Report

Christmas Creek Vegetation Health Monitoring and Management Plan – Annual Report, December 2013

Environment

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Fortescue
The New Force in Iron Ore

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ABBREVIATIONS

Abbreviation	Definition
°C	Degrees Celsius
%	Per cent
ANOVA	Analysis of Variance
Astron	Astron Environmental Services
BoM	Bureau of Meteorology
CCS	Crown Condition Score
cm^2	Centimetres Squared
DBH	Diameter-at-Breast-Height-over-Bark
DEC	Department of Environment and Conservation
DI	Drawdown Impact
DR	Drawdown Reference
EI	Eastern Impact
EPA	Environmental Protection Authority
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
ER	Eastern Reference
Fortescue	Fortescue Metals Group Pty Ltd
g	Grams
m	Metres
Md	Midday
mm	Millimetres
MPa	Mega Pascals
NMDS	Non-metric Multidimensional Scaling
Pd	Predawn
PERMANOVA	Permutational Multivariate Analysis of Variance
PFC	Projected Foliar Cover
SI	Samphire Impact
SR	Samphire Reference
the Program	Vegetation Health Monitoring and Management Program
the Project	Christmas Creek Water Management Scheme Project
the Project area	Christmas Creek Mine Site
VHMMP	Vegetation Health Monitoring and Management Plan
VPD	Vapour Pressure Deficit
w/w %	Percentage Weight for Weight
WI	Western Impact
WR	Western Reference

GLOSSARY

Adaptive management – An approach to management that is based on making decisions as part of an on-going process of monitoring, review and adaptation.

Atmospheric demand – The demand for water from soil and vegetated surfaces owing to weather conditions which determines the rate of water vapour exchange between the given surface and the atmosphere; this represents the amount of water used by vegetation (de Jager & van Zyl 1989).

Basal area – The sum of the cross-sectional areas of all the stems of a tree at diameter at breast height over bark.

Dewater – Process to exclude groundwater from entering a mine via pumping.

Diameter at breast height over bark (DBH) – Measurement of tree trunk diameter (over bark) taken at breast height (1.3 m from the ground).

Drawdown – Decline in water level (usually referring to groundwater) resulting from the rate of extraction exceeding the rate of replenishment.

Ecosystem function – The capacity of a system to provide and maintain essential regulatory, habitat, production and information processes and structures via complex interactions between biotic and abiotic components in order to maintain biodiversity.

Ecosystem service value – The value of processes or materials that are provided by ecosystems; such as clean water, climate regulation and nutrient cycling.

Edaphic – Of or relating to soil, usually in relation to soil properties.

Epicormic growth – Activation and growth of dormant buds in stems of trees that often arise after stress, such as from physical damage (e.g. fire or insect attack) or from physiological changes (e.g. water deficit).

Groundwater – Water found in the saturated zone of a soil profile.

Groundwater abstraction – The removal of groundwater for industrial, commercial or domestic use.

Groundwater reinjection – The return of excess groundwater to the groundwater system (aquifer) following dewatering and abstraction in order to conserve water for future use and to minimise environmental effects.

Keystone species – Species which provide high ecosystem service value to the community, or species with high conservation value of which little precise knowledge regarding ecosystem function is known.

Leaf water potential – The energy state of water within the conducting tissue of a leaf as measured in units of pressure. Leaf water potential is positively correlated with water status of the leaf and whole plant. So, in general, higher plant water contents equate with higher leaf water potential.

Life history – The descriptive account of the stages through which an organism passes during its existence, starting from birth through to death.

Phenology – The study of periodic biological phenomena, such as flowering, in relation to the seasons and/or climate.

Phreatophyte – A plant which is either wholly or partly reliant on groundwater for all or part of the year in order to meet its water demands.

Phyllode – A flat, leaf-like petiole functioning as a photosynthetic organ, usually in the absence of a leaf blade.

Saddle – A low point on a ridge or interfluves, generally a divide between the heads of streams flowing in opposite directions.

Soil moisture – Water contained in the pore spaces of a soil.

Species zonation – The distribution of species across different geographical zones, such as the variation in depth to groundwater.

Stressor – Environmental factor that reduces plant performance.

Water status – Loose term that describes how well a plant's requirements for water are being met, combining factors such as leaf water potential, stomatal conductance and transpiration (Lambers et al. 1998).

Water table – The surface below which soil strata are saturated with water.

EXECUTIVE SUMMARY

Fortescue Metals Group Pty Ltd (Fortescue) operates a series of iron ore mines in the Pilbara region of Western Australia, including the Chichester Operations. The Christmas Creek mine site is one of two operating iron ore mines which form the Chichester Operations. Mining commenced at the Christmas Creek mine site in 2008. Mining post-2011 required access to ore below the water table and a subsequent increase in dewatering. The Christmas Creek Water Management Scheme project (the Project) was approved as per Ministerial Statement 871 in August 2011. According to Ministerial conditions, Fortescue is required to manage groundwater abstraction and disposal (dewatering and injection) to ensure:

1. There is no adverse impact on native vegetation communities attributable to the project outside the predicted impact areas.
2. Within the proposed impact areas there is no mortality of keystone plant species or significant changes in habitat characteristics attributable to the project.

The Vegetation Health Monitoring and Management Plan (VHMMP [CC-PL-EN-0004 Rev2]) was designed to satisfy Condition 8 of Ministerial Statement 871. This plan specifies monitoring management triggers for the four keystone plant species and their associated habitats identified as occurring within the Project area: *Acacia aneura* (mulga), *Eucalyptus victrix, Eucalyptus camaldulensis* and *Tecticornia* spp. (samphire). Despite *Eucalyptus camaldulensis* being mapped within the Project area, none were identified as occurring within the monitoring sites.

The plan outlines that an initial exceedance of a trigger value necessitates an increased frequency of monitoring and additional analysis to determine whether the cause of the exceedance is due to the dewatering or injection (Level 1 Vegetation Management Response Trigger). If Level 1 investigations identify that significant adverse differences attributable to the Project are determined or predicted to occur without management intervention then a Level 2 Vegetation Management Response Trigger is exceeded. If this occurs, the VHMMP requires further monitoring be undertaken along with management intervention and subsequent additional reporting obligations.

Results of the 2013 monitoring surveys indicate that Level 1 monitoring management triggers have been exceeded in all three communities. As such, Fortescue is required to implement the responses as outlined under Section 11 (Corrective Action) of the VHMMP (CC-PL-EN-0004 Rev2) which involves increased frequency of monitoring and a further analysis of cause and effect. However, excluding the results specific to monitoring management triggers, when all trends within the three communities were examined, there was no strong indication that an impact has occurred, especially for the phreatophytic and samphire communities; further investigation as directed by the VHMMP (CC-PL-EN-0004 Rev2) is necessary to confirm this.

At mulga monitoring sites, Level 1 triggers have been exceeded for midday water potential (EI3), canopy cover (EI3 and EI4) and multivariate values for all ecophysiological parameters

(EI3). Despite the exceedances, overall, the condition of mulga in both eastern and western areas as assessed by visual health ratings was good with reference and potential impact sites comparable and trending similarly in 2013. There have also been no deaths of sample trees to date. Declining soil moisture at both the reference and potential impact sites at the end of the dry season (November 2013) indicates that if mounding is occurring, groundwater remains below 0.5 m depth and therefore, below the depth of the majority of mulga roots.

In the phreatophytic community, monitoring management triggers were exceeded for predawn water potential for both potential impact sites during 2013 and for potential impact site DI1 in the multivariate control chart analysis in November 2013. Further investigation of the exceedances is likely to indicate that groundwater drawdown was not the cause of the trends observed and that the trees are maintaining good health. If dewatering was having an effect at the monitoring sites then water potential would be expected to be significantly lower than at the reference site and displaying a negative trend.

Two of the monitoring management triggers were exceeded in monitoring of the samphire community: height of samphires was significantly greater in the potential impact area and there was a difference in the multivariate analysis of height and tip die back (health). Reporting against the monitoring management trigger in relation to community composition change was not possible due to the inability to identify species because of the absence of reproductive structures on the plants at both reference and potential impact sites. Despite the exceedances, samphire communities within both the reference and potential impact areas appear in relatively good health. Further, health of samphires is rated as higher in the potential impact site than at the reference site. Differences in height and trends in health may be due to inherent site differences such as depth of soil and soil salinity as potential impact sites are somewhat further from the centre of the Fortescue Marsh than reference sites.

Based on the findings of the 2013 monitoring surveys, the following recommendations are made:

- To address the exceedances of the Level 1 monitoring management triggers, Fortescue implement the responses as outlined under Section 11 (Corrective Action) in the VHMMP (CC-PL-EN-0004 Rev2).
- Fortescue initiates a review of the VHMMP (CC-PL-EN-0004 Rev2) to assess the suitability of the current monitoring management triggers, the limits that have been set and the statistical analyses that are specified to assess them.

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1. INTRODUCTION

1.1 Project Background

Fortescue Metals Group Pty Ltd (Fortescue) has developed the Pilbara Iron Ore and Infrastructure Project, which involves a series of iron ore mines in the Pilbara region of Western Australia. Included in the Pilbara Iron Ore and Infrastructure Project are the Chichester Operations, which has two operating iron ore mines, Cloudbreak and Christmas Creek. The Christmas Creek mine site (the Project area) is located approximately 110 km north of Newman, in the central Pilbara region (Figure 1). Mining commenced in the Project area in 2008.

Prior to 2011, mining within the Project area had been undertaken above the water table. Ongoing mining required access to ore below the water table, so an increase in dewatering is required. Fortescue submitted a proposal (the Christmas Creek Water Management Scheme Project (the Project)) to the Environmental Protection Authority (EPA) to request the dewatering rate at Christmas Creek be increased to 50 gigalitres per annum and that surplus water be injected into the groundwater aquifers. Under Section 40 of the *Environmental Protection Act 1986* the Project required assessment at the level of 'Assessment on Proponent Information' (EPA 2011). The Project was approved by the State Minister for Environment as per Ministerial Statement 871 (MS 871) on 1 August 2011 and by the Federal Minister for Sustainability, Environment, Water, Population and Communities under *Environment, Protection and Biodiversity Conservation Act 1999* (EPBC Act), approval reference EPBC2010/5706, on 11 August 2011.

The Minister set out in the conditions of approval (MS 871, Condition 8-1) that Fortescue should manage groundwater abstraction and disposal (dewatering and injection) to ensure:

1. There is no adverse impact on native vegetation communities attributable to the project outside the predicted impact areas[1].
2. Within the proposed impact areas there is no mortality of keystone plant species or significant changes in habitat characteristics attributable to the project.

Requirements for monitoring were also specified in MS 871. Condition 8-2 requires Fortescue to prepare a Vegetation Health Monitoring and Management Plan (VHMMP) for the Project to verify and ensure that the requirements of Condition 8-1 shall be met. Condition 8-4 requires that monitoring was undertaken prior to injection activities and is to continue until the Chief Executive Officer of the Office of the EPA determines that monitoring may cease.

[1]The *predicted/proposed impact areas* are defined in Schedule 2 of MS 871 and are provided in Figures 1 & 2

Figure 1: Location of Christmas Creek mine site.

The current VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) uses the framework developed by the International Union for the Conservation of Nature in order to:

- understand the current state of vegetation potentially affected by modified groundwater levels from dewatering and injection activities
- determine the pressures or threats to that vegetation
- evaluate and select adaptive management responses (Astron 2012a).

The VHMMP is designed to address the scientific rationale, vegetation health and community monitoring, and monitoring schedules required to satisfy Condition 8 of MS 871 and Condition 13 of EPBC2010/5706 (Astron 2012a).

1.2 Keystone Species and Habitats

Keystone plant species identified in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) are those species occurring in vegetation communities that provide high ecosystem service value to the community, or are species within communities of high conservation value of which little precise knowledge regarding ecosystem function is known (Astron 2012a, p.7). Keystone plant species and their associated habitats in the Project area as identified in the VHMMP are described below.

1.2.1 Mulga Communities

Mulga communities in the Project area are generally dominated by members of the mulga (*Acacia aneura*) species complex, ranging from low woodland through low open forests to mixed Acacia species scrub (Astron 2012a). Mulga communities occur over a broad range of landscape positions in the Project area including along drainage lines and in upslope positions including on saddles between broad drainage areas (Astron 2012a). Baseline groundwater monitoring indicated that depth to groundwater in areas of mulga communities ranges from around 3 m to greater than 15 m. Characteristics of mulga communities which are targeted for the monitoring of habitat and community health include cover, life history stage, and indicative health using measures of water status of dominant *Acacia* species. Comparison between sites allows for an assessment of any adverse impacts on mulga communities.

1.2.2 Phreatophytic Communities

Keystone plant species of the Project area which are restricted to major drainage lines are the phreatophytic riparian trees river red gum (*Eucalyptus camaldulensis*) and the more predominant coolibah (*E. victrix*) (Astron 2012a). Both species grow in open woodland formations in areas where baseline depth to groundwater ranges from about 3 m to greater than 15 m (Astron 2012a). *E. camaldulensis* are not present at any of the current monitoring sites. To ensure that habitat characteristics are being maintained, monitoring under the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) measures foliage density, canopy health, recruitment and tree water status.

1.2.3 Samphire Communities

Samphire communities of the Project area are largely comprised of *Tecticornia* species and shrubs such as *Muellerolimon salicorniaceum, Sesbania cannabina, Cullen cinereum* and *Frankenia* species (Astron 2012a). Samphire communities are restricted to marsh areas and range from the outer to fringing areas of marsh. The water table is typically between 2 and 5 m deep near the marsh fringe and shallows towards the centre of the marsh (Astron 2012a). Zonation of samphire species in the Project area is likely to reflect edaphic and water quality conditions as well as varying species tolerances to stressors such as drought, salinity and waterlogging. Zonation also likely reflects varying degrees of groundwater dependence (Astron 2012a). Monitoring focuses on species distribution and plant health. Although taxonomic identification of samphires is problematic, changes in distribution will indicate changes in habitat characteristics and allow for adaptive management to be implemented.

1.3 Environmental Management

As part of the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a), a series of environmental management objectives were developed with respect to mitigating potential impacts. These were to:

- prevent adverse impact on native vegetation communities attributable to the Project outside the predicted impact areas
- prevent mortality of keystone plant species or significant changes in habitat characteristics attributable to the Project within the dewatering and mounding impact areas.

In order to meet the goals and objectives of the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a), a detailed monitoring program (the Program) was included as part of the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a). The VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) outlines monitoring management triggers for each of the three vegetation communities with the three keystone species in Tables 6, 7 and 8 of the VHMMP. The plan outlines that an initial exceedance of a trigger value necessitates additional analysis to determine whether the cause of the exceedance was due to the dewatering or injection (Level 1 Vegetation Management Response Trigger). Specifically, the response is:

- re-examination of groundwater levels to validate that groundwater is within water management trigger levels
- increase in vegetation monitoring frequency

- compilation of rainfall, soils, and groundwater monitoring information for detailed statistical analyses using generalized linear modelling/multiple regression approach. The outcome of these analyses is to partition the degree of variance towards predictors of the vegetation impact.

If the investigations undertaken in the Level 1 response identify that significant adverse differences attributable to the project are determined or predicted to occur without management intervention, a Level 2 Vegetation Management Response Trigger is exceeded. In this case the response as outlined in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) involves additional monitoring as well as management intervention and various reporting obligations.

Fortescue engaged Astron Environmental Services (Astron) to implement the monitoring program. Baseline surveys were undertaken in 2011 and ongoing monitoring commenced in 2012. In 2013, Fortescue again engaged Astron to implement the monitoring program associated with the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a).

1.4 Report Outline

This document reports on the findings of the two field surveys undertaken in the Program in 2013, the first between 21 and 29 May and the second between 4 and 11 November. The objective of each survey was to measure the state of keystone species and associated habitats at a number of permanent monitoring sites. The broad monitoring hypothesis is that measurements of ecological parameters within keystone vegetation habitat or of keystone species at potential impact sites (drawdown impact areas or mounding impact areas), do not alter significantly beyond the natural variation of the reference sites. Results are presented with reference to monitoring management triggers as outlined in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a).

2. METHODOLOGY

2.1 Design of the Monitoring Program

Monitoring potential impacts on keystone species involves taking repeat measurements at previously installed potential impact and reference sites. Potential impact sites are located in the dewatering zone, where drawdown is predicted to occur and may have an effect on phreatophytic vegetation (coolibah communities), and two reinjection zones (eastern and western), where groundwater mounding is predicted to occur. Groundwater mounding may have an effect on mulga and samphire communities. Clearing of vegetation for operational areas or ore-body mapping had destroyed all three eastern baseline mulga monitoring sites established in 2011. Consequently, in 2012, reinstallation of all eastern mulga monitoring sites, including both reference and potential mounding impact sites, was required. In May 2013 an additional western potential mounding impact site was installed to replace the removal of an existing site which posed a potential health and safety issue: namely irrigation with treated effluent water. An additional potential dewatering impact site was also installed in May 2013. The structure of the monitoring program as of November 2013 is summarised in Table 1.

Table 1: Details of the monitoring sites in the Vegetation Health Monitoring and Management Program.

Monitoring Sites	Site Label	Site Type	Keystone Species	Potential Impact	No. of Sample Trees	No. of Transects	No. of Soil Bores
Western Reference 1	WR1	Reference	Mulga	n/a	30*#	3	4
Western Impact 2	WI2	Potential Impact	Mulga	Mounding	30*	3	4
Western Impact 3	WI3	Potential Impact	Mulga	Mounding	30*	3	4
Eastern Reference 2	ER2	Reference	Mulga	n/a	30*#	3	4
Eastern Impact 3	EI3	Potential Impact	Mulga	Mounding	30*#	3	4
Eastern Impact 4	EI4	Potential Impact	Mulga	Mounding	30*	3	4
Dewatering Reference 1	DR1	Reference	Phreatophytic	n/a	30*	3	n/a
Dewatering Impact 1	DI1	Potential Impact	Phreatophytic	Drawdown	30*	3	n/a
Dewatering Impact 2	DI2	Potential Impact	Phreatophytic	Drawdown	30*	3	n/a
Samphire Reference	SR3-6	Reference	Samphire	n/a	n/a	4	n/a
Samphire Impact	SI1-4	Potential Impact	Samphire	Mounding	n/a	4	n/a

Notes:
*includes a subset of 10 trees subject to quantitative measurements (quantitative sample).
#includes trees that are also monitored as part of MS707 conditions

The location of all currently monitored sites across the lease area is shown in Figure 2. Reference sites for mulga, coolibah and samphire communities are located outside of the predicted impact zones.

Figure 2: Monitoring site locations within the Project area.

The monitoring criteria and data analyses according to type of potential impact were specified in the VHMMP the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) (Error! Not a valid bookmark self-reference.**). All monitoring criteria have been met; however, some variations in the approach to analyses were necessary (**Error! Not a valid bookmark self-reference.**).Further details regarding statistical analyses, including variations from additional analyses specified in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) that were not listed in Table 5 of the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a), are covered in Section 2.12 below. The measurements taken to meet the monitoring criteria as outlined in** Error! Not a valid bookmark self-reference. **at the reference and potential impact sites include a combination of both qualitative and quantitative assessments and these are summarised in**

Table 3. These measurements were taken in accordance with the descriptions in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) with the exception of soil moisture. In the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a), soil moisture was to be collected at 1 m depth, but penetration beyond 0.5 m was not possible.

Table 2: Summary of monitoring to be conducted as outlined in Table 5 of the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) and any variations necessary in 2013.

Potential Impact	Monitoring Criteria	Data Analysis	Data Analysis (2013)
Groundwater decline due to dewatering.	Qualitative Phreatophytic tree health assessments	Non-parametric ANOVA (Zar 2009)	As specified – Kruskal-Wallis test (a non-parametric ANOVA)
	Quantitative Digital Canopy Photography	Univariate Control Chart – Level 1 management response required in exceedance of 1 Standard Deviation in percentage canopy cover	As specified.
		ANOVA – Level 1 management response required if significant differences normalised data and p<0.05) detected	As specified.
	Quantitative health assessments	Multivariate Control Charts of multiple ecophysiological variables – Level 1 management response required in exceedance of 90% Confidence Interval in Control Chart trend (Anderson and Thompson 2004)	As specified – where sufficient data available (that is, at least three time periods)
		ANOVA – Level 1 management response required if significant differences (normalised data, p<0.05) detected	As specified
Groundwater rise due to reinjection	Qualitative Mulga health assessments	Non-parametric ANOVA (Zar 2009)	As specified – Kruskal-Wallis test (a non-parametric ANOVA)
	Quantitative Mulga water status health assessments	Multivariate Control Charts of multiple ecophysiological variables – Level 1 management response required in exceedance of 90% Confidence Interval in Control Chart trend.	As specified – where sufficient data available (that is, at least three time periods)
		ANOVA – Level 1 management response required if significant differences (normalised data, p<0.05) detected.	As specified
		Tests of association between soil moisture measurements and water status	As specified – correlation analysis
	Samphire community analysis	Multivariate control charts of species presence and cover. Control limit set to 90% Confidence Interval.	Not conducted as species identification has not been possible due to an absence of reproductive parts

Potential Impact	Monitoring Criteria	Data Analysis	Data Analysis (2013)
		Per-MANOVA. Identification of significant species changes. Between year shifts in Samphire community represented in pairwise Analysis of Similarity Ordination Plots (Clarke and Warwick 2001).	Not conducted as species identification has not been possible due to an absence of reproductive parts
	Samphire health	Univariate Control Chart – Level 1 management response required in exceedance of 1 Standard Deviation in tip die off and height.	As specified for height but not for tip die off; calculation of 1 standard deviation not possible for these data due to the 3-category scale of measurement
		MANOVA – Level 1 management response required if significant differences ($p<0.05$) detected.	A non-parametric equivalent to MANOVA (PERMANAOVA) was used due to the data not meeting the assumptions required for parametric tests

Table 3: A summary of methods used in the monitoring program.

Measurement	Method	Sample no. per site	Description	Reference
Climate and Weather	Rainfall and vapour pressure deficit	n/a	Calculation of atmospheric demand from saturated and actual vapour pressure.	Bureau of Meteorology (2013a; 2013b), FMG Cloudbreak station and Webb (2010)
Soil Moisture	Gravimetric soil moisture	4 holes	Soil sampled from 0.4 to 0.5 m	n/a
Predawn Leaf Water Potential	Scholander pressure chamber	10 trees (4 sub-samples per tree)	Shoots are collected before dawn and tested in a pressure chamber. Measures water stress in relation to soil moisture availability.	Turner (1988)
Midday Leaf Water Potential	Scholander pressure chamber	10 trees (4 sub-samples per tree)	Shoots are collected at midday and tested in a pressure chamber. Measures water stress in relation to soil moisture availability and atmospheric loss.	Turner (1988)
Projected Foliar Cover (PFC)	Digital canopy photography	10 trees	Photographs taken looking skyward from permanently marked points.	MacFarlane et al. (2007a; 2007b)
Understorey Composition and Cover	Permanent transects	3 transects	Percentage cover estimates of different species along a fixed line.	Bullock (2006)
Diameter at Breast Height (DBH)	Manual diameter measurement	30 trees	Annual measure of tree diameter.	West (2009)
Visual Health Assessment	Qualitative visual assessment	30 trees	Visual scoring system of tree health characteristics.	Souter et al. (2009) Grimes (1978)
Samphire Community Health	Permanent transects	4 transects	Measure of cover and health of samphire.	Bullock (2006)

2.2 Climate and Weather

Climate data was sourced from the Bureau of Meteorology (BoM) Newman AERO weather station (no. 007176) and from Christmas Creek rainfall monitoring. Vapour pressure deficit is calculated according to Webb (2010).

2.3 Soil Moisture

Four holes in May 2013 and three in November 2013 were excavated by crowbar and shovel to a depth of 0.5 m at the mulga monitoring potential impact and reference sites to determine if mounding affected the level of moisture in soil. Soil samples were taken immediately following excavation of each hole from a depth between 0.4 m and 0.5 m. Samples were sealed in double zip-lock plastic bags that were rolled before closing to remove air pockets. The bags were placed in an esky and kept cool for transport to Perth. Gravimetric moisture analysis was completed by a National Association of Testing Authorities accredited laboratory.

2.4 Predawn and Midday Leaf Water Potential

At reference and potential impact sites, four excised shoots were sampled from the canopy of each quantitative sample tree of the keystone phreatophytic or mulga species, both before dawn and again at midday using a pole pruner. The shoots were immediately sealed in large, zip-lock plastic bags and kept chilled in an esky until water potential was measured using a pressure chamber (Model 1000, PMS Instrument Company, Oregon, USA), usually within one and a half hours of collection.

2.5 Projected Foliar Cover

Digital photographs were taken beneath the canopy of each mulga or phreatophytic tree in the quantitative subset at the reference and potential impact sites. An Olympus Toughshot 12 megapixel camera was mounted on a tripod, pointed skyward and levelled above a fixed position marked by a 600 mm star picket with a yellow cap placed on top. The photographs were taken aligning an arrow on the tripod directly towards the centre of the bole of each tree. The photographs were taken between 7 am and 10 am to reduce glare which can cause the canopy density to be underestimated.

Each photograph was processed by Adobe Photoshop Elements v7.0 using the method developed by MacFarlane et al. (2007a; 2007b). Sky pixels were differentiated from canopy pixels (stem and leaves) so that a relative proportion of canopy cover for each tree in the image was determined. This allows a measure of canopy cover change to be calculated when photography is repeated over time. As stated in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a), data from these images can only be used to interpret changes in foliar cover on a temporal scale.

2.6 Stem Diameter - Basal Area

Measuring stem diameter can provide information on tree water relations, tree growth, habitat dynamics, and seasonal and climatic changes when examined over time. For each tree within the reference and potential impact sites, the standard method of measuring stem diameter was used where a diameter tape is placed around the stem at breast height (1.3 m from the ground);

this method is known as the diameter-at-breast-height-over-bark, or DBH. During 2013, DBH was measured at the two newly installed sites – WI3 and DI2. Previously collected data are presented for all other sites currently part of the monitoring program.

2.7 Qualitative Visual Health Assessment

2.7.1 Mulga Communities

All mulga sample trees at each reference and mounding potential impact site were allocated a Grimes Grimes density score between 0 and 9 (Figure 3) and a series of health rating scores for canopy health based on two sets of health criteria (Fortescue criteria and Astron criteria), new tip growth and reproduction (

Table 4). If mistletoe was present a score based on the same criteria as tip growth and reproduction was recorded for the tree.

