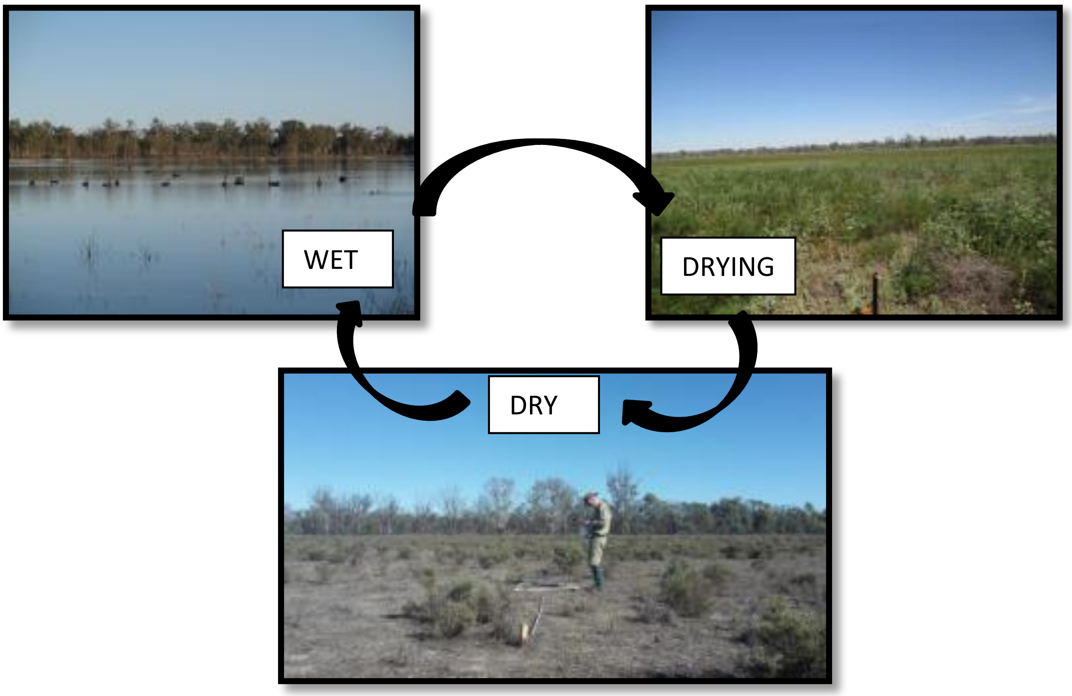

Figure 1. A simplified representation of the wet-dry cycle of floodplain vegetation.

This wet-dry cycle varies over time, and 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.

TLM monitoring program ecological objectives

A major part of TLM is Intervention Monitoring (MDBA 2012), which is Icon Site specific and investigates the links between environmental watering events, on-ground works and measures, and ecological outcomes. A component of this is the understorey vegetation monitoring program, which is detailed in this report and is centred around key watering events to address key knowledge gaps and ecological questions specific to the Hattah Lakes Icon Site (MDBA 2012). Specifically, the understorey vegetation monitoring program seeks to determine the response of vegetation to environmental watering at the Hattah Lakes Icon Site, with a particular focus on River Red Gum (*Eucalyptus camaldulensis*) and Black Box (*Eucalyptus largiflorens*) plant communities and the associated network of permanent and semi-permanent wetlands.

Understorey vegetation monitoring program objectives

This monitoring program is designed to assess changes in floristic composition with respect to environmental watering events at the Hattah Lakes Icon Site. It aims to develop an understanding of the vegetation composition within the floodplain mosaic, particularly in the plant communities along lake edges in terms of both plant species richness and abundance of understorey species. The program addresses key ecological knowledge gaps, which will contribute to informing the development of Icon Site specific ecological targets.

The monitoring design incorporates two experimental approaches: (1) examination of the immediate impacts of the environmental watering events, and (2) examination of the impact of environmental watering events over the long-term by detecting changes over time.

The outcomes of this program will not only aid the management and optimisation of environmental watering events at Hattah Lakes, but may also be applicable for environmental management at a number of other floodplain wetlands in the Murray-Darling Basin.

The primary ecological question which forms the basis of the monitoring program design is:

- What is the effect of environmental watering events on the floristic composition and distribution of key plant communities within the vegetation mosaic?

2015-2016 financial year monitoring activities

A third round of annual monitoring was completed in April 2016. Three key activities to address knowledge gaps were undertaken in the 2015-2016 financial year:

(a) Annual monitoring.

(b) The development and testing of vegetation response models (Moxham and Gwinn 2016).

(c) Key ecological monitoring questions investigated in relation to the effect of the 2014 environmental watering event on the floristic composition were:

1) What is the effect of environmental watering on plant taxa and plant functional groups?
2) What is the effect of environmental watering on plant community structural characteristics?
3) What is the effect of environmental watering on tree canopy cover?

Information gained from investigating these knowledge gaps will assist in determining whether the TLM ecological program objectives are being met – namely maintaining and improving the health of the vegetation at the Hattah Lakes Icon Site.

2 Monitoring program overview

2.1 Understorey vegetation monitoring program

The monitoring program design incorporated a scalable approach to monitoring. The primary scale is the entire lake system including the floodplain at the Hattah Lakes Icon Site. Therefore, each lake within the system was treated as a replicate within the overall lake system, which represented the site. This design was used to investigate the effects of the 45 m inundation environmental watering event on key vegetation communities (e.g. Intermittent Swampy Woodland, Riverine Chenopod Woodland, Lake Bed Herbland). The design allows for a focus on the lake system and the three target vegetation types directly surrounding these lakes (waterways that connect the lakes and Mallee vegetation are excluded). The approach allows reporting at the asset scale which is one of the main knowledge gaps that needs to be addressed. This design also provides a scalable approach to both ecological measures and sampling design, enabling a retraction or expansion of the program depending on resources.

In addition to the entire lake system, a number of questions related to the characteristics of the lakes was also investigated. The secondary scale for the monitoring program investigates whether lake type (semi-permanent, persistent temporary and episodic) influences vegetation community structure and composition.

Monitoring commenced in April 2014, with 20 sites established across ten lakes at the Hattah Lakes Icon Site. Baseline data were collected at all sites prior to the environmental watering event which occurred from late June through to September 2014. Lakes were selected to represent a range of post-regulation watering regimes. These comprised seven persistent temporary lakes, which is the dominant lake type in the system; two of the less common semi-permanent lakes; and one episodic lake (Lake Kramen), which is the only lake within the system of this kind.

The location of monitoring sites at each lake were selected randomly. Sampling methods followed the monitoring protocol developed to provide a systematic sampling regime along a moisture, elevation and vegetation gradient. Each site was centred around a transect line running perpendicular to the lake from the lake edge or bed (lake dependent) onto the surrounding floodplain, along which a range of biological and environmental attributes were measured. The monitoring program design and methods, rationale and sampling method protocols are detailed in Moxham *et al.* (2014), and are not repeated here. Monitoring is scheduled to occur annually in April.

2.2 Annual monitoring 2015-2016

The 20 permanent monitoring sites were resurveyed in April 2016 (Table 1). This year, the floodplain portion of all, but one, site was surveyed (c.f. 2015 where Lake Kramen sites were still under water). Lake Kramen still contained water and thus the lake bed portion of those transects varied from 0 m to 14 m (Table 1). At all other lakes, where the water had receded beyond the 2014 lake edge the transect line was extended onto the lake bed. The length of this extension varied at each lake from 21 m to 50 m (Table 1). Transects that were not extended to a maximum of 50 m will be lengthened in future years as the water level continues to recede.

Table 1: Summary of the 20 monitoring site locations, displaying site number, length of transects at each lake and the vegetation zone sampled. Note: '(106.5)' or similar beside Lake Kramen transects indicates the length of the transect surveyed in 2016 with the remainder of the transect (lake bed) under water. Kramen16 and Kramen 17 are 100 m floodplain transects and Kramen18 – Kramen20 are 50 m floodplain transects. In 2014 all five Kramen transects were extended 50 m onto the lake bed. 'LB' = lake bed and 'F' = floodplain. GPS coordinates are in GDA 94, MGA zone 54 and recorded at the lake edge in April 2014.

Lake	Site number	Transect length (m)	Zone sampled	Easting	Northing
Lake Hattah	1	100	LB - F	623702	6152714
	2	100	LB - F	623796	6152759
Lake Arawak	3	71	LB - F	624419	6152696
	4	77	LB - F	624376	6152411
Lake Marramook	5	100	LB - F	625443	6152406
Lake Nip Nip	6	100	LB - F	627985	6153763
	7	100	LB - F	328118	6153868
Lake Tullamook	8	150	LB - F	627543	6153870
Lake Yelwell	9	100	LB - F	625795	6159277
	10	150	LB - F	625797	6159449
Lake Bitterang	11	100	LB - F	626472	6163266
	12	150	LB - F	626853	6163505
Lake Woterap	13	100	LB - F	623740	6162672
	14	150	LB - F	623713	6162355
Lake Konardin	15	100	LB - F	624025	6160489
Lake Kramen	16	150 (106.5)	LB - F	634355	6150392
	17	150 (100)	LB - F	634051	6150575
	18	100 (64)	LB - F	634048	6149852
	19	100 (56)	LB - F	633339	6151019
	20	100 (54)	LB - F	633249	6150809

Sampling measures

Key ecological attributes were assessed along each transect to examine changes in floristic composition, distribution of target vegetation communities and environmental attributes in relation to environmental watering events (Table 2). Key ecological attributes include: inundation events, plant community mosaics, elevation and soil moisture gradients, salinity levels and water levels. Environmental attributes that also drive community composition including bare ground, litter, and biological soil crust were assessed. For a full description of the sampling measures and methods see Moxham *et al.* 2014.

Table 2: Summary of the ecological components assessed in the monitoring program. Note: in 2015 and 2016 soil moisture and salinity measures were not undertaken. All other components were completed.

