Population & Demography Study (Phase 1) of *Atriplex* sp. Yeelirrie Station

June 2015

Cameco Australia
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Unit 33/6 Keane Street, Midland WA 6056
PO Box 3608 Midland WA 6056
T (08) 9274 0303 F (08) 9274 0136

Report No: WB844

Client Name: Cameco Australia

Client Address: 24 Hasler Road, Osborne Park WA 60147

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V1	D. Leach	G. Cockerton	22 May 2015
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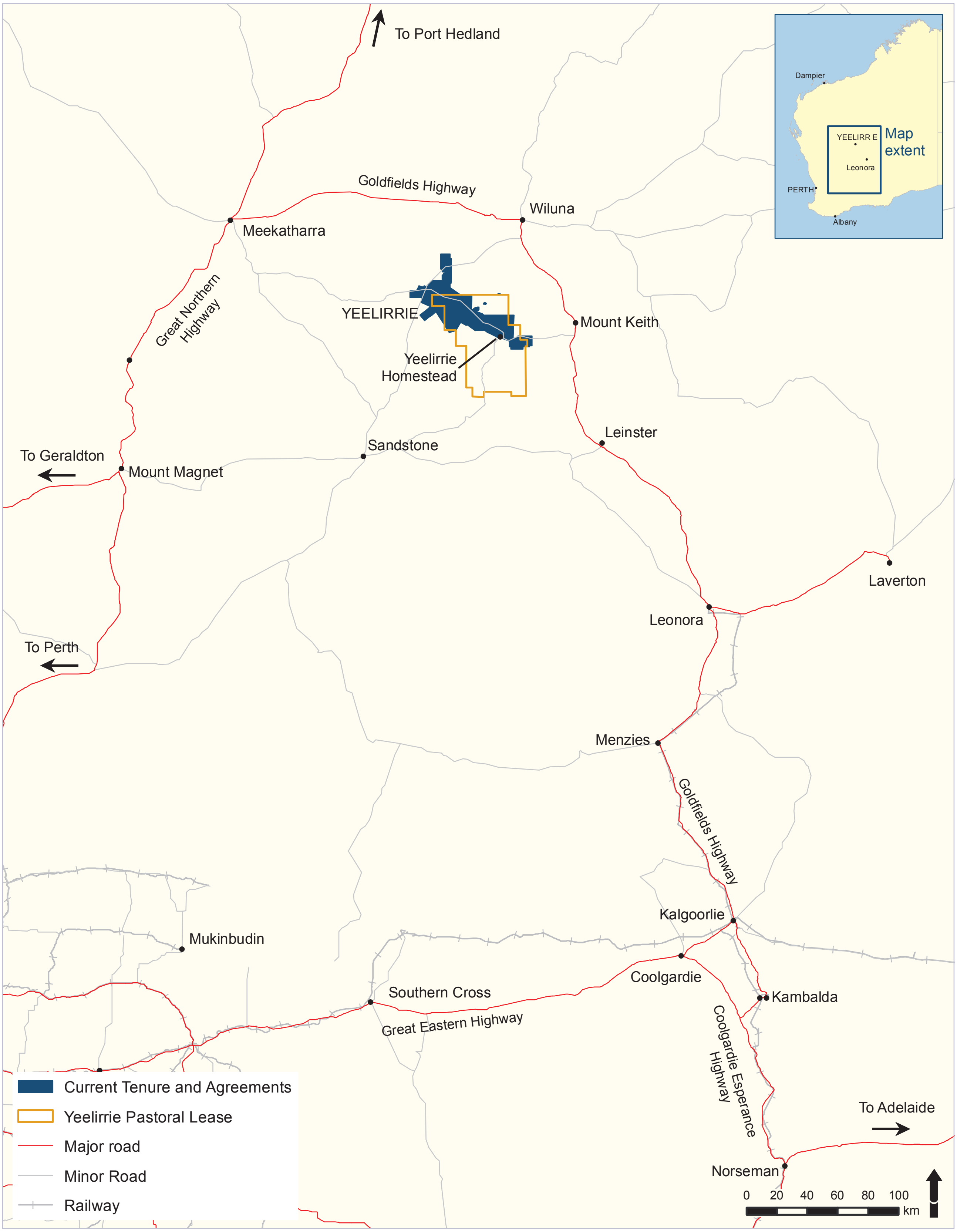
1. Background

The Yeelirrie Project is a proposed uranium ore mine located on the Yeelirrie Pastoral Station (Yeelirrie), 700 km northeast of Perth and 70 km southwest of Wiluna (Figure 1). The Threatened Flora *Atriplex* sp. Yeelirrie Station (L. Trotter & A. Douglas LCH 25025) occurs at Yeelirrie, a western population within the proposed mine footprint and an eastern population approximately 30 km to the east-southeast (Figure 2).

To date, *Atriplex* sp. Yeelirrie Station has been presented within flora and vegetation survey reports (Western Botanical 2011; Western Botanical 2015) and within a preliminary demography investigation (Western Botanical 2014). Two additional studies (Clarke *et al.* 2012; Shepherd *et al.* 2015) focus specifically on genetics and conservation significance of *Atriplex* sp. Yeelirrie Station.

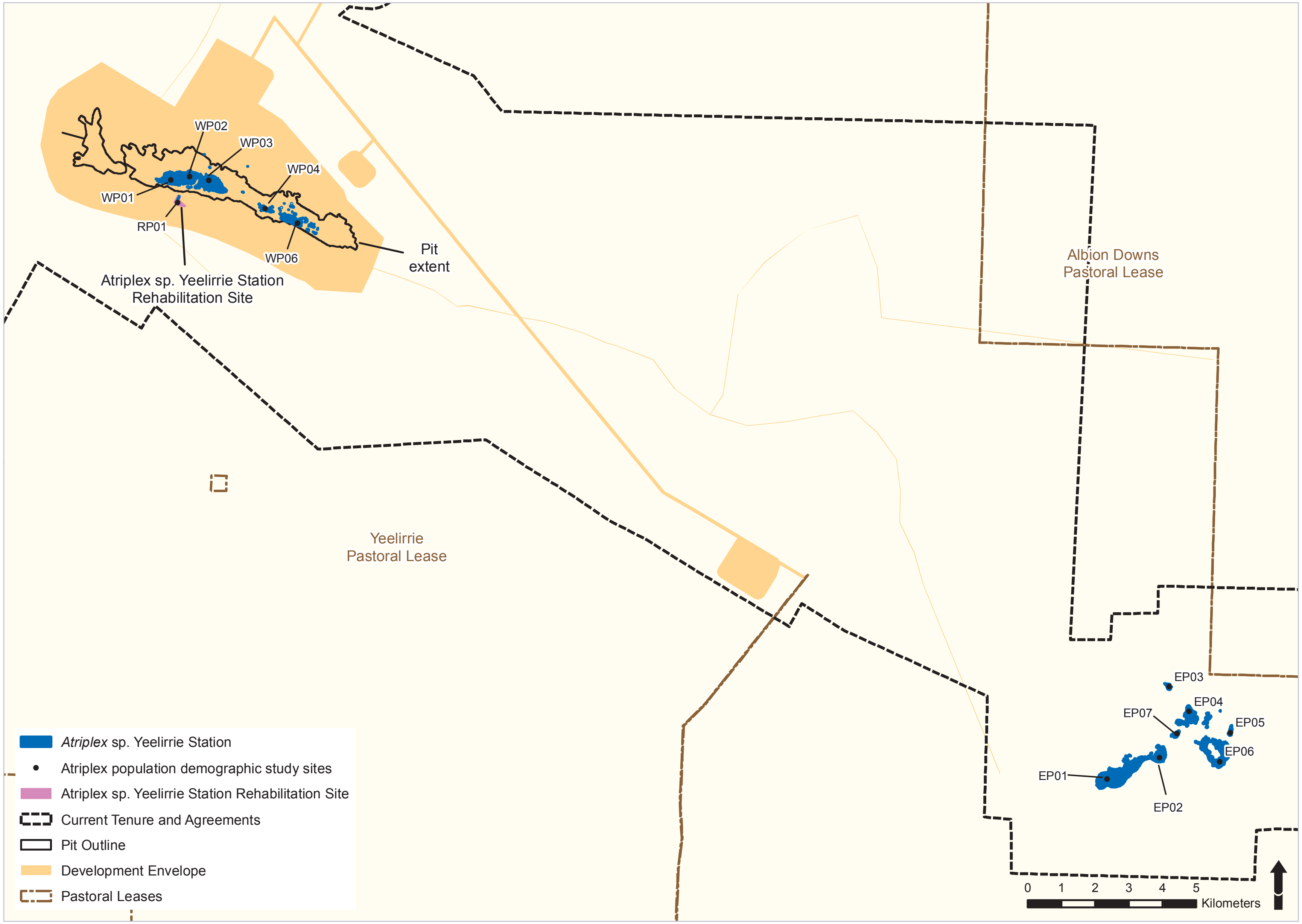
Cameco Australia engaged Western Botanical to initiate a population and demography study of *Atriplex* sp. Yeelirrie Station (L. Trotter & A. Douglas LCH 25025). The purpose of the study is to collect population and demography information of *Atriplex* sp. Yeelirrie Station to assist the management of existing populations and any future translocated populations. Fieldwork for phase 1 of this study was performed 23 – 30 March, 2015 and was preceded by a cyclonic rainfall event. Rainfall at Yeelirrie Station for the preceding 12 months is presented in Figure 3.

Figure 1: Location of the Yeelirrie Project within Western Australia.



To Port Hedland
Goldfields Highway
Wiluna
Meekatharra
Great Northern Highway
YEELIRRIE
Yeelirrie Homestead
Mount Keith
Leinster
Sandstone
To Geraldton
Mount Magnet
Laverton
Leonora
To Perth
Menzies
Goldfields Highway
Kalgoorlie
Mukinbudin
Coolgardie
Southern Cross
Kambalda
Great Eastern Highway
Coolgardie Esperance Highway
To Adelaide
Norseman
Current Tenure and Agreements
Yeelirrie Pastoral Lease
Major road
Minor Road
Railway
0
20
40
60
80
100
km
Dampier
YEELIRR E
Leonora
Map extent
PERTH
Albany

Figure 2: Location of Atriplex sp. Yeelirrie Station and the proposed mining footprint at Yeelirrie.



WP01
WP02
WP03
WP04
WP06
RP01
Pit extent
Atriplex sp. Yeelirrie Station Rehabilitation Site
Albion Downs Pastoral Lease
Yeelirrie Pastoral Lease
EP01
EP02
EP03
EP04
EP05
EP06
EP07
Atriplex sp. Yeelirrie Station
Atriplex population demographic study sites
Atriplex sp. Yeelirrie Station Rehabilitation Site
Current Tenure and Agreements
Pit Outline
Development Envelope
Pastoral Leases
0 1 2 3 4 5
Kilometers

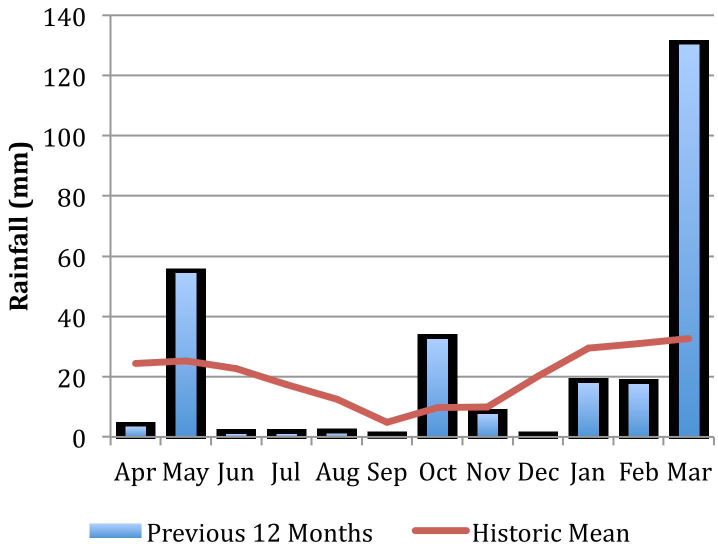


Figure 3. Recent and long-term mean rainfall at Yeelirrie Station.

