# Updated Summary on ecology of *Marianthus aquilonaris*

Prepared For

# Audalia Resources Limited

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Critical Habitat in this document refers to the definitions herein, and does not infer any definition or use of the term under the Biodiversity Conservation Act 2016. It's use is in relation to the requirements of the Environmental Scoping Document for the Medcalf Project (Audalia 2019).

# Quality Assurance

An internal quality review process has been implemented to each project task undertaken by BC. Each document and its contents are carefully reviewed by core members of the Consultancy team and signed off at Director Level prior to issue to the client. Draft documents are submitted to the client for comment and acceptance prior to final production.

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# EXECUTIVE SUMMARY


A range of technical studies have been commissioned by Audalia Resources Limited to seek to explain the occurrence, ecological requirements and demographic and genetic characteristics of *Marianthus aquilonaris* sub-populations in the Bremer Range. The scope and design of technical studies has been informed by the Environmental Scoping Document approved for the Medcalf Vanadium Project. Studies completed to date indicate that the distribution of *Marianthus aquilonaris*:

- Is positively associated with locations where limonite bedrock is present at very shallow depth.
- Is not highly correlated with chemical characteristics of soil, although low pH and low salinity conditions are generally present where the species has been observed.
- Is not directly affected by altitude or aspect.
- Is not conspicuously linked to climatic or hydrological factors, although the occurrence of the plant in areas of very limited soil depth suggests that the species may have a competitive advantage where water availability is limited.

Within the zone defined as 'critical habitat' for *Marianthus aquilonaris*, areas of 'optimal habitat' and 'sub-optimal habitat' have been recognised.

Genetic and pollination studies completed to date have found that:

- Genetic diversity within sub-populations is moderate, but there appears to be very limited flow of genetic material between sub-populations. Sub-populations separated by distances as small as 500 m show genetic divergence.
- The reasons for low rates of inter-population genetic exchange are not yet identified but may be related to pollinator characteristics.
- Lack of suitable pollinators does not appear to be factor that limits seed production: a diverse range of insect taxa including *Lasioglossum*, *Euryglossinae* and *Megachile* were collected during field surveys, even under sub-optimal environmental conditions. Also, high rates of self-pollination are observed.
- While *M aquilonaris* germinates readily, seedling survival rates under trial conditions have been poor.

Baseline sub-population demographic monitoring has been initiated: it is too early to detect trends or draw conclusions about variability in interannual or interpopulation plant survival and recruitment.

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# 1 INTRODUCTION

On 1 April 2019, the WA Environmental Protection Authority (EPA) approved an Environmental Scoping Document (ESD) for the proposed Medcalf Vanadium Project (EPA assessment number 2156). The ESD specifies a range of studies and other work required to be completed to allow the assessment of possible project impacts on populations of Hairy-fruited Billardiera (*Marianthus aquilonaris*) known to be endemic to the Bremer Range region. The work required under the approved ESD includes:

1. Identification and description of the environmental values of the ironstone ridges of the Bremer Range (*M. aquilonaris* habitat) including assessments of soil profile, topography, geology and hydrological regime. Studies to include:
   - Soil profile assessments;
   - Geomorphological assessments;
   - Assessments of surface water flows/hydrological regimes of the Bremer Range; and
   - Microclimatic assessments to identify microhabitats.
2. Identification, description and mapping of habitat for *M. aquilonaris*;
3. Characterisation of genetic diversity and structuring of *M. aquilonaris* populations
4. Demographic monitoring of *M. aquilonaris* sub-populations;
5. Genetic testing on each sub-population of *M. aquilonaris* to determine genetic diversity and pollination of sub-populations;
6. Seed viability testing and germination trials for any *M aquilonaris* populations or subpopulations likely to be directly or indirectly impacted by project implementation; and
7. Identification of potential pollinators for *M aquilonaris*.

This memorandum provides a summary of the findings of technical studies on of *M aquilonaris* required under the approved ESD.

# 2 DESCRIPTION

## 2.1 Taxon Identification

The first collection of *Marianthus aquilonaris*, housed at the WA Herbarium, was made by Neil Gibson and Mike Lyons during a floristic survey of the Bremer Range and Parker Ranges in 1994 (Gibson & Lyons, 1998). In 2002 a new population was discovered on a track near the original population site by a volunteer and a Department of Environment and Conservation (DEC) officer (now known as the Department of Biodiversity, Conservation and Attractions).

At the time of collection by Gibson and Lyons this taxon was referred to as *Billardiera* sp nov (NG&ML 1776) and was subsequently given the phrase name *Marianthus* sp. Bremer. Although a taxonomic review in 2005 determined *Marianthus* sp. Bremer and *M. mollis*[1] to be synonomous, subsequent further examination of vouchered collections showed that Bremer Range populations were morphologically distinct from those near Ravensthorpe and the two taxa were reinstated. In 2009, *Marianthus* sp. Bremer was formally named *Marianthus aquilonaris* (Wege and Gibson, 2009).

## 2.2 Conservation Status

*Marianthus aquilonaris* was declared as Rare Flora under the Western Australian *Wildlife Conservation Act 1950* in 2002 under the name *Marianthus* sp. Bremer, and is ranked as Critically Endangered (CR) under World Conservation Union (IUCN 2001) criteria B1ab(iii,v)+2ab(iii,v); C2a(ii) due to its extent of occurrence being less than 100 km$^2$, its area of occupancy being less than 10 km$^2$, a continuing decline in the area, extent and/or quality of its habitat and number of mature individuals and there being less than 250 mature individuals known at the time of ranking. However, as more plants have since been found, it no longer meets these criteria and a recommendation will be made by DBCA to the Threatened Species Scientific Committee (TSSC) that they be changed to CR B1ab(iii,v)+2ab(iii,v). The species is not currently listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999). The main threats to the species are mining/exploration, track maintenance and inappropriate fire regimes (DEC, 2010).

## *2.3* Taxonomic Description

*Marianthus aquilonaris* is an upright, multi-stemmed *shrub*, 0.3–1.6 m high, 0.15–1 m wide; *stems* with a dense indumentum of ± glandular hairs to 0.2 mm long and scattered pilose hairs 0.5–2 mm long, becoming glabrous with age through abrasion. *Adult leaves* alternate, elliptic to oblong, flat in T.S., 7–22(–25) mm long and 2.3–7(–9) mm wide with a L:W ratio of 2.1–4.1, apex acuminate to acute, margins entire, base attenuate with a petiole 1–2.5 mm long, yellow-green usually with a reddish border, glabrous with the exception of sparse pilose and shorter, ± glandular hairs on the margins of young leaves, margins becoming minutely papillose with age through abrasion. *Inflorescences* axillary, flowers solitary, ± nodding; peduncles suberect to spreading, 3–12(–19) mm long, with a dense covering of ± glandular hairs to 0.2 mm long and very sparse pilose hairs. *Sepals* 3–7 mm long, acute, pilose and glandular. *Petals* 5, cohering at the base then recurving, spathulate, 11–19.5 mm long and 2–4.3 mm wide with a L:W ratio of 3.3–7.1, apex acuminate, margins entire, pale blue to almost white with fine purple striations at anthesis, pilose along central upper surface. *Stamens* 5; filaments 5–9.5 mm long, flared towards the base; anthers dorsifixed, white. *Pistil* 4.5–7.5 mm long; ovary bilocular, with a medium dense indumentum of pilose hairs and shorter, ± glandular hairs; style curved or straight, hairy towards base. *Fruit* capsular, obloid to ellipsoid, 7.5–12 mm long, 6–8 mm wide, with sparse to medium pilose and glandular hairs. *Seeds* broadly elliptic to reniform, *c.* 1.5–1.6 mm long, 1.4 mm wide, dark red-brown, shiny, wrinkled, arillate (DEC, 2010).

[1] Currently listed as a Priority 4 taxon by DBCA and Endangered under the EPBC Act. Previously listed as Declared Rare Flora under the WC Act.