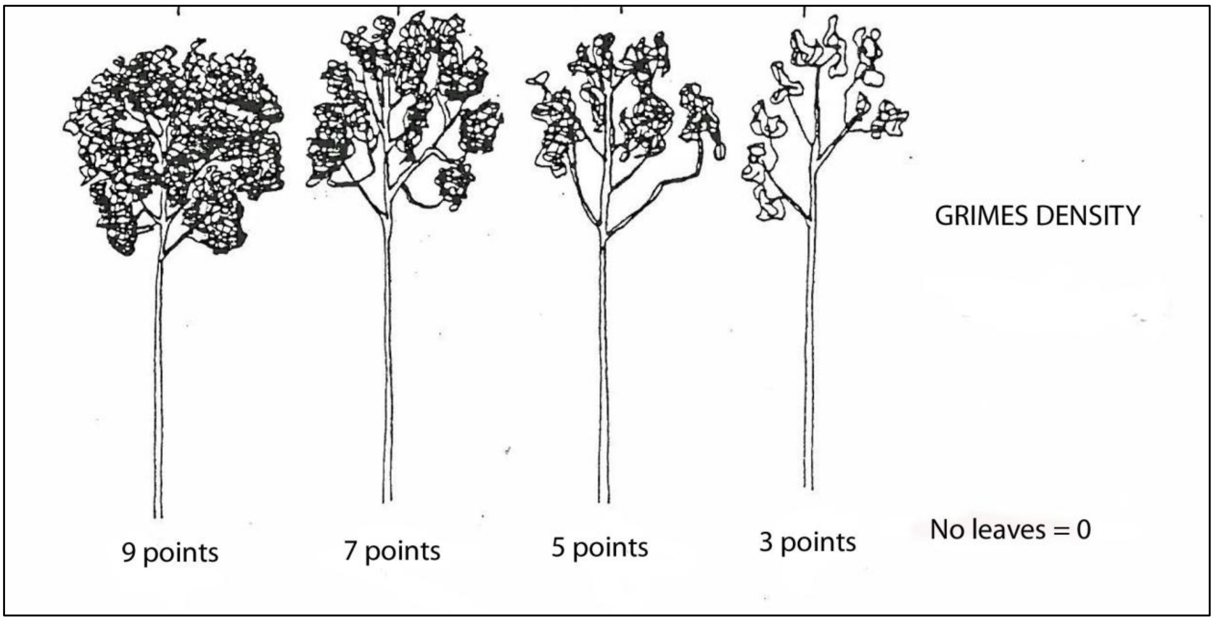

Figure 3: Grimes density scores.

Table 4: Mulga visual health score ratings (Astron 2009; Fortescue 2012). *PFC = projected foliar cover.

Mulga visual condition assessment		
Score	**Health rating**	**Health rating/description**
Canopy health score (Fortescue criteria)		
0	Dead	No phyllodes on canopy and branch ends dry and brittle when snapped (indicating no xylem flow). Bark exfoliating or flaking off.
1	Highly stressed	Pronounced shrivelling (greater than 20%) of buds or shoot tips. If total phyllode loss, then branch ends not dry and brittle when snapped. Evidence of epicormic or adventitious re-sprouting from branchlets.
2	Slightly stressed	Largely full canopy cover, some phyllodes may appear desiccated with brown/yellow hues, less than 20% shrivelling of buds or shoot tips.
3	Alive	Full canopy cover of healthy, green phyllodes present. No shrivelling of buds or shoot tips.
Canopy health score (Astron (2009) criteria)		
1	Dead	Plants beyond regenerative ability (0-5% PFC*) (fire impact excluded) Mostly dead branches Occasional epicormic shoots, mostly dead Cambium under bark no longer green
2	Poor	Plants with (very) sparse canopy (5-40% PFC) Dead branchlets and branches Senescence of older and recent leaves Dying of epicormic shoots Cambium under bark green, indicating potential to regenerate
3	Fair	Tips of branchlets dying or dead (40-60% PFC)) Leaves more susceptible to insect damage Noticeable leaf senescence of older leaves Epicormic shoots (stress related)
4	Good	Plants not as densely green (60-80% PFC) Some yellowing and drying of old leaves Young leaves green to yellow-green Occasional leaf insect damage
5	Excellent	Plants appearing vigorous and green (>80% PFC) Very little leaf senescence Very little insect damage on leaves
New tip growth (growth of new shoots from branch tips) and reproduction scores		
1	Absent	Effect is not visible
2	Scarce	Effect is present within the assessable crown but not readily visible
3	Common	Effect is clearly visible throughout the assessable crown
4	Prolific	Effect dominates the appearance of the assessable crown

2.7.2 Phreatophytic Communities

All sample trees at the reference and potential drawdown impact sites were visually assessed using the method of Souter et al. (2009). The method is based on a conceptual model of the symptoms of decline due to water stress and signs of recovery as conditions improve (Souter et al. 2009). The assessment consisted of both a crown condition score (CCS) and crown condition trajectory. CCS was based on a percentage estimate of crown extent and crown density using a category scale from 0 to 5 (Table 5). Crown extent refers to the amount of foliage on the outer edge of the crown, whilst crown density refers to the amount of foliage within the crown boundary. These scores were added and then 1 was subtracted (except when the value was 0) to derive a total CCS between 0 and 9. The subtraction of 1 was carried out to achieve an evenly distributed scale; if the scores were simply added, a score of 1 would not be possible because a "minimal" crown extent (score of 1) with a crown density score of 0 indicating no leaves, or vice versa, cannot exist. A score of 0 corresponds to no leaves; and a CCS of 9 indicates a tree that has maximum extent and density.

Abundance ratings were used to derive the crown condition trajectory. Three recovery attributes (epicormic growth, reproduction and crown tip growth) and three decline attributes (leaf die-off, leaf damage and mistletoe abundance) were rated from 0 (absent) to 3 (attribute dominates the appearance of the tree). Recovery and decline attributes were summed separately with one additional point added to the decline total if cracked bark was present. Epicormic growth was not counted if it was inactive. A crown condition trajectory was derived by summing both the recovery and decline totals. If recovery exceeded decline by more than one point trees were classified in the recovery trajectory, and vice versa for the decline trajectory. Trees were classified as stable if the difference was one point or less.

Table 5: Category scale used to assess crown extent, crown density, crown condition (extent and density) and abundance based on Souter et al. 2009. Abundance ratings applicable to epicormic growth, reproduction, crown tip growth, leaf die-off, leaf damage and mistletoe.

Crown Extent and Crown Density		
Score	**Description**	**Percentage (%)**
0	None	0
1	Minimal	1-10
2	Sparse	11-25
3	Medium	26-75
4	Major	76-90
5	Maximum	91-100
Crown Condition Score (Extent and Density)		
Score	**Description (Extent/Density)**	
0	No Leaves	
1	Minimal/Minimal	
2	Sparse/Minimal	
3	Medium/Minimal Sparse/Sparse	

Crown Extent and Crown Density		
4	Major/Minimal Medium/Sparse	
5	Major/Sparse Medium/Medium	
6	Maximum/Sparse Major/Medium	
7	Maximum/Medium Major/Major	
8	Maximum/Major	
9	Maximum/Maximum	
Abundance Rating		
Rating	**Description**	**Definition**
0	Absent	Attribute not present
1	Scarce	Attribute is present but not readily visible
2	Common	Attribute is clearly visible throughout the crown
3	Abundant	Attribute dominates the appearance of the crown

2.8 Vegetation Composition and Cover

A measure of habitat characteristics was captured using replicate 20 m line intercept transects in all dewatering and reinjection (drawdown and mounding respectively) reference and potential impact monitoring sites, including in samphire communities. Along each transect, a tape measure was laid out and the live extent of the crown that was intercepted by the tape for each species present was recorded. For each plant, the estimated foliage density within the intercepted section of the crown was also recorded along with the species. The presence and cover of weed species along each transect was also noted. Cover for each plant was calculated as the length of the crown along the transect multiplied by the percentage foliar cover estimate. Cover by species was calculated as the sum of the cover for each plant.

2.9 Samphire Community Health

Samphire community health was monitored along replicate 20 m transects, four located within the area of potential mounding impact and four located within a suitable reference area. Along each transect, the start and end point of each individual intercepting the transect was recorded, as well as the individual's height. A health score was assigned based on the percentage of tip browning (D. Huxtable, pers. comm.) (Table 6). Samphire species identification requires collection and examination of the fruiting material for each plant. The phenology of fruiting in samphire can be episodic and collection of fruits suitable for identification of different species that are morphologically similar is required (S. van Leeuwin, DEC, pers. comm.). One species of samphire was flowering during the May 2013 survey. Plant material was collected and transported back to Perth for identification by a suitably qualified and trained botanist.

Table 6: Health score associated with samphire communities; each individual plant is allocated a score based on per cent of tip browning observed.

Score	Category	Percentage of Tip Browning (%)
1	Poor	76 - 100
2	Moderate	26 - 75
3	Healthy	0 - 25

2.10 Leaf Litter Collection

As a trial to test methods that may improve the effectiveness of the Program, leaf litter fall was assessed by installing leaf litter traps during the May 2012 monitoring trip underneath the canopy of mulga at sites WI1 and WR1; a total of 12 traps were installed, six at each site. Each trap consisted of a 1,500 mm star picket with two black plastic buckets attached to the top. Holes were punched in the base of each bucket to allow water to drain. Holes punched in the sides of each bucket allowed them to be wired to the top of the star picket. The mulga phyllodes were removed from the traps during the November 2012 and May 2013 monitoring surveys and placed in paper bags. The samples were taken back to Perth, dried and weighed. Four traps were missing or destroyed by the May 2013 survey, two at site WR1 and two at site WI1 and could not be sampled. Site WI1 was decommissioned and all traps at that site were removed during May 2013. Traps were retained at WR1 and leaf litter was again collected in November 2013. Between the May and November 2013 surveys, one further trap was missing or destroyed at WR1.

2.11 Secondary Pressures

There are a number of secondary pressures that could affect vegetation at a regional scale and which may be evident within the Project area. These secondary pressures are taken into account as part of the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) and measurement and/or assessment incorporated into the Program. Each of these identified secondary pressures is outlined below.

2.11.1 Weeds

The presence of weeds was captured along line intercept transects as part of the vegetation composition and cover assessment. A qualitative assessment of weed cover across each of the potential impact and reference sites was recorded based on the same abundance rating scale used for the qualitative visual health assessments (Table 5).

2.11.2 Grazing

At each monitoring site the extent of grazing by cattle was assessed using the abundance rating scale. This data will be considered in conjunction with vegetation composition and cover data over time and reported on if changes in vegetation composition and cover are identified and if a statistical correlation with grazing pressure becomes evident.

2.11.3 Fire

In the event of fire within any of the monitoring sites, impacts to vegetation will be assessed as a component of on-ground monitoring activities. During monitoring events, the extent of any fire damage was again assessed using the abundance rating scale.

2.11.4 Climatic Variability

If any significant shift in the perennial plant communities between matched reference and potential impacts sites becomes evident, an assessment of climatic information will be used to indicate if seasonal factors or regional climate variability effects are influencing vegetation response.

2.12 Statistical Analysis

All monitoring sites were allocated to one of three site groups (Table 7). Differences between reference and impact sites were calculated at November 2013 and May 2013. Differences over time at each site were then calculated between:

- the latest 'end-of-dry' season measurements (November 2013) and measurements from the same season of the previous year (November 2012)
- the latest 'end-of-wet' season measurements (May 2013) and measurements from the same season of the previous monitoring period (May 2012)

Table 7: Site group according to type of potential impact and location for each of the eight monitoring sites.

Site Group	Impact	Reference
Drawdown	DI1 and DI2	DR1
Eastern mounding	EI3 and EI4	ER2
Western mounding	WI2 and WI3	WR1

For standard statistical analyses, all leaf water potential, PFC, tree health data (Astron criteria) and parameters for samphire (health, cover and height) were analysed using similar methods. Prior to performing statistical tests, data were checked for normality and equal variance using Shapiro's test and by inspection of boxplots. If both assumptions were met, ANOVA (parametric tests) were conducted to examine the difference between each site within each site group. Whenever the P-value of the ANOVA test was less than 0.05, a Tukey's HSD test was conducted to compare each site within each group. If the data did not fit the assumptions for parametric tests, transformations were attempted to achieve normally distributed data. If these transformations did not succeed, the Kruskal-Wallis test (a non-parametric ANOVA) was applied. If the P-value of this test was less than 0.05, a multiple comparison test was applied to identify differences between sites within groups. No analyses were performed on canopy health (Fortescue criteria), tip growth or reproduction scores.

Leaf water potential data from mulga and phreatophytic communities, PFC data for phreatophytic communities, and height and tip die off (health) for samphire, were also subject to control chart analysis as specified in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a). Multivariate control charts were produced using predawn and midday water potential, and PFC according to the procedure of Anderson and Thompson (2004) with the control limit set at 90%. In order to run the procedure, mean values for each of these variables at each site were calculated. Univariate control charts were prepared for PFC in phreatophytic communities, and height of samphire in samphire communities, with control limits established at one standard deviation from the mean. It was not possible to construct a control chart for tip die off for samphire using one standard deviation as a control limit as was specified in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a). This is because of the simple 3-category scale used to rate die off. As the time series of data available was minimal, all time periods were used to calculate the control limits for both multivariate and univariate control charts. Further, three time points were required to construct a control chart.

Height and tip die off (health) data were also subject to multivariate analysis as specified in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a). However, multivariate analysis of variance (MANOVA) as specified in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) was not possible due to data not conforming to assumptions of normality and equal variance. Therefore, the non-parametric equivalent test, PerMANOVA was used with the Gower distance measure used to construct the distance matrix. This analysis followed the procedures outlined in Clarke and Gorley (2006) and was carried out using the appropriate modules of Primer v6 (Clarke & Gorley 2006. Significance was set at $P < 0.05$.

Where deaths of sample trees for mulga or phreatophytic trees were recorded at a potential impact site, survivorship analysis was undertaken using the method of Kaplan and Meier (1958). Calculations were conducted in Excel and statistical significance was deemed to be $P < 0.05$. In Tables 6 and 7 of the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a), analysis of death using control charts was specified; however, this type of analysis is unsuitable for count data such as this, particular with no deaths recorded at most sites to date. Therefore, control charts have not been prepared in this instance.

Gravimetric soil moisture data were checked for normality and equal variance prior to separation into eastern and western mounding groups for analyses. In one analysis, a linear model was built to include the effect of site and time together. Linear models were tested using ANOVA to determine which of these two factors contributed to the difference, and Tukey's HSD test was conducted if any significant difference was detected. In a second analysis, the association between soil moisture and water potential (midday and predawn separately) was tested using correlation. The value for water potential for the tree adjacent to each hole used to sample soil moisture was assigned as the response variable. These analysis were also performed using R (Version 2.15.0, R Development Core Team 2011). Significant results were deemed to be $P < 0.05$.

Comparisons of understorey community data between sites over time (May 2012 to May 2013 and November 2012 to November 2013) within phreatophytic and mulga communities was achieved with non-metric multidimensional scaling (NMDS) ordination and PerMANOVA based on 9999 actual permutations. Bray-Curtis distances were used in both NMDS and PerMANOVA following square root transformations. PerMANOVA analyses followed the procedures outlined in Clarke and Gorley (2006) and were carried out using the appropriate modules of Primer v6 (Clarke & Gorley 2006). Significance was set at $P < 0.05$. Due to the unavailability of reproductive material on samphire plants, species identification was not possible and the multivariate analyses as outlined in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) for were not able to be run.

3. RESULTS

3.1 Climate and Weather

In the 12 months November 2012 to October 2013 Christmas Creek weather station recorded 435 mm of rainfall, well above the long-term Newman AERO average of 314 mm and well above Newman AERO's annual rainfall of 341 mm. Above-average rainfall was recorded at Christmas Creek in December 2012 and May and June 2013 (Figure 4). In 2011/2012 Newman AERO recorded 453 mm, 44% higher than the long-term mean annual rainfall for this region (314 mm) and in 2010/2011 annual rainfall (416 mm) was approximately 33% above average.

Maximum monthly VPD in the Pilbara is usually recorded from October to February and is associated with high temperatures. In the 12 months to the end of October 2013, monthly average VPD was highest in November 2012, steadily decreasing to a minimum in June 2013. Seasonally low monthly VPD was recorded in January 2013 due to cloud associated with rainfall events. Monthly VPD has been steadily increasing since June 2013.

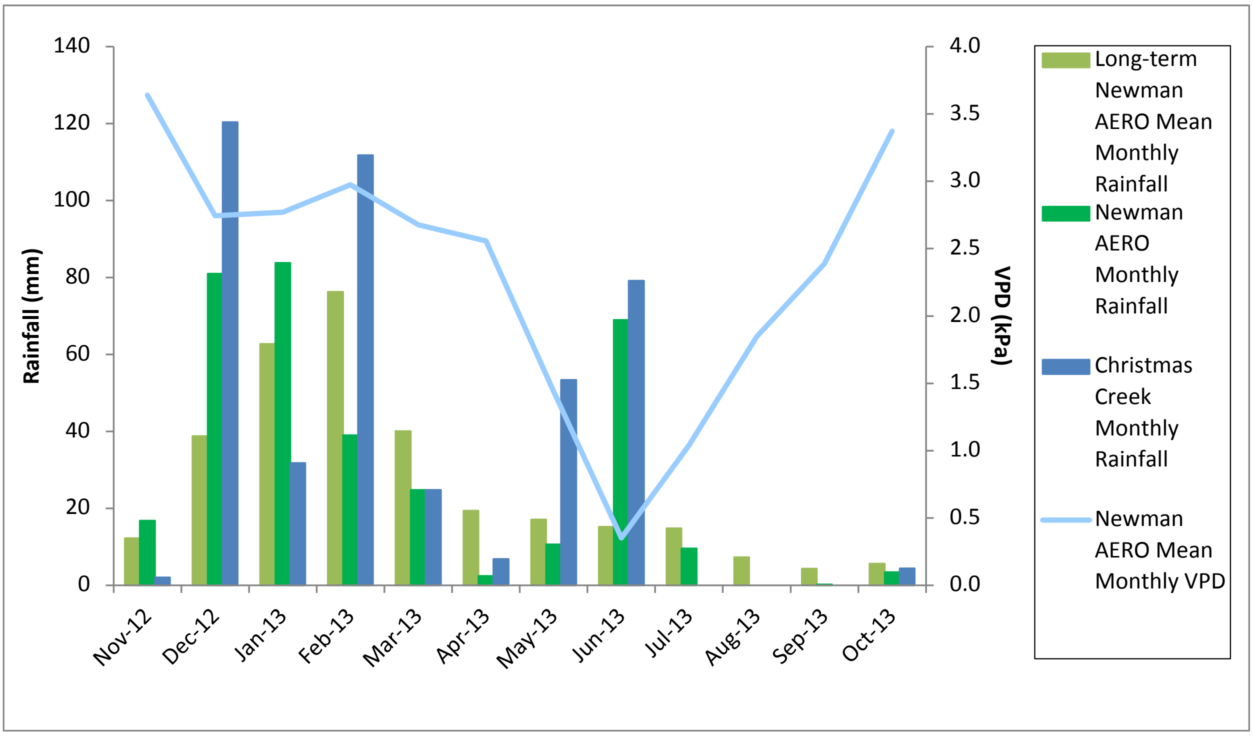

Figure 4: Long-term mean monthly rainfall (1950 to 2013), Newman AERO and Christmas Creek monthly rainfall, and mean monthly vapour pressure deficit (VPD) of the Project area region. Monthly rainfall (November 2012 to October 2013) obtained from the BoM Newman AERO weather station (#007176) and FMG Christmas Creek weather station. VPD was calculated according to Webb (2010) using Newman AERO data.

3.2 Mulga Communities

3.2.1 Soil Moisture

Mean gravimetric soil moisture content at the eastern mulga sites declined from a high recorded in May 2013 to a low in November 2013 (Figure 5). The eastern reference site (ER2) recorded the highest mean gravimetric soil moisture in May and November 2013 and potential impact site EI3 recorded the lowest. There was considerable variation within sites in May 2013. There was a significant difference between sites over time for mean gravimetric soil moisture (ANOVA, $F_{2,5} = 4.03$ $P = 0.028$) with Tukey's pairwise comparison indicating a difference between the reference site and potential impact site EI3 when all results were compared over time ($P = 0.026$).

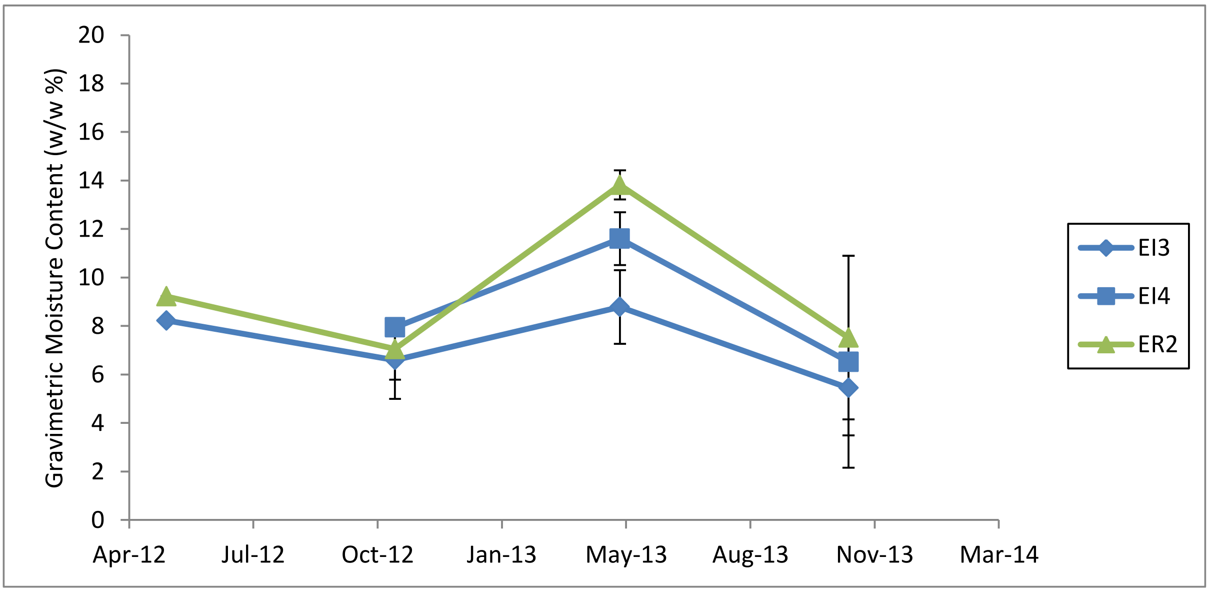

Figure 5: Mean gravimetric moisture content of soil collected at eastern potential impact sites (EI3 and EI4) and reference site (ER2) between May 2012 and November 2013 at depths between 0.4 and 0.5 m (n= 4 for May 2012 to May 2013; n = 3 November 2013). Error bars represent standard deviation.

At the western mulga sites, mean gravimetric soil moisture content has fluctuated seasonally since August 2011 (Figure 6). The highest soil moisture content was recorded at the western reference site (WR1) in both May and November 2013; there was some variation within the site. The soil moisture content at both of the western potential impact sites was similar in May and November 2013 and there was less variation within the potential impact sites than within the reference site. Mean gravimetric soil moisture content at the western reference site was significantly different to both western potential impact sites since monitoring commenced (ANOVA, $F_{2,5} = 18.68$ $P < 0.001$) with Tukey's pairwise comparison indicating a difference between the reference site and both potential impact sites when all results were compared over time ($P < 0.001$).

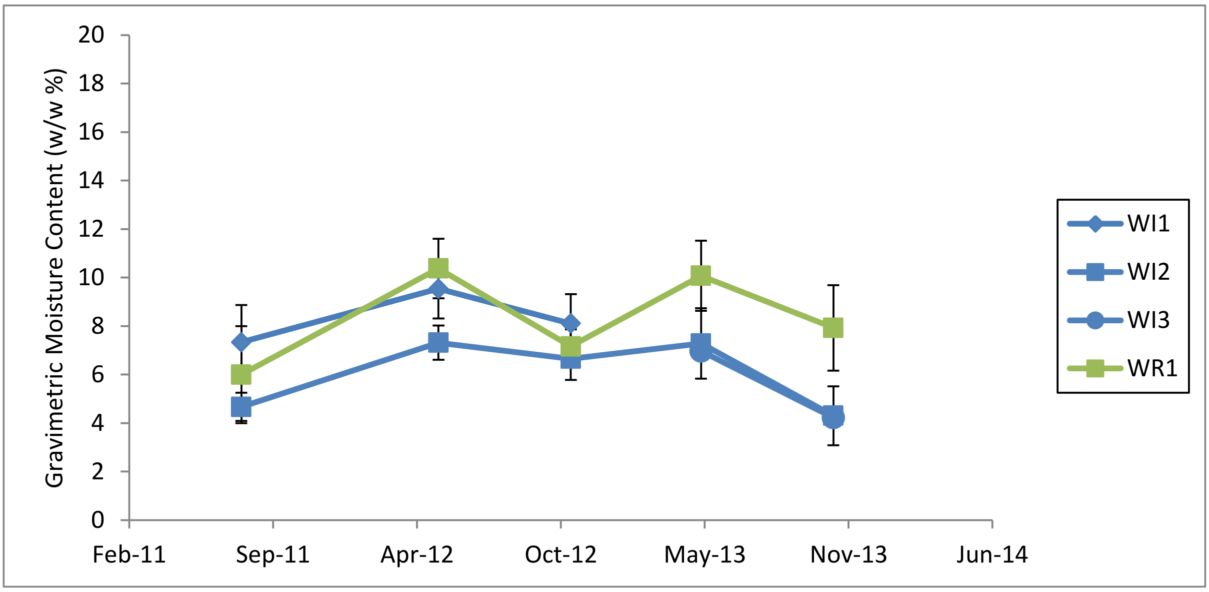

Figure 6: Mean gravimetric moisture content of soil collected at western potential impact sites (WI1, WI2 and WI3) and reference site (WR1) between August 2011 and November 2013 at depths between 0.4 and 0.5 m (n= 4 August 2011 and May 2013; n = 3 November 2013). Error bars represent standard deviation.

3.2.2 Leaf Water Potential

Mean predawn and midday leaf water potentials have trended similarly over time at all of the eastern mulga sites (Figure 7). A strong seasonal influence on leaf water potentials at all sites is evident. Both predawn and midday water potentials remain the highest at potential impact site EI3, while remaining similar at the reference site ER2 and potential impact site EI4.

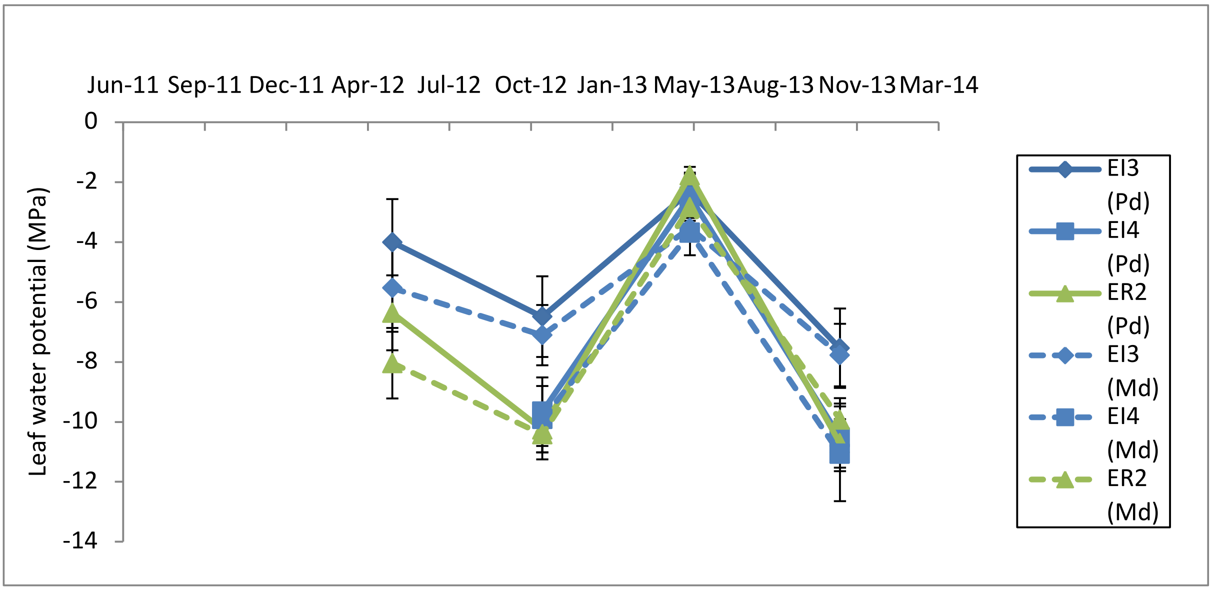

Figure 7: Mean predawn (Pd) and midday (Md) leaf water potential (MPa) of *Acacia aneura* at eastern potential impact sites (EI3 and EI4) and reference site (ER2) from May 2012 to November 2013 (n= 10). Error bars represent standard deviation.

