Monitoring the response of littoral and floodplain vegetation and soil moisture flux to weir pool raising – 2015

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EXECUTIVE SUMMARY

A series of 11 Locks and Weirs along the River Murray are managed to provide stable water levels for irrigation and navigation, resulting in reduced hydrological variability and complexity. Flow stablisation favours species adapted to comparatively stable, lentic conditions and potentially limits the life history processes of native biota adapted to intermittent and lotic environments. Flow regulation contributes to reduced river-floodplain connectivity leading to a subsequent decline in riparian and floodplain vegetation. Various water level management interventions have been trialed along the River Murray to provide environmental benefits by restoring a greater range of water regimes. Weir pool surcharge is one method used to increase river channel water level variability and deliver water to temporary wetlands and low-lying floodplain. This can benefit vegetation that has reduced in condition, distribution and abundance because they are less tolerant of stable regulated conditions or have become water stressed as a result of a loss in river-floodplain connectivity or increased dry intervals between inundation events.

In spring 2014, a weir pool raising event was trialed in Weir Pool 1 and Weir Pool 2 demonstrating minor, but positive vegetation responses in littoral understorey and river red gum (*Eucalyptus camaldulensis*) trees. Changes in littoral wetland plant communities were most apparent at the lowest elevations of wetlands and river channels, relative to normal pool level; with increases in the abundances of a range of amphibious, floodplain and emergent taxa following inundation. River red gum condition across weir pools and between surveys also responded; with most trees shifting from moderate to moderate-good condition.

A further trial of weir pool raising was proposed for spring/summer 2015. In August 2015, water levels at Lock 2 were gradually raised (~2 cm day^{-1}), reaching 50 cm above pool level in October 2015, then held for 4 weeks before returning to normal pool level by December 2015. Similarly, water levels in Lock 5 were raised in late August 2015, but raising occurred as a stepped operation, where water levels were originally raised to 10–15 cm above normal pool level, held for two weeks and then gradually raised a further 30 cm and held for ~3 weeks. Water levels were then lowered until they were ~10–15 cm above normal pool level in December and held a further 2–3 weeks before water levels returned to normal pool levels in mid-December 2016.

To monitor the response of vegetation to the 2015 weir pool raising event, sites were selected at Woolenook Bend (Weir Pool 5) and Big Toolunka Flat (Weir Pool 2) in the lower reaches of the managed weir pools, while a third site at Moorook (Weir Pool 3) was selected in the lower reach of the weir pool that was not manipulated, for reference.

To characterise whether vegetation composition and structure would respond as a result of weir pool raising, three 100 × 100 m monitoring plots were established within each site, adjacent to the river edge, the wetland edge and in between both, where possible. Within each plot, cover estimates of vegetation and substrate types, as well as estimates of canopy cover and structure were undertaken before and after weir pool raising along 10 crisscrossing point-intercept transects (White *et al.* 2012). The results showed that vegetation diversity and structural composition of the sites are highly variable. Across the survey period there were few changes in vegetation composition and structure at the sites before and after weir pool raising. In the monitoring plots where weir pools were raised, there were generally minimal changes in the proportion of live riparian and/or floodplain understorey and live canopy cover intercepted before and after weir pool raising. As none of the floodplain areas within this investigation were inundated, this result was not unexpected as increases in soil moisture within 1 m of the surface (where roots of understorey vegetation are most active) were unlikely to occur as a result of lateral recharge. Nonetheless there were observed increases in the interception of live canopy cover within the Woolenook Bend plot positioned on the river's edge, suggesting improvement in canopy cover in the riparian zone.

To assess whether soil moisture reserves might increase as a result of bank flux through temporary wetlands and floodplains a range of soil parameters were monitored. Soil cores were collected from the Big Toolunka Flat (Weir Pool 2) site. Soil cores were sampled every 5, 10, 20, 30, 60, 90, 120 and 150 m along three transects perpendicular to the river edge and a further three transects from the wetland edge. The soil profile was sampled in 50 cm increments from the surface to the saturated zone (to a maximum depth of 3 m) below ground level. Samples were analysed to determine gravimetric soil moisture content, soil suction, soil texture and electrical conductivity. Assessments of the soil profile from the river and wetland edges suggested that prior to the weir pool raising a low saline (<3000 EC), saturated zone occurred within 60 m (at depths > 2.5 m) from the river edge and within 60 m (depths > 1 m) from the wetland edge. During weir pool raising, the saturated zones increased upwards and away from the river and wetland, soil moisture remained high, and soil EC decreased and correspondingly soil suction became less negative, thereby increasing available soil water availability due to the increase in the saturated zone and the subsequent capillary rise and improvements in water quality.

To measure whether the condition of overstorey floodplain trees might improve due to soil moisture reserves increasing as a result of bank flux, a subsample of trees within the monitoring plots were selected to assess crown condition and changes in tree water status (predawn shoot water potential). Similarly, changes in canopy cover within each monitoring plot were also assessed by taking hemispherical photographs to measure Plant Area Index

(PAI). Improvements in tree water status and crown condition/extent were observed in floodplain trees during the time weir pools were raised. Although variable between sites, trees positioned close to the river's or wetland's edge, or with access to the unsaturated zone where there were improvements in soil water availability and freshening occurred, showed the greatest improvements. Following weir pool raising, however, tree crown condition either remained unchanged or had started to decline depending on the site studied. More noticeably, in all sites studied, tree water status had started to decline to measurements lower than those observed prior to weir pool raising, suggesting that improvements in tree vigour may have only persisted temporarily (months) where soil water availability was not sustained.

To assess whether the littoral plant communities of wetlands might increase in diversity and abundance at elevations that were inundated by weir pool raising, three transects were established perpendicular to the waterline of wetlands within each site. Species abundances (measured as frequencies) were determined from quadrats established at 0 cm (pool level), and at increasing 10 cm intervals from +0.1 m to +0.6 m (inclusive) above pool to the wetland shoreline. Prior to weir pool raising there were large differences characterising the composition of the wetland littoral plant communities between sites. These differences tended to mask the patterns of change that could be detected at the higher elevations (+30, +40, +50 above normal pool level) at Woolenook Bend and Big Toolunka Flat, where weir pool raising occurred, but not at Moorook. Following weir pool raising there were no changes in the plant communities at lower elevations (0, +10, +20 cm) detected, but at Big Toolunka Flat, typical floodplain and amphibious species (*Stemodia florulenta, Glycyrrhiza acanthocarpa, Ludwigia peploides, Samolus repens*, and the parasite *Cuscuta campestris*) were observed in February 2016 at the higher elevations following weir pool raising that were not recorded before weir pool raising occurred. Similarly, at Woolenook Bend wetland, there were also several amphibious and floodplain species (*Alternanthera denticulata, Crassula sieberana, Erodium cicutarium, Sporobolus mitchellii, Conyza bonariensis, Xanthium strumarium*) that were recorded following weir pool raising at the higher elevations that were not observed in August 2015. In contrast, Moorook was dominated by perennial species that remained largely unchanged across the survey period.

In this study, soil water availability and quality in the unsaturated zone increased during weir pool raising as a result of bank flux, although the extent of freshening and soil moisture increase is likely to have varied from site to site. However, an increase in tree vigour was apparent in trees positioned close to the river's or wetland's edge, or in areas where trees have access to the freshened unsaturated zone in weir pools where water levels were raised. This demonstrates that trees were capable of responding to increased water availability and quality although the response may have only persisted for a few months. Hence weir pool raising events may prove beneficial for contributing towards forest/woodland maintenance within these areas if they occur more frequently (as part of regime and not as discrete ‘events’), occur for longer durations, and are potentially of a greater magnitude since weir pool raising increased and freshened the zone of deep soil water availability. Furthermore, weir pool manipulations provide a management tool to introduce limited water level variability in the absence of unregulated flows and increase biodiversity. They have the potential to provide conditions suitable for recruitment of floodplain and amphibious species in littoral plant communities providing there is a resident seed bank and there is sufficient area inundated that is free of competitive taxa such as *Typha domingensis, Phragmites australis* and *Paspalum distichum*.

1. INTRODUCTION

1.1. Background

Since the 1920s, the lower River Murray has become a highly regulated system with a series of eleven low level weirs and barrages built between Mildura and the Lower Lakes (Walker 1985). The weirs are primarily managed to provide stable water levels for irrigation and navigation (Maheshwari *et al.* 1995), resulting in decreased hydrological variability, increased water level stability, and reduced hydraulic complexity (Walker *et al*. 1995; Bunn *et al.* 2006). Altered river channel hydrodynamics as a result of river regulation, may no longer facilitate the life history processes of native biota adapted to dynamic lotic environments (e.g. flood dependent vegetation) but instead favour the proliferation of generalist biota (native and non-native), which are more tolerant of comparatively stable lentic conditions (Geddes 1990; Walker and Thoms 1993; Blanch *et al.* 2000; Roberts and Marston 2000; Clavero *et al*. 2004; Jensen *et al*. 2008; Gehrig 2010; Bice *et al.* 2014).

Changes in flow regime (in conjunction with upstream water diversions) have: affected channel morphology, increased salinity in some regions, reduced connectivity between river and floodplain, altered the littoral zone, isolated floodplain wetlands or led to permanent flooding of temporary wetlands (Jolly *et al.* 1993; Walker and Thoms 1993; Maheshwari *et al.* 1995; Blanch *et al.* 1999; Kingsford 2000). The River Murray is now constrained within its channel for prolonged periods and subsequently floodplain vegetation health, in particular, has severely declined (Roberts 2003; Overton *et al.* 2006; Cunningham *et al.* 2009; Mac Nally *et al.* 2011). The distribution patterns of littoral plant communities inhabiting the margins of rivers and wetlands have transformed so that species from permanent backwaters and wetlands on the floodplain have now colonised the main channel (Blanch *et al.*1999). In the absence of overbank flooding, understorey floodplain plant communities also shift towards drought and salt tolerant terrestrial taxa (Department of Environment, Water and Natural Resources 2012; Gehrig *et al.* 2014). Similarly, long-lived vegetation such as river red gums (*Eucalyptus camaldulensis*) and black box (*Eucalyptus largiflorens*) have suffered pervasive mortality and condition loss (Cunningham *et al.* 2009; MacNally *et al.* 2011). This decline is primarily attributed to soil salinisation as a result of altered surface water regimes and changes in groundwater-surface water interactions between the River Murray and its floodplain (Jolly *et al.* 1993; Slavich *et al.* 1999; Overton *et al.* 2006).

To promote plant diversity and prevent further decline of the main channel, wetland and floodplain vegetation along the River Murray, a greater range of water regimes can be restored by manipulating the rate, duration and timing of flooding and drying of the floodplain through existing flow control structures (see Galat *et al*. 1998; Jenkins *et al.* 2008). Weir pool raising is one method of increasing river channel water level variability and delivering water to the temporary wetlands and low lying floodplain, independently of elevated discharge, and may provide promise as a method of improving floodplain and wetland vegetation health. In 2000, Lock 5 water levels were raised to 50 cm above the normal pool level (herein referred to as NPL), for a period of two weeks, inundating a small area of low lying floodplain and temporary wetlands and resulting in significant recruitment of flood dependent species and a decrease in abundance of terrestrial species (Siebentritt *et al.* 2004). Similarly, in 2005–2006 a combination of weir pool surcharge and increased flow was used to raise water levels in the Chowilla Anabranch system (Souter *et al.* 2014). As a result of increased water levels in anabranch creeks on the Chowilla Floodplain and through horizontal recharge freshening of the adjacent groundwater, there was a significant improvement in the condition of river red gum (*Eucalyptus camaldulensis*) trees (Souter *et al.* 2014).

A weir pool raising event was conducted in Weir Pool 1 (Lock 1–2) and Weir Pool 2 (Lock 2–3) in spring 2014 and a range of ecological investigations were undertaken, including an assessment of the response of littoral understorey and river red gums (Gehrig *et al.* 2015). This work found that there were minor changes in the plant community in response to weir pool manipulation. The changes in understorey plant communities were most apparent at the lowest elevations of wetlands, with increases in the abundances of a range of amphibious, floodplain and emergent taxa following inundation. There were also distinct differences between weir pool zones, where the lower zones of each weir pool tended to be characterised by a larger number of indicator species than the middle and upper zones. Hence, following inundation, the changes in plant communities at the lowest elevations were often more pronounced in the lower river reaches. There were also observed changes in river red gum condition across weir pools and between survey trips; with an overall shift from the majority of trees being in moderate condition to the majority of trees being in moderate to good condition. There were also observed changes in the littoral vegetation of wetlands and at the lower elevations of riverbanks (in Weir Pool 2 only). Although the changes were only slight, the responses suggest that if weir pool manipulations were to occur more frequently (and for longer duration), the opportunities for increasing diversity and re-distribution of taxa at these lower elevations is likely to increase.

As part of the *Riverine Recovery Project* (RRP), a further weir pool manipulation event was proposed for Weir Pool 2 (Lock 2–3) and Weir Pool 5 (Lock 5–6) of the lower River Murray during spring/summer 2015 to build upon weir pool raising (WPR) trials conducted in 2014.

1.2. Objectives

The overarching aim of this project is to build on the body of knowledge that came out of the previous year's monitoring by monitoring vegetation response again. Specifically, the aims are to:

- Measure the response of littoral understorey plant communities in response to weir pool raising with particular focus on wetlands,
- Assess the condition and physiological changes of dominant floodplain woodland trees (including river red gums, *Eucalyptus camaldulensis* and black box, *Eucalyptus largiflorens*) in response to weir pool raising,
- Measure soil moisture flux due to lateral recharge under conditions of weir pool raising and relate to observed vegetation responses,
- Gather data such that it can be used to inform and validate remotely sensed data with a high degree of efficacy.

#	Hypothesis	Hypotheses related to in 'Ecological Objectives and Monitoring Plan' (Department of Environment, Water and Natural Resources 2015)
1	Littoral plant communities of wetlands will increase in diversity and abundance at elevations that were inundated (0 to +0.5 m elevation)	H5, H6, H7, H11
2	Frequency and abundance of wetland invasive plants will increase at elevations that were inundated (0 to +0.5 m elevation)	H21
3	Soil moisture reserves will increase as a result of bank flux through temporary wetlands and floodplains	H3
4	Water status and crown condition/extent of overstorey floodplain trees (e.g. river red gum, black box and river cooba) will improve due to soil moisture reserves increasing as a result of bank flux	H1, H4
5	Floodplain understorey plant communities that are inundated may change in diversity, abundance and/or condition as terrestrial species are drowned out (i.e. top-flooded) and high soil moisture as a result of vertical infiltration encourages germination of floodplain and amphibious taxa. However, for floodplain understorey plant communities that are not inundated the diversity, abundance and condition is unlikely to change unless soil moisture in the unsaturated zone (<1 m depth; where roots are most active) increases as a result of bank flux.	

2. METHODS

2.1. Weir pool raising event

Weir pool raising in Lock 5 (Weir Pool 5) commenced in late August 2015 (Figure 1). Initially water levels were raised approximately 10–15 cm above normal pool level of 16.3 m AHD, and held for approximately 2 weeks to assess whether there were any adverse impacts to infrastructure and/or property. Water levels were then gradually raised (approximately 2 cm day^{-1}) to a peak of 40– 45 cm above normal pool level and held for ~3 weeks until the first week of November 2015. Water levels gradually returned to levels that were approximately 10–15 cm above normal pool level in late November 2015 and remained at this level for a further 2–3 weeks before water levels returned to normal pool level in mid-December 2016 (Figure 1a).

Weir pool raising in Lock 2 of the River Murray also commenced in late August 2015 (Figure 1). Water levels were gradually raised (~2 cm day^{-1}), without a stepped operation, reaching 50 cm above normal pool level of 6.1 m AHD in the first week of October 2015. Water levels were then held for approximately 4 weeks above normal pool level until the first week of November 2015, when water levels gradually returned to water levels approximately 5 cm above normal pool level for the remainder of the study period (Figure 1b).

In Weir Pool 3, water levels were not manipulated and hence, daily water levels immediately upstream of Lock 3 remained consistent above normal pool level of 9.8 m AHD, although small variations (+/- 2–3 cm) were observed (Figure 1c).

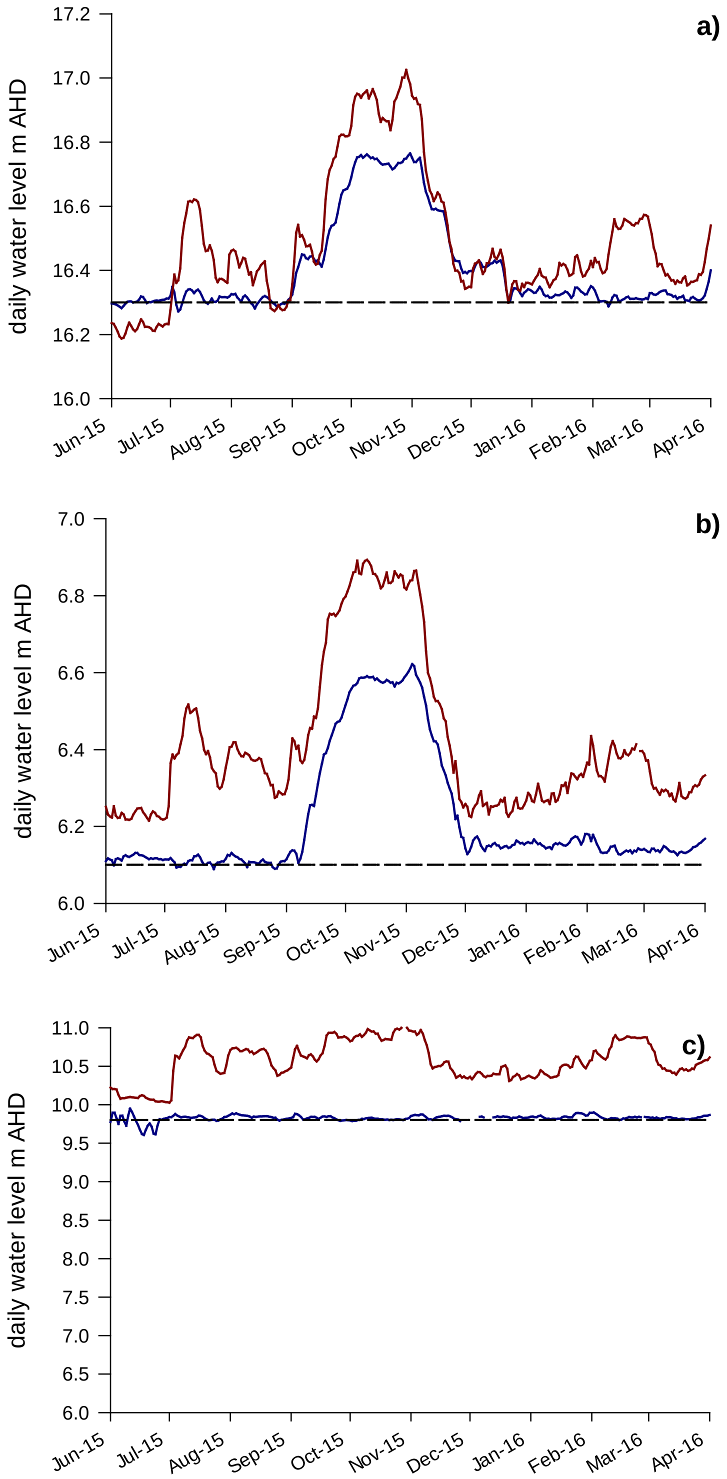

Figure 1: Daily surface water levels (m AHD) recorded upstream of the controlling Lock and Weir (blue lines) and downstream of the antecedent (upstream) Lock and Weir (red lines), relative to full supply level (dashed black lines) for a) Weir Pool 5 (Lock 5– 6) b) Weir Pool 2 (Lock 1–2 reach) and c) Weir Pool 3 (Lock 3– 4 reach) between June 2015 to March 2016. Grey bars represent survey trip times. Note wetland littoral vegetation surveys and vegetation plot composition point-intercept surveys were not undertaken *during* the weir pool raising (October 2015).

2.2. Site Selection

One study site within each of the weir pools where manipulations occurred (i.e. Weir Pool 2 and Weir Pool 5) was selected (Figure 2), as well as one site within a weir pool that was not manipulated (i.e. Weir Pool 3) (Figure 2).

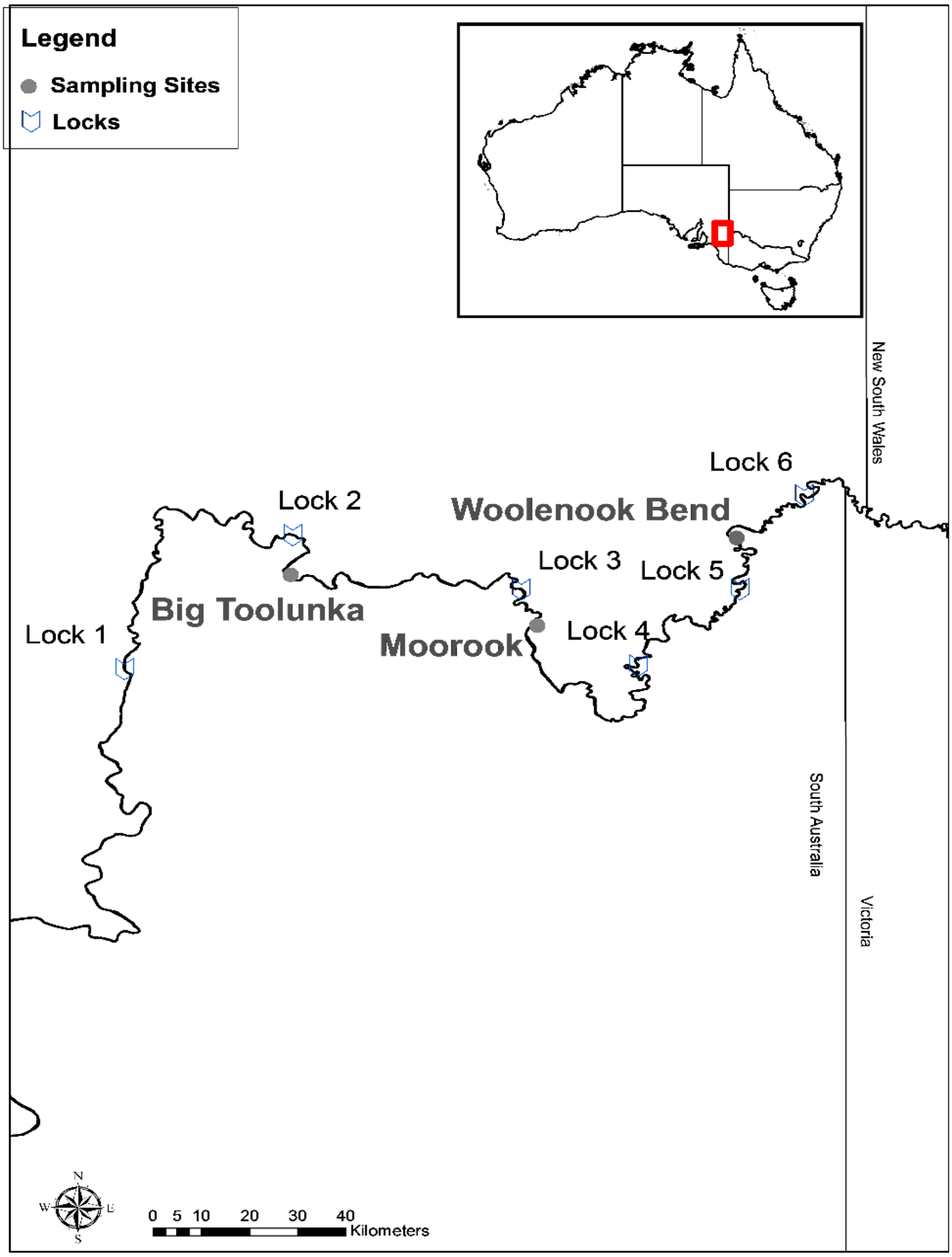

Figure 2: Map of the study sites locations within the 2 manipulated weir pools (Big Toolunka Flat, Weir Pool 2 and Woolenook Bend, Weir Pool 5) and one weir pool that was not manipulated (Moorook, Weir Pool 3) within the Lower River Murray (South Australia).

2.3. Vegetation Monitoring Plots

Within each of the study locations, three 100 × 100 m monitoring plots were established as per the AusPlots methods outlined in White *et al.* (2012). Where practical, one monitoring plot was established adjacent to the river channel edge, one adjacent to the wetland edge and the other positioned in between at each study location (as shown in Figure 3).

The AusPlots method was chosen in order to gather vegetation data at scales adequate to inform and validate remotely sensed data. The method assists in gathering vegetation data at a scale of nine (3 × 3), 30 m Landsat satellite pixel clusters. Within each of the monitoring plots, a range of surveys were conducted to provide an assessment of vegetation diversity and cover, to assess changes in condition of dominant overstorey vegetation and to monitor changes in soil moisture in response to weir pool manipulations (Figure 4).

Plot locations were chosen to align with a North-South direction and the corners and centre of each plot marked out using a differential GPS (see White *et al.* 2012). Note that a wetland monitoring plot could not be established at the Moorook site because an impenetrable stand of *Phragmites australis* was present, hence vegetation composition was very different to the sites at Big Toolunka Flat and Woolenook Bend. An additional "river" monitoring plot was therefore established at Moorook to establish monitoring plots along the river-floodplain gradient (Appendix 1Appendix 2Appendix 3).