## 2.4 Biology and ecology

*Marianthus aquilonaris* is an erect, straggly shrub to 1.6 m high with hairy stems, alternate, elliptic to oblong leaves, a glabrous calyx and a pale blue and white corolla. Flowers appear between September and October. *Marianthus aquilonaris* appears to be a disturbance opportunist as it was found growing in abundance in areas that had been recently burnt (DEC, 2010).

*Marianthus aquilonaris* is considered to be a facultative seeder-sprouter, with many plants re-sprouting from basal stock following fire, however plants are also able to germinate from seed. Based on assessments conducted by DBCA, the juvenile period is approximately 36 months (DEC, 2011).

**Plate 1: Image of *Marianthus aquilonaris* (Botanica Consulting)**

## 2.5 Distribution

*Marianthus aquilonaris* is known only from the Bremer Range which is listed as a Priority 1 Ecological Community (PEC), located approximately 100 km west, south-west of Norseman, Western Australia (**Figure 1**). The extent of occurrence for this taxon is likely to be less than 0.5 $km^2$ (DEC, 2010).

## 2.6 Population Extent

Currently there are six known sub-populations of *Marianthus aquilonaris,* all of which occur within Bremer Range. Population 1a to 1c and 1f were previously known populations listed by the Department of Biodiversity, Conservation and Attractions (DBCA). Population 1d and 1e were newly identified populations located by Botanica Consulting (Botanica) in September/ October 2014. Details on the current status of all sub-populations are summarised in **Table 1**. Images of each population are provided in Attachment 1. Threatened Flora Report Forms detailing these new sub-populations were lodged with DBCA on the 14th October 2015.

**Table 1: Summary of *Marianthus aquilonaris* sub-populations**

| Population No. | DBCA Live Total Count (2011)[1] | DBCA Live Total Count (2015/2016)[2] | Area Occupied ($m^2$)[3] (2015) | Area Occupied ($m^2$)[4] (2018) | Population Condition[3] |
|---|---|---|---|---|---|
| 1a | 9820 | 2259 | 25,288 | 16,050 | Moderate |
| 1b | 787 | 247 | 5,645 | 2,124 | Moderate |
| 1c | 7091 | 3205 | 16,719 | 8,668 | Healthy |
| 1d | N/A* | 8255 | 25,400 | 17,630 | Healthy |
| 1e | N/A* | 661 | 2,200 | 638 | Healthy |
| 1f | N/A* | 1 | 11 | 0 | Healthy |
| **TOTAL** | **17,698** | **14,628** | **75,263** | **45,110** | |

[1] Population monitoring conducted by DBCA in October 2011.

[2] Simple plant count conducted by DBCA 29th September 2015 and 7th September 2016 (listed on the TPFL database).

[3] Area occupied/ population condition as listed on DBCA TPFL database based on assessments conducted by Botanica and DBCA.

[4] Area occupied based on assessments conducted by Botanica 28th to 30th November 2018

*N/A-Sub-populations were not identified during the 2011 count conducted by DBCA

As shown by the DBCA plant counts, plant numbers have declined over time since the mass germination event following bushfires in the area in 2010. Recent observations of the population area were made by Botanica in November 2018, where a number of plants were observed to have died off. Plant numbers are expected to continue to decline with increasing time since fire disturbance.

[redacted]

Figure 1: Regional Map of Bremer Range and *Marianthus aquilonaris*

## 2.7 Sub-population Demographics

A program of twice-yearly demographic monitoring was established in Spring (September and November) 2018. Further demographic monitoring of *Marianthus aquilonaris* sub-populations has been conducted subsequently in Autumn (May) 2019 and Spring (October) 2019. A total of twenty-seven monitoring quadrats (10m X 10m) were established within the *Marianthus aquilonaris* sub-populations (Figure 2). The following parameters were monitored at each quadrat:

- Number of mature plants
- Number of juvenile plants
- Number of dead plants
- Number of seedlings
- Number of sprouting plants
- Number of flowering plants
- Number of fruiting plants
- Height / width of plants
- Number of fruits per plant
- Number of flowers per plant
- Dominant species in quadrat

Salient findings are summarised below. As this is the first two-year of monitoring it is not possible to identify trends in the reproductive or mortality rates of each population. The data collected in 2018 and 2019 will serve to establish a baseline against which to compare future twice-yearly monitoring results. This will allow estimation of 'effective population size' (that is the proportion of each sub-population that are mature and capable of reproducing), average mortality rates, average reproduction/recruitment rates and age distribution of each sub-population (Botanica, 2020).

- Mature plants consistently outnumber juvenile or dead plants (Figure 3);
- Flowers were only present during the Spring monitoring periods (2018 and 2019). The mean number of plants with flowers was for all populations in Spring 2019, compared to the previous spring (Figure 4);
- In Spring 2018, the percentage of fruiting plants ranged from 11% (Population 1e) to 38% (Population 1b), while in Spring 2019, only one quadrat from Population 1d (Q1-2) had fruits present.
- The mean numbers of fruits and flowers per plant varies between sub-populations and also shows year-to-year variability (Figure 5).