Comparison of predawn water potential and midday water potential between reference and potential impact sites was significant at the eastern sites in May and November 2013 (Table 8). Post-hoc comparisons revealed significant differences between reference sites and potential impact sites for both parameters at both times. There was one incidence when midday water potential was significantly greater than at the reference site, representing an exceedance of the Level 1 monitoring management trigger: EI3 in November 2013 (Figure 7 and Table 8).

Table 8: Results of ANOVA and Kruskal Wallis tests comparing predawn and midday water potential between monitoring sites in the Eastern reference and potential impact areas. Where ANOVA or Kuskal Wallis test was significant, Tukey's pairwise comparisons or multiple comparison after Kruskal Wallis test was conducted to determine if potential impact sites were different to reference sites.

	Predawn				Midday			
			Sig. diff. to reference?				Sig. diff. to reference?	
	F or χ^2	P	EI3	EI4	F or χ^2	P	EI3	EI4
May	32.6 (χ^2)	< 0.001	Yes	Yes	43.9 (χ^2)	< 0.001	Yes	Yes
November	68.2 (χ^2)	< 0.001	Yes	No	64.35 (F)	< 0.001	Yes	Yes

Year-on-year change between May 2012 and May 2013 saw an increase in predawn leaf water potentials at EI3 and ER2 (Figure 8). The greater than 4 MPa increase in predawn leaf water potential at ER2 was significantly different (ANOVA $F_{1,18}$ = 20.09 $P < 0.001$; HSD $P < 0.001$) to the less than 2 MPa increase recorded at EI3. Similarly, the greater than 5 MPa increase in midday leaf water potential recorded at ER2 was significantly different (ANOVA $F_{1,18}$ = 28.08 $P < 0.001$; HSD $P < 0.001$) to the 2 MPa increase recorded at EI3.

Change in predawn leaf water potential between November 2012 and November 2013 was similar at all eastern mulga sites, recording a slight decrease (Figure 8). At ER2, a small increase (less than 1 MPa) in midday leaf water potential was recorded between November 2012 and November 2013. The small declines recorded at EI3 and EI4 over the same period were significantly different (ANOVA $F_{2,27}$ = 8.369 $P = 0.001$; HSD $P = 0.027$ and $P = 0.001$ respectively) to the increase recorded at the reference site.

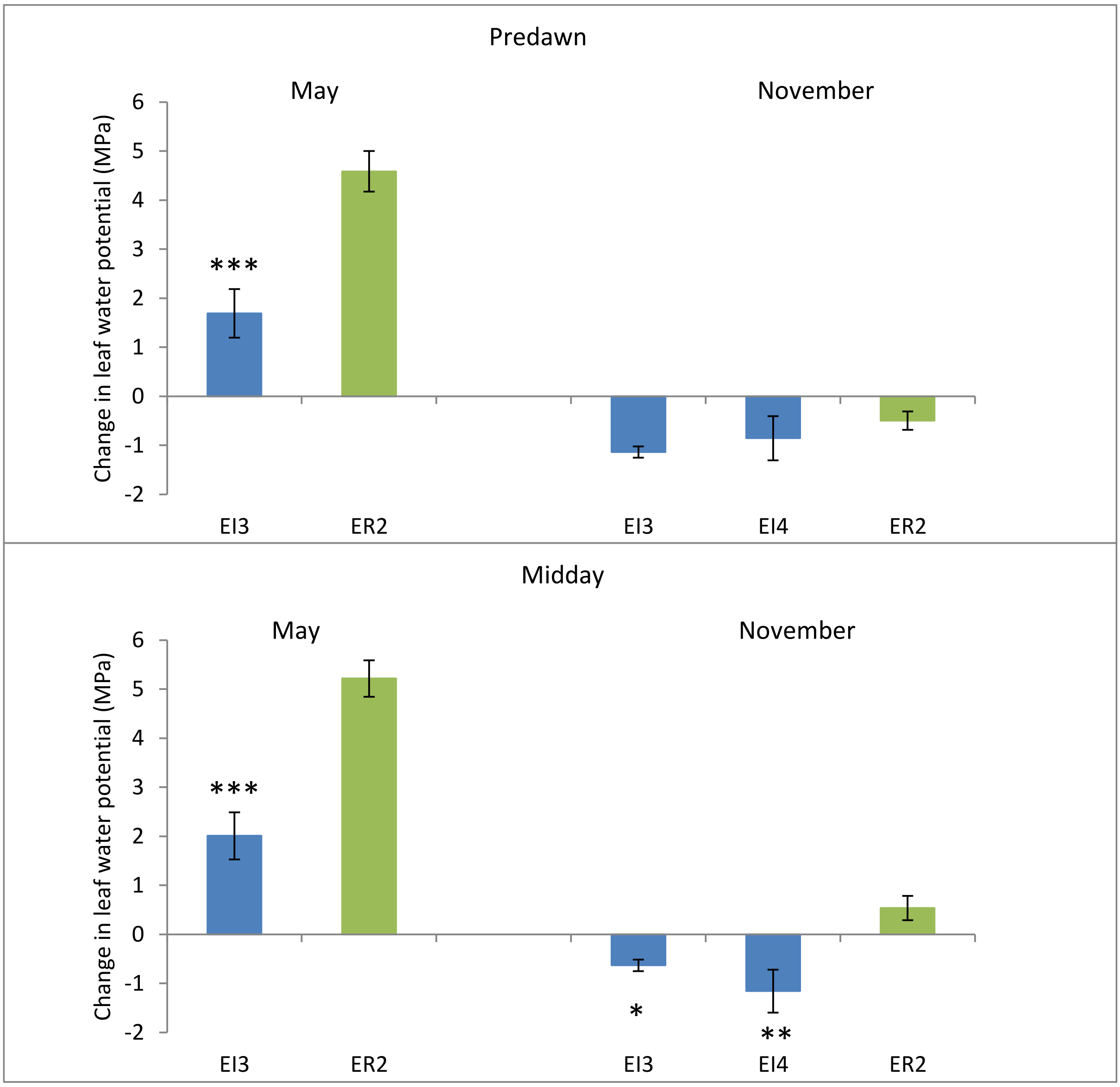

Figure 8: Change in mean predawn (Pd) and midday (Md) leaf water potential (MPa) of *Acacia aneura* at eastern potential impact site (EI3) and reference site (ER2) (n= 10) between May 2012 and May 2013 and at eastern potential impact sites (EI3 and EI4) and reference site (ER2) (n= 10) between November 2012 and November 2013. Error bars represent standard error. Asterisk (*) indicates significant difference between sites (* = P < 0.05; ** = P < 0.01;* = P < 0.001).**

Mean predawn and midday leaf water potentials have trended similarly over time at the western mulga sites (Figure 9). A seasonal influence on leaf water potentials at all sites is evident. Both predawn and midday water potentials at WI2 were higher than at the reference site in May and November 2012 but by May 2013 there was little separating both potential impact sites WI2 and WI3 from the reference site WR1. This trend continued in November 2013.

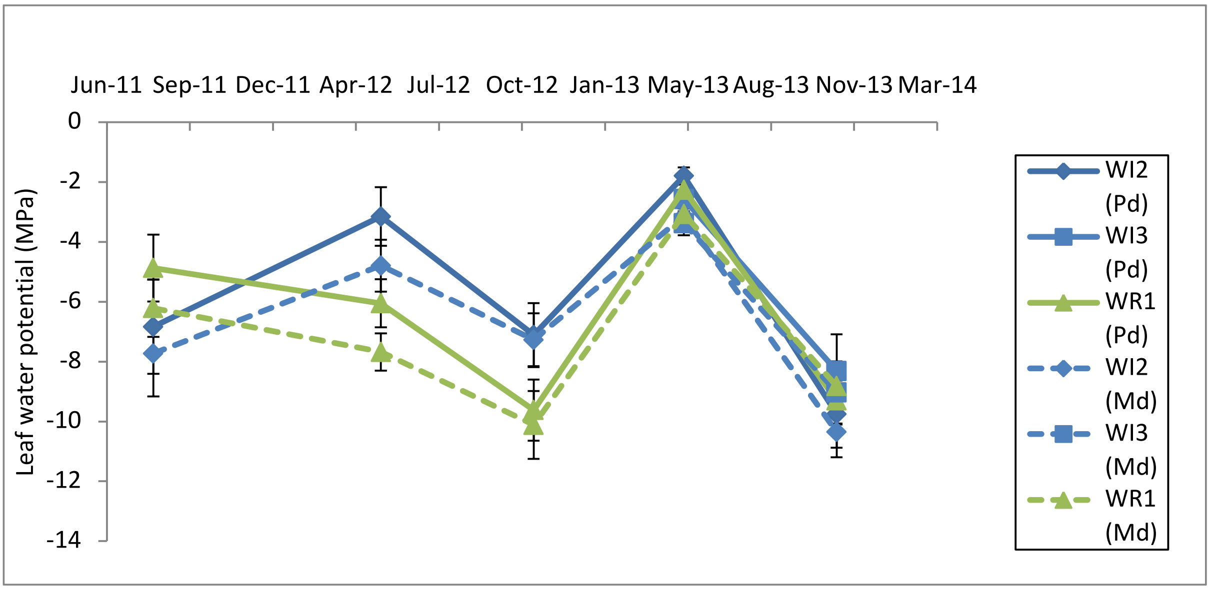

Figure 9: Mean predawn (Pd) and midday (Md) leaf water potential (MPa) of *Acacia aneura* at western potential impact sites (WI2 and WI3) and reference site (WR1) from August 2011 to November 2013 (n= 10). Error bars represent standard deviation.

Comparison of predawn water potential and midday water potential between sites revealed significant differences at the western sites in May and November 2013 (Table 9). Post-hoc comparisons indicated significant differences between reference sites and potential impact sites for both parameters at both times. There was no incidence where midday water potential at a potential impact site was significantly greater than at the associated reference site, the situation that would result in an exceedance of a Level 1 monitoring management trigger (Figure 9 and Table 9).

Table 9: Results of ANOVA and Kruskal Wallis tests comparing predawn and midday water potential between monitoring sites in the Western reference and potential impact areas. Where ANOVA or Kuskal-Wallis test was significant, Tukey's pairwise comparisons or multiple comparison after Kruskal Wallis test was conducted to determine if potential impact sites were different to reference sites.

	Predawn				Midday			
			Sig. diff. to reference?				Sig. diff. to reference?	
	F or χ^2	P	WI2	W13	χ^2	P	WI2	W13
May	62.5 (χ^2)	<0.001	Yes	Yes	11.3 (χ^2)	< 0.001	No	Yes
November	24.5 (χ^2)	<0.001	Yes	No	29.95 (F)	< 0.001	Yes	No

Change between May 2012 and May 2013 saw an increase in predawn leaf water potentials at WI2 and WR1 (Figure 10). The 4 MPa increase in predawn leaf water potential at WR1 was significantly different (ANOVA $F_{1, 18}$ = 36.74 P < 0.001; HSD P < 0.001) to the less than 2 MPa increase recorded at WI2. Similarly, the greater than 4 MPa increase in midday leaf water potential recorded at WR1 was significantly different (Kruskal-Wallis χ^2 = 14.286 P < 0.001) to the less than 2 MPa increase recorded at WI2.

Change in predawn leaf water potential between November 2012 and November 2013 was significantly different (ANOVA $F_{1,18}$ = 65.25 P < 0.001; HSD P < 0.001) between WI2 and WR1 (Figure 10). The potential impact site recorded a decrease of greater than 2 MPa in predawn leaf water potential while WR1 recorded a small increase. Similarly, the change in midday leaf water potential recorded between November 2012 and November 2013 was significantly different (ANOVA $F_{1,18}$ = 17.04 P < 0.001; HSD P < 0.001) between WI2 and WR1. WR1 recorded a greater than 1 MPa increase in midday leaf water potentials over the year, whereas WI2 recorded a greater than 3 MPa decrease.

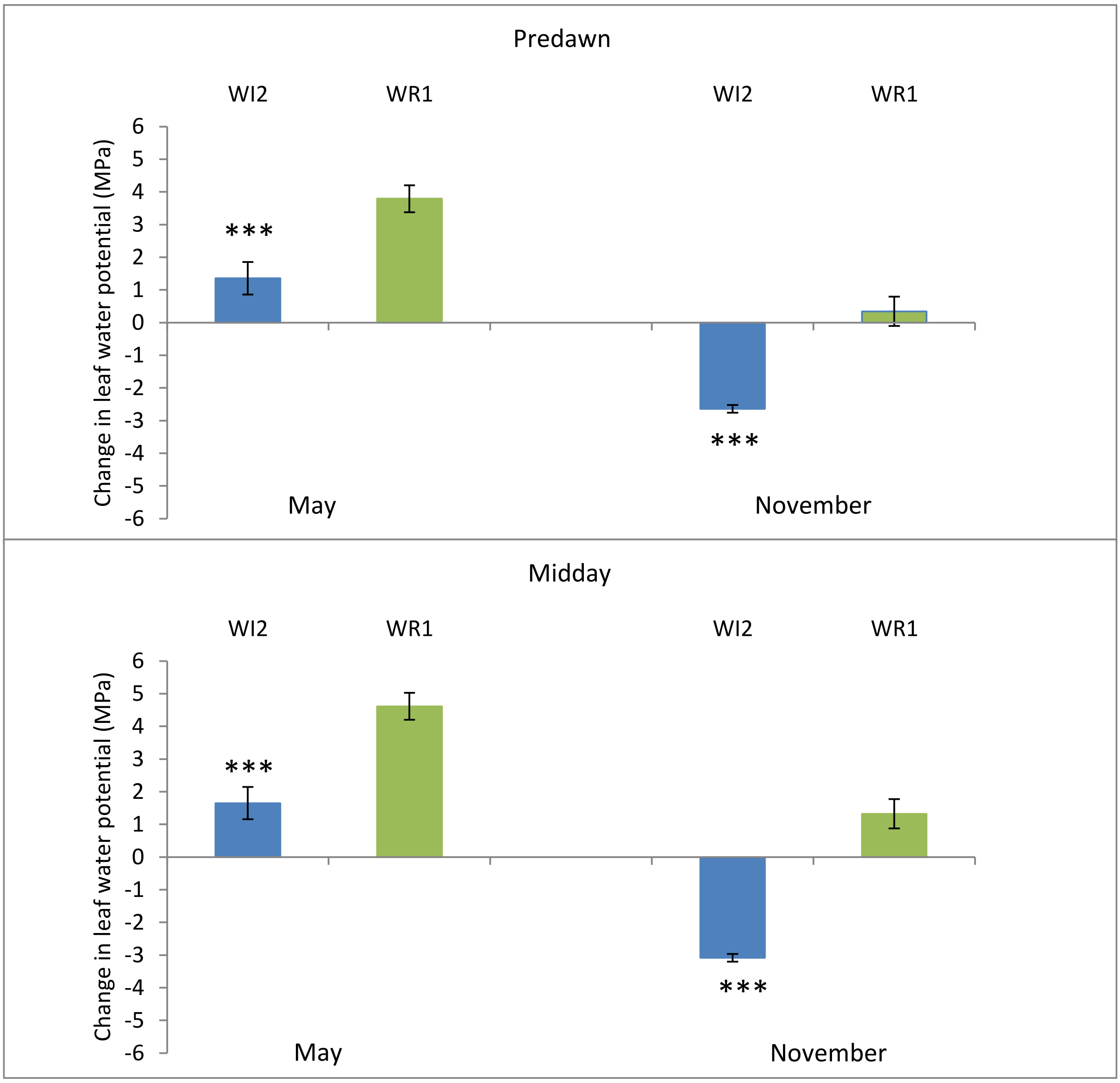

Figure 10: Change in mean predawn (Pd) and midday (Md) leaf water potential (MPa) of *Acacia aneura* at western potential impact site (WI2) and reference site (WR1) (n= 10) between May 2012 and May 2013 and between November 2012 and November 2013. Error bars represent standard error. Asterisk (*) indicates significant difference between sites (* = P < 0.001).**

Correlation tests between water potential values and soil moisture content did not reveal any significant associations between these variables (Table 10).

Table 10: Tests of association between water potential of trees and soil moisture content (0.4 to 0.5 m depth) in 2013.

Date	Predawn			Midday		
	Correlation Co-efficient	P	n	Correlation Co-efficient	P	n
May	0.325	0.151	21	-0.284	0.253	21
November	0.387	0.083	18	0.030	0.906	18

3.2.3 Projected Foliar Cover

Mean PFC remained relatively stable at the eastern reference site ER2 between November 2012 and November 2013 (Figure 11). While mean PFC declined at potential impact site EI3 between May and November 2013, there was a notable increase at potential impact site EI4 over the same period.

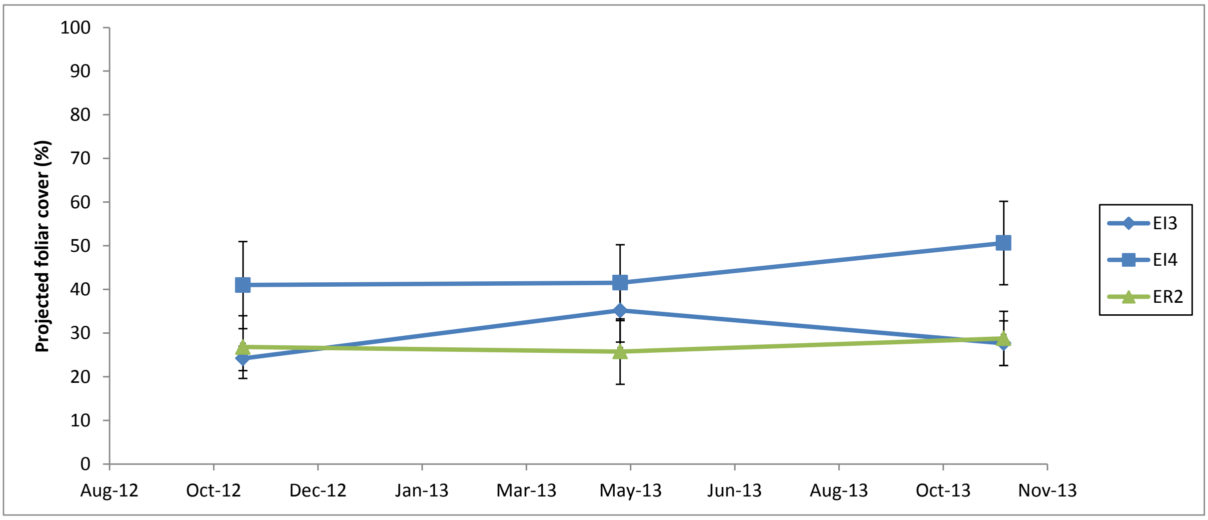

Figure 11: Mean projected foliar cover (%) of *Acacia aneura* at eastern potential impact sites (EI3 and EI4) and reference site (ER2) from November 2012 to November 2013 (n= 10). Error bars represent standard deviation.

The seasonal (May to November 2013) decrease in mean PFC at EI3 was significantly different (ANOVA $F_{2,27}$ = 35.08 P < 0.001; HSD P < 0.001) to the increase recorded at ER2 (Figure 12). Conversely, the seasonal increase in mean PFC recorded at EI4 (> 5%) was significantly different (ANOVA $F_{2,27}$ = 35.08 P < 0.001; HSD P = 0.014) to the increase at ER2 (< 5%). Mean PFC increased at all sites year-on-year (November 2012 to November 2013) with ER2 recording the smallest increase over the period. The large annual increase recorded at EI4 was significantly different (ANOVA $F_{2,27}$ = 9.01 P < 0.001; HSD P = 0.001) to the reference site.

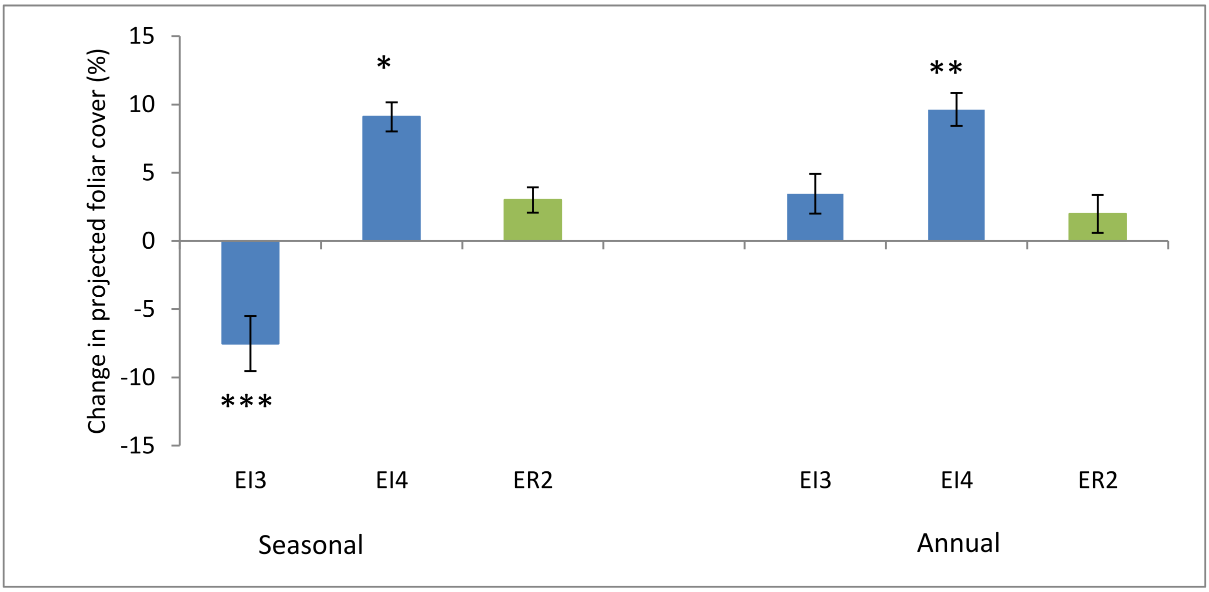

Figure 12: Change in mean projected foliar cover (%) of *Acacia aneura* at eastern potential impact sites (EI3 and EI4) and reference site (ER2) (n= 10) seasonally: May 2013 to November 2013 and annually: November 2012 to November 2013. Error bars represent standard error. Asterisk (*) indicates significant difference between sites (* = P < 0.05; ** = P < 0.01; *** = P < 0.001).

Mean PFC increased at potential impact site WI2 and reference site WR1 between May and November 2013 and declined slightly at potential impact site WI3 (Figure 13). While the increase at WR1 was considerable, PFC remains lower than recorded in November 2012.

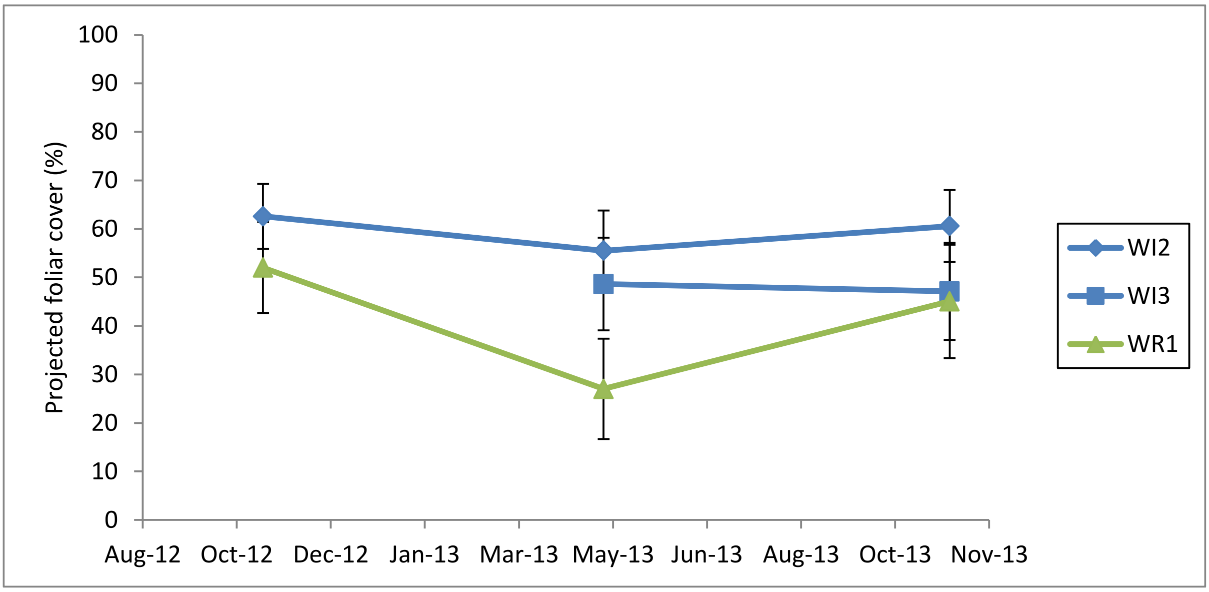

Figure 13: Mean projected foliar cover of *Acacia aneura* at western potential impact sites (WI2 and WI3) and reference site (WR1) from November 2012 to November 2013 (n= 10). Error bars represent standard deviation.

A small seasonal (May to November 2013) decrease in mean PFC at WI3 was significantly different (ANOVA $F_{2,27}$ = 8.236 P = 0.002; HSD P = 0.001) to the large seasonal increase recorded at WR1, and the smaller seasonal increase recorded at WI2 was also significantly different (ANOVA $F_{2,27}$ = 8.236 P = 0.002; HSD P = 0.035) to the change at WR1 (Figure 14).

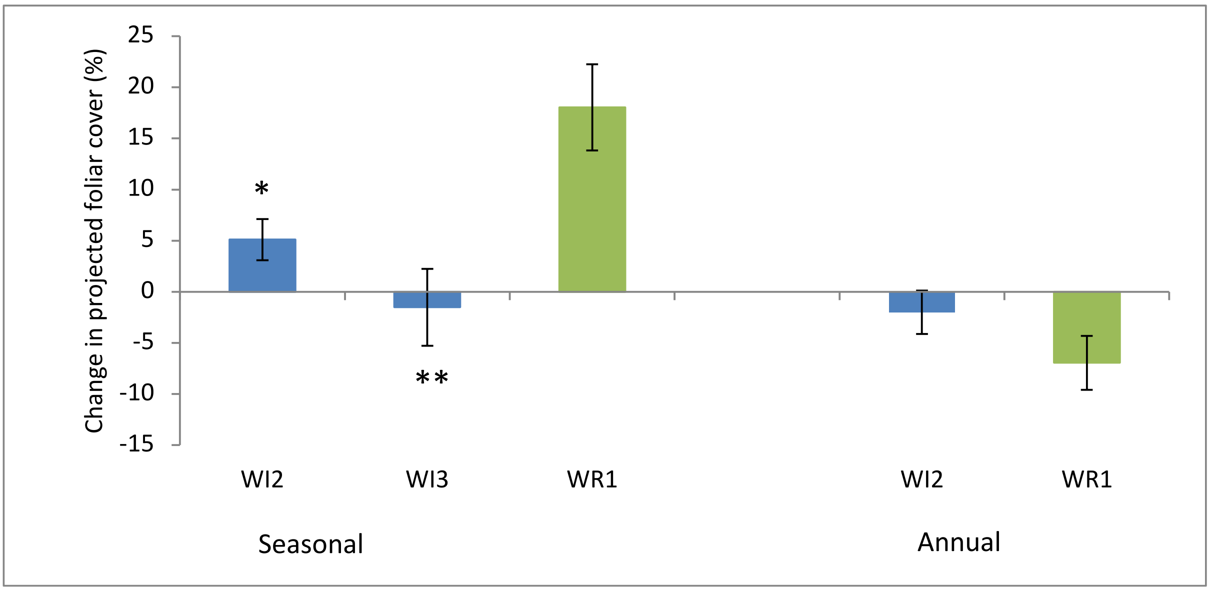

Figure 14: Seasonal change (May to November 2013) in mean projected foliar cover of *Acacia aneura* at western potential impact sites (WI2 and WI3) and reference site (WR1) (n= 10) and annual change (November 2012 to November 2013) between WI1 and WR1. Error bars represent standard error. Asterisk (*) indicates significant difference between sites (* = P < 0.05; ** = P < 0.01).