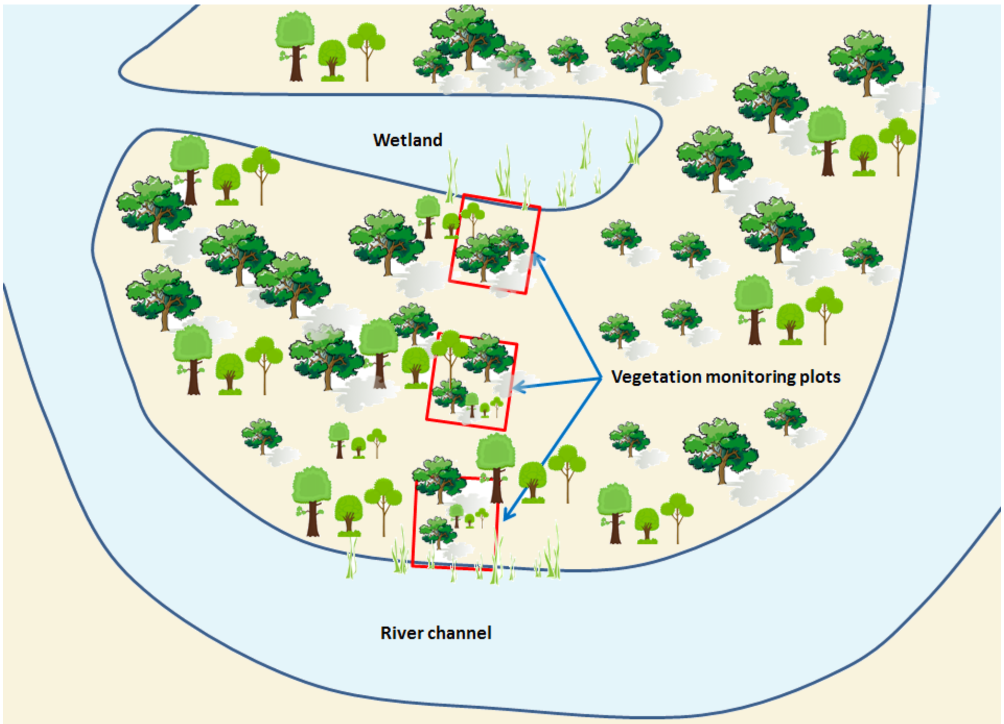

Figure 3: Vegetation monitoring plots: ideal plan view showing placement of monitoring plots relative to wetland and main river channel.

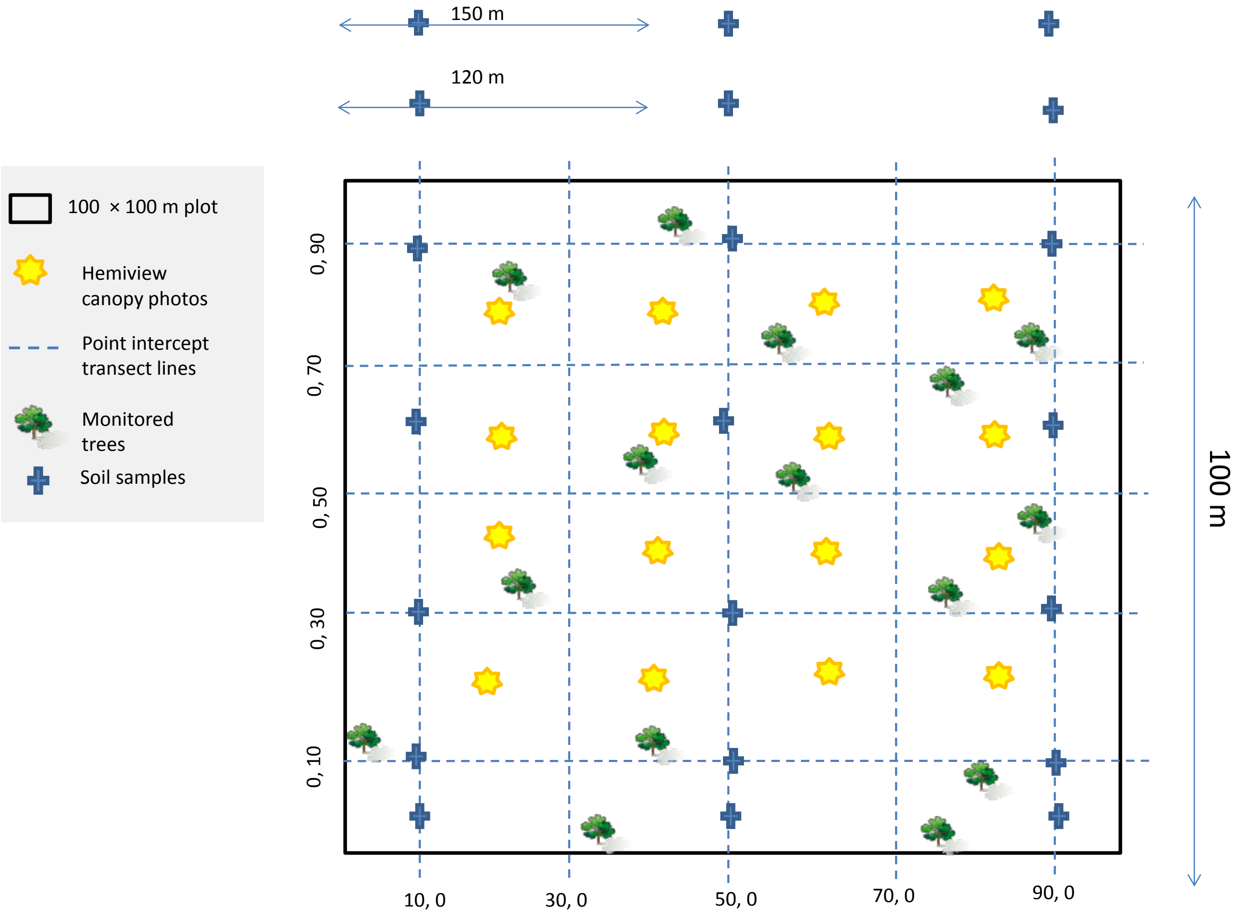

Figure 4: Monitoring Plots: ideal plan view showing layout of 100 × 100 m vegetation monitoring plots and the incorporation of the hemiview canopy photopoints; the 10 point-intercept (PI) transects; 15 randomly sampled trees for tree predawn water potential measurements and tree condition surveys, and the soil sampling locations (5, 10, 20, 30, 60, 90, 120 m) along three transects (*note soil sampling only occurred within the river and wetland plots at the Big Toolunka Flat site, within Weir Pool 2).

2.3.1 Vegetation plot composition

To quantify vegetation composition and cover within each monitoring plot, the point intercept method was used, as outlined in White *et al.* (2012). This method has the advantages of providing a rapid, repeatable and accurate method for quantifying the cover of individual species and/or total vegetation. It can also provide cover estimates of substrate types (e.g. bare soil, litter, rocks and biological soil crusts) and the height of lower, mid and upper level vegetation strata. Vegetation cover was measured along 10 transects that crisscrossed each of the 100 × 100 m monitoring plots (i.e. 5 in a N/S and 5 in an E/W direction; as illustrated in Figure 4). Briefly, using a 1.5 m staff with laser pointer and densitometer attached, measurements of substrate cover (e.g. bare soil, leaf litter, coarse woody debris, rock, biological soil crust), plant cover (with a record of individual species, growth form and height) and canopy cover were recorded every 1 m along each transect (*n* = 1010 points per monitoring plot).

2.3.2 Trees

To assess changes in the condition of woodland trees along river-floodplain and/or wetland-floodplain gradients; a sub-sample of individual trees were surveyed based on increasing distances from either the river and/or wetland edges and then assigned to distance categories (note: where possible trees were selected to be within the monitoring plots) These distance categories varied within each site (Table 1; Appendix 1 to Appendix 3).

Table 1: Distance categories for surveyed trees within site locations

Site	Distance category	Description
Big Toolunka Flat (Lock 1–2)	<80R	less than 80 m from river's edge
	81–120R	within 81–120 m of river's edge
	121–150R	within 121–150 m of river's edge
	81–150W	within 81–150 m of wetland's edge
	<80W	less than 80 m from wetland's edge
Moorook (Lock 3–4)	<80R	less than 80 m from river's edge
	81–120 R	within 81–120 m of river's edge
	121–200 R	within 121–200 m of river's edge
	201–260 R	within 201–260 m of wetland's edge
Woolenook Bend (Lock 5–6)	<60 R	less than 60 m from river's edge
	61–115 R	within 61–115 m of river's edge
	116–200 R	within 116–200 m of river's edge
	61–115 W	within 61–115 m of wetland's edge
	<60 W	less than 60 m from wetland's edge

Tree crown condition

The sub-sample of trees (*n* = 45 per study location) were randomly selected within each river-floodplain and/or wetland-floodplain distance category (Table 1) and tagged (using yellow cattle tags). Tree position was recorded using a handheld GPS (Garmin® GPSMap62s) so that the same trees could be monitored for the period of the weir pool raising. An assessment of tree crown condition was undertaken using the technique developed by Souter *et al*. (2008; 2010). This method takes into consideration: crown extent and density, bark form, epicormic growth and state, reproduction, crown growth, leaf die off and damage, and mistletoe (Souter *et al.* 2010). Therefore, condition and trajectory (whether condition is improving or declining) was assessed (Souter *et al.* 2008; 2010). The presence and location of any germinated *Eucalyptus camaldulensis* seedlings observed during the field surveys (if any) were also recorded (and marked with GPS).

Tree water status

Predawn water potential ($\Psi_{predawn}$) measurements are used to indicate plant water status because $\Psi_{predawn}$ can vary between individuals and co-existing species, providing an index of the water extraction capacity of root systems (Aranda *et al.* 2000). Predawn shoot potentials, in particular, are useful as a consistent measure of soil moisture, based on the assumption that $\Psi_{predawn}$ is in equilibrium with the soil-water (Ψ_{soil}) accessed by roots (Schulze and Hall 1982). In particular, $\Psi_{predawn}$ is not influenced by daytime transpiration, while daytime leaf water potential measurements depend strongly on transpiration as well as soil water status. Predawn water potentials are also independent of differences in rooting depth and soil water access and unlike volumetric soil moisture content, $\Psi_{predawn}$ is independent of soil texture (Zhou *et al.* 2016). Hence $\Psi_{predawn}$ 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).

Predawn water potential of the shoots (a shoot being approximately 5-10 leaves) were measured using a PMS Instrument Company Model 1000 Pressure Bomb (Oregon, USA) (Scholander *et al.* 1965) from the aforementioned sub-sample of 45 trees per study location; randomly selected within each river-floodplain and/or wetland-floodplain distance category (Table 1). Two shoots from each tree (n = 90) were collected before sunrise ($\Psi_{predawn}$ MPa) transferred to seal lock bags and processed within approximately ten minutes of sampling. Measurements were also conducted at midday (Ψ_{midday} MPa) solar radiation (~11:00 to 13:30) to confirm that trees were actively transpiring (i.e. (Ψ_{midday} (more negative) $\neq$ $\Psi_{predawn}$ (less negative) in actively transpiring trees).

Canopy cover: Plant Area Index

Changes in Plant Area Index (PAI) were also measured to assess changes in tree canopy within the monitoring plots. To determine changes in PAI, 16 digital hemispherical photopoints were established within the middle of each monitoring plot (Figure 4) to take photographs of the canopy cover each survey trip (Hale *et al.* 2013). PAI was determined from hemispherical photographs taken using a digital camera and fisheye lens with full 180° field of view. For each survey trip, the tripod and digital camera (CANON EOS 700D; Sigma 4.5 mm F2.8 circular fisheye lens adapter) was positioned at 1.3 m height and once levelled, three upward facing (i.e. lens pointing 90° to the horizontal plane) images were taken using the following settings:

- AV mode
- F-value = >9.0
- ISO = > 800
- Exposure/AEB: 0 (normal), +1 (overexposure) and -1 (underexposure)
- Picture style: standard
- RAW + JPEG file type

2.4. Wetland littoral vegetation

Within each wetland monitoring plot, three transects were established (Figure 4) perpendicular to the waterline (Figure 5). Note that a wetland monitoring plot could not be established at the Moorook site because an impenetrable stand of *Phragmites australis* was present, hence vegetation composition was very different to the sites at Big Toolunka Flat and Woolenook Bend. For Moorook, the wetland littoral vegetation surveys were therefore undertaken at the nearby Loch Luna wetland (34°13'51.19"S, 140°22'54.27"E) to monitor changes. Quadrats (1 x 15 m) were established on each transect at 0 cm (River Murray NPL), and then at 10 cm elevation intervals from +0.1 m to +0.6 m (inclusive), measured using a laser level, parallel to the shoreline or bank (Figure 5).

Species abundance was measured by frequencies; where the quadrat was split into fifteen, 1 x 1 m cells and plants present in each cell recorded. Therefore, a species has a score of between 0 (not present) and 15 (present in each cell) for a quadrat. A cell with no live plants present was given a score of one for bare soil. This method has been used successfully for a number of vegetation monitoring projects in South Australia upstream of Wellington (Weedon and Nicol 2006; Weedon e*t al.* 2007; Marsland *et al.* 2008; 2009; Gehrig *et al.* 2010; Nicol 2010; Nicol *et al.* 2010), at Markaranka (Marsland and Nicol 2009) and the Lindsay Mullaroo system and Hattah Lakes (C. Campbell *pers. comm.*) and are recommended standardised methods for obtaining vegetation data (Department of Environment, Water and Natural Resources 2012).

Plants were identified to species (where possible) using keys in Jessop and Tolken (1986), Jessop *et al.* (2006), Cunningham *et al.* (1992), Dashorst and Jessop (1998), Sainty and Jacobs (1981; 2003), Prescott (1988) and Romanowski (1998). Nomenclature follows the Centre for Australian National Biodiversity Research and Council of Heads of Australasian Herbaria (2016). The presence and location of any germinated weed species observed during the field surveys (if any) were also recorded (and marked with GPS).

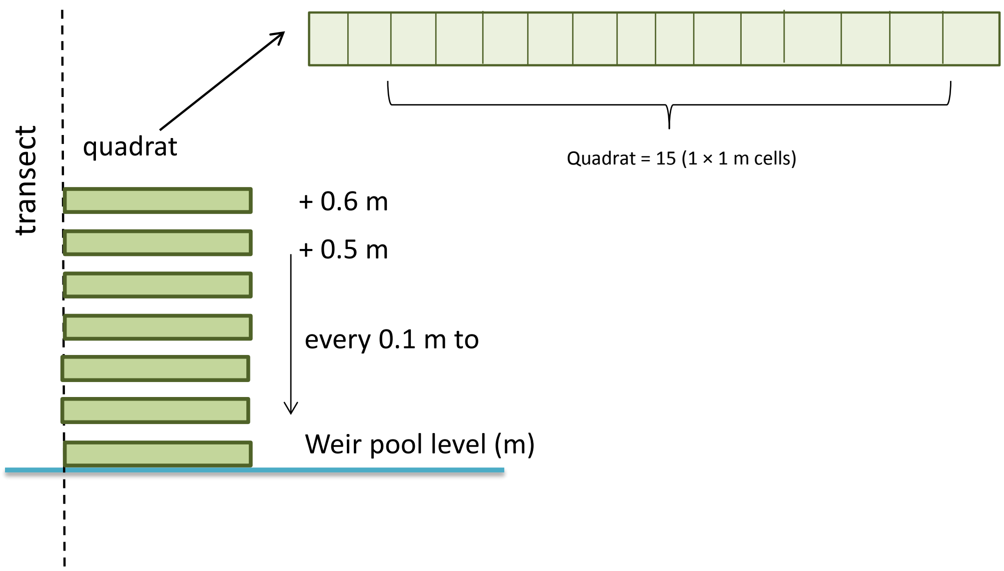

Figure 5: Littoral vegetation transect: plan view showing proposed placement of quadrats relative to waterline.

2.5. Soil flux

To monitor changes in soil moisture parameters, soil core samples were collected within one manipulated weir pool only (namely Big Toolunka Flat, within Weir Pool 2) for each survey trip (before, during and after weir pool raising) (Appendix 4). Three transects were established (perpendicular to the waterline) and soil cores were sampled within the river and wetland monitoring plot only, at 5, 10, 20, 30, 60, 90, 120 and 150 m distances along each transect (n = 24 cores per river and wetland locations) (Appendix 4). The soil profile was sampled in 50 cm increments from the surface to the saturated zone or a maximum depth 3 m below ground level (therefore maximum of 6 samples per soil core) using mechanical push tube sampling (SPK Geodrill P/L).

Soil samples (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; %), which is measured by oven drying samples at 80°C for three days (Klute 1986; Rayment and Higginson 1992), soil suction (or soil matric potential, Ψ_{soil} MPa), which was determined using the filter paper technique (Greacen *et al.* 1989) and electrical conductivity and pH (1:5 soil water extract method) (Rayment and Higginson 1992) using a TPS water quality meter.

Soil texture/type was also determined for soil samples (MacDonald *et al.* 1990) as clay soils tend to hold greater amounts of water, but water may be held too tightly within the soil matrix and therefore not readily available for uptake by plant roots (Hall *et al.* 2009). Soils with minimal clay content (e.g. sandy and loamy soils) hold less water, but water may be more readily available; furthermore they provide better structure for unrestricted root growth and adequate pore spaces for movement of air and water (Hall *et al.* 2009).

2.6. Analysis

A tree condition index score was determined as the product of tree crown extent and crown density per cent scores, producing a range of values between 0–1 (modified from Harper and Shemmield 2012; Department of Environment, Water and Natural Resources 2012; Equation 1):

Equation 1: $$TCI\ score\ (y') = \frac{y_{extent} \times y_{density}}{10000}$$

Where y' is the standardised value for the TCI score (between 0 and 1), y_{extent} is the raw percentage score for crown extent and $y_{density}$ is the raw percentage score for crown density.

Plant Area Index (PAI) values for individual hemiview photopoints were calculated from digital hemispherical photograph images using SpaceLAI (version beta 2.0, 2015, based on MacFarlane *et al.* 2007)

To assess changes in TCI scores and PAI for trees between survey trips (before, during and after weir pool raising) and along river-floodplain and/or wetland-floodplain gradients between sites; the individual trees surveyed or photopoint positions were grouped into distance (m) categories from either the river and/or wetland edges. Distance categories varied between sites; therefore, a two-way mixed model univariate PERMANOVA design was used (Anderson 2001, Anderson and Ter Braak 2003), which had the random factor Survey Trips (random) × fixed factor Sites (where Distance was nested within sites) to avoid pseudo replication due to repeated measures.

Changes in predawn leaf water potential ($\Psi_{predawn}$) within woodland trees along river-floodplain and/or wetland-floodplain gradients were assessed by calculating the difference or change (Δ) in $\Psi_{predawn}$ for a) before and during weir pool raising (between survey trip 1 and 2) and b) before and after weir pool raising (between survey trip 1 and 3). The individual trees surveyed were grouped into the same distance categories used to assess changes in TCI scores (see above). Differences (Δ) in $\Psi_{predawn}$ were then analysed using a one-way univariate PERMANOVA design (Anderson 2001, Anderson and Ter Braak 2003) comparing Sites (where Distance was nested within sites) per time period a) before and during weir pool raising and b) before and after weir pool raising.

Changes in gravimetric soil content (g g^{-1}), soil electrical conductivity (µS cm^{-1}) and soil suction (MPa) within the soil profile from either the river or wetland edge were also assessed by using a three way univariate PERMANOVA design (Anderson 2001, Anderson and Ter Braak 2003) where changes in the above soil parameters were compared in relation to Depth × Distance × Survey trips.

The package PRIMER version 6.1.12 (Clarke and Gorley 2006) was used to undertake all univariate PERMANOVA analyses. Because only one variable was used, Euclidean distances were used to calculate the similarity matrices for all univariate PERMANOVA analyses and $\alpha = 0.05$ for all statistical analyses. Multiple comparisons (where appropriate) where conducted using the Bonferroni correction (Quinn and Keogh 2002).

The changes in wetland littoral floristic composition before and after weir pool raising were analysed using a multivariate two factor (wetland and survey trips) PERMANOVA design (Anderson 2001, Anderson and Ter Braak 2003) and NMS ordination using the software package PRIMER version 6.1.12 (Clarke and Gorley 2006). Species with a Spearman correlation coefficient of greater than 0.5 were overlaid on the ordinations as vectors. Bray-Curtis (1957) similarities were used to calculate the similarity matrices for the multivariate PERMANOVA analyses and NMS ordinations.

3. RESULTS

3.1. Site climate

Prior to weir pool raising in August 2015, daily maximum temperatures at all sites were cool to moderate (13– 25ºC) and steadily increased across the following months, where many days temperatures exceeded 40ºC during the summer months (December, January and February). In particular, it was a very hot spring, especially in October where temperatures often exceeded 35 ºC (Figure 6a, b and c).

At Woolenook Bend there was no rainfall in July 2015 preceding weir pool raising, but monthly rainfall totals for August and September 2015 ranged from 16–26 mm, while rainfall during October 2015, when water levels were 40–45 cm above NPL, was minimal (11 mm). Total monthly rainfall in November was 24.8 mm and low (<5 mm) in December 2015, as the weir pool was being lowered (Figure 6a). Rainfall in January 2016 was moderate (33.4 mm) once water levels had returned to NPL, followed by no rainfall in February 2016 when surveys were undertaken following weir pool raising (Figure 6a).

At Moorook, monthly rainfall totals for July, August and September 2015 ranged from 18–29 mm, but was minimal (<5 mm) in October 2015 (Figure 6b). Monthly rainfall total in November was 25.8 mm, but low <3 mm in December, followed by a notable rainfall event (40.3 mm) in January 2016 across a couple of days, followed by total monthly rainfall of 12 mm in February 2016 (Figure 6b).

For Big Toolunka Flat, monthly rainfall total for July 2015, prior to weir pool raising was 16.2 mm. Similarly, during August and September 2015 rainfall monthly totals ranged from 14–18 mm, respectively prior to and during weir pool raising, but was <10 mm in October 2015 when water levels had reached 50 cm above NPL (Figure 6c). The highest monthly rainfall of 52 mm recorded was at the township of Ramco (near the Big Toolunka Flat) where the majority of which (43 mm) occurred in one day (Figure 6c). Rainfall was minimal (<5 mm) in December 2015 once weir pools had returned to normal full supply level (Figure 6c). Monthly total in January 2016 was 29 mm, but scarce (<1 mm) in February 2016 (Figure 6c).

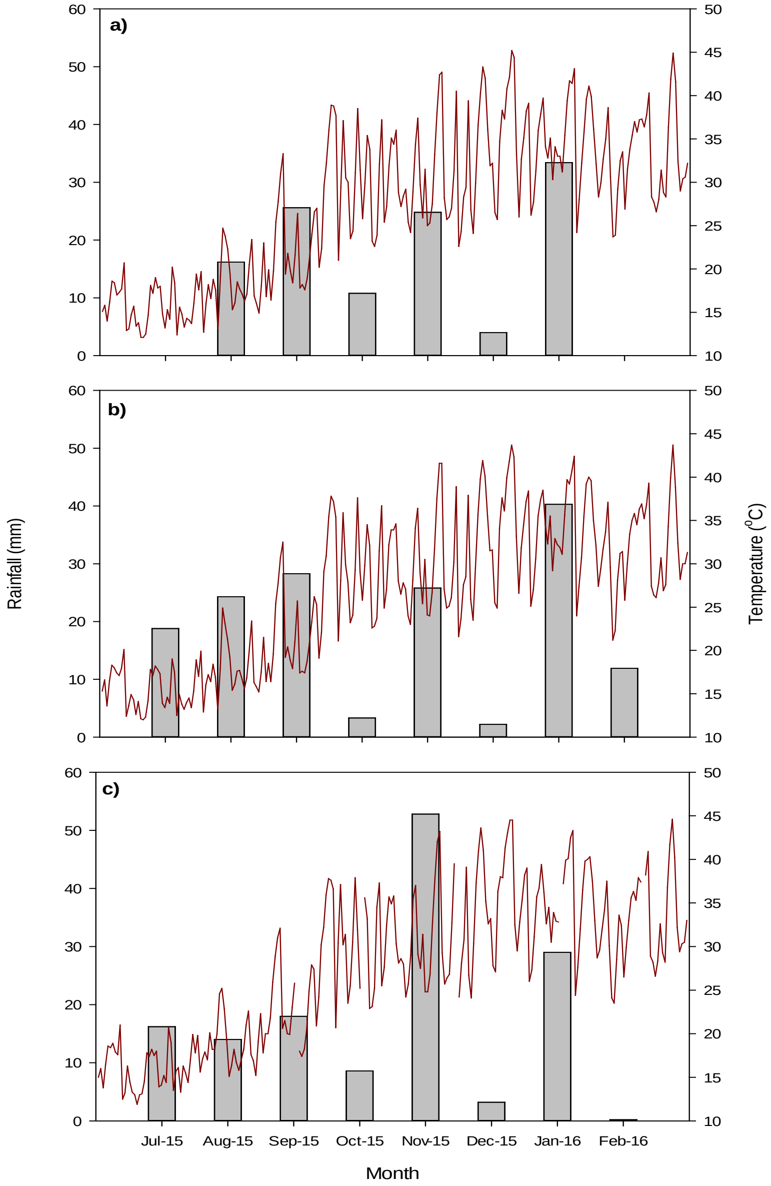

Figure 6: Daily temperatures (ºC) (red lines) and monthly rainfall totals (mm) (grey bars) for weather stations closest to a) Woolenook Bend* b) Moorook** and c) Big Toolunka Flat***. Data obtained from Bureau of Meteorology (www.bom.gov.au).