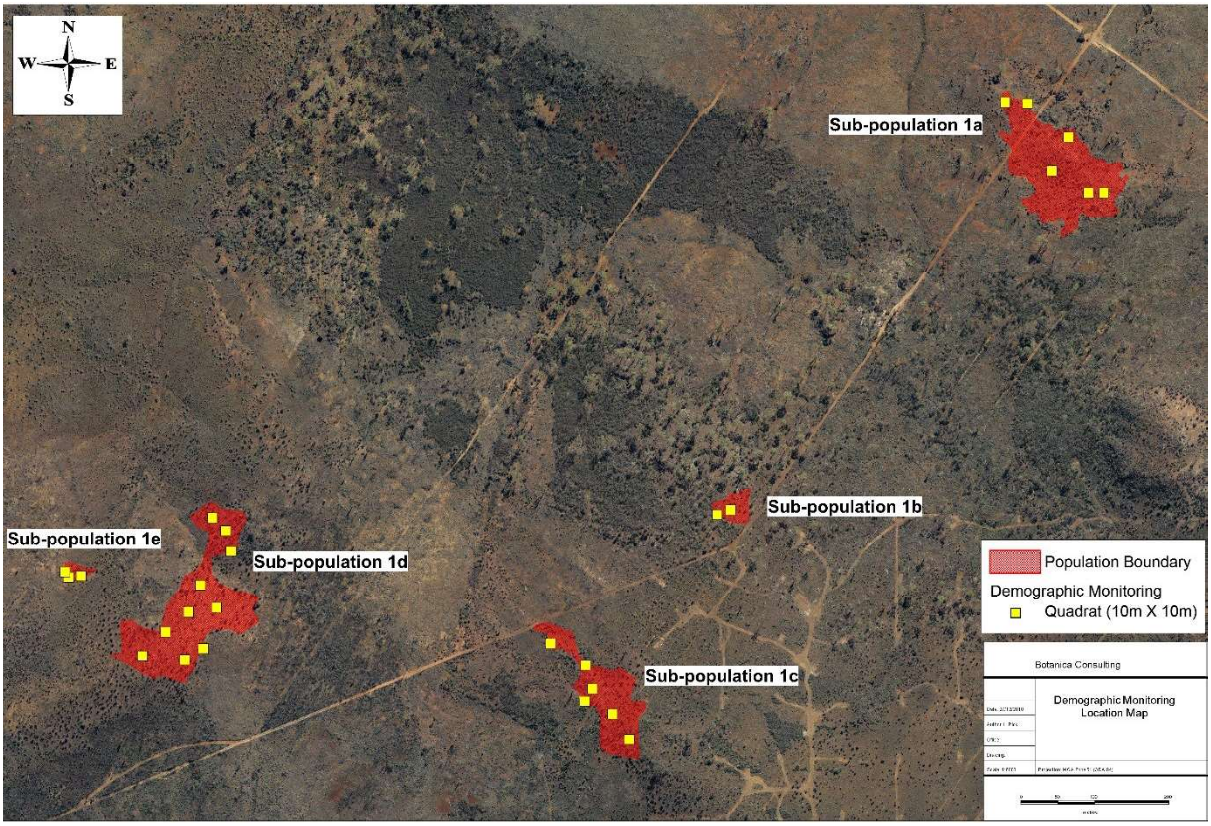
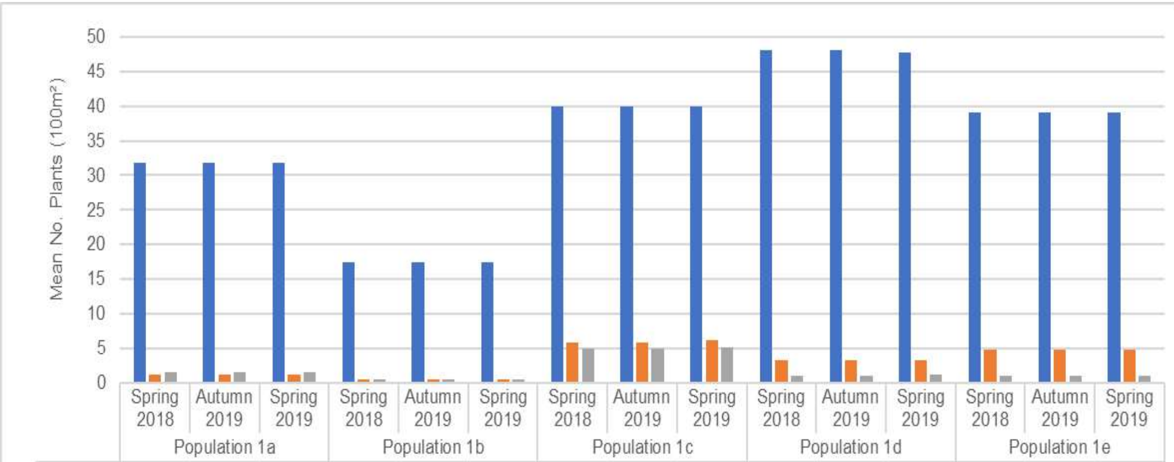
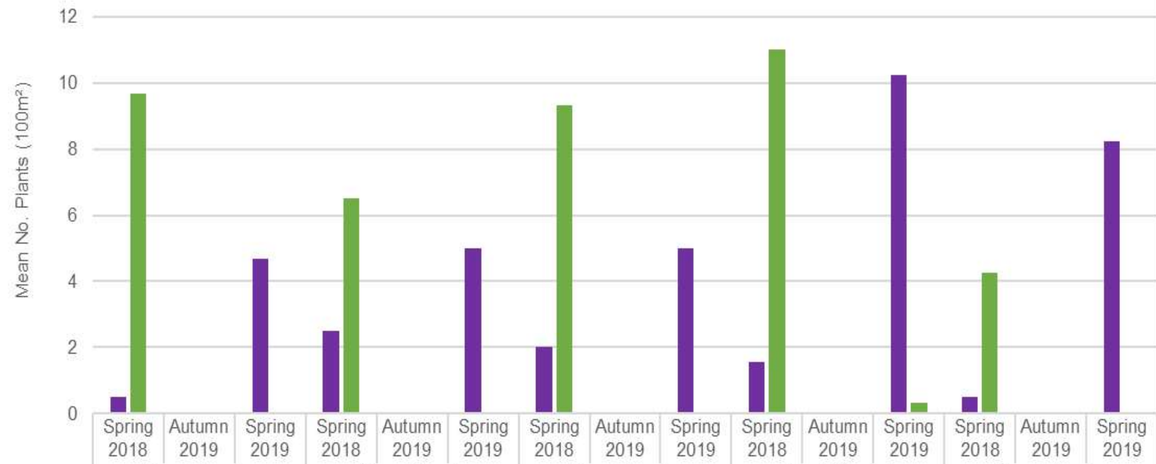



**Figure 2: Locations of demographic monitoring quadrats**



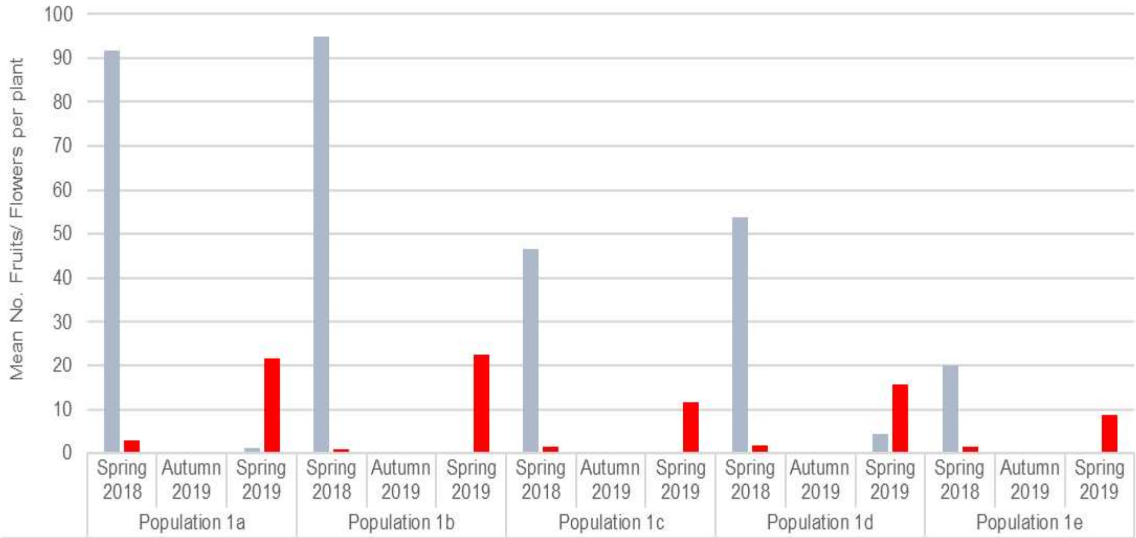

| | Population 1a | | | Population 1b | | | Population 1c | | | Population 1d | | | Population 1e | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 |
| Mature | 32 | 32 | 32 | 18 | 18 | 18 | 40 | 40 | 40 | 48 | 48 | 48 | 39 | 39 | 39 |
| Juvenile | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 6 | 6 | 3 | 3 | 3 | 5 | 5 | 5 |
| Dead | 2 | 2 | 2 | 1 | 1 | 1 | 5 | 5 | 5 | 1 | 1 | 1 | 1 | 1 | 1 |

**Figure 3: Age structure of each MA sub-population (Spring 2018-Spring 2019)**




| | Population 1a | | | Population 1b | | | Population 1c | | | Population 1d | | | Population 1e | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 |
| Flowering | 1 | 0 | 5 | 3 | 0 | 5 | 2 | 0 | 5 | 2 | 0 | 10 | 1 | 0 | 8 |
| Fruiting | 10 | 0 | 0 | 7 | 0 | 0 | 9 | 0 | 0 | 11 | 0 | 0 | 4 | 0 | 0 |

**Figure 4: Number of Flowering/Fruiting Plants of each sub-population (Spring 2018-Spring 2019)**




| | Population 1a | | | Population 1b | | | Population 1c | | | Population 1d | | | Population 1e | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 |
| Fruits | 92 | 0 | 1 | 95 | 0 | 0 | 47 | 0 | 0 | 54 | 0 | 4 | 20 | 0 | 0 |
| Flowers | 3 | 0 | 22 | 1 | 0 | 23 | 2 | 0 | 12 | 2 | 0 | 16 | 2 | 0 | 9 |

**Figure 5: Mean no. flowers/fruits per plant of each sub-population (Spring 2018-Spring 2019)**

# 3 BREMER RANGE HABITAT ASSESSMENT

This section reviews the habitat information for *Marianthus aquilonaris* based on historical and recent studies.

