

Field trial investigating use of drip irrigation to improve condition of black box (*Eucalyptus largiflorens*) woodlands Phase 1: Infrastructure Test Report



Susan Gehrig

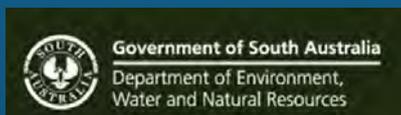
SARDI Publication No. F2013/000438-1
SARDI Research Report Series No. 706

SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

August 2013



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This Publication may be cited as:

Gehrig, S.L. (2013). Field trial investigating use of drip irrigation to improve condition of black box (*Eucalyptus largiflorens*) woodlands Phase 1: Infrastructure Test Report. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2013/000438-1. SARDI Research Report Series No. 706. 74pp.

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Printed in Adelaide: August 2013

SARDI Publication No. F2013/000438-1

SARDI Research Report Series No. 706

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Date: 23 August 2013

Distribution: SAMDBNRM Board, DEWNR, Riverland West Landcare, Treasury Wine Estates, SAASC Library, University of Adelaide Library, Parliamentary Library and National Library

Circulation: Public Domain

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Acknowledgements

The author would like to thank Kelly Marsland, Tanya Doody, Kate Holland, Kerri Muller and Jason Nicol for consultation and development and initiation of the project. Special mention to Kelly Marsland, Kate Frahn, Rod Ward, Thiago Vasques Mari and Irene Wegner for their valuable field assistance and to Jason Nicol, Kate Holland and Tanya Doody for assistance with data analysis and interpretation. Thank you to Kelly Marsland and Luciana Bucater for compiling site maps.

The infrastructure development and trial would not have been possible without Michael Jungfer and staff at Berri Irrigation Service for installation of the experimental drip irrigation system. Likewise, the author would like to thank Treasury Wine Estates Limited and staff from Markaranka Station (in particular, Brendan Turner and 'Mackie') for their kind assistance with site, experimental and infrastructure maintenance. Thank you to Megan Lefournour from Isotope Analysis Service (CSIRO Land and Water) for sample processing.

Thank you to Jason Nicol, Rebecca Turner and Kate Frahn for comments on early drafts of this report. Finally, thank you to the South Australian Murray-Darling Basin Natural Resource Management Board's Biodiversity Fund Grant for funding this project, with assistance from Riverland West Landcare, CSIRO Land and Water and Treasury Wine Estates Limited for their ongoing in-kind assistance.

Executive Summary

From 2001 to 2009, the southern Murray-Darling Basin (MDB) experienced severe drought conditions and a concomitant dieback of floodplain eucalypts (river red gums, *Eucalyptus camaldulensis* and black box, *Eucalyptus largiflorens*). To improve floodplain eucalypt health during low flow periods and drought, regular watering interventions (e.g. filling of deflation basins, weir pool surcharge, groundwater freshening) were used as effective management intervention tools. In 2010/11, there was widespread flooding across the MDB leading to improved catchment conditions. Nonetheless, many black box trees at higher elevations on the floodplain remained unflooded, leaving these trees vulnerable to further decline without short to medium term interventions.

To alleviate further declines in tree health the use of drip irrigation as a direct watering technique for black box woodlands was trialled on the Markaranka Floodplain (lower River Murray, South Australia). The preliminary phase of the project tested the effectiveness and feasibility of this technique using a range of tree condition, eco-physiological and understorey vegetation assessments. During the 10-week experimental period (November 2012 to January 2013), irrigated, treated plots were watered weekly at a precipitation rate of ~ 20 mm week⁻¹ (total water volume = 2.03 ML).

Prior to watering, the population structure of black box within the experimental area was unbalanced with no evidence of young growth stages (i.e. seedlings or saplings) present. Furthermore, the majority of black box trees had poor condition scores and low plant water status. Despite seasonal variations, black box tree condition scores, tree water status and understorey species richness/ percentage cover all significantly improved in irrigated versus non-irrigated plots, indicating the drip irrigation technique was effective and that the method can provide an accessible water source for stressed floodplain vegetation. Ongoing trials are recommended to focus on determining the optimal watering regime (volume, frequency, duration) to identify key thresholds and indicators of black box woodland condition.

1. Introduction

Forest degradation (Bradshaw 2012), particularly floodplain forests, is increasing in magnitude and severity worldwide (Busch and Smith 1995; Stromberg *et al.* 2007; Palmer *et al.* 2008; Mac Nally *et al.* 2011). The floodplain woodlands of the River Murray in south eastern Australia are no exception, where the two dominant tree species, river red gum (*Eucalyptus camaldulensis* Dehnh.) and black box (*Eucalyptus largiflorens* F. Muell), are suffering pervasive mortality and condition loss (Cunningham *et al.* 2009; Mac Nally *et al.* 2011). Water requirements are strong determinants shaping the distribution, growth and survival of long-lived vegetation, such as trees (Taylor *et al.* 1996). In riverine environments, water sources for vegetation may include surface river water, precipitation, soil water and/or groundwater. In most instances, however, the availability of surface-water declines with increasing distance from the river (Mensforth *et al.* 1994; O'Grady *et al.* 2002) so growth and survival for vegetation positioned further away from the river will be influenced by the capacity to use other water sources, such as groundwater and precipitation (Taylor *et al.* 1996) or to tolerate reduced water availability (Stromberg *et al.* 1991); especially during periods of low river flow.

In the last 200 years, the effects of intensive land clearance, compounded by river regulation (Zubrinich *et al.* 2000; Robertson *et al.* 2001; George *et al.* 2005; Jensen *et al.* 2008), drought (MDBC 2003; George *et al.* 2005; MDBC 2005; Cunningham *et al.* 2009) and changes in groundwater–surface water interaction and increased soil salinisation (Jolly *et al.* 1993; Jolly and Walker 1996; Slavich *et al.* 1999; Overton *et al.* 2006) all contribute to the extensive decline in existing floodplain eucalypt woodlands on the lower River Murray floodplain (Cunningham *et al.* 2007). The marked decline in eucalypt woodland communities has the potential to profoundly affect the integrity and function of floodplain systems (Robertson *et al.* 2001; Leyer 2005).

Prior to river regulation there was greater flow variability along the River Murray and floodplains were inundated more frequently, for longer duration and greater depth (Maheshwari *et al.* 1995); however, since river regulation, which commenced in the 1920s, small- to medium-sized floods have generally been lost; resulting in less frequent floodplain inundations, of shorter duration and reduced depths (Maheshwari *et al.* 1995). Then from 2001-2009, the Murray-Darling Basin (MDB) experienced the driest period since 1900 (Bond *et al.* 2008; van Dijk *et al.* 2013). As a result, below average stream flows, coupled with upstream extraction and river regulation, resulted in reduced inflows to South Australia (Timbal and Jones 2008) and hence across this period there was widespread mortality and condition loss in floodplain eucalypts; river red gums and black box (MDBC 2003; George *et al.* 2005; MDBC 2005).

To arrest the decline, maintain and/or improve floodplain eucalypt condition during this drought period, several management intervention tools were trialled, such as the pumping of water to temporary wetlands (Holland *et al.* 2009) and a weir pool surcharge to enhance local floodplain inundation (Siebentritt *et al.* 2004). In these instances, the extent of the vegetation response to artificial watering was linked to the extent of groundwater freshening arising from bank recharge; a factor largely controlled by floodplain

hydraulic conductivity. Another method included the injection of fresh river water into a saline floodplain aquifer to target stressed river red gums on the Lower River Murray (Berens *et al.* 2009). As a result of this method, there was a localised, short-lived freshening of the groundwater which reduced salinity in the associated capillary fringe; however, the extent of freshening was limited (~10 m) and therefore not considered particularly successful, as most trees lay beyond the extent of freshening. The method also had to be abandoned due to aquifer and well clogging and increases in the groundwater head, breaching the confining clay layer within the soil horizon. An additional method involved the lowering of the saline watertable combined with groundwater freshening, thereby creating the availability of a freshwater lens to water-stressed floodplain vegetation (Doody *et al.* 2009a). Results indicated that the method could provide an accessible water source for stressed floodplain vegetation, especially for vegetation not located close to permanent or ephemeral surface water sources. While all methods had their advantages and disadvantages, overall management strategies that frequently replenish low-salinity soil water sources beyond the immediate zone of surface water margins are likely to improve the maintenance, persistence and regeneration of native riparian and floodplain communities (George *et al.* 2005; Jensen *et al.* 2008).

In 2010-2011, inflows to the River Murray system increased, resulting in widespread flooding across the MDB; although the extent of flooding varied considerably due to the pattern of rainfall and nature of the floodplain. By the end of May 2011, total annual flow into South Australia was ~14,000 GL, (highest since 1975-76, peaked at 93,000 ML day⁻¹, February 2011, and floodplain inundation persisted for ~11 months. Hence for the first time in ten years, flows not only watered red gum woodlands and wetland areas, but also reached some black box communities in the lower River Murray system (MDBA 2011).

On the whole, there was a marked improvement in floodplain eucalypt condition, especially for river red gums, but many black box trees still remained unflooded. Black box are small- to medium-sized trees (~20 m), with short trunks and spreading crowns of narrow dull grey or greenish leaves (Costermans 2005). They tend to dominate inland floodplain woodlands; forming open, sparse woodlands at often slightly higher elevations than river red gums, on occasionally inundated, heavy alluvial clay floodplains (Roberts and Marston 2000). They are opportunistic water users, able to access a wide range of water sources, such as surface water, rainfall and groundwater (Thorburn *et al.* 1993; Holland *et al.* 2006) and hence are considered relatively tolerant of flood and drought (Roberts and Marston 2000). However, survival and population maintenance hinges upon both water availability and quality (Slavich *et al.* 1999; Doody *et al.* 2009b). What ultimately determines their distribution within the landscape is a reflection of their tolerance of flooding events, frequency and intensity, drought, soil property requirements, optimal temperatures, and micro-site conditions for recruitment (Roberts and Marston 2000, 2011), but established black box communities are more likely to have responded to historical flow regimes rather than current flow regimes (Stokes *et al.* 2010b). So while black box in certain areas (usually at the break of slope on the junction between the floodplain and highland) can access sufficient rainfall or shallow fresh groundwater to meet transpiration demands (Jolly and Walker 1996), after the drought and subsequent flood of 2010/11, many high elevation black box woodlands in Lower River Murray are potentially still vulnerable to ongoing decline in condition and health.

The overarching objective of this study was to develop a scientifically robust experimental procedure that can be used to investigate and trial the use of drip irrigation as a direct watering intervention technique to maintain high elevation black box woodlands. The specific aims of this study were to trial infrastructure and test the feasibility of using drip irrigation as a water source for black box woodlands.

Markaranka Floodplain, Lower River Murray (South Australia) is approximately 25 km downstream from the township of Waikerie (139°59'08"E, 34°10'54"S) (Figure 1) The climate is semi-arid and characterised by mild winters and hot summers and rainfall is highly variable with an average annual rainfall of 254 mm yr⁻¹ (minimum = 87.5 mm yr⁻¹; maximum = 541 mm yr⁻¹). Rainfall is typically higher from May to October and lower across the spring to autumn period (Bureau of Meteorology 2013). The floodplain is predominantly an open lignum (*Duma florulenta*) shrubland with salt and desiccation tolerant understorey such as *Atriplex* spp., *Sclerolaena* spp. and *Maireana macrocarpa*. In the areas adjacent to the large (197.8 Ha) temporary wetland, Markaranka Flat Lagoon, the floodplain is dominated by open river red gum (*Eucalyptus camaldulensis* var. *camaldulensis*) woodland with a diverse understorey assemblage of *Atriplex* spp., *Sclerolaena* spp. and *Maireana macrocarpa*, interspersed with *Duma florulenta*, *Senna artemisioides* spp. *filiofolia* and *Dodonea attenuata*. At the higher elevations, the floodplain is an open black box (*Eucalyptus largiflorens*) woodland with a sparse understorey, including *Duma florulenta*, *Atriplex* spp. and *Sclerolaena* spp., and it was within this area that we established the experimental site.

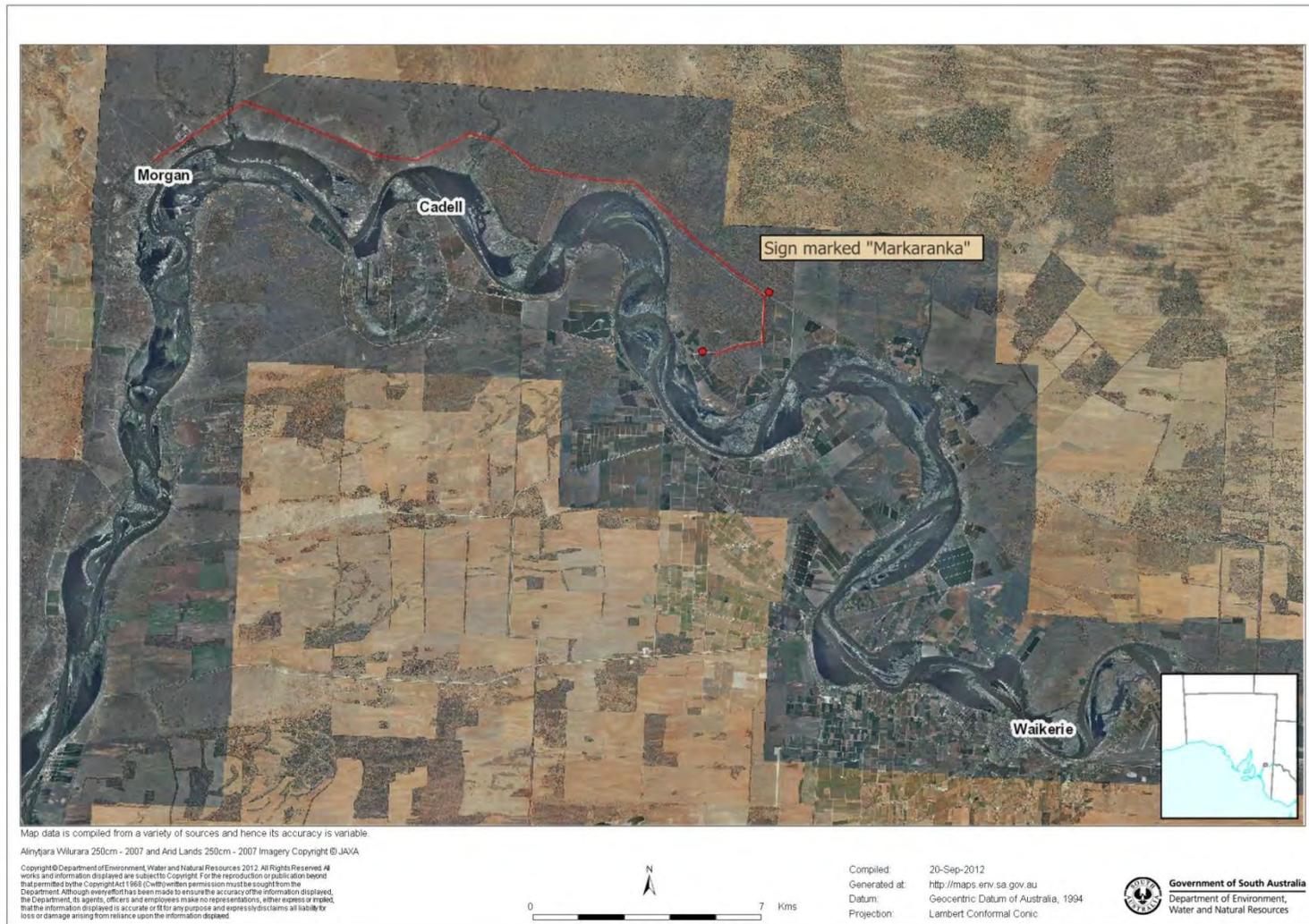


Figure 1: Location of Markaranka Floodplain on the Lower River Murray, adjacent Markaranka Station, Treasury Wine Estates Limited (near Cadell, South Australia). Compiled by K. Marsland on 20 September 2012. Generated at <http://maps.env.sa.gov.au>. Datum Geocentric Datum of Australia, 1994.

2. Methods

2.1. Experimental Design

Experimental Design

The experimental plot is located on the Markaranka Floodplain (Figure 2). A total of nine (55×55 m; 0.3025 Ha) plots were marked out within the Markaranka Floodplain black box woodland. One of the plots (M1) is a monitoring plot and of the eight remaining plots, 4 controls (C2 to C5) and 4 treatment (T1 to T4) plots were randomly assigned (Figure 3). Measurements pre- and post-treatment (drip irrigation) included tree health, tree water stress and soil and woodland condition (understorey vegetation surveys, photopoints, comparison of vegetation under canopy versus open areas). A watering point was located on the southern edge of the adjacent Treasury Wine Estates' property (Figure 2) and a manually operated hydraulic valve (80 mm diameter) was installed to isolate the experimental system from the vineyard operations. A length of PVC ($4 \text{ m} \times 100 \text{ mm}$) was connected to the valve and buried under the track to allow vehicle access. To reach the floodplain field site, a length of SunnyRed Layflat™ hose ($100 \text{ mm} \times 2 \text{ km}$) was installed along the edge of the access track (Figure 4A). At the experimental site a series of four (50 mm) manually operated ball valves were installed to deliver water to each treatment plot. The ball valve system was designed to operate all treatment plots at once and/or independently (Figure 4B). Lengths of poly submain (50 mm diameter) were connected to each ball valve to deliver water to each treatment plot (Figure 4C). Rows of dripper lines ($50 \text{ m} \times 20 \text{ mm}$) were connected to the submain poly lines, spaced at 3 m intervals (i.e. total 17 rows per plot) (Figure 4D). Drippers (capacity = 2.2 L hr^{-1}) were installed every 50 cm along the dripper lines to provide a flow rate of 1.1 L s^{-1} to each experimental treatment plot (0.25 Ha).