*rainfall: Renmark irrigation station number: 24003; *temperature: Renmark Aero Station number: 24048. **rainfall: Moorook station number: 24010; temperature: Loxton station number 24042. ***rainfall (Duffield Ramco station number: 24031; temperature: Gluepot Station number: 20028.

3.2. Vegetation Plot composition

The composition of the monitoring plots were assessed to quantify vegetation diversity, abundances and cover prior to weir pool raising (August 2015) and again in early February 2016, approximately 9 weeks after Weir Pool 2 had returned to within 5 cm of full supply level, and approximately 6 weeks after water levels had returned to NPL for Weir Pool 5 (Figures 1 and 2; Appendix 1, Appendix 2 and Appendix 3).

The sites varied in their vegetation diversity and structural composition (Table 2). Vegetation diversity and abundance also varied depending on position relative to river and/or wetland edges (Table 2). For instance, the Woolenook Bend (Weir Pool 5) river monitoring plot was predominantly characterised by mixed black box (*Eucalyptus largiflorens*)/river red gum (*Eucalyptus camaldulensis*) low open forest with mid stratum of lignum (*Duma florulenta*) and other chenopods and terrestrial floodplain vegetation (Table 2). The middle plot was also characterised by a dominant black box forest overstorey, with some river red gums and river cooba (*Acacia stenophylla*) present, a mid-stratum of chenopods and a ground stratum of dominant terrestrial floodplain species (Table 2). While the wetland monitoring plot was a more open black box woodland, with some river red gums and river cooba present. Lignum and nitre goosefoot (*Chenopodium nitrariaceum*) formed a dense middle stratum in the wetland monitoring plot, where a substantial proportion was recorded as dead (Table 2).

In contrast, the reference site, Moorook (Weir Pool 3) was highly variable. The first river plot was characterised by a river red gum forest, with scattered black box and river cooba trees present. Branching groundsel (*Senecio cunninghamii*) formed a dense ground stratum and a cohort of juvenile river red gums were also present (Table 2). The second river plot was characterised as a river red gum woodland, with many dead trees present (Table 2). The middle plot was dominated by an open black box woodland, with a dense ground stratum of branching groundsel and a few scattered river cooba and lignum (Table 2).

At Big Toolunka Flat (Weir Pool 2), the site was definitively a more open woodland. The river monitoring plot was characterised by a low black box woodland, with some river red gums present closer to the river’s edge. There were dense patches of lignum and some chenopods and terrestrial floodplain species present (Table 2). Similarly the middle plot was also characterised by black box low woodland and dense bands of lignum (Table 2). The wetland plot was more open, with patches of low black box woodland and lignum (Table 2).

Table 2: Summary of vegetation composition and structure for monitoring plots where weir pools were raised (Woolenook Bend and Big Toolunka Flat) and within the weir pool not raised (Moorook).

Location	Ausplot Name	SARDI Plot Name	Structural Description
Weir Pool 5 (Lock 5–6)	SAA RIV 0001	Woolenook Bend River	*Eucalyptus largiflorens* (40%)/ *Eucalyptus camaldulensis* (20%) low open forest. Mid stratum dominated by *Chenopodium nitrariaceum* with some isolated *Eremophila bignoniiflora* and *Duma florulenta*. Ground stratum of *Senecio cunninghamii, Enchylaena tomentosa* and *Disphyma crassifolium* subsp. *clavellatum*.
	SAA RIV 0002	Woolenook Bend Middle	*Eucalyptus largiflorens* (40%) mid open forest with *Eucalyptus camaldulensis* (15%). Upper Mid stratum dominated by *Acacia stenophylla* (15%) with lower mid stratum of *Chenopodium nitrariaceum* and *Atriplex nummularia*. Ground stratum sparse but dominated by *Disphyma crassifolium* subsp. *clavellatum*, *Enchylaena tomentosa* and *Tecticornia pergranulata subsp. pergranulata*
	SAA RIV 0003	Woolenook Bend Wetland	*Eucalyptus largiflorens* (20%) woodland with *Eucalyptus camaldulensis* (5%) and *Acacia stenophylla*. Mid stratum is a dense layer of *Chenopodium nitrariaceum* with *Duma florulenta*. Ground stratum sparse but dominated by *Senecio runcinifolius, Einadia nutans* and other forbs. Large proportion of dead *Chenopodium* and *Duma*.
Weir Pool 3 (Lock 3–4)	SAA RIV 0005	Moorook River	*Eucalyptus camaldulensis* (25%) mid open forest with scattered *Eucalyptus largiflorens* (5%) and isolated *Acacia stenophylla*. A dense ground stratum of *Senecio cunninghamii* with *Cyperus gymnocaulos* and a cohort of juvenile *E. camaldulensis*.
	SAA RIV 0006	Moorook River 2	*Eucalyptus camaldulensis* (7%) low woodland. A dense ground stratum of *Senecio cunninghamii* with *Cyperus gymnocaulos*. Many dead trees.
	SAA RIV 0004	Moorook Middle	*Eucalyptus largiflorens (*10%) low woodland with a dense ground stratum of *Senecio cunninghamii* and *Myoporum parvifolium.* A few scattered *Acacia stenophylla* and *Duma florulenta*.
Weir Pool 2 (Lock 1– 2)	SAA RIV 0008	Big Toolunka Flat River	*Eucalyptus largiflorens* (12%) low woodland with *Eucalyptus camaldulensis* (2%) along south western edge. Dense mid stratum of *Duma florulenta*. Ground stratum dominated by *Enchylaena tomentosa* with *Atriplex stipitata*. *Duma florulenta* and *E. largiflorens* forming alternating bands through the site.
	SAA RIV 0007	Big Toolunka Flat Middle	*Eucalyptus largiflorens* (15%) low woodland with a dense mid stratum of *Duma florulenta*. *D. florulenta* and E. *largiflorens* forming alternating bands through the site. Ground stratum sparse but dominated by *Atriplex stipitata* and *Einadia nutans*.
	SAA RIV 0009	Big Toolunka Flat Wetland	*Eucalyptus largiflorens* (5%) low open woodland. A mid-stratum dominated by *Duma florulenta*. Ground stratum sparse but dominated by *Enchylaena tomentosa var. tomentosa, Einadia nutans* and *Atriplex stipitata*

In the monitoring plots where weir pools were raised, there were generally minimal changes (+/- 5 %) in the proportion of bare and/or dead, understorey or canopy abundances before and after weir pool raising. An exception was the Woolenook Bend river monitoring plot, where there were less bare/dead points intercepted and an increase (~15%) in the interception of live canopy cover (Table 3). There was also a similar increase in canopy cover in the Woolenook Bend middle plot, but to a lesser extent (~8%) (Table 3).

Within the monitoring plots at Moorook, where the weir pool was not raised, there were similarly minimal changes in the proportions of bare and/or dead, understorey or canopy abundances before and after weir pool raising (Table 3).

Table 3: Proportion of points intercepted where the uppermost strata was either: non-photosynthetic (bare substrate and/or dead vegetation only), understorey only (i.e. no live canopy) or live canopy (although understorey may be present) for each monitoring plot where weir pools were raised (Woolenook Bend and Big Toolunka Flat) and within the weir pool not raised (Moorook).

Site Name	% bare substrate and/or dead vegetation		% live understorey only		% live canopy	
	Aug-15	Feb-16	Aug-15	Feb-16	Aug-15	Feb-16
Woolenook Bend River	27.60	15.00	9.20	6.30	63.21	78.70
Woolenook Bend Middle	24.26	22.70	15.84	9.60	59.90	67.70
Woolenook Bend Wetland	41.39	43.40	22.18	18.40	36.43	38.20
Moorook River	20.10	19.00	48.20	45.50	31.70	35.50
Moorook Middle	39.50	29.8	48.22	56.9	12.28	13.3
Moorook River 2	26.63	25	62.57	63.3	10.80	11.7
Big Toolunka Flat River	55.94	54.4	30.30	31.3	13.76	14.3
Big Toolunka Flat Middle	31.58	27.3	53.47	56.6	14.95	16.1
Big Toolunka Flat Wetland	65.89	60.8	22.84	25.2	11.27	14.0

3.3. Trees

Tree crown condition

PERMANOVA analyses comparing changes in TCI (tree condition index) scores before, during and after weir pool raising at Big Toolunka Flat, Woolenook Bend and Moorook indicate that the responses of trees varied between survey trips, sites and the distances trees were located from either the river and/or wetland edges. The significant Survey trip × Site interaction indicated that TCI scores for woodland trees varied across surveys, but patterns of variation were not consistent between sites (Table 4). Prior to the weir pool raising, the TCI scores indicate that the trees at Woolenook Bend had sparse–medium crown densities and extents (Figure 7a; Appendix 6). In contrast, the TCI scores for Big Toolunka Flat and Moorook suggest trees were in slightly better condition, with medium crown extents and densities (Figure 7b and c; Appendix 6).

During weir pool raising, trees at Big Toolunka Flat and Woolenook Bend showed an increase in TCI scores (and hence improvements in crown extent/densities) across all distance categories; whereas TCI scores for trees at Moorook, where the weir pool was not raised, remained largely unchanged (Figure 7a, b and c).

After weir pool raising, trees at Big Toolunka Flat showed significantly decreased TCI scores for trees located less than 150 m from the river edge from TCI scores observed during weir pool raising; although TCI scores for trees located less than 150 m of the wetland edge were unchanged (Figure 7b). For trees within Woolenook Bend, TCI scores did not change significantly during and after weir pool raising (Figure 7a) indicating that improvements in crown extent/densities following weir pool raising were maintained. Within Moorook, TCI scores for woodland trees remained largely unchanged across the entire study period, with the exception of trees located less than 80 m from the river's edge which showed a slight, but not significant, improvement in TCI scores in February 2016 (Figure 7c).

Table 4: PERMANOVA results comparing TCI (tree condition index) scores of woodland trees at Big Toolunka Flat, Woolenook Bend (weir pools raised 50 cm and 45 cm respectively) and Moorook (weir pool not raised) between August 2015 (before raising), October 2015 (during raising) and February 2016 (after raising) at increasing distances from either the river and/or wetland edges (df = degrees of freedom; p-value = probability value, α = 0.05).

Factor	***dF***	***Pseudo-F***	***p-value***
Survey Trip	2, 404	34.22	***0.001***
Site	2, 404	2.96	0.125
Distance (site)	11, 404	22.16	***0.001***
Trip × Site	4, 404	12.19	***0.001***
Trip × Distance (site)	22, 404	0.49	0.97

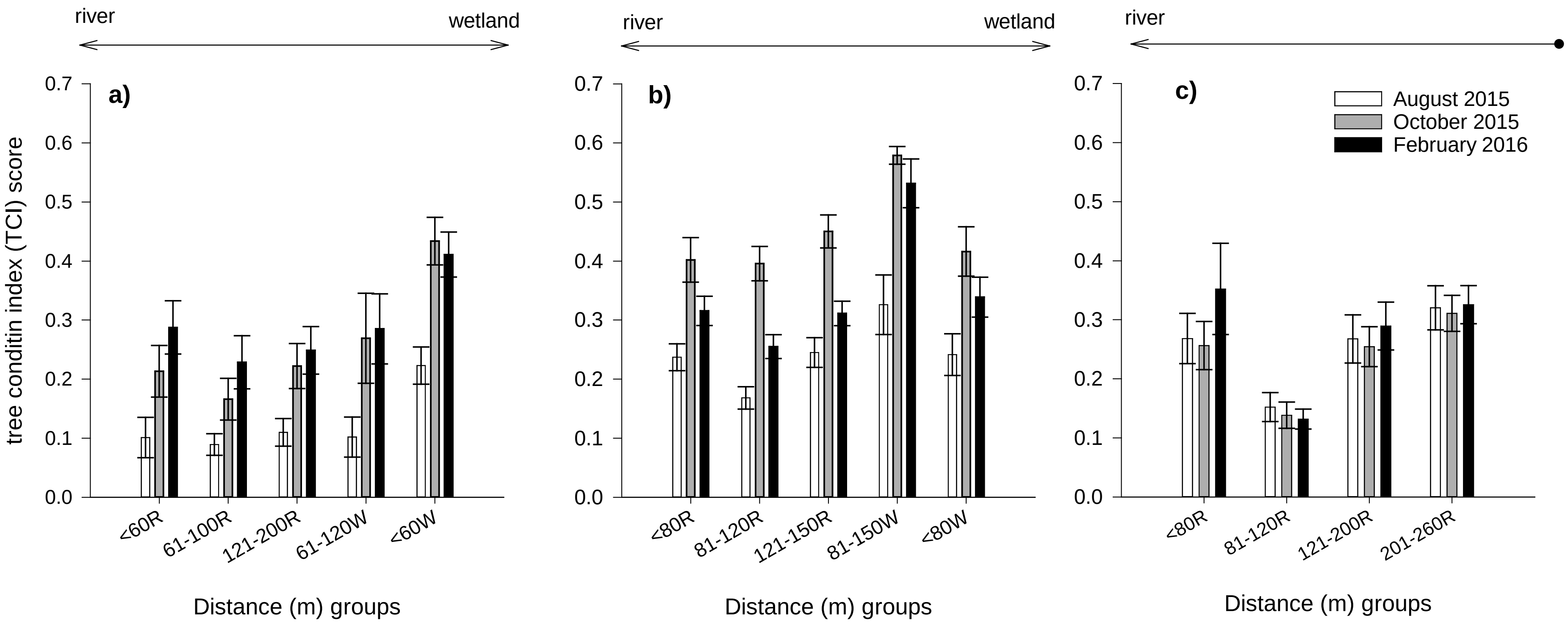

Figure 7: Comparison of mean ± S.E. TCI (tree condition index) scores for trees along increasing distances from river and/or wetland edges (n.b. distance categories varied between sites, see Table 1) at the managed a) Woolenook Bend, b) Big Toolunka Flat sites and unmanaged c) Moorook site between August 2015 (before raising), October 2015 (during raising) and February 2016 (after raising).

Tree water status

Comparisons of the relative changes in predawn water potential measurements ($\Delta\Psi_{predawn}$) a) before and during weir pool raising and b) before and after weir pool raising indicate that there were significant differences between sites and the distances trees were located from either the river and/or wetland edges (Table 5; Figure 8). Overall, across the entire study period, $\Psi_{predawn}$ measurements were generally more negative (i.e. lower water status) in the manipulated weir pools (Big Toolunka Flat and Woolenook Bend) compared to the $\Psi_{predawn}$ measurements of woodland trees within the weir pool that was not raised (Moorook site) (Figure 8a, b and c).

A comparison of relative changes in $\Psi_{predawn}$ of the trees in Woolenook Bend before and during the weir pool raising indicate that there was a significant improvement in water status for trees located within 60 m of the wetland edge, but no significant changes for trees located elsewhere within the site (Figure 8a). After weir pool raising, there was a significant decline in $\Psi_{predawn}$ for trees located within 60 m of the river's edge to values lower than those measured in August 2015, but no significant difference $\Delta\Psi_{predawn}$ for trees located elsewhere within the site (Figure 8a and b).

The most significant changes in $\Psi_{predawn}$ were observed in Big Toolunka Flat, where trees showed a trend for slight improvement in water status during the weir pool raising, but significant improvements for trees located within 81–150 m of the river's edge and less than 80 m from the wetland's edge (Figure 8b). However, a comparison of relative changes in $\Psi_{predawn}$ before and after weir pool raising then showed decreasing water status, with significant declines in $\Psi_{predawn}$ recorded for trees across all distances from river and/or wetland edges to $\Psi_{predawn}$ measurements lower than those observed in August 2015 (Figure 8b).

Within Moorook, where the weir pool was not raised, $\Delta\Psi_{predawn}$ measurements were minor. There were improvements in water status for all trees in October 2015, but after the weir pool raising event this improvement was only maintained in trees located within 81–120 m of the river's edge by February 2016; whereas $\Psi_{predawn}$ measurements for all other trees were once again similar to measurements observed in August 2015 (Figure 8c).

Table 5: PERMANOVA results comparing change in predawn water potentials ($\Delta\Psi_{predawn}$, MPa) of woodland trees at Big Toolunka Flat, Woolenook Bend (weir pools raised 50 cm and 45 cm respectively) and Moorook (weir pool not raised) between August 2015 and October 2015 (before and during weir pool raising) and between August 2015 and February 2016 (before and after weir pool raising) at increasing distances from either the river and/or wetland edges (df = degrees of freedom; p-value = probability value, α = 0.05).

Time	**Factor**	***dF***	***Pseudo-F***	***p-value***
Before and during weir pool raising (survey trip 1 and 2)	Site	2, 267	5.71	***0.003***
	Distance (site)	11, 267	2.42	***0.013***
Before and after weir pool raising (survey trip 1 and 3)	Site	2, 267	28.66	***0.001***
	Distance (site)	11, 267	3.19	***0.002***

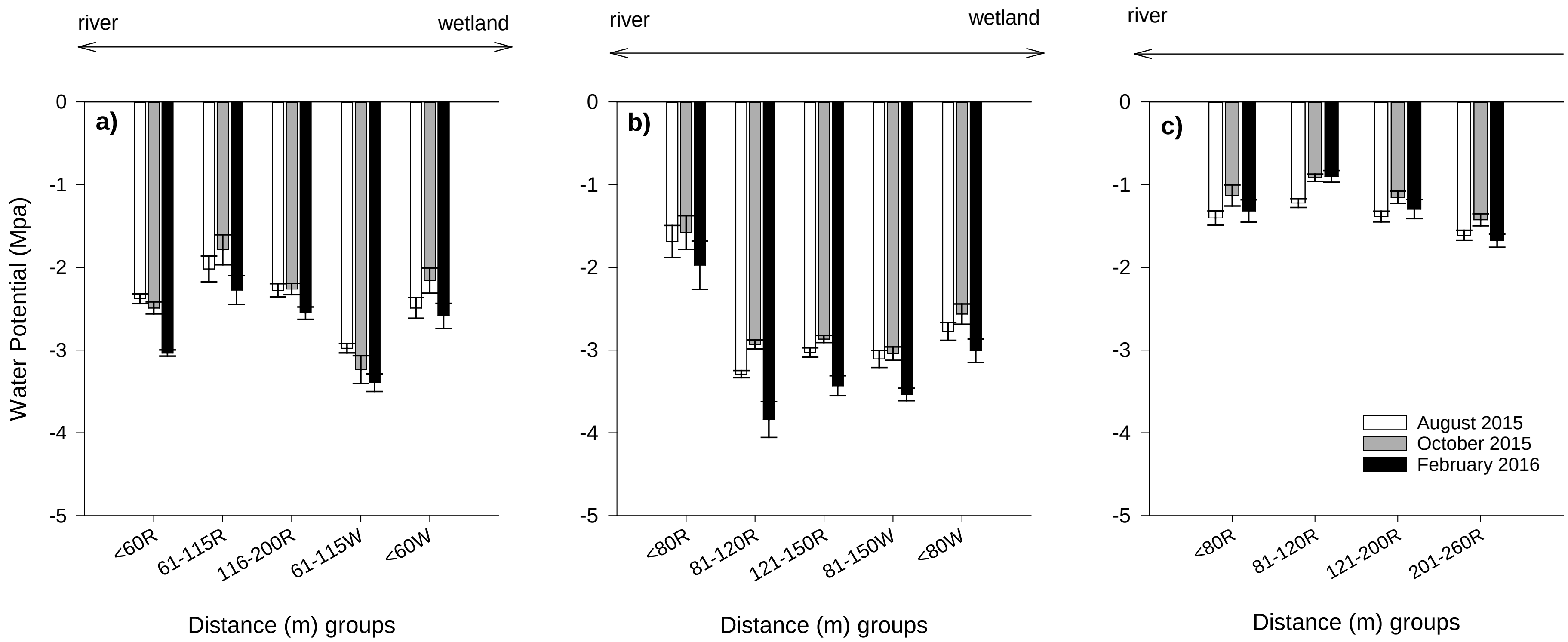

Figure 8: Comparison of mean ± S.E. predawn water potential ($\Delta\Psi_{predawn}$, MPa) for woodland trees along increasing distances from river and/or wetland edges (n.b. distance categories varied between sites, see Table 1) at the managed a) Woolenook Bend and b) Big Toolunka Flat sites and unmanaged c) Moorook site between August 2015 (before raising), October 2015 (during raising) and February 2016 (after raising).

Canopy cover: Plant Area Index

Comparisons of the changes in PAI (plant area index) before, during and after weir pool raising indicate that there were significant differences between sites and the distances that the hemispherical view canopy photopoints were located from either the river and/or wetland edges (Table 6; Figure 9). At the site level, Woolenook Bend in general had a higher PAI, reflecting significantly greater canopy cover compared to the other sites; Big Toolunka Flat and Moorook (Figure 9a, b and c).

Within Woolenook Bend, PAI was highest, and relatively consistent, within 200 m from the river edge compared to PAI of the area located within 120 m of the wetland edge (Figure 9a). A similar trend was observed at Moorook, where PAI was greater within 120 m of the river's edge, but decreased within increasing distance from the river's edge (Figure 9c). In contrast, the PAI at Big Toolunka Flat was the lowest within 80 m of the river's edge, but then increased within increasing distance from the river (up to 150 m distance). However, PAI for the area closest to the wetland was slightly greater, but decreased with increasing distance from the wetland's edge (Figure 9b), highlighting the variability within the site.

There were no significant differences detected in PAI between survey trips, although a trend of increasing PAI for trees within 60 m of the river's edge at Woolenook Bend can be seen (Figure 9a).

Table 6: PERMANOVA results comparing PAI (plant area index) of canopy cover at Big Toolunka Flat, Woolenook Bend (weir pools raised 50 cm and 45 cm respectively) and Moorook (weir pool not raised) between August 2015 (before raising), October 2015 (during raising) and February 2016 (after raising) at increasing distances from either the river and/or wetland edges (df = degrees of freedom; p-value = probability value, α = 0.05).

Factor	***DF***	***Pseudo-F***	***p-value***
Survey Trip	2, 430	1.10	0.326
Site	2, 430	14.03	***0.001***
Distance (site)	11, 430	164.33	***0.001***
Trip × Site	4, 430	2.32	0.103
Trip × Distance (site)	22, 430	0.23	1

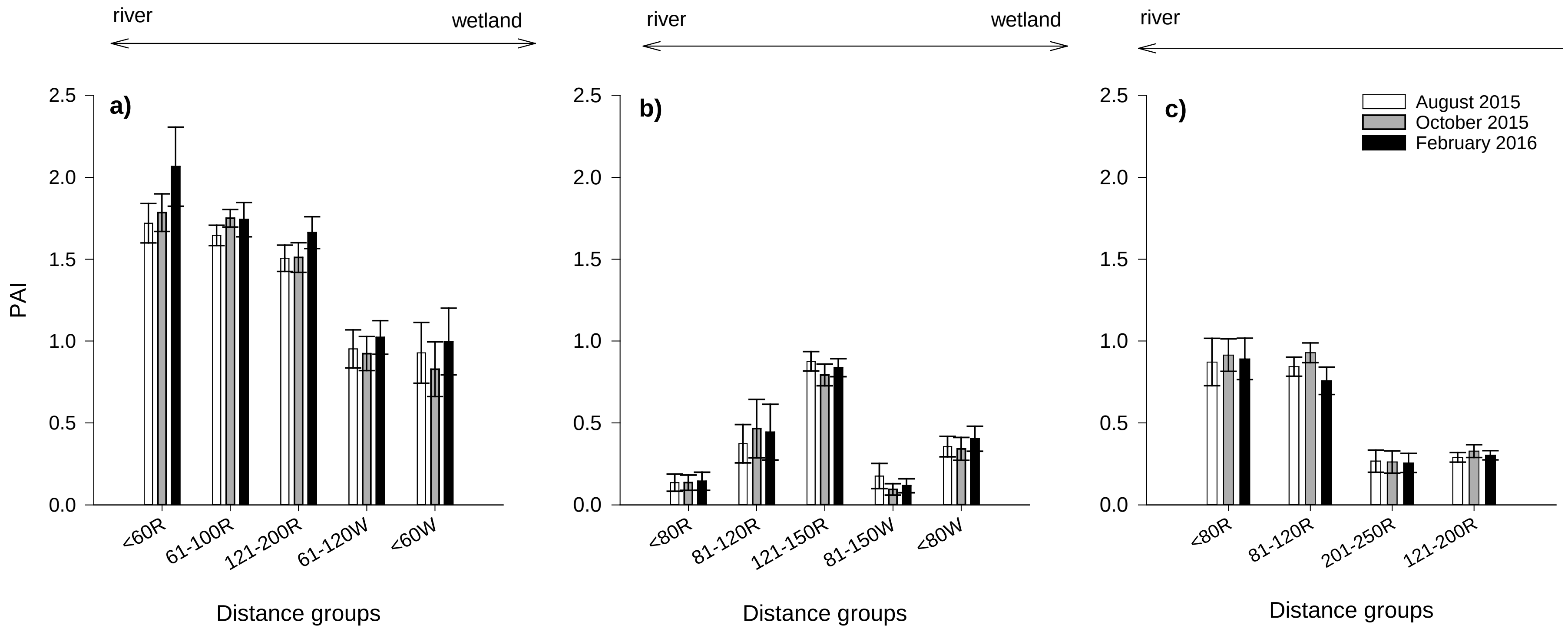

Figure 9: Comparison of mean ± S.E. plant area index (PAI) for woodland tree canopy cover along increasing distances from river and/or wetland edges (n.b. distance categories varied between sites, see Table 1) at the managed a) Woolenook Bend and b) Big Toolunka Flat sites and unmanaged c) Moorook site between August 2015 (before raising), October 2015 (during raising) and February 2016 (after raising).