Typical habitat for *Marianthus aquilonaris* has been defined by DEC (2011) as: Ironstone ridges (ca. 400 m above sea level) with a laterite capping and exposed iron oxide (commonly referred to as limonite). Plants tend to be located within shallow drainage lines on the ridge, on rocky red-orange sandy loam. Habitat is Open Low Woodland dominated by *Eucalyptus livida* over Dwarf Scrub dominated by *Eremophila clavata*, *Pultenaea arida*, *Acacia erinacea*, *Westringia cephalantha* var. *caterva*, *Waitzia fitzgibbonii*, *Asteridea athrixioides* and *Lepidosperma* sp.

In 2011, the (then) Department of Department of Environment and Conservation (DEC – now Department of Biodiversity Conservation and Attractions, DBCA) defined habitat critical to the survival of *Marianthus aquilonaris* as follows:

> *…the area of occupancy of* [known] *populations, areas of similar habitat surrounding and linking populations (these providing potential habitat for population expansion and for pollinators), additional occurrences of similar habitat that may contain undiscovered populations of the species or be suitable for future translocations, and the local catchment for the surface and/or groundwater that maintains the habitat of the species* (DEC, 2011).

Previous mapping of the critical habitat for *Marianthus aquilonaris* was conducted by DBCA in 2011 based on the definition above. The resulting map defines critical habitat of *Marianthus aquilonaris* around the immediate area where the (then known) populations occur and the habitat linking them (**Figure 12**). The resulting critical habitat includes areas of the ironstone ridge which feed shallow drainage lines where large numbers of plants are observed to occur (DEC, 2011). It includes areas of high elevation and south facing slopes that were possibly considered to be similar habitat (topographically similar) and have potential to find undiscovered populations. The mapping was completed prior to identification of sub-population 1d to 1f and hence excludes them.

As required by the ESD (Audalia 2019), further studies have been conducted for *Marianthus aquilonaris* to facilitate impact assessment for the Medcalf Project. The studies required included further surface soil testing within/ outside of the population extent, establishment of demographic monitoring, landform monitoring and hydrological studies in order to further define the habitat, and specifically to identify critical habitat, optimal habitat and sub-optimal habitat for *Marianthus aquilonaris*. The results of these studies are provided as separate reports and have been used to inform the definition of critical habitat proposed in this report.

Based on these assessments, habitat preferences for *Marianthus aquilonaris* include:

- Gravelly, shallow loamy soils with an indurated, mottled zone layer that occurs within 30 cm of the soil surface (referred to as 'Shallow gravel over indurated mottled zone' soil).
- Acidic to neutral soils (pH 4.5-7) and low salinity soils (<200mS/m).
- Shallow brown to orange/ red-brown sandy-clay loam soils/ loamy earths (≤58mm depth).
- Areas of exposed bedrock (predominately limonite ≥8%) with high percentage plant litter (≥20%) and bare ground (≥53%).
- Elevations ranging from 380m-425m with the north-eastern populations (Population 1a and 1b) occurring lower in the landscape of the Bremer Range (380-405m) and the north-western populations (Population 1c, 1d and 1e) occurring higher in the landscape (400m-425m).

- North-eastern and north-western face of rocky slopes which is likely associated with the surface drainage of the hills which generally drains toward the north.

A map of the proposed critical habitat for *Marianthus aquilonaris* (including areas of additional occurrences of similar habitat that may contain undiscovered populations of the species or be suitable for future translocations) is provided in **Figure 13**. A summary of the aspects used in determining the potential boundary of the proposed critical habitat (based on the definition provided by DBCA (DEC, 2011) is provided in **Table 2**.

**Table 2: *Marianthus aquilonaris* critical habitat definition**

| **DBCA Definition (DEC, 2011)** | **Botanica Assessment** |
| --- | --- |
| *Habitat critical to the survival of M. aquilonaris includes:* | |
| Area of occupancy of populations. | Known occurrence of *Marianthus aquilonaris* populations. |
| Areas of similar habitat surrounding and linking populations (these providing potential habitat for population expansion and for pollinators). | Areas of shallow gravel over indurated mottled zones identified during soil investigations conducted by Neil Lantzke (Western Horticultural Consulting, 2019). |
| | Area of suitable habitat between the populations which includes rocky hillslopes and vegetation types mapped by Botanica Consulting (Botanica, 2017a) which are known to support *Marianthus aquilonaris* populations; HS-MWS1 (*E. livida*) and HS-OS1 (regrowth shrubs). |
| | Low to mid north facing slopes. Mottled zone has only been identified between elevation 380m-425m. No *Marianthus aquilonaris* located on the upper slope/ hill crest likely due to absence of mottle zone and greater exposure. |
| Additional occurrences of similar habitat that may contain undiscovered populations of the species or be suitable for future translocations. | Areas of shallow gravel over indurated mottled zones identified during soil investigations conducted by Neil Lantzke (Western Horticultural Consulting, 2019) on low-mid north facing slopes with *Eucalyptus livida* vegetation. |
| The local catchment for the surface and/or groundwater that maintains the habitat of the species. | Catchment above the communities including the catchment area that would drain through the actual area occupied by *Marianthus aquilonaris* and the catchment area that would drain through the shallow gravel over indurated mottled zone soil type. Surface drainage flow of the range extends in a northern direction as assessed by Groundwater Resource Management (GRM, 2020). *Marianthus aquilonaris* plants are very unlikely to draw water from the regional groundwater table, given that the groundwater is hypersaline and the depth to groundwater is in excess of 45 m (GRM, 2020). |

## 3.1 Areas of Occupancy

**Figure 6** shows in red the areas of occupancy based on the most recent (2019) mapping by Botanica. Areas of occupancy are indisputably defined as critical habitat **–** the proposed critical habitat boundary encompasses all areas of occupancy. Areas of occupancy would be also described as optimal habitat.

## 3.2 Soil Type (areas of shallow gravel over indurated mottled zones)

**Figure 7** shows the areas mapped as shallow gravel over indurated mottled zones. All of the areas of occupancy are located on mid to low north facing slopes of the Vesuvius deposit range within this soil type. Additional occurrences of shallow gravel over indurated mottled zones occur north-east of the known sub-populations, located lower in the landscape (350-365m elevation) and south-west of the known sub-populations, located on the southern face of the Egmont deposit range (considered as sub-optimal habitat as described in **Section 3.7**).