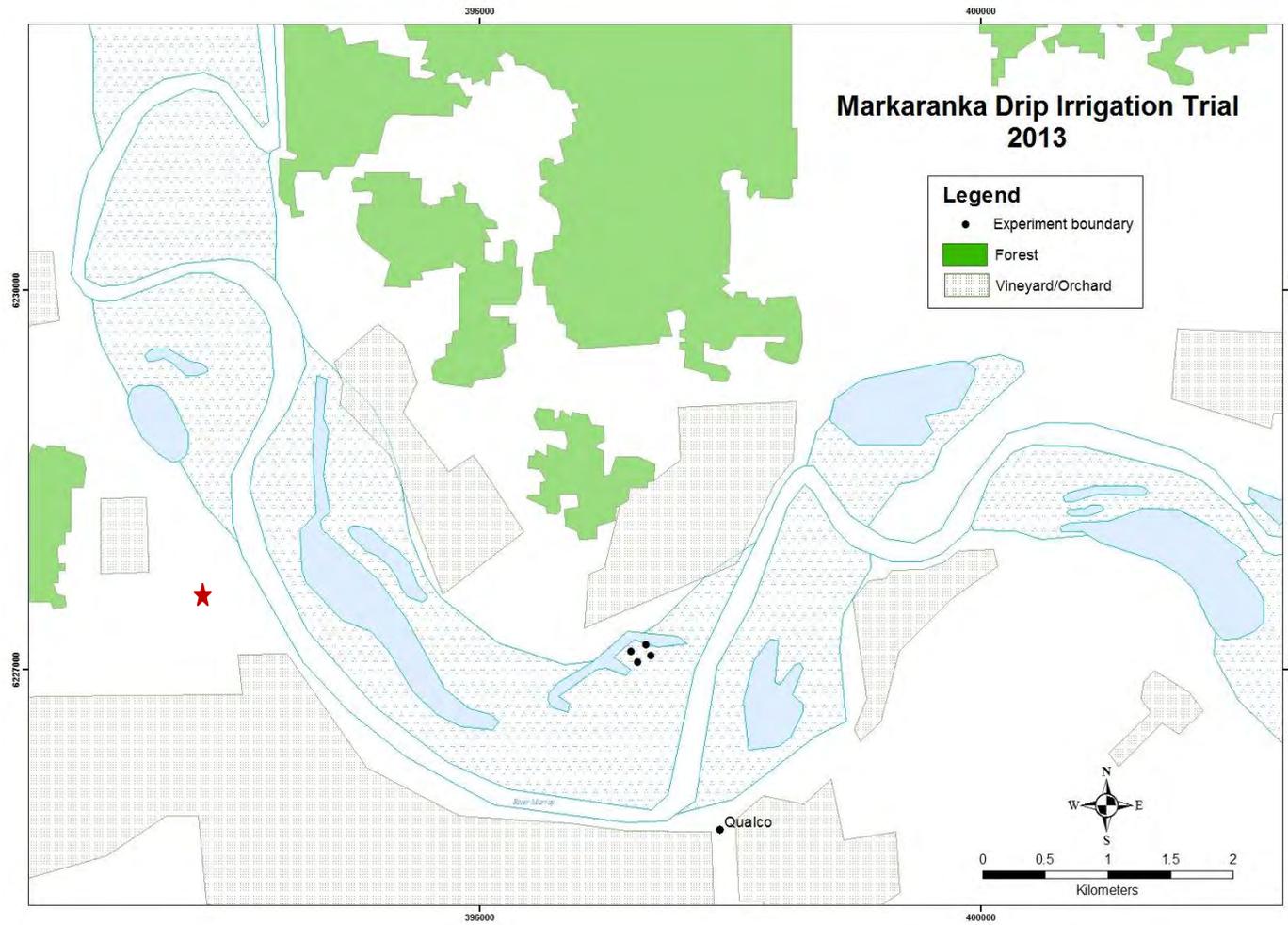


Figure 2: Map indicating the location of the experimental plot (black dots) within the Markaranka floodplain in relation to the River Murray and surrounding agriculture (vineyard/orchards) and silviculture. The watering point where the manually operated hydraulic valve (red star) was installed is positioned at the edge of Markaranka Station, Treasury Wine Estates Limited vineyards. Compiled by L. Bucater.

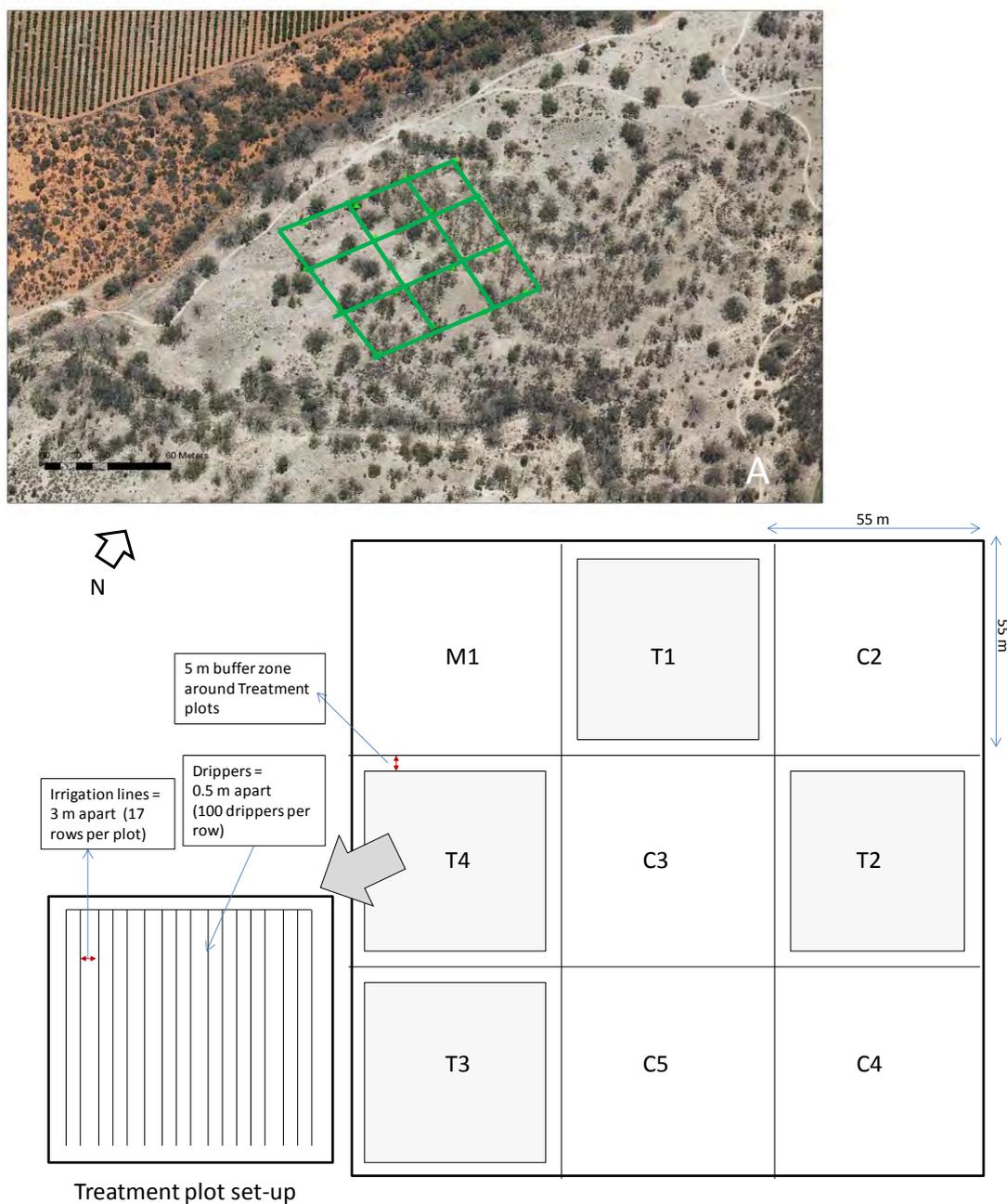


Figure 3: Experimental set up and design. M1 = monitoring plot, C2, C3, C4, C5 = control plots, T1, T2, T3, T4 = treatment plots (shaded). All experimental plots are 55 × 55 m². Within treatment plots the dripper system is within 50 × 50 m area (i.e. 17 rows, 3 m apart, dripper spaced every 0.5 m), creating a 5 m buffer zone around the irrigated area within each treatment plot. Insert (A) shows aerial view image of experimental set up on the Markaranka floodplain.



Figure 4: Experimental set up of drip irrigation system for Markaranka Floodplain trial. **(A)** 2 km hose connected to pump valve on adjacent Treasury Wine Estates vineyard to reach floodplain experimental site; **(B)** 4 multi-valve system set-up to pump water to each treatment plot; **(C)** green/black poly submain pipe in foreground and **(D)** dripper lines spaced 3 m apart, 50 m length in each treatment plot.

2.2. Field measurements

Tree condition (stand structure)

Prior to Phase 1 irrigation, all trees within the experimental area ($165\text{ m} \times 165\text{ m} = 27255\text{ m}^2 = 2.7\text{ Ha}$) were tagged (using yellow cattle tags) and their position recorded using a handheld GPS (Magellan® eXplorist 600). Measurements of circumference at breast height (CBH; m) for each trunk were recorded at 1.3 m following the technique described by Souter *et al.* (2009); then converted to diameter at breast height (DBH, m). Where there were multiple stems, the CBH of each stem was recorded. Where swelling or a limb occurred at 1.3 m, two unaffected points equally spaced above and below were measured and averaged to give an estimate of CBH. The point(s) on the tree where the measurements were made were marked with spray paint (see Souter *et al.* 2009). Trees considered long-term dead (i.e. no bark, or severe cracks present, that go into the sapwood) were excluded, but trees where no foliage was visible, but bark was still intact were tagged and measured.

Tree condition (tree health surveys)

Assessments of tree condition were undertaken in November 2012 (pre-irrigation) and January 2013 (post-irrigation). A sample of 10 trees from each experimental plot was selected using a random number generator (within the range of the number of trees per experimental plot) and the same trees will continue to be monitored for ongoing trial phases. A visual assessment tool, incorporating a range of crown measurement variables that are known to be responsive to changes in water stress were used (see Souter *et al.* 2010). Measurements of crown variables included: *crown extent* (percentage of assessable crown with live leaves, including epicormic growth); *crown density* (percentage of skylight blocked by the portion of the crown containing live leaves). Both crown extent and crown densities are measured as descriptive categories and percent divisions (Table 1).

Table 1: Category scale used to assess crown condition; such as crown extent and density, as per (Souter *et al.* 2009)

Score	Percentage of assessable crown (for extent) and foliated crown portion (for density)	Description
0	None	0
1	Minimal	1-10
2	Sparse	11-25
3	Moderate	26-75
4	Major	76-90
5	Maximum	91-100

Remaining variables: *epicormic growth* (growth of new shoots from the main trunk or support branches); *new tip growth* (growth of new shoots from branch tips, readily identifiable by its yellow/light green colour compared to darker green of older leaves); *reproduction* (measure of the

combined relative abundance of buds, flowers and/or fruit); *leaf die-off* (relative abundance of dead leaves, including non-living portion of partially dead leaves); *leaf damage* (relative abundance of insect damaged and/or infected leaves); and *mistletoe* (visual effect of the mistletoe) were assessed using the four-categorical scale provided in Table 2.

Table 2: Category scale for reporting epicormic growth, new tip growth, reproduction (buds, flowers, fruit), leaf die-off, leaf damage and mistletoe in the TLM tree condition assessment (derived from (Souter *et al.* 2009, 2010).

Score	Description	Definition
0	Absent	Effect not visible
1	Scarce	Effect is present, but not readily visible
2	Common	Effect is clearly visible
3	Abundant	Effect is abundant and dominates appearance of assessable crown

Other variables, such as *bark condition* were assessed using a two-categorical classification of either intact (I) or cracked (C) (indicating cracks that go into the sapwood). Assessments of epicormic *state* as either active (A) or inactive (I) were also recorded (Souter *et al.* 2009, 2010).

Tree condition (hemispherical canopy photography)

An analysis of leaf area index (LAI) helps to describe the photosynthetic and transpiration surface architecture of forest and woodland canopies (Coops *et al.* 2004). It represents the amount of leaf surface area per unit ground area and provides an indication of tree canopy structure in response to variables such as hydrological cycles, competition, disease and/or climate change (Gower and Norman 1981).

Assessments of tree canopy changes were undertaken in November 2012 (pre-watering) and January 2013 (post-watering). Hemispherical photography provides an upward looking view of all, or part of the sky, using a digital camera with a hemispherical (fisheye) lens. The images provide permanent records with an extremely wide-angle, upward-looking image, generally with a 180° field of view for a snapshot in time. A sub-sample of 4 trees per plot were randomly selected from the sample of 10 trees that were selected to be permanently monitored for tree condition (see above). This was done using a random number generator within the range of the number of trees per experimental treatment/control plot. The self-levelling camera tripod mount was positioned 2 m away from the NNE side of the sample tree, at a recorded height (0.85 to 1 m high). Once levelled, the camera was orientated to the magnetic north and three replicates of hemispherical photographs were then taken looking vertically from beneath the woodland canopy using a 180° fisheye lens, with a high resolution camera (NIKON COOLPIX 4500). Digital images were taken pre-dusk to ensure similar sky conditions and then downloaded to a personal computer.

Tree condition (shoot water potentials)

Shoot water potential (Ψ_{shoot}) measurements are used to indicate plant water status because Ψ_{shoot} can vary between individuals and co-existing species, providing an index of the water extraction capacity of root systems (Aranda *et al.* 2000). Measurements of the diurnal and seasonal fluctuations in Ψ_{shoot} provide a relative assessment of how individual plants and populations are responding to reduced water availability within their habitat (Busch and Smith 1995; Loewenstein and Pallardy 1998; Horton *et al.* 2001). Predawn shoot potentials (Ψ_{predawn}), in particular, are used as a measure of soil water potential based on the assumption that predawn plant Ψ is in equilibrium with the soil-water (Ψ_{soil}) accessed by roots. Hence Ψ_{predawn} is often compared with measurements of Ψ_{soil} at different soil depths to infer where plants may be sourcing their water (Flanagan *et al.* 1992). Water potential of the shoots (a shoot being approximately 5-10 leaves) was measured using a PMS Instrument Company Model 1000 Pressure Bomb (Oregon, USA) within ~10 min of excision (Scholander *et al.* 1965). Prior to each sampling trip (pre- and post-irrigation), a sub-sample of 4 trees ($n = 32$ trees) were randomly selected within each treatment and control plot using a random number generator within the range of trees per plot. Two shoots from each tree ($n = 64$) were collected before sunrise (Ψ_{predawn}) and during the midday (Ψ_{midday}) solar radiation (~11:00 to 13:30); transferred to seal lock bags and processed within approximately 10 minutes of sampling.

Soil condition (soil core samples)

Within two treatment and two control plots ($n = 4$) the soil profile was sampled every 0.5 m increments from the surface to the saturated zone (ranging from 4 to 6.5 m below ground level) using push tube sampling (GeoDrill). Soil samples of approximately 300 - 400 g were placed into airtight containers and transported to SARDI, where the following analyses were conducted: total soil moisture (gravimetric water content; g g^{-1}) measured by oven drying samples at 80 °C for 3 days (Klute 1986; Rayment and Higginson 1992), soil suction (or soil matric potential, Ψ MPa) was determined using the filter paper technique (Greacen *et al.* 1989) and electrical conductivity and pH (1:5 soil water extract) (Rayment and Higginson 1992).

Tree water sources (isotope signatures)

Within one treatment plot twig samples from a subsample of 4 selected trees from each plot (using a random number generator within the range of the number of trees within that plot) were collected and analysed for their $\delta^{18}\text{O}$ isotope composition using the method described by Holland *et al.* (2006). Within the same plot, soil samples were collected every 0.5 m increments from the surface to the saturated zone (ranging from 4 to 6.5 m below ground level) using push tube sampling (GeoDrill) and processed and analysed for $\delta^{18}\text{O}$ isotope composition by the Isotope Analysis Service, CSIRO, Land using the method described by Holland *et al.* (2006).

Woodland understory condition (photopoints)

In each plot, diagonal transects were established from the NW to SE corners of each plot (Figure 5). The corners were the “fixed point” or photopoint (Figure 5) and photos were sighted along both directions of the transect line.

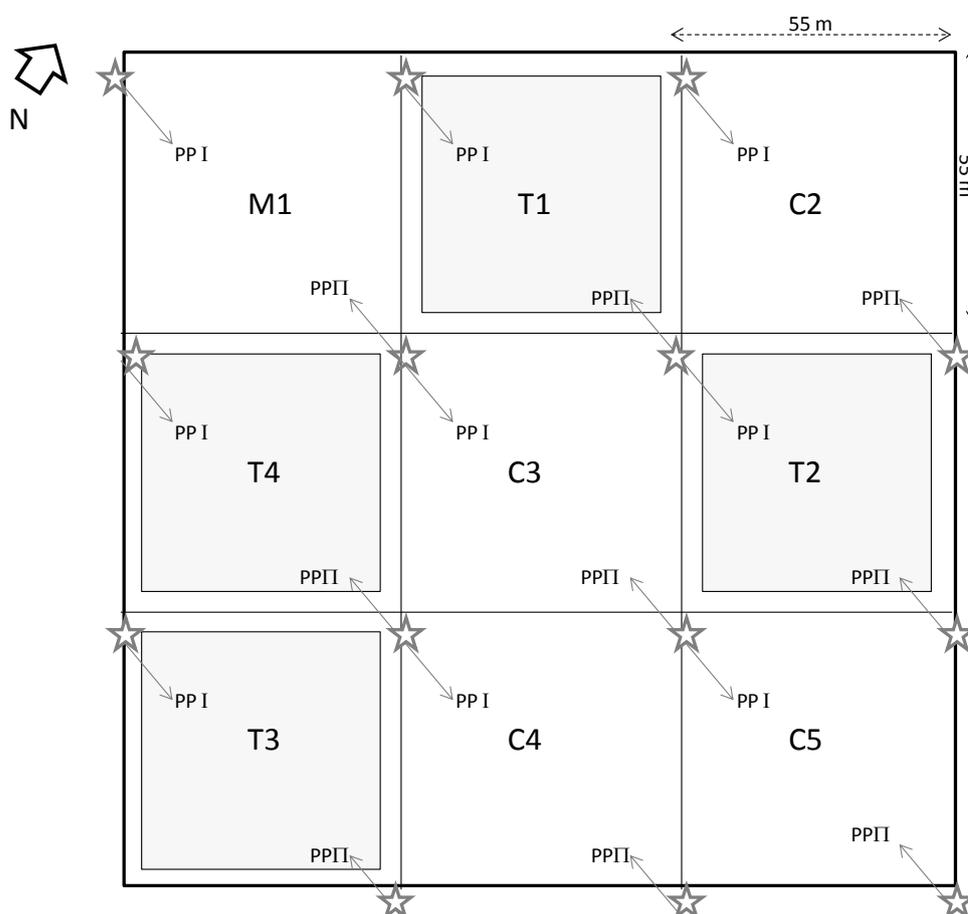


Figure 5: Photopoint sampling protocol for experimental field site: plan view showing placement of photopoint fixed point position (stars), direction of transect view (arrows; PP I = photopoint 1, PP II = photopoint 2) for each plot. Photopoints were taken in collaboration with staff from the South Australian Natural Resources Management Murray Darling Basin Board (SA NRM MDB Board).