3.4. Wetland littoral vegetation

PERMANOVA analyses and NMS ordinations comparing the change in the plant community between August 2015 and February 2016 at individual elevations at Woolenook Bend, Big Toolunka Flat and Moorook showed that there were significant differences between wetlands (Table 7, Figure 10-16). At the low elevations (normal pool level to 20 cm above normal pool level) there were no significant interactions between wetland and survey trip (Table 7), which suggests that there was no significant effect of weir pool raising on understorey vegetation at these elevations. However, at the higher elevations (30 to 60 cm above normal pool level) there was a significant interaction between survey trip and wetland (Table 7), which suggests that the response of the vegetation over the study period was different between sites and survey trips at these elevations. The significant interaction detected at these elevations is most likely due to changes in the plant community brought about by inundation at Woolenook Bend and Big Toolunka Flat (Figure 17, Figure 18Figure 19).

Table 7: PERMANOVA results comparing the understorey wetland plant communities at Big Toolunka Flat, Woolenook Bend (weir pools were raised 50 cm and 45 cm respectively) and Moorook (weir pool not raised) between August 2015 (before weir pool raising) and February 2016 (after weir pool raising) at normal pool level and 10, 20, 30, 40, 50 and 60 cm above normal pool level. (df = degrees of freedom; p-value = probability value, α = 0.05).

Elevation	Factor	*df*	*Pseudo-F*	*p-value*
Pool level	Wetland	2, 17	6.36	***0.027***
	Survey Trip	1, 17	1.96	0.097
	Wetland x Survey Trip	2, 17	1.82	0.074
+10 cm	Wetland	2, 17	6.41	***0.045***
	Survey Trip	1, 17	1.86	0.109
	Wetland x Survey Trip	2, 17	1.87	0.064
+20 cm	Wetland	2, 17	7.39	***0.017***
	Survey Trip	1, 17	1.94	0.081
	Wetland x Survey Trip	2, 17	1.53	0.125
+30 cm	Wetland	2, 17	7.44	***0.019***
	Survey Trip	1, 17	3.34	***0.02***
	Wetland x Survey Trip	2, 17	2.58	***0.014***
+40 cm	Wetland	2, 17	7.15	***0.022***
	Survey Trip	1, 17	2.23	0.051
	Wetland x Survey Trip	2, 17	1.91	***0.048***
+50 cm	Wetland	2, 17	8.54	***0.036***
	Survey Trip	1, 17	2.27	0.056
	Wetland x Survey Trip	2, 17	2.29	***0.038***
+60 cm	Wetland	2, 17	7.32	***0.024***
	Survey Trip	1, 17	4.95	***0.004***
	Wetland x Survey Trip	2, 17	4.54	***0.002***

NMS ordination showed that there was change in the plant community at Big Toolunka Flat and Woolenook Bend before and after weir pool raising (except at 60 cm above normal pool level) but there was no clear pattern of change at Moorook (Figure 10 to Figure 19). The large differences in the plant community between wetlands often obscured significant differences within sites and the significant interaction between wetland and survey trips, which was the case for the elevations 30, 40, 50 and 60 cm above normal pool level (Figure 10). However, when ordinations for each wetland were undertaken separately there were clear patterns of change at Big Toolunka Flat (Figure 17) and Woolenook Bend (Figure 18) but not at Moorook (Figure 19).

The species that drove the change in plant community between survey trips at Big Toolunka Flat were typically floodplain or amphibious species (*Stemodia florulenta, Glycyrrhiza acanthocarpa, Ludwigia peploides, Samolus repens*) and the parasite *Cuscuta campestris* (Appendix 5a). All of the aforementioned species were absent in August 2015 and present in February 2016 (Appendix 5a). In addition, there were several winter annuals (*Lactuca serriola, Conyza bonariensis, Daucus glochidiatus, Medicago* spp. and *Vicia sativa*) that were present in August 2015 but absent in February 2016 (Appendix 5a).

Similar to Big Toolunka Flat, at Woolenook Bend there were several amphibious and floodplain species (*Alternanthera denticulata, Crassula sieberana, Erodium cicutarium, Sporobolus mitchellii, Conyza bonariensis, Xanthium strumarium*) that were present in February 2016 but absent in August 2015 (Appendix 5b). However, *Centipeda minima* and *Stemodia florulenta* were present at the low elevations for both survey trips but only present in February 2016 at the high elevations (Appendix 5b) and *Ludwigia peploides* and *Myriophyllum verrucosum* were present at both surveys at the low elevations but absent at the high elevations (Appendix 5b).

In contrast, Moorook was dominated by perennial species that were present in August 2015 and February 2016 (Appendix 5c). However, there were several species (*Duma horrida, Melilotus indicus, Senecio cunninghamii, Sonchus asper* and *Teucrium racemosum*) that were present in August 2015 but absent in February 2016 (Appendix 5c). The only species that was absent in August 2015 but present in February 2016 was *Wahlenbergia fluminalis*, which was uncommon (Appendix 5c).

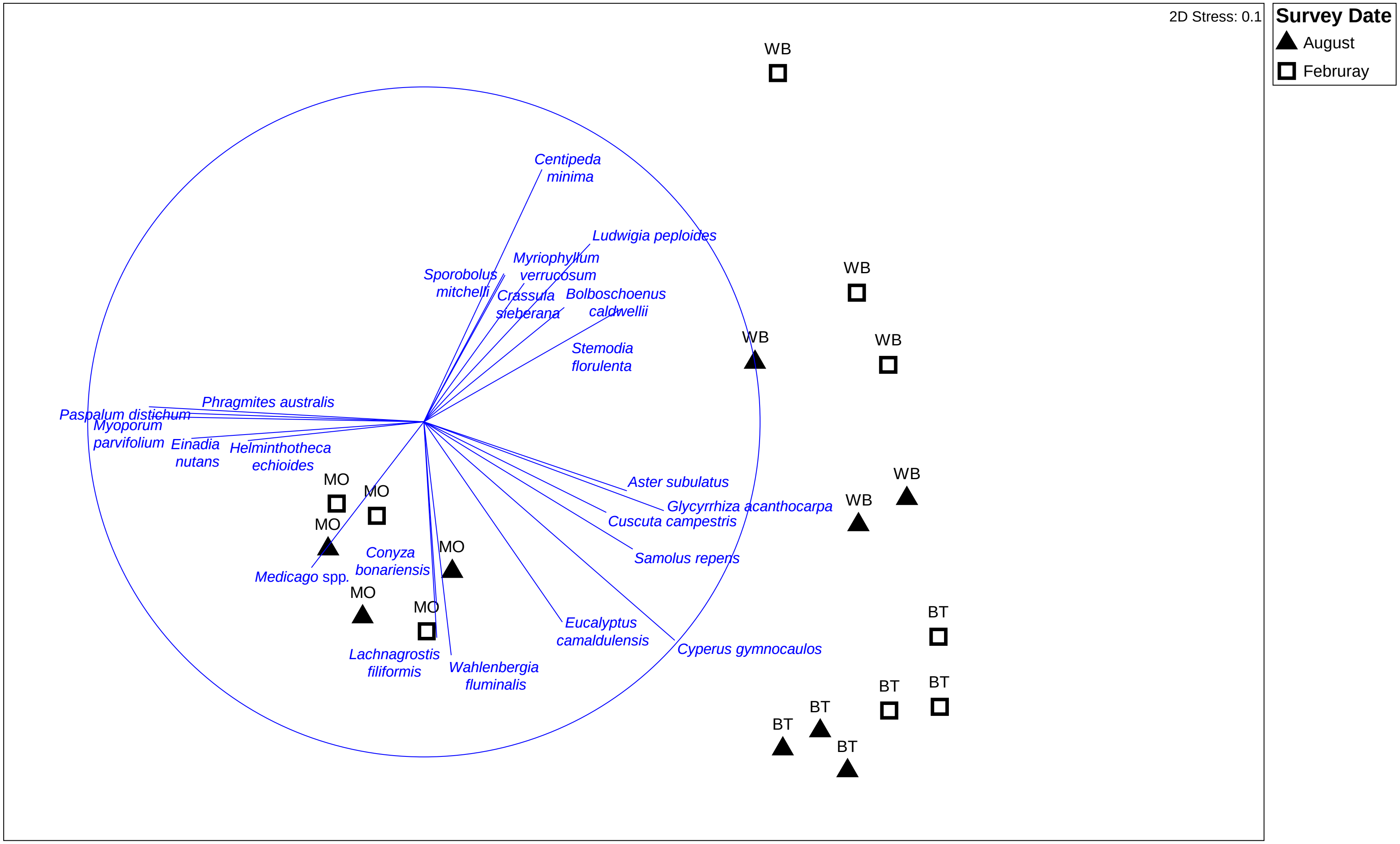

Figure 10: NMS ordination comparing wetland plant community at normal pool level at Big Toolunka Flat (BT), Woolenook Bend (WB) (weir pools were raised 50 cm) and Moorook (MO) (weir pool was not raised) between August 2015 (before weir pool raising) and February 2016 (after weir pool raising).

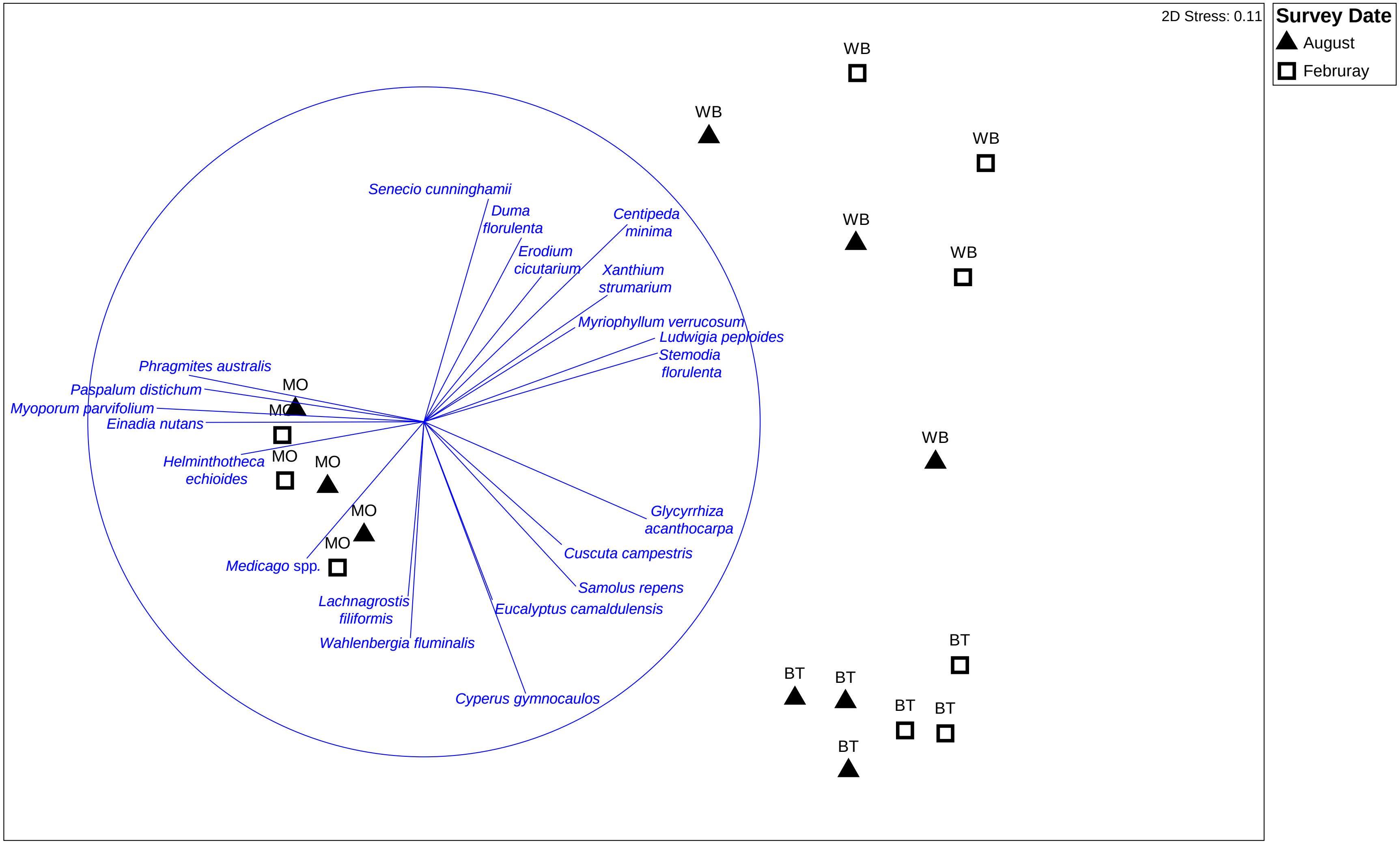

Figure 11: NMS ordination comparing wetland plant community at 10 cm above normal pool level at Big Toolunka Flat (BT), Woolenook Bend (WB) (weir pools were raised 50 cm) and Moorook (MO) (where pool was not raised) between August 2015 (before weir pool raising) and February 2016 (after weir pool raising).

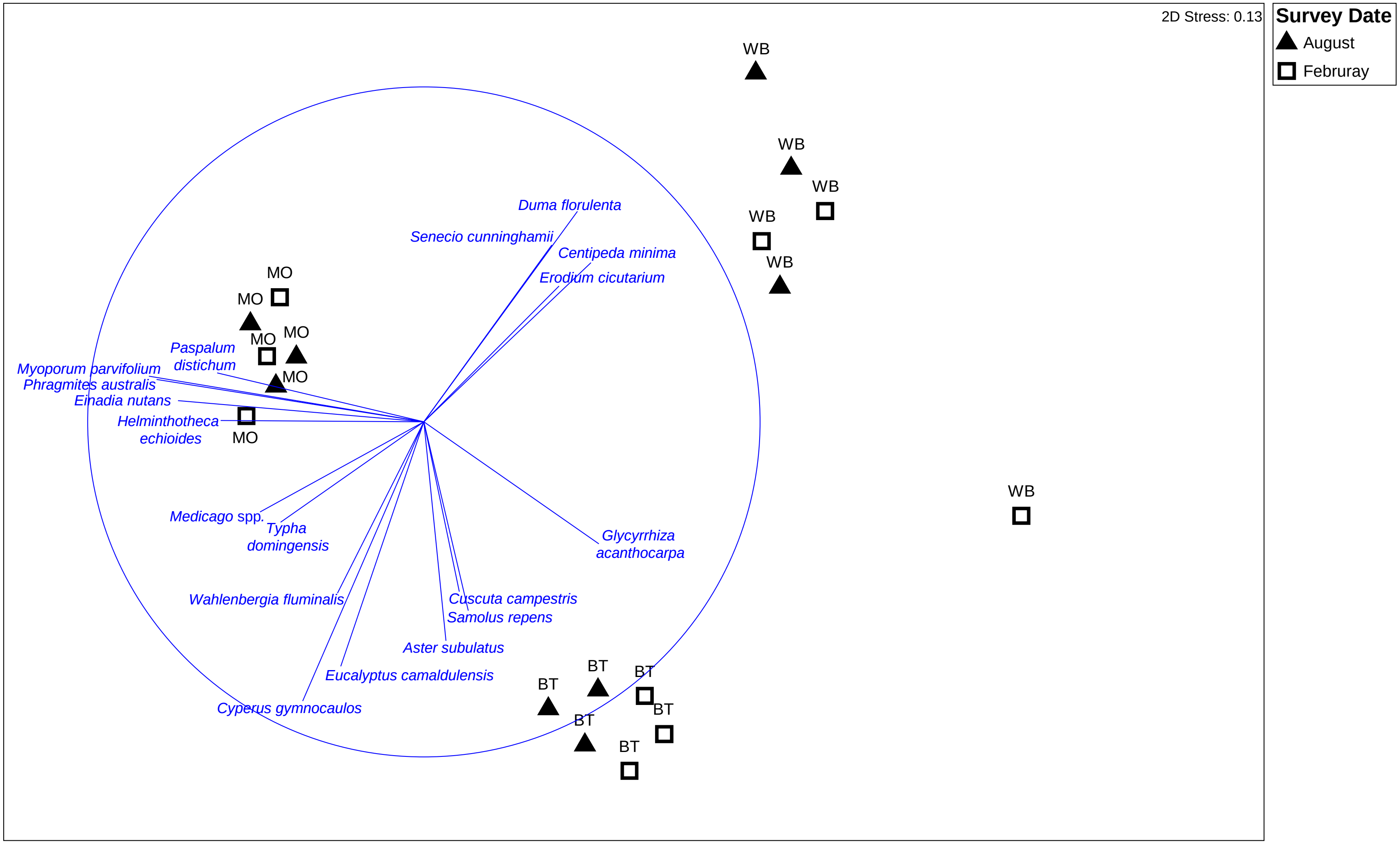

Figure 12: NMS ordination comparing wetland plant community at 20 cm above normal pool level at Big Toolunka Flat (BT), Woolenook Bend (WB) (weir pools were raised 50 cm) and Moorook (MO) (weir pool was not raised) between August 2015 (before weir pool raising) and February 2016 (after weir pool raising).

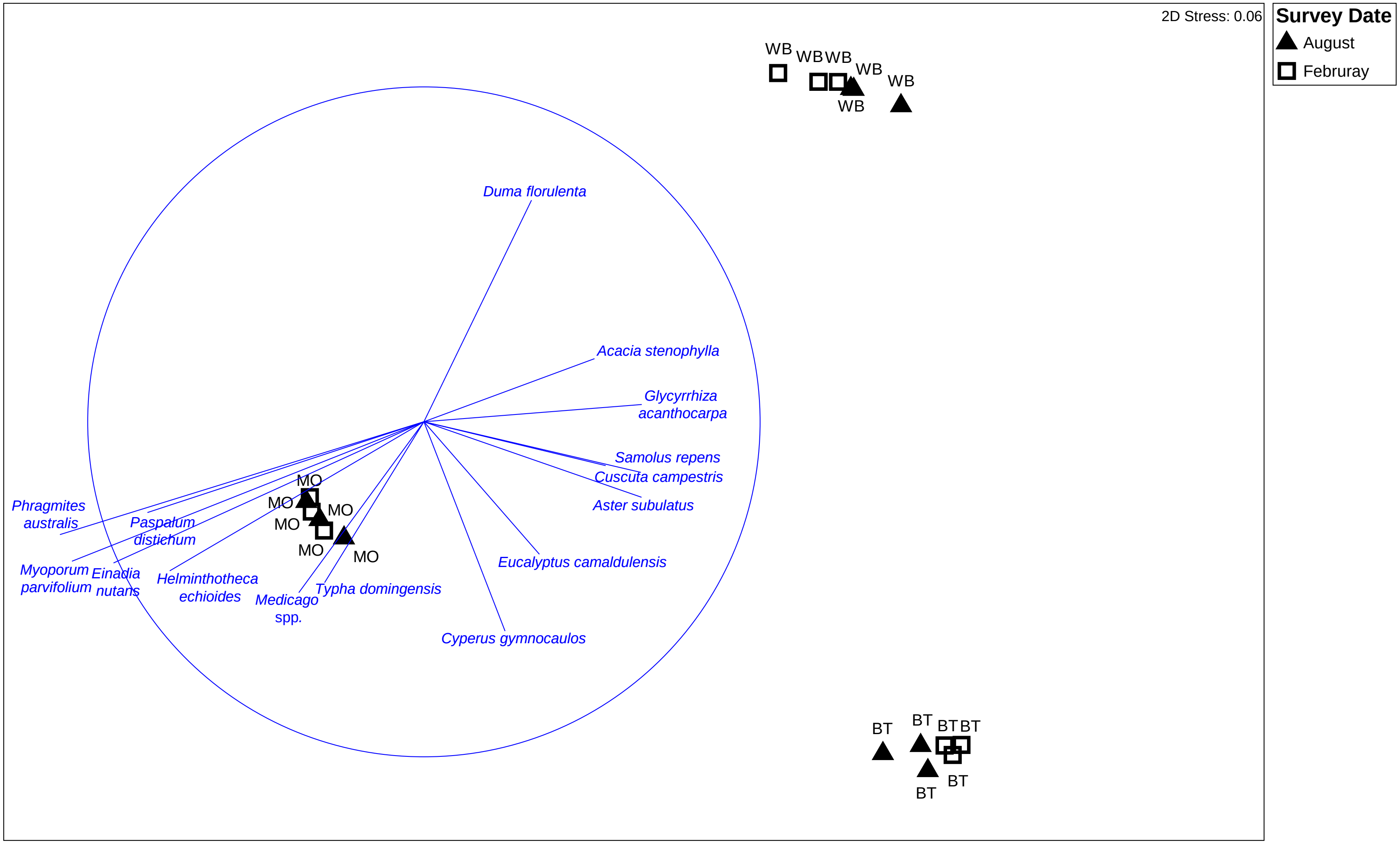

Figure 13: NMS ordination comparing wetland plant community at 30 cm above normal pool level at Big Toolunka Flat (BT), Woolenook Bend (WB) (weir pools were raised 50 cm) and Moorook (MO) (weir pool was not raised) between August 2015 (before weir pool raising) and February 2016 (after weir pool raising).

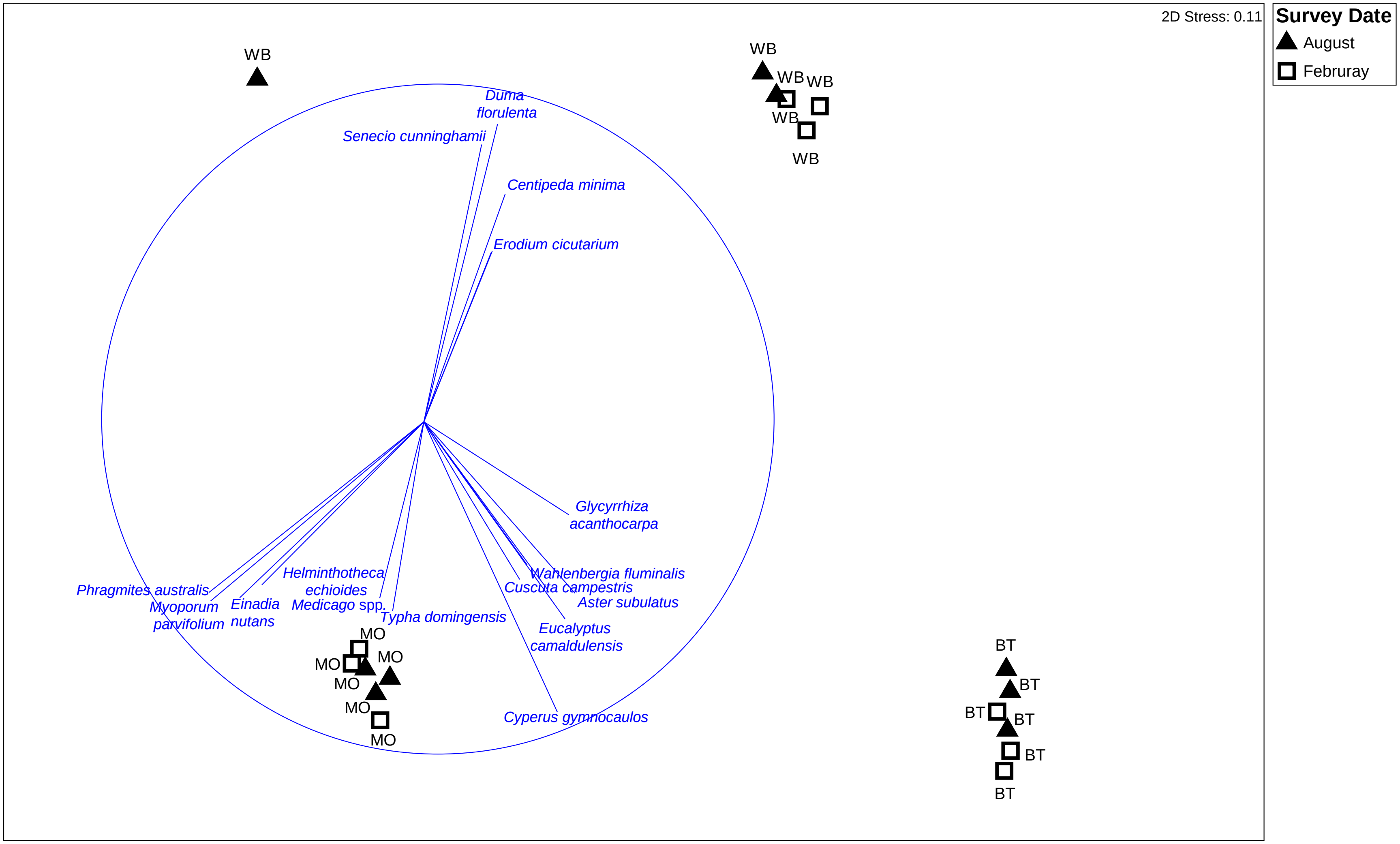

Figure 14: NMS ordination comparing wetland plant community at 40 cm above normal pool level at Big Toolunka Flat (BT), Woolenook Bend (WB) (weir pools were raised 50 cm) and Moorook (MO) (weir pool was not raised) between August 2015 (before weir pool raising) and February 2016 (after weir pool raising).