2. Methods

2.1. Field Survey

Fieldwork for phase 1 of the population and demography field study was conducted March 23 – 30, of 2015 and was preceded by a ~130 mm cyclonic rainfall event. Study sites were selected to adequately represent both eastern and western populations as a whole, and also represent a majority of subpopulations within both populations. Fourteen field sites were established and surveyed; seven within the eastern population, six within the western population, and one within a rehabilitation population (location coordinates within Appendix A). Site locations were selected prior to fieldwork using aerial imagery. The exact location of each site was adjusted in the field to ensure plot contents adequately represented typical configuration of *Atriplex* sp. Yeelirrie Station plants at that location.

A strip plot (2 m x 24 m) was installed at each site to provide access to plants while minimising trampling disturbance to seedlings and the cracking crust of the clay soil. Plots were orientated north-south with all four corners permanently marked by galvanised metal fence droppers. For each site the following metadata were collected (and presented in Appendix A):

- Coordinates – hand held GPS unit with ±5 m accuracy.
- Associated flora species – uncertain specimens collected and determined post fieldtrip.
- Vegetation condition – using the Keighery Scale (in Government of Western Australia 2000).
- Soil profile and texture – outside of and within 5 m of plot, to ~35 cm depth.
- Soil samples – of each major horizon encountered; for future use if required (analysis of salinity and nutrient content).

Within the strip plots, *Atriplex* sp. Yeelirrie Station plants were assessed in order from north to south to assist future repeat surveys. As plants often grow amongst each other with enmeshed canopies, careful inspection of plants was undertaken to help ensure individual plants were not overlooked. Care was also taken when searching for seedlings, which typically grew under the dense canopies of adult plants. Numbers of seedlings (< 5 cm) and juveniles (5 to ~15 cm) were tallied separately for each 2 x 2 m section of a strip plot. The following data was collected for each (non-seedling) plant:

- Dimensions of live canopy to nearest centimetre; length (maximum), width (perpendicular to length), and height.
- Leading shoot length; length of longest branch/shoot (difficult at times due to branch switchbacks).
- Condition; percentage of live canopy on a six-point scale (0 – none, 1 – up to 20%, 2 – up to 40%, 3 – up to 60%, 4 – up to 80%, and 5 – up to 100%).
- Sex; male, female, or unknown (further information below).

- Flower abundance; four-point scale (0 – none, 1 low, 2 – intermediate, and 3 – high).
- Fruit abundance; four-point scale (0 – none, 1 low, 2 – intermediate, and 3 – high).

Assessment of plant sex in the field was problematic. Mature plants with (usually abundant) terminal male flower heads were scored as male plants, while plants absent of male flowers (and typically abundant in fruit) were scored as female plants. Due to the sessile axial female flowers (occurring in abundance on female plants but less so on male plants) being difficult to identify with the naked eye, assessment of female flower presence or abundance was not practicable. Plants with neither male flowers nor any fruit were scored as unknown sex (missing value within data).

2.2. Statistical Analysis

SPSS v11.5.0 (IBM 2002) statistical software pack was used to conduct analysis of collected field data. Descriptive statistics were explored to help ensure that appropriate data treatments and statistical tests were performed. All tests were assigned an alpha-value of 0.05 to determine significant difference.

Plant canopy dimension data (length, width, height) were used to produce a canopy volume index (Figure 4) based on the formula for an ellipsoidal hemisphere, which approximates the shape of plants observed in the field. Canopy volume index and leading shoot length were log-transformed to attain normal distributions and homogeneity of variances suitable for parametric statistical tests. Remaining nominal and ordinal variables (canopy condition, sex, flower abundance, and fruit abundance) were not suitable for transformation and remained untreated for nonparametric tests.

A suite of statistical tests was performed (Table 1) with a focus on determining baseline population and demography characteristics of phase 1 of the study. Plant numbers within strip plots were tested to detect any differences in plant density amongst populations and survey sites. Differences in plant characters between sexes were tested due to field observations suggesting male and female plants differed in flowering and fruiting abundance. Significant differences between plant sexes were found for canopy condition ($p = 0.013$) and fruit abundance ($p = 0.000$), resulting in those variables being split by sex for subsequent analysis. Flower abundance was also split by sex as a precaution; difficulty in reliably observing female flowers in the field resulted in insufficient Ns to statistically confirmed difference in flower abundance between sexes. Plant characters were then tested by location to determine if plants differed amongst populations and amongst survey sites.

$$I_{CV} = \frac{2\pi}{3} \times \frac{L}{2} \times \frac{W}{2} \times H$$

Where:	I_{CV}	= Index of Canopy Volume	L	= Plant Length
	W	= Plant Width (perpendicular to Length)	H	= Plant Height

Figure 4. Formula used to calculate plant canopy volume index.

Table 1. Summary of statistical tests performed for analysis of *Atriplex* sp. Yeelirrie Station population and plant characters.

Target (Dependent) Variables	Grouping (Independent) Variables	Test and Details
Numbers (density) of adult, juvenile plants.	Location (by population and survey site).	Chi-square test. Expected values based on assumption of equal distributions.
Plant sex proportion	None (one variable analysis)	Chi-square test. Expected values calculated based on assumption of 50-50% sex split.
	Location (by population and survey site).	Chi-square test. Expected values based on assumption of equal sex proportions amongst locations.
Plant characters: canopy volume index, leading shoot length, canopy condition, male flower abundance, male fruit abundance, female fruit abundance).	Plant sex (where known)	One-way ANOVA test (parametric suitable variables) and Mann-Whitney-U test (nonparametric suitable variables). No post hoc tests performed.
Plant characters: canopy volume index, leading shoot length, canopy condition, male flower abundance, male fruit abundance, female fruit abundance).	Location (by population and survey site).	One-way ANOVA test (parametric suitable variables) and Kruskal-Wallis test (nonparametric suitable variables). Mann-Whitney-U post hoc tests performed.

3. Results and Discussion

Field site profiles, including site photographs (north to south), are presented in Appendix A. Data collected is intended as a baseline for future survey phases, particularly for tracking population dynamics (recruitment and mortality). Statistical analysis (quantitative) and observational (qualitative) findings are presented in the following sections.

3.1. Statistical Analysis

Statistical analysis for phase 1 of the population and demography study focused on detecting if differences occur i) between plant sexes, ii) amongst the three populations, and iii) amongst the 14 field sites.

3.1.1. Differences in Plant Density and Recruitment

A summary of statistical test results for differences in plant numbers (density) and recruitment of *Atriplex* sp. Yeelirrie Station plants is presented in Table 2.

A significant difference in adult plant numbers within strip plots (density) was found amongst the three populations ($p = 0.000$). Further inspection found that rehabilitation site RP01 and western site WP02 were outliers, containing 11% and 305% of expected plant numbers, respectively (Figure 5). With the western population outlier (WP02) removed from analysis, there was no significant difference in observed adult plant numbers between western and eastern populations ($p = 0.343$) (Figure 5, right). It is recommended that both outlier sites be excluded from any future analysis focusing on plant density. When outliers are excluded, the mean density of adult *Atriplex* sp. Yeelirrie Station is 31.0 plants per strip plot (0.646 per m^2), with a 95% confidence interval range of 23.5 to 38.5 plants per plot (0.490 to 0.802 per m^2).

Observed seedling numbers within strip plots significantly differed from expected numbers ($p = 0.000$) amongst the three populations (Figure 6, left). The mean density of seedlings was 114.5 per strip plot, with a 95% confidence level range of 67.1 to 162.9 per plot. No juvenile plants were found within the rehabilitation strip plot (though limited numbers were observed outside the plot). Observed juvenile numbers within strip plots did not significantly differ from expected numbers ($p = 0.086$) between western and eastern populations, but probably a type II error due to extreme variance amongst eastern population sites (Figure 6, right); a single site (EP05) contains 76% of recorded live juvenile plants.

Numbers and proportions of all plants (adult, juvenile, and seedling) within each survey site are shown in Figure 7. These phase 1 graphs provide a snapshot of possible population dynamics for *Atriplex* sp. Yeelirrie Station:

- Generally high proportion (3.33:1) of seedlings relative to adult plants.
- High rate of seedling mortality with low numbers surviving to juvenile stage.
- Considerable variability in both numbers and proportions of adult, juvenile, and seedlings plants by site.
- Site WP02 containing a high number of smaller mature plants, suggesting an early successional stage of development.

These points suggest a pattern of pulse recruitment for *Atriplex* sp. Yeelirrie Station, with site factors affecting (perhaps independently) density of adult plants, density of seedlings, and survival rates to the juvenile stage. Site WP02 may be of interest for future study phases; the high number of smaller mature plants may indicate a younger population stage, with plant numbers expected to decrease over time.

Variance in rainfall pattern does not well explain the observed variability in seedling recruitment, since nearby sites often differ greatly in seedling numbers. The variability in recruitment may instead be due to site differences in lake/playa/channel hydrology (e.g. seasonal inundation depth, run-on and run-off characters, moisture retention and inundation period) affecting available moisture for germination and establishment and survival of young plants. Future monitoring phases are expected to provide further information on the link between site factors and population dynamics.

Table 2. Summary of statistical test results for differences in plant numbers (density) and recruitment of *Atriplex* sp. Yeelirrie Station.