Woodland understorey condition (transects)

In each experimental plot (4 treatment; 4 control) a diagonal transect with seven, 2×5 m quadrats (separated by 5 m) were established (Figure 6). The cover and abundance of each understorey taxa present (including leaf litter, bare soil and soil lichen crust) per quadrat were estimated using the method outlined in Heard and Channon (1997), except that scores of N and T were replaced by 0.1 and 0.5 to enable statistical analyses (Figure 6).

Table 3: Modified (Braun-Blanquet 1932) categorical scale estimating cover/abundance as per Heard and Channon (1997).

Score	Modified Score	Description
N	0.1	Not many, 1 – 10 individuals
T	0.5	Sparsely or very sparsely present, cover very small (< 5%)
I	1	Any number of individuals covering 1 – 20% of the area
II	2	Any number of individuals covering 21-40% of the area
III	3	Any number of individuals covering 41 - 60% of the area
IV	4	Any number of individuals covering 61-80 % of the area
V	5	Any number of individuals covering 81 - 100 % of the area

Plants were identified using keys in (Cunningham *et al.* 1981; Jessop and Tolken 1986; Jessop *et al.* 2006). In some cases plants were identified to genus only due to immature individuals or lack of floral structures. In some cases, due to immature individuals or lack of floral structures, plants were identified to genus only. Nomenclature follows the Centre for Australian National Biodiversity Research and Council of Heads of Australasian Herbaria (2013).

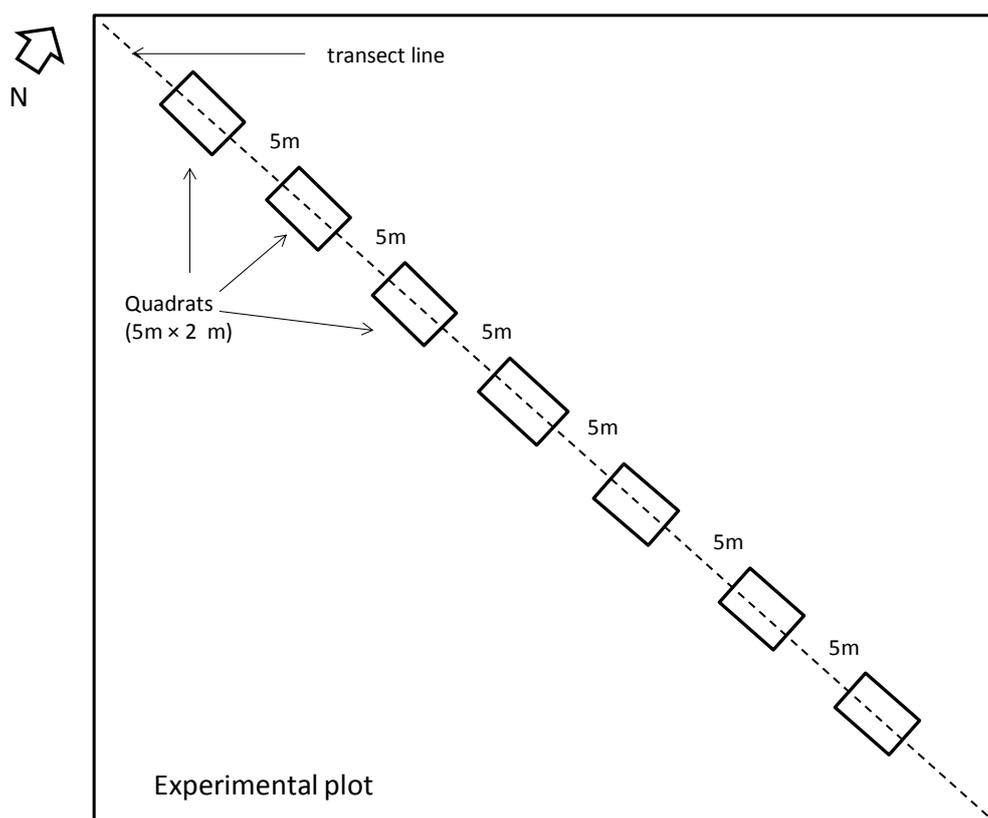


Figure 6: Plan view of the understorey vegetation sampling protocol within each experimental control and treatment plots. A diagonal transect with seven, 2×5 m quadrats (separated by 5 m) was established

Woodland understorey condition (under canopy versus open areas)

Prior to each sampling trip (pre- and post-irrigation), a subsample of 4 trees ($n = 32$ trees) were randomly selected within each treatment and control plot (using a random number generator within the range of trees per plot). On the South-southeast (SSE) side of each tree a perpendicular transect was established and two, 1×0.5 m quadrats were set up under the tree canopy (1 m) and in the open (5 m) (Figure 7). In one, 0.5×0.5 m quadrat cell, all above ground understorey biomass was removed and bagged. Similarly, in the adjacent 0.5×0.5 m quadrat cell, all leaf litter was removed and bagged (Figure 7). Bagged samples were then transported back to SARDI to be oven-dried at $\sim 60^\circ\text{C}$ for three days. Dried plant samples were then weighed and recorded to provide biomass (g) estimates per m^2 . A soil sample (~ 100 g) was also collected within the 1×0.5 m quadrat from the soil surface (0 – 10 cm depth) using a 50 mL Dormer soil auger. Soil samples were placed into airtight containers and transported to SARDI, where the following analyses were conducted: total soil moisture (gravimetric water content; g g^{-1}) (Klute 1986; Rayment and Higginson 1992), electrical conductivity and pH (1:5 soil water extract) (Rayment and Higginson 1992).

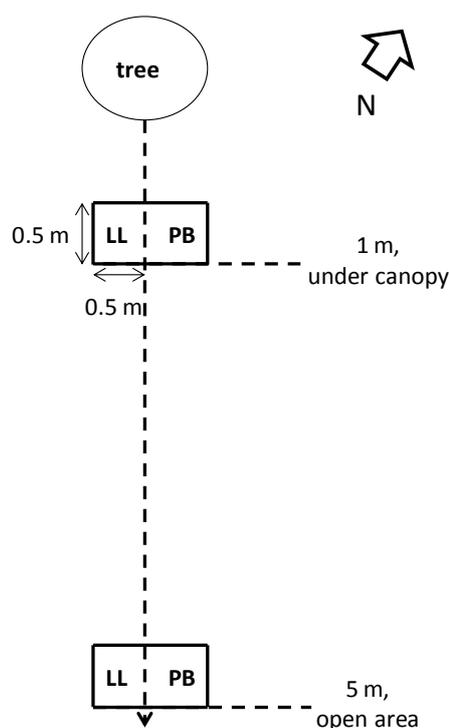


Figure 7: Sampling protocol for leaf litter (LL) and understorey plant biomass (PB) under black box canopy (1 m) and in open (5 m) within experimental control and treatment plots.

2.3. Data Analysis

Tree condition was assessed as the product of crown extent and density category scores, producing a range of values between 0 – 0.9025. Equation 1 was then used to standardise scores to a range between 0 – 1.

Equation 1:

$$\text{condition score} = \frac{y_i - y_{\min}}{y_{\max} - y_{\min}}$$

Where, y_i is the raw condition index, $y_{\min} = 0$ and $y_{\max} = 0.9025$.

Standardised tree condition index scores were then assigned to a five-class score based on a matrix of the product of the crown extent and density categories as per (Harper and Shemmiel 2012) (Table 4).

Table 4: Five-class tree condition rating as derived from the standardised condition score.

Condition Score	Condition Rating
0 – 0.01	Extremely poor
0.01 – 0.1	Very poor
0.1 – 0.04	Poor
0.04 – 0.07	Good
>0.07	Very Good

A Future Trend Index for tree condition is determined by summing the category scores for variables: epicormic growth, tip growth, reproductive capacity, leaf dieback, leaf damage and

mistletoe (however the latter 3 variables are recorded as negative values). Equation 1 was then used to standardised summed scores to a range between 0 – 1.

Equation 2:

$$\text{future trend score} = \frac{y_i - y_{\min}}{y_{\max} - y_{\min}}$$

Where, $y_{\min} = -10$, which is the maximum negative future trend score a tree can receive (i.e. no positive future trends, maximum negative variables) and $y_{\max} = 9$, which is the maximum positive value future trend score a tree can receive. Subtracting 0.526 (occurs when $y_i = 0$ and neither positive or negative trends variables are dominant) from the future trend score (Equation 2) to provide a final future trends value. This provides a direction of likely future change, where positive values indicate a future improvement and negative values indicate likelihood of future deterioration.

Multivariate analyses were undertaken using the statistical software packages PRIMER v. 6.1.12 (Clarke and Gorley 2006) and PERMANOVA+ (Anderson 2005; Anderson *et al.* 2008) and PCOrd version 5.12 (McCune and Mefford 2006). Changes in shoot water potentials were compared between watering times (pre- and post-irrigation), sampling time (predawn and midday) and experimental plots (control and treatment) using multivariate three-factor PERMANOVA (Anderson 2001; Anderson and Ter Braak 2003).

Differences in understorey floristic composition between watering times (pre- and post-irrigation) and control and treatment plots were analysed using multivariate two-factor PERMANOVA (Anderson 2001; Anderson and Ter Braak 2003) and Non-Metric Multi-Dimensional Scaling (MDS; McCune and Mefford 2006) ordination plots generated from Bray-Curtis similarity matrices (Bray and Curtis 1957; Clarke and Gorley 2006). Indicator species analysis (Dufrêne and Legendre 1997) was also used to determine whether a specific taxa had a significantly greater proportion of cover associated with a control and/or treatment plots during pre- or post-irrigated conditions ($\alpha = 0.05$).

Differences in leaf litter, understorey plant biomass and soil variables (gravimetric water content, pH, soil EC) were also compared between watering times (pre- and post-irrigation), sampling position (under canopy and open) and experimental plots (control and treatment) using multivariate three-factor PERMANOVA (Anderson 2001; Anderson and Ter Braak 2003) on pre-treated square root transformed data.

Bray-Curtis (1957) similarities were used for all multivariate analyses where species composition was compared and Euclidean distances were used for PERMANOVA analyses on all non-biological data. For all statistical analyses $\alpha = 0.05$, and was corrected for multiple comparisons (where appropriate) using the Bonferroni correction (Quinn and Keogh 2002).

3. Results

3.1. Site climate

Total precipitation across November 2012 to April 2013 was 63.8 mm, with minimal rainfall (<7 mm per month) occurring in November 2012, January and March 2013 (Table 5). Maximum temperatures peaked within 30.5 to 33.4 °C from November to March, but were lower in April (Table 5). Minimum temperatures followed a similar pattern, with the lowest minimum temperature recorded in April compared to preceding months (Table 5). During the 10-week Phase 1 period rainfall was less than 25 mm (Table 5).

Table 5: Total precipitation, maximum temperature and average minimum temperatures recorded at Markaranka Station across the six month experimental watering period (November 2012 – April 2013). Data courtesy of Markaranka Station, Treasury Wine Estates Limited.

Month	Total Rainfall (mm)	Maximum temperature (°C)	Minimum temperature average (°C)
November	6	32.7	10.5
December	15	31.1	12.5
January	2.4	33.4	13.0
February	12	32.9	14.7
March	6.8	30.5	13.2
April	20.6	24.9	8.7

3.2. Irrigation Regime

Phase 1: Infrastructure Trial

During the first weeks of November 2012 there was a “test” phase for the irrigation system and different durations were trialled (i.e. 12, 16, 18 and 24 hour duration) (Figure 8), hence varying water volumes were delivered. It was deemed that a weekly watering regime of 16 hr was a workable operational sequence for Treasury Wine Estates Limited staff (every Thursday, start time = 15:30; finish time = 7:30) and was estimated to deliver approximately 50 kL of water per treatment plot (0.25 Ha); equivalent to precipitation rate of approximately 20 – 25 mm week⁻¹ (per treatment plot). Regular weekly, 16 hour watering applications began 23 November 2012. The Phase 1 irrigation period finished on 18 January 2013 (10 wk) and encompassed the initial experimental watering period designed to investigate whether black box trees would use the water provided via the installed drip irrigation infrastructure. There were episodic incidents within this period where dripper lines were pierced or the caps or the end of lines blew out (due to pressure), accounting for the variation in total water volume and watering duration applied per treatment plot (Figure 8). In general, however, application rates remained consistent across the period, with each treatment plot receiving between 0.46 – 0.57 ML across the watering period, which equated to an average precipitation rate of 22.59 ± 7.65 mm week⁻¹ per treatment plot (Table 6). Please note, regular weekly, 16 hour duration watering continued until 18 April 2013 (= total of 22 week watering period) so that the total volume of water delivered to the experimental area to the date of this report was 4.235 ML (Table 6).

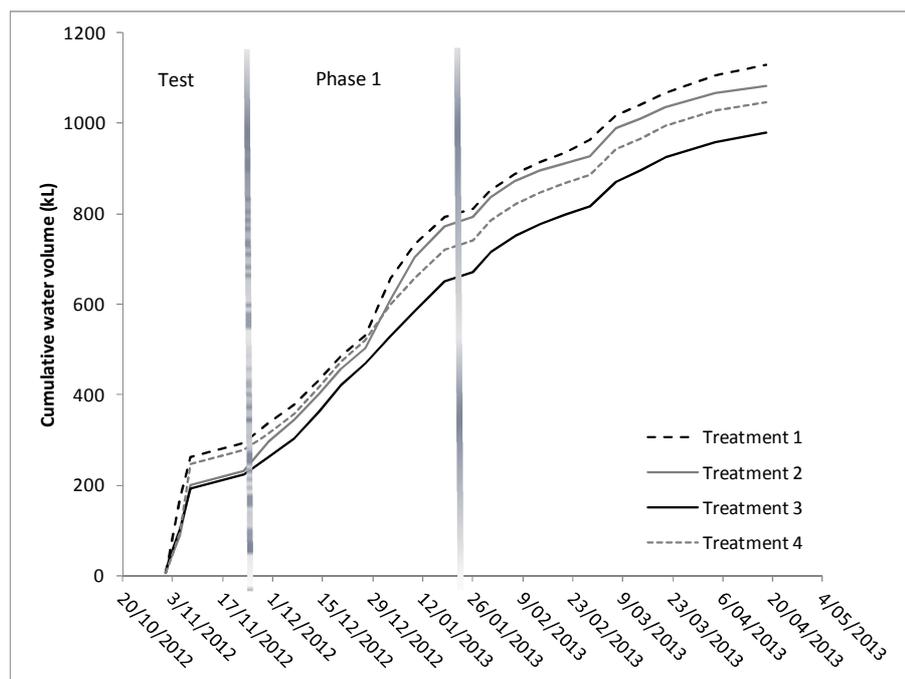


Figure 8: Cumulative water volumes applied to treatment plots across the total six month experimental watering trial (November 2012 to April 2013) at Markaranka Floodplain. Phase I irrigation began 23 November and finished 18 January 2013.

Table 6: Water volume (kL) applied per treatment plot during Phase 1 (23/11/2012 to 18/04/2013), plus the plus the breakdown of mean volume of water (kL week⁻¹) and equivalent precipitation rate (mm week⁻¹) across the weekly Phase 1 watering period and total water volumes (kL) per treatment plot for the entire experimental watering period (1/11/2012 to 18/4/2013).

Valve #	Phase 1 watering period (23/11/2012 – 18/1/2013)		Phase I water Volume (kl)	*Total volume (kL)
	Mean volume (kL week ⁻¹)	Precipitation rate (mm week ⁻¹) mean ± S. D		
Treatment 1	58.78 ± 27.59	23.47 ± 11.03	529	1128
Treatment 2	63.56 ± 23.85	25.42 ± 9.54	572	1082
Treatment 3	50.78 ± 11.11	20.35 ± 4.49	457	978
Treatment 4	52.78 ± 13.87	21.11 ± 5.55	475	1047

*Total volume used across during infrastructure testing + experimental watering period (1 November 2012 to 18 April 2013). Phase 1 irrigation (23 November to 18 January 2013).

3.3. Tree condition (stand structure)

A total of 298 trees were recorded within the experimental area. The majority of the trees tagged were *Eucalyptus largiflorens*, but two *Acacia stenophylla* trees were also present (and subsequently tagged) (Table 7). The minimum number of trees per plot were found in the monitoring plot 1 ($n = 4$), whereas control plot 2 had the highest number of trees per plot ($n = 87$).

The diameter at breast height of black box was variable within the experimental area, with an overall DBH of 24.85 ± 14.12 (mean \pm standard deviation cm) for the population; ranging from 4.93 to 103.77 cm. Furthermore, a moderate proportion of trees within the experimental field plot were also multi-stemmed (up to 12 stems per tree in some instances; Table 8).