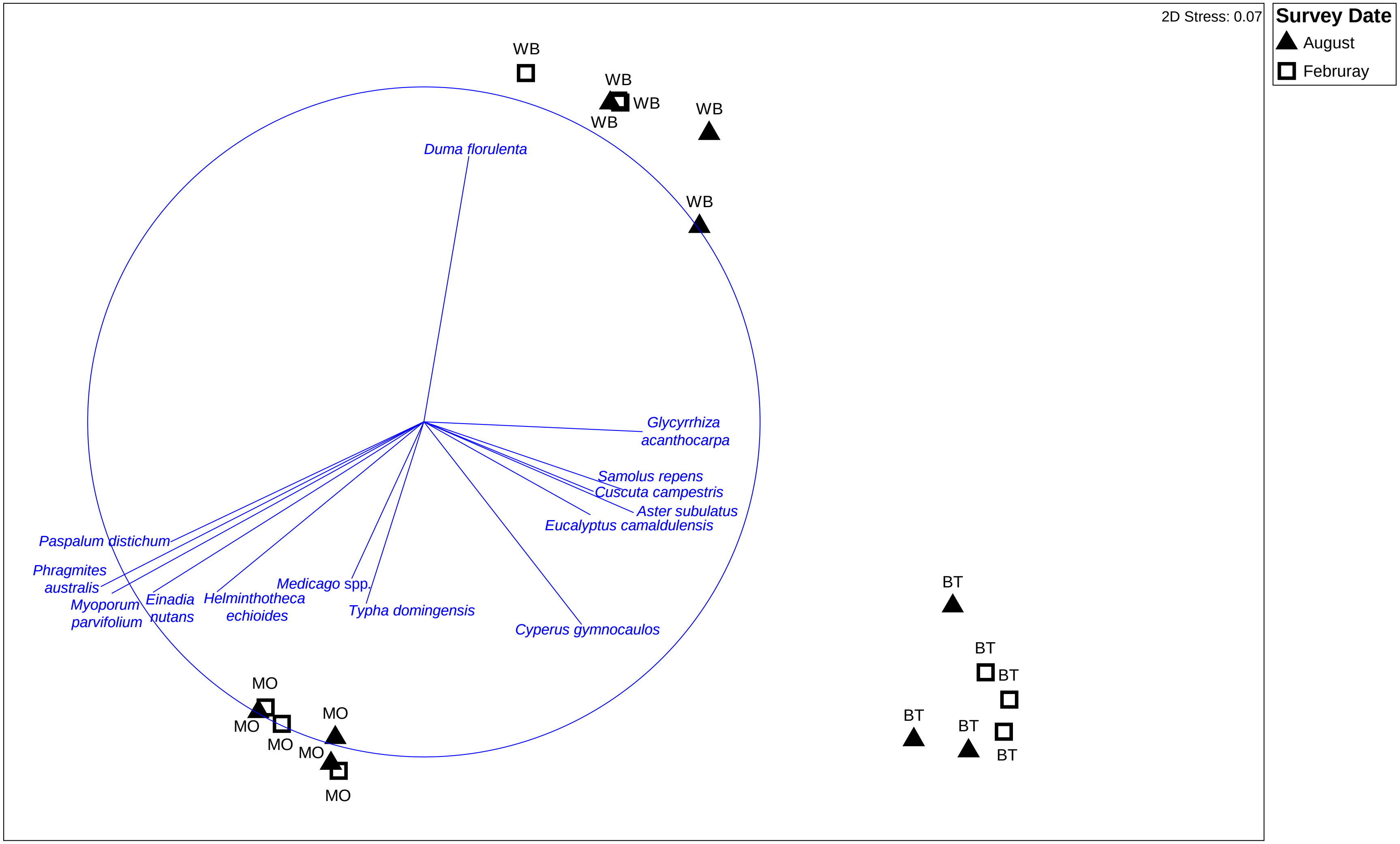

Figure 15: NMS ordination comparing wetland plant community at 50 cm above normal pool level at Big Toolunka Flat (BT), Woolenook Bend (WB) (weir pools were raised 50 cm) and Moorook (MO) (weir pool was not raised) between August 2015 (before weir pool raising) and February 2016 (after weir pool raising).

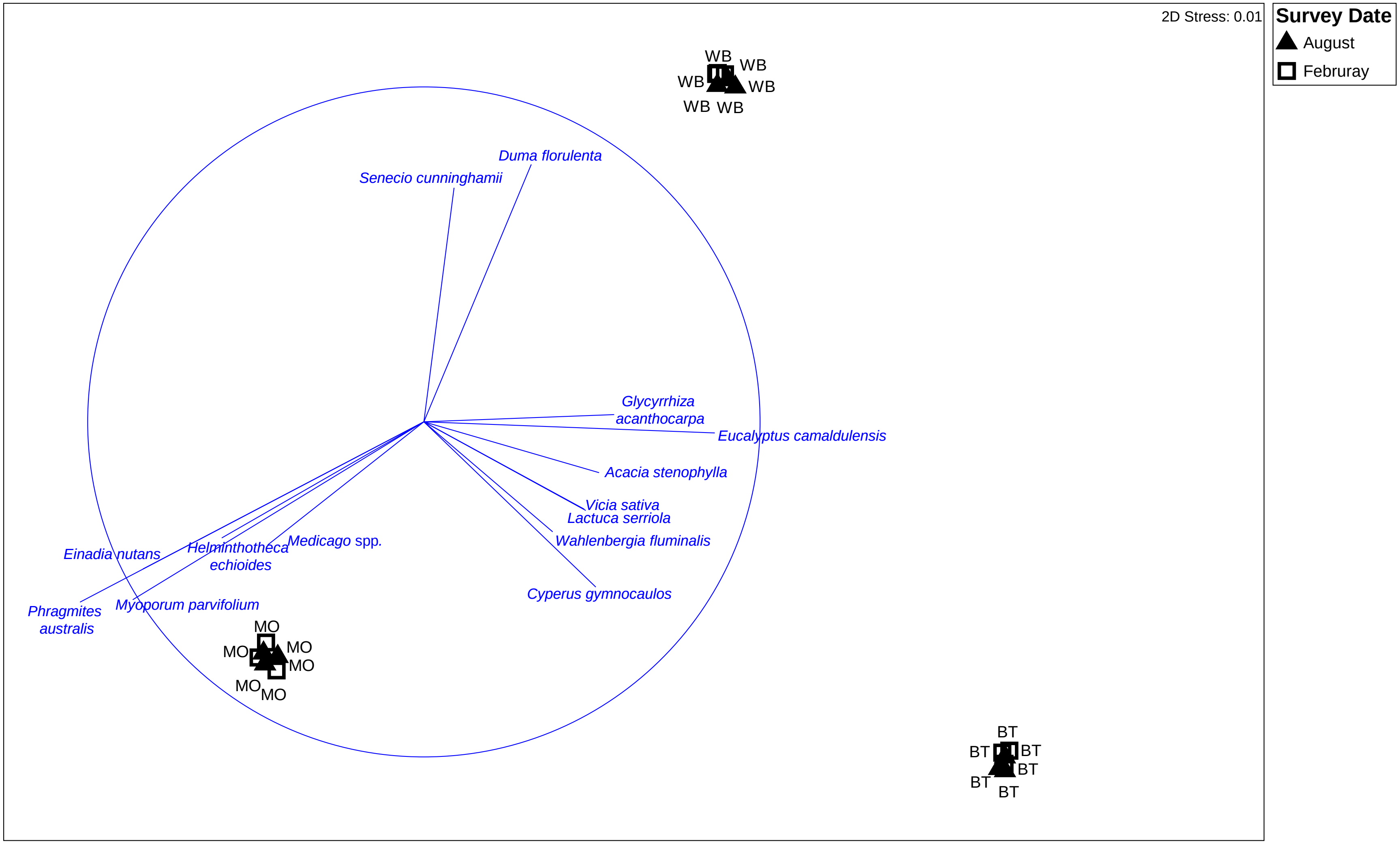

Figure 16: NMS ordination comparing wetland plant community at 60 cm above normal pool level at Big Toolunka Flat (BT), Woolenook Bend (WB) (weir pools were raised 50 cm) and Moorook (MO) (weir pool was not raised) between August 2015 (before weir pool raising) and February 2016 (after weir pool raising).

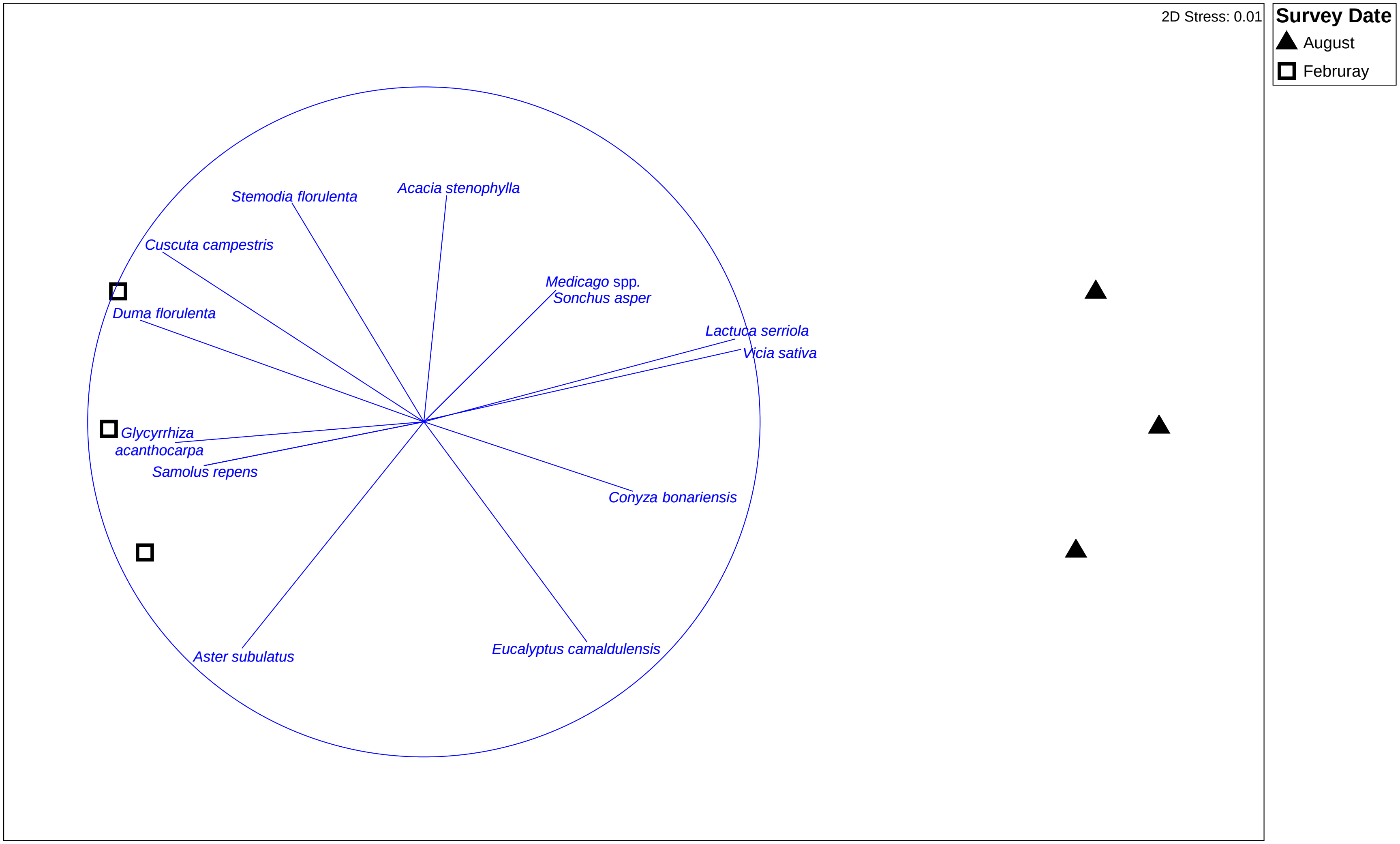

Figure 17: NMS ordination comparing wetland plant community at 60 cm above normal pool level at Big Toolunka Flat between August 2015 (before weir pool raising) and February 2016 (after weir pool raising).

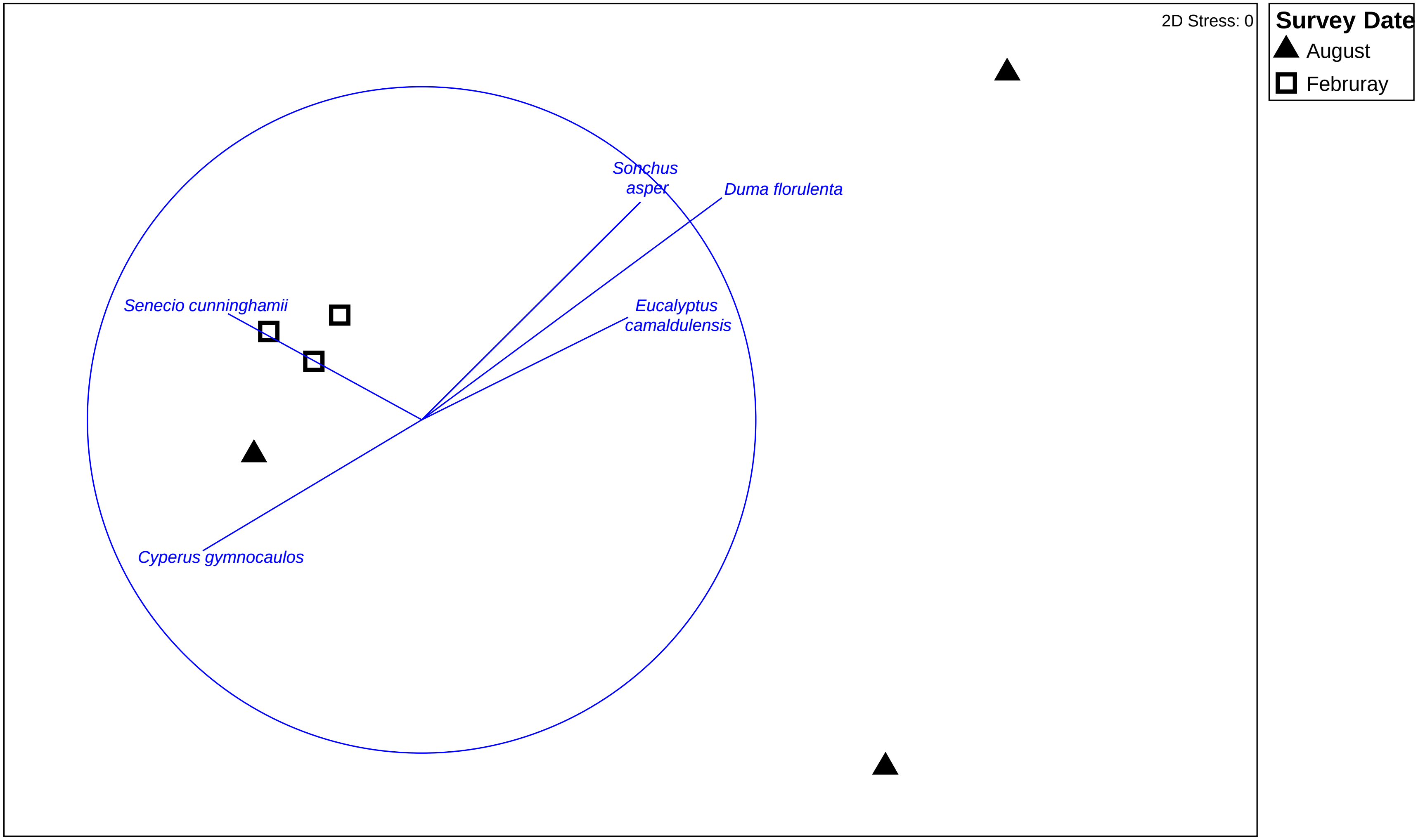

Figure 18: NMS ordination comparing wetland plant community at 60 cm above normal pool level at Woolenook Bend between August 2015 (before weir pool raising) and February 2016 (after weir pool raising).

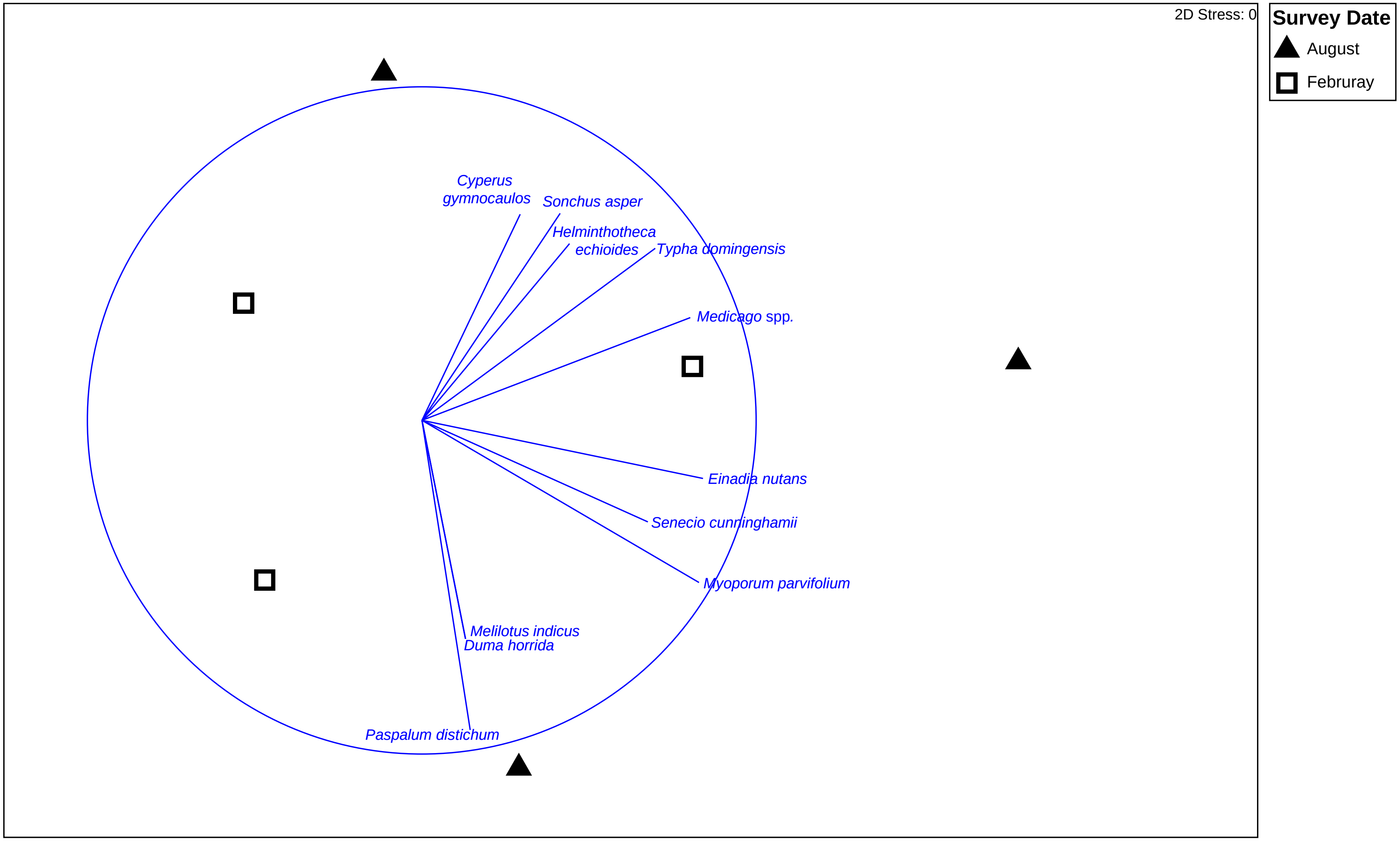

Figure 19: NMS ordination comparing wetland plant community at 60 cm above normal pool level at Moorook between August 2015 and February 2016.

3.5. Soil flux

River to floodplain soil types

The soil type within 5–30 m of the river's edge was patchy, but predominantly composed of loam and small patches of sand, although there was a clay surface layer (<50 cm) within 10–20 m from the river's edge. From 30 m to 150 m from the river's edge there was predominantly a clay surface layer (up to 150 cm deep) overlying a predominantly loamy soil (Table 8). During the survey trips, the saturated zone was generally deeper than 3 m, although at 60 m from the river's edge, the saturated zone was intercepted at 250–300 cm (Table 8).

Table 8: Table illustrating soil types throughout the soil profile (depth, cm) and increasing distance (m) from river edge at Big Toolunka Flat. L = loam, C = clay, S = sand. Blue bars represent depth that saturated zone was intercepted.

River

Depth (cm)								
0-50	L	C	C	S	C	C	C	C
50-100	L	L	L	L	C	C	C	C
100-150	L	L	S	L	L	L	L	C
150-200	L	L	S	S	C	L	L	L
200-250	L	S	S	L	L	S	L	L
250-300	L	L	L	L		L	L	L
	5	10	20	30	60	90	120	150

Distance (m)

River – floodplain soil moisture

Comparisons of soil moisture content along transects from the river's edge indicate that there was a significant Distance × Depth interaction, suggesting soil moisture varied with increasing distance and depth but patterns of variation were not consistent and there were no significant changes between survey trips (Table 9; Figure 20a, b and c) although there was a slight increase in soil moisture at depths >2.5 m within 5–10 m of the river's edge, which may reflect direct connectivity with raised water levels.

In general, the soil moisture was highly variable throughout the soil profile, but consistently lower (<0.05 to 0.015 g g^{-1}) within distances of 30 to 40 m from the river's edge and up to depths up of 2.5 m (Figure 20a, b and c) where river banks were steep. Soil moisture was also generally lower (0.10 to 0.15 g g^{-1}) at the surface (<0.5 m) across the lengths of transects (up to 150 m from river edge); however between depths of 1 to 3 m, at distances >50 m from the river's edge, soil moisture appeared consistently higher (0.20 to 0.25 g g^{-1}) (Figure 20a, b and c).

Table 9: PERMANOVA results gravimetric soil moisture content (g g^{-1}) of soil for increasing distance from river (up to 150 m) and for increasing depths (up to 3 m) at Big Toolunka Flat (Weir Pool 2) between August 2015 (before raising), October 2015 (during raising) and February 2016 (after raising) (df = degrees of freedom; p-value = probability value, α = 0.05).