Test Description	Observed N	Expected N	χ^2	df	p-value
Adult plant numbers amongst three populations.	Western – 269 Eastern – 208 Rehabilitation – 4	Western – 206.1 Eastern – 240.5 Rehabilitation – 34.4	50.402	2	0.000
Adult plant numbers between western and eastern populations (outlier WP02 removed).	Western – 164 Eastern – 208	Western – 155.0 Eastern – 217.0	0.898	1	0.343
Seedling plant numbers amongst three populations.	Western – 458 Eastern – 1121 Rehabilitation – 24	Western – 687.0 Eastern – 801.5 Rehabilitation – 114.5	275.207	2	0.000
Juvenile plant numbers between western and eastern populations.	Western – 38 Eastern – 63	Western – 46.6 Eastern – 54.4	2.954	1	0.086

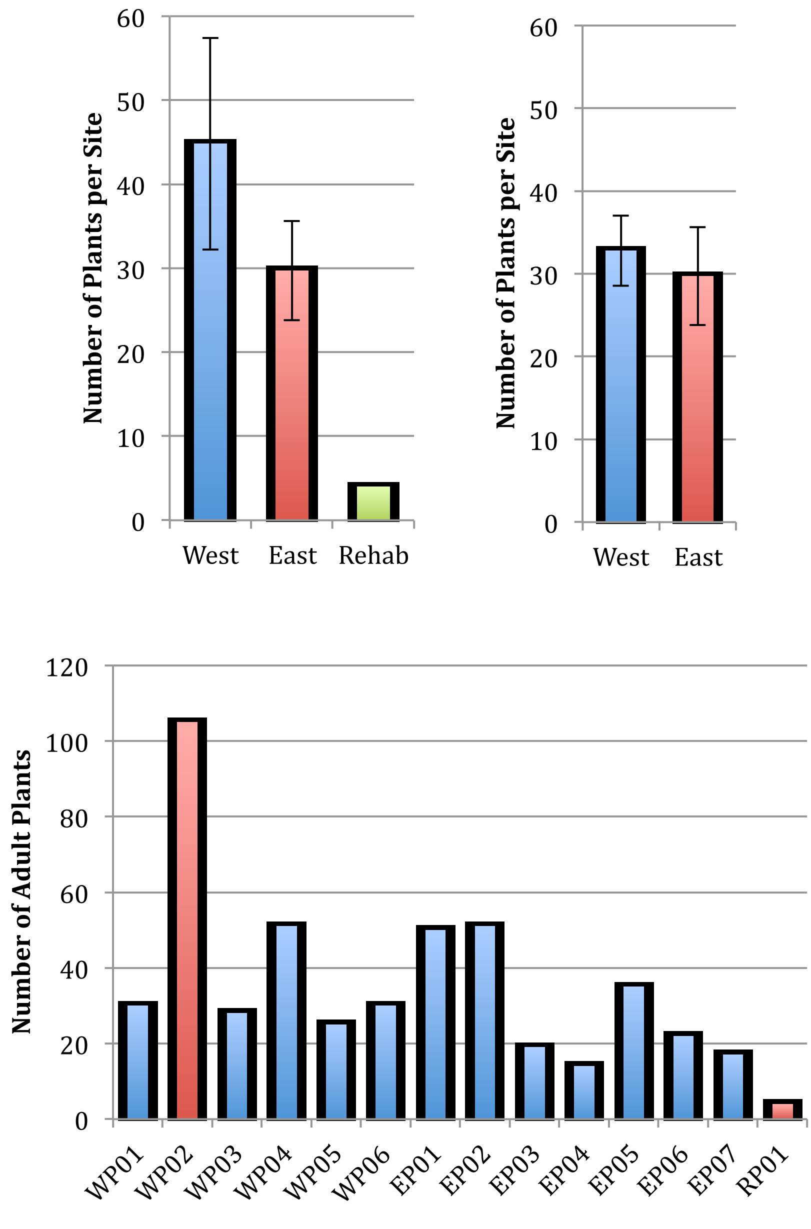


Figure 5. Comparison of adult plant numbers in strip plots amongst populations of *Atriplex* sp. Yeelirrie Station including (left) and excluding (right) outlier plots WP02 and RP01 (bars represent standard error). Number of adult plants per site, red bars represent outlier plots (below).

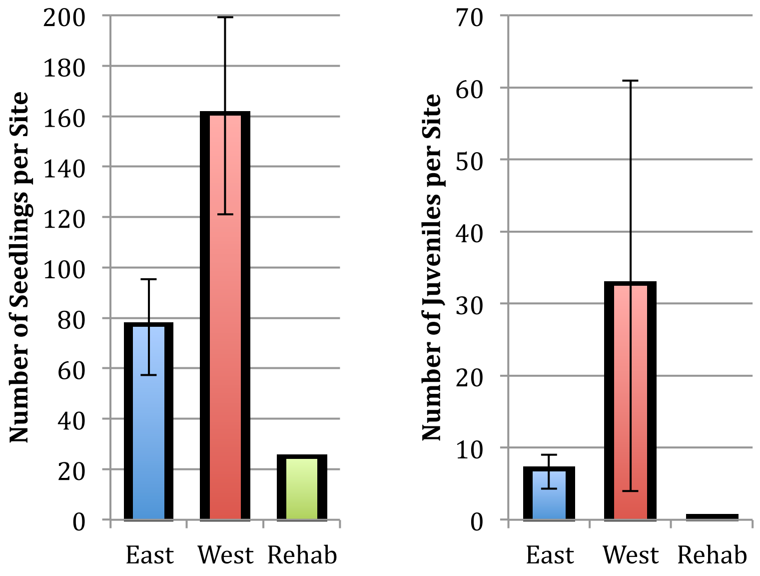


Figure 6. Numbers of seedlings (left) and juveniles (right) of *Atriplex* sp. Yeelirrie Station per strip plot by population.

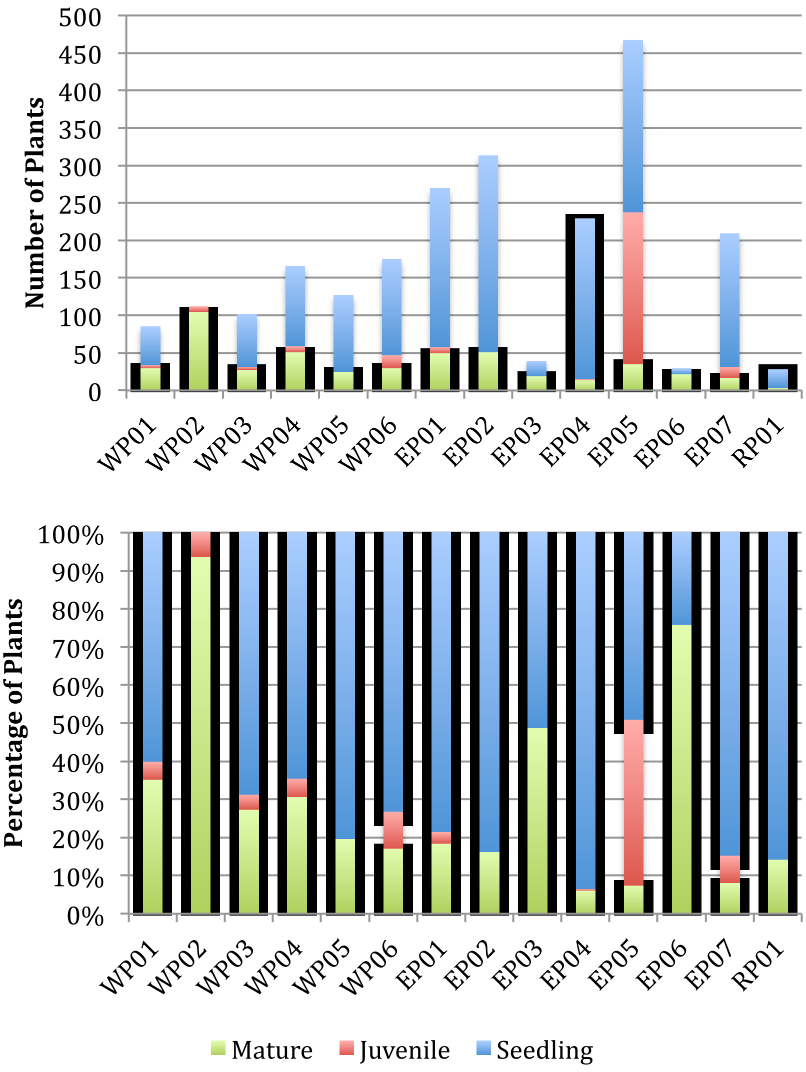


Figure 7. Numbers and proportions of all *Atriplex* sp. Yeelirrie Station plants (adult, juvenile, and seedling) within each survey site.

3.1.2. Differences Between Plant Sexes

A summary of statistical test results for differences in sex of *Atriplex* sp. Yeelirrie Station plants is presented in Table 3.

No significant difference was found in the observed proportion (expected 50/50% split) of male and female plants for all plants surveyed (p = 0.262). Additionally, no differences in the proportion of plant sexes were found amongst populations (p = 0.120), or amongst survey sites (p = 0.697). This confirms past observations of equal numbers of male and female plants, with no difference in sex proportion by location.

Collectively for all plants surveyed, canopy condition of male plants was slightly (but statistically significant, p = 0.013) higher than for female plants (Figure 8). This difference was not readily apparent during the field survey. However, the finding does connect to the observation of oldest heavily fruit-bearing branches (predominantly a female plant character), being senescent and absent of foliage. If female plants live longer (currently unknown) they may have greater opportunity than male plants to accumulate senescent branches and thus a lower canopy condition (% alive) percentage.

Difference in flower abundance between plant sexes was not assessed since very few female flowers were recorded. However, fruit abundance significantly and dramatically differed by sex (p = 0.000), as was expected from previous field observations. Female plants typically had high abundance of fruit compared to male plants where low abundance or no fruit was the norm (Figure 9). A limitation to this result is the confounding inability to reliably assess female flowers in the field due to their very small size. Though probably low in occurrence, male plants bearing some fruit but lacking in male flowers would present as female plants; this would, however, lead to reduced difference in fruiting abundance between sexes, rather than increasing the apparent difference.

There was no significant difference between the sexes of *Atriplex* sp. Yeelirrie Station for canopy volume index (p = 0.395) or leading shoot length (p = 0.071) (Figure 10).

Table 3. Summary of statistical test results for differences in sexes of *Atriplex* sp. Yeelirrie Station.

Test Description	Observed N	Expected N	Test Statistic	df	p-value
Sex ratio, all plants.	Male – 222 Female – 199	Male – 210.5 Female – 210.5	$\chi^2 = 1.257$	1	0.262
Sex ratio, amongst populations.	Not calculated	Not calculated	$\chi^2 = 4.248$	2	0.120
Sex ratio, amongst sites	Not calculated	Not calculated	$\chi^2 = 9.966$	13	0.697
Canopy condition (% alive), between plant sexes.	Male – 222 Female – 199	N/A	Z = -2.474	–	0.013
Fruit abundance, between plant sexes	Male – 222 Female – 199	N/A	Z = -14.960	–	0.000
Canopy volume index, between plant sexes.	Male – 222 Female – 199	N/A	F = 0.724	1	0.395
Leading shoot length, between plant sexes.	Male – 222 Female – 199	N/A	F = 3.270	1	0.071

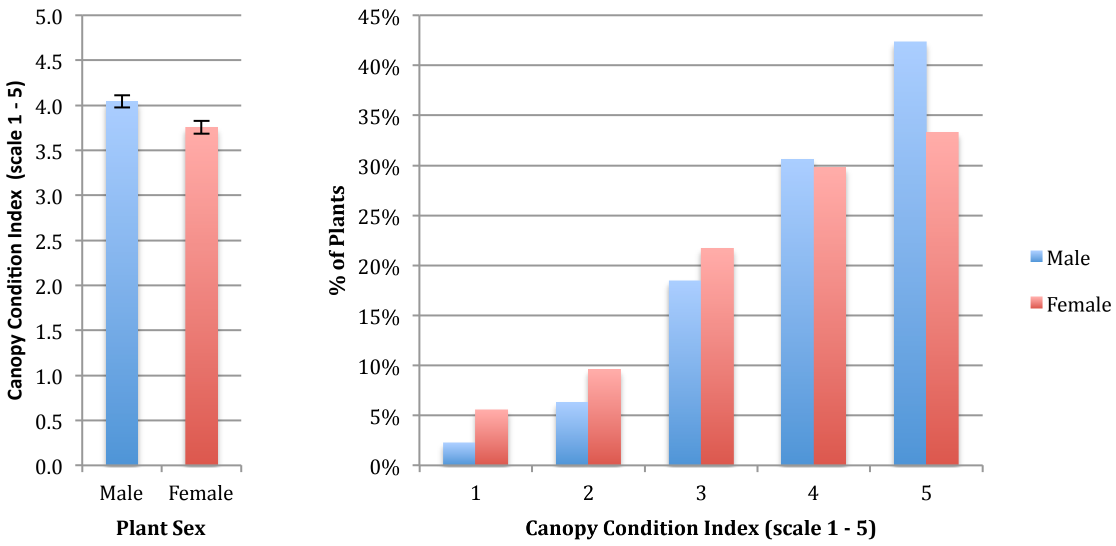


Figure 8. Left: Significant difference in mean canopy condition index (% alive; scale 1 to 5) of male and female plants (bars represent standard error). Right: Comparative distribution of male and female plant canopy condition index (% alive, scale 1 – 5.)