Table 7: Number and type of tree tagged in each experimental plot in October 2012.

Plot #	<i>Eucalyptus largiflorens</i>	<i>Acacia stenophylla</i>	Total
Control 2	87	0	87
Control 3	15	1	16
Control 4	26	0	26
Control 5	38	0	38
Treatment 1	26	0	26
Treatment 2	42	1	43
Treatment 3	33	0	33
Treatment 4	26	0	26
Monitoring 1*	4	0	4

*note monitoring plot used for photopoints assessments only, due to low number of trees present.

Table 8: Diameter at breast height (DBH; cm) of all stems (#1 to 12) of tagged black box within experimental Control (C) and Treatment (T) plots measured in October 2012; pre-irrigation. Values are presented as mean \pm standard deviation (*sample number*).

Stem #	C2	C3	C4	C5	T1	T2	T3	T4
1	19.85 \pm 8.45 (87)	28.47 \pm 18.05 (15)	29.38 \pm 10.29 (26)	20.32 \pm 12.03 (38)	27.75 \pm 16.68 (26)	26.10 \pm 11.19 (42)	28.80 \pm 12.65 (33)	32.93 \pm 24.36 (26)
2	13.80 \pm 6.78 (27)	20.87 \pm 10.51 (10)	25.05 \pm 13.05 (12)	14.15 \pm 7.73 (21)	20.12 \pm 17.01 (18)	16.39 \pm 4.76 (9)	17.59 \pm 8.69 (17)	14.89 \pm \pm 8.63 (12)
3	10.38 \pm 5.80 (8)	11.46 \pm 10.66 (4)	15.16 \pm 10.27 (4)	10.25 \pm 4.75 (12)	15.47 \pm 10.72 (13)	15.68 \pm 4.32 (4)	17.12 \pm 8.31 (7)	25.76 \pm 17.19 (6)
4	7.43 \pm 3.19 (3)	9.31 \pm 7.31 (2)	6.37 \pm 4.42 (3)	22.55 \pm 7.43 (7)	10.68 \pm 5.75 (10)	16.39 \pm 6.53 (2)	5.41 (1)	24.09 \pm 20.11 (3)
5	4.21 \pm 1.91 (2)	7.17 \pm 5.18 (2)	10.19 \pm 12.15 (2)	11.46 \pm 7.42 (7)	10.82 \pm 5.02 (6)	7.32 \pm 8.10 (2)	0	2.22 (1)
6	12.73 (1)	1.59 (1)	1.59 (1)	7.32 (1)	12.31 \pm 8.44 (3)	18.46 (1)	0	2.86 (1)
7	0	1.59 (1)	4.46 (1)	16.87 (1)	20.53 \pm 6.98 (2)	1.59 (1)	0	1.59 (1)
8	0	12.41 (1)	1.59 (1)	0	24.75 \pm 8.67 (2)	1.59 (1)	0	1.59 (1)
9	0	16.88 (1)	1.59 (1)	0	18.30 (1)	0	0	2.86 (1)
10	0	4.45 (1)	1.59 (1)	0	12.57 (1)	0	0	0
11	0	14.64 (1)	3.18 (1)	0	13.85 (1)	0	0	0
12	0	0	0	0	31.03 (1)	0	0	0
Total	68.4							

3.4. Tree condition (tree health surveys)

Tree condition scores between experimental plots were similar, with condition index scores in the control plots ranging from 0 – 0.66 and treatment plots from 0 – 0.71. Tree condition scores prior to Phase I irrigation indicated the majority of trees within the experimental area (control and treatment plots) scored a poor condition rating (condition index scores between 0.1-0.4) (Table 9). Furthermore, a small proportion of these trees showed a negative trajectory for future condition

(Table 9), mostly due to high scores for negative growth variables, such as leaf die off and leaf damage.

Following Phase I irrigation, the majority of trees in the control plots maintained poor condition scores, while the majority of trees in the treatment plots scored good condition ratings (condition index score between 0.4-0.7) (Table 9). A proportion of trees in the control plots continued to record negative trajectories for future condition, whereas all trees in the treatment plots scored positive trajectories (Table 9), indicating a likely future improvement in tree condition. Following irrigation, the trees within the treatment plots recorded maximum scores for positive growth variables, such as epicormic and crown tip growth.

Table 9: Tree condition scores for black box in experimental plots (control versus treatment) pre-irrigation (October 2012) and post-irrigation (January 2013). Ratings based on Condition Index Scores using Table 4. Values in brackets represent the number trees within that condition score class where a Negative Future Trend value was calculated (indicating further deterioration in tree condition predicted).

Condition Rating	Pre-irrigation		Post-irrigation	
	Control	Treatment	Control	Treatment
<i>Extremely Poor</i>	2 (1)	2	2	5
<i>Very Poor</i>	2 (1)	3 (2)	2 (1)	0
<i>Poor</i>	21 (3)	28 (7)	28 (8)	8
<i>Good</i>	15 (5)	6 (1)	8 (2)	24
<i>Very Good</i>	0	1	0	3

3.5. Tree condition (hemispherical canopy photography)

Compared to trees in the control plots following watering (Appendix 1–4; inclusive), the increase in both canopy extent and density is evident in the post-irrigation hemispherical images of the sampled trees within the post-irrigation treatment plots (Appendix 5–8; inclusive). Signs of marked improvements in variables such as epicormic growth and crown tip growth after 10 weeks of watering are particularly evident for the trees (#119 and #139) in Treatment plot 4 (Appendix 8).

3.6. Tree water status (shoot water potentials)

A significant plot \times irrigation \times time interaction (Table 10) indicates that shoot water potentials for black box trees behaved differently between sampling times, experimental plots and irrigation periods. In general, Ψ_{predawn} were markedly higher (less negative; -2.05 ± 0.15 MPa) in the treatment plots post-irrigation compared to shoot Ψ_{predawn} in control plots (-3.09 ± 0.22 MPa), which remained similar between irrigation periods (Figure 9a). In contrast, Ψ_{midday} of trees within the treatment plots remained similar pre- and post-irrigation (-3.63 ± 0.16 and -3.70 ± 0.10 MPa, respectively), while Ψ_{midday} values for trees in control plots were lower (more negative) post-irrigation (-4.43 ± 0.14 MPa) compared to pre-irrigation (-3.72 ± 0.18 MPa) (Figure 9b).

Table 10: Multivariate three-factor PERMANOVA results for comparing shoot water potentials within plots (control versus treatment), irrigation periods (pre- and post-irrigation) and time of day (predawn versus midday). (df = degrees of freedom; p-value = probability value; $\alpha = 0.05$).

Factor	df	Pseudo-F statistic	p-value
Plot	1, 258	54.35	0.001
Irrigation	1, 258	5.13	0.021
Time	1, 258	267.21	0.001
Plot \times Irrigation	1, 258	58.22	0.001
Plot \times Time	1, 258	0.16	0.068
Irrigation \times Time	1, 258	78.13	0.001
Plot \times Irrigation \times Time	1, 258	4.53	0.038

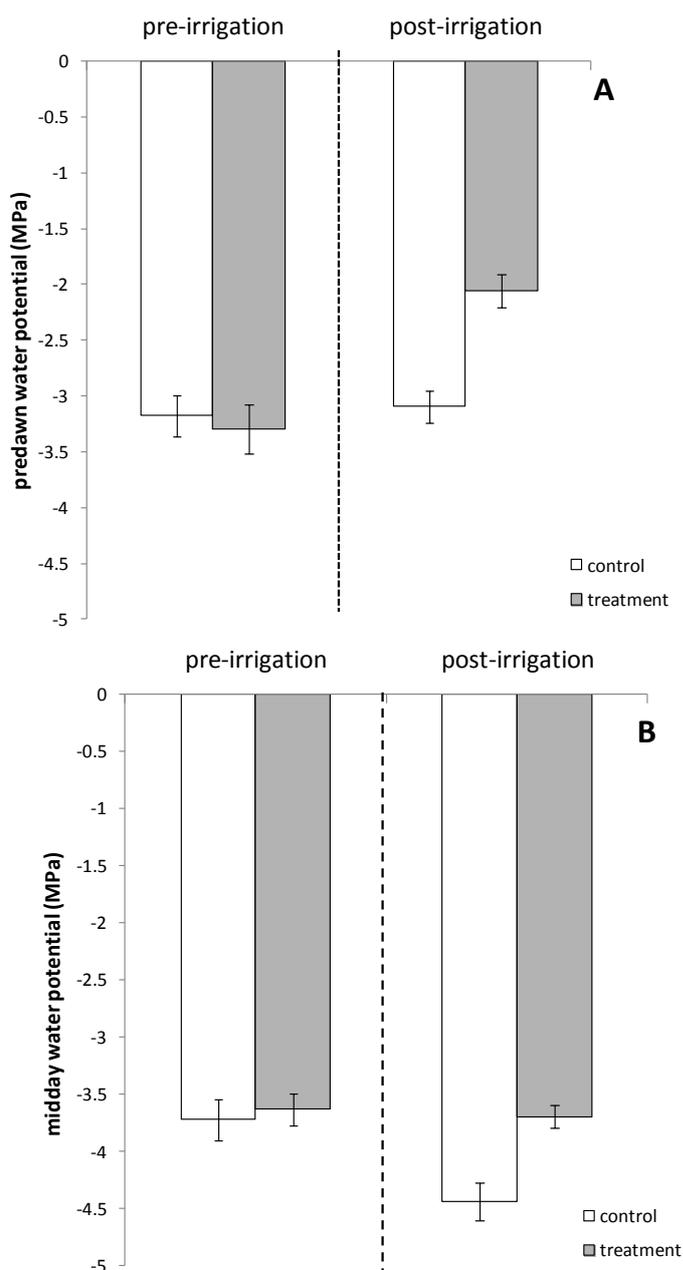


Figure 9: Predawn (A; Ψ_{predawn}) and midday (B; Ψ_{midday}) shoot water potentials for black box within the pre-irrigated (November 2012) and post-irrigated (January 2013) control and treatment plots; Markaranka field irrigation trial.

3.7. Soil condition (soil core samples)

Due to the methodology used, sample sizes to assess soil condition were limited, but general trends are readily detectable. Saturated soil (groundwater) was intercepted at depths of approximately 5.5 m. In November 2012 (pre-irrigation), soil suction was low (more negative; < -30 MPa) in the upper soil profile (> -1.0 m) compared to the consistently higher soil suctions (-0.1 to -0.005 MPa) at depths > -1.5 m; indicating that trees may have accessed water at any depth between -1.3 and -1.5 m given the range of black box Ψ_{predawn} values (Figure 10a). By January 2013 (post-irrigation), soil suction values decreased (more negative; < -55 MPa) in the upper soil profile (-0.5 to -1.5 m), but remained consistently high (-0.19 to -0.004 MPa) at depths > -2.0 m, suggesting trees may have accessed water at any depth between -1.8 and -2.0 m given the black box Ψ_{predawn} values were within the soil suction values recorded at these depths (Figure 10b).

Prior to irrigating the treatment plots, soil suction in the upper profile was low (more negative; < -6 MPa) in the upper soil profile (> -1 m) compared to the consistently higher suctions (-0.16 to -0.004 MPa) at depths > -1.5 m; indicating trees may have accessed water at any depth > -0.8 m given the black box Ψ_{predawn} values recorded during this period (Figure 11a). By January 2013, following irrigation, soil suction at the surface (0 m) remained low (more negative; < -18 MPa), but then increased (less negative; -2.3 MPa) slightly before decreasing (-3.9 MPa) at -1.0 m, then remaining consistently higher (-0.1 to -0.06 MPa) at depths > -1.5 m. This suggests soil moisture improved at this depth following irrigation. Concomitantly, shoot Ψ_{predawn} values for trees within treatment plots suggest trees were either able to access water from depths of -0.5 m or at depths > -1.3 m (Figure 11b).

Prior to irrigation, soil EC ($\mu\text{S cm}^{-1}$) in the upper soil surface (< 1.5 m depth) was very low (< 100 EC) in the control plots, and low to moderate (< 1500 $\mu\text{S cm}^{-1}$) in the treatment plots (Table 11). In both control and treatment plots, soil EC increased with increasing depth, but never exceeded 4000 $\mu\text{S cm}^{-1}$; indicating reasonable water source quality (Table 11). Similarly, soil pH values were lower (more neutral) in the upper soil surface, but became increasingly more alkaline with increasing depth (Table 12).

In January 2013, soil EC values in the upper soil surface of the control plots increased slightly (< 600 $\mu\text{S cm}^{-1}$), while soil EC values in the upper soil surface (< 1 m) of the treatment plots decreased (< 500 $\mu\text{S cm}^{-1}$) following irrigation (Table 11). Similarly, soil pH values were lower (more neutral) in the upper soil surface of both treatment and control plots, but became increasingly more alkaline with increasing depth (Table 12).

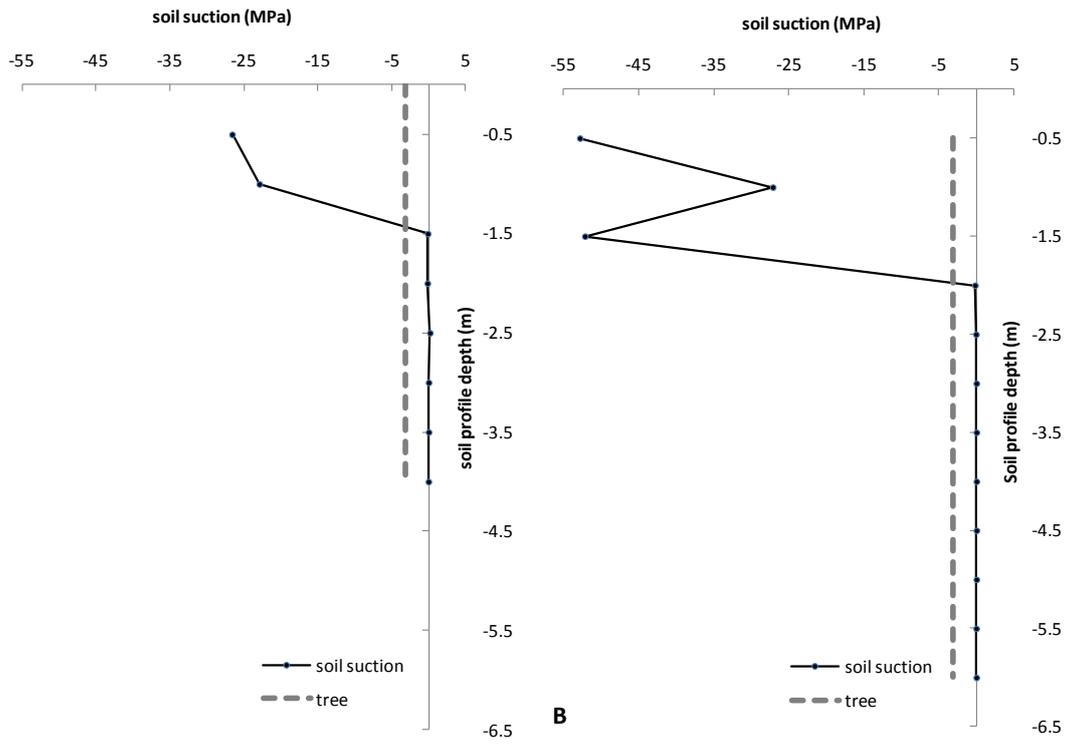


Figure 10: Soil suction (MPa) of the soil profile (0 to -6.5 m) and predawn shoot water potential (MPa) of black box within the pre-irrigated (A) and post-irrigated (B) control plots.

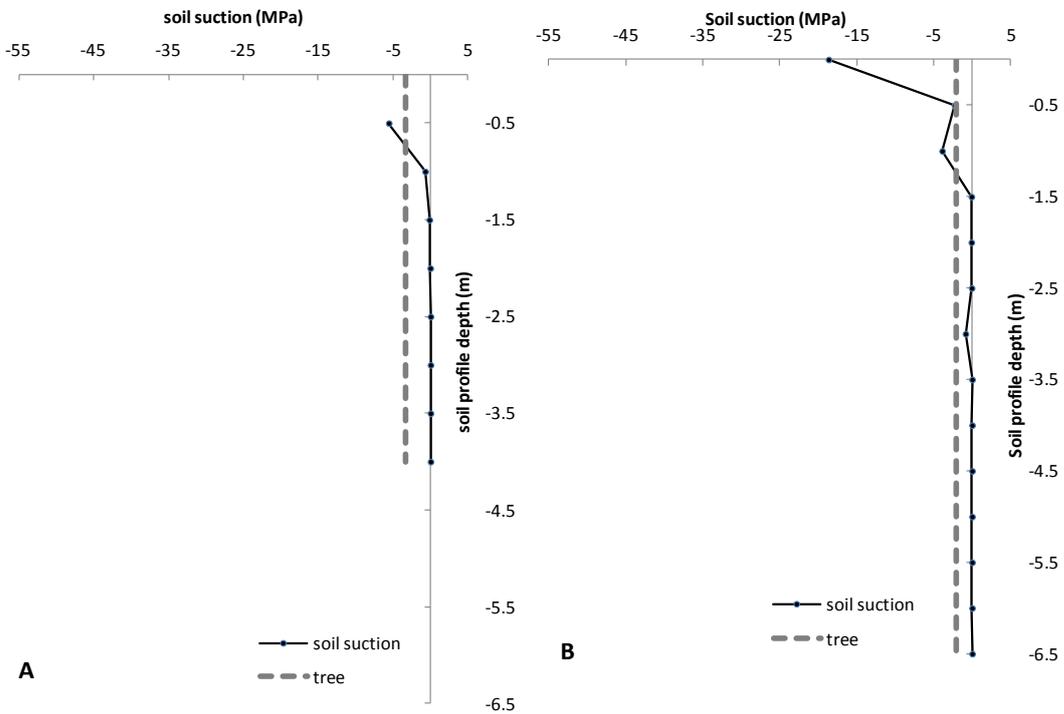


Figure 11: Soil suction (MPa) of the soil profile (0 to -6.5 m) and predawn shoot water potential (MPa) of black box within the pre-irrigated (A) and post-irrigated (B) plots.