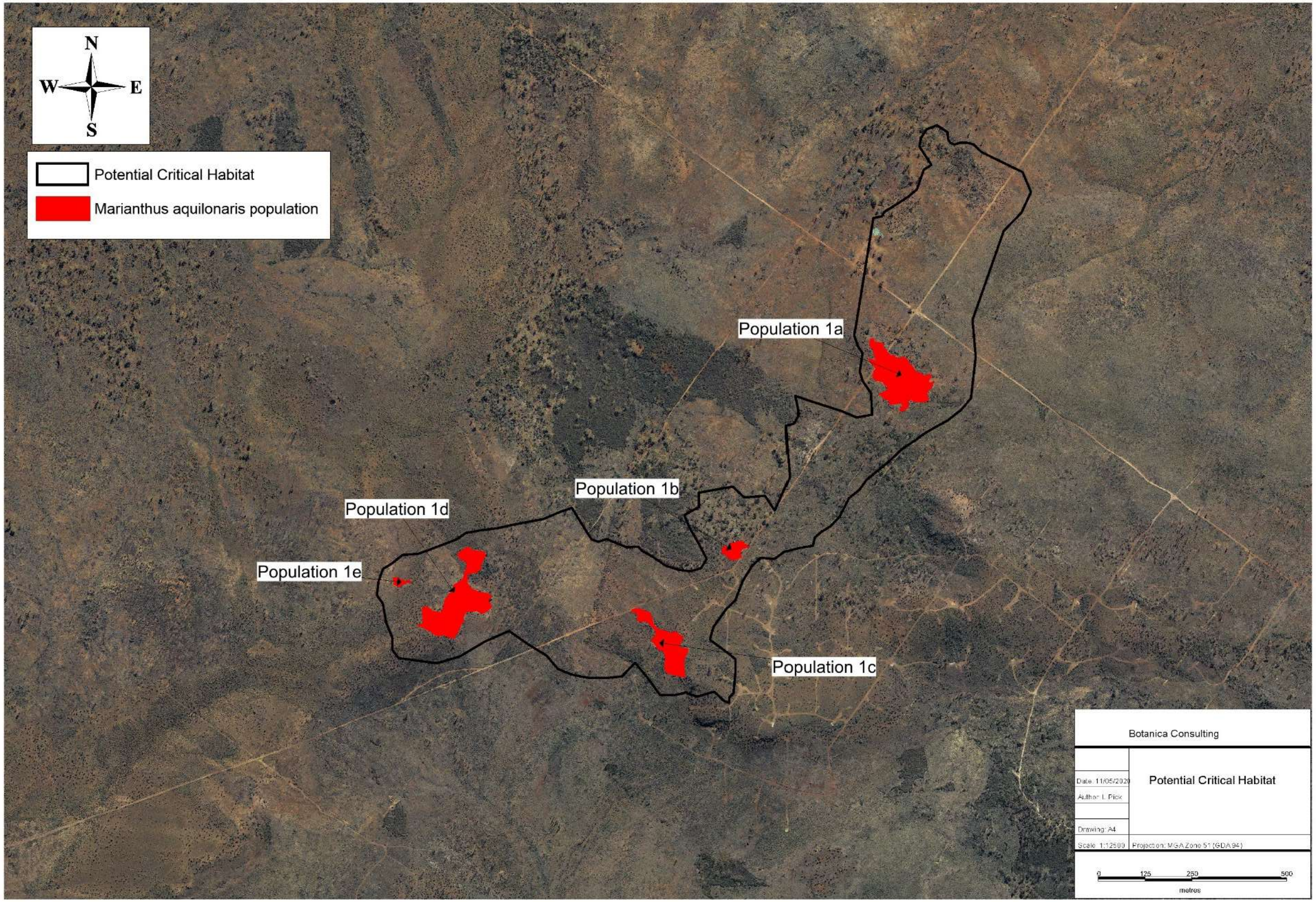



Figure 6: Population occupancy areas and proposed critical habitat boundary

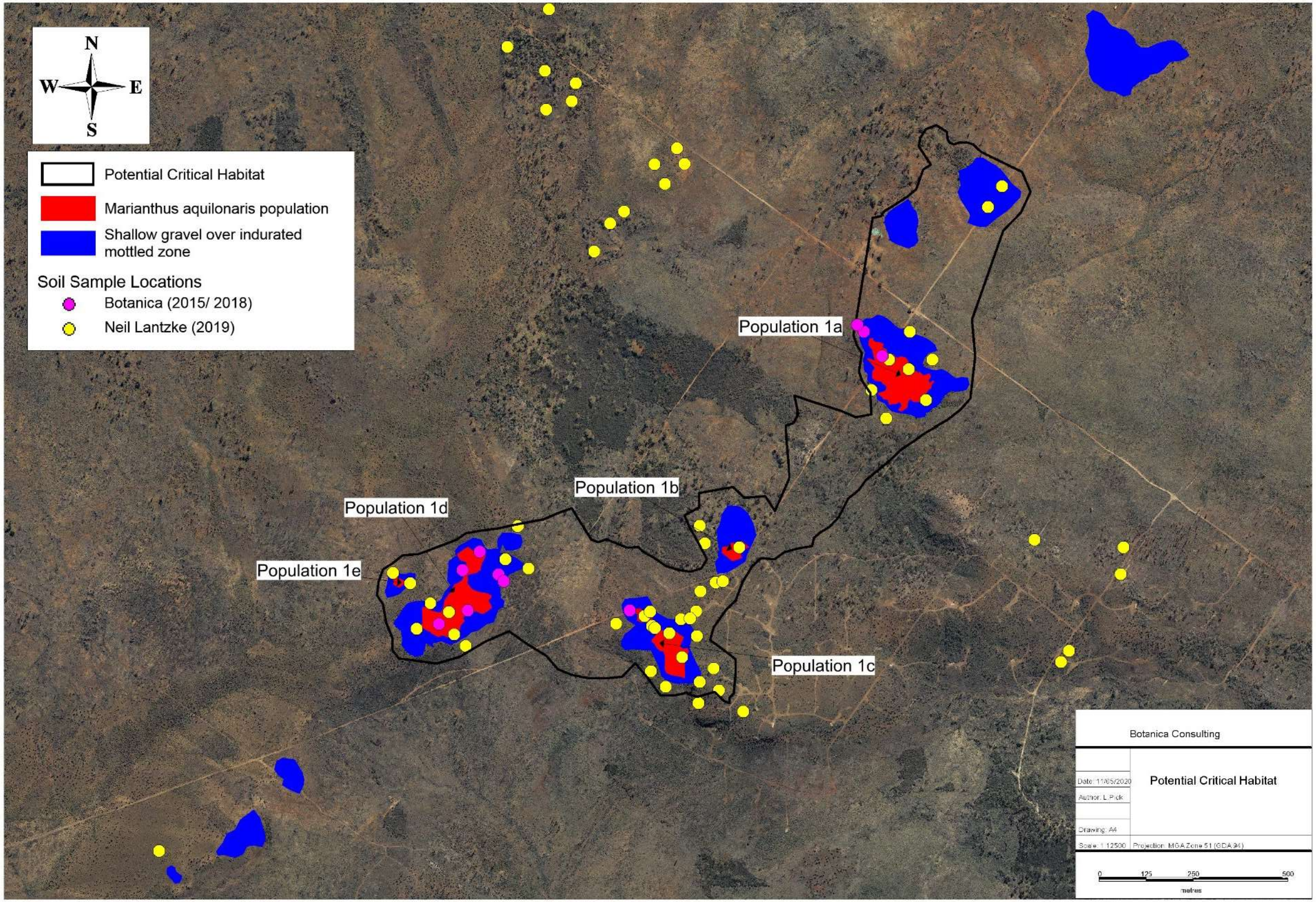



Figure 7: Areas of shallow gravel over indurated mottled zone (in blue) showing soil sample locations

## 3.3 Vegetation type

All of the populations are within areas mapped as Regrowth mixed low shrubland on hillslope (HS-OS1) or Regrowth mid open mallee woodland of *Eucalyptus livida* over mid open shrubland of *Hakea pendens* and open low shrubland of *Goodia medicaginea* on hillslope (HS-MWS1). HS-MWS1 contains *Eucalyptus livida* which Botanica have noted to be present at all areas of occupancy. However, the presence of *E. livida* does not necessarily indicate that *Marianthus aquilonaris* will be present. The fact that insects noted to be visiting *E. livida* (Prendergast, 2019) were also noted on *Marianthus aquilonaris* suggests that potential pollinators are not specific to *Marianthus aquilonaris*, and the heavy and widespread flowering of *E. livida* potentially provides alternative food sources to potential pollinators. It is proposed that vegetation type be considered in the mapping of boundaries due to these linkages.

Because of the need to retain linkages between the subpopulations for potential pollinators, is proposed that anywhere in a straight line between sub-populations be considered critical habitat, provided it is mapped as HS-OS1 or HS-MWS1. Surrounding vegetation types occur on deeper colluvial soils that do not contain outcrops of limonite and are not suitable for *Marianthus aquilonaris.*

## 3.4 Catchment areas

The DEC 2011 definition includes *the local catchment for the surface and/or groundwater that maintains the habitat of the species.* **Figure 9** shows the catchment above the communities including the catchment area that would drain through the actual area occupied by *Marianthus aquilonaris* and the catchment area that would drain through the shallow gravel over indurated mottled zone soil type. Surface drainage flow of the range extends in a northern direction as assessed by Groundwater Resource Management (GRM, 2020). *Marianthus aquilonaris* plants are very unlikely to draw water from the regional groundwater table, given that the groundwater is hypersaline and the depth to groundwater is in excess of 45 m (GRM, 2020). Downslope of the areas of occupancy is not considered as important for critical habitat as the water is flowing out of the area and not available to the plants.