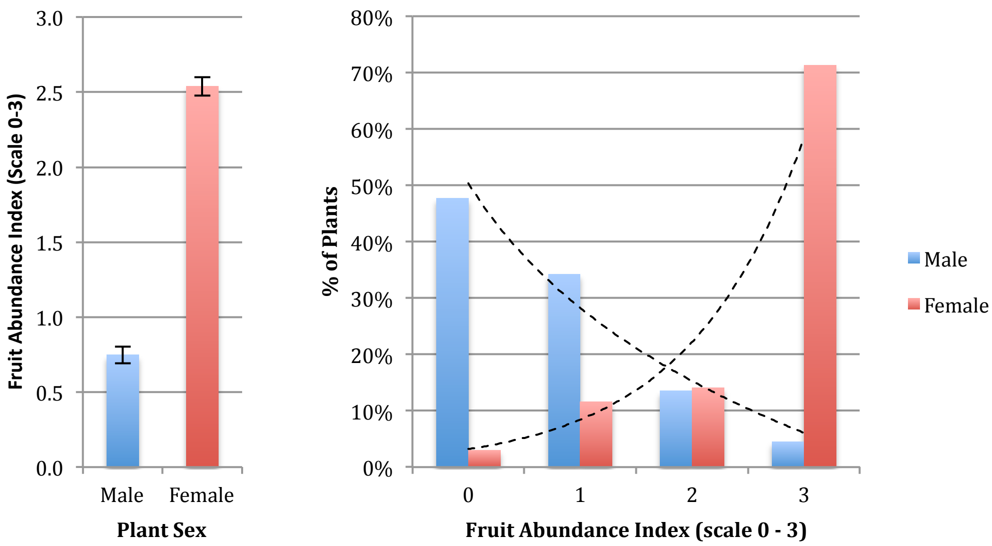


Figure 9. Left: Significant difference in fruit abundance between male and female plants (bars represent standard error). Right: Comparative distribution of male and female plant fruit abundance index (scale 0-3), with trend lines showing an inverse relationship.

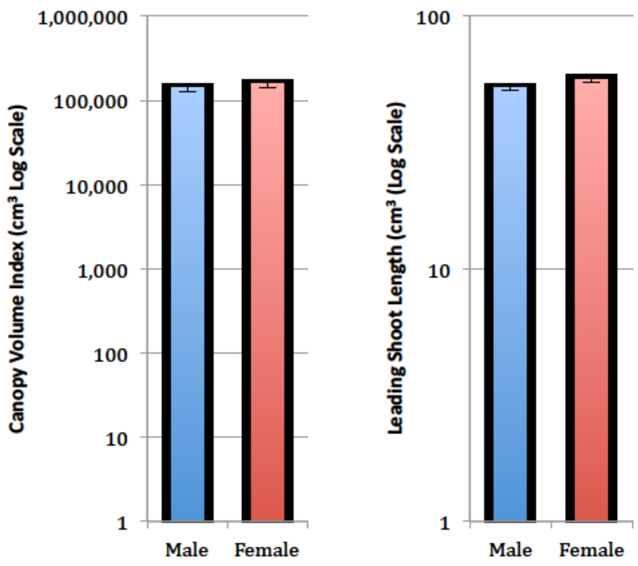


Figure 10. No significant difference between male and female plants for canopy volume index (left) or leading shoot length (right) (bars represent standard error).

3.1.3. Differences in Plant Characters amongst Populations

A summary of statistical test results for differences in plant characters of *Atriplex* sp. Yeelirrie Station plants amongst populations (western, eastern, and rehabilitation) is presented in Table 4.

For plant measure variables, the only significant difference found amongst the three populations of *Atriplex* sp. Yeelirrie Station was female plant canopy condition ($p = 0.005$). Planned post hoc tests revealed that female canopy condition at the rehabilitation populations was significantly lower than at both the eastern ($p = 0.003$) and western population ($p = 0.004$) (Figure 11). There was no statistically significant difference in female canopy condition between western and eastern populations ($p = 0.183$).

No significant difference ($p >= 0.05$) in canopy volume index, leading shoot length, male canopy condition index, male flowering abundance, male fruit abundance, or female fruiting abundance occurred amongst the three *Atriplex* sp. Yeelirrie Station populations (Figure 12). Low Ns within the rehabilitation population may have prevented tests finding statistically significant differences.

In conclusion there was no detected difference between the western and eastern population for any of the measured plant variables, and no difference in plant density once outlier sites were accounted for (see Section 3.1.1). As such, the western and eastern populations of *Atriplex* sp. Yeelirrie Station can be considered equivalent in adult plant characteristics.

Table 4. Summary of statistical test results for differences amongst populations of *Atriplex* sp. Yeelirrie Station.

Test Description	Observed N	Test Statistic	df	p-value
Canopy volume index, amongst populations.	Western – 269 Eastern – 208 Rehabilitation – 4	F = 0.481	2	0.618
Leading shoot length, amongst populations.	Western – 269 Eastern – 208 Rehabilitation – 4	F = 0.822	2	0.440
Male plant canopy condition, amongst populations.	Western – 119 Easter – 102 Rehabilitation – 1	$\chi^2 = 3.898$	2	0.142
Female plant canopy condition, amongst populations.	Western – 121 Eastern – 74 Rehabilitation –3	$\chi^2 = 10.449$	2	0.005
Post hoc paired comparisons:				
Rehab vs. West		Z =	–	0.003
Rehab vs. East		Z =	–	0.004
West vs. East		Z =	–	0.186
Male plant flower abundance, amongst populations.	Male – 116 Female – 101 Rehabilitation – 0	$\chi^2 = 2.161$	1	0.142
Male plant fruit abundance, amongst populations.	Western – 119 Eastern – 102 Rehabilitation – 1	$\chi^2 = 3.650$	2	0.161
Female plant fruit abundance, amongst populations.	Western – 122 Eastern – 74 Rehabilitation - 3	$\chi^2 = 4.400$	2	0.111

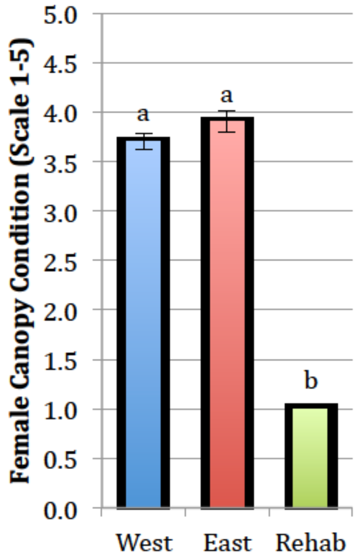


Figure 11. Significant difference in female canopy condition of the rehabilitation population (n = 1) compared to the western and eastern populations (letters designate groups, bars represent standard error).

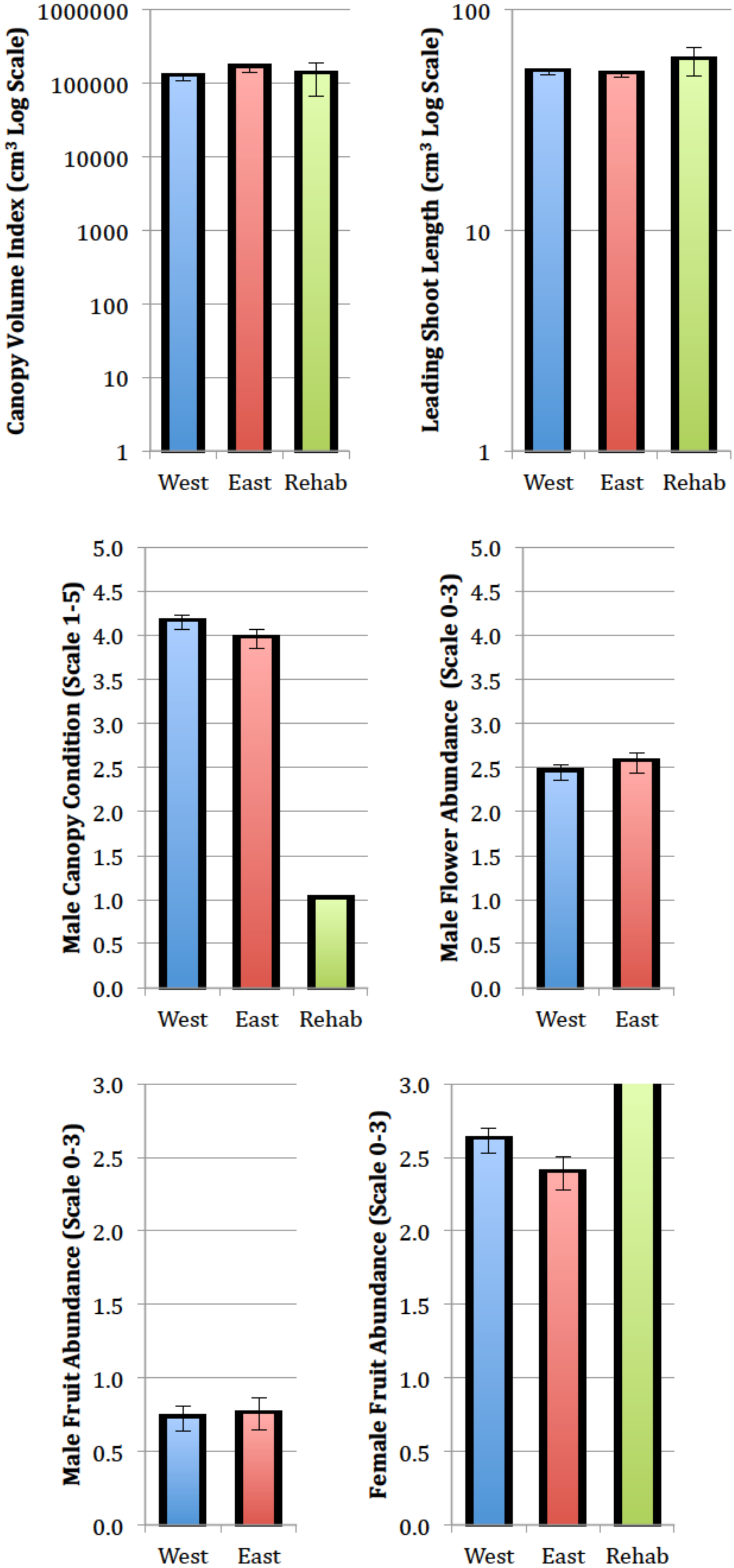


Figure 12. No significant difference amongst populations for canopy volume index, leading shoot length, male canopy condition, male flower abundance, male fruit abundance, or female fruit abundance (bars represent standard error).