3.2.4 Multivariate Analysis of Ecophysiological Variables

Multivariate control charts for the three ecophysiological variables indicated a marginal exceedance of the 90% limit (Level 1 trigger) for site EI4 in May 2013 (Figure 15). There were no other exceedances of the 90% limit for any of the other potential impact sites. The value for reference site WR1 was higher than the 90% limit in May 2013 (Figure 16).

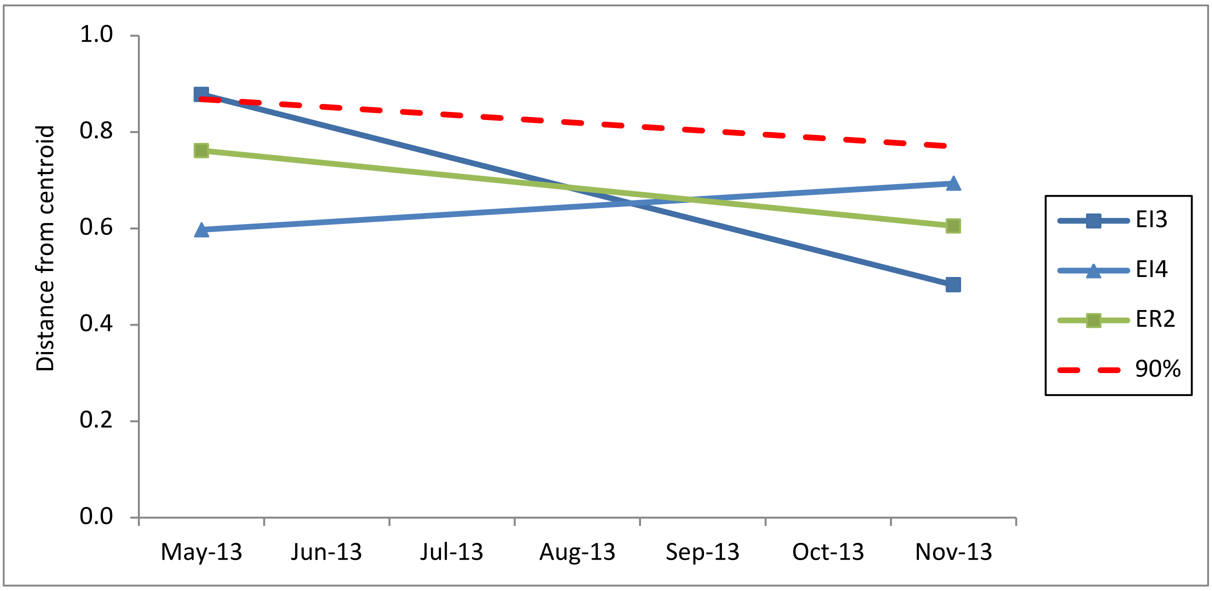

Figure 15: Multivariate control chart of predawn and midday water potential and PFC for *Acacia aneura* at eastern potential impact sites (EI3 and EI4) and reference site (ER2) from May 2013 to November 2013. The 90% line represents the control limit representing the Level 1 monitoring management trigger.

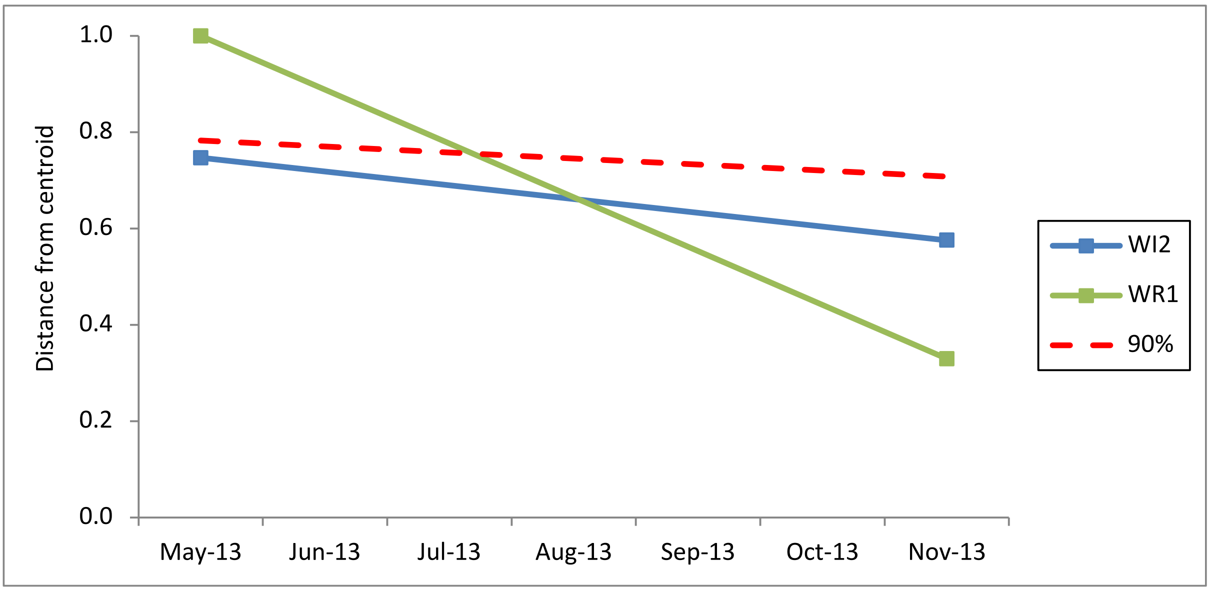

Figure 16: Multivariate control chart of predawn and midday water potential and PFC for *Acacia aneura* at western potential impact sites (WI2) and reference site (WRI) from May 2013 to November 2013. The 90% line represents the control limit representing the Level 1 monitoring management trigger. There were an insufficient number of time series data points to construct values for WR3.

3.2.5 Visual Health Assessment

Grimes Density

Mean Grimes density has remained stable at all eastern mulga sites since May 2012. All sites recorded a similar mean Grimes density in May and November 2013 (Figure 17). A small decrease in mean Grimes density was recorded at EI3 and ER2 between May 2012 and May 2013 (Figure 18). The small annual decrease in mean PFC at EI3 was significantly different (Kruskal-Wallis χ^2 = 17.63 P < 0.001; multiple comparison P < 0.05) to the increase recorded at ER2.

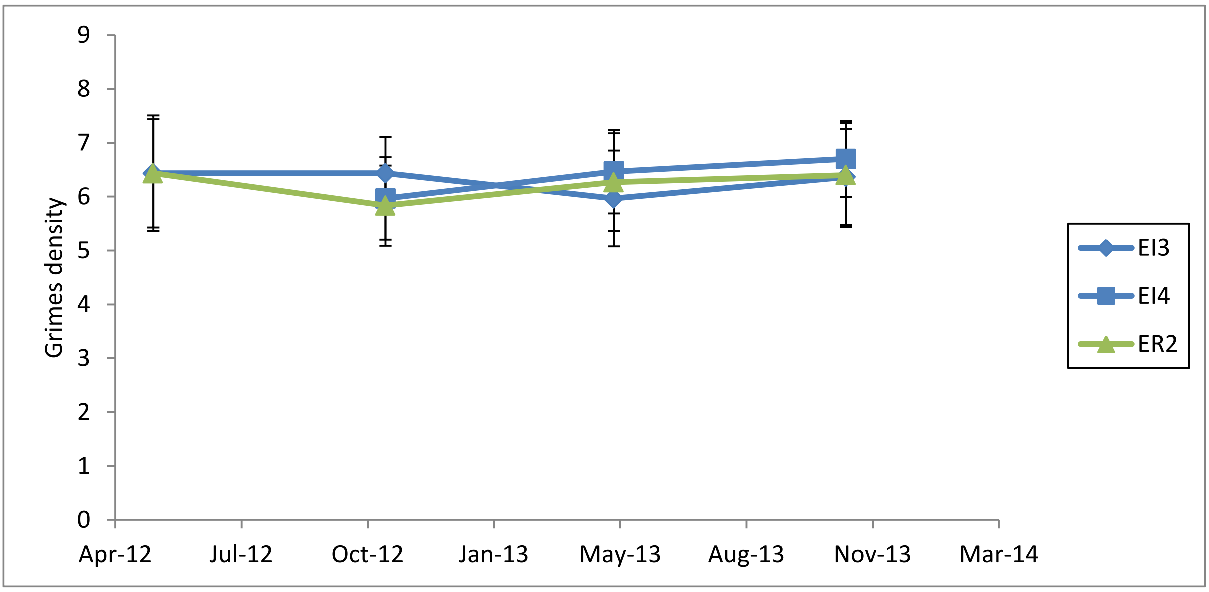

Figure 17: Mean Grimes density of *Acacia aneura* at eastern potential impact sites (EI3 and EI4) and reference site (ER2) from May 2012 to November 2013 (n= 30). Error bars represent standard deviation.

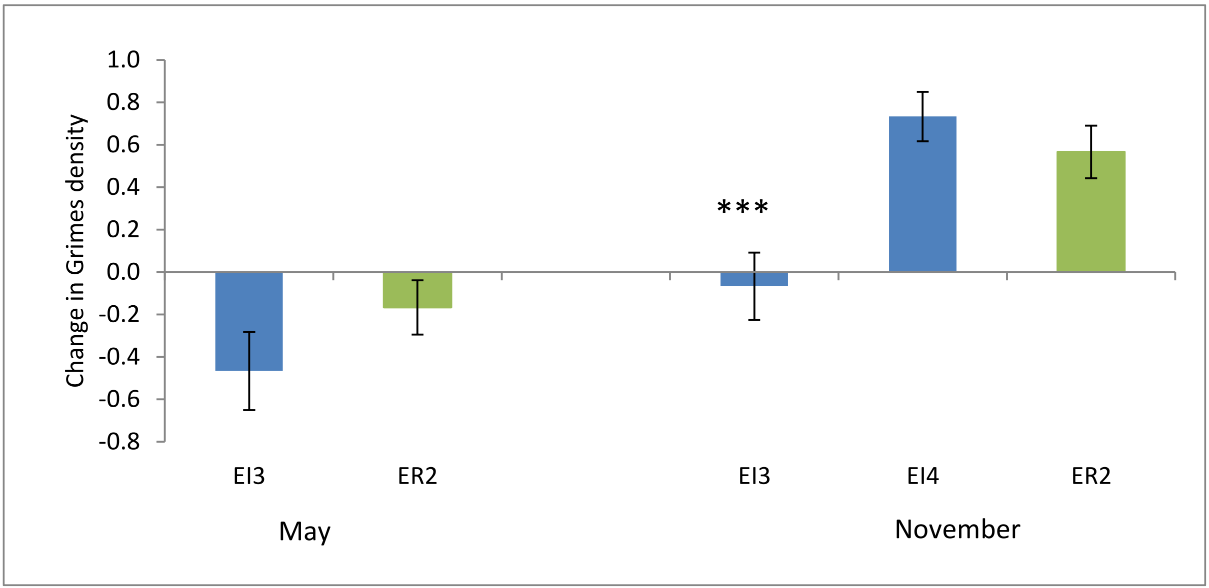

Figure 18: Change in mean Grimes density of *Acacia aneura* at eastern potential impact site (EI3) and reference site (ER2) (n= 30) between May 2012 and May 2013 and between potential impact sites (EI3 and EI4) and reference site (ER2) between November 2012 and November 2013. Error bars represent standard error. Asterisk (*) indicates significant difference between sites (* = P < 0.05).

Mean Grimes density remained higher at the two potential impact sites (WI2 and WI3) in May and November 2013 compared to the western reference site (WR1) (Figure 19). There was little difference between WI2 and WI3 in 2013. The increase in mean Grimes density at WI2 between May 2012 and May 2013 was significantly different (Kruskal-Wallis χ^2 = 7.132 P =0.008; multiple comparison P < 0.05) to the decrease recorded at WR1 (Figure 20). Similarly, the increase at WI2 between November 2012 and November 2013 was significantly different (Kruskal-Wallis χ^2 = 9.384 P =0.002; multiple comparison P < 0.05) to the smaller increase at WR1 over the same period.

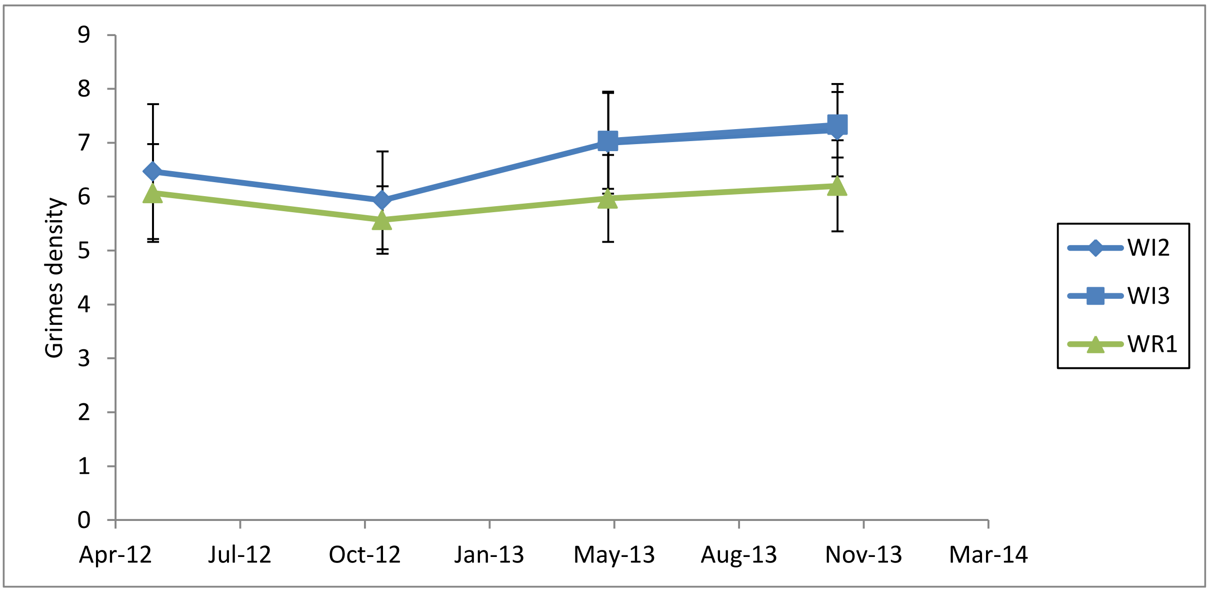

Figure 19: Mean Grimes density of *Acacia aneura* at western potential impact sites (WI2 and WI3) and reference site (WR1) from May 2012 to November 2013 (n= 30). Error bars represent standard deviation.

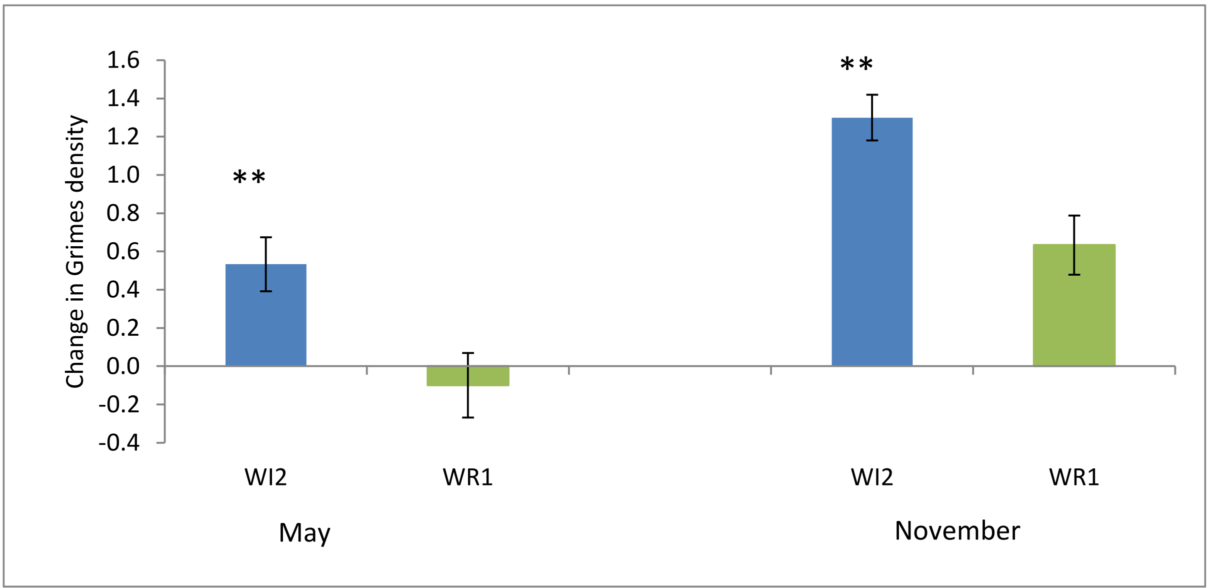

Figure 20: Change in mean Grimes density of *Acacia aneura* at western potential impact site (WI2) and reference site (WR1) (n= 30) between May 2012 and May 2013 and November 2012 and November 2013. Error bars represent standard error. Asterisk (*) indicates significant difference between sites (* = P < 0.05).

Tree Health Rating

The mean tree health rating (Astron criteria) of eastern mulga remained relatively stable between May and November 2013 at all sites, although at marginally lower levels than in May 2012 (Figure 21). However, the mean tree health rating of mulga at EI3 declined markedly in May 2013 compared to levels recorded in November 2012.

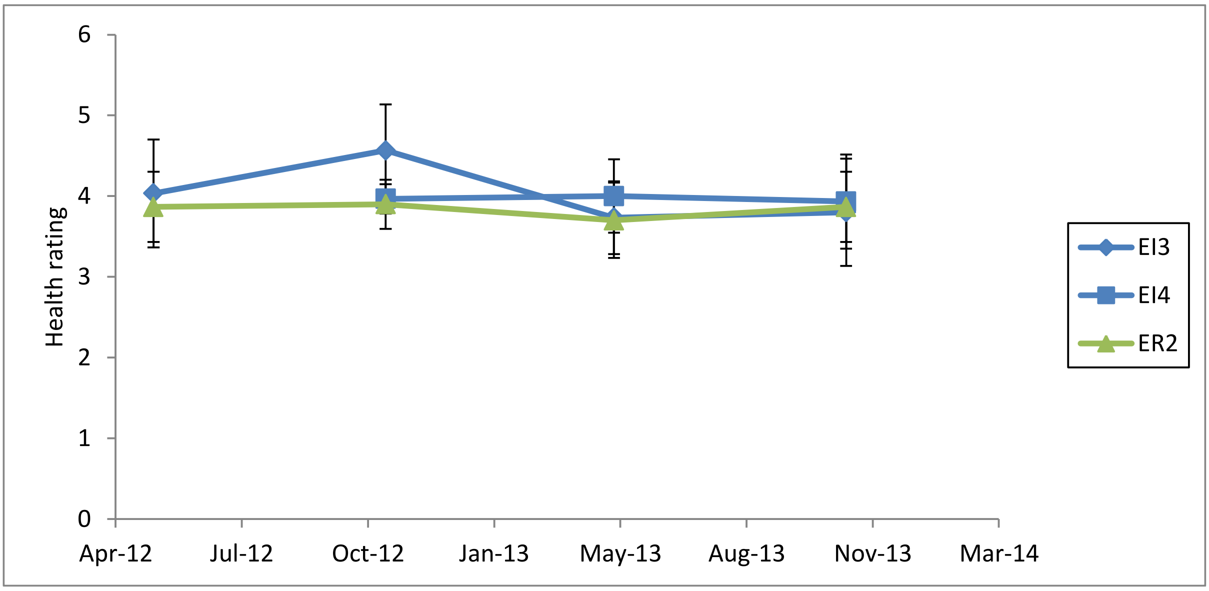

Figure 21: Mean health rating (1 to 5) of *Acacia aneura* at eastern potential impact sites (EI3 and EI4) and reference site (ER2) from May 2012 to November 2013 (n= 30). Error bars represent standard deviation.

The small decrease in the tree health rating at EI3 between May 2012 and May 2013 was similar to that recorded at ER2 (Figure 22). However, the larger decrease recorded at EI3 between November 2012 and November 2013 was significantly different (Kruskal-Wallis χ^2 = 46.431 $P < 0.001$; multiple comparison $P < 0.05$) to the small decrease recorded at ER2 and EI4.

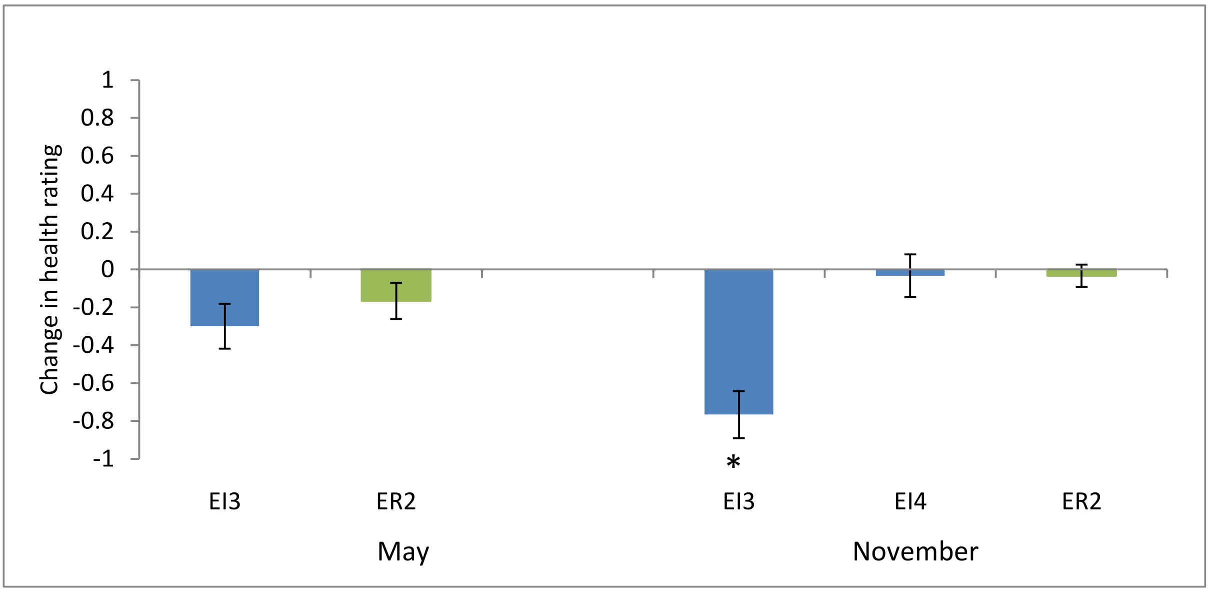

Figure 22: Change in mean health rating (1 to 5) of *Acacia aneura* at eastern potential impact sites (EI3 and EI4) and reference site (ER2) (n= 30) between May 2012 and May 2013 and November 2012 and November 2013. Error bars represent standard error. Asterisk (*) indicates significant difference between sites (* = P < 0.05).

Using Fortescue criteria, the mean health rating of eastern mulga has varied little since May 2013 (Figure 23). The largest change has been at EI4 and ER2 between November 2012 and May 2013 when the mean health rating increased from around 2 to almost 3. The mean health rating has been steadily declining at EI3 between November 2012 and November 2013.

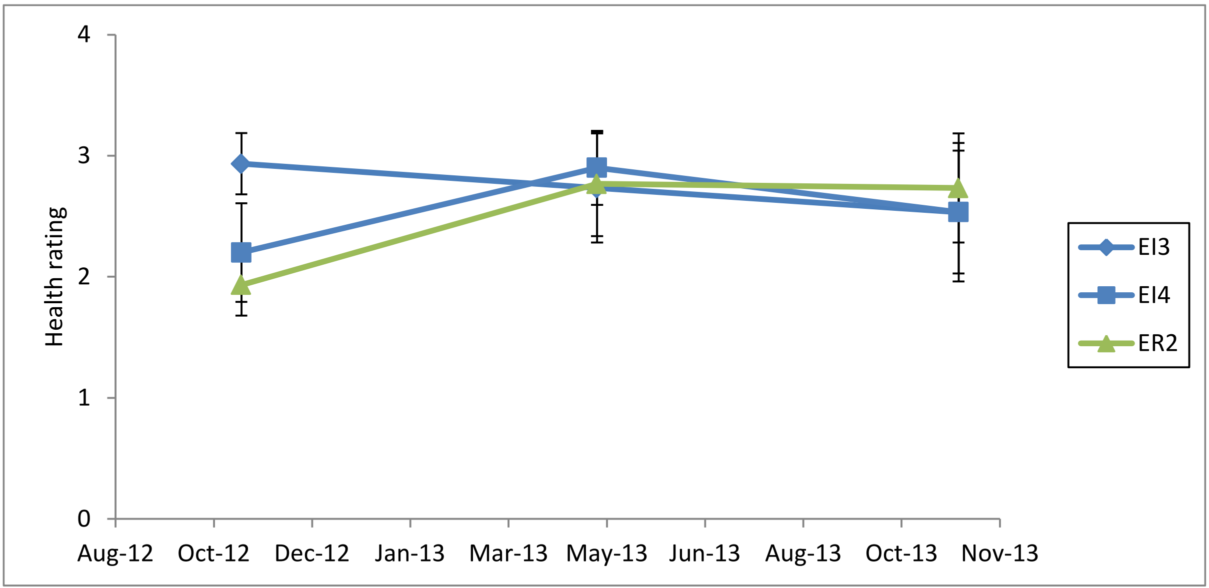

Figure 23: Mean health rating (0 to 3) of *Acacia aneura* at eastern potential impact sites (EI3 and EI4) and reference site (ER2) from November 2012 to November 2013 (n= 30). Error bars represent standard deviation.

The mean tree health rating (Astron criteria) of western mulga have trended similarly since May 2012, with health ratings remaining consistently higher at the potential impact (WI2 and WI3) sites than at the reference (WR1) site (Figure 24). Mean tree health ratings decreased between May 2012 and May 2013 at both WI2 and WR1 and increased at both sites between November 2012 and November 2013 (Figure 25).