Table 11: Soil EC ($\mu\text{S cm}^{-1}$) at 0.5 m increments throughout soil profile in control and treatment plots, pre- and post- irrigation. Values are mean \pm standard deviation ($n = 2$).

Depth	Pre-irrigation		Post-irrigation	
	Control	Treatment	Control	Treatment
0.5	86.5 \pm 29.70	1225 \pm 688.01	275.3 \pm 289.49	243
1	74.35 \pm 61.73	1779.5 \pm 105.36	523 \pm 395.98	476
1.5	629 \pm 1.41	1665	1071.5 \pm 297.69	1040
2	1502.5 \pm 222.73	1853.5 \pm 50.20	1341.5 \pm 293.71	1900
2.5	2665 \pm 7.07	2211 \pm 323.85	1777.5 \pm 357.09	2460
3	3210 \pm 678.82	2530 \pm 226.27	2224 \pm 248.9	2890
3.5	2389 \pm 694.38	3165 \pm 205.06	2607 \pm 513.36	2960
4	2905 \pm 318.20	3135 \pm 120.21	3140 \pm 339.41	2960
4.5			3240 \pm 42.43	3180
5			1928 \pm 441.23	2820
5.5			2430 \pm 1484.22	1381
6			2011.5 \pm 98.29	2081

Table 12: Soil pH at 0.5 m increments throughout soil profile in control and treatment plots, pre- and post- irrigation. Values are mean \pm standard deviation ($n = 2$; where possible).

Depth	Pre-irrigation		Post-irrigation	
	Control	Treatment	Control	Treatment
0.5	7.04 \pm 0.60	7.07 \pm 0.80	7.68 \pm 1.39	7.82
1	7.37 \pm 0.25	8.60 \pm 0.25	8.91 \pm 1.15	8.95
1.5	7.81 \pm 0.69	8.7	8.56 \pm 0.75	8.57
2	8.45 \pm 0.34	8.17 \pm 0.72	8.33 \pm 0.01	8.94
2.5	8.98 \pm 0.17	8.79 \pm 0.05	8.45 \pm 0.32	8.90
3	8.48 \pm 0.52	8.75 \pm 0.34	8.62 \pm 0.13	8.78
3.5	8.93 \pm 0.37	8.42 \pm 0.53	8.44 \pm 0.20	9.33
4	8.85 \pm 0.28	8.74 \pm 0.6	8.40 \pm 0.08	8.40
4.5			9.00 \pm 0.21	8.82
5			8.51 \pm 0.01	8.32
5.5			8.35 \pm 0.04	8.31
6.0			8.54 \pm 0.04	8.51

3.8. Tree water sources (isotope signatures)

Following irrigation, black box in the treatment plots had $\delta^{18}\text{O}$ stem tissue values that ranged from -0.41 to 0.22 ‰ $\delta^{18}\text{O}$ (mean value = -0.31‰ $\delta^{18}\text{O}$). The isotopic composition of the soil samples ranged from 5.45 ‰ $\delta^{18}\text{O}$ at the surface (0 – 25 cm) to -3.16 ‰ $\delta^{18}\text{O}$ at the saturated watertable level (6.5 m). The isotopic composition of the tree stem tissues correspond to soil-water $\delta^{18}\text{O}$ values measured at \sim 0.5 m depth (Figure 12). Similarly, the enriched $\delta^{18}\text{O}$ soil-water values measured at this depth correspond to the increase in soil suction (-2.3 MPa) recorded at this particular depth following irrigation (Figure 11b).

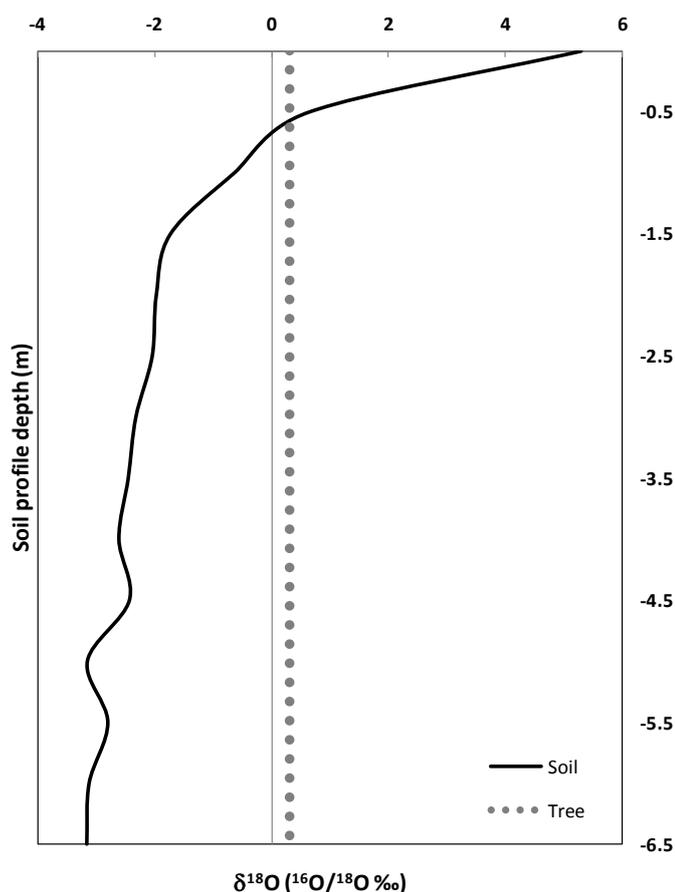


Figure 12: $\delta^{18}\text{O}$ values for black box stem tissue and soil-water samples (0 to -6.5 m) within the irrigated soil profile treatment plot (1) of Markaranka field irrigation trial (January 2013).

3.9. Woodland understorey condition (photopoints)

Photopoints show tree and understorey condition within the treatment and control plots (see Appendix 9–24; inclusive) prior to irrigation and post-irrigation. There was a visible improvement in tree and understorey condition (see Appendix 17–24; inclusive) following watering.

3.10. Woodland understorey condition (transects)

A total of 15 understorey species (excluding lichen crust, leaf litter and bare soil; Table 13) were recorded in both control and treatment plots pre-irrigation (November 2012). Following watering (January 2013) there was a slight increase to a total of 20 species (excluding lichen crust, leaf litter and bare soil; Table 13). NMS ordination (Figure 13) showed that understorey plant communities were different between control and treatment plots prior to watering, however, these differences were more evident following irrigation.

Prior to irrigation, control plots were characterised by significant understorey species *Atriplex prostrata** ($p = 0.005$) and *Brachyscome basaltica* var. *gracilis* ($p = 0.049$), whereas there were no

significant taxa that characterised the understorey vegetation within the treatment plots pre-irrigation. However, following irrigation several taxa significantly characterised the control plots, namely *Atriplex* sp. ($p = 0.0002$), bare soil ($p = 0.0002$), leaf litter ($p = 0.0002$), *Maireana* sp. ($p = 0.0002$), lichen crust ($p = 0.0102$), *Rhagodia spinescens* ($p = 0.025$) and *Sclerolaena brachyptera* ($p = 0.047$). Similarly there were also several taxa that significantly characterised the understorey vegetation within the treatment plots following irrigation, such as *Atriplex paludosa* ($p = 0.0002$), *Marsilea* sp. ($p = 0.015$), *Sporobolus mitchellii* ($p = 0.017$), *Sclerolaena stelligera* ($p = 0.021$), *Teucrium racemosum* ($p = 0.0004$) and seedlings of an unknown dicot C ($p = 0.017$). Species such as *Atriplex paludosa*, *Marsilea* sp. and *Teucrium racemosum* were only recorded post-irrigation (Table 13).

Table 13: List of species present in experimental control and treatment plots pre Phase I irrigation (November 2012) and post-irrigation (January 2013). * indicates exotic species.

Species	Common name	pre-irrigation	post-irrigation
<i>Atriplex paludosa</i>	marsh saltbush		P
<i>Atriplex prostrata</i> *	mat saltbush	P	P
<i>Atriplex</i> spp.	saltbush	P	P
Bare Soil		P	P
<i>Brachyscome basaltica</i> var. <i>gracilis</i>	swamp daisy	P	P
<i>Disphyma crassifolium</i> ssp. <i>clavellatum</i>	rounded noon-flower	P	P
<i>Duma florulenta</i>	tangled lignum	P	P
<i>Enchylaena tomentosa</i>	ruby saltbush	P	P
Leaf litter		P	P
Lichen crust		P	P
<i>Maireana</i> sp.	bluebush	P	P
<i>Marsilea</i>	nardoo		P
<i>Morgania floribunda</i>	blue rod	P	P
<i>Plantago coronopus</i> *	buck's horn plantain	P	P
<i>Rhagodia spinescens</i>	creeping saltbush	P	P
<i>Sclerolaena brachyptera</i>	short-winged copperbur	P	P
<i>Sclerolaena divaricata</i>	pale poverty-bush	P	P
<i>Sclerolaena stelligera</i>	star copperbush	P	P
<i>Senecio cunninghamii</i>	branching groundsel	P	P
<i>Spergularia diandra</i> *	alkali sandspurry		P
<i>Sporobolus mitchellii</i>	rat's tail couch	P	P
<i>Teucrium racemosum</i>	grey germander		P
Unknown dicot C	N/A		P
Total		18	23

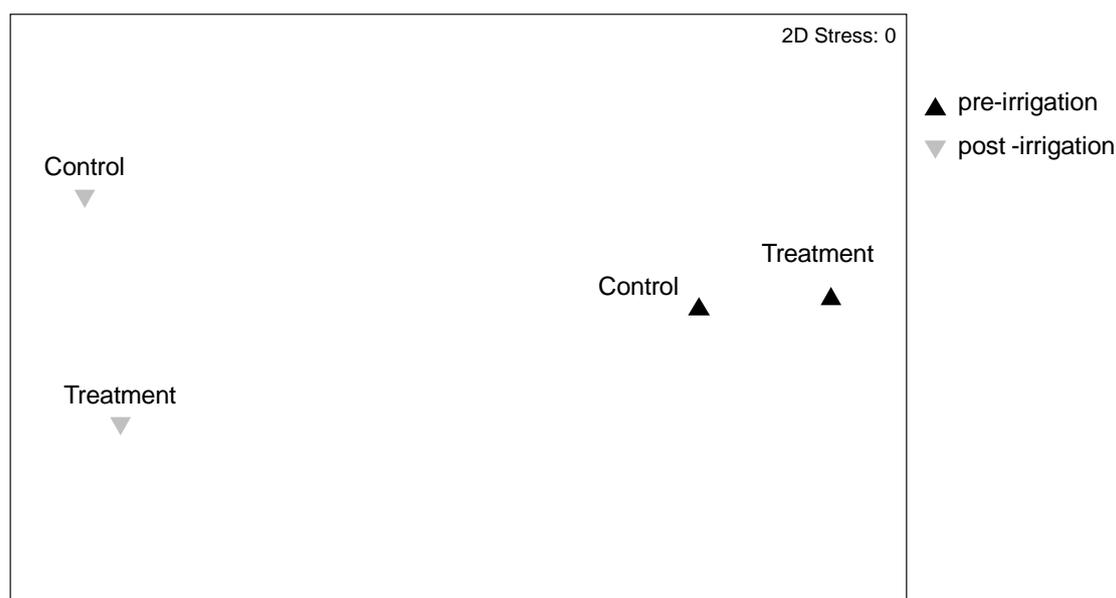


Figure 13: NMS ordination comparing per cent ground cover of understorey species, bare soil, leaf litter and lichen crust) of control and treatment plots during pre- and post-irrigation (stress = 0%).

3.11. Woodland understorey condition (under canopy versus open areas)

There was a significant difference in soil moisture between irrigation periods (pre- and post-irrigation) and plots (control and treatment) (Table 14). In November 2012, soil moisture was generally consistent between distances from the tree (under canopy versus open), but mean soil moisture values in control plots were slightly less (0.28 g g^{-1}) than soil moisture values for treatment plots (0.33 g g^{-1}) (Figure 14). However, post-irrigation soil moisture in control plots had decreased markedly (0.1 g g^{-1}) while soil moisture in treatment plots remained similar to pre-irrigation soil moisture levels; although post-irrigation variability was much greater (Figure 14).

Table 14: Multivariate three-factor PERMANOVA results for comparing soil moisture (g g^{-1}) between irrigation periods (pre- and post-irrigation), plots (treatment and control) and distance (under canopy versus open). (df = degrees of freedom; p-value = probability value; $\alpha = 0.05$).

Factor	df	Pseudo-F statistic	p-value
Irrigation	1, 93	2.73	0.1
Plots	1, 93	6.40	0.02
Distance	1, 93	0.85	0.33
Irrigation \times Plot	1, 93	2.03	0.18
Irrigation \times Distance	1, 93	0.12	0.74
Plot \times Distance	1, 93	0.08	0.79
Irrigation \times Plot \times Distance	1, 93	0.59	0.46

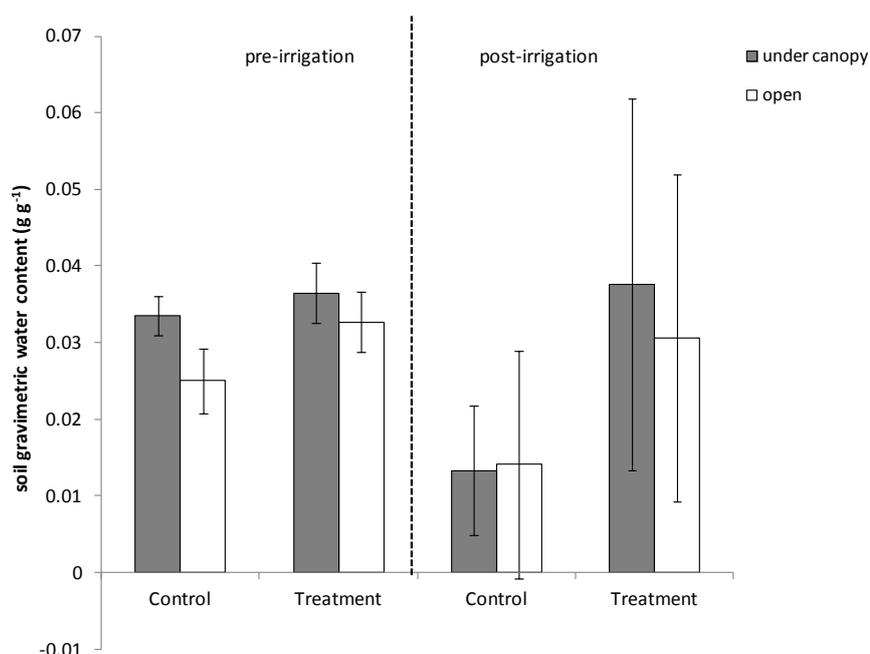


Figure 14: Comparison of soil gravimetric water content (g g^{-1}) under black box canopy (1 m) and in the open (5 m) for control and treatment plots during pre-irrigation (October 2012) and post-irrigation (January 2013); Markaranka field trial. Measurements are mean \pm S.E \times 1.96.

There was a significant plot \times distance interaction (Table 15) suggesting plant biomass values varied inconsistently between distances from the tree (under canopy versus open), between plots and as a result of irrigation. Prior to watering, plant biomass under canopy (1 m) was greater in control plots ($108.29 \pm 137.65 \text{ g m}^{-2}$) compared to treatment plots ($52.31 \pm 29.03 \text{ g m}^{-2}$), although variability between sampling was large (Figure 15). Following watering, plant biomass was largely similar between control ($40.75.82 \pm 31.55 \text{ g m}^{-2}$) and treatment ($31.68 \pm 16.20 \text{ g m}^{-2}$) plots under canopy (Figure 15). Conversely, mean plant biomass in the open areas (5 m) of the control plots was lower ($16.24 \pm 17.19 \text{ g m}^{-2}$) compared to treatment plots ($92.82 \pm 68.38 \text{ g m}^{-2}$) prior to watering. This same pattern was repeated following irrigation for control ($69.04 \pm 80.86 \text{ g m}^{-2}$) and treatment ($135.50 \pm 77.16 \text{ g m}^{-2}$) plots in open areas, although mean plant biomass had increased in control and treatment plots (Figure 15).

Table 15: Multivariate three-factor PERMANOVA results for comparing understorey plant biomass (g m^{-2}) between irrigation periods (pre- and post-irrigation), plots (treatment and control) and distance (under canopy versus open). (df = degrees of freedom; p-value = probability value; $\alpha = 0.05$).

Factor	df	Pseudo-F statistic	p-value
Irrigation	1, 93	0.0015	0.96
Plots	1, 93	0.43	0.49
Distance	1, 93	0.50	0.48
Irrigation \times Plot	1, 93	0.22	0.63
Irrigation \times Distance	1, 93	3.55	0.07
Plot \times Distance	1, 93	4.51	0.03
Irrigation \times Plot \times Distance	1, 93	0.41	0.53

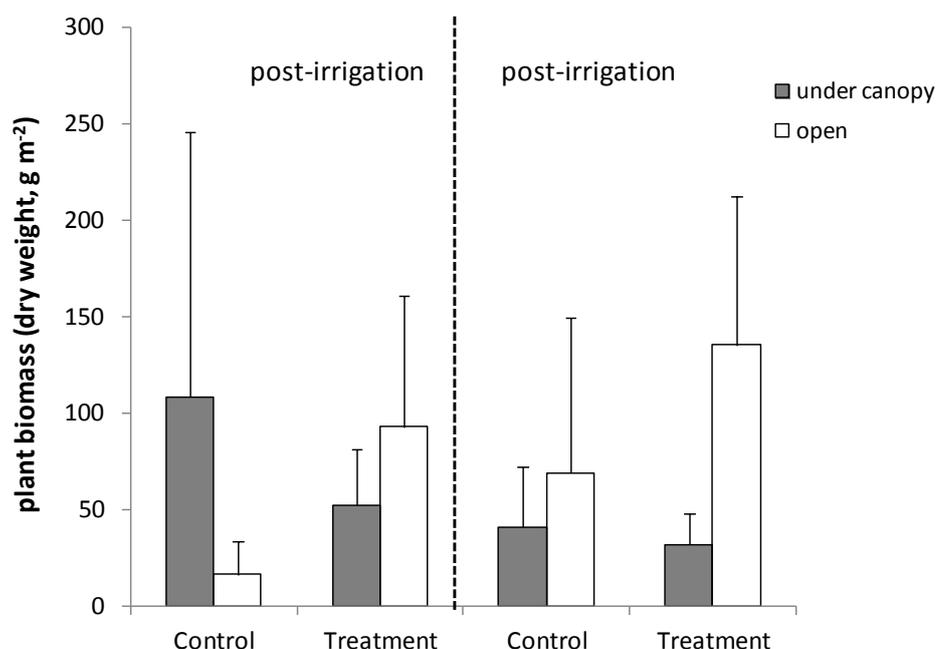


Figure 15: Comparison of understorey plant biomass (dry weight, g m⁻²) under black box canopy (1 m) and in the open (5 m) for control and treatment plots during pre-irrigation (November 2012) and post-irrigation (January 2013) surveys; Markaranka field trial. Measurements are mean \pm S.E \times 1.96.