Ecological Component	Assessment type	Rationale
1. Floristics	1.1 Broad-scale assessments (15 m^2 quadrats)	Measure plant species richness at broader scales
	1.2 Floristic assessments (1m^2 quadrats)	Floristic and ground layer assessments of presence and abundance
	1.3 Fine scale understorey floristics and structure (point quadrats)	Detailed floristic and ground layer attribute assessments of presence and abundance
2. Woody plant recruitment	2.1 Quadrat searches	Woody species recruitment
3. Canopy cover	3.1 Canopy photo points	Canopy abundance and health
4. Environmental attributes	4.1 Soil moisture	Site characterisation
	4.2 Soil salinity	Site characterisation
	4.3 Elevation gradient	Site characterisation
5. Site description	5.1 Fixed photo points	Visual representation of sites
	5.2 Water level	
	5.3 Vegetation community changes	
	5.4 Browsing levels	Site characterisation browsing
	5.5 Canopy health	Site characterisation tree health
	5.6 Presence of fire	Site characterisation
	5.7 GPS locations	Site characterisation

Data management

All data was entered into a Microsoft Access database developed as part of this program. The floristic data is also linked to the Victorian Biodiversity Atlas (VBA; DELWP 2015) flora species list to ensure that plant species nomenclature is current, and to facilitate annual upload of the monitoring data into the VBA.

Monitoring schedule

To obtain a direct before and after comparison of the floristic composition in relation to the environmental watering event, monitoring in 2016 was undertaken in the same month as previous sampling in 2014 and 2015. This approach ensures that seasonal patterns will not have a strong influence on any changes observed. It is recommended that annual sampling be carried out in April on a yearly basis.

3 Rainfall

It is important that monitoring programs exploring temporal trends in a drought-prone landscape (e.g. Mallee region) consider rainfall as an important influence on plant communities. If combined with other local changes in environment (e.g. land use, disturbance etc.) the power to detect true changes in response to the imposed treatment (e.g. herbicide application) are increased. Hence, we modelled rainfall across the study area to provide context for current (i.e. this report) and future (i.e. subsequent reporting) results. Two rainfall models were produced: recent monthly rainfall (2009-2015, Figure 2a) and longer term annual rainfall (1950-2015, Figure 2b).

Periods of drought are commonplace in many parts of Australia. Over recent decades rainfall has become more variable, with longer dry periods and an increase in the number of extreme rainfall events (Min *et al.* 2011; Smith 2011). Rainfall in the Mallee region fluctuates both within and between years depending on changes in the Southern Oscillation Index (SOI; from periods of El Niño to La Niña). Drought is not uncommon in the region with the most recent drought (i.e. 'The Millennium Drought') lasting ~14 years between 1995 and 2009, followed by a period of above-average rainfall ('The Big Wet') in 2010-2011 (Figure 2b). It is anticipated that the Mallee is entering another drought period.

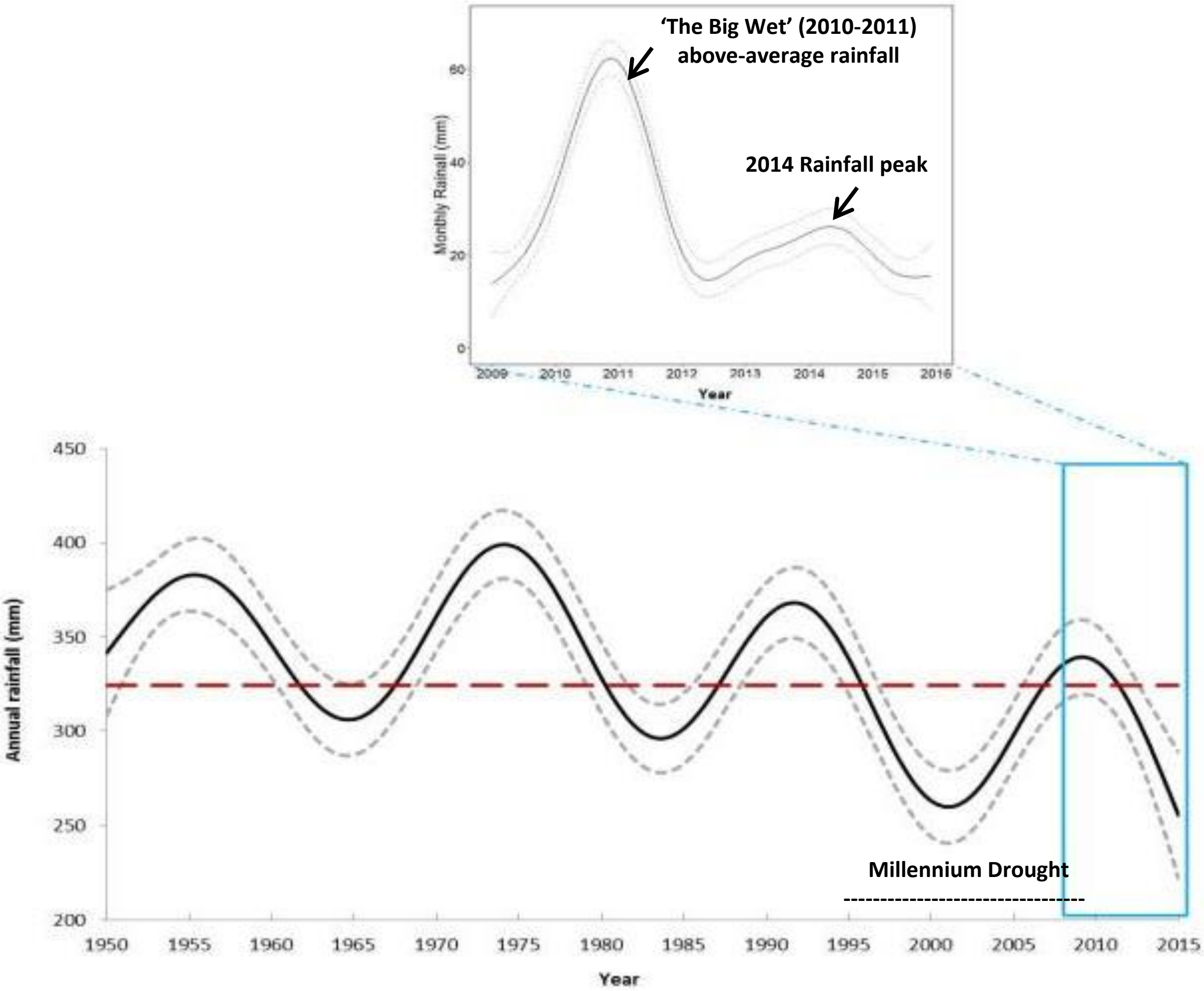

Figure 2. Response curves generated by generalised additive models (GAMs) of Mallee rainfall showing (a) monthly rainfall, as a subset of (b) annual rainfall. Dotted lines represent 95% confidence intervals of regression models. The horizontal dashed line in (b) shows the long-term average annual rainfall across the Mallee region.

4 Development of vegetation response models

Background

Predicting and demonstrating the effectiveness of 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. Response monitoring is an important component of the water management process as it provides the necessary feedback on system responses to competing management actions and allows for the refinement of management strategies.

Monitoring the effectiveness of environmental watering events on vegetation condition can be problematic often due to the wide variety of vegetation response indicators, or summary metrics, that have been used, either alone or in combination (e.g. species richness, species abundance, functional group classifications), to inform environmental watering outcomes that occur over various spatial and temporal scales. This provides a challenge to scientists, and land managers, as to which response variables to examine and at which scale. Furthermore, the choice of indicator influences the allocation of monitoring resources and usefulness of data collected to inform and communicate management outcomes.

Objective

The objective of this subproject was to (i) explore the relative value of community summary metrics and taxa-specific information for response monitoring, and (ii) lay the groundwork for the development of a predictive tool for guiding future water management strategies. To achieve these objectives, we developed and implemented a multi-taxa statistical model which examines all scales of the plant community in a single analysis (i.e. plant taxa, life forms and water plant functional groups).

This section provides a brief overview of the subproject. For a full project description please refer to the report (Moxham and Gwinn 2016).

Model development – a new tool

A multi-taxa Bayesian hierarchical model of plant occurrence was developed. Using this model, we investigated vegetation community change at multiple scales of the plant assemblage. At the lowest possible taxonomic level (e.g. genus, species), as well as on common plant functional groups, including origin, life history, and life form groupings. The scale (broad to fine) of plant community metrics examined include:

1) origin - native or exotic taxa of Australia;
2) life history - annual, perennial, and mixed (annual, perennial, biennial);
3) broad life form group - trees, shrubs, forbs, and graminoids;
4) water plant functional groups (WPFGs) based on their expected response to inundation (Brock and Casanova 1997; Casanova 2011; Campbell *et al.* 2014); and,
5) individual plant taxa.

Testing the model

We then tested the model on 2014 and 2015 survey data from this program to investigate the relative influence of different plant taxa and vegetation community summary metrics to demonstrate the value of taxa-specific information for environmental watering intervention monitoring at the Hattah Lakes Icon Site.

Key findings:

1) At the lake system scale, individual *taxa* models proved more useful response indicators than *plant functional group* metrics.
2) Of the 100 plant taxa evaluated 46 taxa displayed significant responses to the watering event.
3) Plant taxa fell into two main groups: species favouring either the lake edge or the floodplain.
4) Overall plant taxa favouring the lake edge had positive responses to the watering event, whereas plant taxa favouring the floodplain had a more even mix of both positive and negative responses.

Model outcomes

The development of the multi-plant taxa Bayesian hierarchical model of occurrence is the first step in providing explicit information that addresses key knowledge gaps in relation to vegetation responses to environmental watering. The model developed here can be further utilised and explored through:

- Incorporation of long-term data - Results to date are based on a single watering event. Long-term data are required to fully evaluate the effects of environmental watering on vegetation quality. This data would then be used to refine the watering response models through the Hattah Lakes Intervention Monitoring Program – Understorey Vegetation.
- The multi-taxa models developed here can be used to predict and demonstrate the effects of future environmental watering events and scenarios on plant assemblages.
- External climatic drivers (e.g. rainfall, natural flooding) could also be incorporated into the model.
- The new modelling tool provides a suitable approach to analysing other long-term data types (e.g. Icon Site Condition monitoring) to gain an understanding of the temporal effects of environmental watering on vegetation responses.
- The modelling tool could be further developed into an online management tool outlining generalised vegetation responses and environmental watering scenarios.

The model provides a new tool to predict and evaluate the effectiveness of management interventions to inform environmental watering planning. The unique advantage of a multi-taxa model developed here is that inference can be drawn at the plant community level while maintaining species (taxa) identity for further inquiry when the management context necessitates. This enables the development of site specific management tools for use by on-ground managers.

5 The effect of environmental watering on plant community composition

The most immediate short-term change in the vegetation following a disturbance event such as environmental watering, is likely to be a compositional and structural change in the understorey (e.g. herbs, grasses, sedges, shrubs). To determine if the environmental watering event contributed to meeting the TLM ecological objectives of improving or maintaining vegetation quality the following monitoring question was examined:

What is the effect on plant taxa and plant functional groups two years after the watering event?