3.1.4. Differences in Plant Characters Amongst Survey Sites

Though no significant differences were found in *Atriplex* sp. Yeelirrie Station in adult plant variables amongst populations (Section 3.1.3), descriptive statistics indicated high variance amongst field sites. Subsequent non-parametric analysis of variance found significant differences amongst field sites for canopy volume index, leading shoot length, male canopy condition, female canopy condition, male flower abundance, and male fruit abundance (Table 5, Figure 13 & Figure 14). Female fruit abundance was the only measured plant character that did not significantly vary by field site (Figure 14, bottom (2^{nd} series)).

Though variance amongst sites is high, a lack of significant differences between the western and eastern populations indicates that the variance is equivalent within both major populations. The cause(s) for the observed variance may be of interest for future management of *Atriplex* sp. Yeelirrie Station. From observations during field survey (see Section 3.3) complexity of habitat soil stratigraphy characters within the clay flats and paleochannel is suspected as the cause.

While some soil profile data was collected at each site (and full exploration by Soil Water Group occurred at some sites), a full and conclusive analysis of texture, salinity, water holding capacity, nutrient content, and potential elemental toxicities is beyond the scope of the phase 1 survey. Soil samples collected by Western Botanical are stored and may be used in analysis of future study phases.

Correlational investigation of the current limited data for site/habitat characters (clay horizon depth and soil texture ribbon length) did produce some interesting indicative results (Table 6). Depth of the upper clay horizon was significantly but weakly inversely correlated with canopy volume index ($p = 0.000$, $r_s = -0.236$), leading shoot length ($p = 0.000$, $r_s = -0.315$), and male plant fruit abundance ($p = 0.001$, $r_s = -0.295$); as the depth of the clay increased, the size of plants and the abundance of fruit on male plants decreased. While strengths of the correlations are weak, they perhaps indicate a stronger relationship with another site/soil factor not yet fully assessed. A possible explanation is the marked difference (or differences) between the upper clay layer and the underlying gypsiferous sand or loam in factors such as salinity, available moisture, nutrient content or potential elemental toxicities.

No significant correlation ($p >= 0.05$) existed between soil texture ribbon lengths and any of the plant characters measured. No significant correlation ($p >= 0.05$) existed between depth of the top clay horizon with male or female canopy condition, male flower abundance, or female plant fruit abundance.

Further investigation and collection of site/habitat data is recommended to allow future analysis beyond correlations, and comprehensively describe *Atriplex* sp. Yeelirrie Station habitat preferences.

Table 5. Summary of statistical test results for differences amongst survey sites of *Atriplex* sp. Yeelirrie Station.

Test Description	Total N	χ^2 Statistic	df	p-value
Canopy volume index, amongst sites.	481	140.971	13	0.000
Leading shoot length, amongst sites.	478	175.605	13	0.000
Male plant canopy condition, amongst sites.	222	53.333	13	0.000
Female plant canopy condition, amongst sites.	198	47.376	13	0.000
Male plant flower abundance, amongst sites.	217	34.505	12	0.001
Male plant fruit abundance, amongst sites.	221	60.470	12	0.000
Female plant fruit abundance, amongst sites.	199	20.446	13	0.085

Table 6. Summary of correlation test results between the upper clay soil horizon and plant characters of *Atriplex* sp. Yeelirrie Station.

Variable 1	Variable 2	Total N	Correlation Coefficient	p-value
Depth of top clay horizon	Canopy volume index	267	-0.236	0.000
	Leading shoot length	264	-0.315	0.000
	Male Plant Condition	126	0.220	0.013
	Female Plant Condition	109	0.077	0.427
	Male Plant Flower Abundance	121	0.058	0.527
	Male Plant Fruit Abundance	125	-0.295	0.001
	Female Plant Fruit Abundance	109	-0.182	0.058
Texture ribbon length of top clay horizon	Canopy volume index	481	-0.003	0.946
	Leading shoot length	478	0.035	0.443
	Male Plant Condition	222	0.072	0.287
	Female Plant Condition	198	-0.122	0.086
	Male Plant Flower Abundance	217	-0.101	0.136
	Male Plant Fruit Abundance	221	0.007	0.913
	Female Plant Fruit Abundance	199	0.019	0.786

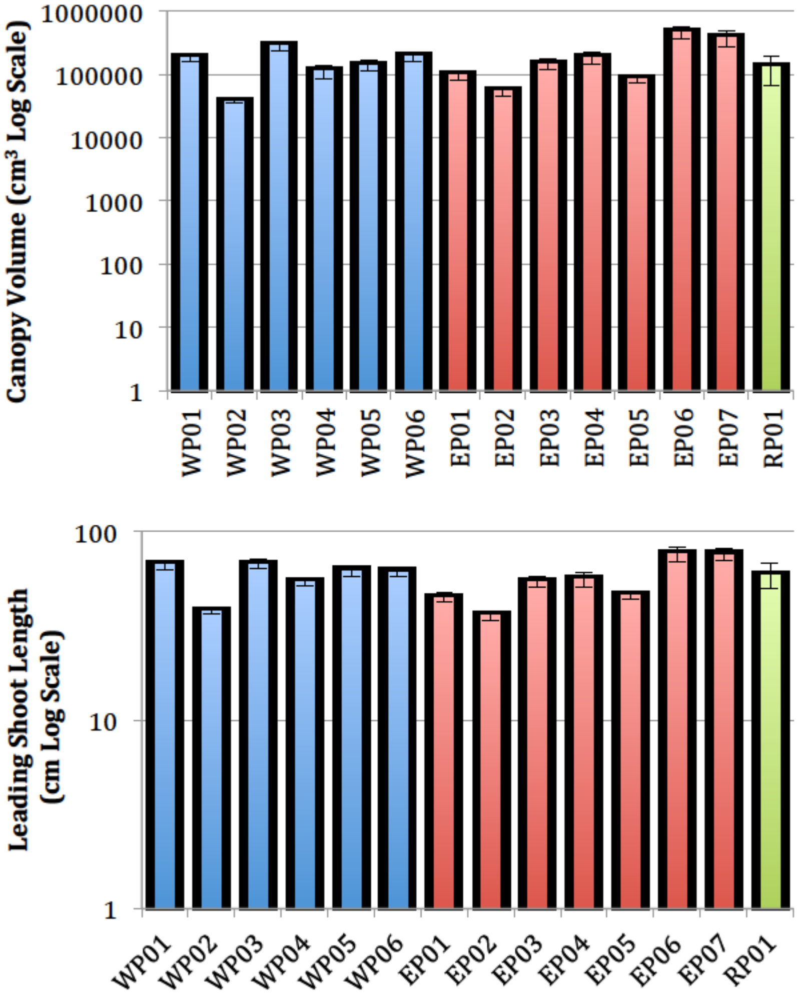


Figure 13. Canopy volume index and leading shoot length by field site (log scale, bars represent standard error).

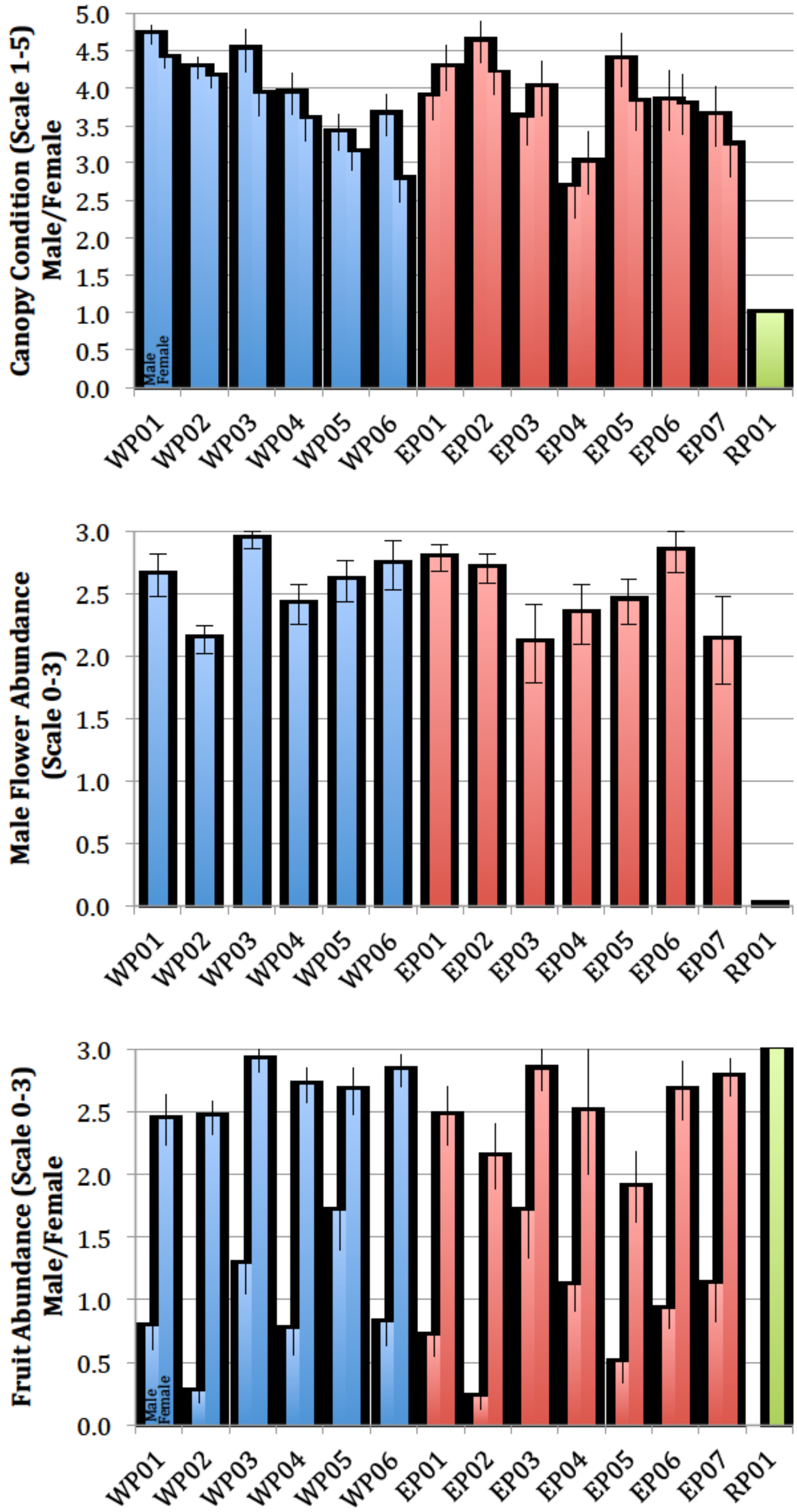


Figure 14. Male and female canopy condition (top), male flower abundance (centre), and male and female fruit abundance (bottom), by field site (bars represent standard error).