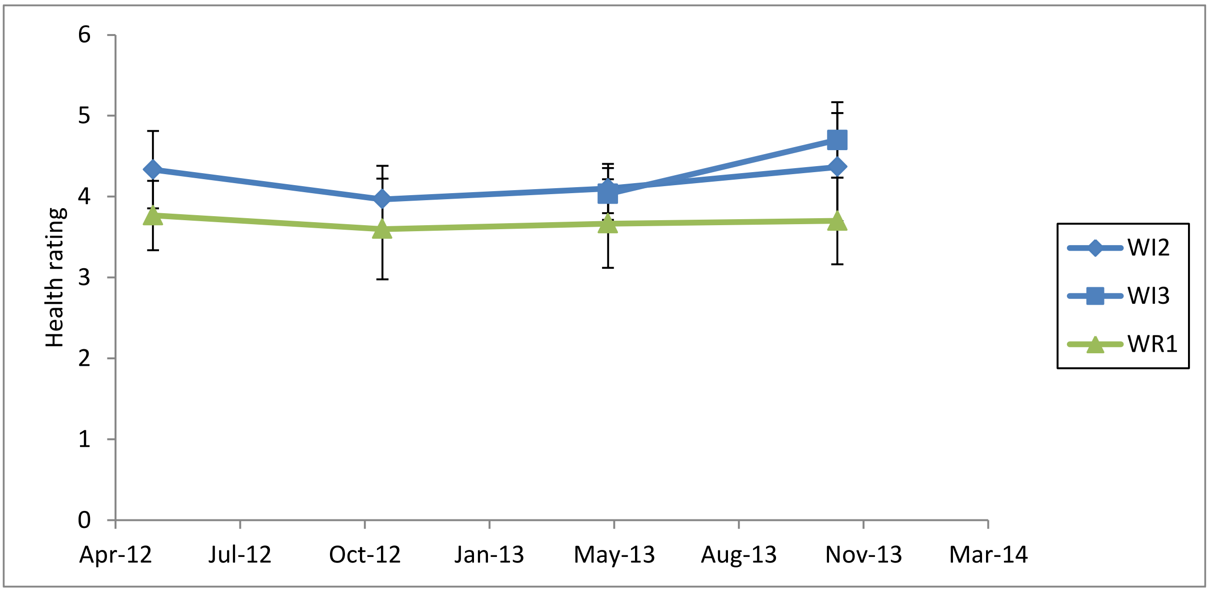

Figure 24: Mean health rating (1 to 5) of *Acacia aneura* at western potential impact sites (WI2 and WI3) and reference site (WR1) from May 2012 to November 2013 (n= 30). Error bars represent standard deviation.

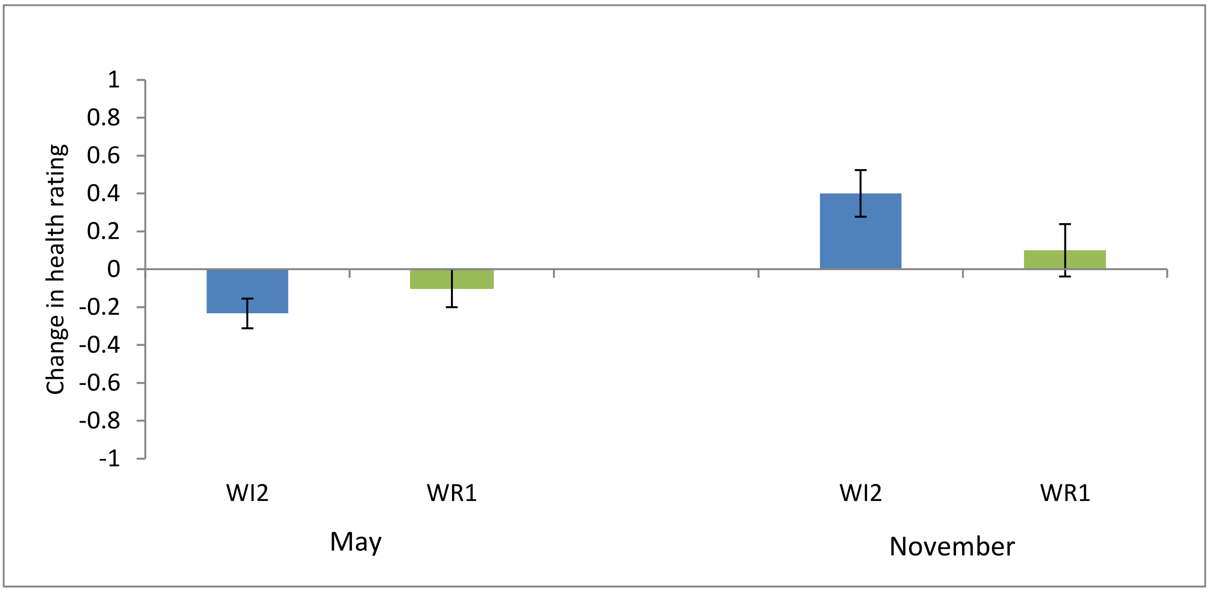

Figure 25: Change in mean health rating (1 to 5) of *Acacia aneura* at western potential impact site (WI2) and reference site (WR1) (n= 30) between May 2012 and May 2013 and November 2012 and November 2013. Error bars represent standard error. There were no significant differences between sites.

The mean health rating (Fortescue criteria) has been close to the maximum at both of the western mulga potential impact sites since May 2013, after increasing from 2 at WI2 (Figure 26). The mean tree health rating has been slightly lower at the western reference site since May 2013.

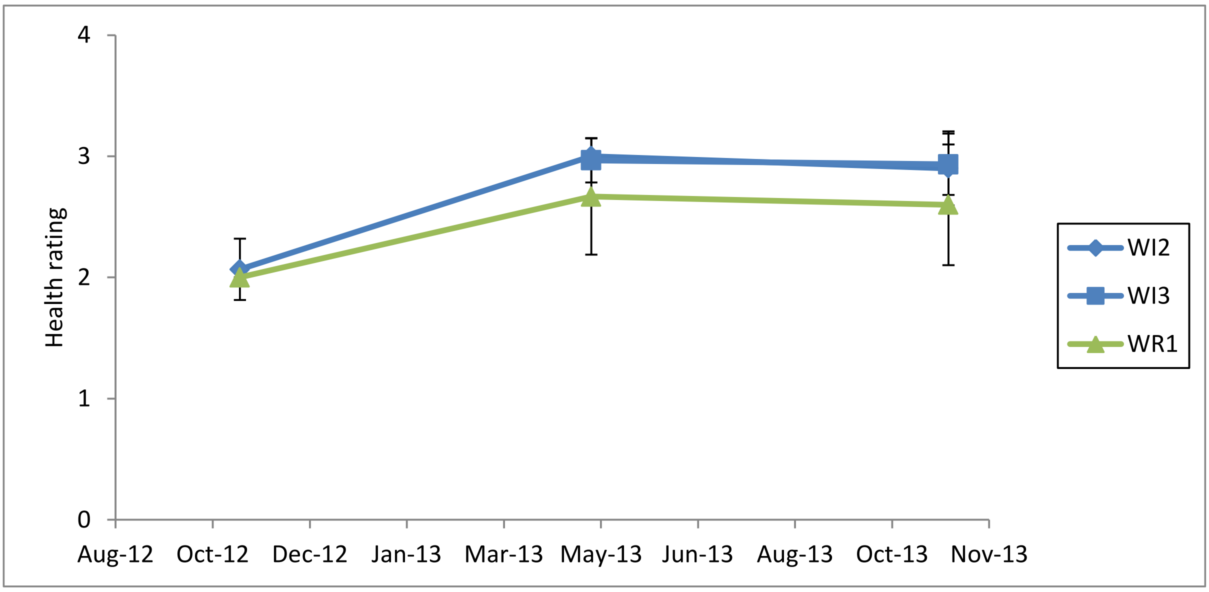

Figure 26: Mean health rating (0 to 3) of *Acacia aneura* at western potential impact sites (WI2 and WI3) and reference site (WR1) from November 2012 to November 2013 (n= 30). Error bars represent standard deviation.

Reproduction

The mean abundance of reproduction increased at all eastern mulga sites in November 2013, where little to no reproduction had previously been recorded at these two sites (Figure 27). Similarly, mean reproduction scores increased at all western mulga sites in November 2013, although similar levels of reproduction had been recorded at the WI2 site in November 2012 (Figure 28). Variation within sites was notable across the eastern and western areas.

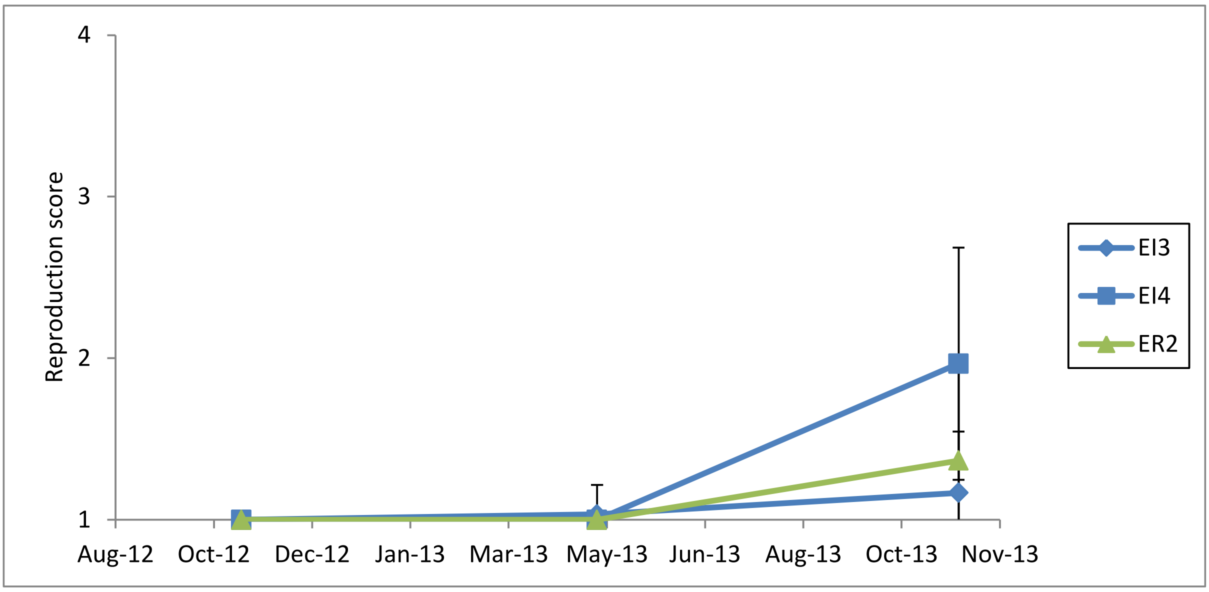

Figure 27: Mean reproduction score of *Acacia aneura* at eastern potential impact sites (EI3 and EI4) and reference site (ER2) from November 2012 to November 2013 (n= 30). Error bars represent standard deviation.

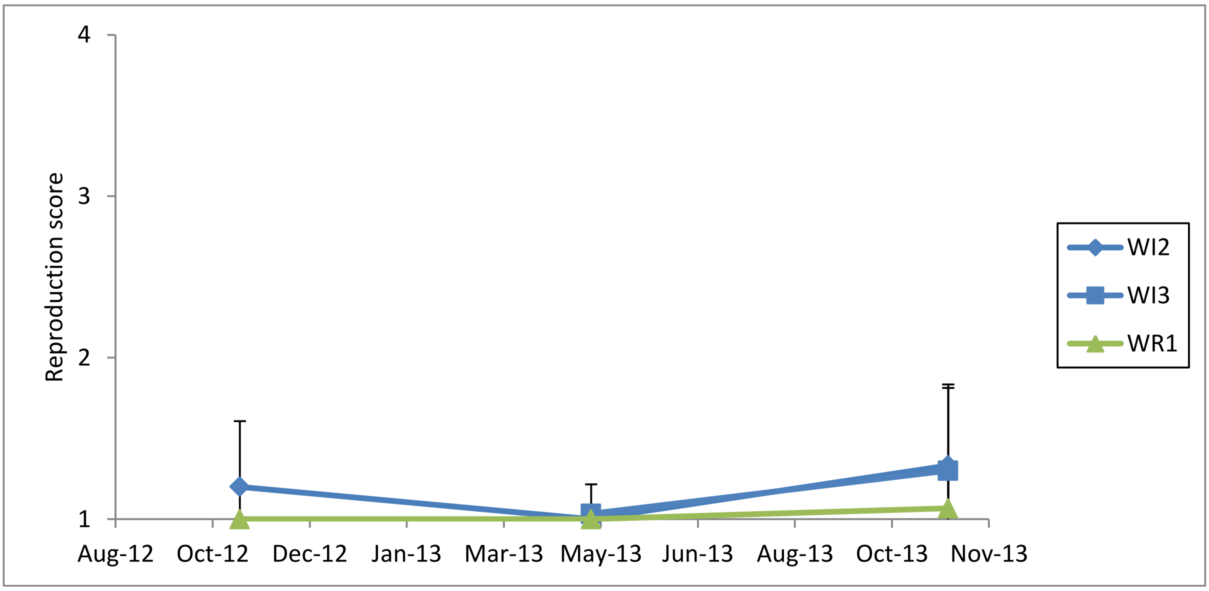

Figure 28: Mean reproduction score of *Acacia aneura* at western potential impact sites (WI2 and WI3) and reference site (WR1) from November 2012 to November 2013 (n= 30). Error bars represent standard deviation.

Tip Growth

Tip growth was absent from all mulga sites in November 2013, similar to November 2012, declining from absent to common in May 2013 (Figure 29; Figure 30). Variation within sites in May 2013 was notable, with tip growth abundance ranging from absent to common at most sites.

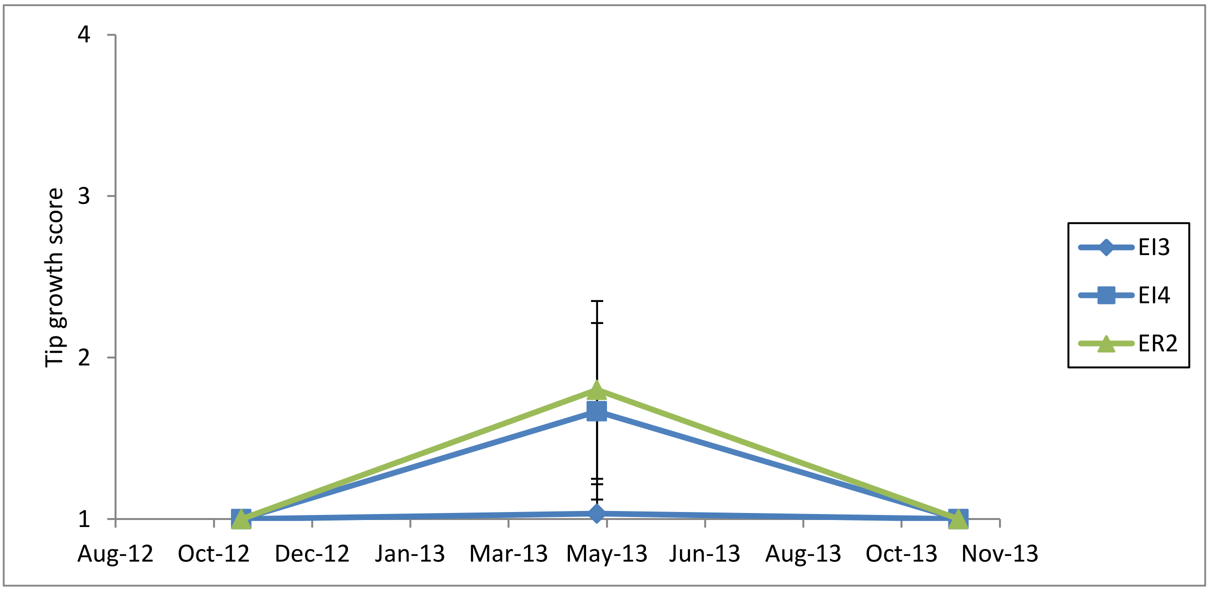

Figure 29: Mean tip growth score of *Acacia aneura* at eastern potential impact sites (EI3 and EI4) and reference site (ER2) from November 2012 to November 2013 (n= 30). Error bars represent standard deviation.

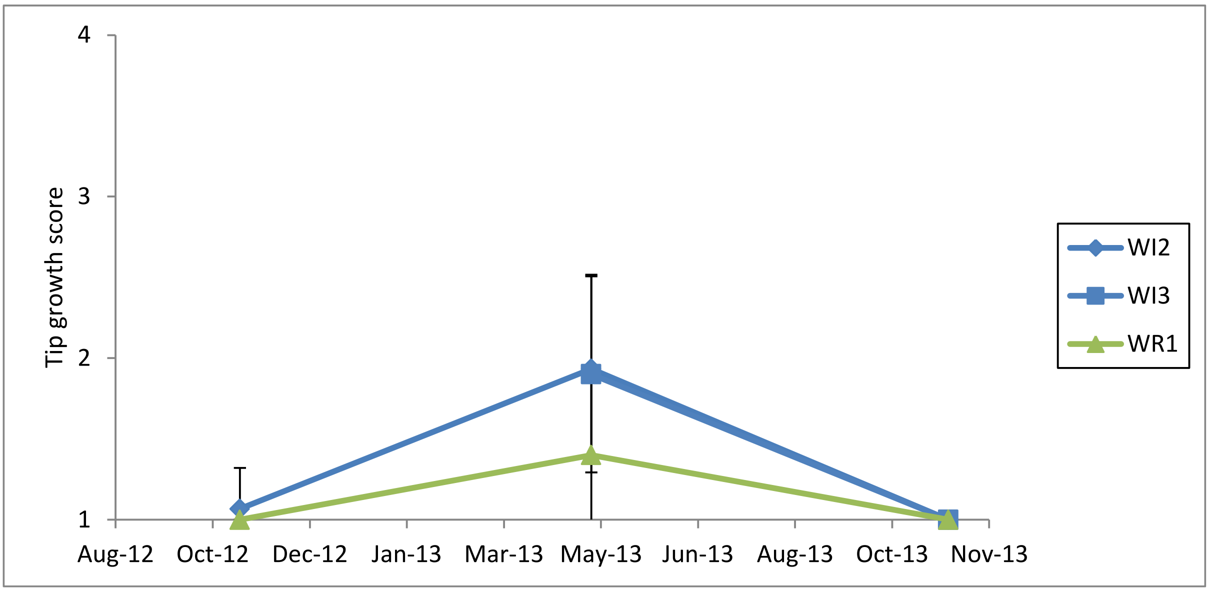

Figure 30: Mean tip growth score of *Acacia aneura* at western potential impact sites (WI2 and WI3) and reference site (WR1) from November 2012 to November 2013 (n= 30). Error bars represent standard deviation.

3.2.6 Leaf Litter Collection

There was a considerable increase in the mean weight of leaf litter collected at both WI1 and WR1 between November 2012 and May 2013 (Table 11). The mean weight of leaf litter collected over the two time periods was consistently greater at the western mulga reference site compared to that collected at the potential impact site. Only a small decrease in mean weight of leaf litter was recorded between May and November 2013 at WR1. Leaf litter traps were removed from WI1 during the May 2013 monitoring survey.

Table 11: Mean weight of leaf litter (grams) ± standard error collected during November 2012 and May 2013 at WR1 and WI1 and at WR1 in November 2013; (n = number of samples at each site).

Collection date	WI1	WR1
November 2012	2.75 ± 0.50 g (n = 5)	4.09 ± 0.58 g (n = 6)
May 2013	4.95 ± 1.22 g (n = 4)	7.01 ± 3.07 g (n = 4)
November 2013	No data	6.54 ± 0.97 g (n = 3)

3.2.7 Monitoring Management Triggers

Two management triggers were exceeded for the mulga vegetation community (Table 12): midday water potential was significantly greater at site EI3 than at the reference site in November 2013 and changes in PFC at the reference sites were significantly different from the changes in both mounding impact sites. No deaths of mulga sample trees were found in 2013.

Table 12: Results for Mulga vegetation communities in 2013 in relation to monitoring management triggers in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a)

Trigger	Trigger Exceeded	Description
Midday leaf water potentials significantly greater in mounding impact areas in comparison to reference	Yes	Midday leaf water potentials were significantly greater at EI3 in November 2013
Percentage canopy cover of Mulga trees significantly greater than or less than reference in reinjection zones	Yes	Increase in percentage canopy cover of Mulga trees was significantly different at EI4 in May and November 2013 and EI3 in May 2013.
Death of keystone Mulga trees significantly greater than or less than reference	No	No deaths of sample trees occurred in 2013
Multivariate control chart of multiple ecophysiological variables – Level 1 management response required in exceedance of 90% confidence interval in control chart trend	Yes	Exceedance of the 90% level occurred at EI3 in May 2013

3.3 Phreatophytic Communities

3.3.1 Leaf Water Potential

Mean predawn leaf water potential declined in all of the phreatophytic communities between May and November 2013 (Figure 31). Since August 2011 there has been a steadily declining trend at both the potential impact and reference phreatophytic communities. This trend has been similar for midday leaf water potentials at all phreatophytic monitoring sites. The decrease in predawn leaf water potential at potential impact site DI1 between May 2012 and May 2013 was significantly different to the larger decrease at reference site DR1 (ANOVA $F_{1,18} = 6.61$ $P = 0.019$; HSD $P = 0.019$) (Figure 32). Change in predawn leaf water potentials at the two sites between November 2012 and November 2013 was similar, as was the change in midday leaf water potentials over the two periods.

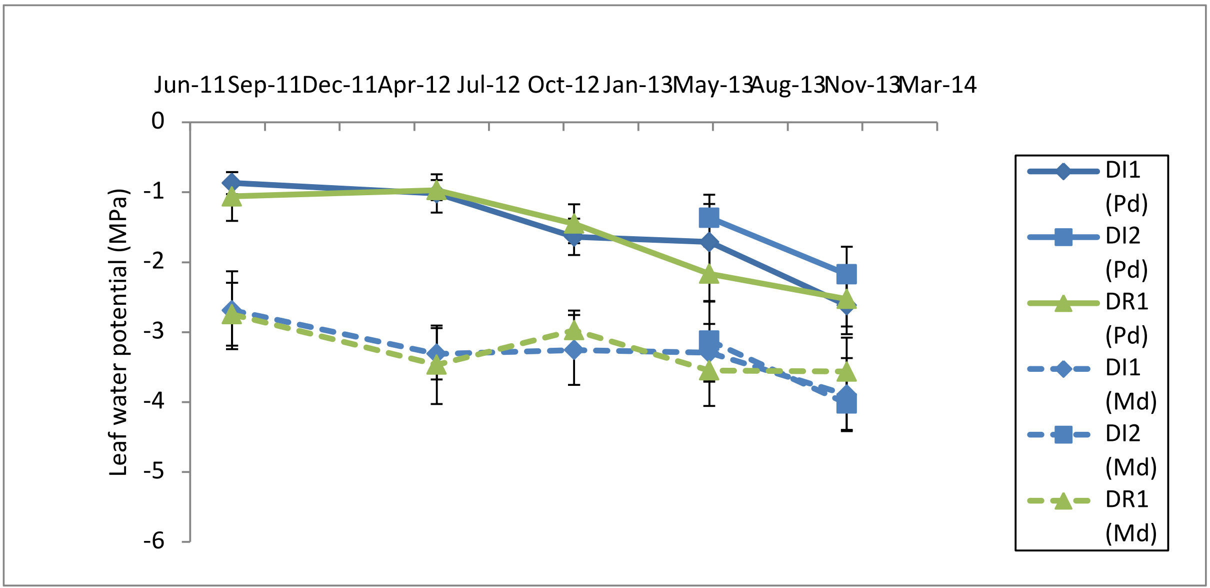

Figure 31: Mean predawn (Pd) and midday (Md) leaf water potential (MPa) of *Eucalypts victrix* at drawdown potential impact sites (DI1 and DI2) and reference site (DR1) from August 2011 to November 2013 (n= 10). Error bars represent standard deviation.

Site differences for both predawn water potential and midday water potential were significant in May and November 2013 (Table 13). Post-hoc comparisons revealed significant differences between reference sites and potential impact sites for both parameters at both times. Predawn water potential at both potential impact sites was greater than at the reference sites in May 2013 and greater at potential impact site DI2 than at the reference site in November 2013 (Figure 31 and Table 13). These differences represent exceedances of the Level 1 monitoring management trigger.

Table 13: Results of ANOVA comparing predawn and midday water potential between monitoring sites in the reference and potential drawdown areas. Where the ANOVA test was significant, Tukey's pairwise comparisons were conducted to determine if potential impact sites were different to reference sites.

	Predawn				Midday			
			Sig. diff. to reference?				Sig. diff. to reference?	
	F	P	DI1	DI2	χ^2	P	DI1	DI2
May	34.7	<0.001	Yes	Yes	7.4	0.001	No	Yes
November	11.8	<0.001	No	Yes	10.2	< 0.001	Yes	Yes

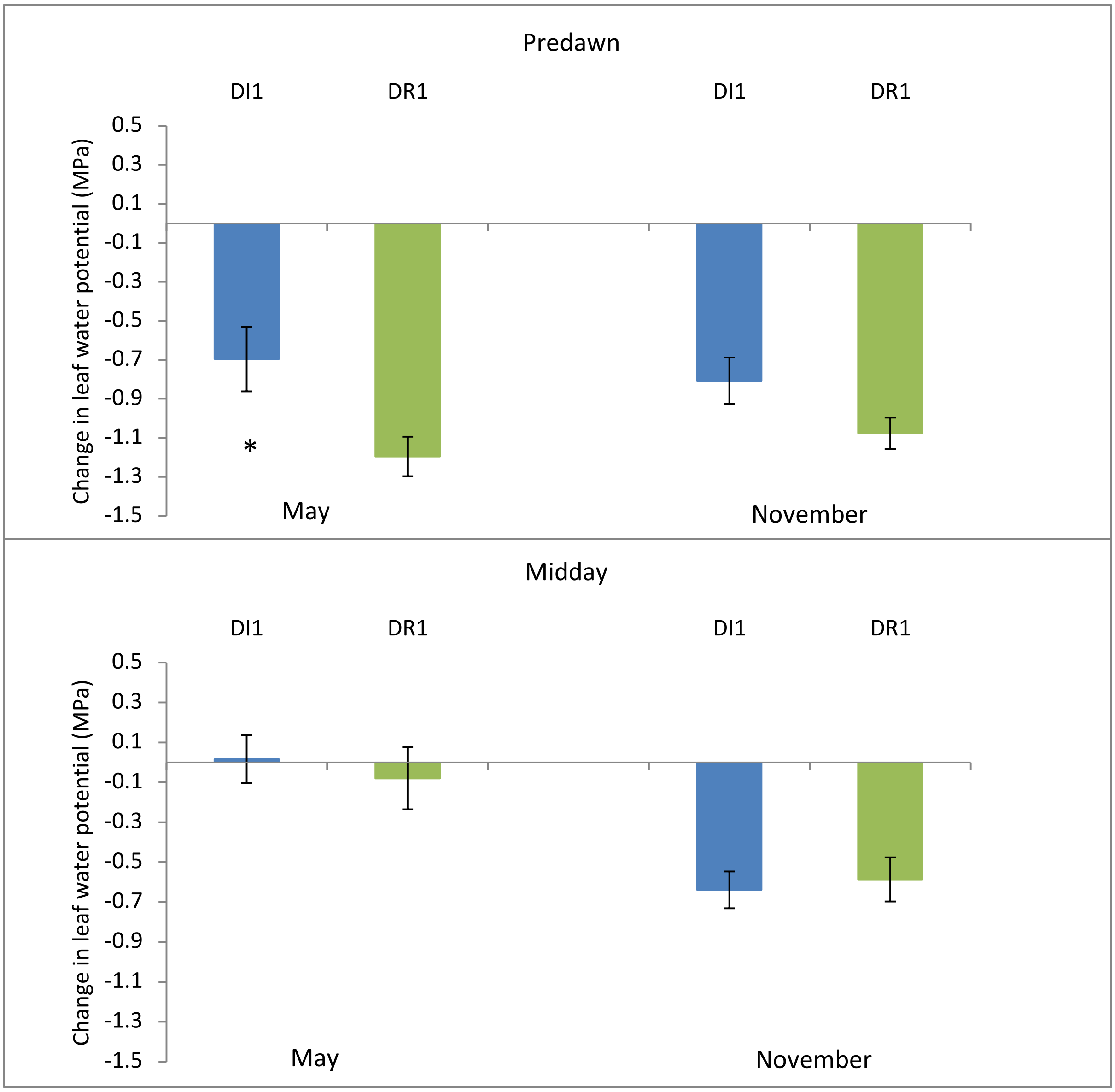

Figure 32: Change in mean predawn (Pd) and midday (Md) leaf water potential (MPa) of *Eucalypts victrix* at drawdown potential impact site (DI1) and reference site (DR1) (n= 10) between May 2012 and May 2013 and November 2012 and November 2013. Error bars represent standard error. Asterisk (*) indicates significant difference between sites (P < 0.05).