5.1 Model implementation

The multi-taxa Bayesian hierarchical model of plant occurrence previously developed (Moxham and Gwinn 2016) was implemented on the three year data set to investigate vegetation community change at multiple scales of the plant assemblage. The model was implemented using the 1m^2 floristic quadrat data.

The following metrics were modelled:

1. origin - native or exotic taxa of Australia;
2. life history - annual, perennial, and mixed (annual, perennial, biennial);
3. broad life form group - trees, shrubs, forbs, and graminoids;
4. water plant functional groups (WPFGs) based on their expected response to inundation (Brock and Casanova 1997; Casanova 2011; Campbell *et al.* 2014): Terrestrial dry (Tdr) taxa are not dependent on flooding but will respond to rainfall events. Terrestrial damp (Tda) taxa germinate in moist soil, but cannot tolerate water saturation in a vegetative state (Casanova 2011). Amphibious fluctuation tolerator low growing (ATl) taxa germinate under water or on damp soil (Casanova 2011). Amphibious fluctuation tolerator woody (ATw) taxa are perennials with an aerial seed bank which require a moist root zone throughout the year (Casanova 2011). Amphibious fluctuation tolerator emergent (Ate) taxa inhabit saturated soil or shallow water, but require the majority of their vegetative parts to remain above water (Casanova 2011); and
5. individual plant taxa.

5.2 Findings

5.2.1 Broad responses to the watering event

Mean plant occurrence before and after the environmental watering event over the three monitoring periods changed in quadrats that were inundated and not inundated (Figure 3). In quadrats that were inundated by the watering event vegetation decreased over the three monitoring periods. Whereas, in quadrats not inundated by the watering event vegetation tended to increase in the second monitoring period (2015), but then decrease by the third monitoring period (2016) to levels below that of 2014; although this result was not significant and therefore is a trend only.

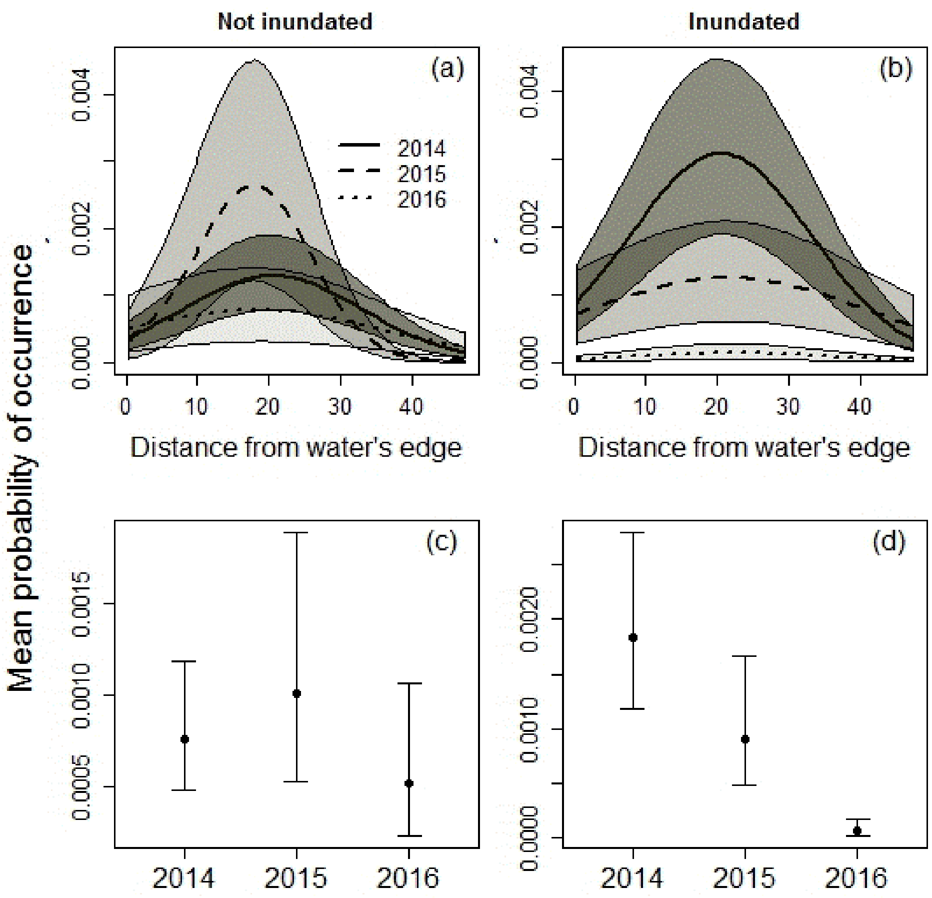

Figure 3. Predicted mean plant occurrence before and after a watering event. Panels (a) and (b) are the predicted occurrence relative to the distance from the 2014 water's edge. The shading represent the 90% confidence intervals. Panels (c) and (d) are the mean plant occurrence before and after the watering event, controlling for distance from the water's edge. The error bars represent 90% confidence intervals.

5.2.2 Plant functional group responses

Native richness increased, albeit slightly, after the environmental watering event, but significantly decreased by the third monitoring period in 2016 to below 2014 levels (Figure 4a). This response likely reflects increased water availability. There was above-average rainfall prior to the 2014 surveys and environmental watering prior to the 2015 surveys, thus increased water availability and plant growth. Whereas, plant growth had decreased by 2016 as a result of below-average rainfall prior to the surveys. Conversely, exotic richness decreased over time which was an unexpected result as exotic species are generally able to outcompete native species during periods of recolonization (i.e. after inundation).

Both perennial and annual plant life cycle groups were relatively consistent in richness in the first two monitoring periods but then richness decreased in the third monitoring period two years after the environmental watering event (Figure 4b).

Of the life form groups, forbs displayed the most change over the three monitoring periods, responding to increased water availability. Forb richness increased significantly after the environmental watering event in 2015, but then decreased in 2016 (Figure 4c). Shrub richness declined over the monitoring period, whereas, graminoid and tree richness remained constant.

Terrestrial damp taxa richness followed a similar pattern to forbs, increasing significantly in response to the environmental watering event and then decreasing in 2016 (Figure 4d). Terrestrial dry taxa richness decreased over the three monitoring periods. In contrast, amphibious fluctuation tolerator low growing taxa increased in response to environmental watering but then declined by the third monitoring period in 2016 (Figure 4d). The amphibious fluctuation tolerator emergent and woody groups remained consistent across the three monitoring periods (Figure 4d).

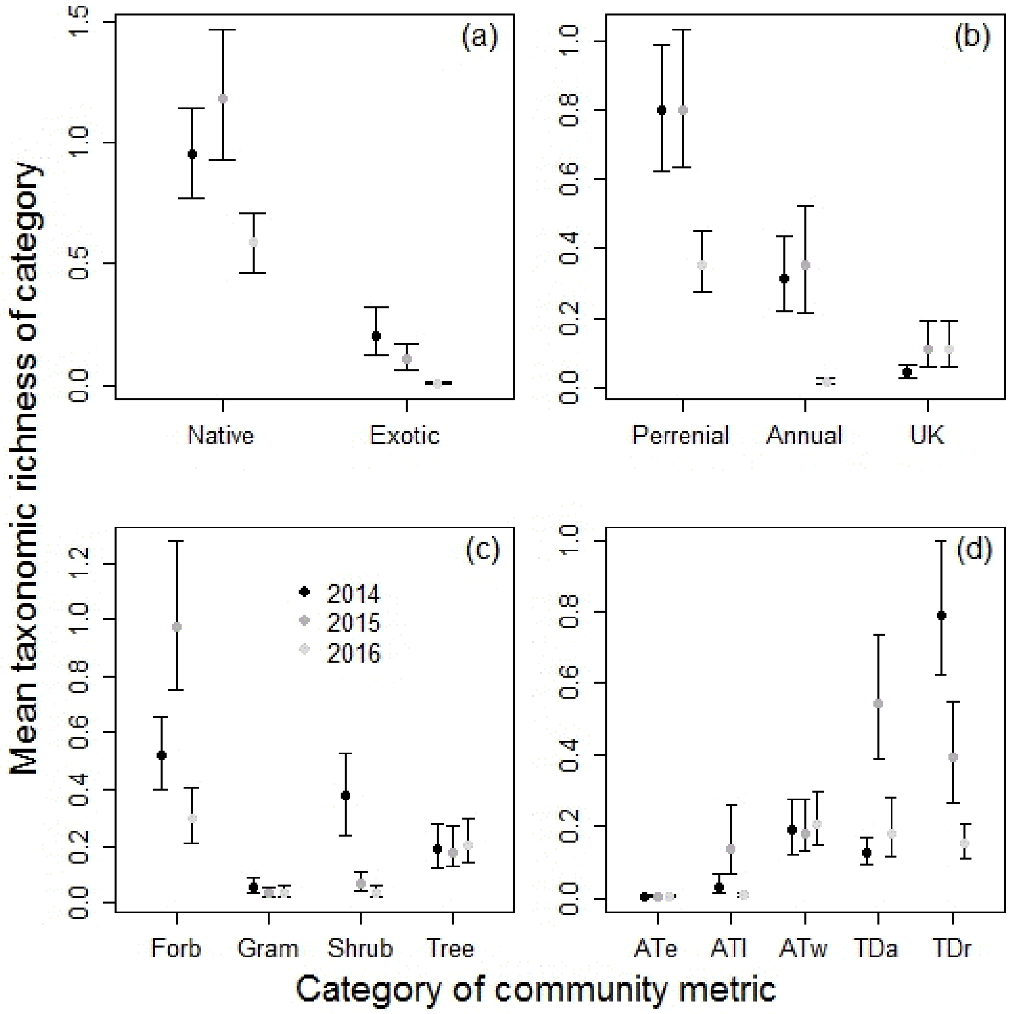

Figure 4. Mean taxonomic richness of the four main community metrics (functional groups) showing responses to environmental watering over the three monitoring periods (2014 before environmental watering, 2015, one year post watering, and 2016 two years post watering). Where functional groups are (a) origin (native or exotic), (b) life cycle (perennial, annual and unknown), (c) life forms (forbs, graminoids, shrubs and trees), and (d) WPFGs (ATe amphibious fluctuation tolerator emergent, ATl amphibious fluctuation tolerator low growing, ATw amphibious fluctuation tolerator woody, TDa terrestrial damp, TDr terrestrial dry). The 95% confidence interval is shown.