There was a significant difference in leaf litter biomass between distances, with higher leaf litter loads under canopy (1 m) than out in the open (5 m) (Table 16; Figure 16). However, there were no significant differences between control and treatment plots, nor did irrigation have a significant effect on leaf litter biomass.

Table 16: Multivariate three-factor PERMANOVA results for comparing leaf litter biomass (g m⁻²) between irrigation periods (pre- and post-irrigation), plots (treatment and control) and distance (under canopy versus open). (df = degrees of freedom; p-value = probability value; α = 0.05).

Factor	df	Pseudo-F statistic	p-value
Irrigation	1, 95	2.69	0.08
Plots	1, 95	1.01	0.34
Distance	1, 95	4.61	0.01
Irrigation \times Plot	1, 95	0.72	0.47
Irrigation \times Distance	1, 95	1.56	0.19
Plot \times Distance	1, 95	0.52	0.61
Irrigation \times Plot \times Distance	1, 95	0.86	0.41

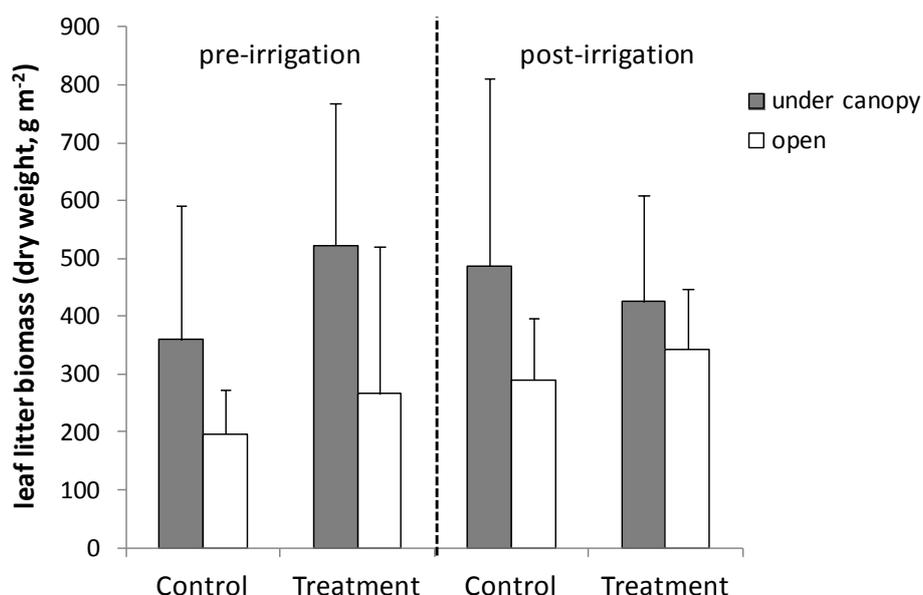


Figure 16: Comparison of leaf litter biomass (dry weight, g m⁻²) under black box canopy (1 m) and in the open (5 m) for control and treatment plots during pre-irrigation (October 2012) and post-irrigation (January 2013); Markaranka field trial. Measurements are mean \pm S.E \times 1.96.

There was a significant difference in soil surface pH between irrigation periods, with soil surface pH measurements being slightly higher in January 2013 (range 6.12–6.47) compared to November 2012 (range 5.97–6.20) (Table 17; Figure 17); although there were no significant differences between control and treatment plots, nor did distance from the tree have a significant effect on soil surface pH.

Table 17: Multivariate three-factor PERMANOVA results for comparing soil pH between irrigation periods (pre- and post-irrigation), plots (treatment and control) and distance (under canopy versus open). (df = degrees of freedom; p-value = probability value; α = 0.05).

Factor	df	Pseudo-F statistic	p-value
Irrigation	1, 95	9.74	0.003
Plots	1, 95	0.42	0.51
Distance	1, 95	3.41	0.07
Irrigation \times Plot	1, 95	0.03	0.85
Irrigation \times Distance	1, 95	0.25	0.60
Plot \times Distance	1, 95	2.09	0.15
Irrigation \times Plot \times Distance	1, 95	2.22	0.15

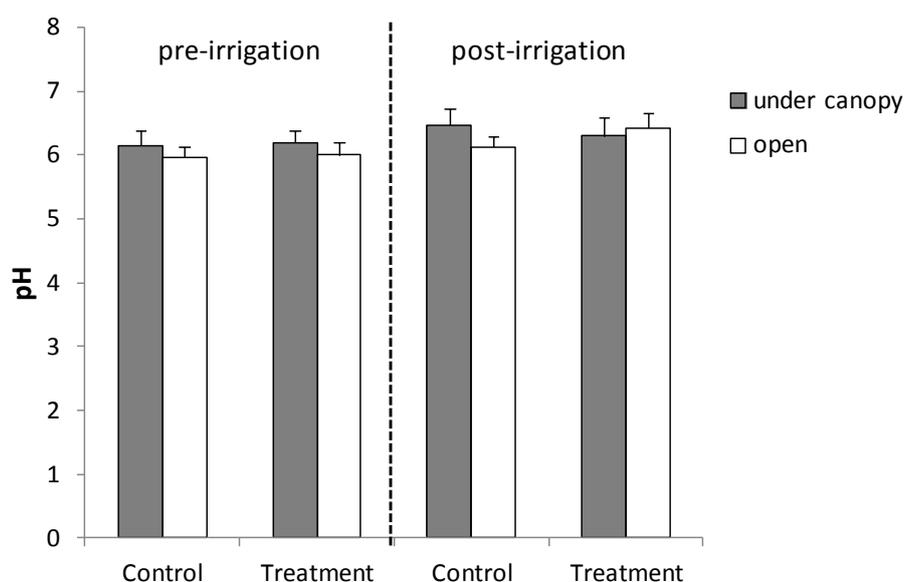


Figure 17: Comparison of soil pH under black box canopy (1 m) and in the open (5 m) for control and treatment plots during pre-irrigation (October 2012) and post-irrigation (January 2013); Markaranka field trial. Measurements are mean \pm S.E \times 1.96.

There were significant differences in soil surface EC between irrigation periods and distance from tree although there were no significant differences between plots (Table 18). In general, soil surface EC was lower in January 2013 (range 90.08–193.07) compared to November 2012 (range 192.17–300.09) (Figure 18). Soil surface EC was also generally greater under tree canopy (1 m) compared to open areas (Figure 18), although variability among and between samples was high.

Table 18: Multivariate three-factor PERMANOVA results for comparing soil EC between irrigation periods (pre- and post-irrigation), plots (treatment and control) and distance (under canopy versus open). (df = degrees of freedom; p-value = probability value; $\alpha = 0.05$).

Factor	df	Pseudo-F statistic	p-value
Irrigation	1, 95	46.77	0.001
Plots	1, 95	3.41	0.06
Distance	1, 95	20.39	0.001
Irrigation \times Plot	1, 95	0.002	0.97
Irrigation \times Distance	1, 95	0.73	0.39
Plot \times Distance	1, 95	0.56	0.43
Irrigation \times Plot \times Distance	1, 95	0.004	0.95

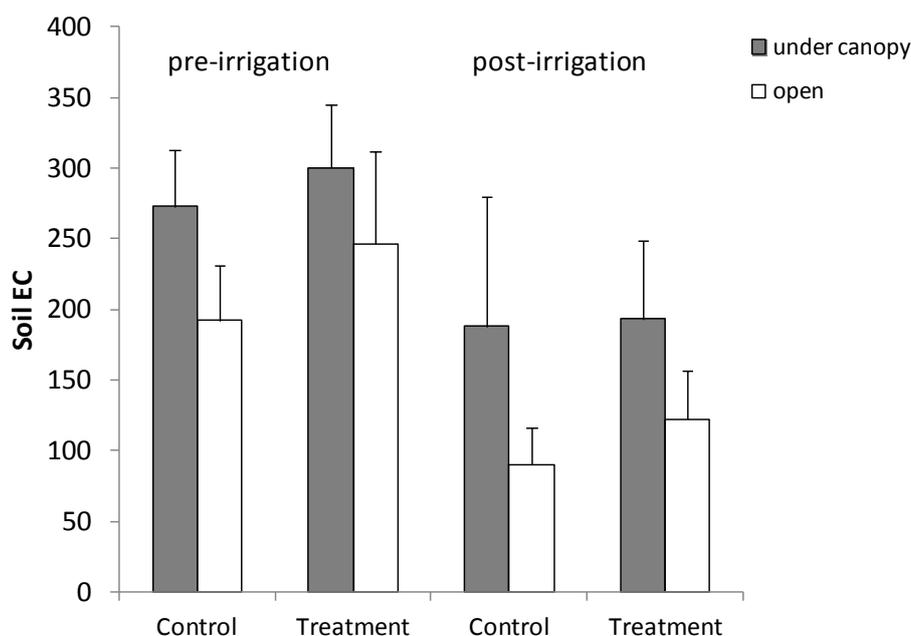


Figure 18: Comparison of soil surface EC under black box canopy (1 m) and in the open (5 m) for control and treatment plots during pre-irrigation (October 2012) and post-irrigation (January 2013); Markaranka field trial. Measurements are mean \pm S.E. \times 1.96.

4. Discussion

The stand structure of black box within the site was variable, ranging from large, single-stemmed individuals to numerous multi-stemmed individuals that showed signs of coppicing. While river red gums are often grown in plantations for commercial purposes, black box has a limited commercial value, sometimes used as fence posts and firewood (Cunningham *et al.* 1992). Hence it is possible that trees at this site may have been harvested at one point in time for these purposes. More importantly there was no evidence of seedlings or saplings (single-stemmed; < 10 cm DBH) within the site, suggesting that the present population is unbalanced, with young growth stages conspicuously absent (George *et al.* 2005). Aged trees within woodland populations are important because mature eucalypts form hollows providing shelter and nesting places for a variety of fauna (Tidemann and Flavel 1987; Gates 1996). The majority of suitable hollows in river red gums and/or black box woodlands were only found in trees with a DBH > 70 cm (Bennet *et al.* 1994); stressing the importance of maintaining present woodland condition, but also insuring that recruitment and regeneration of these communities is assured.

It tends to be accepted that recruitment events of floodplain eucalypts are driven by natural flood regimes (Jensen *et al.* 2008), however, the actual germination requirements for black box are still largely unknown (Roberts and Marston 2000). Black box seedlings have been observed following flooding, but rarely after rainfall (Treloar 1959) suggesting black box reproduction and regeneration may be cued to flooding. The acute lack of regeneration in black box is therefore believed to be correlated to decreased flooding as a result of altered water regimes (Roberts and Marston 2011).

At the completion of Phase I, no black box individuals were flowering within the treated, irrigated plots, yet many individuals within control plots were flowering (as were individual black box surrounding the experimental site; Gehrig, S. *personal observations*) despite evidence that the majority of trees in the control plots maintained poor condition ratings across the experimental period. In contrast, after only 10 weeks of watering, trees within the irrigated plots had visibly improved in terms of positive growth variables such as canopy extent and density and crown tip and epicormic growth, whereas the negative growth variables such as leaf die off and leaf damage had declined. As the experiment continued into April 2013, many of the trees within the treated plots had started to flower and form buds (Gehrig, S., *unpublished data*); hence there is the potential that the general improvement of trees within the treated, irrigated plots leads to improvements in both seed yield and release. Asynchronous flowering between co-occurring individuals and/or populations is a common occurrence in black box. Flowering does not appear to be regulated by seasonal conditions within the year, but rather by environmental conditions from previous years (Boland *et al.* 1981). Black box produces abundant flowers (Cunningham *et al.* 1992); with production peaking between August and January (Boland *et al.* 1981), although this varies geographically and may occur between May to October (Roberts and Marston 2000; George *et al.* 2005; Jensen *et al.* 2008). Furthermore, little is known about seed yields, but seeds mature within months (Boland *et al.* 1986) often coinciding with historically peak flooding times in the MDB. Fruits are retained in the canopy for up to two years before seeds are released under suitable conditions (Jensen 2008). The triggers for seed release still remain largely unknown.

The improvement in tree condition corresponded with a significant increase in soil moisture in the upper 0.5 m of the soil profile following the drip irrigation trial. Accordingly there was a concomitant increase in black box water status (Ψ_{predawn}) within the irrigated plots compared to non-irrigated, control plots. As previously mentioned, shoot Ψ_{predawn} measurements are compared with measurements of soil water potentials to infer where plants may be sourcing their water (Flanagan *et al.* 1992). The Ψ_{predawn} measurements of trees within the experimental site showed black box were using soil-water at depths of 1.5–2 m below ground level prior to irrigation. This particular soil water source (at depths of 1.5–2 m) was of low-moderate salinity, overlying the moderately saline ($\sim 3,500 - 4,000 \mu\text{S cm}^{-1}$) groundwater source between 4 – 5.5 m; suggesting the quality of water available was relatively fair. It is possible that irrigation in the adjacent highland, vineyards reduces groundwater salinity in this particular floodplain region since the groundwater source seems a reasonable quality, especially when compared to extreme instances where groundwater may exceed $40,000 \mu\text{S cm}^{-1}$ in certain floodplain regions in the lower River Murray (Holland *et al.* 2006). Black box may use the available groundwater sources, but may also use overlying deep soil water sources, which are often available via recharge a) vertically through the soil profile or via preferential flow paths by rainfall or floodwaters or b) horizontally by bank recharge from surface water on top of saline water (Holland *et al.* 2006). Bank recharge, such as this is often likely to occur for trees within 50 m of permanent or ephemeral water bodies, which is the

case for the site at Markaranka where a flood runner is located within 50 – 80 m of the site (Figure 1).

Still, despite the availability of a fair quality water source prior to irrigation, the majority of black box trees within the experimental area had poor condition scores and signs of low water status. Low plant water status, as reflected by low (more negative) shoot water potentials can lead to xylem cavitation, where the xylem sap is under tension due to critically low pressures (Pockman *et al.* 1995), thereby pulling air bubbles into xylem conduits, disrupting water transport and reducing hydraulic conductivity. It has been previously reported that xylem cavitation and a 50% loss in hydraulic conductivity occurs in river red gums when water potentials fall between -3.8 to -4.2 MPa (Pammenter and van der Willigen 1998). While xylem cavitation has not been investigated in black box, Ψ_{shoot} measurements at times were even lower than -4.2 MPa throughout the trial phase, hence, it is possible that black box were suffering the effects of xylem cavitation, which may explain their poor condition and health.

Access to water can be constrained by root system development, however, *Eucalyptus* spp. produce bimodal root systems (Awe *et al.* 1976) with sinker roots capable of accessing deeper groundwater sources (up to depths >20 m, Stone and Kalisz 1991) plus shallow-buried roots that allow for the uptake of surface water, precipitation and most importantly, nutrients. Deep groundwater sources are a vital water source in water-limited environments and may contribute a significant amount to the tree water balance budgets (Lubczynski 2009). Groundwater quality, however, may do little to improve tree condition, instead merely extending growing periods and/or ensuring survival (Feikema *et al.* 2010). Alternatively the substantial volumes of fine roots (< 2 mm diameter) that some eucalypts are capable of producing (Jonsson *et al.* 1988; Nasra *et al.* 2005) may be more than 50% of the total volume concentrated in the upper 10 cm of the soil profile (Tedala 2004), allowing opportunistic responses to shallow soil water sources and soluble nutrients. Hence, bimodal, responsive root systems allow eucalypts to switch water sources when surface or soil water sources are unreliable (Mensforth *et al.* 1994; Jolly and Walker 1996; Fiekema *et al.* 2010). Indeed, the isotopic $\delta^{18}\text{O}$ composition of twig tissue showed that the black box trees in irrigated plots were accessing soil water from the upper 0.5 m at the end of 10-week, Phase I irrigation period. These results suggest black box trees in irrigated plots may have switched from using the slightly higher, but still relatively low-moderate salinity soil water (<1,500 $\mu\text{S cm}^{-1}$) present between a depth of 1.5-2 m below ground level, and started to use the irrigation water source available at much shallower depths of < 0.5 m below ground level.

In contrast, soil moisture and soil water availability in the non-irrigated, control plots decreased slightly (1.5 m down to 2 m deep) across the 10-week, Phase I irrigation period and this decrease corresponded to a significant decrease in Ψ_{midday} for black box trees and a slight increase in the number of trees with a poor condition rating. Maximum shoot water potentials (Ψ_{midday}) provide an index of the water extraction capacity of root systems (Aranda *et al.* 2000) and the relative

tensions required to satisfy water demands (Smith *et al.* 1991); hence the slightly lower (more negative) shoot Ψ_{midday} for black box in the non-irrigated, control plots signalled a decrease in soil water availability across the course of the trial period. The decrease in soil water availability across this time most likely reflects the progressive seasonal decline across the summer months due to decreased precipitation and highlights the benefits of regular seasonal monitoring to detect these natural, background changes.