Factor	***dF***	***Pseudo-F***	***p-value***
Survey Trip	2, 364	2.14	0.127
Distance	7, 364	103.76	0.001
Depth (distance)	8, 364	30.19	0.001
Survey trip × Distance	14, 364	0.65	0.823
Survey trip × Depth	10, 364	0.82	0.611
Distance × Depth	36, 364	6.5	0.001
Survey trip × Distance × Depth	69, 364	0.31	1

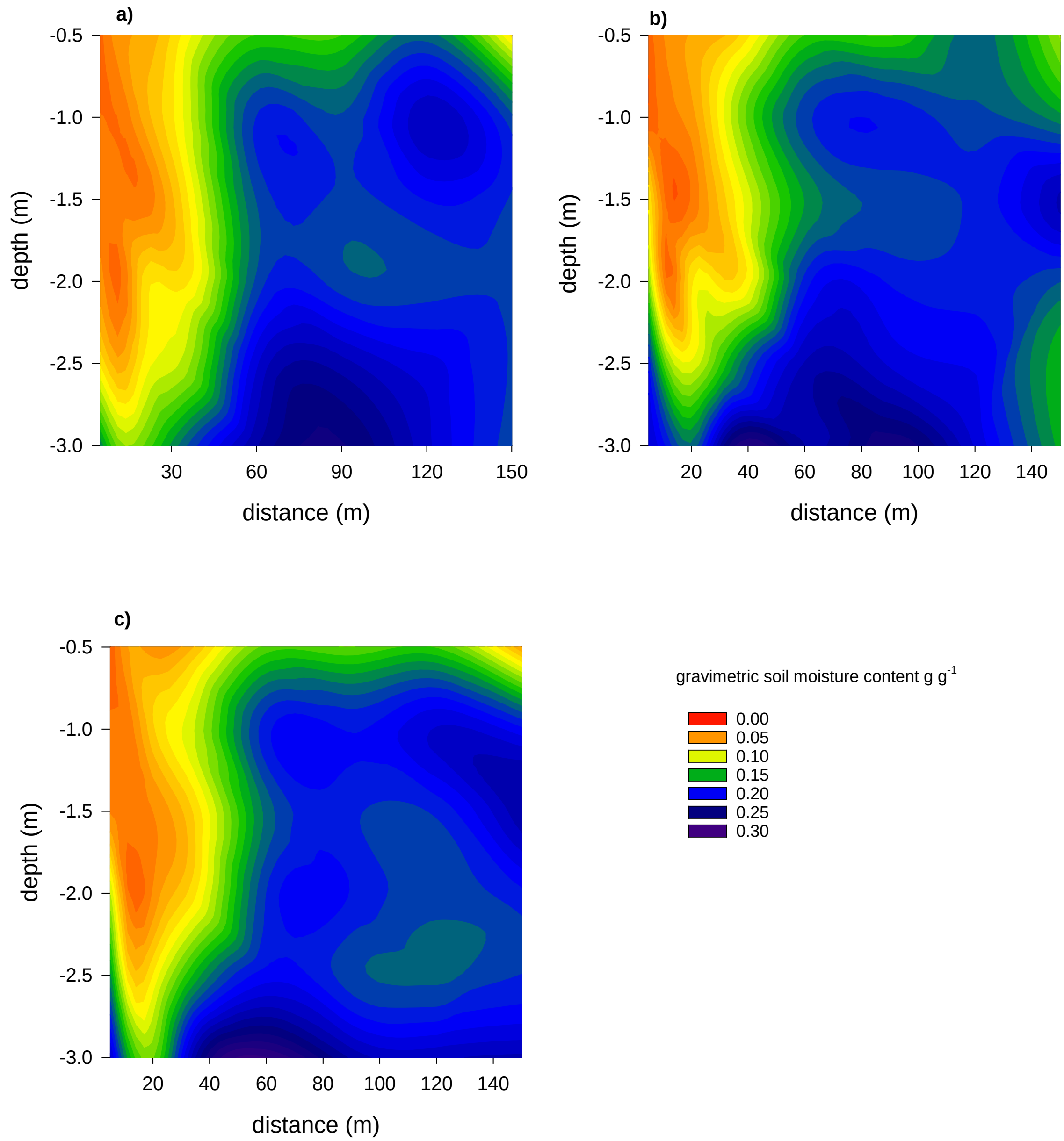

Figure 20: Contour fill plot of mean gravimetric soil moisture content (g g^{-1}) of soil for increasing distance from river (up to 150 m) and for increasing depths (up to 3 m) at Big Toolunka Flat wetland between a) August 2015: before weir pool raising, b) October 2015: during weir pool raising and c) February 2016: after weir pool raising.

River – floodplain soil suction

Comparisons of total soil suction (i.e. matric + osmotic) along transects from the river's edge indicate that there were significant Survey Trip × Depth and Distance × Depth interactions, suggesting total soil suction varied between trips and within increasing distances and depths but patterns of variation were not consistent (Table 10; Figure 21 a, b and c).

In general, soil suction was highly variable throughout the soil profile from the river's edge across all survey trips. In August 2015, soil suction was higher (greater than -4 MPa) within 5–30 m from the river's edge and up to depths up of 2 to 2.5 m indicating decreased water availability. Otherwise soil suction was quite low (less than 2 MPa) throughout the rest of the soil profile, up to 150 m from the river's edge.

During weir pool raising, soil suction became less negative (less than -2 MPa) within 10 m of the river's edge up to depths of 3 m indicating increased water availability, but between 20–60 m (depths up to 1.5 m) soil suction increased further (greater than -8 MPa) indicating water availability decreased at within the unsaturated zone.

By February 2016, following weir pool raising, soil suction was much higher (greater than -8 MPa) at the surface (<1 m depth) across the lengths of transects (up to 150 m from river edge). In addition, within 5–60 m of the river's edge, between depths of 1 to 2 m, there was a pronounced region where soil suction was high (-5 to -8 MPa) indicating decreased water availability (Table 10; Figure 21a, b and c).

Table 10: PERMANOVA results of suction (MPa) of soil for increasing distance from river (up to 150 m) and for increasing depths (up to 3 m) at Big Toolunka Flat (Weir Pool 2) between August 2015 (before raising), October 2015 (during raising) and February 2016 (after raising) (df = degrees of freedom; p-value = probability value, α = 0.05).

Factor	***dF***	***Pseudo-F***	***p-value***
Survey Trip	2, 365	9.12	0.001
Distance	7, 365	4.34	0.007
Depth	8, 365	2.91	0.036
Survey trip × Distance	14, 365	0.94	0.47
Survey trip × Depth	10, 365	3.67	0.001
Distance × Depth	36, 365	1.99	0.006
Survey trip × Distance × Depth	69, 365	0.64	0.99

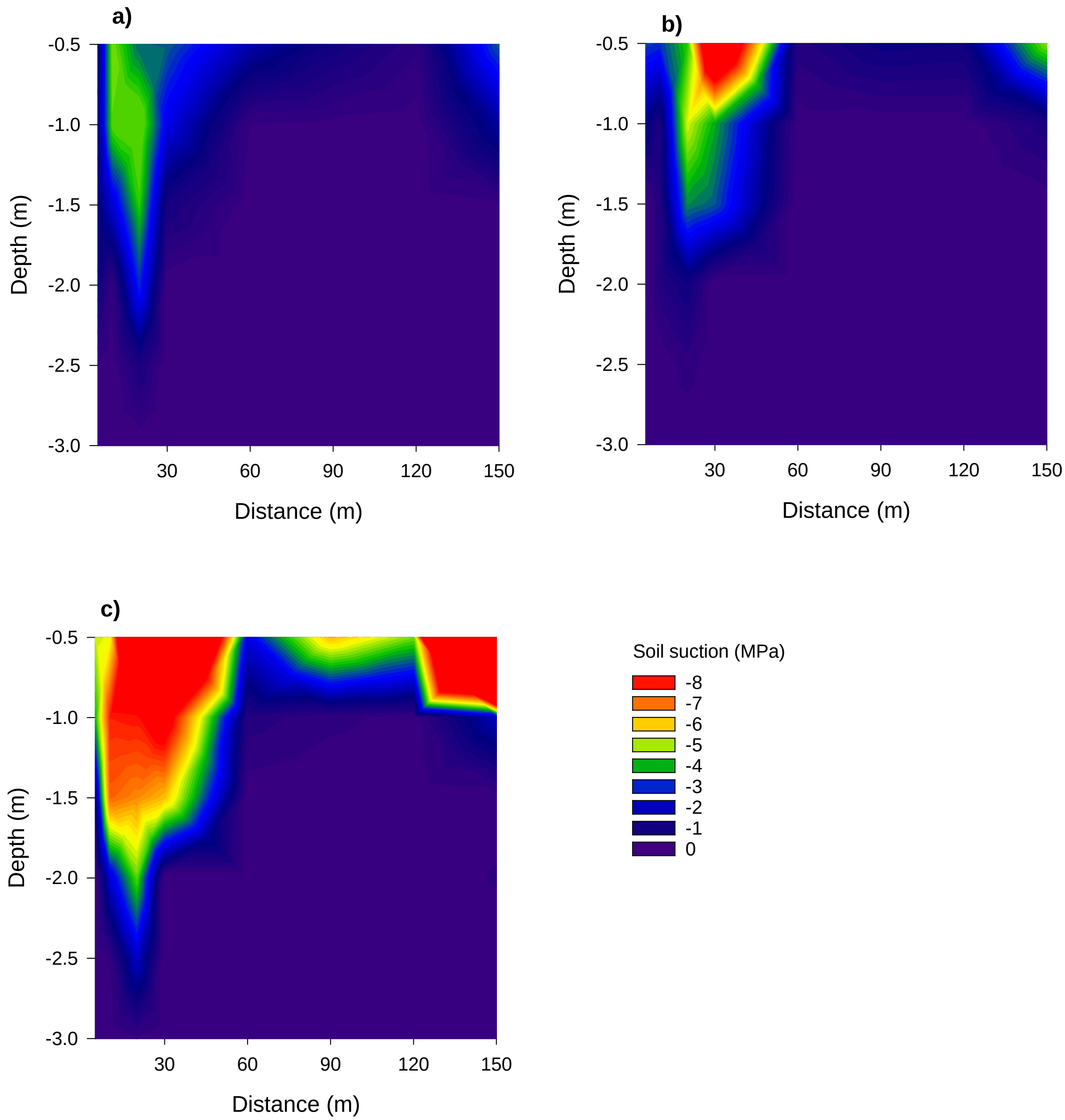

Figure 21: Contour fill plot of mean soil suction (kPa) for increasing distance from river (up to 150 m) and for increasing depths (up to 3 m) at Big Toolunka Flat river between a) August 2015: before weir pool raising, b) October 2015: during weir pool raising and c) February 2016: after weir pool raising.

River – floodplain soil EC

Comparisons of soil electrical conductivity along the soil profile from the river's edge indicate that there was a significant Survey Trip × Distance interaction, suggesting soil EC varied with increasing distance across survey trips, but patterns were not consistent (Table 11; Figure 22).

In August 2015, soil EC throughout the profile was variable, but within 50–60 m distance of the river's edge (and up to depths of 3 m) soil EC was very low (<1000 µS cm^{-1}), whereas soil EC beyond 60 m from the river's edge was slightly greater (2000– 3500 µS cm^{-1}) (Figure 22a).

By October 2015, during weir pool raising, soil EC throughout the entire soil profile decreased significantly and remained homogeneously low (0 to 1000 µS cm^{-1}) throughout the soil profile (Figure 22b).

The soil profile remained low throughout the profile when sampled again in February 2016, after weir pool raising had ceased; although slightly higher EC (~2000 µS cm^{-1}) was recorded at depths of 2.5 m, approximately 150 m from the river's edge suggesting freshening may not have persisted for long (Figure 22c).

Table 11: PERMANOVA results of electrical conductivity (µS cm^{-1}) of soil for increasing distance from river (up to 150 m) and for increasing depths (up to 3 m) at Big Toolunka Flat (Weir Pool 2) between August 2015 (before raising), October 2015 (during raising) and February 2016 (after raising) (df = degrees of freedom; p-value = probability value, α = 0.05).

Factor	***dF***	***Pseudo-F***	***p-value***
Survey Trip	2, 364	259.11	0.001
Distance	7, 364	1.56	0.221
Depth	8, 364	1.45	0.257
Survey trip × Distance	14, 364	21.31	0.001
Survey trip × Depth	10, 364	1.76	0.61
Distance × Depth	36, 364	1.25	0.198
Survey trip × Distance × Depth	69, 364	0.477	0.91

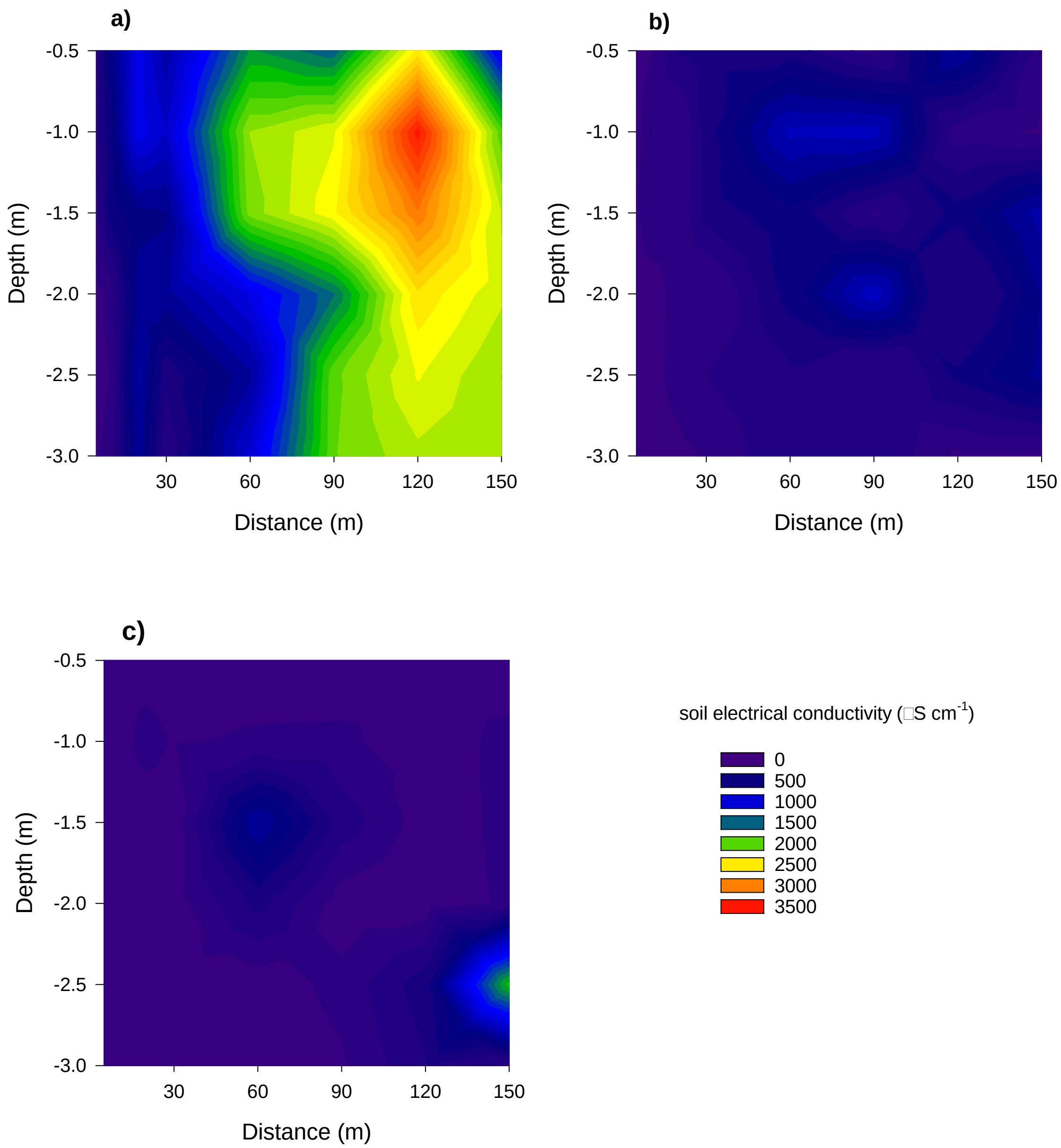

Figure 22: Contour fill plot of mean soil electrical conductivity (µS cm^{-1}) of soil for increasing distance from river (up to 150 m) and for increasing depths (up to 3 m) at Big Toolunka Flat wetland between a) August 2015: before weir pool raising, b) October 2015: during weir pool raisig and c) February 2016: after weir pool raising.

Wetland – floodplain soil types

The soil types within the profile sampled from the wetland's edge were patchy, but predominantly composed of clay and loam. In particular there was a clay surface layer (<100–150 cm deep) that extended up to 150 m from the wetland edge. From 20 m to 150 m the subsurface was loam. The saturated zone was intercepted between depths of 1.5 m and 2.5 m within 90 m from the wetland edge and became deeper (>3 m), within increasing distance (Table 12).

Table 12: Table illustrating soil types throughout the soil profile (depth, cm) and increasing distance (m) from the wetland edge at Big Toolunka Flat. L = loam, C = clay, S = sand. *blue bars represent depth that saturated zone was intercepted.

Wetland

Depth (cm)								
0-50	C	C	C	C	C	C	C	C
50-100	C	C	C	C	C	C	C	C
100-150	C	C	L	L	C	L	C	L
150-200					C	L	C	L
200-250					L	L	L	L
250-300							L	L
	5	10	20	30	60	90	120	150

Distance (m)

Wetland – floodplain soil moisture

A comparison of soil moisture content along transects from the wetland's edge indicate that there was a significant Distance × Depth interaction, suggesting soil moisture varied with increasing distance and depth (Table 13; Figure 23a, b and c).

In general, soil moisture content was higher (0.20 to 0.30 g g^{-1}) from the wetland edge up to distances of 120 m from the wetland edge. From 120–150 m, soil had lower soil moisture content (0.10 – 20 g g^{-1}) from the surface to depths of 3 m. There were significant differences in soil moisture between trips (Table 13; Figure 23), suggesting a trend of soil moisture content decreasing between the zone 90–150 m from the wetland's edge between survey trips, but between 5–90 m, soil moisture content remained high (0.20 to 0.30 g g^{-1}) (Figure 23a, b and c).

Table 13: PERMANOVA results comparing gravimetric soil moisture content (g g^{-1}) of soil for increasing distance from wetland (up to 150 m) and for increasing depths (up to 3 m) at Big Toolunka Flat (Weir Pool 2) between August 2015 (before raising), October 2015 (during raising) and February 2016 (after raising) (df = degrees of freedom; p-value = probability value, α = 0.05).

Factor	***dF***	***Pseudo-F***	***p-value***
Survey Trip	2, 311	3.26	0.035
Distance	7, 311	28.91	0.001
Depth	18, 311	3.74	0.04
Survey trip × Distance	14, 311	0.25	1
Survey trip × Depth	10, 311	0.95	0.50
Distance × Depth	40, 311	4.23	0.001
Survey trip × Distance × Depth	49, 311	0.34	1

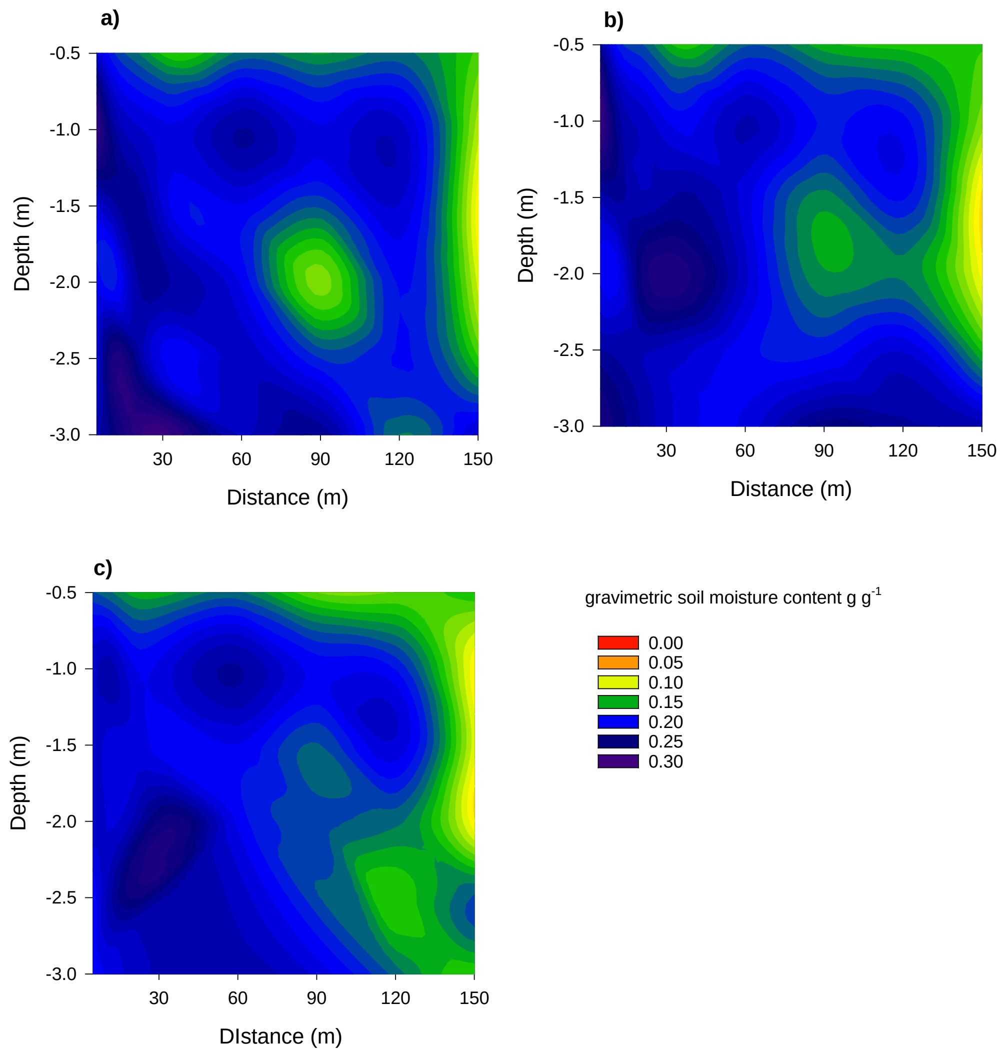

Figure 23: Contour fill plot of mean gravimetric soil moisture content (g g^{-1}) of soil for increasing distance from wetland (up to 150 m) and for increasing depths (up to 3 m) at Big Toolunka Flat wetland between a) August 2015: before weir pool raising, b) October 2015: during weir pool raising and c) February 2016: after weir pool raising.

Wetland – floodplain soil suction

A comparison of total soil suction (i.e. matric + osmotic) along transects from the wetland's edge indicate that there was a significant Survey trip × Distance × Depth interaction, suggesting soil suction varied between trips and with increasing distances and depths (Table 14; Figure 24a, b and c).

In August 2015, the saturated zone was intersected by push tube sampling between depths of 1.5 to 2.7 m, within 60 m of the wetland's edge and within this zone, soil suction was less negative (0 to -0.5 MPa) indicating high water availability. Soil suction was generally more negative (-2 to -4 MPa) indicating decreased water availability at the soil surface (<1 m depth) across the lengths of transects (20–150 m from the wetland's edge) (Table 14; Figure 24a).

During weir pool raising (October 2016) the saturated zone rose to be intercepted by push tube sampling between depths of 0.8 to 2.1 m within 60 m of the wetland's edge. At distances less than 30 m from the wetland's edge soil suction was less negative (0 to -0.5 MPa) throughout the entire profile, indicating high water availability. At distances between 30–100 m from the wetland's edge, at depths 0–1 m soil suction was more negative (-0.5 to -2.5 MPa) indicating decreased water availability at the surface of the soil profile (Figure 24).

Following weir pool raising, the saturated zone lowered, to be intercepted by push tube sampling between depths of 1.5 to 2.5 within 60 m of the wetland's edge. Soil suction at the surface (<1 m) generally increased (-2 to -4 MPa) whereas soil suction throughout the remainder of the soil profile remained low and indicative of high water availability (Figure 24).

Table 14: PERMANOVA results comparing suction (MPa) of soil for increasing distance from wetland (up to 150 m) and for increasing depths (up to 3 m) at Big Toolunka Flat (Weir Pool 2) between August 2015 (before raising), October 2015 (during raising) and February 2016 (after raising) (df = degrees of freedom; p-value = probability value, α = 0.05).

Factor	***dF***	***Pseudo-F***	***p-value***
Survey Trip	2, 309	5.41	0.007
Distance	7, 309	1.73	0.188
Depth	18, 309	4.93	0.002
Survey trip × Distance	14, 309	1.57	0.097
Survey trip × Depth	10, 309	8.13	0.001
Distance × Depth	39, 309	1.75	0.024
Survey trip × Distance × Depth	49, 309	1.68	0.01

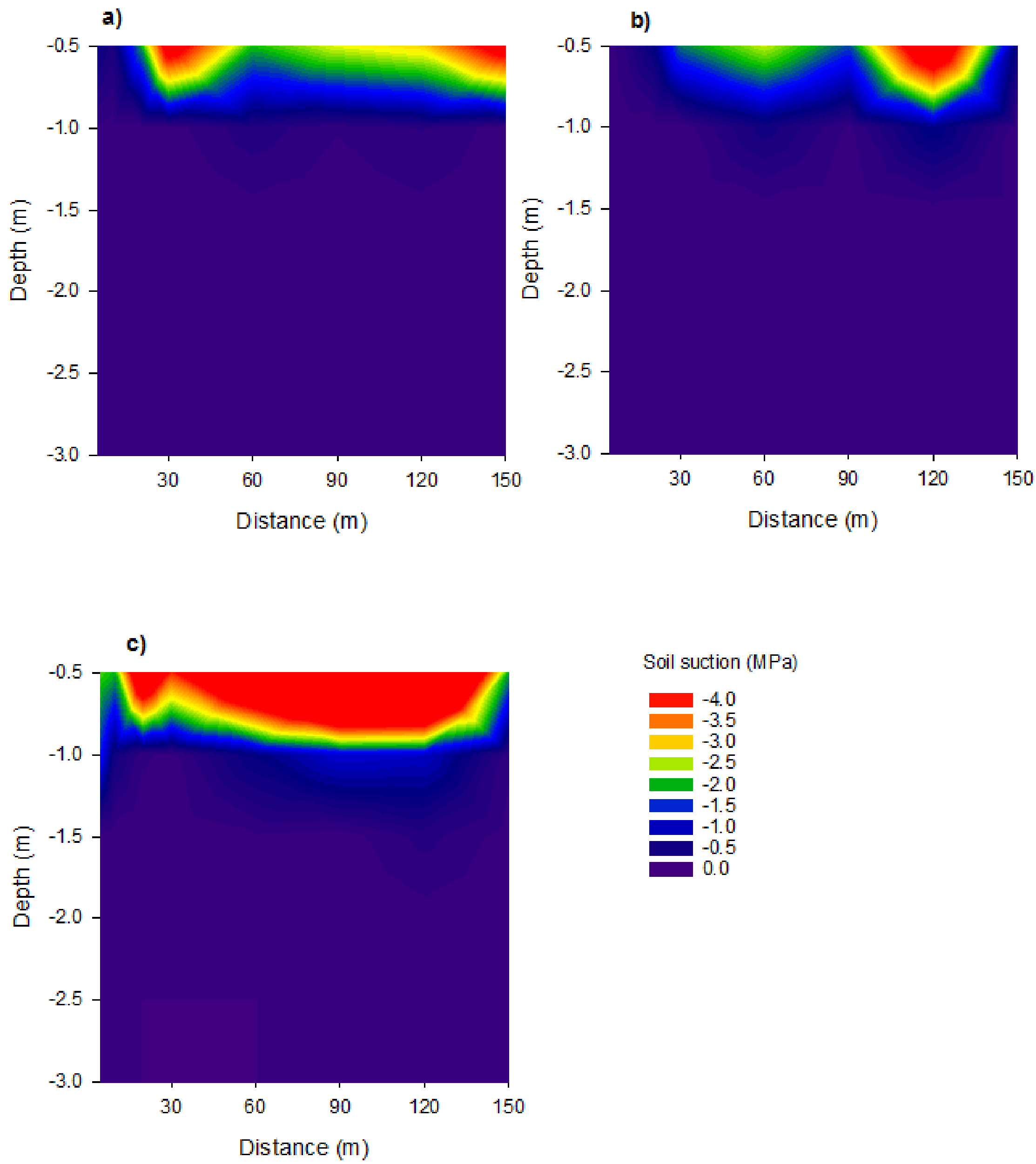

Figure 24: Contour fill plot of mean soil suction (MPa) for increasing distance from wetland (up to 150 m) and for increasing depths (up to 3 m) at Big Toolunka Flat wetland between a) August 2015: before weir pool raising, b) October 2015: during weir pool raising and c) February 2016: after weir pool raising.