5.2.3 Individual taxa responses

As per the model testing on the 2014 and 2015 monitoring data (Moxham and Gwinn 2016), plant taxa fell into two main groups: species favouring either the lake edge or the floodplain (Figure 5). Overall plant taxa favouring the lake edge had positive responses (i.e. increased in abundance) to the watering event, whereas plant taxa favouring the floodplain had a more even mix of both positive and negative responses.

Of the 91 taxa modelled 60 had either significant negative or positive responses either one year post inundation (change between 2014-2015, 25 taxa) or two years post inundation (change between 2015-2016, 15 taxa), and 20 taxa were significant in both time periods (Appendix 2, Table S1). One year post inundation (2014-2015) responses were a mixture of positive and negative responses. Whereas, two years post inundation the majority of taxa responses were negative. Taxa that had significant responses across all time periods, generally had positive responses one year post watering and negative responses two years post watering.

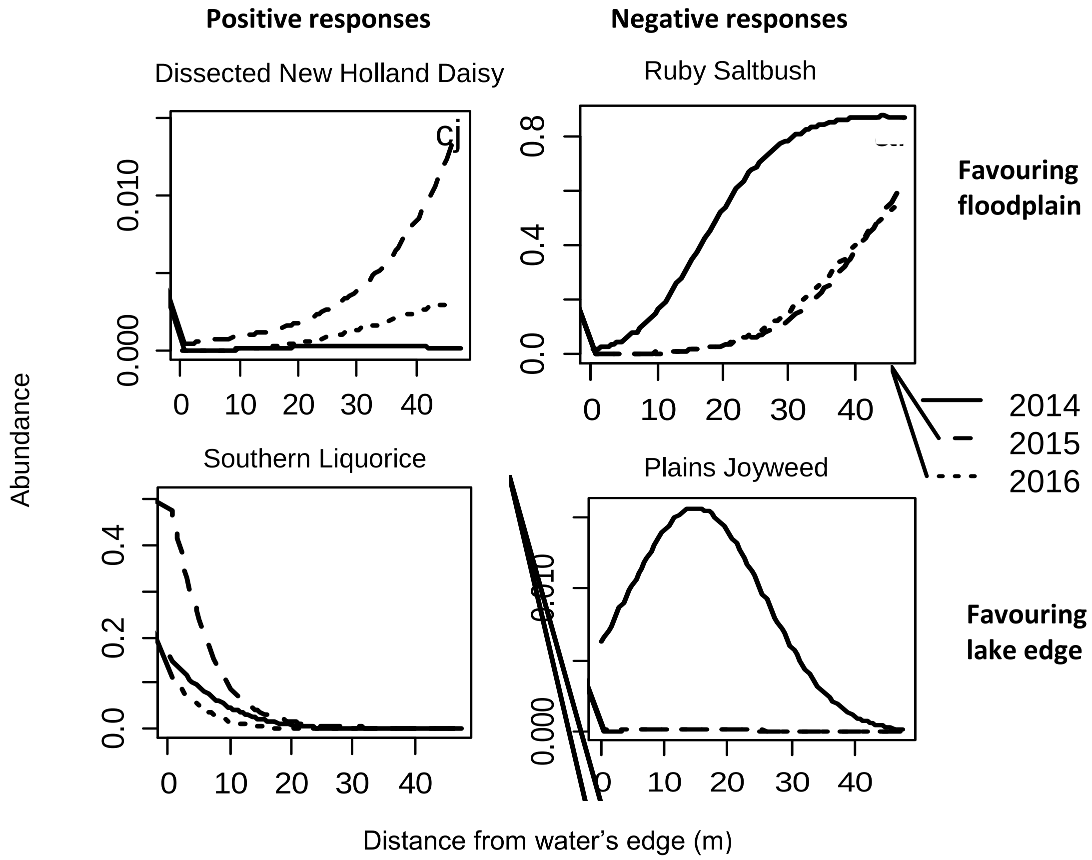

Figure 5. The modelled predicted taxa-specific occurrence (abundance) relative to the distance from the water's edge over the three monitoring periods. These are example taxa that favour either the floodplain or lake edge, and had either positive or negative responses to the environmental watering event.

5.2.4 Canopy tree responses and recruitment

There was no significant difference detected in the two dominant canopy trees (River Red Gum and Black Box) in relation to the environmental watering event over the monitoring period (Figure 6, Appendix 2 Table S1). However, there does appear to be a trend for these species to increase by the third monitoring period in 2016 (Figure 6).

In contrast, there was a significant increase in eucalypt seedling recruitment, particularly at either ends of the transect line, close to the lake edge and higher on the floodplain (Figure 6, Appendix 2 Table S1).

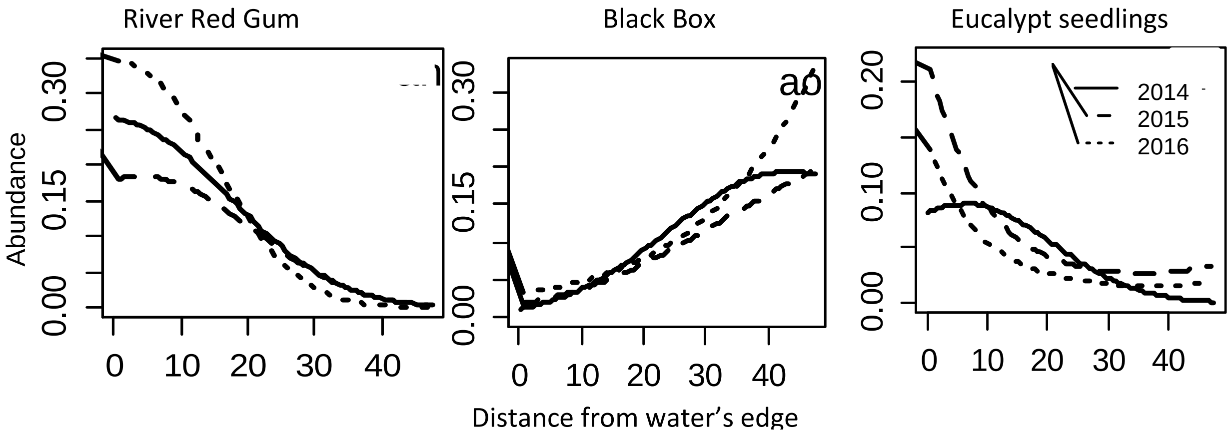

Figure 6. The modelled predicted taxa-specific occurrence (abundance) of River Red Gum, Black Box and Eucalypt seedlings, relative to the distance from the water's edge over the three monitoring periods.

6 The effect of environmental watering on plant community structure

This key question examined the effect of the environmental watering event on plant community structural characteristics before and over the two years after the watering event.

6.1 Methods and data analysis

The presence and structure of species and ground cover was recorded along each transect line from the waters' edge onto the floodplain, using the point quadrat technique (Kent and Coker 1996) at 0.5 m intervals. At each point the number of 'hits' of each plant species in contact with a steel pin (1 m in height) held perpendicular to the ground was recorded to infer plant abundance. The structure pin was divided into five 200 mm height intervals, representing vegetation structural classes (0-200, 200-400, 400-600, 600-800, 800-1000 mm). The ground cover attributes bare ground and litter were also recorded.

Generalised additive mixed models (GAMMs) were used to compare floristic structural change between years (2014, 2015, 2016), for 15 sites (excluding Lake Kramen) and in relation to distance from the lake edge (0-50 m; mean elevation change = 3.44 ±0.22 m /transect). Total abundance was used for all vegetation combined; forbs, graminoids and shrubs in all height classes combined (<1 m); as well as each height class individually (see above). In some instances, individual height classes were not undertaken as there were too few 'hits' of the different vegetation categories to make the model results meaningful (see Appendix 1). In addition, bare ground and litter were examined to determine change along the transect line over the three years. GAMMs are an appropriate analytical technique when data are spatially clustered, as they allow the specification of both fixed and random effects (Zuur *et al.* 2009). A full description of the analysis methods is provided in Appendix 1. All analyses were conducted within R version 3.2.3 (R Core Team 2016).

6.2 Findings

6.2.1 Total vegetation abundance

Understorey vegetation abundance was greater before the environmental watering event in 2014 (Figure 7, Appendix 2 Table S2), where on average vegetation abundance peaked at 43 m, with smaller peaks at 15 m and 28 m. In 2015, one year after the environmental watering event, vegetation abundance was lower and more consistent along the transect line. Again, two years later (2016), abundance is largely consistent along the transect line and in lower abundance than in 2014, although it has increased somewhat since 2015.

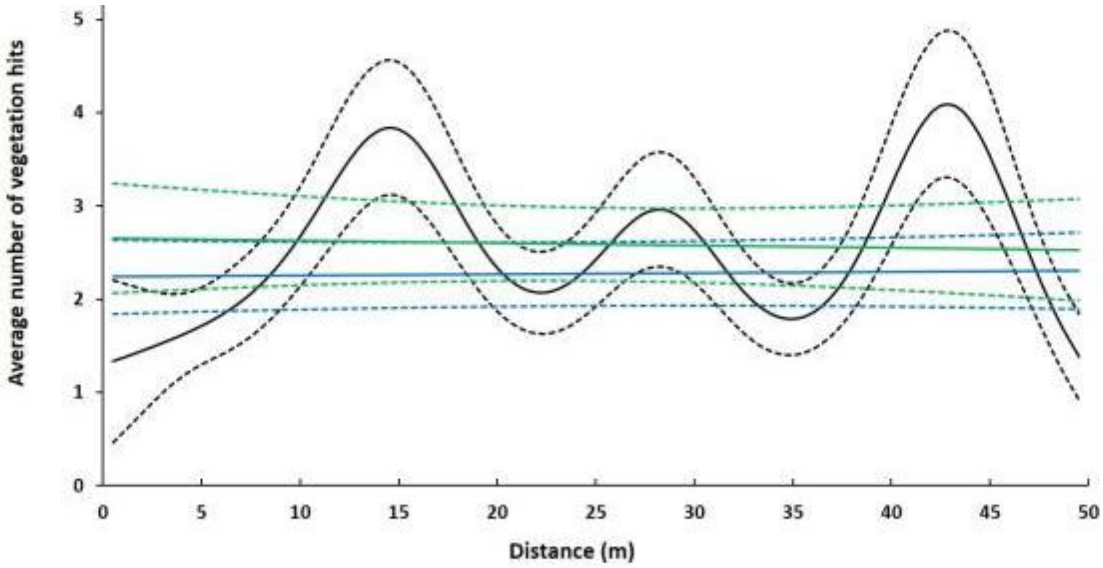

Figure 7. The average number of understorey vegetation 'hits' (abundance) along the 0-50 m transect line across the three monitoring periods (2014 = black, 2015 = blue, 2016 = green). Dashed lines represent the 95% confidence interval.