3.2. Future Monitoring

3.2.1. Survey Phase Timing

Observations during phase 1 field survey strongly suggest that *Atriplex* sp. Yeelirrie Station undergoes a pulse recruitment pattern. The timing of future monitoring phases are expected to be important in capturing the most appropriate data for determining population dynamics. Ideally, future survey phases should be timed to follow periods of maximum i) post rainfall event seedling recruitment, and ii) end of dry season seedling (and mature plant) mortality. Due to seasonal variation of rainfall events in the Murchison biogeographic region, such timing of future survey phases may need to be performed on an ad hoc basis.

3.2.2. Recruitment and Mortality Assessment

When repeated for additional survey phases, with appropriate seasonal timing, the current study design should be adequate to capture Atriplex sp. Yeelirrie Station population dynamics (recruitment and mortality patterns). Dynamics of a population are measured by an equation (i.e. Figure 15) that measures change in population numbers over time, accounting for births, deaths, immigration, and emigration.

$$N_{t+1} = N_t + B - D + I - E$$

Where:	N = Number	D = Deaths
	t = time	I = Immigration
	B = Births	E = Emigration

Figure 15. Formula for calculating change in population over time.

3.2.3. Suggested Analysis

The addition of future survey phases for existing survey sites would compel the use of repeated measures statistical analysis. If a similar approach to this report's analysis is used, suggested tests would be repeated measures ANOVA tests for canopy volume index and leading shoot length, and Friedman's tests for repeat measures of canopy condition, flower, and fruit variables.

The option of adding additional field sites to future monitoring phases may enhance analysis power, particularly for greater investigation into *Atriplex* sp. Yeelirrie Station density amongst sites and the relationships amongst plant measurement variable and site/habitat factors.

3.3. Observations

3.3.1. Habitat Preference and Performance in Rehabilitation

Atriplex sp. Yeelirrie Station occurs almost exclusively on red, alkaline, moderately saline (89 to 515 µS/m within the first 10 to 15 cm of the soil profile, overlying up to 2,500 µS/m from 15+ cm), clay within the Yeelirrie paleochannel on Yeelirrie Station. In March 2015, these soils were dry in the upper 10 to 15 cm but moist below that depth. Plants within the rehabilitation population occur on neutral, non-saline, massive loamy sand, characteristic of that supporting the adjacent *Acacia ayersiana* (a mulga) shrubland with some residual calcrete gravel at the surface from the former stockpile.

Plants within the rehabilitation population have experienced high mortality (35% dead) since August 2014 and demonstrate poor canopy condition in March 2015. A comparison of canopy condition between rehabilitation population plants and the nearby natural western population plants (Western Botanical 2014) is presented in Figure 16 and shows a strong inverse relationship in between the two sites. The higher mortality and lower canopy condition of rehabilitation plants is likely the result of reduced moisture availability compared to the clay of the natural populations.

Within the eastern population particularly, areas of apparently suitable clay existed near and/or adjacent to existing *Atriplex* sp. Yeelirrie Station subpopulations but these areas contained no *Atriplex* sp. Yeelirrie Station plants. These patches often supported *Lawrencia helmsii* shrublands or *Tecticornia* spp. shrublands, indicating higher soil salinities in the range of 1700 to 4700 micro Siemens per metre. One small eastern subpopulation (site EP03) surrounded by a lower relief *Tecticornia laevigata* shrubland flat, cohabitated with *Tecticornia indica* subsp. bidens. This limited cohabitation with a more salt tolerant species may indicate that *Atriplex* sp. Yeelirrie Station has some limited tolerance of higher salinity that may be relevant for selection of translocation sites. Of additional note, *Lycium australe* was typically present in low numbers scattered amongst *Atriplex* sp. Yeelirrie Station plants with greater numbers at the periphery of *Atriplex* populations. This may indicate tolerance differences in soil type, salinity, soil chemistry or inundation periodicity.

Within *Atriplex* sp. Yeelirrie Station habitat it was widely and consistently observed that adult plants did not occur in the wettest and lowest portions of the clay flat. Low numbers of live seedlings were found within these lower relief areas, but dead seedlings found with a coating of clay dust indicate they typically die during seasonal inundation. Mature plants were also noted at some sites to have a similar pattern of clay dust deposited on dead lower branches; indicating height of the recent flood level and foliage intolerance of submersion.

Mature adults within lower relief of the clay flat tend to grow upon shallow soil and organic material mounds/islands that often join to form irregular and spreading 'bars' where plants were densest. Formation of these shallow mounds would be due to trapping or retention of sediments by plant canopy and/or roots in dry periods and protection from erosion during seasonal inundation.

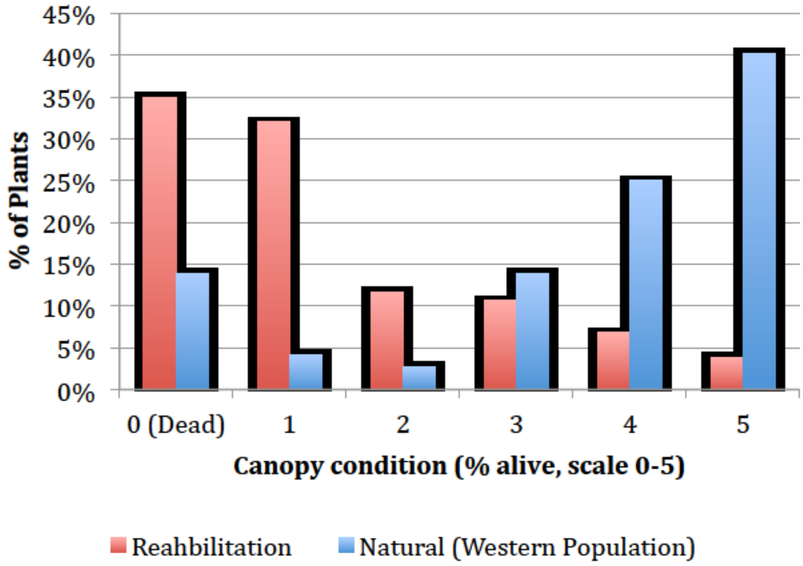


Figure 16. Comparison of plant canopy condition between rehabilitation plants and nearby natural western population plants.

3.3.2. Reproduction

Field assessment of female flowers (on both female and male plants) was not practicable due to their small size being essentially indistinguishable to the naked eye. This remains a noted limitation to this initial phase of the population and demography study. However, some conclusions could be made from observations of flowering and fruiting behaviour.

Mature male plants are easily distinguishable by their relatively large terminal yellow flowers. While mature female plants are distinguishable by the absence of male flowers and typically high volume of fruit (versus male plants low volume of fruit). Fruit on both female and male plants are axial on branches, signifying that female flowers occurring on mostly-male plants are axial as on female plants. Such a pattern of reproduction could be described as gynoecious for female plants and subandroecious for male plants.

Wind appears to be the primary vector for pollination. Incidental shaking of male plant branches was observed to release a small cloud of pollen that travelled readily on a light breeze. However, pollination by insect has not been discounted; sexes differ in flower colour (male flowers yellow, female flowers pale pink) and UV light reflectance has yet to be investigated.

Dehiscence of seeds from the enclosing bracts and dispersal of fruit requires investigation. Fruit on both male and female plants are strongly attached to branches. High fruit-yielding branches on female plants had a tendency to be senescent (absent of foliage) and persistent on plants, usually at the base of the canopy below newer fresher branches. This may explain the slight but statistically significant difference in canopy condition between plant sexes. Loose fruits were rarely observed in the field, but this is probably due to fruit settling unseen into deep cracks of the clay that *Atriplex* sp. Yeelirrie Station inhabits. At some survey sites old detached branches laden with fruit were found at the base of plant canopies; as often at plants that had not reached reproductive maturity as at mature plants. This indicates that detached branches with fruit may be transported by wind or by water during times of seasonal flooding, and presents a possible vector for fruit and seed dispersion.

The vast majority of seedling recruitment was observed to occur on the low soil mounds beneath the canopy of mature plants. Though additional effort was undertaken to search for seedlings, numbers recorded are likely a slight underestimate due to the difficulty of finding seedlings within dense canopies of mature plants. Explanations for a higher rate of recruitment beneath adult *Atriplex* sp. Yeelirrie Station plants include; i) shelter from direct sunlight, ii) protection from grazing, iii) likely location for direct seedfall, iv) likely trapping location of water-mobile fruit-bearing branches, and v) flood-relief afforded by the shallow soil mounds around adult plants reducing inundation mortality of germinants. While reduced recruitment was observed to occur away from mature plant canopies, standing dead juvenile plants (to 15 cm) in open areas indicate an eventual high mortality rate of young seedlings.

3.3.3. Cattle Grazing

Widespread grazing of *Atriplex* sp. Yeelirrie Station by cattle was previously reported in Western Botanical (2011), and Western Botanical (2015). The extent of grazing was sufficient in the eastern population to apply a vegetation condition rating of ‘degraded’ on the Keighery Scale (Appendix B). However, during phase 1 of the population and demography field survey, no signs of recent cattle grazing were observed at any of the survey sites (western or eastern). Evidence of grazing was only found at one location (in proximity to EP02) and for one plant only, though cattle trampling was also observed at this location. The field assessment followed a period of substantial cyclonic rainfall and associated perennial grasses such as *Eragrostis falcata* and *E. tenellula* were vigorously growing in adjacent habitats (for example, in the *Atriplex vesicaria* low shrubland).

The general lack of observed cattle grazing results in an improved vegetation condition rating for both populations of *Atriplex* sp. Yeelirrie Station compared to previous observations. Vegetation condition recorded at each field site is presented in Table 7, and provides an overall condition rating of ‘good-excellent’ and ‘good’ for western and eastern populations, respectively.

Differences in reported cattle grazing may be due to season of observations. It is likely that cattle preferentially graze more palatable grass species when available and only graze *Atriplex* sp. Yeelirrie Station when the more palatable feed is unavailable.

Table 7. Vegetation condition recorded at each site during population and demography study, April 2015.

Site Number	Condition Rating (Keighery Scale)	Impacts and Description
WP01 – Western Population	Excellent	Cattle tracks and dung, but no grazing. Caterpillar grazing. Atriplex generally healthy.
WP02 – Western Population	Good	Cattle tracks and dung, but no grazing. Caterpillar grazing.
WP03 – Western Population	Excellent	Cattle tracks and dung, but no grazing. Caterpillar grazing. Atriplex flowering and fruiting well.
WP04 – Western Population	Good	Cattle tracks and dung, but no grazing. Caterpillar grazing severe on some plants.
WP05 – Western Population	Good	Cattle tracks and dung, but no grazing. Caterpillar grazing.
WP06 – Western Population	Excellent	Cattle tracks and dung, but no grazing. Caterpillar grazing.
EP01 – Eastern Population	Good	Cattle tracks and dung, but no grazing. Caterpillar grazing.
EP02 – Eastern Population	Good	Cattle tracks and dung, but no grazing. Caterpillar grazing.
EP03 – Eastern Population	Degraded - Good	Some cattle tracks, but no grazing. Caterpillar grazing. Interzone Atriplex population with *Tecticornia* sp. dominant and in poor condition.
EP04 – Eastern Population	Good	Cattle tracks and dung, but no grazing. Caterpillar grazing. Atriplex plants sparser.
EP05 – Eastern Population	Good	Cattle tracks and dung, but no grazing. Caterpillar grazing. Atriplex generally smaller, many juvenile plants (5-10 cm).
EP06 – Eastern Population	Excellent	Cattle tracks and dung, but no grazing. Caterpillar grazing.
EP07 – Eastern Population	Good	Cattle tracks and dung, but no grazing. Caterpillar grazing.
RP01 – Rehabilitation Population	Degraded	Vegetation generally stressed and/or dying, alive plants small. Atriplex sp. Yeelirrie Station very poor condition, widespread deaths, some seedlings within canopies.