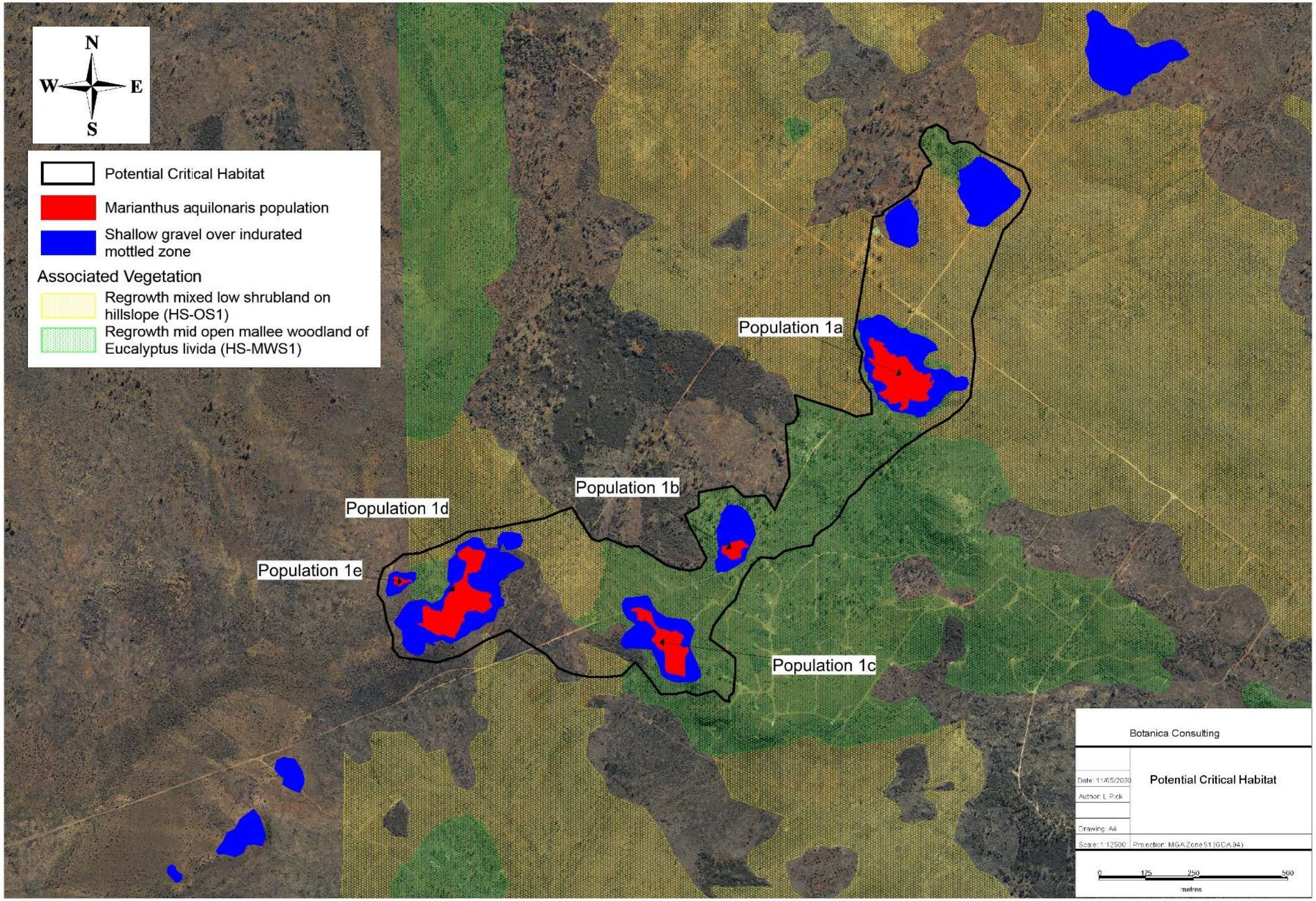



**Figure 8: Vegetation type, areas of occupancy and soil type with critical habitat**

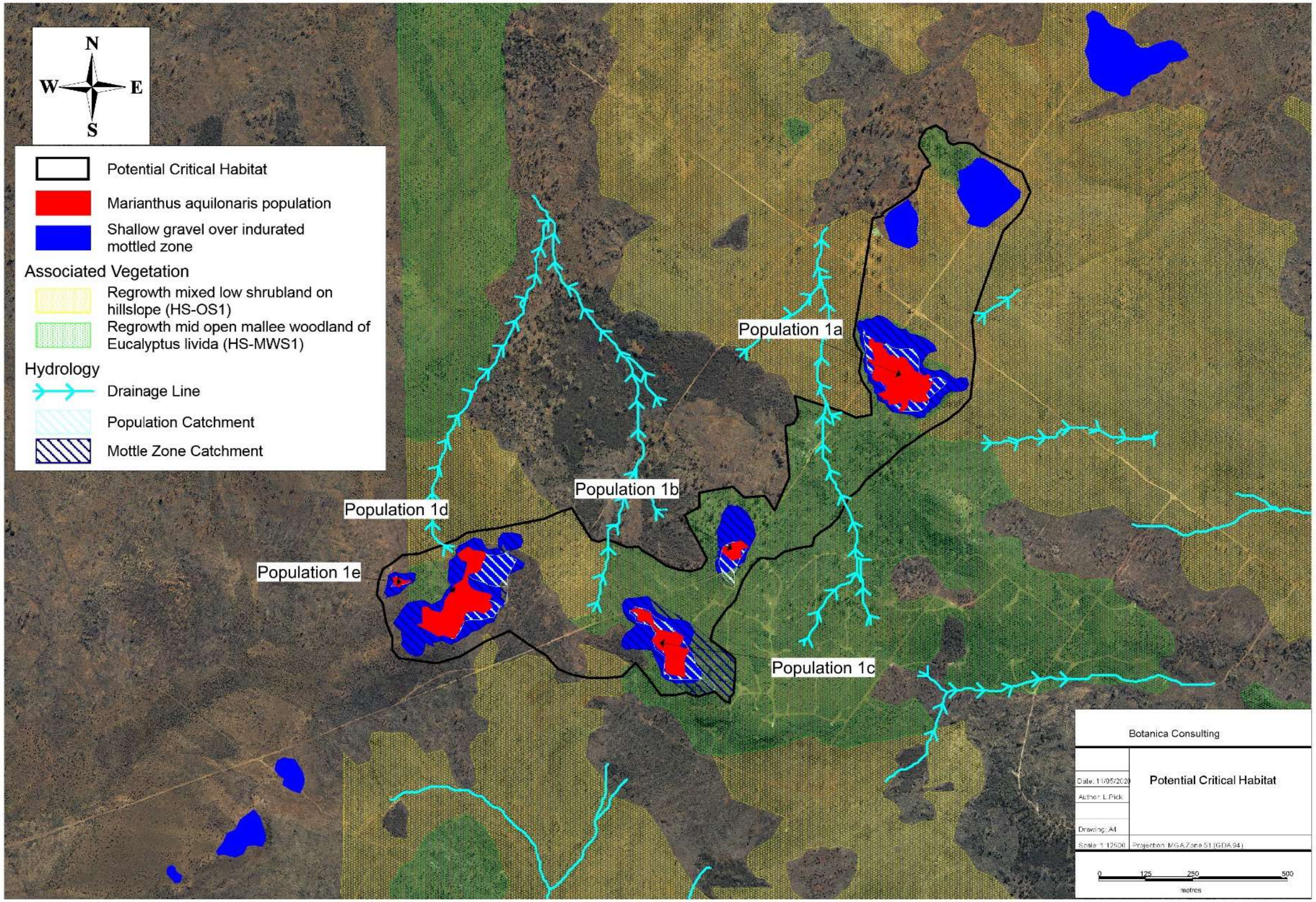



**Figure 9: Drainage lines and catchment boundaries**

## 3.5 Elevation

All of the areas of occupancy are at elevations ranging from 380m-425m (**Figure 10**). The north-eastern populations (Population 1a and 1b) occur lower in the landscape of the Bremer Range (380-405m) and the north-western populations (Population 1c, 1d and 1e) occur higher in the landscape (400m-425m).