This relationship is largely mirrored in the five different height classes. Total vegetation abundance in 2016 was significantly different to that in 2014 for all the height classes combined (<1 m), and the three lower level structural classes (0-200 mm, 200-400 mm and 400-600 mm), but not in the two upper level classes (600-800 mm and 800-1000 mm; Appendix 2 Table S2 and Figures S1, S2). In addition, total vegetation abundance (<1 m) in 2015 was significantly different to 2014 but was not significantly different for any individual height class (Appendix 2 Table S2).

This is not an unexpected result as the environmental watering event removes understorey vegetation through prolonged inundation which many species cannot survive (Figure 8). Thus, a strong difference in understorey vegetation, as seen between 2014 and 2015, merely underlines the importance of inundation in 're-setting' understorey vegetation composition and structural complexity. While it was expected that vegetation structural complexity would increase from 2015 to 2016, this largely did not happen. Vegetation abundance did marginally increase from 2015 to 2016, but remained consistent along the transect line. The below average rainfall between sampling periods in 2015 and 2016 may have also influenced the slower than expected structural complexity recovery at these sites.

6.2.2 Life form abundance

Forb abundance in all height classes combined (<1 m), and the two lower level structural classes (0-200 and 200-400 mm) were significantly different after the environmental watering event (Appendix 2 Table S2). In contrast, graminoid abundance in all height classes combined (<1 m), and the two lower level structural classes (0-200 and 200-400 mm) were significantly different only at two years (2016) after the environmental watering event (Appendix 2 Table S2). Shrub abundance in all height classes combined (<1 m), and the three lower level structural classes (0-200, 200-400 and 400-600 mm) were significantly different both one and two years after the environmental watering event.

6.2.3 Bare ground and litter abundance

Bare ground and litter abundance was significantly different following the environmental watering event (Appendix 2 Table S2, Figure S3). Before the environmental watering event in 2014 bare ground abundance decreased along the transect from the water's edge to the higher floodplain. One year after the watering event in 2015, bare ground abundance increased along the transect line, but by 2016 (two years post-water) abundance was consistently lower along the transect line. Similarly, litter abundance largely increased along the transect line in 2015 and remained consistent in 2016.

The increase in bare ground following the environmental watering event was expected as the period of inundation removes both vegetation and to a lesser extent the litter layer. Interestingly, litter abundance also increased following the environmental watering event which was somewhat unexpected as it could be expected to decrease through degradation while inundated. However, some of this litter could have also been replaced through litter fall by shrubs and trees which were not completely inundated and which continued to shed leaves, bark and twigs as part of their natural cycle.

2014

2015

2016

Figure 8. The change in structural complexity over time at Lake Marramook. The photos are taken from the floodplain end of the transect looking towards the lake bed. Note the small shrub and forb understorey in 2014 which is missing in both 2015 and 2016.

7 The effect of environmental watering on tree canopy cover

It is expected that environmental watering will improve the health of floodplain trees by providing a constant source of fresh water deep in the soil profile (Jolly *et al.* 1993). However, the outcomes of environmental watering on improving tree health may take years to be evident due to the long response times that trees have (Metzger *et al.* 2009).

Here we investigated the effect of a single environmental watering event on maintaining or improving tree canopy cover before and over the two years after the watering event.

7.1 Methods and data analysis

Along each transect one digital canopy image was taken at 10 m intervals, using a tripod-mounted digital camera, pointed upwards and parallel to the ground (see right). The pixels in each image were allocated to either canopy or sky on the basis of colour, using the proprietary software WINCAM (Regent Instruments 2012), to derive a value for average canopy cover.

Generalised linear mixed models (GLMMs) were used to compare tree canopy cover between years (2014, 2015, 2016), for 15 sites (excluding Lake Kramen) and in relation to distance from the lake edge (0-50 m; mean elevation change = 3.44 ±0.22 m /transect). GLMMs are an appropriate analytical technique when data are spatially clustered, as they allow the specification of both fixed and random effects (Zuur *et al.* 2009). A full description of the analysis methods is provided in Appendix 1. All analyses were conducted within R version 3.2.3 (R Core Team 2016).

7.2 Findings

Tree canopy cover was largely unchanged in the two years after the environmental watering event (Figure 9a, Appendix 2 Table S3). Conversely, canopy cover declined by ~10% as the distance from the lake edge (i.e. 0 m) increases to 50 m (Figure 9b). This result was expected as the transect graduates from the lake edge onto the higher floodplain the spacing of the canopy trees increases. In addition, River Red Gum (and/or Black Box) tend to dominate the lake edges, whereas at the higher elevation floodplain is dominated by only Black Box.

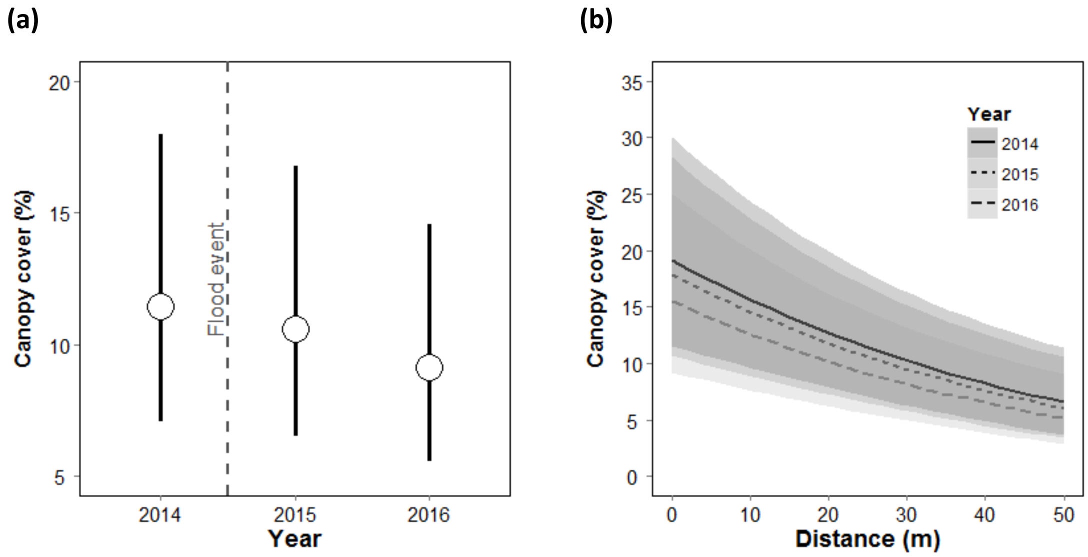

Figure 9: (a) Mean % canopy cover for all years. Dashed vertical line indicates the timing of the flood event. (b) Response curves of % canopy cover across years over the upslope distance from the water mark (0-50m). The 95% confidence intervals are displayed for all years.

8 Synthesis

8.1 Key findings

This annual report outlined the 2015-2016 monitoring activities and has furthered our understanding of the response of native understorey vegetation to environmental watering events through detailed analyses. These findings will enable improved management and ecosystem health of the Hattah Lakes Icon Site.

Key activities and findings include:

(a) 2016 Annual monitoring

Twenty sites were monitored in April 2016. The data has been incorporated into a Microsoft Access database and the Victorian Biodiversity Atlas.

(b) ***Development and implementation of vegetation response models***

The development of the multi-plant taxa Bayesian hierarchical model of occurrence is the first step in providing explicit information that addresses key knowledge gaps in relation to vegetation responses to environmental watering. The model provides a new tool to predict and evaluate the effectiveness of management interventions to inform environmental watering planning. The unique advantage of the multi-taxa model developed here is that inference can be drawn at the plant community level while maintaining species (taxa) identity for further inquiry when the management context necessitates. This enables the development of site specific management tools for use by on-ground managers.

(c) Examination of key ecological monitoring questions to determine the effect on environmental watering on vegetation composition two years after the watering event

1) The effect on plant taxa and plant functional groups two years after the watering event:

- At the lake system scale, individual *taxa* models proved more useful response indicators than *plant functional group* metrics.
- Of the 91 plant taxa evaluated 60 taxa displayed significant responses to the watering event.
- Plant taxa fell into two main groups: species favouring either the lake edge or the floodplain.
- Overall plant taxa favouring the lake edge had positive responses to the watering event, whereas plant taxa favouring the floodplain had a more even mix of both positive and negative responses.
- Total vegetation and shrub (e.g. terrestrial dry WPFG) occurrence decreased over the three year monitoring.
- Native, perennial and forb (e.g. terrestrial damp WPFG) richness increased one year post-watering, but then decreased by 2016, which is likely due to below average rainfall conditions.
- Eucalypt seedling occurrence increased post-watering.

2) The effect on plant community structure two years after the watering event:

- Vegetation abundance and structural complexity decreased over the three years of monitoring.

3) The effect on tree canopy cover two years after the watering event:

- Tree canopy cover of River Red Gum and Black Box remained largely unchanged over the three year monitoring. However, the new modelling tool (above) does indicate an increasing trend in canopy cover over time.
- Tree canopy cover decreases away from the lake edge onto the higher floodplain.

8.2 Management implications and TLM ecological objectives

The ultimate aim of the TLM program is to ensure that a benchmark proportion of vegetation types is restored or maintained in a healthy condition (MDBA 2012). That is, the overarching ecological objective related to the vegetation of the Hattah Lakes Icon Site is to 'restore a mosaic of healthy wetland and floodplain communities to maintain the ecological character of the Ramsar site' (MDBA 2012).

The large environmental watering event from late June through to September 2014 targeted not only the *E. camaldulensis* plant communities but also the higher elevation (45 m ADH) *E. largiflorens* plant communities and their associated network of permanent and semi-permanent wetlands.

This monitoring program has demonstrated that the environmental watering event over a two year period has maintained, and in some instances improved, the lake edge water dependent plant communities of Hattah Lakes Icon Site. Tree cover (and thus health) has been maintained and recruitment increased in the short term. The higher elevation floodplain plant community has demonstrated the expected ecological response to the environmental watering event, with an initial decrease in plant community composition due to inundation, followed by an increase due to greater soil moisture. This has been slow to realise, likely due to the below average rainfall in 2016; however, it is expected that over time this floodplain community will also increase in species richness and abundance.