3.3.2 Projected Foliar Cover

Mean PFC at the three phreatophytic communities (DI1, DI2 and DR1) has remained relatively stable since November 2012, although a slight decline in PFC has been recorded at each site since monitoring began (Figure 33). Seasonally, a small increase in PFC was recorded at the potential impact site DI1 (Figure 34); this increase was not significantly different to the decrease recorded at the reference site (DR1) (ANOVA $F_{2,26}$ = 2.566 P = 0.096). The annual decrease at both DI1 and DR1 was similar.

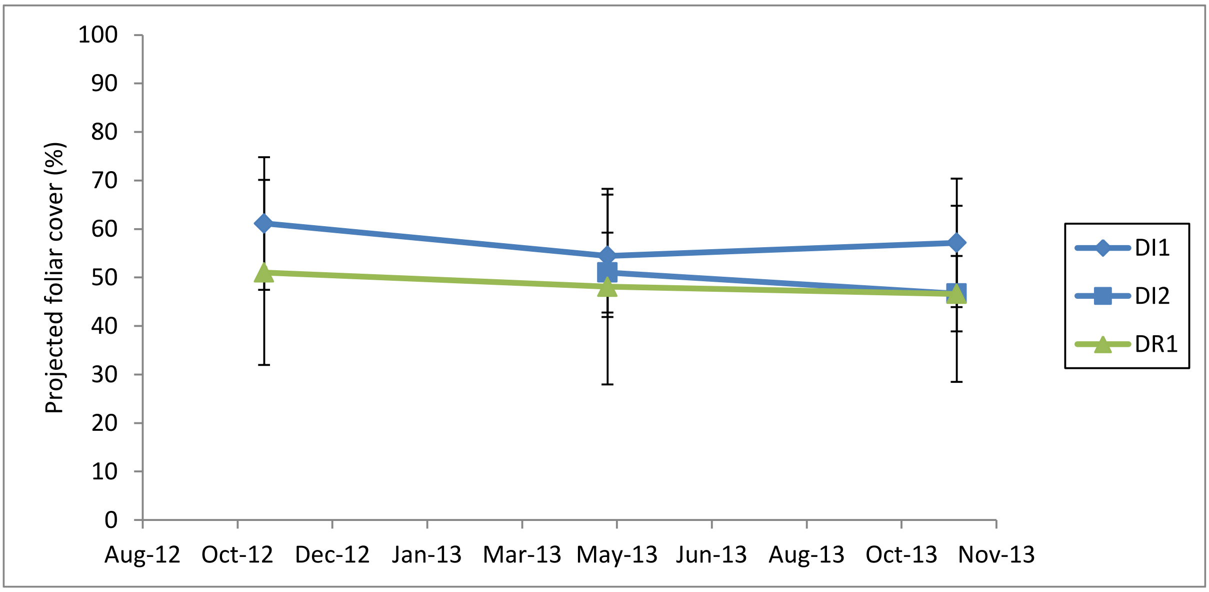

Figure 33: Mean projected foliar cover (%) of *Eucalyptus victrix* at drawdown potential impact sites (DI1 and DI2) and reference site (DR1) from November 2012 to November 2013 (n= 10). Error bars represent standard deviation.

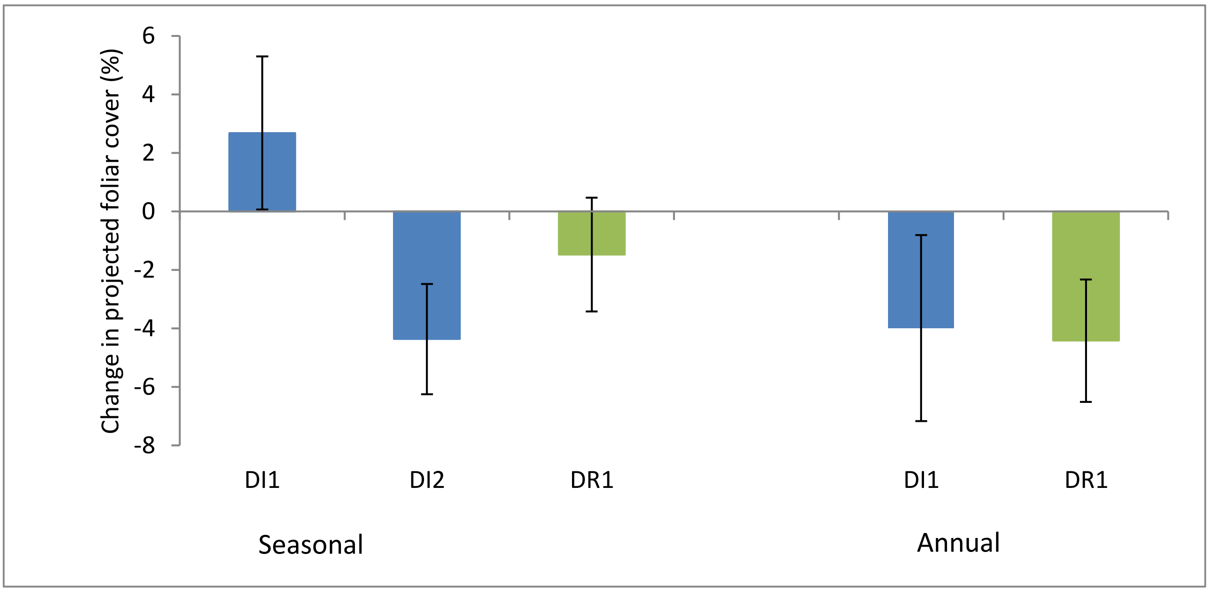

Figure 34: Change in seasonal (May to November 2013) mean projected foliar cover (%) of *Eucalyptus victrix* at drawdown potential impact sites (DI1 and DI2) and reference site (DR1) (n= 10) and annual change (November 2012 to November 2013) at DI1 and DR1. Error bars represent standard error. No significant difference was found between sites.

Control chart analysis indicated the PFC at potential impact site DI1 was within one standard deviation of the mean (Figure 35). Mean PFC at the reference site (DR1) in November 2013 exceeded one standard deviation below the mean (Figure 36). Potential impact site DI2 has not been monitored for long enough to enable a control chart to be constructed.

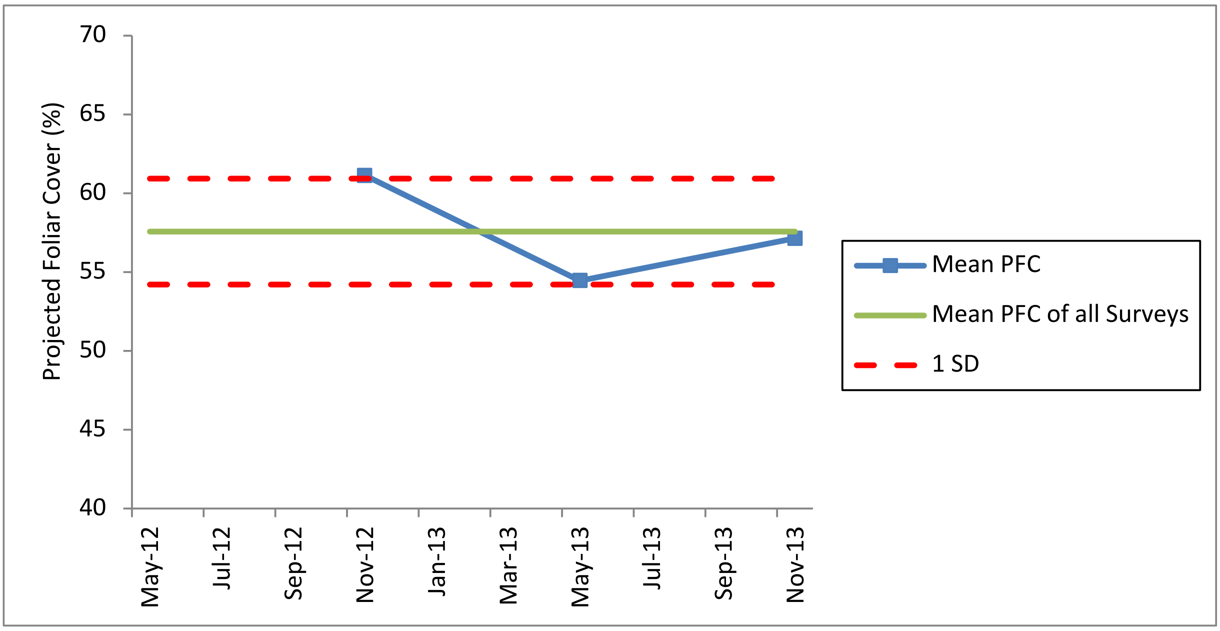

Figure 35: Control chart for PFC for *Eucalyptus victrix* at drawdown potential impact site DI1 (n = 10 at all times). Control limit is one standard deviation (SD) from the mean.

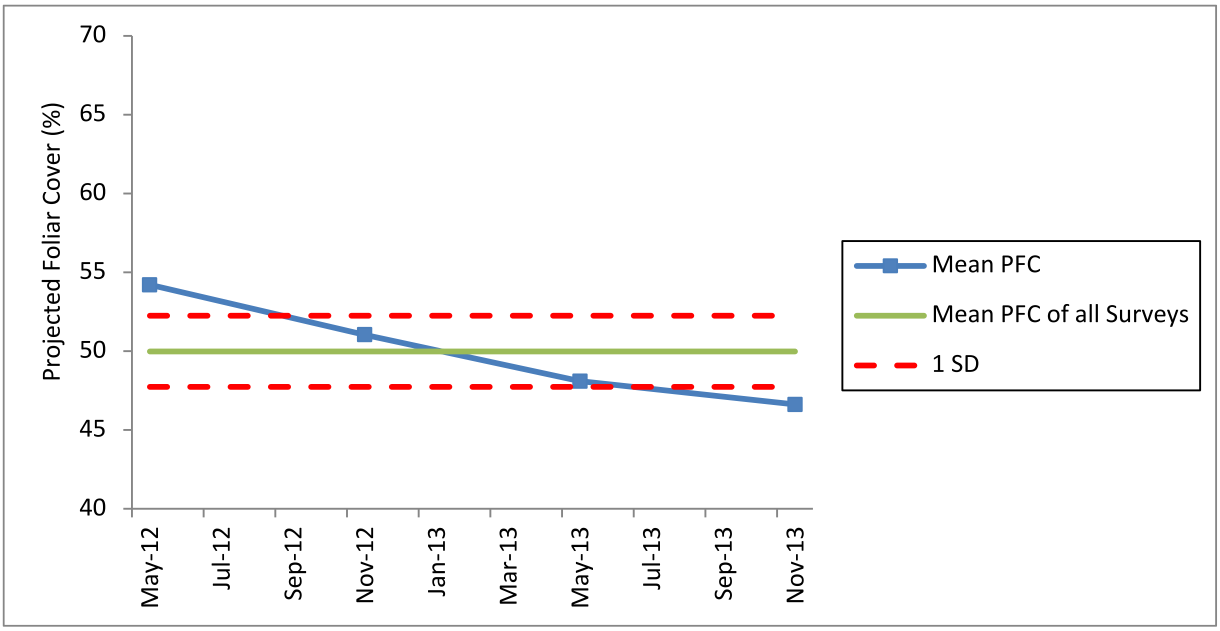

Figure 36: Control chart for PFC for *Eucalyptus victrix* at drawdown potential impact site DR1 (n = 10 at all times). Control limit is one standard deviation (SD) from the mean.

3.3.3 Multivariate Analysis of Ecophysiological Variables

Multivariate control charts for the three ecophysiological variables indicated that the potential impact site DI1 exceeded the 90% limit (Level 1 trigger) in November 2013, while the value for the reference site DR1 remained in control (Figure 37).

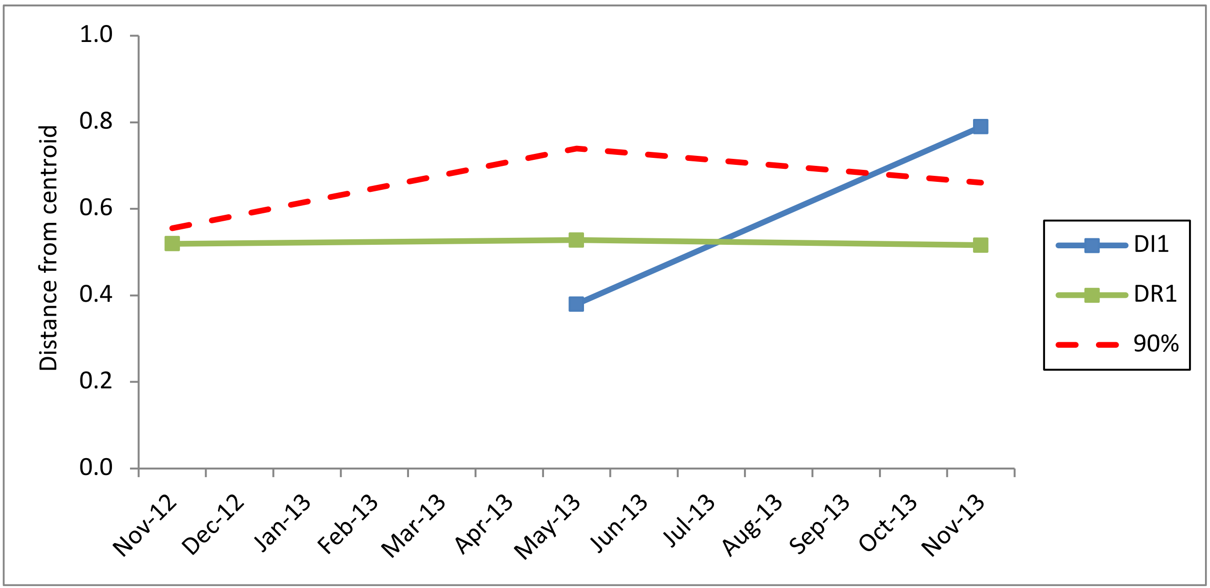

Figure 37: Multivariate control chart of predawn and midday water potential and PFC for *Eucalyptus victrix* at drawdown potential impact sites (DI1) and reference site (DRI) from November 2012 to November 2013. The 90% line represents the control limit representing the Level 1 monitoring management trigger. There were an insufficient number of time series data points to construct values for DI2.

3.3.4 Visual Health Assessment

Crown Condition Score

In November 2013, mean CCS at the three phreatophytic sites was similar, with values decreasing at both DR1 and DI1 between May and November 2013 and increasing marginally at site DI2 (Figure 38). The annual change between May 2012 and May 2013 was similar at DI1 and DR1, while the decrease in mean CCS between November 2012 and November 2013 was significantly different at DI1 compared to DR1 (Kruskal-Wallis χ^2 = 18.28 P < 0.001; Multiple comparison P < 0.05) (Figure 39).

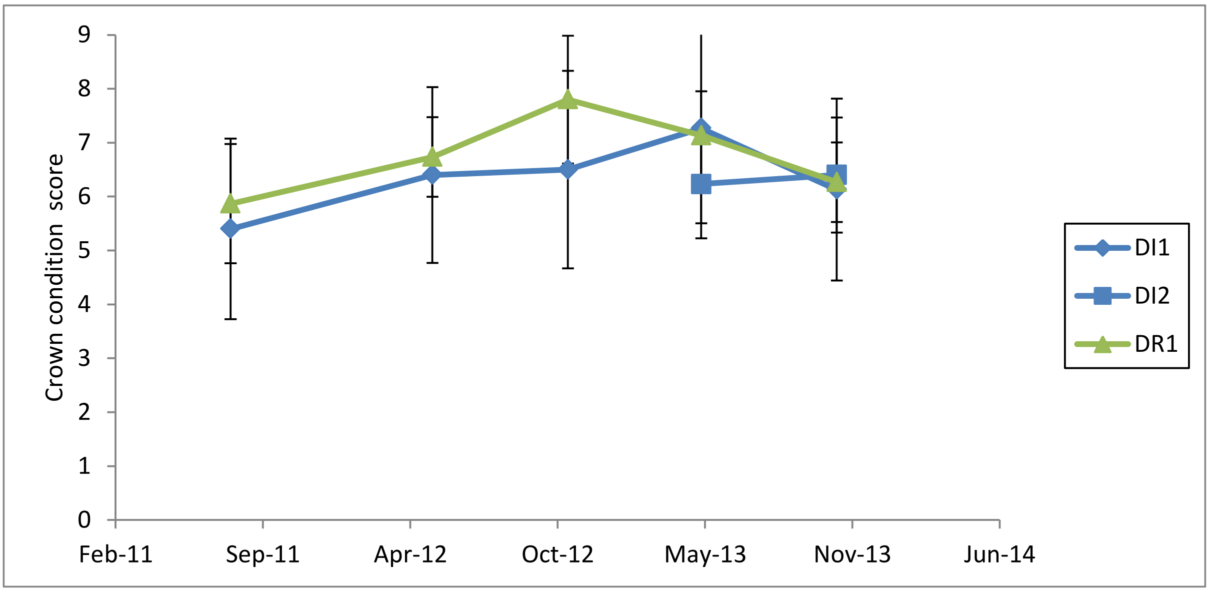

Figure 38: Mean crown condition score of *Eucalyptus victrix* at drawdown potential impact sites (DI1 and DI2) and reference site (DR1) from August 2011 to November 2013 (n= 30). Error bars represent standard deviation.

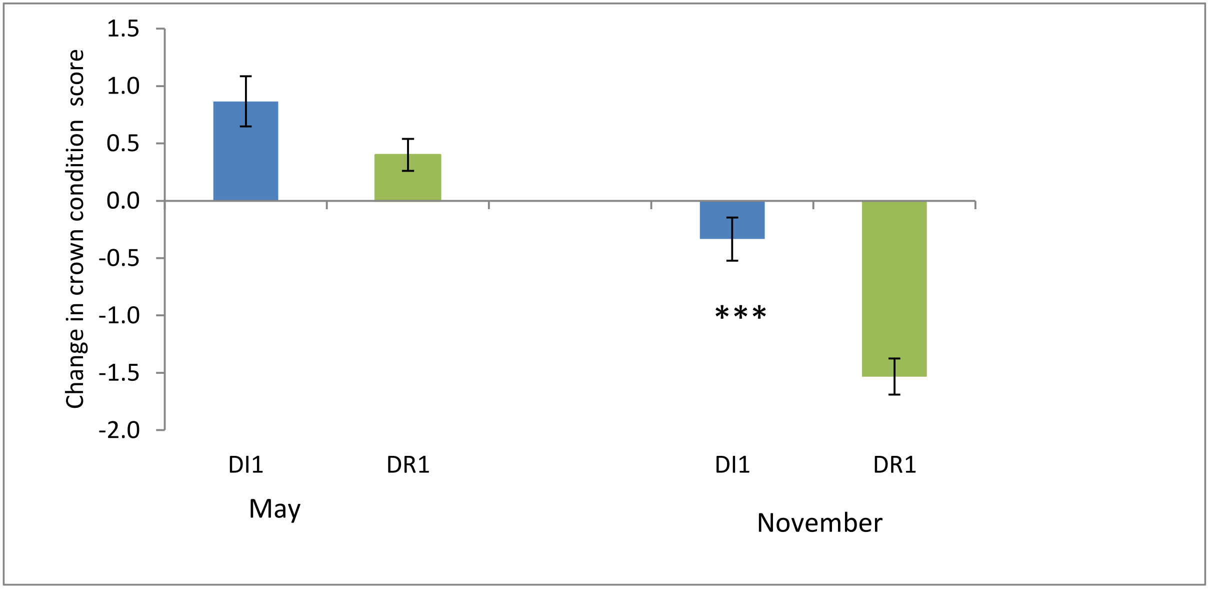

Figure 39: Change in mean crown condition score of *Eucalypts victrix* at drawdown potential impact site (DI1) and reference site (DR1) (n= 30) between May 2012 and May 2013 and November 2012 and November 2013. Error bars represent standard error. Asterisk (***) indicates significant difference between sites (P < 0.001).

Crown Condition Trajectory

The number of trees on a recovery trajectory decreased at the potential impact site DI1 and at the reference site DR1 between November 2012 and November 2013, with the number of trees on a decline trajectory increasing over the same period at DR1 (Figure 40). The number of trees on a recovery trajectory at DI1 was at the lowest level in November 2013. One tree was recorded as dead at DI1 in 2013. Survivorship analysis indicated no significant difference between the number of deaths at this site and the reference site: θ = 1, P = 0.317.

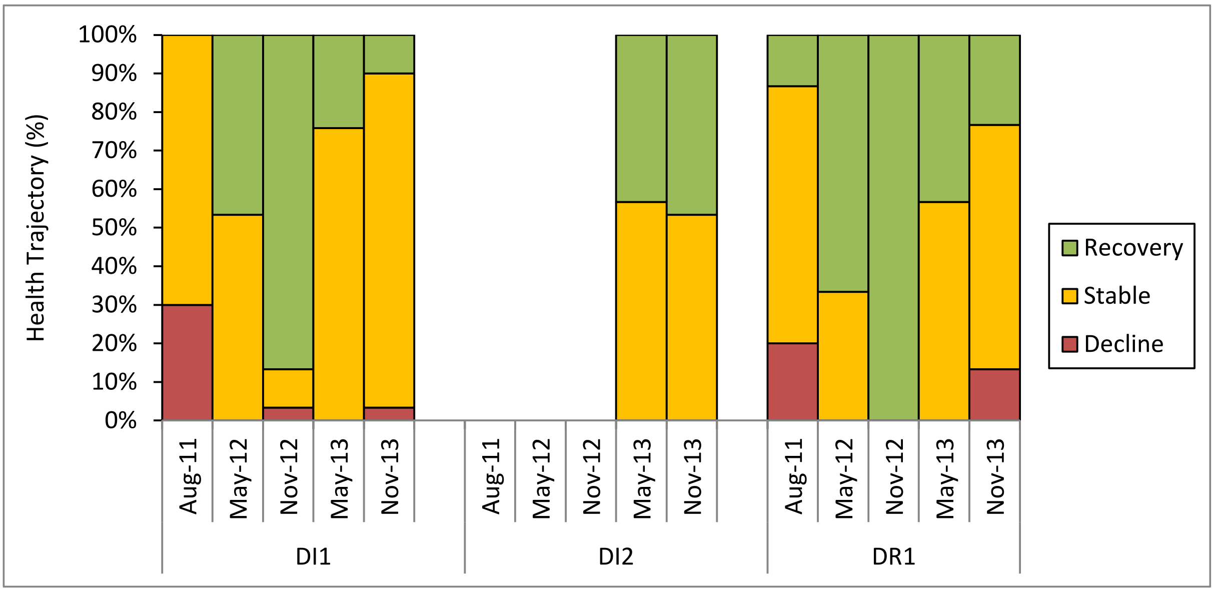

Figure 40: Percentage of *Eucalypts victrix* in different health trajectories (recovery, stable and decline) based on Souter et al. 2009 at drawdown potential impact sites (DI1 and DI2) and reference site (DR1) (n= 30) from August 2011 to November 2013.

3.3.5 Monitoring Management Triggers

Monitoring management triggers for phreatophytic communities were exceeded for predawn water potential and in the multivariate analysis of ecophysiological variables (Table 14).

Table 14: Results for phreatophytic vegetation communities in 2013 in relation to monitoring management triggers in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) .

Trigger	Trigger Exceeded	Description
Pre-dawn leaf water potentials significantly greater in dewatering zones in comparison to reference	Yes	Values significantly greater at potential impact sites DI1 and DI2 in May 2013 and again at DI2 in November 2013 compared to reference sites.
Percentage canopy cover significantly greater than reference (p<0.05) and/or greater than 1 Standard Deviation from the control chart mean	No	Change in PFC was not significantly greater between potential impact and reference sites and control chart analysis indicates DI1 is in control.
Death of keystone tree species significantly greater than reference (p<0.05) and/or greater than 1 Standard Deviation from the control chart centerline	No	Death of one tree (at DI1) did not lead to a significant difference between potential impact and reference sites in the survival analysis.
Multivariate control chart of multiple ecophysiological variables – Level 1 management response required in exceedance of 90% confidence interval in control chart trend	Yes	Exceedance of control limit at potential impact site DI1 in November 2013

3.4 Mean Basal Area

Mean basal area of the sample trees across the eastern and western mulga sites was similar. The mulga trees at the western potential impact site (WI3) were the largest of the trees across the six sites (Figure 41). Site WI3 had the greatest spread of individuals across size classes and also contained the two largest individual mulga trees. Mean basal area of trees at the phreatophytic potential drawdown site DI1 is the smallest of the three phreatophytic communities and the least variable for mean basal area per tree. The variation within the phreatophytic communities was considerably greater than the variation recorded in the mulga communities.

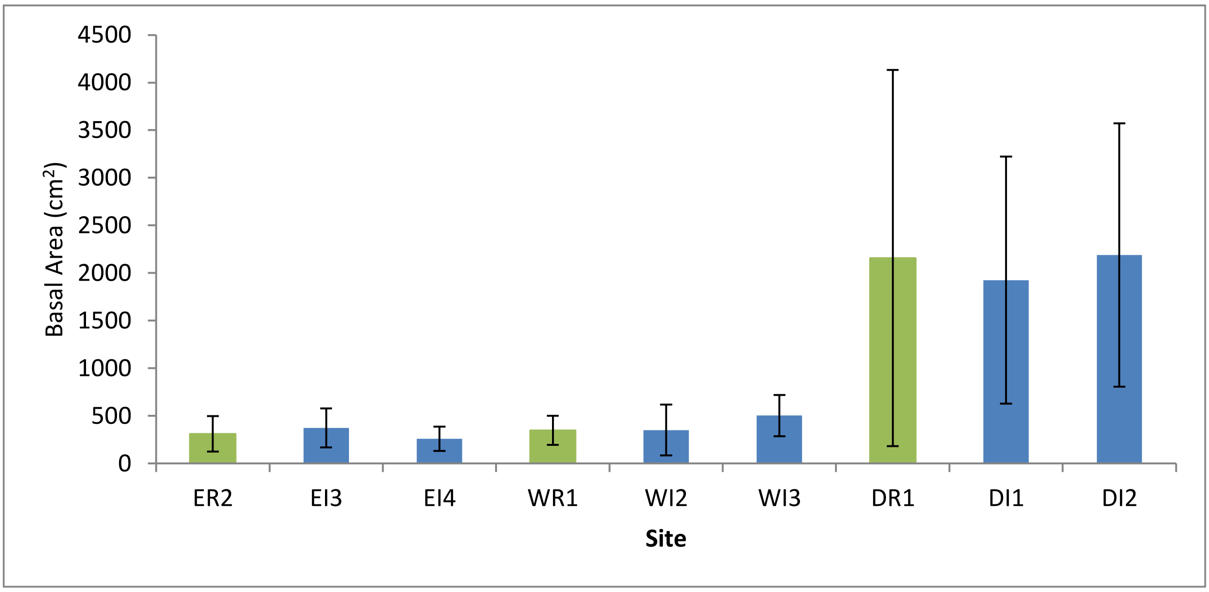

Figure 41: Mean basal area (cm^2) at each site. Error bars indicate standard deviation.

3.5 Vegetation Composition and Cover

Community composition and cover for eastern mulga has changed similarly over time at the potential impact and reference sites (Figure 42). There has been no significant difference (PerMANOVA; $P > 0.05$) between any of the eastern mulga sites over the four survey periods analysed.