It is not clear what the apparent topographic control is based upon – these upper areas in the landscape tend to have different geology, soils, hydrological regimes and microclimates. It is considered likely that a combination of these factors are controlling plant distribution, rather than topography per se.

Contour levels have been considered but are not significantly controlling the location of the proposed critical habitat boundaries. It is noted that all of the proposed critical habitat is between 370-430 m.

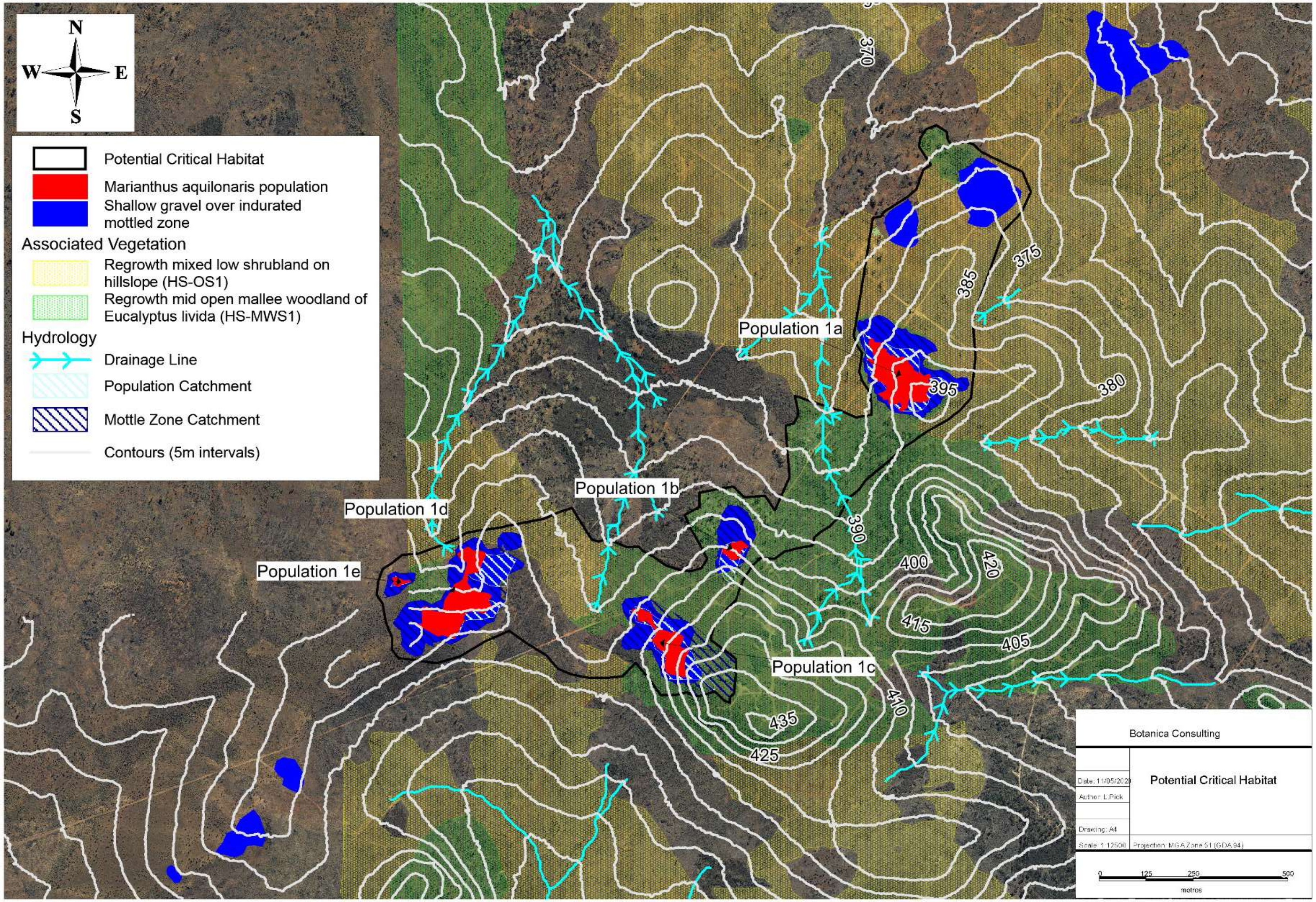



**Figure 10: Elevation**

## 3.6 Optimal habitat

As discussed in sections 3.1 and 3.2, it is proposed to adopt the areas of shallow gravel over indurated mottled zones within the critical habitat boundary (majority of which contains the *Marianthus aquilonaris* sub-populations) as optimal habitat on the basis that it is the only soil type upon which the species is known to grow. Based on the DBCA definition of critical habitat (**Table 2**) the area proposed as 'optimal habitat' meets all the critical habitat definition criteria excluding area of occupancy, with sections of the optimal habitat not currently occupied by *Marianthus aquilonaris.* A map of the optimal habitat is provided in **Figure 11**. The previous record of *Marianthus aquilonaris* population 1f has not been included in optimal habitat as this population (which included a single plant that has not been observed/ identified since 2014) does not occur on the shallow gravel over indurated mottled zones which is the only known soil type to support *Marianthus aquilonaris.* The historic record of population 1f has been included in the sub-optimal habitat of the critical habitat boundary, which is described below.

## 3.7 Sub-optimal habitat

Sub-optimal habitat is considered to be area that the species may be able to grow, but is not preferred or optimal. Sub-optimal habitat has been identified as the habitat within the critical habitat boundary, outside of the area of occupancy and optimal habitat. Logically this may extend further in distance, include other soil and vegetation types, landscape positions etc, but it needs to be limited in some way to enable definition of areas. Based on the DBCA definition of critical habitat (**Table 2**) the area proposed as 'sub-optimal habitat' only meets the following critical habitat criteria; Areas of similar habitat surrounding and linking populations (these providing potential habitat for population expansion and for pollinators). A map of the sub-optimal habitat is provided in **Figure 11**.

Previously, areas of limonite outcrop mapped regionally in geology maps were proposed as potential habitat. Despite considerable time and effort searching for *Marianthus aquilonaris* plants in these locations by Botanica, no new populations have been discovered.

A summary of the extent of proposed critical habitat, optimal habitat and sub-optimal habitat (including the area of *Marianthus aquilonaris* occupied and unoccupied within each habitat) is provided in **Table 3**.

**Table 3: Extent of Critical, Optimal and Sub-Optimal Habitat**

| Habitat | Extent (ha) | Marianthus occupied area (ha) | Marianthus unoccupied area (ha) |
|---|---|---|---|
| Critical Habitat | 64.50 | 4.51 | 59.99 |
| Optimal Habitat | 16.82 | 4.51 | 12.31 |
| Sub-Optimal Habitat | 52.57 | 0 | 52.57 |