9 Recommendations

To date, the monitoring program has created a dataset that can be utilised for a range of analyses now and into the future to provide robust evidence-based decision making. The current program outcomes also highlight activities that can add value to the monitoring program, to address key ecological knowledge gaps. Recommendations and future activities are outlined below.

Monitoring in April on an annual basis

Annual monitoring will allow for a comprehensive assessment of the temporal changes experienced by understorey vegetation following an environmental watering event. More specifically, long-term monitoring will enable us to determine if and when the understorey plant communities return to their original (i.e. pre-watering) state, or migrate towards another state, and the influence of environmental watering events and environmental factors in this process. The analysis and reporting as a result of this post-inundation data will provide managers with a better insight into the changes that occur following an environmental watering event.

- The next monitoring period is scheduled for April 2017.
- Use predictive models on the four year monitoring data and update the models if required.

Woody species recruitment

The lack of woody species recruitment of the canopy has been highlighted as a concern (e.g. MDBA 2012). Two key activities could be undertaken to address this knowledge gap. Firstly, the existing data set can be modelled to gain an understanding of the environmental and inundation characteristics influencing eucalypt recruitment and survival. Secondarily, in partnership with this monitoring program, the development of detailed population models of key species (e.g. *A. stenophylla, E. largiflorens*) would add value to the existing data, providing a greater understanding of the species life cycle requirements and enabling better targeting of management interventions to maintain sustainable populations.

- Model the existing data to gain an understanding of the environmental and inundation characteristics influencing eucalypt recruitment and survival.
- Design, implement data collection and develop population models for key woody species.

Model outcomes

The model provides a new tool to predict and evaluate the effectiveness of management interventions to inform environmental watering planning. The unique advantage of the multi-taxa model developed here is that inference can be drawn at the plant community level while maintaining species (taxa) identity for further inquiry when the management context necessitates. This enables the development of site specific management tools for use by on-ground managers.

The development of the multi-plant taxa Bayesian hierarchical model of occurrence is the first step in providing explicit information that addresses key knowledge gaps in relation to vegetation responses to environmental watering. The model developed here can be further utilised and explored through:

- Incorporation of long-term data - results to date are based on a single watering event. Long-term data (i.e. more than one watering event) are required to fully evaluate the effects of environmental watering on vegetation quality.
- The multi-taxa models developed here can be used to predict and demonstrate the effects of future environmental watering events and scenarios on plant assemblages.
- The new modelling tool provides a suitable approach to analysing other long-term data types (e.g. Icon Site Condition monitoring) to gain an understanding of the temporal effects of environmental watering on vegetation responses.
- The modelling tool could be further developed into an online management tool outlining generalised vegetation responses and environmental watering scenarios.

Communication activities

A range of monitoring program communication activities can be developed to value add to program outputs. Some program findings can be developed into communication activities now and some after a more comprehensive analysis. Communication activities may include:

- Scientific publication of key results to highlight a robust evidence base for decision making
- Short communication products (e.g. fact sheets, media and web articles)

10 Conclusion

The monitoring of vegetation across a moisture elevation gradient from lake bed to floodplain has contributed to fulfilling key ecological knowledge gaps at the Hattah Lakes Icon Site. In the short-term this monitoring program has generated evidence-based ecological knowledge that aids in improving land management practices to maintain or improve the health of understorey vegetation in the face of environmental watering events. Ultimately this monitoring program will generate evidence-based ecological knowledge that aids in improving land management practices to maintain or improve the health of understorey vegetation in the face of environmental watering events (MDBA 2009b). These areas of monitoring are currently poorly researched, or no quantitative data or published information is readily available (MDBA 2009b). Therefore, the results of this monitoring program will contribute important information to inform the management of the Hattah Lakes floodplain system, and may be extrapolated to other floodplain systems within the Murray-Darling Basin.

For the 2016-2017 financial year the monitoring program should consider the following activities:

- Monitoring conducted in April 2017;
- Analysis of the four year monitoring data;
- Analysis of eucalypt recruitment data;
- Further develop and utilise the new modelling tool;
- Communication activities; and
- Scientific publication of key results as an evidence base for decision making.

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Appendix 1. Analysis methods

1.1 Model implementation

See: Moxham C. and Gwinn D. (2016). The Living Murray Hattah Lakes Intervention Monitoring: vegetation response models. Unpublished Report for the Mallee Catchment Management Authority. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

1.2 Plant community structure

Generalised additive mixed models (GAMMs) were used to compare vegetation and substrate abundance between years (2014, 2015, 2016) along a 50 m transect line running from the 2014 water's edge. GAMMs were chosen as they allow for non-linearity in the data and for the relationship between the response and predictor variables to be viewed without choosing a particular mathematical function, i.e. parametric form (Crawley 2007; Wood 2004). Mixed models were used, with site as a random factor, to account for the spatial clustering of sites (Zuur *et al.* 2009). The Poisson distribution was used for all vegetation GAMMs as the data is the number of 'hits' of the different vegetation categories. For bare ground and litter, the Binomial distribution was used as these were recorded as presence/absence data. 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). Modelling was undertaken using gamm4 v0.2-3 (Wood 2004) package in R v3.2.3 (R Core Team 2016).

Vegetation abundance was calculated per distance along the transect (0.5 – 50 m at 0.5 m intervals) for each site in multiple categories (all height classes combined (<1 m), 0-200 mm, 200-400 mm, 400-600 mm, 600-800 mm, 800-1000 mm) within all vegetation, forbs, graminoids and shrubs. For all vegetation, GAMMs were undertaken for all height classes. However, for forbs and graminoids, three height classes (400-600 mm, 600-800 mm, 800-1000 mm) were not analysed as the data was strongly dominated by zeros and thus model outcomes would not be meaningful. Shrub abundance was not analysed at 600-800 mm and 800-1000 mm for the same reasons. Bare ground and litter is simply presence/absence data at each point along the transect line.

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1.3 Canopy cover

Sampling methods

Along each transect one digital canopy image was taken at 10 m intervals, using a tripod-mounted digital camera, pointed upwards and parallel to the ground. Once taken, photos were analysed using user-defined settings in WinCAM® software to calculate the proportion of canopy cover (percent of two-dimensional image area covered by leaves, branches etc.) within an image. The software does this by partitioning each pixel within an image (>5,000,000 pixels per image) to either canopy or sky according to a colour palette determined by the user from a subset of the entire image set (24 colours in total). The pixels in each image were allocated to either canopy or sky on the basis of colour, using the proprietary software WINCAM (Regent Instruments 2012), to derive a value for average canopy cover.

Data analysis

Generalised linear mixed models (GLMMs) were used to compare tree canopy cover between years (2014, 2015, 2016), and in relation to distance (standardised: $Z = (\times - \mu) \ / \ \sigma$; where $\times$ = value, μ = mean and σ = standard deviation) from the water line (50 m; mean elevation change = 3.44 ±0.22 m /transect). GLMMs are an appropriate analytical technique when data are spatially clustered, as they allow the specification of both fixed and random effects (Zuur *et al.* 2009). The inclusion of random effects was necessary to account for possible correlation structures in the data due to the spatial clustering of transects. This experimental design means that transects within lakes are not independent, and therefore need to be treated statistically as pseudoreplicates. To achieve this, a single random effect was included reflecting the clustered nature of the experimental design, in which transects are positioned within a series of lakes. The pre-watering monitoring year (i.e. 2014) was specified as the reference category, allowing a direct comparison of canopy cover in post-watering years (i.e. 2015 and 2016) with measures in the pre-watering state. GLMMs were fit using the lme4 package (Bates and Maechler 2010).

Canopy cover was expressed as a proportion. Hence, for true percentage data (e.g. % cover), the most appropriate distribution would be a beta distribution; however, this distribution is not currently widely used in mixed models and to our knowledge cannot be specified in lme4 or any other mixed model package within the R environment. Therefore, a binomial distribution of errors was specified, with data being modelled as the number of successes and failures within a fixed number of Bernoulli trials (i.e. 100 trials for percentage 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), and tests for overdispersion were undertaken to assess whether there was additional variance in the data than assumed by the binomial distribution (Crawley, 2007). As overdispersion was evident (i.e. dispersion parameter >1.0), an additional residual term was included to act as a latent variable accounting for the extra variance not explained by the fixed or random effects (Zuur *et al.* 2012). 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).

All analyses were conducted within R version 3.2.3 (R Core Team 2016).

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Appendix 2. Results

2.1 Modelling results - significant model results individual plant taxa

Table S1. The model results for 60 plant taxa that displayed significant responses in either 2014-2015 or 2015-2016. No. is the number of records, LC is life cycle, BLF is broad lifeform group, WPFG is the water plant function group, Mean change is the estimated change in occurrence between 2014 and 2015 on the logit scale (the sign tells you the direction of the change AND how far it is from zero tells is you the strength of the relationship), Sig (significant) is where a value of one indicates the "Mean" is statistically significant, Change is the direction of change (- negative, + positive or no change), and P is the P-value.