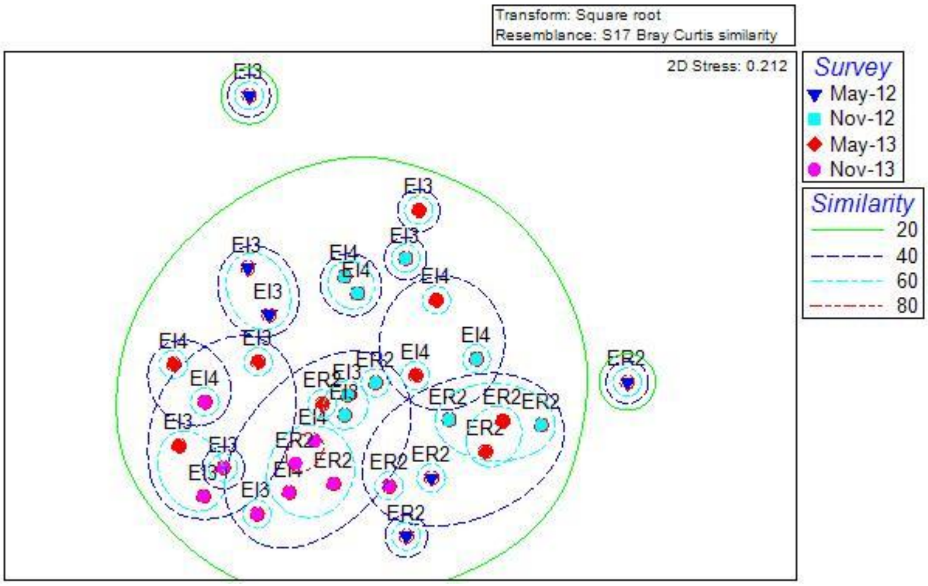

Figure 42: Non-metric multi-dimensional scaling (NMDS) plot of vegetation community composition along transects at all eastern mulga sites (n = 3 per site).

There has been no clear trend over time in community composition and cover at western mulga sites when potential impact and reference sites were compared in an NMDS (Figure 43). In November 2012 there was a significant difference (PerMANOVA; P (Monte Carlo) = 0.049) between sites WI2 and WR1 which is also evident in the ordination, however by May 2013 this difference was no longer evident (PerMANOVA; P = 0.094).

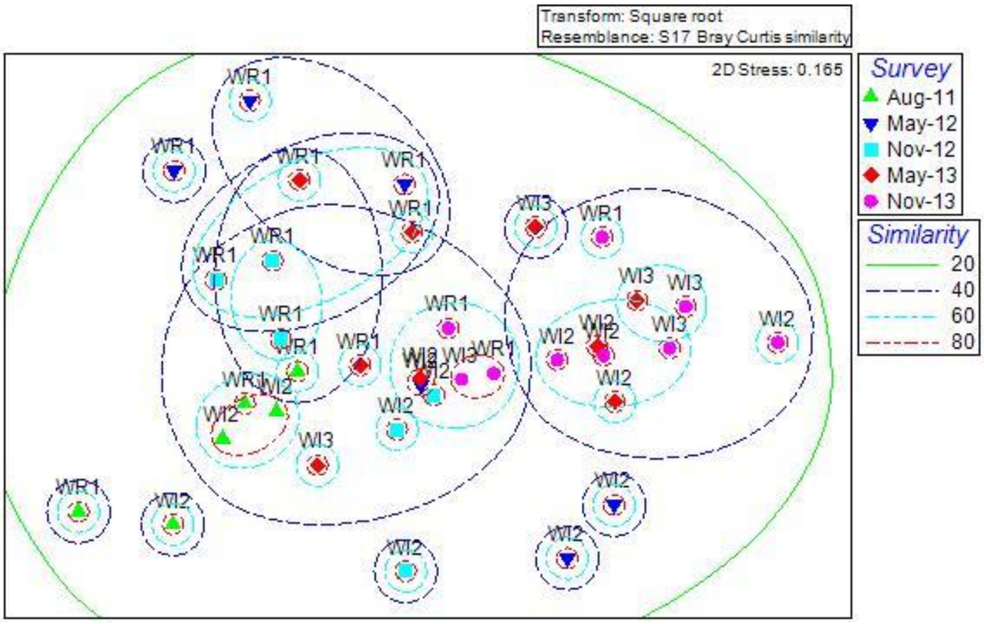

Figure 43: Non-metric multi-dimensional scaling (NMDS) plot for vegetation community composition along transects at all western mulga sites (n = 3 per site).

Community composition and cover at the phreatophytic potential impact and reference sites has changed similarly over time (Figure 44). There has been no significant difference (PerMANOVA; P > 0.05) between any of the phreatophytic sites over time.

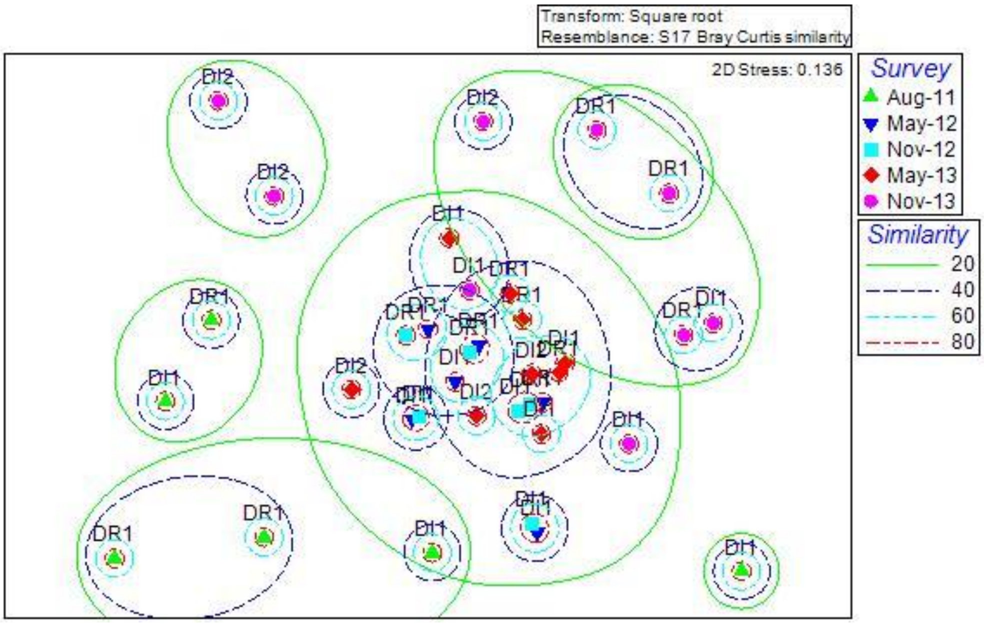

Figure 44: Non-metric multi-dimensional scaling (NMDS) for vegetation community composition along transects at all phreatophytic sites (n = 3 per site).

3.5.1 Weeds

Weed species were present at both of the eastern mulga potential impact sites in every period that monitoring occurred (Figure 45). Weed species richness (5) was greatest at EI3 in November 2013. The eastern mulga reference site had only one weed species recorded, **Portulaca oleracea*, during one survey in May 2013.

Weed species richness was greatest at the western reference site in May 2013 (Figure 46). **Malvastrum americanum* was first recorded at WR1 in May 2012 and was recorded again in May and November 2013. **Bidens bipinnata* was present at WI3 in November 2013 but was dead, therefore not included in the live extent. WI2 remains weed free along the line intercept transects.

For the phreatophytic community, **Aerva javanica* was recorded at potential impact site DI2 in May 2013 and this is the only weed species that has been identified as a serious environmental weed in the Fortescue (2011) Weed Management Plan (45-PL-EN-0013) (Figure 47). **Cenchrus ciliaris* was the most common weed species at each of the phreatophytic sites in May 2013. In November 2013, **C. ciliaris* was again present at all sites but live plants were only recorded along the line intercept transects at potential impact site DI1. **Malvastrum* *americanum* was again recorded at the reference site DR1 after first being recorded at this site in May 2012.

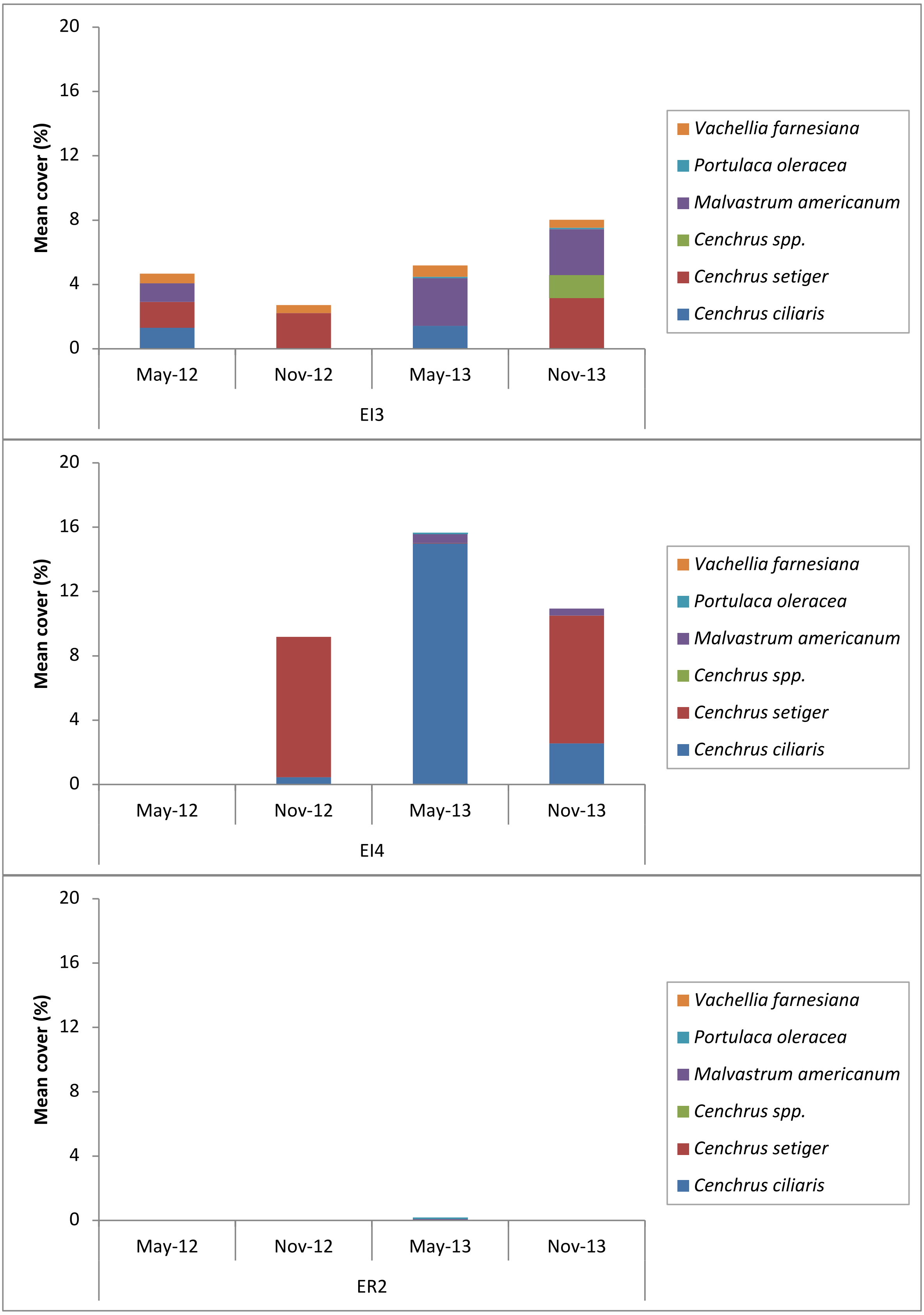

Figure 45: Mean cover (%) of weed species along three transects per eastern mulga potential impact and reference sites between May 2012 and November 2013.

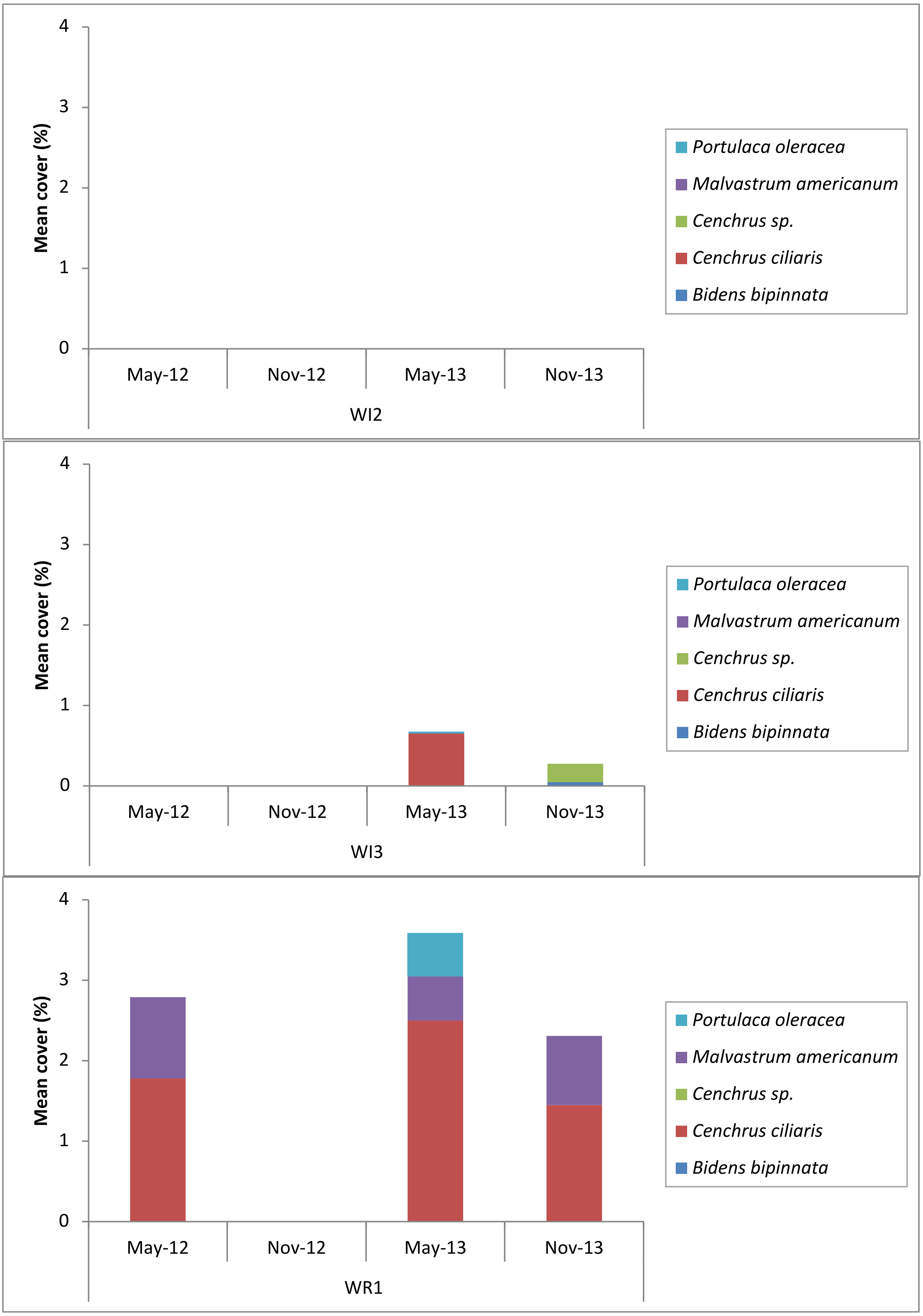

Figure 46: Mean cover (%) of weed species along three transects per western potential impact and reference sites between May 2012 and November 2013.

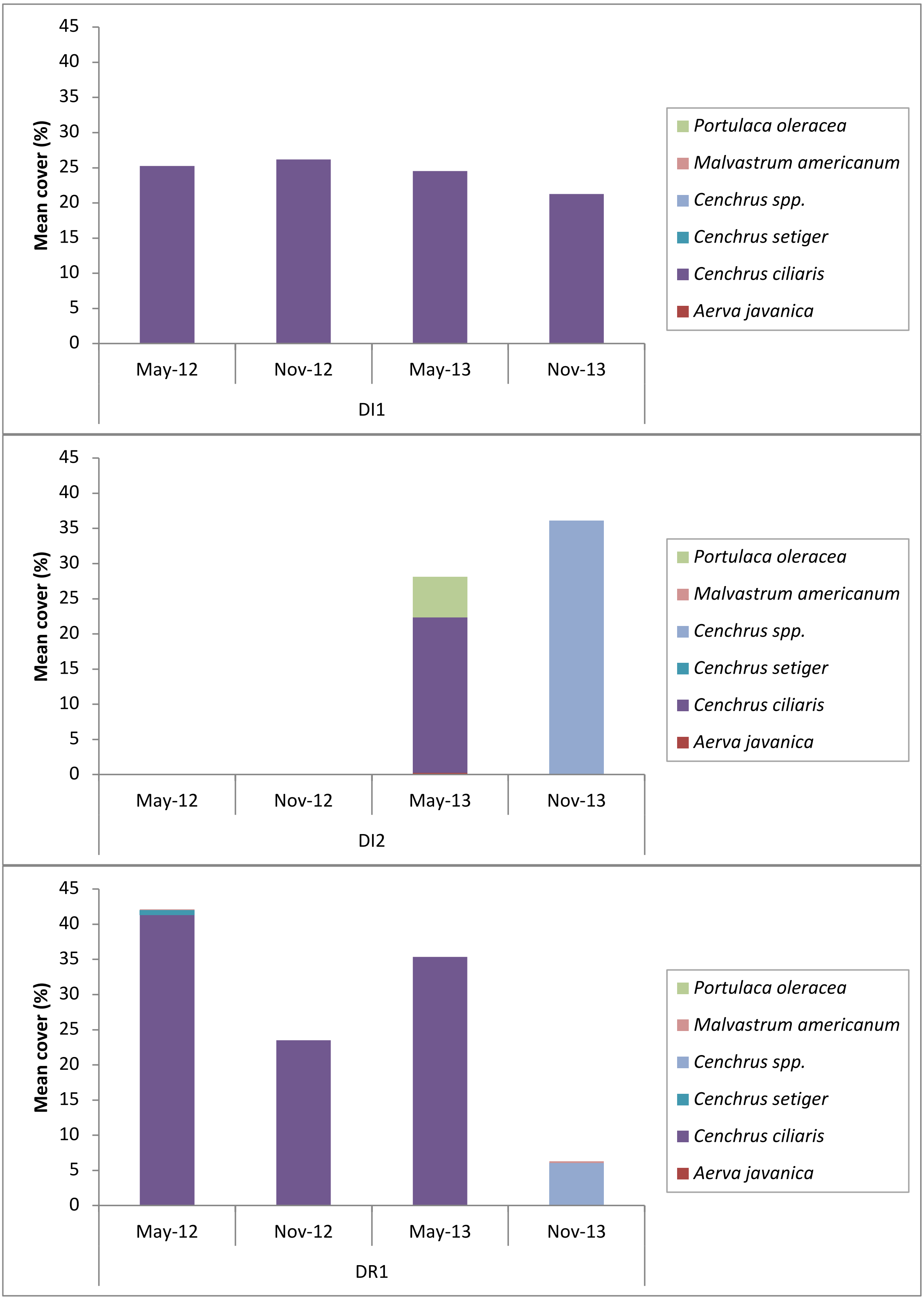

Figure 47: Mean cover (%) of weed species along three transects per drawdown potential impact and reference sites between May 2012 and November 2013.

3.6 Samphire Communities

3.6.1 Percentage Cover

Trends in mean percentage cover of samphire species have been generally comparable between the potential impact and reference communities (Figure 48). Cover remains higher within the potential impact communities, although variation across transects is considerably greater than within the reference communities. Mean percentage cover decreased between May 2012 and May 2013 across potential impact and reference communities and increased between November 2012 and November 2013 (Figure 49). No significant differences were found between the communities (May ANOVA $F_{1,6}$ = 1.328 P = 0.293; November ANOVA $F_{1,6}$ = 0.26 P = 0.628).

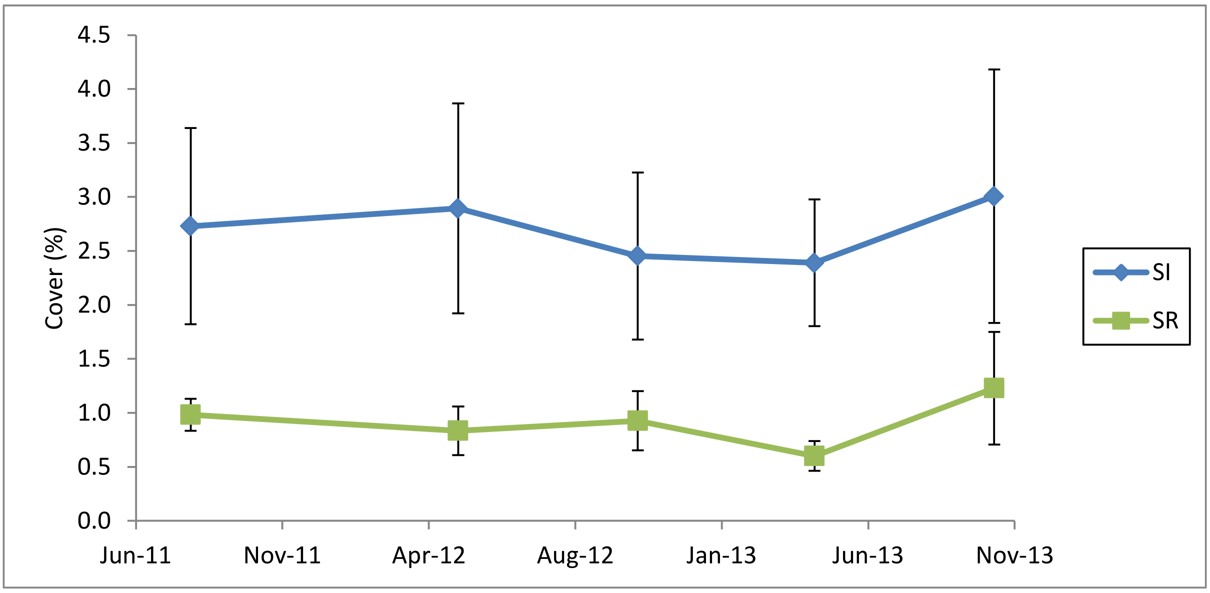

Figure 48: Mean cover (%) of samphire species along permanent transects within potential impact (SI1-4) and reference (SR3-6) areas (n = 4) between September 2011 and November 2013. Error bars represent standard deviation.

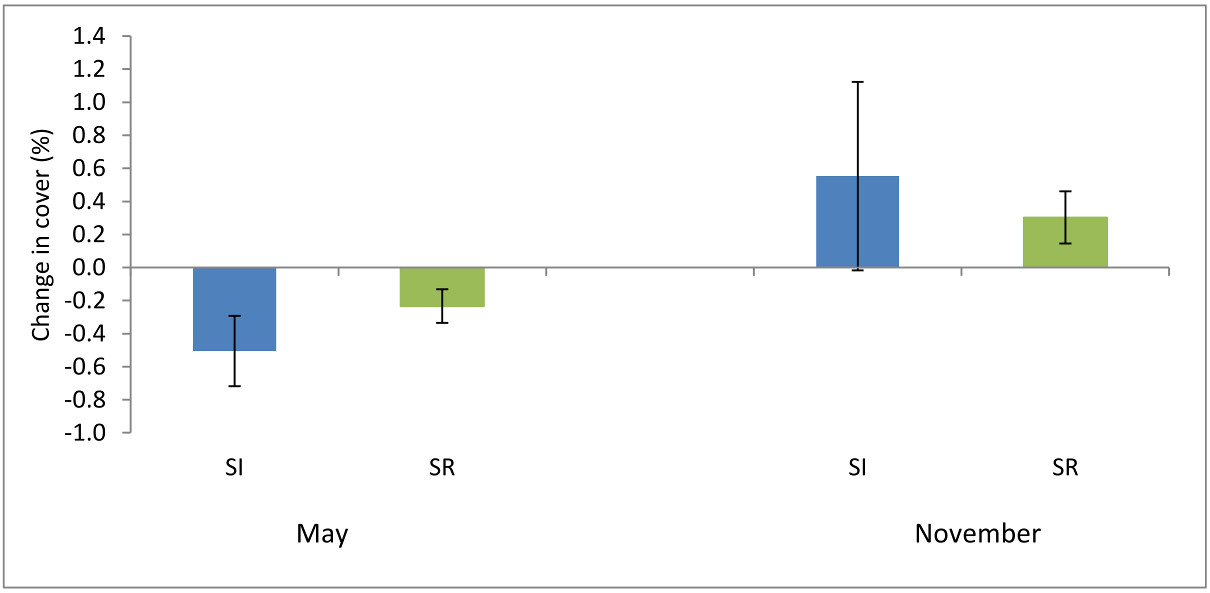

Figure 49: Change in mean cover (%) of samphire species along permanent transects within potential impact (SI1-4) and reference (SR3-6) areas (n = 4) between May 2012 and May 2013, and November 2012 and November 2013. Error bars represent standard error. No significant difference was found between sites.

3.6.2 Health Score

The mean health of samphire at the potential impact site was higher (less tip die off) in May 2013 and similar in November 2013 when compared to the reference site. These differences were significant in May (ANOVA $F_{1,6}$ = 7.46, P = 0.034) but not in November (Kruskal-Wallis χ^2 = 0.11, P = 0.741). Mean values in these areas changed similarly between September 2011 and May 2013 (Figure 50). In November 2013, this trend changed when the mean health score of samphire communities in the potential impact area declined while the health of reference communities increased. Between May 2012 and May 2013 the mean health of potential impact and reference samphire communities changed very little at both sites (ANOVA $F_{1,6}$ = 0.004 P = 0.953) (Figure 51). The increase in mean health in the two areas between November 2012 and November 2013 was significantly different (ANOVA $F_{1,6}$ = 72.58 P < 0.001).

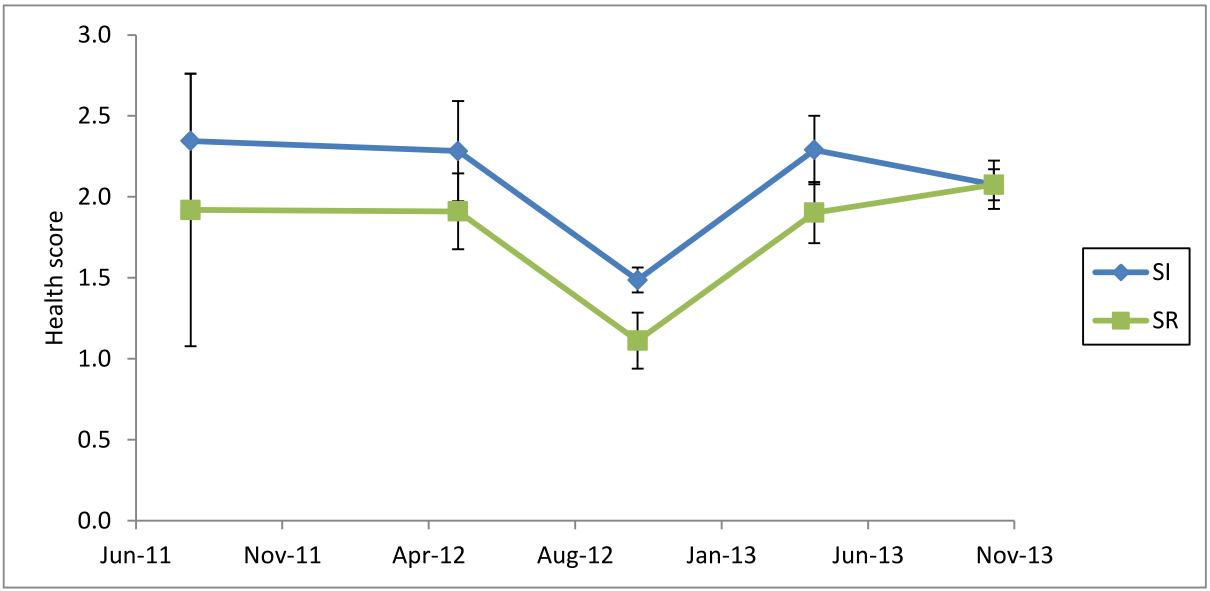

Figure 50: Mean health score of samphire species along permanent transects within potential impact (SI1-4) and reference (SR3-6) areas (n = 4) between September 2011 and November 2013. Error bars represent standard deviation.