3.3.4. Caterpillar Grazing

Caterpillars and their silk were found on a majority of *Atriplex* sp. Yeelirrie Station plants during the phase 1 field survey (March 23rd – 31st) (Plate 1). Damage due to caterpillar grazing was readily visible and typically minor, though isolated plants appeared to have lost up to ~50% of their leaves. These caterpillars were not exclusively found on *Atriplex* sp. Yeelirrie Station plants and were also noted on a range of other shrub plant species within and around *Atriplex* sp. Yeelirrie Station populations. Three weeks later (April 20th – 22nd) caterpillars and all but minor traces of silk and grazing were absent from plants indicating they had completed that part of their life cycle.

Plate 1. Caterpillar and silk found on *Atriplex* sp. Yeelirrie Station. Note grazing of most leaves from the branchlet (left) and extent of silk webs and frass over plant (right).

3.3.5. Increasing salinity

Some bare salt scalded areas of the clay flats adjacent to live populations of *Atriplex* sp. Yeelirrie Station demonstrated high measured soil salinities (14,750 micro Siemens per metre at 2 to 8 cm depth). These showed remnants of *Atriplex* sp. Yeelirrie Station occupation in the form of dead plants and remnant branches on eroded soil mounds. It is inferred that salinity is increasing in some parts of the eastern population, particularly adjacent to low gypsum rises supporting *Lawrencia helmsii* or medium-heavy clay flats supporting *Tecticornia* spp. are present. It is inferred therefore that the area of occupancy of *Atriplex* sp. Yeelirrie Station within the paleochannel's clay flat soil landscape may change over time. The changes in plant community distribution within the eastern population of *Atriplex* sp. Yeelirrie Station should also therefore be monitored.

3.3.6. Plant Roots

During assessment of survey strip plots some large mature plants of *Atriplex* sp. Yeelirrie Station were observed to possess short adventitious roots growing on branches partially buried in the clay surface (Plate 2). It is currently unknown if these roots are persistent or a seasonal response to rainfall events. It is also unknown if these roots would facilitate vegetative reproduction. However, the vast bulk of plants observed were single stemmed and the species is not considered to regularly propagate by vegetative means.

A soil profile and root investigation was conducted within populations of by *Atriplex* sp. Yeelirrie Station in 2015 by Soilwater Group Pty Ltd. *Atriplex* sp. Yeelirrie Station was found to possess a thick tap thick root descending to ~ 30 – 40 cm, with multiple strong lateral roots spreading from the lower half (Plate 3, left). Lateral roots are generally ~0.5 – 1.5 cm in diameter with individual roots found to extend beyond a length of 2 m (Plate 3, bottom). Fine roots (<1 mm diameter) were scattered throughout the upper clay horizon and difficult to track within soil, breaking readily during exploration. Fine roots were also found scattered throughout the lower gypsiferous horizon, though this varied depending on the horizon's density (also variable); solid gypsiferous horizons appeared to act as a barrier to fine roots (Plate 3, right).

The root system investigations were undertaken under DRF Permit 162-1415 issued to Geoff Cockerton, Western Botanical, and allowed for up to 50 plants of Atriplex sp. Yeelirrie Station to be impacted. Field supervision of root investigations was undertaken by Dr. David Leach, Western Botanical and Soilwater Group Pty Ltd, under direction.

Plate 2. Example of roots (holding clay soil) growing from partially buried branches of mature *Atriplex* sp. Yeelirrie Station plant.

Plate 3. Examples of *Atriplex* sp. Yeelirrie Station taproot (left), fine roots at the clay to gypsiferous horizon boundary (right), and a 2+ m lateral root (bottom).

3.4. Limitations

- Information is presented for phase 1 of a population and demography study and additional survey phases may affect the conclusions presented.
- Female flowers (on both male and female plants) were too small for practicable field determination of female flower abundance and precise determination of sex for non-fruiting female plants.
- Considerable variance in plant density and characters were found amongst the 14 field sties established. Additional data collection of site/habitat factors would be needed for future survey phases to investigate such variability.

4. References

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5. List of Participants

Role / Position	**Name**
Project Manager	Geoff Cockerton
Senior Botanist	Dr David Leach
Botanists	Simon Colwill

Appendix A. Study site location coordinates

Table 8. Field site metadata (location, condition, associated flora, and soil profile).

Site#	Population	Zone	Easting (GDA94)	Northing (GDA94)	Condition	Associated Flora	Soil Profile
WP01	Western	50 J	0787161	6990470	Excellent	*Zygophyllum aurantiacum, Lawrencia densiflora, Tribulus* sp., *Salsola australis*, Asteraceae sp. (seedlings).	< 1 cm cracking clay, medium clay to 36+ cm (11 cm ribbon), dry to 11 cm then moist.
WP02	Western	50 J	0787711	6990564	Good	*Atriplex* sp. Yeelirrie Station appears smaller/young. *Zygophyllum aurantiacum, Lawrencia densiflora, Eragrostis* sp., *Melaleuca xerophylla* (nearby) with *Lycium australe* in between.	Cracking clay crust 1cm, medium clay to 34+ cm (10-14 cm ribbon), dry to 9 cm, then moist.
WP03	Western	50 J	0788285	6990453	Excellent	Dead *Sclerolaena cuneata*.	Cracking clay ~1 cm, medium-heavy clay to 35+ cm (15-17 cm ribbon).
WP04	Western	50 J	0789963	6989626	Good	Very open *Melaleuca xerophylla* woodland, *Templetonia incrassata, Lycium australe, Vittadinia* sp., *Zygophyllum* sp., *Lawrencia densiflora, Sclerolaena cuneata*.	Cracking clay to 7 cm, medium clay to 25 cm (10-14 cm ribbon), gypsum silky clay to 35+ cm (6 cm ribbon).
WP05	Western	50 J	0794405	6989470	Good	*Zygophyllum aurantiacum, Santalum* sp., *Dissocarpus paradoxus*, Sclerolaena sp., *Lawrencia densiflora*. Nearby: *Lycium australe Melaleuca xerophylla, Acacia aneura sens. lat.*	Cracking clay crust ~1 cm, medium clay to 19 cm (11-14 cm ribbon), intergrades to 26 cm, then gypsum silty clay loam to 27+ cm (4-5 cm ribbon).
WP06	Western	50 J	0790922	6989172	Excellent	*Melaleuca xerophylla* on outskirt. *Scaevola spinescens, Solanum lasiophyllum, Sclerolaena fusiformis, Asteraceae* sp., *Eragrostis* sp., *Lawrencia densiflora, Euphorbia drummondii. Acacia victoriae.*	< 1 cm crust, medium clay to 35+ cm (12 cm ribbon), dry to 15 cm then damp.
EP01	Eastern	51 J	0221237	6973568	Good	*Frankenia* sp., *Lycium australe, Senna artemisioides* subsp. *filifolia*.	Light clay to 30 cm (7 cm ribbon), over gypsum-calcrete.
EP02	Eastern	51 J	0222765	6974261	Good	*Lycium australe, Lawrencia densiflora* (seedlings).	Cracking medium clay crust to 3 cm (8 cm ribbon), medium clay to 35+ cm (13 cm ribbon).

Site#	Population	Zone	Easting (GDA94)	Northing (GDA94)	Condition	Associated Flora	Soil Profile
EP03	Eastern	51 J	0222953	6976389	Degraded to Good	*Lycium australe, Tecticornia* sp., *Lawrencia densiflora, Asteraceae* sp. (seedlings). Nearby: *Scaevola spinescens* (terete leaf from), *Melaleuca xerophylla, Eremophila forrestii.*	Cracking clay crust 1 cm, light-medium clay (8 cm ribbon) grading to gypsum silty clay loam to 16 cm (8 cm ribbon), over gypsum silty clay to 30 cm (4-7 cm ribbon), hard gypsum-calcrete 30+ cm.
EP04	Eastern	51 J	0223570	6975674	Good	*Lycium australe, Lawrencia densiflora* (seedlings), Asteraceae sp. (seedlings), *Eragrostis* sp. (seedlings).	Cracking clay crust 1 cm, light clay to 21 cm (9 cm ribbon), gypsum-calcrete 21+ cm.
EP05	Eastern	51 J	0224827	6975114	Good	*Lycium australe, Lawrencia densiflora* (seedlings), *Eragrostis* sp. (seedlings).	Medium heavy clay to 30+ cm (13+ cm ribbon).
EP06	Eastern	51 J	0224558	6974245	Excellent	*Lycium australe, Frankenia* sp., *Lawrencia densiflora* (seedlings), *Eragrostis* sp. (seedlings).	Light clay to 7 cm (7 cm ribbon), gypsum silty clay loam to 30+ cm (3.5-5 cm ribbon).
EP07	Eastern	51 J	0223253	6975003	Good	*Melaleuca xerophylla* to west side, *Acacia aneura sens. lat.* to east, *Lawrencia densiflora, Eragrostis* sp. (seedlings).	< 1 cm cracking clay, medium clay to 12 cm (10-11 cm ribbon), hard packed gypsum silty clay loam with gypsum nodules (up to 2.5 cm) to 30+ cm (4-5 cm ribbon), profile dry to 4 cm then moist.
RP01	Rehabilitation	50 J	0787365	6989795	Degraded	*Acacia aneura sens. lat., Acacia burkittii, Maireana pyramidata, Ptilotus obovatus, Solanum lasiophyllum, Solanum ellipticum, *Acetosa vesicaria, Ptilotus nobilis, Maireana georgei, Dissocarpus paradoxus,* Poaceae spp., *Asteraceae* sp. (seedlings), *Eriachne mucronata, Eremophila longifolia.*	Sandy clay loam to 30+ cm (3.5 cm ribbon), occasional gypsum-calcrete nodules (to 1 cm).