Taxa	No.	LC	BLF	WPFG	Mean change 2014-2015	Mean change 2015-2016	Sig 2014-2015	Sign 2015-2016	Change 2014-2015	Change 2015-2016	P
Alternanthera denticulata s.l.	121	A	Forb	Tda	3.38	-6.18	1	1	+	-	0.001
Alternanthera nodiflora	11	A/P	Forb	Tda	-2.03	5.37	0	1	.	+	0
Alternanthera sp. 1 (Plains)	37	P	Forb	Tda	-4.35	2.06	1	0	-	.	0.002
*Asphodelus fistulosus**	26	A	Forb	Tdr	0.36	-8.13	0	1	.	-	0.001
Atriplex semibaccata	9	P	Forb	Tdr	-1.85	1.17	1	0	-	.	0.001
Atriplex suberecta	88	A/P	Forb	Tdr	3.18	2.03	1	1	+	+	0.001
Austrostipa spp.	93	P	Gram	Tdr	-1.26	-1.71	1	1	-	-	0.012
*Brassica tournefortii**	156	A	Forb	Tdr	-6.9	-2.41	1	0	-	.	0.041
Brassicaceae spp.	15	A/P	Forb	NA	-4.98	-2.48	1	0	-	.	0.001
Calostemma purpureum s.l.	15	P	Forb	Tda	-1.95	-4.65	1	0	-	.	0.001
Centipeda cunninghamii	188	P	Forb	ATl	1.57	-4.8	1	1	+	-	0.014
*Citrullus lanatus**	51	A	Forb	Tdr	3.71	-9.03	1	1	+	-	0
*Conyza bonariensis**	33	A	Forb	Tdr	3.2	-1.74	1	1	+	-	0
Cucumis myriocarpus subsp. *leptodermis**	14	A	Forb	Tdr	-4.44	-2.98	1	0	-	.	0.003
Cynodon dactylon	84	P	Gram	Tdr	-0.17	-1.59	0	1	.	-	0.016
Cynodon dactylon var. *dactylon*	12	P	Gram	Tdr	-2.34	5.61	0	1	.	+	0
Cynodon dactylon var. *pulchellus*	15	P	Gram	Tdr	1.12	-7.56	0	1	.	-	0
Cyperus squarrosus	6	A	Gram	ATe	-3.71	-2.64	1	0	-	.	0
Dysphania cristata	86	A	Forb	Tdr	-6.08	-2.71	1	0	-	.	0.008
Dysphania glomulifera subsp. *glomulifera*	25	A	Forb	Tdr	-1.05	-6.38	0	1	.	-	0.001
Dysphania pumilio	184	A	Forb	Tdr	2.31	-4.34	1	1	+	-	0.007
Einadia nutans	109	P	Forb	Tdr	-1.03	0.13	1	0	-	.	0.007
Enchylaena tomentosa var. *tomentosa*	412	P	Shrub	Tdr	-2.63	-0.29	1	0	-	.	0.099
Eragrostis parviflora	15	A/P	Gram	Tdr	-3.79	-3.82	1	0	-	.	0.002
Eragrostis spp.	6	A	Gram	Tdr	2.48	-7.6	1	1	+	-	0
Eucalyptus spp.	151	P	Tree	ATw	1.23	-0.19	1	0	+	.	0.007
Euphorbia dallachyana	42	P	Forb	Tdr	-2.14	7.53	0	1	.	+	0
Euphorbia drummondii	101	P	Forb	Tdr	0.94	-8.73	1	1	+	-	0.006
Glycyrrhiza acanthocarpa	148	P	Shrub	Tda	1.51	-2.02	1	1	+	-	0.007
Goodenia glauca	9	P	Forb	Tda	-0.42	-5.89	0	1	.	-	0

Goodenia spp.	11	P	Forb	Tda	2.85	-7.98	1	1	+	-	0
Haloragis aspera	11	P	Forb	Tda	0.84	-7.01	0	1	.	-	0
Helichrysum luteoalbum	32	A	Forb	Tda	1.63	-4.77	1	1	+	-	0.001
*Heliotropium europaeum**	161	A	Forb	Tda	1.17	-4.65	1	1	+	-	0.023
Lipocarpha microcephala	9	A	Gram	ATe	-0.03	-6.42	0	1	.	-	0.001
Maireana brevifolia	27	P	Shrub	Tdr	-2.06	0.58	1	0	-	.	0.001
Medicago spp.*	9	A	Forb	Tdr	0.08	-6.65	0	1	.	-	0.001
Phyllanthus lacunellus	57	P	Shrub	Tdr	0.39	-4.26	0	1	.	-	0.001
Poaceae spp.	45	A/P	Gram	NA	-0.74	4.55	0	1	.	+	0.001
Polycalymma stuartii	6	A	Forb	Tdr	2.01	-7.05	0	1	.	-	0
Rhagodia spinescens	22	P	Shrub	Tdr	-4.37	3.76	1	1	-	+	0.001
Rumex brownii	13	P	Forb	Tda	3.31	-8.4	1	1	+	-	0
Rumex dumosus	26	P	Forb	Tda	-4.67	-2.29	1	0	-	.	0.001
Salsola tragus	51	A	Forb	Tdr	-1.47	-1.98	1	1	-	-	0.004
Salvia verbenaca var. *vernalis**	7	P	Forb	Tdr	-4.05	-2.63	1	0	-	.	0
*Salvia verbenaca**	26	P	Forb	Tdr	2.67	-0.33	1	0	+	.	0
Sclerolaena diacantha	55	P	Shrub	Tdr	-2.83	0.93	1	0	-	.	0.008
*Sisymbrium erysimoides**	10	A	Forb	Tdr	-2.48	-4.46	1	0	-	.	0.001
Solanum nigrum s.l.*	47	P	Forb	Tdr	1.53	-3.12	1	1	+	-	0.001
Sphaeromorphaea australis	317	P	Forb	Tda	2.2	-2.78	1	1	+	-	0.01
Stemodia spp.	311	A/P	Forb	Tda	1.29	0.36	1	0	+	.	0.038
Swainsona microphylla	10	P	Forb	Tdr	-2.12	-0.68	1	0	-	.	0.001
Teucrium racemosum s.l.	50	P	Forb	Tdr	0.84	-0.46	1	0	+	.	0.003
Tricoryne spp.	15	P	Forb	Tdr	-4.49	-2.39	1	0	-	.	0.001
Trifolium spp.*	10	A	Forb	Tdr	-4.03	-2.61	1	0	-	.	0.001
Verbena officinalis var. *africana*	38	P	Forb	Tdr	-3.41	5.24	1	1	-	+	0.001
*Verbena supina**	14	P	Forb	Tda	0.49	-6.72	0	1	.	-	0.001
Vittadinia dissecta var. *hirta*	12	A	Forb	Tdr	2.42	-1.69	1	0	+	.	0
Wahlenbergia fluminalis	17	P	Forb	Tda	-3.61	2.68	1	0	-	.	0.004
*Xanthium spinosum**	9	A	Forb	Tdr	2.27	-2.77	1	1	+	-	0

2.2 Plant community structure results

Table S2. Estimated model coefficients for total vegetation, different life forms (forbs, graminoids, shrubs) and substrate (bare ground, litter) abundance. Coefficients in bold represent years in which abundance is significantly different to the 2014 baseline.

Predictor variable	Parameter	Estimate	Standard error	z-value	*p*
Total veg. (<1 m)	Intercept	-0.13	0.12	-1.09	0.28
	2015	**-0.09**	**0.04**	**-2.33**	**0.02**
	2016	**-1.13**	**0.05**	**-20.82**	**<0.0001**
Total veg. (0-200 mm)	Intercept	-0.56	0.12	-4.79	<0.0001
	2015	-0.02	0.05	-0.4	0.69
	2016	**-1.32**	**0.07**	**-18.08**	**<0.0001**
Total veg. (200-400 mm)	Intercept	-1.96	0.21	-9.15	<0.0001
	2015	-0.09	0.09	-1.01	0.31

	2016	**-1.29**	**0.13**	**-9.94**	**<0.0001**
Total veg. (400-600 mm)	Intercept	-3.64	0.38	-9.63	<0.0001
	2015	0.01	0.17	0.06	0.96
	2016	**-0.78**	**0.21**	**-3.65**	**0.0003**
Total veg. (600-800 mm)	Intercept	-5.17	0.57	-8.99	<0.0001
	2015	0.71	0.39	1.81	0.07
	2016	-0.42	0.62	-0.68	0.49
Total veg. (800-1000 mm)	Intercept	-5.8	0.73	-7.94	<0.0001
	2015	-0.3	0.64	-0.47	064
	2016	-2.03	1.96	-1.04	0.29
Forbs (<1 m)	Intercept	-1.62	0.24	-6.79	<0.0001
	2015	**0.5**	**0.07**	**7.2**	**<0.0001**
	2016	**-3.16**	**0.29**	**-10.81**	**<0.0001**
Forbs (0-200 mm)	Intercept	-1.67	0.24	-6.98	<0.0001
	2015	**0.47**	**0.07**	**6.69**	**<0.0001**
	2016	**-2.67**	**0.2**	**-13.32**	**<0.0001**
Forbs (200-400 mm)	Intercept	-5.43	0.52	-10.52	<0.0001
	2015	**1.08**	**0.39**	**2.77**	**0.006**
	2016	**-1.48**	**0.68**	**-2.18**	**0.03**
Graminoids (<1 m)	Intercept	-4.84	0.75	-6.47	<0.0001
	2015	0.29	0.19	1.53	0.13
	2016	**-1.57**	**0.39**	**-4.05**	**<0.0001**
Graminoids (0-200 mm)	Intercept	-4.69	0.64	-7.28	<0.0001
	2015	0.25	0.19	1.32	0.19
	2016	**-1.22**	**0.37**	**-3.34**	**0.0008**
Graminoids (200-400 mm)	Intercept	-9.77	1.69	-5.75	<0.0001
	2015	0.75	0.4	1.88	0.06
	2016	**-1.04**	**0.5**	**-2.06**	**0.04**
Shrubs (<1 m)	Intercept	-1.65	0.26	-6.29	<0.0001
	2015	**-0.45**	**0.12**	**-3.69**	**0.0002**
	2016	**-1.92**	**0.19**	**-10.27**	**<0.0001**
Shrubs (0-200 mm)	Intercept	-2.11	0.25	-8.46	<0.0001
	2015	**-0.58**	**0.16**	**-3.53**	**0.0004**
	2016	**-1.48**	**0.19**	**-7.54**	**<0.0001**
Shrubs (200-400 mm)	Intercept	-2.91	0.28	-10.25	<0.0001
	2015	**-0.43**	**0.19**	**-2.27**	**0.02**
	2016	**-3.22**	**0.87**	**-3.72**	**0.0002**
Shrubs (400-600 mm)	Intercept	-4.59	0.43	-10.62	<0.0001
	2015	**-0.89**	**0.34**	**-2.64**	**0.008**
	2016	**-1.24**	**0.33**	**-3.74**	**0.0002**
Bare ground	Intercept	-0.99	0.18	-5.58	<0.0001
	2015	**0.71**	**0.08**	**8.75**	**<0.0001**
	2016	**0.42**	**0.08**	**5.14**	**<0.0001**
Litter	Intercept	0.88	0.15	6	<0.0001
	2015	**0.55**	**0.09**	**6.25**	**<0.0001**
	2016	**0.88**	**0.09**	**9.51**	**<0.0001**