Despite the general decline in tree condition in control plots, it is worth noting that for a few individual trees within the non-irrigated, control plots the condition scores and water status (Ψ_{predawn} and Ψ_{midday}) markedly improved across the trial period. These particular individuals were positioned close (< 3 m) to the boundaries of the irrigated, treatment plots, suggesting that the 5 m buffer zone within the irrigated plots may not have been adequate enough (under the current watering regime). A buffer zone of more than 10 m may be more appropriate (Berens *et al.* 2009). This occurrence stresses the benefits of establishing the control plots and perhaps the inclusion of a nearby reference site may also prove beneficial (Greet *et al.* 2013).

Water balance calculations to compare total evapotranspiration by black box between irrigated and non-irrigated plots are recommended. While it has been shown that black box transpiration rates can be as low as 0.05 mm day^{-1} , these values were for trees that were exhibiting signs of stress and poor condition (Doody *et al.* 2009); hence it is expected that in order to maintain good to very good tree condition (and/or ultimately encourage reproduction and regeneration) higher transpiration rates are required. Calculations of the volumes of irrigated water used by black box plus the amount of time for this water to be discharged as evapotranspiration complement regular, ongoing assessments of tree condition responses to watering and assist in determining the optimal watering regime (i.e. volume and frequency/duration of application) to maintain black box woodlands. Furthermore, these calculations and ongoing assessments may also begin to provide some indication of how much and what type of watering is required to trigger reproduction and regeneration of black box.

The regeneration niche of black box is, as previously discussed, still largely unknown. Once seed is released, it is believed that flooding provides the primary source of moisture needed for germination (George *et al.* 2005; Jensen *et al.* 2008). Germination success however is also governed by optimal temperature requirements (Grose and Zimmer 1958; Magann *et al.* 2012) and micro-site conditions (Facelli and Ladd 1996). For instance, temperatures outside the optimum range may induce dormancy (Yates *et al.* 1996), which will negatively impact upon successful germination for black box, given that they do not appear to form a persistent soil seed bank (Nicol 2004; Jensen *et al.* 2008; Roberts and Marston 2011). Magann *et al.* (2008) found that constant temperatures and moderate to high levels of leaf litter cover suppress black box seed germination. Specifically, germination responses in black box were greatest under fluctuating temperatures within $15\text{-}30 \text{ }^{\circ}\text{C}$ (diel fluctuations $>10 \text{ }^{\circ}\text{C}$).

In the lower River Murray, naturally occurring floods assist in the removal of leaf litter and occur during the warmer months, coinciding with peak seed release and optimal germination temperatures for black box. However, the accumulation of litter tends to decrease with increasing rainfall (Facelli and Pickett 1991) and the removal of litter potentially increases soil temperatures (Facelli and Ladd 1996) and also creates available space for germination (George *et al.* 2005) so it is possible that drip irrigation could induce these conditions, potentially providing suitable conditions for seed germination (providing reproduction is triggered) within black box woodlands. Black box seedlings are vulnerable to water stress following germination since they do not possess well developed root systems compared to mature trees, hence irrigation across the typically drier, summer months could also assist in providing suitable conditions for regeneration. Comparisons of leaf litter underneath black box canopies versus open sites did not show any significant difference as a result of irrigation; however, the variability between samples was high, so a larger sample size may be required to detect differences as a result of treatment. In addition, a longer period of irrigation (> 10 weeks) may be required to ascertain whether drip irrigation potentially reduces leaf litter loading. Nevertheless, soil moisture increased and soil EC decreased in irrigated, treated plots within the time assessed.

While one of the key aims of this project was to improve black box condition, it is also hoped that the condition of the woodland as a whole would improve as a result of drip irrigation. Restoration activities are often focused on the canopy layer species, with the assumption that the regeneration of the understorey elements will occur as a consequence (Harris *et al.* 2012). Nonetheless, for this trial the irrigation system was designed to uniformly irrigate the plots as much as possible (i.e. not target individual trees only). As a consequence there were signs that the understorey woodland condition began to improve in irrigated, treated plots compared to controls. Within the first day of watering, dormancy of the biological soil crusts (complex assemblages of mosses, lichens, liverworts, algae, fungi and bacteria present on the surface of dryland soils; Eldridge and Rosentreter 1999) was broken in the irrigated, treated plots (Gehrig, S. *personal observations*). Biological soil crusts are indicative of healthy productive ecosystems (Eldridge 2001), helping to moderate essential processes such as nutrient cycling and landscape stability, but they are particularly susceptible to trampling by livestock (Read *et al.* 2011) and/or drought (Williams *et al.* 2008); although as observed, recovery can be rapid once stressors are removed.

Nevertheless, following irrigation the percent cover of biological soil (lichen) crusts did not necessarily increase, most likely because the condition of the existing dryland understorey species (*Atriplex* spp. *Rhagbodia spinescens*, *Duma florulenta*, *Enchylaena tomentosa*, *Sclerolaena* spp.) improved. Species such as *Atriplex paludosa*, *Marsilea* sp. and *Teucrium racemosum* were only recorded in irrigated, treated plots, indicating species richness of the understorey increased. Interestingly, *Marsilea* sp. is a flood responder, capable of germinating after flood waters recede and/or wetlands drawn down (Nicol 2004), but generally not responding to rainfall, so their presence suggests soil moisture levels were high. This reinforces the one serious concern that the practice of irrigating the woodlands from spring to summer may encourage exotic species, especially since winter annuals (e.g. *Poa*

annua) and agricultural grass weeds of southern Australia, which are cool-season grasses that typically germinate in autumn (Howell and Benson 2000; Stokes *et al.* 2010a; Greet *et al.* 2013). After 10 weeks of irrigation, exotics were not prevalent, but ongoing monitoring is ideally required and it is possible that other interventions to decrease exotic invasion (e.g. weed removal) and increase native species richness in the understorey (revegetation) may also need to be considered as part of management practices (Harris *et al.* 2012).

Future Studies

To fully assess the benefits of drip irrigation it is recommended that the current trial continue longer term, with the addition of trialling a range of watering regimes (testing amount, duration, and frequency of application) that might be required to:

- a) maintain condition of black box populations,
- b) trigger reproduction,
- c) enhance regeneration.

Regular monitoring of tree condition, tree water status and understorey condition in response to various watering regimes is also recommended to not only capture the short- to medium-term responses of tree/woodland to irrigation regimes, but also identify any natural regeneration that may be occurring and/or alert managers to any intervention management strategies (e.g. weed removal) that may be needed.

Water balance investigations to calculate the amount of irrigated water used by black box, plus estimates of the amount of time irrigation water takes to be discharged as evapotranspiration would be complementary.

While the project ideally seeks to promote natural regeneration, there is also a possibility to explore the potential for restoration by planting black box seedlings (or other understorey species) and then monitor survival, establishment and growth.

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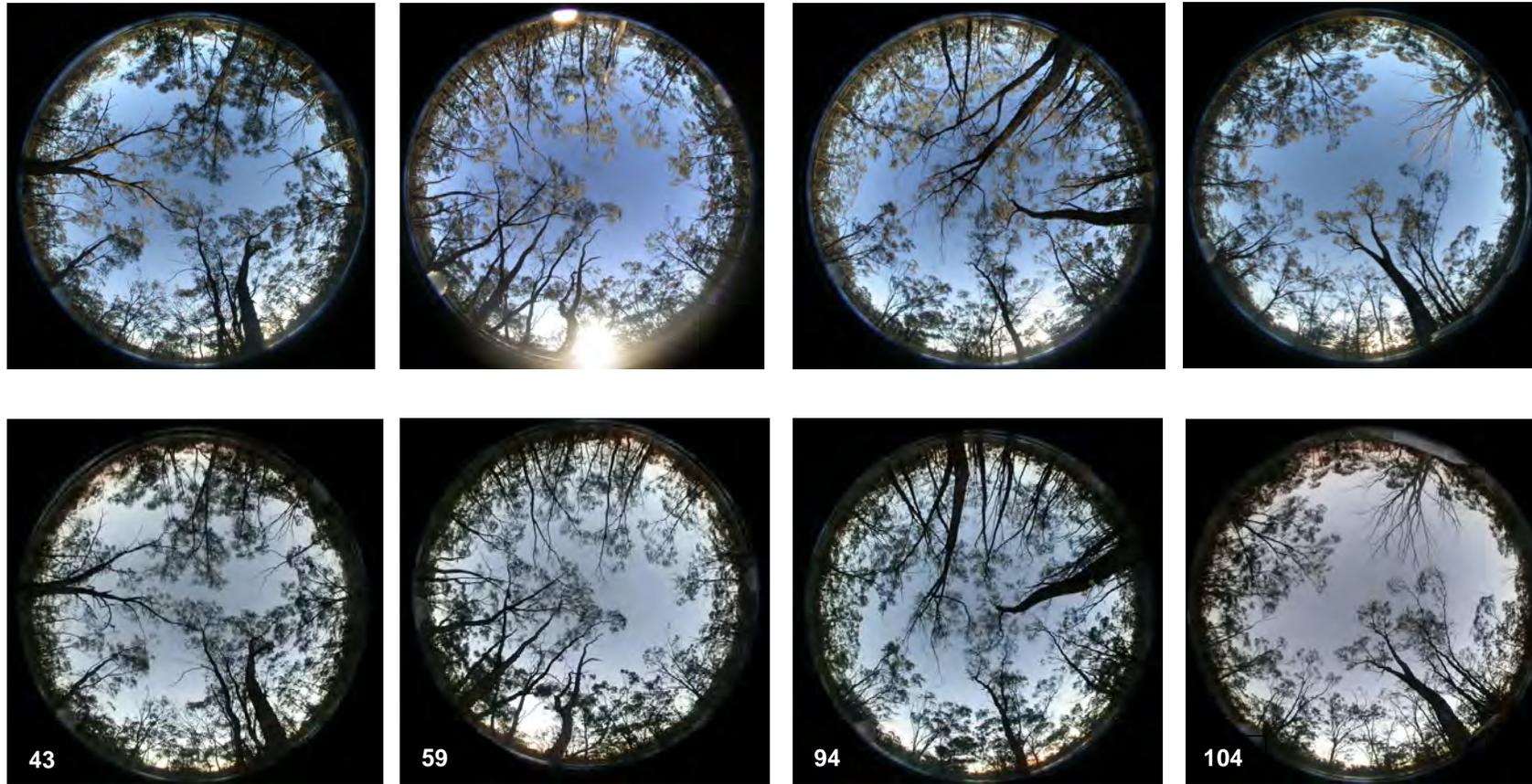
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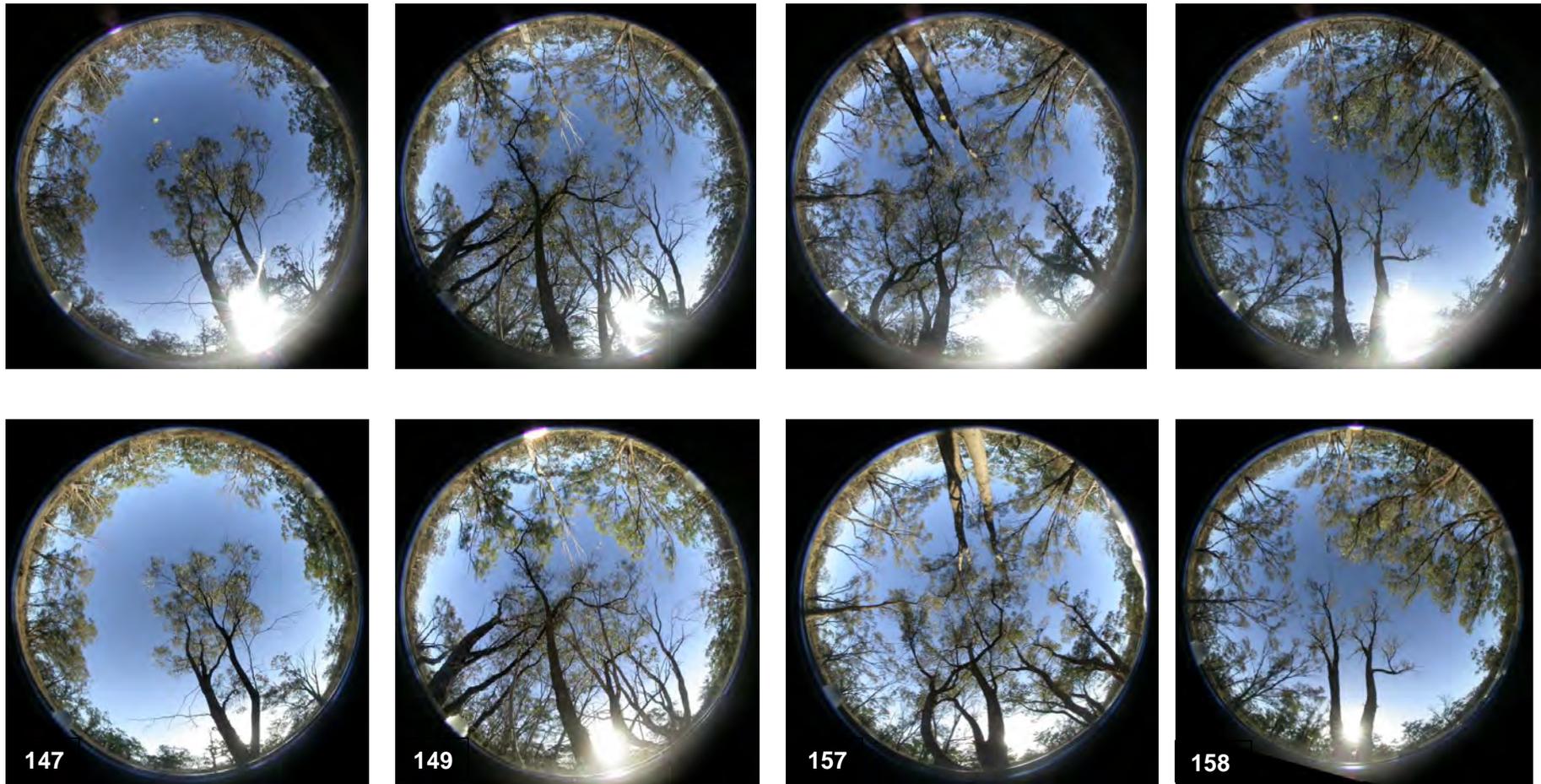
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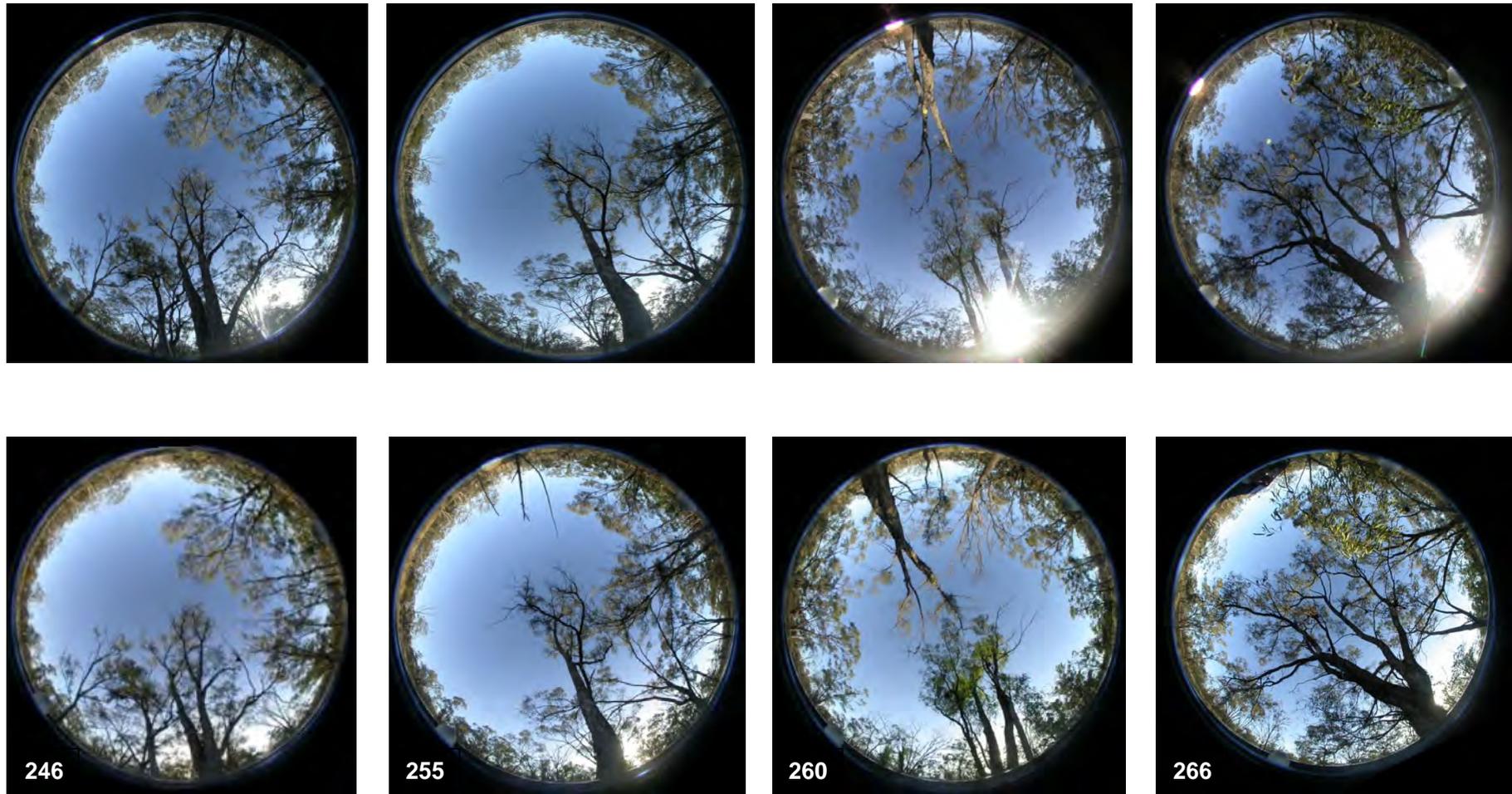
6. Appendices