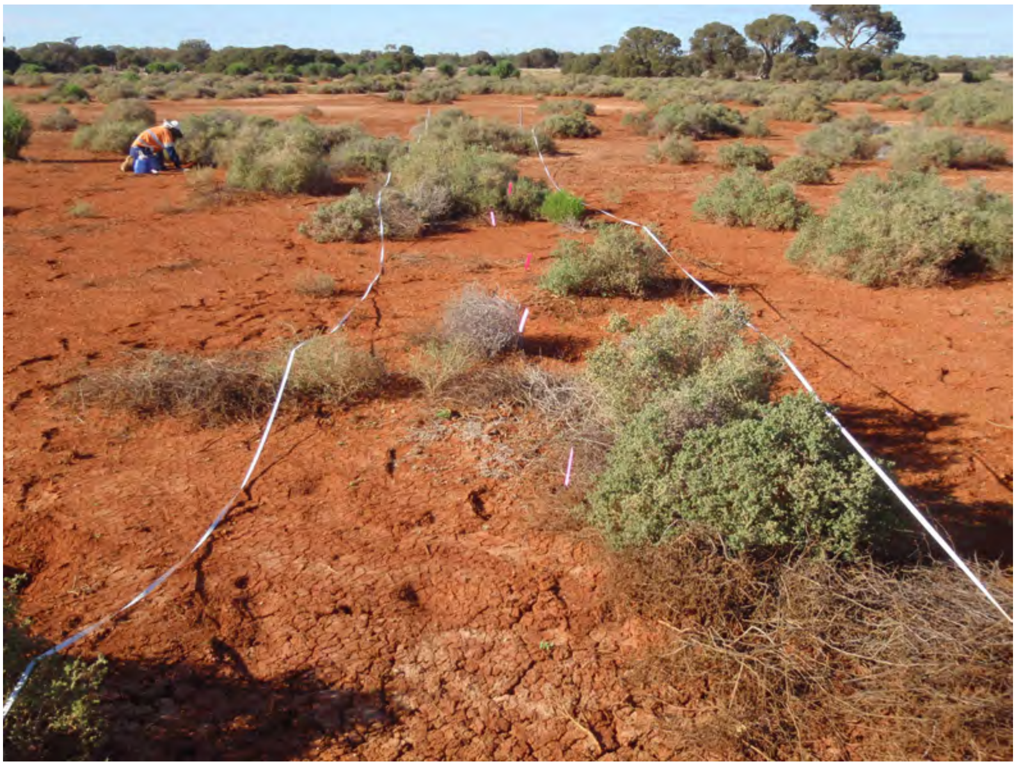

Plate 4. Photo of survey site WP01, western population.

Plate 5. Photo of survey site WP02, western population.

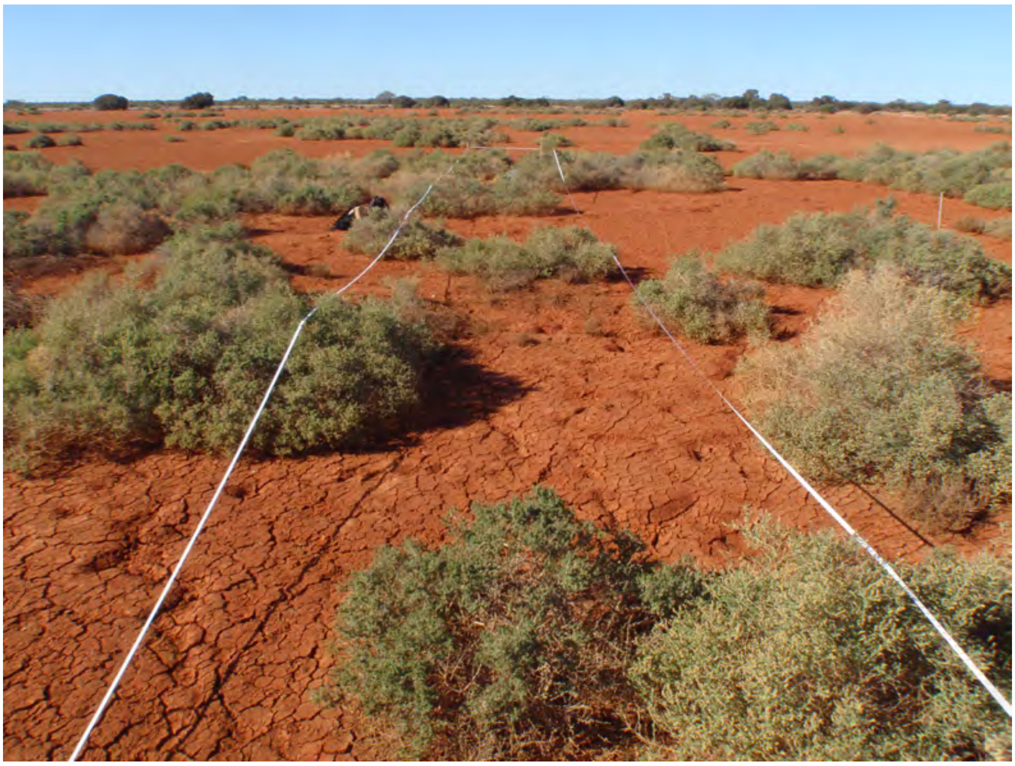

Plate 6. Photo of survey site WP03, western population.

Plate 7. Photo of survey site WP04, western population.

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Plate 8. Photo of survey site WP05, western population.

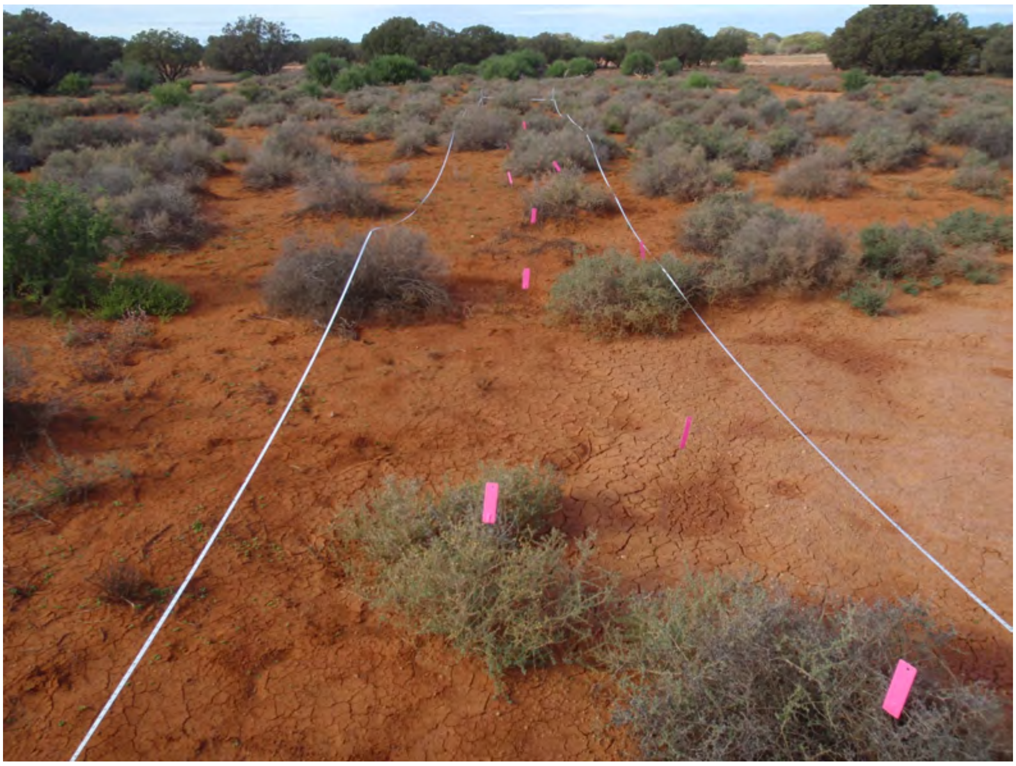

Plate 9. Photo of survey site WP06, western population.

Plate 10. Photo of survey site EP01, eastern population.

Plate 11. Photo of survey site EP02, eastern population.

Plate 12. Photo of survey site EP03, eastern population.

Plate 13. Photo of survey site EP04, eastern population.

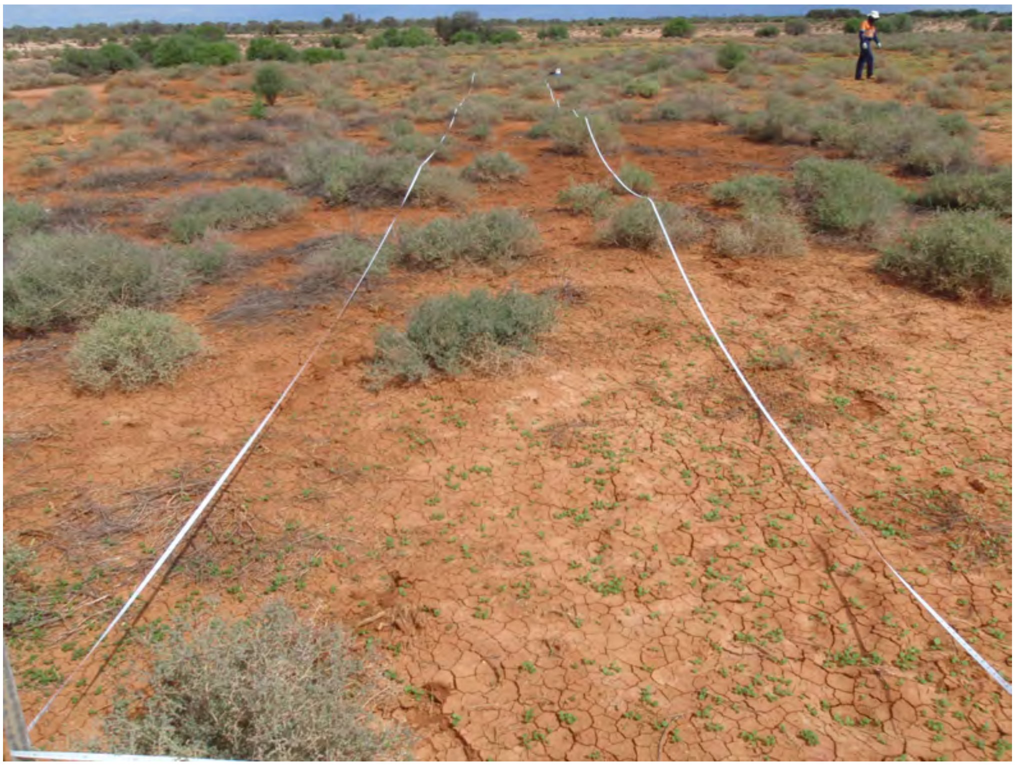

Plate 14. Photo of survey site EP05, eastern population.

Plate 15. Photo of survey site EP06, eastern population.

Plate 16. Photo of survey site EP07, eastern population.

Plate 17. Photo of survey site RP01, rehabilitation population.

Appendix B. Keighery vegetation condition scale

From Government of Western Australia (2000).

Condition Code	Condition Description
Pristine (1)	Pristine or nearly so, no obvious signs of disturbance.
Excellent (2)	Vegetation structure intact, disturbance affecting individual species and weeds are non-aggressive species.
Very Good (3)	Vegetation structure altered, obvious signs of disturbance. For example, disturbance to vegetation structure caused by repeated fires, the presence of some more aggressive weeds, dieback, logging and grazing.
Good (4)	Vegetation structure significantly altered by very obvious signs of multiple disturbances. Retains basic vegetation structure or ability to regenerate it. For example, disturbance to vegetation structure caused by very frequent fires, the presence of some very aggressive weeds at high density, partial clearing, dieback and grazing.
Degraded (5)	Basic vegetation structure severely impacted by disturbance. Scope for regeneration but not to a state approaching good condition without intensive management. For example, disturbance to vegetation structure caused by frequent fires, the presence of very aggressive weeds, partial clearing, dieback and grazing.
Completely Degraded (6)	The structure of the vegetation is no longer intact and the area is completely or almost completely without native species. These areas are often described as 'parkland cleared' with the flora comprising weed or crop species with isolated native trees or shrubs.

Western Botanical

P (08) 9270 0999
F (08) 6278 4988

E info@westernbotanical.com.au
www.westernbotanical.com.au