Wetland – floodplain soil EC

Comparisons of soil EC along the soil profile from the wetland's edge indicate that there was a significant Survey trip × Distance and Survey trip × Distance × Depth interactions, suggesting soil EC varied inconsistently with increasing distance and depths between survey trips (Table 15; Figure 25a, b and c).

In August 2015, prior to weir pool raising, soil EC throughout the profile was highly variable, but within 40 m from the wetland's edge (and up to 3 m depth), soil EC was low (<1000 µS cm^{-1}). In contrast, soil EC beyond 40 m from the wetlands' edge was higher (Figure 25a). By October 2015, during weir pool raising, there was a significant decrease in soil EC throughout the entire soil profile (Figure 25b), which remained homogeneously low throughout the profile when sampled again in February 2016, after weir pool raising had ceased (Figure 25c).

Table 15: PERMANOVA results of electrical conductivity (µS cm^{-1}) of soil for increasing distance from wetland (up to 150 m) and for increasing depths (up to 3 m) at Big Toolunka Flat (Weir Pool 2) between August 2015 (before raising), October 2015 (during raising) and February 2016 (after raising) (df = degrees of freedom; p-value = probability value, α = 0.05).

Factor	***dF***	***Pseudo-F***	***p-value***
Survey Trip	2, 311	152.22	0.001
Distance	7, 311	2.04	0.1
Depth	18, 311	0.90	0.56
Survey trip × Distance	14, 311	10.42	0.001
Survey trip × Depth	10, 311	1.06	0.39
Distance × Depth	40, 311	0.59	0.615
Survey trip × Distance × Depth	49, 311	1.75	0.011

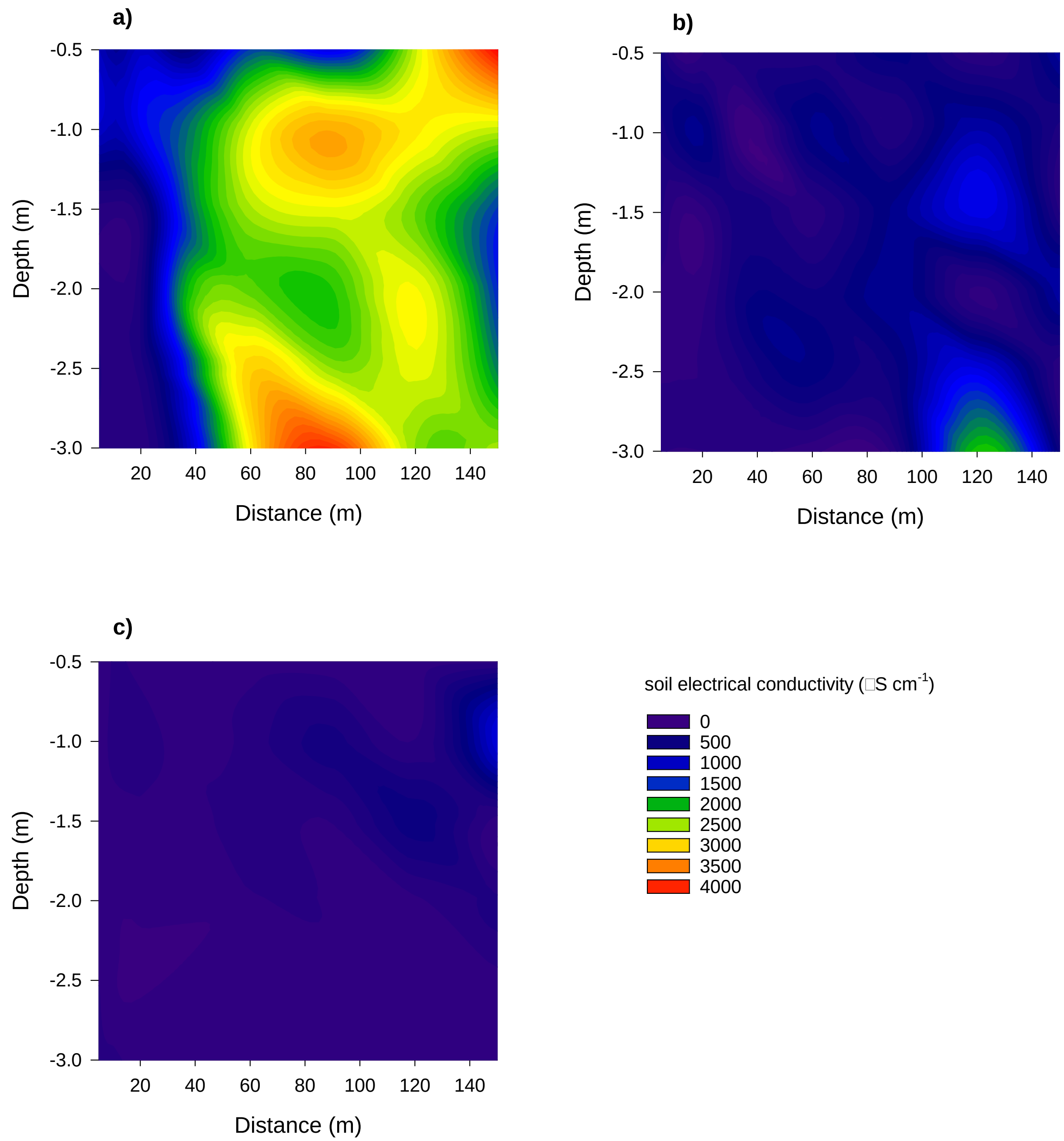

Figure 25: Contour fill plot of mean soil electrical conductivity (µS cm^{-1}) of soil for increasing distance from wetland (up to 150 m) and for increasing depths (up to 3 m) at Big Toolunka Flat wetland between a) August 2015: before weir pool raising, b) October 2015: during weir pool raising and c) February 2016: after weir pool raising.

4. DISCUSSION

Overall, the vegetation composition and cover varied considerably within and between sites. Vegetation diversity and abundance varied depending on the position of plots relative to river and or wetland, which is not unexpected as water requirements and hydrology are strong factors shaping the distribution, growth and survival of vegetation in freshwater habitats (Taylor *et al.* 1996, Brock *et al.* 2006, Capon *et al.* 2006). Other factors shaping distribution of vegetation within the landscape include drought tolerance, soil property requirements, optimal temperatures and micro-site conditions for recruitment (Roberts and Marston 2000, 2011).

Although the dominant tree species of the Lower River Murray are few, namely river red gums and black box, the floodplains and forests show considerable diversity and over 22 communities have been identified (Roberts 2004). The various forest and woodland types are distributed down the River Murray floodplain in a non-uniform manner, and their extent and condition have been highly impacted, especially in the Lower River Murray (Roberts 2004). Stands dominated by different eucalypts may occur on the same floodplain, but usually at different elevations or on different soil types and fluvial forms (Roberts and Marston 2000). For instance, black box tend to dominate inland floodplain woodlands; forming open sparse woodlands at slightly higher elevations than river red gums, which are found on occasionally inundated, heavy alluvial floodplain clays (Roberts and Marston 2000).

Despite the variable communities studied in this investigation, Woolenook Bend site appeared in better condition than Moorook, followed by Big Toolunka Flat; with a greater level of native plant composition, vegetation structure and cover. Black box trees, in particular, can grow across a range of conditions, and this adaptability is often reflected in the range of height, form and canopy density (Roberts and Marston 2000). For instance, on the Chowilla Floodplain, tree height often decreases with decreased water availability (Palmer and Roberts 1996). At Woolenook Bend, tree height was generally higher and there were more diverse vegetation layers/strata, in contrast with Big Toolunka Flat, where low-growing, open black box woodland dominated and was characterised by low species understorey diversity and minimal vegetation layers, suggesting this site is generally more water-limited, with Moorook being somewhat in between.

Similarly, PAI within monitoring plots also show that canopy cover at Woolenook Bend and areas of Moorook within 120 m of the river's edge were higher (range 1–2.3), but at Big Toolunka Flat and within the area of Moorook >121 m from the river's edge, PAI values were lower. Furthermore some areas recorded values <0.5, which is considered a possible critical threshold value;

indicative of a considerable level of drought stress (Doody *et al.* 2015). A change towards drier conditions on floodplains can shift woodland composition towards the dominance of terrestrial species (Gehrig and Frahn 2015); diminishing overall value as habitat (Corey and Doody 2016) and the capacity to respond and recover (i.e. resilience) during more favourable conditions (Roberts 2004).

The application of certain aspects of the AusPlots field method (White *et al.* 2012) proved useful for distinguishing fundamental differences in site composition, but also for allowing the potential differences in response of woodland communities to management interventions (i.e. response of better condition woodlands versus degraded woodlands) to be assessed. The AusPlots field method was also useful for determining the abundance of understorey/groundcover vegetation and/or the amount of non-vegetated substrate; all of which can confound remote sensing measurements from tall canopy vegetation (Heute *et al.* 1985), particularly in more open woodland areas.

Assessments of the soil profile from the river and wetland edges suggests that prior to the weir pool raising a low saline (<3000 EC), saturated zone occurred within 60 m (at depths > 2.5 m) from the river edge and within 60 m (depths > 1 m) from the wetland edge. During weir pool raising, the saturated zones increased somewhat, soil moisture remained high, and soil EC decreased and correspondingly soil suction also became less negative thereby increasing available soil water availability due to the increase in saturated zone and the subsequent capillary rise and improvements in water quality. Total soil suction (matric + osmotic suction +gravimetric) is one of the most important parameters describing the moisture condition of unsaturated soils. Matric suction comes from the capillarity, texture and surface adsorptive, whereas osmotic suction arises from the dissolved salts contained in the soil water; where pure water will have an osmotic potential of 0 MPa and solutions have more negative osmotic potentials. Gravimetric has a minor influence and is hence often not reported (Hall *et al.* 2009). In this instance, drier soils will have a more negative matric suction, while a decrease in osmotic suction to values closer to 0 MPa, will increase soil water availability. River water EC across the survey period ranged from 201–375 EC, hence the marked decline in EC during weir pool raising could be attributed to freshening as a result of lateral recharge, even though soil EC values prior to weir pool raising were still well within the upper tolerance limits for both river red gum (19, 500 EC µS cm^{-1}) and black box (35, 750 EC µS cm^{-1}) (Overton and Jolly 2004), understorey floodplain vegetation such as chenopods (<10, 000 EC) (Hassam 2007), and within the range that is tolerable by most agricultural crops (ANZECC and ARMCANZ 2000). For instance, mature river red gums may still grow in soils where

EC is <16,000 µS cm^{-1}, but growth rates start to decline at values >5,000 µS cm^{-1} (Primefacts 2010). Seedlings are even more susceptible and may show signs of reduced growth rates at <4,000 µS cm^{-1} (El-Juhany *et al.* 2008). Hence, these reported salinity values represent upper limit threshold values for salinity tolerance and not necessarily the target values that will support good condition. At sites where EC in the saturated zone is considerably higher, the degree of freshening provided by lateral recharge may not have been so significant, especially from an ecological perspective.

Following weir pool raising, these zones contracted somewhat. Soil at the surface became increasingly drier and soil suction increased, although soil EC remained low. Surface drying was not unexpected as this is most likely related to evapotranspiration demands across the typically drier spring/summer months within the region. Precipitation was relatively consistent prior to weir pool raising, and there was significant precipitation event in January 2016 at Big Toolunka that may have contributed to sustaining the freshening observed following weir pool raising. Small volumetric inputs from periodic rainfall are not likely to provide a major recharge mechanism for the saturated zone at the site level that will persist (Allison and Hughes 1983). Nonetheless, rainfall can contribute to providing some freshening of the unsaturated zone at the immediate-short term scale or help to sustain soil freshening (Meredith *et al.* 2015). Conversely, indirect recharge, such as from rivers, can provide a greater volume of water, but can be much more difficult to estimate site to site (Allison and Hughes 1983).

River red gums and black box trees have life history stages where water requirements exceed the volumes of water provided by rainfall alone and hence needs are also met by inundation or by accessing groundwater (Doody *et al.* 2009). During times of water deficit, river red gums and black box rely on water stored deep within the soil profile and have considerable capacity for water regulation when water is scarce (Doody *et al.* 2015). As a further adaptation to semi-arid environments, river red gums and black box are opportunistic in their water use (Mensforth *et al.* 1994, Holland *et al.* 2006, Holland *et al.* 2009, Gehrig and Frahn 2015), capable of using alternative water sources to rainfall, including fresh to moderate saline groundwater and lateral bank recharge and overbank flooding, which can replenish groundwater (Mensforth *et al.* 1994, Holland *et al.* 2006, Doody *et al.* 2009, 2014b, Holland *et al.* 2009, Gehrig and Frahn 2015).

Prior to weir pool raising, tree crown condition and tree water status varied across sites, with trees sampled in Woolenook Bend having sparse-medium crown densities/extents, while trees at Big Toolunka Flat and Moorook were in slightly better condition. The slight differences in tree condition observed, namely the slightly poorer condition of the trees surveyed at Woolenook Bend (compared to the other sites) may have been an artefact of the sampling methods used to collect shoots from the trees for measurements of tree water status. The point-intercept surveys, characterising vegetation composition and cover, showed trees at Woolenook Bend were generally taller and formed a more closed canopy, than those observed at the other sites, which makes harvesting shoots difficult. Hence, there can be an inherent bias to selecting trees that are shorter (<5 m tall) so that shoots can be reached with the 4 m long-handled secateurs, without having to resort to alternative, potentially more destructive methods.

Despite the slightly poorer crown condition observed prior to weir pool raising, the trees surveyed at Woolenook Bend showed an increase in crown condition scores during weir pool raising, although water status did not improve significantly, with the exception of trees within 60 m of the river's edge. Following weir pool raising, the improvements in crown condition observed were maintained, although measurements of tree water status suggested that there was a trend of declining water status for all trees within Woolenook Bend, especially for trees located on the river's edge, where tree water status declined to measurements lower than those recorded prior to weir pool raising.

The response of stressed trees to watering is difficult to predict at the population scale as individual trees may use remaining physiological resources to produce epicormic growth (i.e. shoots/branches that originate from main branches). If watering is maintained and trees do not sustain ongoing stress, epicormic growth will normalise and growth will occur from tips in the following season. Trees will therefore have the capacity to regrow a full canopy and contribute resources to healthy seed production (Souter et al. 2010; Gehrig and Frahn 2015). However, if watering is not sustained, there is a risk that stressed trees deplete their physiological reserves in attempts to improve crown condition and reproductive cycles. Results at Big Toolunka showed that during weir pool raising there were significant improvements in crown condition and water status; however, after weir pool raising, the trees at Big Toolunka Flat showed decreased crown condition for trees located >150 m from the river's edge although trees <150 m of the wetland edge remained unchanged. Likewise, after weir pool raising, water status decreased significantly for all trees at Big Toolunka Flat, suggesting that the improvement in tree vigour may have potentially only persisted for a few months. Without follow-up surveys it is difficult to ascertain whether tree condition may have returned to the levels observed prior to weir pool raising, or declined further.

In contrast, trees within Moorook, where the weir pool was not raised, did not change significantly across the survey period, with the exception that trees located <80 m from the river's edge showed slight improvements in crown condition. The lack of response from this site may reflect better site conditions to begin with and hence a lack of seasonal responsiveness, but the point-intercept characterisation of vegetation composition and cover of the monitoring plots within this site, suggests this was not the case. Hence, it would appear that the trees at both Woolenook Bend and Big Toolunka Flat were responding to increased water availability and quality as a result of weir pool raising.

Remote sensing of ecological response of vegetation to the 2014 weir pool raising event demonstrated that a historical temporal baseline of vegetation greenness (determined from MODIS NDVI) occurs, which is driven by climatic factors, such as rainfall and temperature. Vegetation greenness in the lower River Murray corridor tends to be at a maximum in winter and at a minimum in mid-summer and hence is strongly seasonal (Clarke *et al.* 2015). Lateral bank recharge is an important mechanism for maintaining vegetation condition along the River Murray channel (Doody *et al.* 2014a). Soil and groundwater recharge mechanisms are linked to vegetation health, with lateral hydrological connectivity between river banks and riparian zones critical for tree maintenance and survival (Bacon *et al.* 1993; Jolly *et al.* 1998; Holland *et al.* 2006; 2009). Holland *et al.* (2006, 2009) identified a 40–50 m zone of influence for river red gums following environmental watering interventions (e.g. wetland pumping); whereas following the 2010/11 flood, the zone of lateral recharge influence was much greater (i.e. between 90–120 m, Doody *et al.* 2014a). During the 2015 weir pool raising, lateral recharge, at the site surveyed, may have extended up to or beyond 150 m.

There is a clear link between increased within-channel river height and improvements in health of river red gum forests and woodlands in relation to increased zone of lateral bank recharge influences, although the degree of influence may be highly variable at the site-specific level (Doody *et al.* 2014a). Even though flows may remain in-channel, raising river height provides a mechanism to distribute additional water within the banks adjacent the River Murray, effectively increasing water availability (Doody *et al.* 2014a). In the investigation by Doody *et al.* (2014a) trees appeared sensitive to changes in river height, responding to improved water availability when river levels were raised (as observed by the increase in NDVI (vegetation greenness) and hence a corresponding increase in tree vigour), but NDVI declined once river levels returned to base flow; with a 2 month lag time between the NDVI increase and subsequent NDVI decline (Doody *et al.* 2014a). In this instance the response in tree vigour to increased river height may have potentially only persisted for a few months, especially for the trees at Big Toolunka where decreasing tree water status and TCI scores suggest the results may have only persisted temporarily (months). Nonetheless, results demonstrated that the trees were capable of responding to increased water availability and quality and that in-channel flow pulses may be beneficial for contributing towards river red gum and black box maintenance (Doody *et al.* 2014a).

During times of reduced water availability, river red gums and black box reduce water use and sapwood to minimise stress damage, but when water availability increases (e.g. high rainfall, lateral recharge and/or flooding), these trees can allocate resources to produce dense roots in the upper soil layer to maximise water uptake, thereby responding with increased transpiration and sapwood growth (Doody *et al.* 2015). Hence, response to increased or decreased water availability can be rapid and physiological parameters, such as increased stomatal conductance, transpiration, photosynthetic rates and improved water status can occur in hours to days (Gehrig 2010, Doody *et al.* 2014a). In comparison, the lag time for detecting improvements/declines in morphological adaptations, such as changes in sapwood area and/or crown extent/condition are typically longer (weeks to months) (George *et al.* 2005, Gehrig 2013, 2014, Gehrig and Frahn 2015).

At Big Toolunka Flat, $\Psi_{predawn}$ of the trees measured, ranged from -1.9 to -3.5 MPa across the trial, suggesting they were at equilibrium at depths just above the saturated soil zone (capillary fringe) where soil suction also matched this range. Therefore, any increase in soil water availability will most likely be utilised. Freshening of this zone also contributes, as the observed dieback in river red gum floodplain forests and woodlands is most likely attributed to the combination of reduced flooding frequency, the recent Millennium drought and an increased reliance on groundwater, so freshening can improve water quality (Cunningham *et al.* 2010, Le Blanc *et al.* 2012). Although in this instance, groundwater salinity was low prior to weir pool raising and suggests that the mature trees within this particular site were primarily water-limited.

In regards to wetland littoral vegetation response, the results showed that there were large differences in the plant community between sites; however, the significant interaction between survey trip and wetland at the elevations 30, 40, 50 and 60 cm above pool level provided evidence that weir pool raising changed the plant community at these elevations. The reason for the change at the higher elevations is probably due to the lower elevations having higher soil moisture and subjected to wetting and drying events under normal weir operations and wind setup (Webster *et al.* 1997). This was supported by the presence of *Centipeda minima* and *Stemodia florulenta* (species that recruit after inundation (Cunningham *et al.* 1992) in both surveys at Woolenook bend at low elevations. In contrast, the higher elevations would not be subjected to wetting and drying events in the absence of weir pool raising or higher river flows. Therefore, weir pool raising provided conditions suitable for species to recruit over a larger area compared to normal weir operations. The longer intermittent regimes are implemented (i.e. > 5 years), wetland vegetation communities can be expected to become more diverse and more abundant.

Despite the non-significant interactions at the lower elevations, NMS ordination showed separation of points between the survey trips (indicating a change in floristic composition) at Big Toolunka Flat and Woolenook Bend and no separation at Moorook. These patterns suggested that there was an interaction at the lower elevations; however, it may not have been detected due to low statistical power. Furthermore, results from the 2014-15 weir pool raising vegetation monitoring showed that differences between sites can be so great that it can make detecting differences due to an intervention very difficult (Gehrig *et al.* 2015). This was overcome to some degree by the inclusion of a control site in 2015-16; however, between site differences were much larger than differences potentially due to weir pool raising.

Within this study a range of hypotheses were investigated as part of this trial and are summarised below (Table 16). While some of the hypotheses were met they may have only been met in part from a spatial and temporal perspective, or the changes were not significant and/or ecologically relevant.

Table 16: Summary of key hypotheses investigated and whether hypotheses were met during investigation.

#	Hypothesis	Hypothesis met
1	Littoral plant communities of wetlands will increase in diversity and abundance at elevations that were inundated (0 to +0.5 m elevation)	In part: littoral plant communities at elevations >+0.3 to 0.6 m above normal pool level increased in diversity and abundance after weir pool raising, with increased abundances of floodplain and amphibious species detected, but no significant changes in littoral plant communities were observed at elevations between normal pool level and <+0.3 m.
2	Frequency and abundance of wetland invasive plants will increase at elevations that were inundated (0 to +0.5 m elevation)	Not significantly: some exotic, naturalised species were observed before and after weir pool raising, but not in abundances that would be considered problematic and requiring intervention.
3	Soil moisture reserves will increase as a result of bank flux through temporary wetlands and floodplains	In part: soil moisture in the unsaturated zone increased somewhat during the weir pool raising thereby increasing soil water availability. Furthermore, soil EC within the unsaturated and saturated zones decreased significantly during and after weir pool raising, thereby also increasing soil water quality and availability. Although it should be noted that soil EC within that site was low (<3000 EC) prior to weir pool raising and therefore improvements may not have been as significant and therefore as ecologically relevant in other sites if soil EC values were much higher.
4	Water status and crown condition/extent of overstorey floodplain trees (e.g. river red gum, black box and river cooba) will improve due to soil moisture reserves increasing as a result of bank flux	In part: improvements in tree water status and crown condition/extent were observed in floodplain trees during the time weir pools were raised. Although the extent of tree vigour improvements were variable between sites, trees positioned close to the river's or wetland's edge, or with access to the unsaturated zone showed the greatest improvements. Following weir pool raising, however, tree crown condition either remained unchanged or had started to decline depending on the site studied. More noticeably, tree water status had started to decline in all sites studied to values lower than those observed prior to weir pool raising, suggesting that improvements in tree vigour may have only persisted temporarily (months) if soil water availability was not sustained.
5	Floodplain understorey plant communities that are inundated may change in diversity, abundance and/or condition as terrestrial species are drowned out (i.e. top-flooded) and high soil moisture as a result of vertical infiltration encourages germination of floodplain and amphibious taxa. However, for floodplain understorey plant communities that are not inundated, diversity, abundance and condition is unlikely to change unless soil moisture in the unsaturated zone (<1 m depth; where roots are most active) increases as a result of bank flux.	In part: none of the floodplain areas surveyed were inundated during this investigation therefore although some seasonal changes in floodplain understorey plant communities were observed, no changes could be directly attributed to weir pool raising. Although it should be noted that areas outside of the investigated sites may have been inundated and therefore may have responded.

5. CONCLUSION

Overall, some positive vegetation responses to weir pool raising were observed. For established trees, the critical aspects of water regime are frequency and duration of inundation, the frequency of the dry period between inundation and the variability of these factors (Roberts and Marston 2000). Successful regeneration of floodplain trees tends to follow floods, as following major floods there is usually enough surface and sub-surface soil moisture to ensure widespread seedling establishment if grazing pressure is reduced (Roberts and Marston 2000).