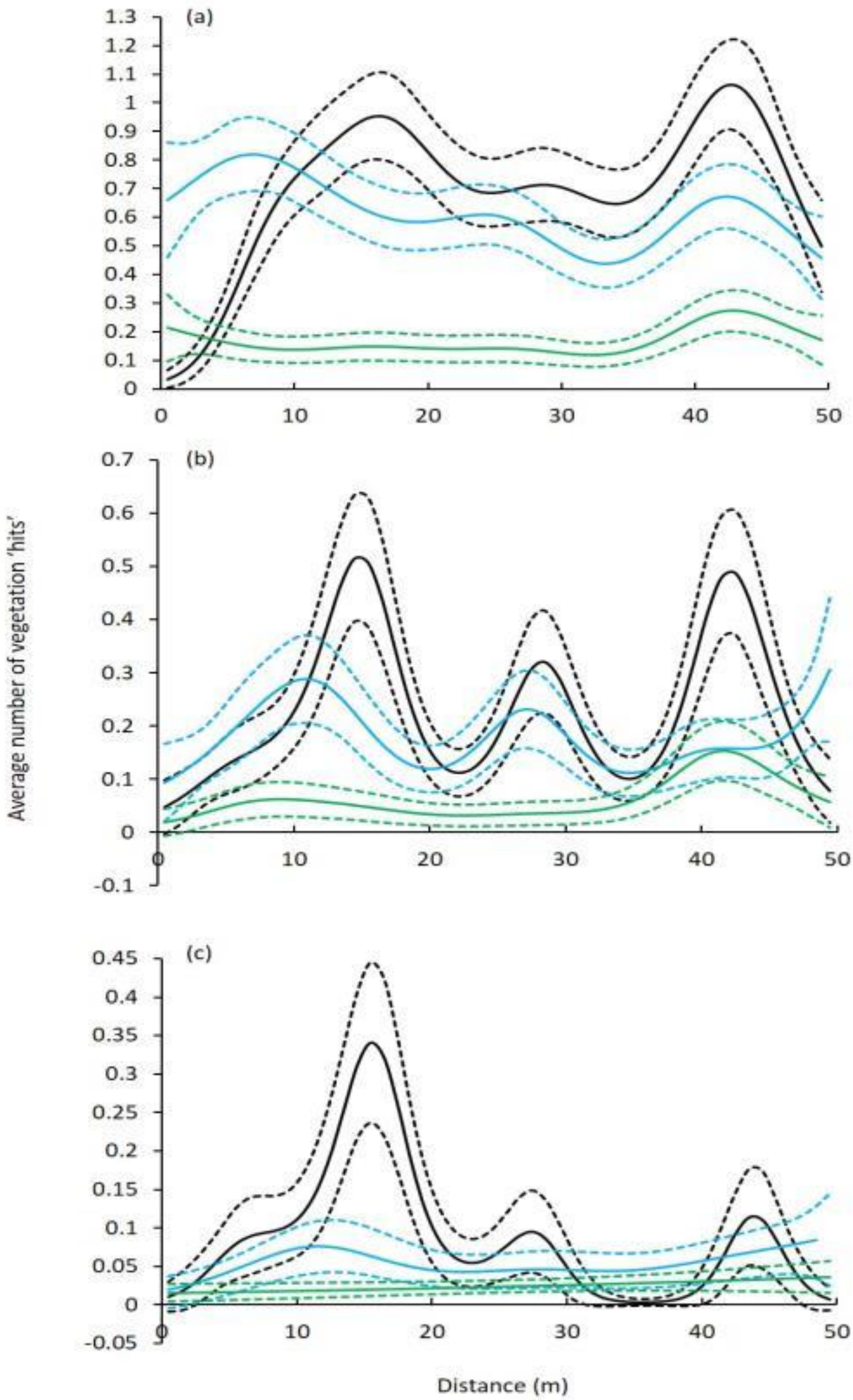

Figure S1. The average number of understorey vegetation 'hits' at (a) 0-200 mm, (b) 200-400 mm and (c) 400-600 mm heights along the 50 m transect line across the three monitoring periods (2014 = black, 2015 = blue, 2016 = green). Dashed lines represent the 95% confidence interval.

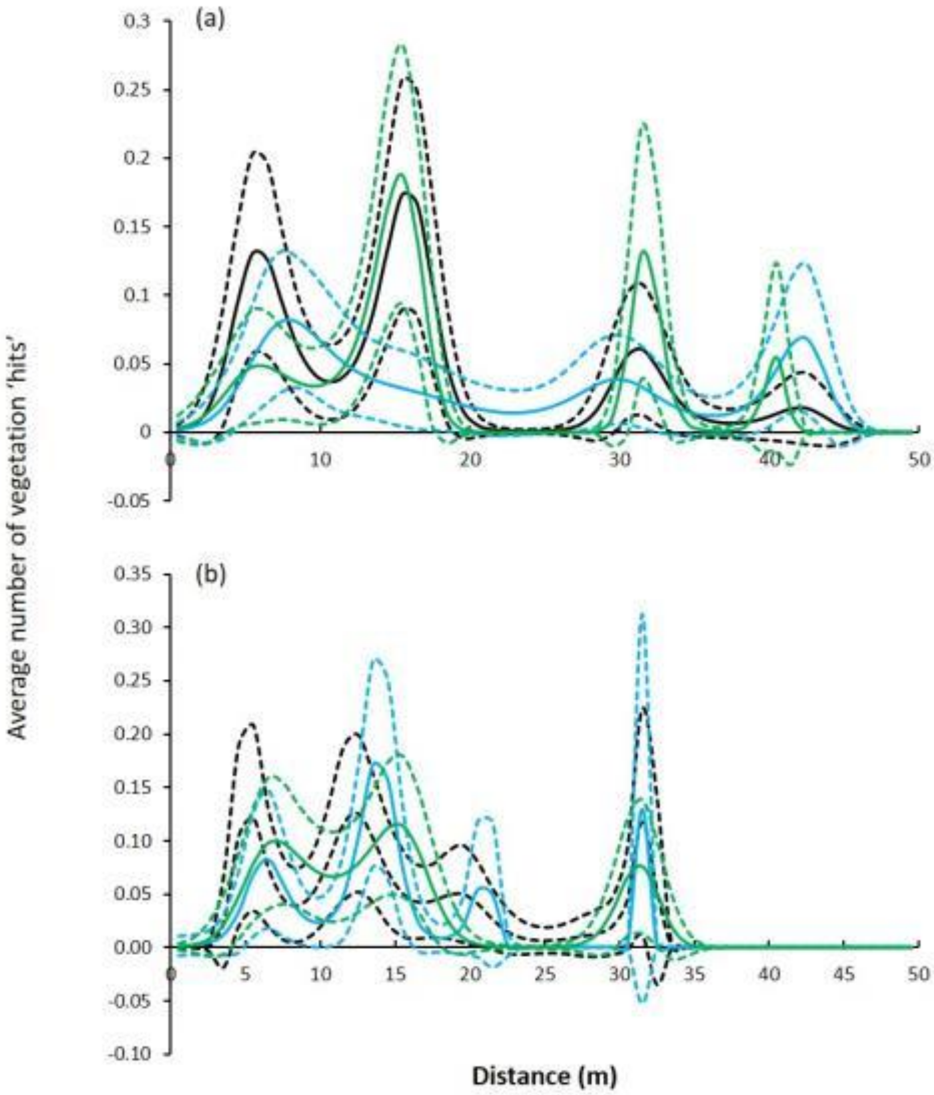

Figure S2. The average number of understorey vegetation 'hits' at (a) 600-800 mm and (b) 800-1000 mm heights along the 50 m transect line across the three monitoring periods (2014 = black, 2015 = blue, 2016 = green). Dashed lines represent the 95% confidence interval.

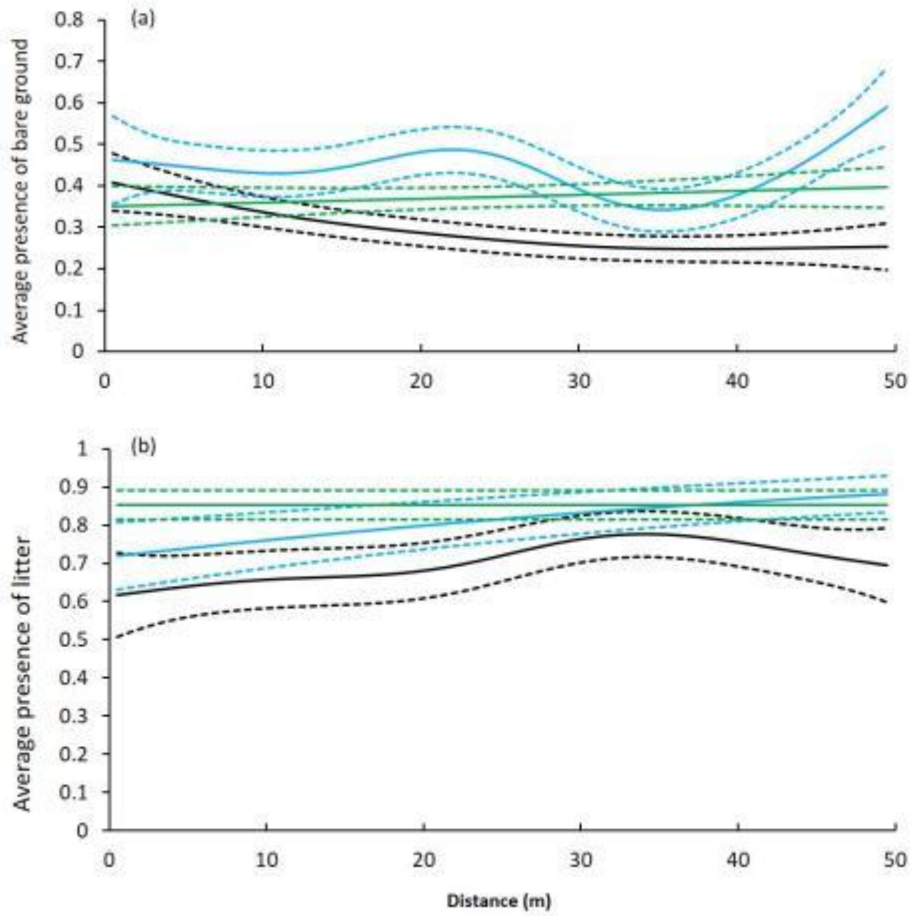

Figure S3. The average presence of (a) bare ground and (b) litter along the 50 m transect line across the three monitoring periods (2014 = black, 2015 = blue, 2016 = green). Dashed lines represent the 95% confidence interval.

1.3 Canopy cover results

Table S3: Estimated model coefficients for canopy cover

Predictor variable	Parameter	Coefficient	SE	z	P
Year + Distance	Intercept	-2.05	0.27	-7.57	<0.001
	2015	-0.09	0.24	-0.37	0.714
	2016	-0.25	0.24	-1.07	0.287
	Distance	**-0.42**	**0.10**	**-4.27**	**<0.001**

SE = standard error of parameter estimates; z = z-value showing whether differences are evident between levels, as indicated by z values of > 1.96 or < -1.96 (or P-values). Coefficients in bold represent an important (i.e. significant) relationship.

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