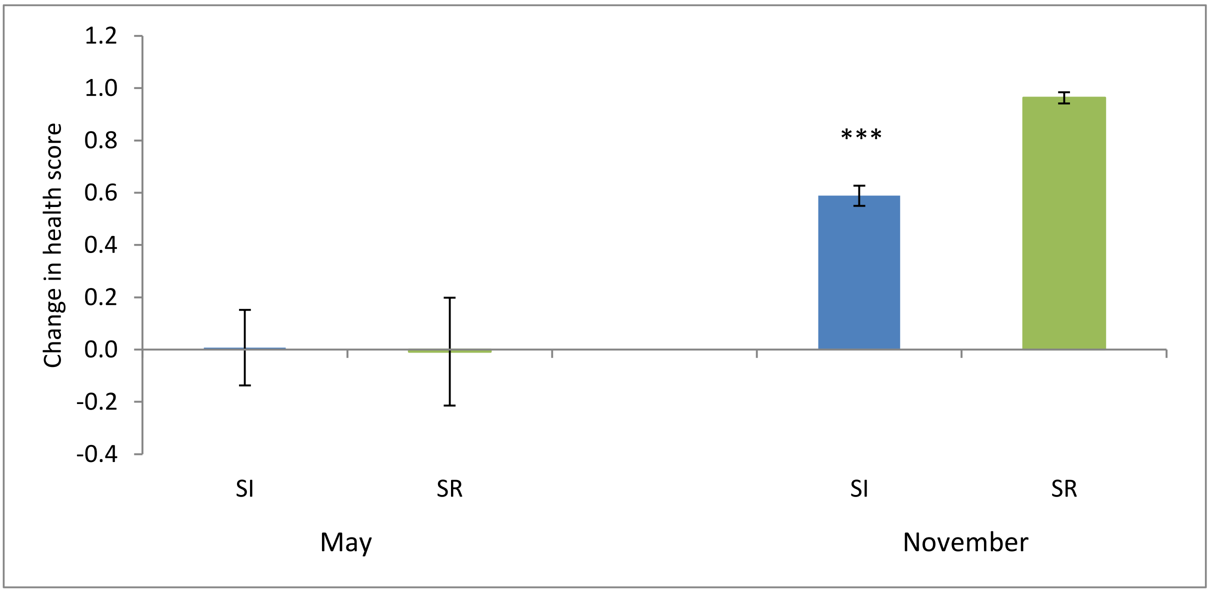

Figure 51: Change in mean health score of samphire species along permanent transects within potential impact (SI1-4) and reference (SR3-6) areas (n= 4) between May 2012 and May 2013, and November 2012 and November 2013. Error bars represent standard error. Asterisks (***) represent significant difference between potential impact and reference areas (P < 0.001).

3.6.3 Height

The mean height of samphire in the potential impact and reference areas has followed a similar pattern since September 2011 although there has been a greater degree of variation within the potential impact area (Figure 52). In May 2013 and November 2013, mean height of samphire was greater in the potential impact area compared to reference area and these differences were significant: ANOVA $F_{1,6}$ = 34.81, P = 0.001 (May 2013) and ANOVA $F_{1,6}$ = 23.47, P = 0.003 (November 2013). Change in samphire height between May 2012 and May 2013 (ANOVA $F_{1,6}$ = 0.936 P = 0.371) and November 2012 and November 2013 (ANOVA $F_{1,6}$ = 2.211 P = 0.188) has not been significantly different between the potential impact and reference sites (Figure 53). Change within the potential impact areas between November 2012 and November 2013 was greater than that seen within the reference area over the same period.

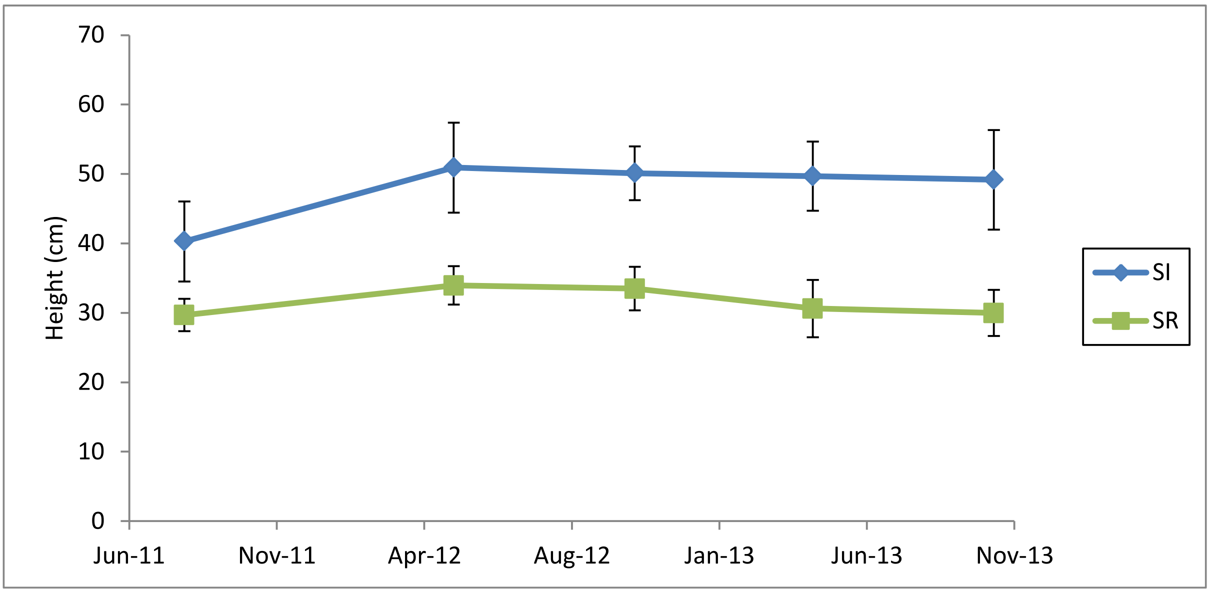

Figure 52: Mean samphire height along permanent transects within potential impact (SI1-4) and reference (SR3-6) areas (n = 4) between September 2011 and November 2013. Error bars represent standard deviation.

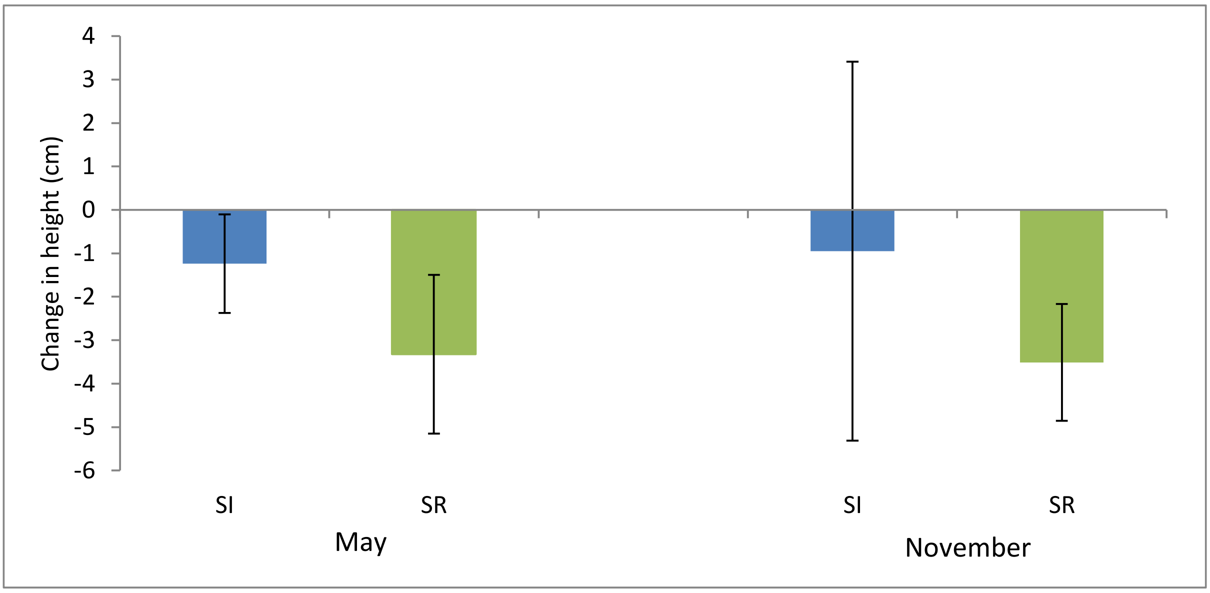

Figure 53: Change in mean samphire height along permanent transects within potential impact (SI1-4) and reference (SR3-6) areas (n = 4) between May 2012 and May 2013, and November 2012 and November 2013. Error bars represent standard error. No significant difference was found between sites.

Control chart analysis revealed that mean height at the potential impact and reference sites was in control during 2013 (Figure 54 and Figure 55).

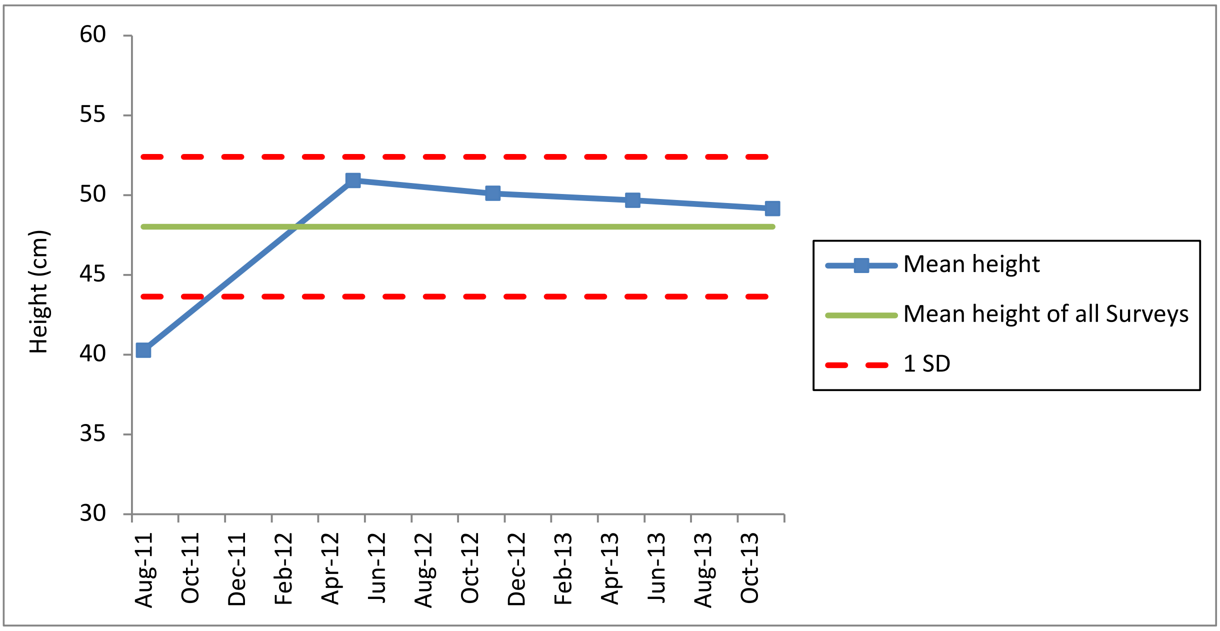

Figure 54: Control chart for height of samphire along permanent transects within potential impact area SI1-4 (n = 4). Control limit is one standard deviation (SD) from the mean.

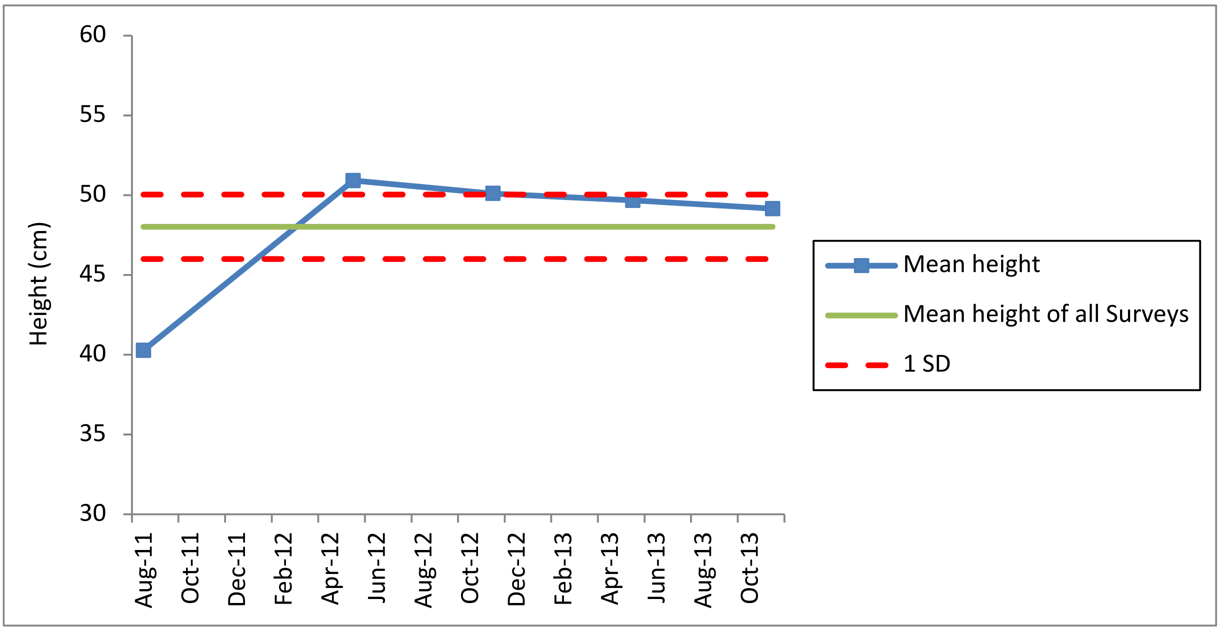

Figure 55: Control chart for height of samphire along permanent transects within reference SR3-6 area (n = 4). Control limit is one standard deviation (SD) from the mean.

3.6.4 Multivariate Analysis: Height and Health

There were significant differences between the reference and potential impact site in the PerMANOVA analysis of multivariate data (height and health [tip die off]): pseudo F = 40.1, P = 0.001 (May 2013), pseudo F = 24.7 and P = 0.001 (November 2013).

3.6.5 Monitoring Management Triggers

Level 1 monitoring management triggers have been exceeded for the samphire community (

Table 15). The exceedances related to the greater mean height (lower tip die off) and mean health of samphire in the potential mounding impact area in comparison to the reference sites, and the multivariate difference for height and health between the two areas. Results for species composition were unable to be assessed against the trigger.

Table 15: Results for samphire vegetation communities in 2013 in relation to monitoring management triggers in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a)

Trigger	Trigger Exceeded	Description
Plant species composition within communities within mounding areas does not alter significantly as measured by non-parametric multivariate analyses from vegetation transects in reference areas (identification with reliable reproductive material from surveyed plants)	N/A	Specimens with reproductive material were not available; hence they were unable to be identified to species level. As a result, the multivariate analysis could not be undertaken
Tip die off or tip growth of samphire plants is not significantly greater in mounding impact areas in comparison to reference areas	Yes (Figure 51)	• Mean height of samphires significantly greater at mounding impact sites in 2013 compared to reference sites. • Significantly lower tip die off (greater health) at mounding impact sites compared to reference sites in May 2013.
Univariate control chart – Level 1 management response required in exceedance of 1 standard deviation in tip die off and height	No	• Not applicable to tip die off (health) • Mean heights at potential impact sites were within control limits
MANOVA – Level 1 management response required if significant differences ($P < 0.05$) detected	Yes	• Non-parametric equivalent test to MANOVA (PerMANOVA) indicated a significant difference between potential impact and reference sites.

4. DISCUSSION

4.1 Mulga Communities

The overarching hypothesis for monitoring of mulga communities was that groundwater reinjection would not adversely affect mulga communities in areas of potential mounding impacts beyond natural variation recorded at reference sites. Based on the management monitoring triggers that have been set, this monitoring hypothesis must be rejected for the eastern potential impact sites (EI3 and EI4). Level 1 triggers have been exceeded for midday water potential (EI3), canopy cover (EI3 and EI4) and multivariate values for all ecophysiological parameters (EI3). Therefore, Fortescue needs to implement the responses as outlined in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) with respect to increased frequency of monitoring and a further analysis of cause and effect.

Despite the exceedance of the Level 1 trigger, overall, the condition of mulga in both eastern and western areas as assessed by visual health ratings is good, with reference and potential impact sites comparable and trending similarly. There have been no deaths of sample trees to date. Thus, it is not readily apparent as to whether mounding has had an impact at this stage or the exceedances are a natural phenomenon.

Contrasting trends in water potential and PFC between reference and potential impact sites were apparent. However, at present, it is unclear as to whether mounding accounts for these differences. Trends for PFC vary between potential impact sites in comparison to the reference sites whereas water potential is generally trending lower at potential impact sites than at the reference. If groundwater was rising within the root zone of mulga, and this groundwater was not saline, water potential would be expected to increase, at least in the early stages of mounding; it is less clear as to whether ongoing rise would lead to a reduction or a further increase in water potential. The declining soil moisture at both the reference and potential impact sites at the end of the dry season (November 2013) indicates that if mounding is occurring, groundwater remains below 0.5 m depth. The lack of correlation between water potential and soil moisture content at 0.5 m suggests that stores of moisture below this depth may be influencing the water status of mulga. The majority of mulga roots are found in the 0 to 0.5 m depth zone, but fine roots can extend down to 1.6 m (Astron 2012b). Regardless, if any impact from mounding is present, water potential measures are capturing seasonal response to changing water availability, generally becoming more negative after the dry season and indicating a strong physiological response to available water. Inherent site factors such as differences in topography and soil type may account for the differences in trends that have been observed. Additional data would need to be examined to evaluate whether this is the case.

Grimes density and health scores do not as yet reveal clear trends attributable to changing water availability, making interpretation difficult. Early indications suggest phenological processes such as phyllode development, flowering and fruit set in mulga may be associated with rainfall and temperature changes and therefore may be useful indicators of increasing soil water availability.

Leaf litter trap trial

Seasonal change in litter fall within a site can lend valuable information to understanding mulga phenology and response to environmental change. Whether or not mulga phyllode shed occurs to some degree as a response to drought is not clearly understood. While Winkworth (1973) suggested that mulga phyllode shedding peaks at times of increased soil moisture, the mean weight of phyllodes collected at the western reference site in November 2013 (at the end of the dry season) was not considerably different to that collected in May 2013 (at the end of the wet season). The stability in the mean weight of phyllodes collected between May and November 2013 appears to belie the considerable increase in PFC recorded at this site over the same period but does appear to correspond to the stable Grimes density measure.

While there has been some difficulty with this element of the Program owing to the loss of field infrastructure between surveys it would be helpful to retain leaf litter traps at the western reference site throughout 2014 in order to continue to investigate if there is a relationship between water availability and phyllode drop. The scientific literature is surprisingly lacking in manuscripts providing detailed understanding of mulga physiology. Change in phyllode litter collected over seasons and years may reveal interesting information on mulga growth dynamics and findings may yield observations that can be used to guide future research and development of mulga monitoring methods.

4.2 Phreatophytic Vegetation

The overarching hypothesis for monitoring of phreatophytic communities was that groundwater abstraction would not adversely affect phreatophytic communities in areas of potential drawdown beyond natural variation recorded at reference sites. However, monitoring management triggers were exceeded for both potential impact sites during 2013 for predawn water potential and for the multivariate control chart analysis of potential impact site DI2 in November 2013. Therefore, Fortescue will need to implement the responses as outlined in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) with respect to increased frequency of monitoring and a further analysis of cause and effect.

Further investigation of the exceedance is likely to indicate that groundwater drawdown was not the cause of the trends observed and that the trees are maintaining good health. If dewatering was having an effect at the monitoring sites then water potential values would be expected to be significantly lower than at the reference site and displaying a negative trend. This highlights a need for the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) to be revised so that this monitoring management trigger can be amended to account for the likely effect of groundwater drawdown: lower water potential at the potential impact sites. Further support for an absence of impact is the fact that trends in water potential in 2013 were similar if not slightly better at the potential impact sites than at the reference site. Trends for tree health also provide no evidence of any impact with visual health ratings similar between reference and potential impact sites. One tree death was recorded at potential impact site DI1 in 2013; however, the dead tree has been in poor or declining health since the Program commenced in August 2011; therefore no association between the death and dewatering is apparent. A replacement tree has been incorporated in to the monitoring program at this site.

4.3 Samphire Communities

The overarching hypothesis for monitoring of samphire communities was that groundwater reinjection would not adversely affect samphire communities in areas of potential mounding impacts beyond natural variation recorded at reference sites. This hypothesis must be rejected as monitoring management triggers were exceeded: height of samphires was significantly greater in the potential impact area, health was significantly higher in the potential impact area in May 2013 and there was a difference in the multivariate analysis of height and tip die back (health) between the potential impact and reference areas. Therefore, Fortescue will need to implement the responses as outlined in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) with respect to increased frequency of monitoring and a further analysis of cause and effect. Reporting against the monitoring management trigger in relation to community composition change was not possible due to the inability to identify species in the absence of reproductive structures being present on the plants at both reference and potential impact sites. There has been one occasion, during the May 2013 survey, when flowering samphire material was collected at potential impact site SI3 and subsequently identified as *Tecticornia indica*.

Overall, samphire communities within both the reference and potential impact areas appear in relatively good health. However, the significantly smaller increase in health recorded at the potential impact site in comparison to the reference site provides a further indication of a difference between potential impact and reference sites. Differences in height and trends in health may be due to inherent site differences. Potential impact sites are somewhat further from the centre of the Fortescue Marsh, and the decline in health may be a seasonal response to drying conditions. Further, the depth to any hard layer or saline water table may be greater here, allowing plants to grow taller. Despite the decline, mean health across both areas remains moderate and mean percentage cover and height of samphires in the potential impact area remain greater than in the reference areas. For these reasons, it is unlikely that mounding has had an adverse impact on samphires to date.

4.4 Secondary Pressures

Grazing by cattle, fire, seasonal variability and weeds have the potential to degrade vegetation communities. Cattle and evidence of grazing is persistent throughout the project area, although cattle evidence is low at WI2. Fire had not disturbed any of the monitoring sites in 2013, although there is some evidence of historic fire events at WI3 and ER2. The weather of 2013 was typical for the Pilbara. Weeds were present at all mulga and phreatophytic monitoring sites in May 2013 likely owing to favourable climatic conditions. Weeds were not apparent at WI2 in November 2013 but were present at all other sites. Only samphire species have been monitored in the Fortescue Marsh area following the baseline survey and observations and photographic evidences suggests there has been little change since that time. Monitoring of weed species and cover should resume in this community in 2014.

5. EVALUATION OF THE PROGRAM

5.1 Soil moisture monitoring

Since acceptance of the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a), Fortescue has completed an investigation of mulga root architecture and determined that mulga roots do not penetrate to depths much greater than 1 m and all large, and the majority of fine, roots are found in the top 0.5 m of soil (Astron 2012b). Soil sampling for gravimetric moisture content at a depth of 0.5 m is therefore likely to indicate whether soil moisture is increasing in the vicinity of mulga roots as a result of mounding due to reinjection of water. Use of hand tools for soil sampling is a better approach than machinery because it is minimally disturbing to the monitoring sites.

5.2 Changes in monitoring sites

During 2013 the western potential impact site WI1 was decommissioned and all infrastructure associated with monitoring was removed. This site was immediately adjacent to the camp waste water irrigation area, and it was felt that if any impact was observed it may not be possible to assign cause to either mounding or irrigation. In May 2013, a new western potential impact site was installed further west of WI1 and downslope of reinjection bores in the vicinity of groundwater monitoring bores in order to better represent vegetation in the western mounding area.

5.3 Maintaining seasonal consistency

The Program should be implemented during the same months, May and November, in coming years. This will ensure that monitoring captures annual fluctuations in monitored parameters which will better guide management decisions and reduce artefacts arising in data analysis and interpretation. The merit of this approach is becoming apparent in the current data set with seasonal fluctuations in soil moisture and leaf water potentials strongly evident. With a further year of data recorded at the same seasonal intervals, patterns and response to environmental conditions in mulga phenology will become more apparent. This will guide further refinements of mulga monitoring methods across the Pilbara.

5.4 Evaluation of the VHMMP

The current monitoring management triggers in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) and associated statistical tests should be reviewed and revised now that several years' data are available. The following issues exist with the present triggers or the analyses specified to determine whether a trigger has been exceeded:

- Some triggers are arguably too conservative; for example, one standard deviation is used as the trigger in univariate control charts whereas two or three standard deviations are generally adopted as common practice for monitoring trigger levels (see Gove et al 2013).
- Rather than comparing values at reference and potential impact sites at the latest point in time, analyses should account for differences between sites under baseline conditions (for example, by using baseline values as covariates) or triggers should refer to statistical differences in trends.
- Some triggers are unable to be reported against; for example, the multivariate analysis of samphire community composition is not possible because species are unable to be identified consistently during the monitoring surveys.
- The description of the trigger in some cases could better align with potential impacts; for example, predawn water potential should be expected to be significantly lower, rather than significantly greater, at potential dewatering impact sites.

6. CONCLUSION

This report has highlighted the exceedance of Level 1 monitoring management triggers in all three communities during 2013. As such, Fortescue is required to implement the responses as outlined under Section 11 (Corrective Action) in the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) which involves increased frequency of monitoring and a further analysis of cause and effect. Excluding the results specific to the triggers, when all trends for the parameters measured in the three communities were examined, there was no strong indication that an impact has occurred, especially for the phreatophytic and samphire communities. However, further investigation as directed by the VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) will be necessary to confirm this. Additional surveys, undertaken in August and February, should include primary monitoring parameters as set out in the Significant Flora and Vegetation Monitoring Guidelines (FMG 2012 45-GU-EN-0001), particularly:

- population structure – an age class assessment of each Mulga survey tree and any recent deaths
- condition assessment – visual health assessments of keystone species present at each site
- climate data.

Data on secondary parameters such as groundwater help to explain and confirm the cause of shifts in vegetation health and ultimately may contribute to the development of robust management triggers and thresholds (FMG 2012 45-GU-EN-0001). Groundwater data (a secondary monitoring parameter) should be sourced in order that primary parameters can be analysed and interpreted in context. The installation of piezometers or monitoring bores at each monitoring site would greatly inform the Program. It should be noted that additional surveys are not recommended as a permanent inclusion of the VHMMP at this stage and should be reviewed on an on-going basis.

It is also recommended that the present VHMMP (CC-PL-EN-0004 Rev 2) (Astron 2012a) undergo a review and the suitability of the current monitoring management triggers are assessed now that two years of monitoring data has been collected.

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