Critical aspects of flood regime for tree regeneration are frequency, duration, magnitude (flood peak) and timing. Prolonged favourable growing conditions following inundation are needed if the establishing seedling is to avoid desiccation (i.e. root systems are deep and extensive enough to access deeper soil reserves to persist during intervening dry periods) (Roberts and Marston 2000). When pre-regulated versus current inundation regimes are compared, the frequency of inundation has altered more than duration, but both are reduced and demonstrate a consistent pattern of change towards drier conditions down the River Murray (Roberts 2004).

Tree vigour has become a primary focus for intervention management, but as the intervals between floods increase, and as what was once rare or unusual under natural regimes becomes the norm under current inundation regimes, long-lived vegetation like river red gums and black box experience less ideal conditions and their capacity to recover is reduced (Roberts 2004).

In this study, the increase in tree vigour to weir pool raising was apparent demonstrating that the trees were capable of responding to increased water availability and quality, and that weir pool raising events may be beneficial for contributing towards river red gum maintenance, especially if they occur more frequently (as part of a watering regime and not as ‘discrete’ events), occur for longer durations and are potentially of greater magnitude, especially as weir pool raising increased and freshened deep soil water availability (to at least 150 m from the channel and wetland at Big Toolunka). For instance, Jensen *et al.* (2008) suggested the effectiveness of environmental interventions for river red gum recruitment could be increased by linking the timing of late spring–early summer watering with local rainfall, to promote seedling survival to sapling stage and also retain bud crops in autumn.

Furthermore, weir pool manipulations provide a management tool to introduce limited water level variability in the absence of unregulated flows and increase biodiversity (*sensu* Nielsen and Chick 1997). They have the potential to provide conditions suitable for recruitment of floodplain and amphibious species providing there is a resident seed bank and there is sufficient area inundated that is free of competitive taxa such as *Typha domingensis, Phragmites australis* and *Paspalum distichum*. However, while weir pool raising can provide variability in water levels and groundwater freshening as a result of lateral recharge, it cannot provide many of the functions of a flood or flow pulse, such as disturbance creating bare or sparsely vegetated patches suitable for plant recruitment (e.g. Pettit and Froend 2001; Polzin and Rood 2006) or extensive hydrochory that is provided by natural floods (e.g. Middleton 2000; Goodson *et al.* 2003).

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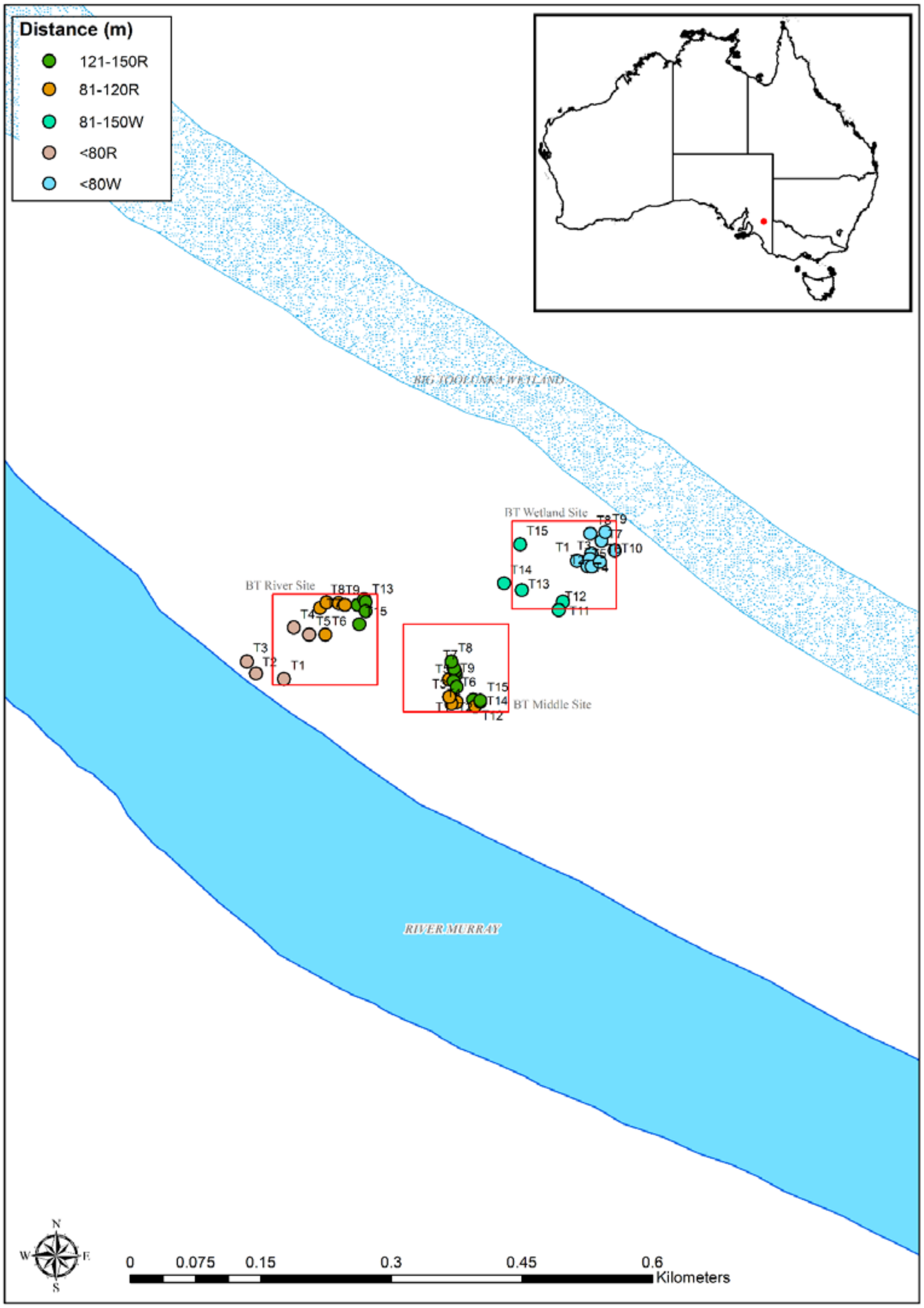
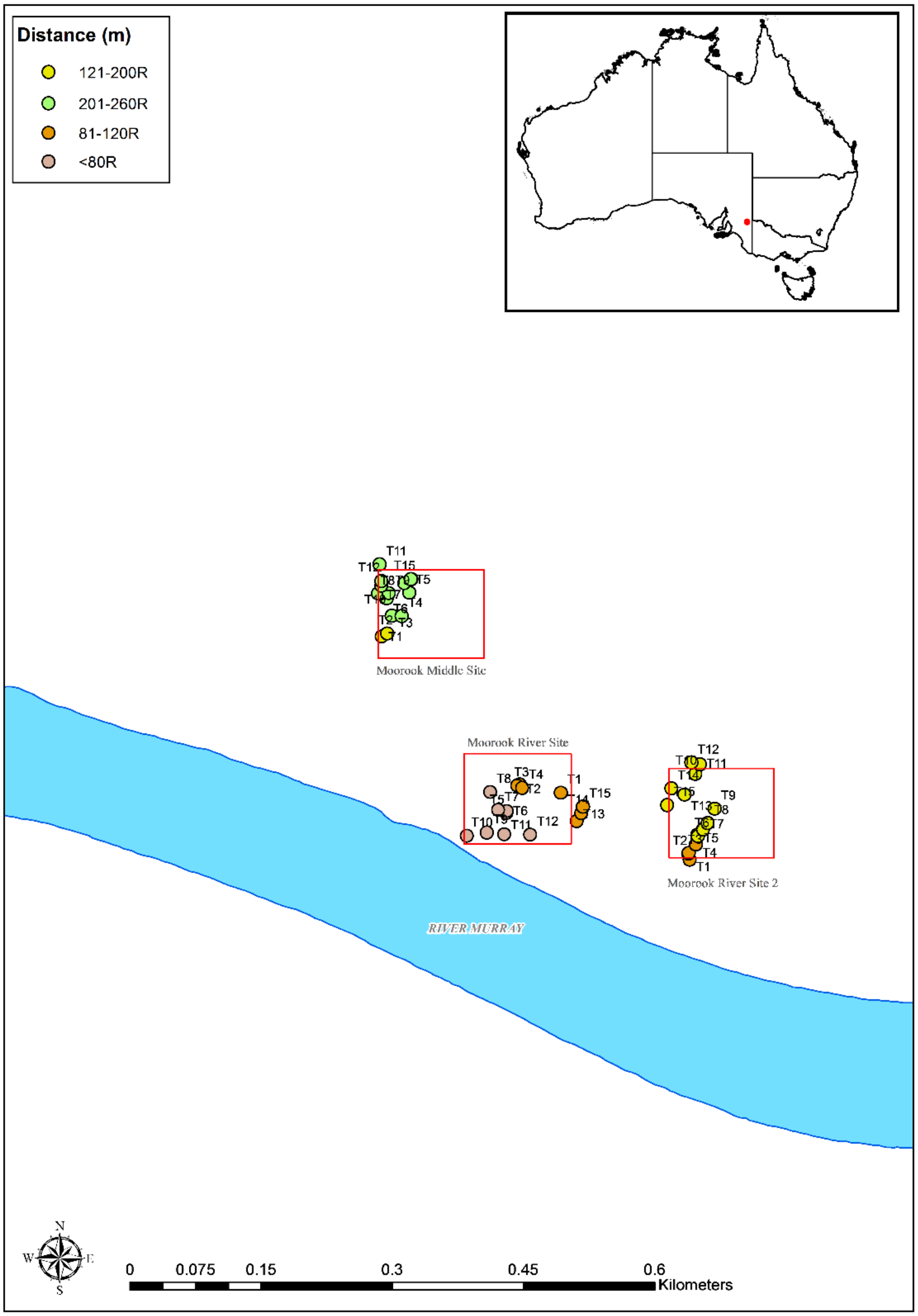
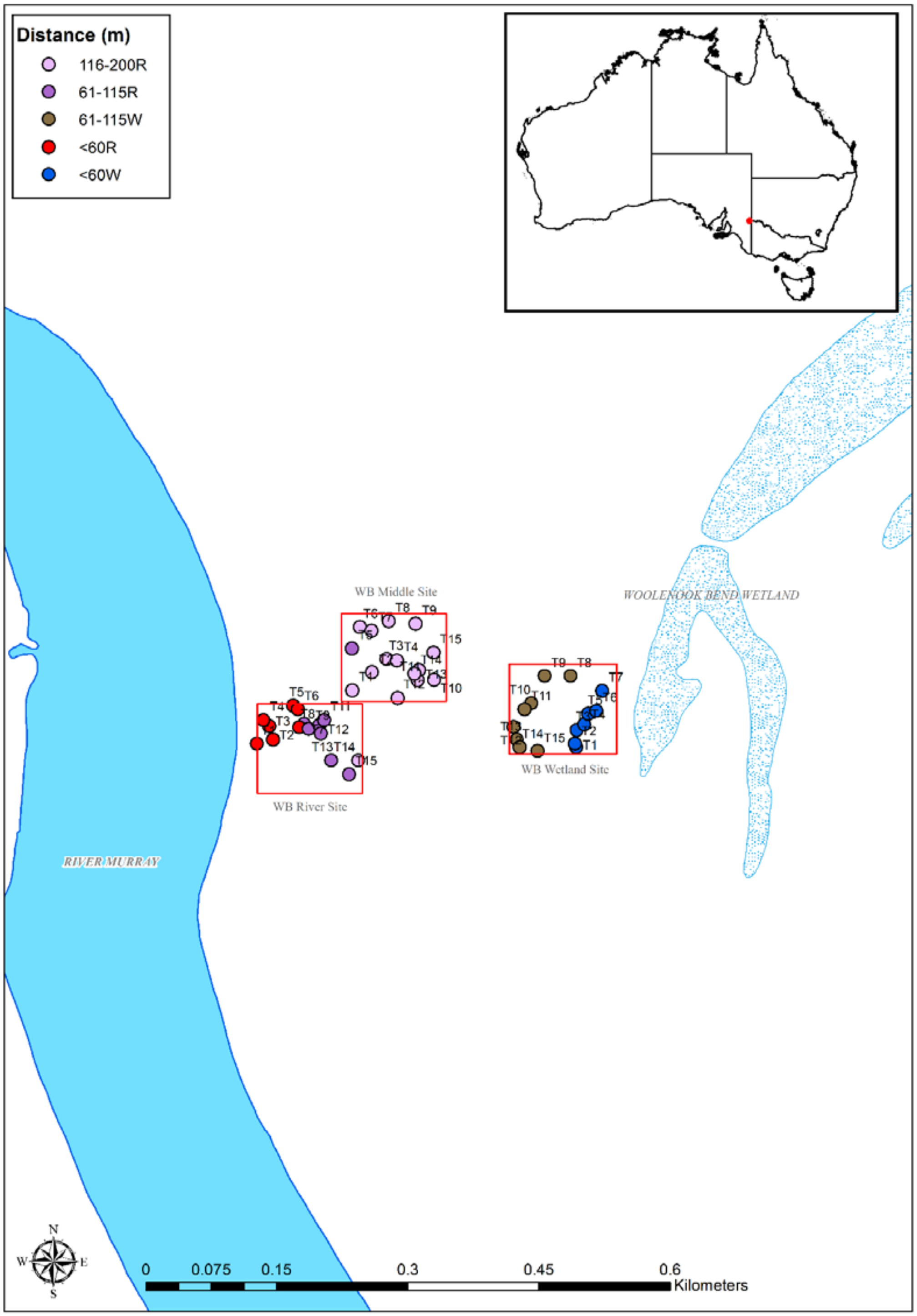
APPENDIX



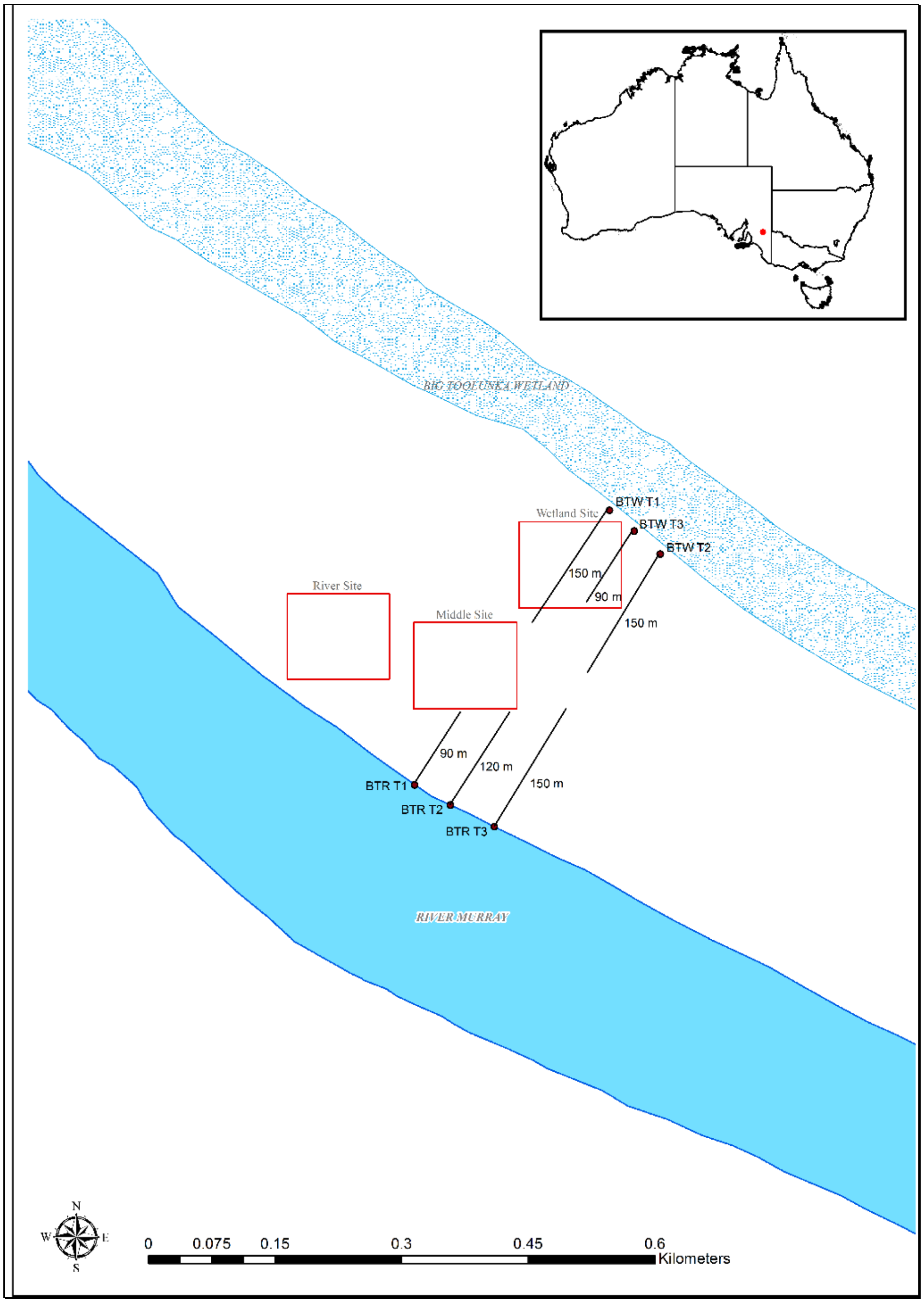
Appendix 1: Location of trees surveyed within categories assigned for distance from river (<80 m; 81–120 m; 121–150 m) or from wetland (<80 m; 81 – 150 m) edges within the managed Big Toolunka Flat, within Weir Pool 2 (Lock 2–3 reach of the River Murray, South Australia).



Appendix 2: Location of trees surveyed within categories assigned for distance from river (<80 m; 81–120 m; 121–200 or 201–-260 m) edge for Moorook site, within the unmanaged Weir Pool 3 (Lock 3–4 reach of the River Murray, South Australia).



Appendix 3: Location of trees surveyed within categories assigned for distance from river (<60 m; 61–115 m; 116 –200) or from wetland edge (<60 m; 61–115 m) edge within the managed Woolenook Bend site, within Weir Pool 5 (Lock 5–6 reach of the River Murray, South Australia).



Appendix 4: Location of soil transects within the managed Big Toolunka Flat site, relative to monitoring plots within Weir Pool 2 (Lock 2–3 reach of the River Murray, South Australia).

Appendix 5: Species list for the understorey wetland surveys at: a. Big Tollunka Flat, b. Woolenook Bend and c. Moorook (*denotes exotic species, **denotes proclaimed pest plant in South Australia, # denotes listed as rare in South Australia, ### denotes listed as endangered in South Australia).

a).

Elevation	**Pool level**		**10 cm**		**20 cm**		**30 cm**		**40 cm**		**50 cm**		**60 cm**	
Survey Date	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**
Taxon														
Acacia stenophylla	*	*	*	*	*	*	*	*	*	*	*	*	*	*
*Asparagus officinalis**														*
*Aster subulatus**	*	*	*	*	*	*	*	*	*	*	*	*		*
*Conyza bonariensis**	*		*		*		*		*		*		*	
*Cuscuta campestris***		*		*		*		*		*		*		*
Cyperus gymnocaulos	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Daucus glochidiatus	*		*		*		*		*		*		*	
Duma florulenta	*	*	*	*	*	*	*	*	*	*	*	*		*
Eucalyptus camaldulensis	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Glycyrrhiza acanthocarpa		*		*		*		*		*		*		*
Juncus usitatus	*		*		*		*		*		*			
Lachnagrostis filiformis	*		*		*		*		*		*			
*Lactuca serriola**	*		*		*		*		*		*		*	
Ludwigia peploides		*		*		*		*		*		*		
Medicago spp.*	*		*		*		*		*		*		*	
*Riechardia tingitana**		*		*		*		*		*		*		
Samolus repens		*		*		*		*		*		*		*
Senecio runcinifolius													*	
Senecio cunninghamii	*		*		*		*		*		*		*	
*Solanum nigrum**		*		*		*		*		*		*		
*Sonchus asper**													*	
Sporobolus mitchellii													*	*
Stemodia florulenta		*		*		*		*		*		*		*
Teucrium racemosum													*	*
Typha domingensis	*	*	*	*	*	*	*	*	*	*	*	*		
*Vicia sativa**	*		*		*		*		*		*		*	
Wahlenbergia fluminalis	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Total	**15**	**14**	**15**	**14**	**15**	**14**	**15**	**14**	**15**	**14**	**15**	**14**	**14**	**13**

b).

Elevation	**Pool level**		**10 cm**		**20 cm**		**30 cm**		**40 cm**		**50 cm**		**60 cm**	
Survey Date	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**
Taxon														
Acacia stenophylla	*	*	*	*	*	*	*	*		*		*		
Alternanthera denticulata		*		*		*								
*Anagallis arvensis**			*				*							
*Aster subulatus**	*		*											
Bolboschoenus caldwellii	*	*	*	*										
Centipeda minima	*	*	*	*	*	*		*		*		*		
Chamaesyce drummondii					*									
Chenopodium nitrariaceum														*
*Conyza bonariensis**				*		*		*		*				
Cotula coronopifolia		*						*		*				
Crassula helmsii	*		*											
Crassula sieberana ###		*		*										
Cyperus gymnocaulos	*	*	*	*	*	*		*		*	*		*	
Duma florulenta	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Enchylaena tomentosa										*				
Epaltes australis	*		*											
*Erodium cicutarium**		*		*		*		*		*		*		*
Eucalyptus camaldulensis	*		*								*		*	*
Glycyrrhiza acanthocarpa	*		*	*	*	*	*	*		*	*		*	
Helichrysum luteo-album	*		*											
*Heliotropium europaeum**						*		*		*		*		
Juncus usitatus		*		*										
Lepidium sp.							*		*		*			
Ludwigia peploides	*	*	*	*										
*Melilotus indicus**	*		*		*									
Mimulus repens		*												
Myriophyllum verrucosum	*	*	*	*										
*Paspalum distichum**										*				
Phragmites australis				*				*						
Senecio runcinifolius			*											

Elevation	**Pool level**		**10 cm**		**20 cm**		**30 cm**		**40 cm**		**50 cm**		**60 cm**	
Survey Date	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**
Taxon														
Senecio cunninghamii	*	*	*	*	*	*	*	*	*	*	*	*	*	*
*Solanum nigrum**						*		*		*				
*Sonchus asper**		*		*		*		*	*		*		*	
*Sonchus oleraceus**					*		*							
Sporobolus mitchellii		*		*						*				
Stemodia florulenta	*	*	*	*		*		*		*		*		
*Xanthium strumarium***		*		*		*		*		*				
Total	**16**	**18**	**18**	**19**	**9**	**14**	**7**	**15**	**4**	**16**	**7**	**7**	**6**	**5**

c).

Elevation	**Pool level**		**10 cm**		**20 cm**		**30 cm**		**40 cm**		**50 cm**		**60 cm**	
Survey Date	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**	**August 2015**	**February 2016**
Taxon														
Cyperus gymnocaulos	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Duma florulenta	*	*	*	*	*	*	*	*	*	*	*	*		*
Duma horrida #	*		*		*		*		*		*		*	
Einadia nutans	*	*	*	*	*	*	*	*	*	*	*	*	*	*
*Helminthotheca echioides**	*	*	*	*	*	*	*	*	*	*	*	*	*	
Lepidium sp.													*	
Medicago spp.*	*	*	*	*	*	*	*	*	*	*	*	*	*	
*Melilotus indicus**	*		*		*		*		*		*		*	
Myoporum parvifolium #	*	*	*	*	*	*	*	*	*	*	*	*	*	*
*Paspalum distichum**	*	*	*	*	*	*	*	*	*	*	*	*		
Phragmites australis	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Senecio runcinifolius													*	
Senecio cunninghamii	*		*		*		*		*		*		*	
*Sonchus asper**	*		*		*		*		*		*			
Teucrium racemosum	*		*		*		*		*		*			
Typha domingensis	*	*	*	*	*	*	*	*	*	*	*	*		
Wahlenbergia fluminalis		*		*		*		*		*		*		*
Total	**14**	**10**	**14**	**10**	**14**	**10**	**14**	**10**	**14**	**10**	**14**	**10**	**11**	**6**

Appendix 6: Description of TCI scores and how trees respond to increase water availability. Modified from Souter *et al.* (2010)

TCI score range	Descriptor	Tree responsiveness to increased water availability
0	None	Tree may or may not be dead and only a small proportion of the tree may respond to increased water availability through epicormic growth.
0.001 – 0.01	Minimal	Tree can respond through epicormic growth, but it is localized and often dense. Response might be slow and crown contraction may be evident.
0.011 – 0.04	Sparse	Can respond through epicormic growth and crown contraction. Epicormic growth is localized, but often dense.
0.041 – 0.16	Sparse- Medium	Respond through both crown and epicormic growth will similarly increase in extent/density
0.161 – 0.360	Medium	Respond through both crown and epicormic growth will similarly increase in extent/density
0.361 – 0.640	Medium - Major	Respond with growth at edge of crown, slowly increasing density
0.641 – 0.810	Major	Respond with growth at edge of crown, slowly increasing density
>0.81	Maximum	N/A