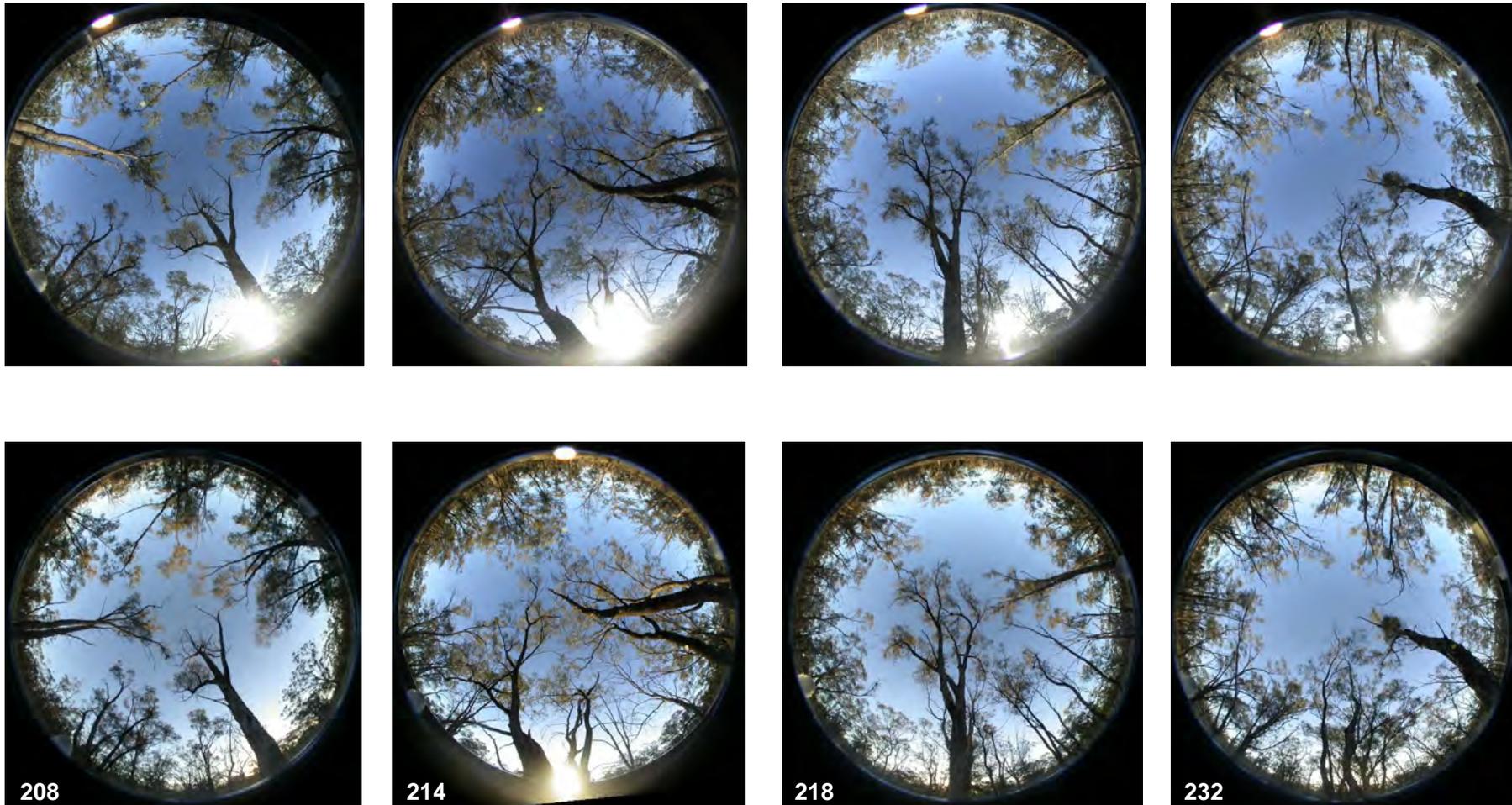
Appendix 1: Pre-irrigation (top row) and post-irrigation (bottom row) hemiview images of canopy for black box trees #43, 59, 94 and 104 in Control plot 2.



Appendix 2: Pre-irrigation (top row) and post-irrigation (bottom row) hemiview images of canopy for black box trees #147, 149, 157 and 158 in Control plot 3.



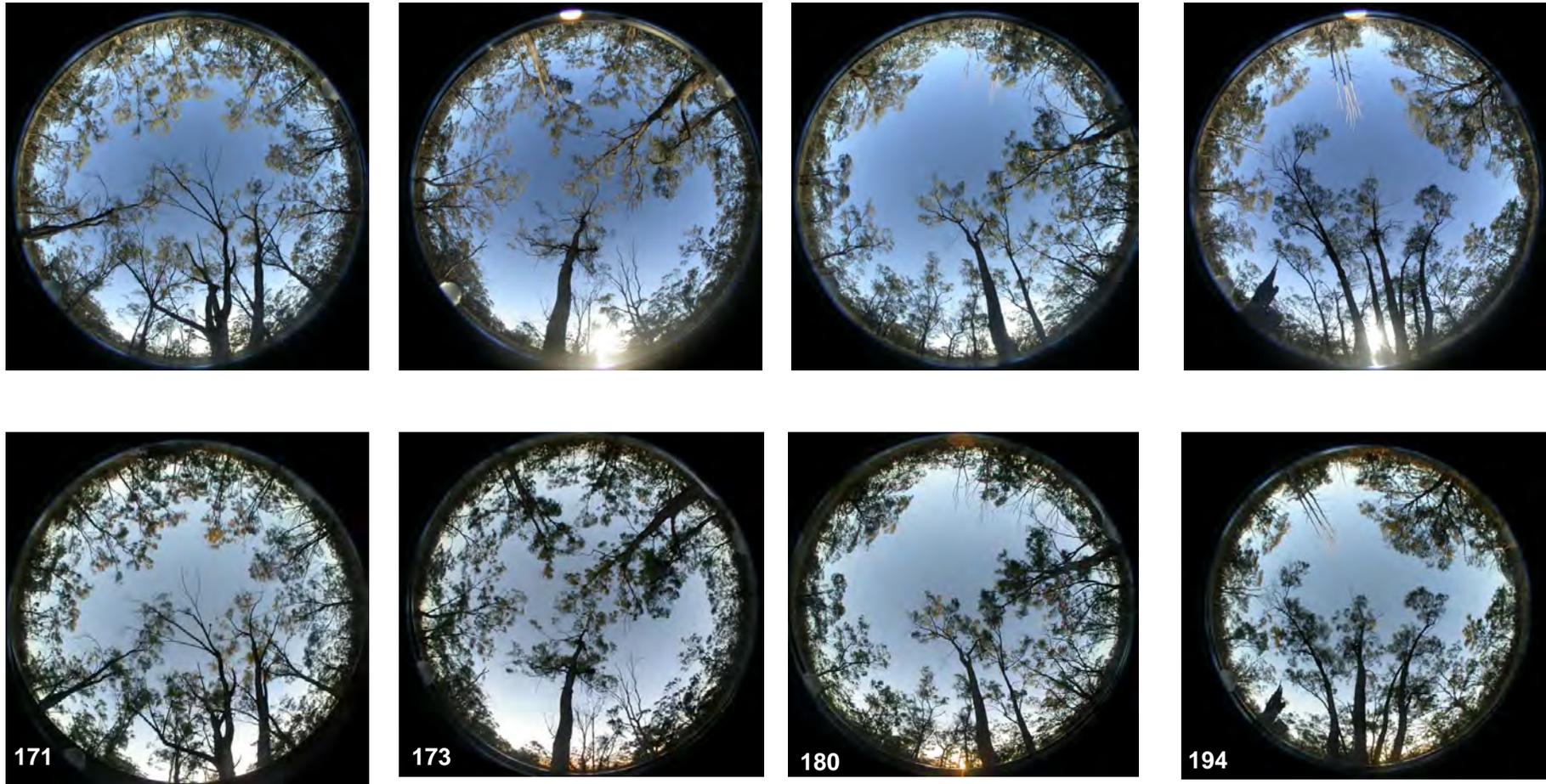
Appendix 3: Pre-irrigation (top row) and post-irrigation (bottom row) hemiview images of canopy for black box trees #246, 255, 260 and 266 in Control plot 4.



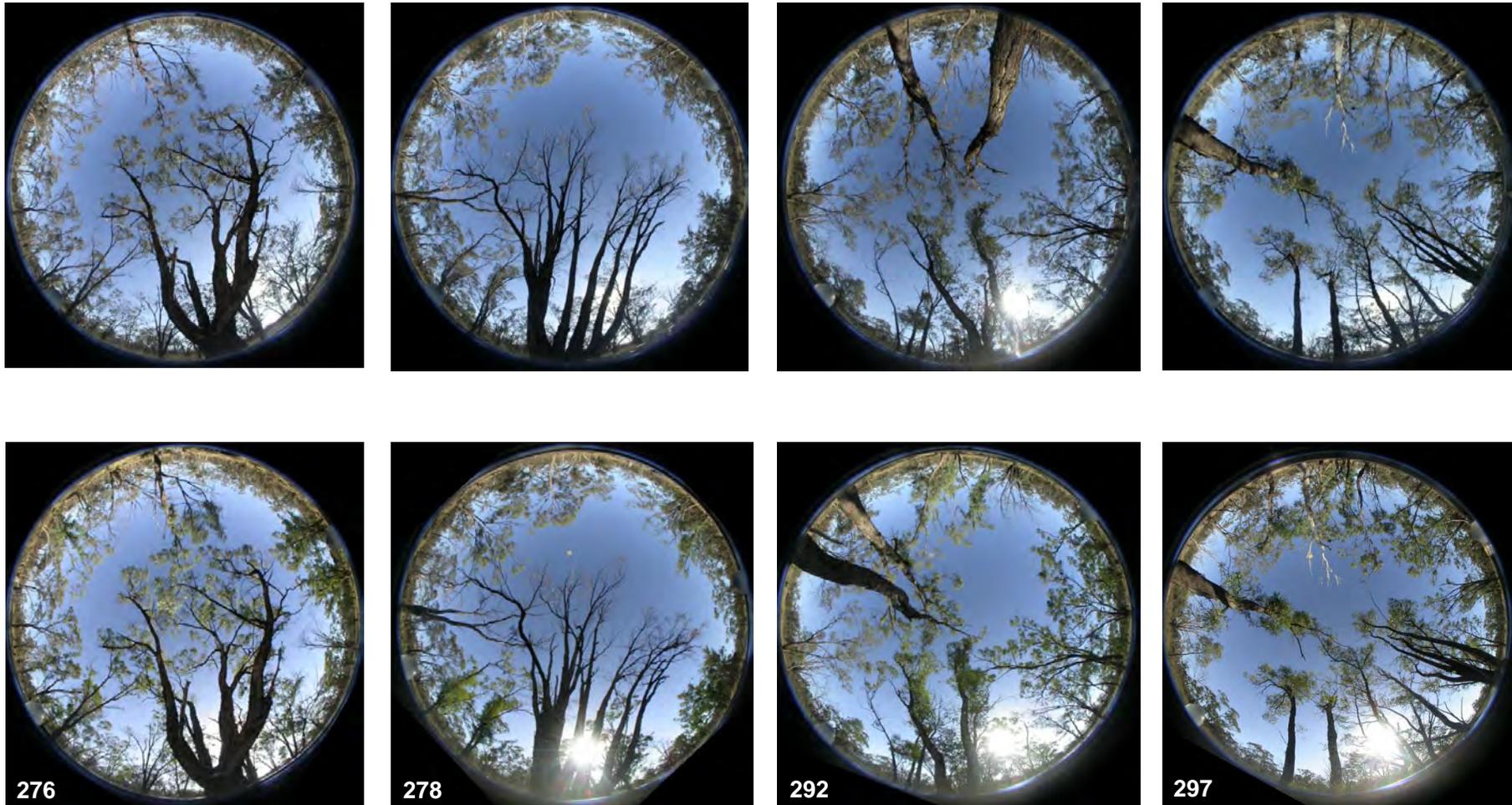
Appendix 4: Pre-irrigation (top row) and post-irrigation (bottom row) hemiview images of canopy for black box trees #208, 214, 218 and 232 in Control plot 5.



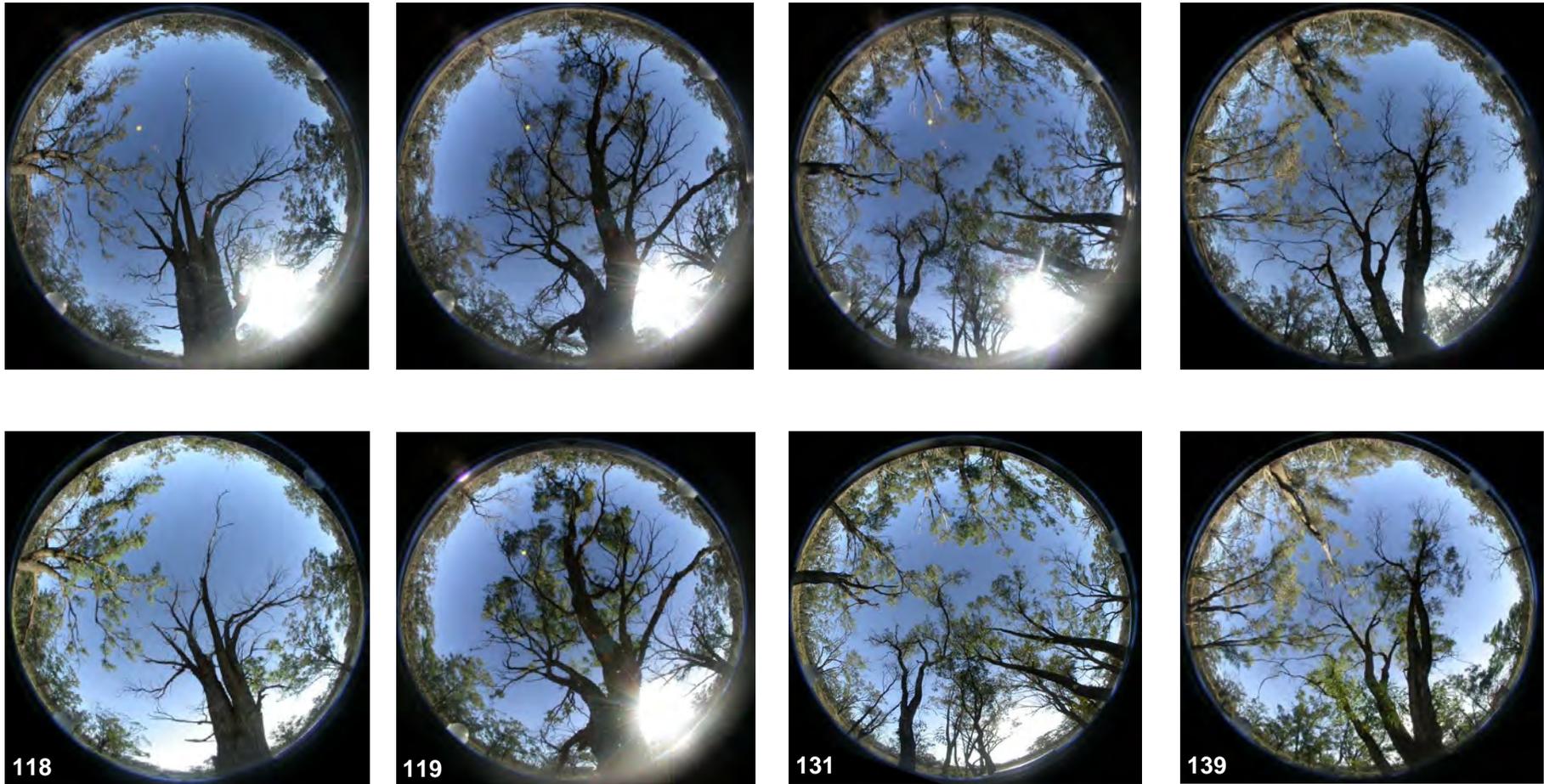
Appendix 5: Pre-irrigation (top row) and post-irrigation (bottom row) hemiview images of canopy for black box trees #9, 14, 19 and 21 in Treatment plot 1.



Appendix 6: Pre-irrigation (top row) and post-irrigation (bottom row) hemiview images of canopy for black box trees #171, 173, 180 and 194 in Treatment plot 2.



Appendix 7: Pre-irrigation (top row) and post-irrigation (bottom row) hemiview images of canopy for black box trees #276, 278, 292 and 297 in Treatment plot 3.



Appendix 8: Pre-irrigation (top row) and post-irrigation (bottom row) hemiview images of canopy for black box trees #118, 119, 131 and 139 in Treatment plot 4.



Appendix 9: Photopoint PI for control plot 2; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial.



Appendix 10: Photopoint P11 for control plot 2; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial.



Appendix 11: Photopoint PI for control plot 3; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial.



Appendix 12: Photopoint PII for control plot 3; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial.



Appendix 13: Photopoint PI for control plot 4; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial.



Appendix 14: Photopoint PII for control plot 4; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial.



Appendix 15: Photopoint PI for control plot 5; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial.



Appendix 16: Photopoint PII for control plot 5; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial.



Appendix 17: Photopoint PI for treatment plot 1; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial.



Appendix 18: Photopoint P11 for treatment plot 1 pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial.



Appendix 19: Photopoint PI for treatment plot 2; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial.



Appendix 20: Photopoint PII for treatment plot 2; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial



Appendix 21: Photopoint PI for treatment plot 3; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial



Appendix 22: Photopoint PII for treatment plot 3; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial



Appendix 23: Photopoint PI for treatment plot 4; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial



Appendix 24: Photopoint PII for treatment plot 4; pre-irrigation (above; 19/10/2012 and post-irrigation (below; 22/01/2013); Markaranka field irrigation trial