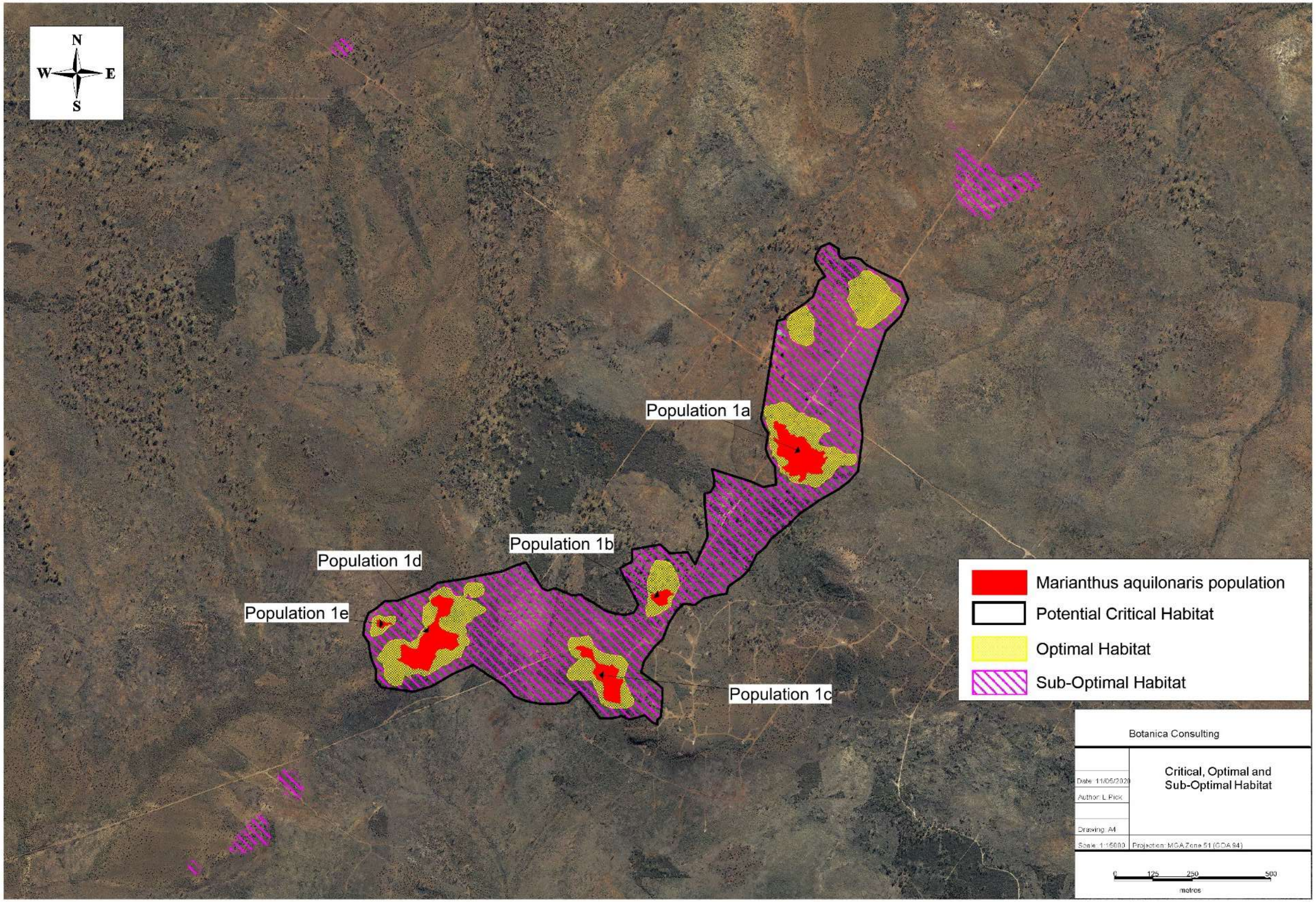



Figure 11: Critical, optimal and sub-optimal habitat

## 3.8 Critical habitat summary

The differences (and reasons in brackets) between the DEC 2011 mapped critical habitat and proposed critical habitat (as shown in **Figure 14**) are due to:

- Inclusion of sub-populations 1d and 1e which were not identified by DEC in 2011 (required update based on newly identified sub-populations);
- Inclusion of areas within direct lines of areas of occupancy (for protection of potential pollinator pathways);
- Inclusion of areas of shallow gravel over indurated mottled zones within close proximity to areas of occupancy (capable of sustaining cross-pollination via linkages to existing sub-populations should plants be established there);
- Refined northern boundary to follow the same vegetation type boundary of the *Marianthus aquilonaris* populations (vegetation types often have relationships with fauna, soil type, topography and drainage that make them a logical linkage **–** therefore direct paths between subpopulations are included where they follow the same vegetation type);
- Refined the southern boundary to exclude the hillcrest areas and the southern faces of the range which were included in the 2011 area mapped by DEC as critical habitat (population extent, upper catchment areas, associated soil types/ landforms and topography has been further defined). Populations, associated mottle zone and upper catchment areas that would drain through the populations and associated mottle zone do not occur on the hill crest/ southern slopes.

[redacted]

**Figure 12: Critical habitat mapped for *M. aquilonaris* (DEC, 2011)**

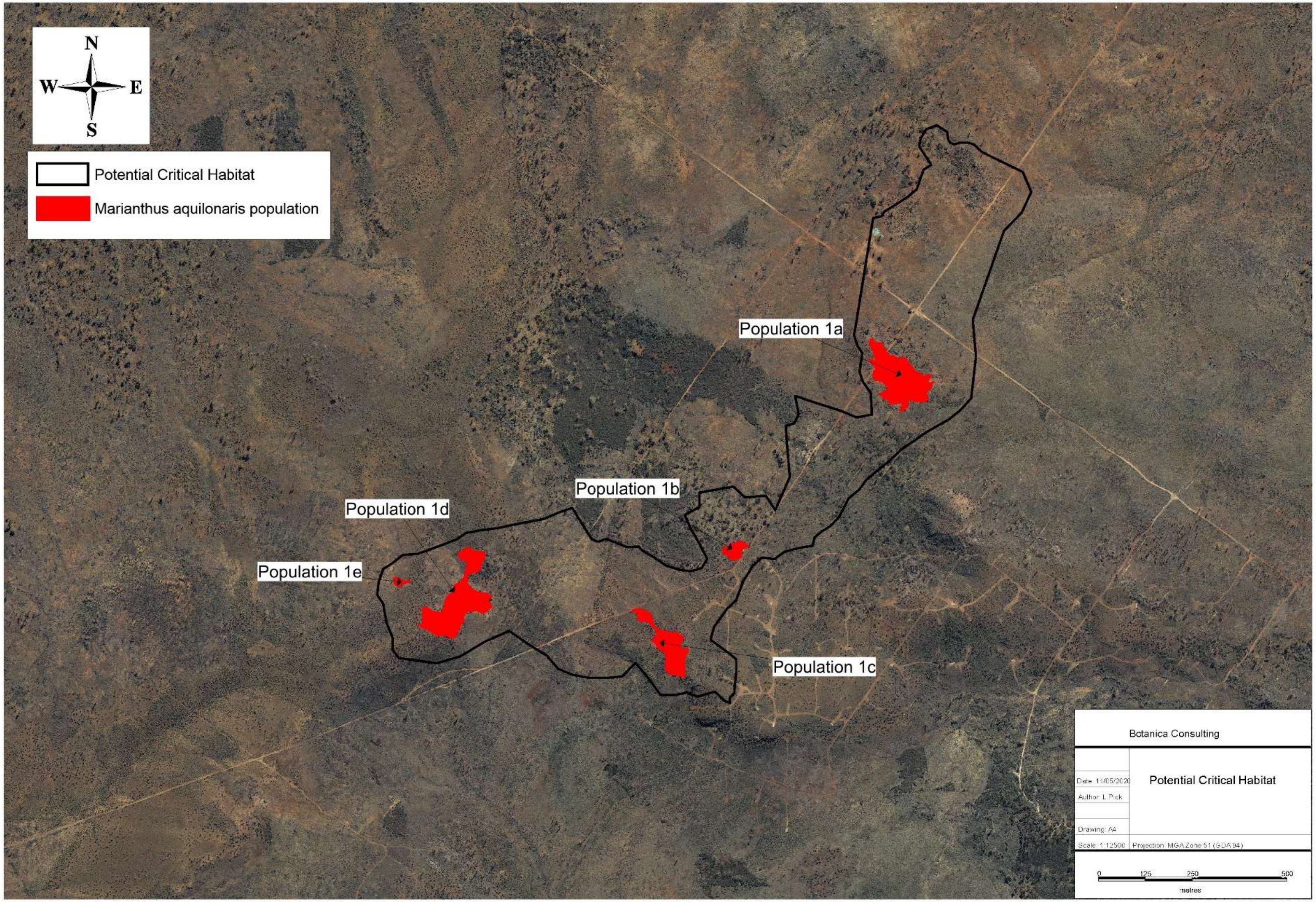



**Figure 13: Revised critical habitat map for *M. aquilonaris***

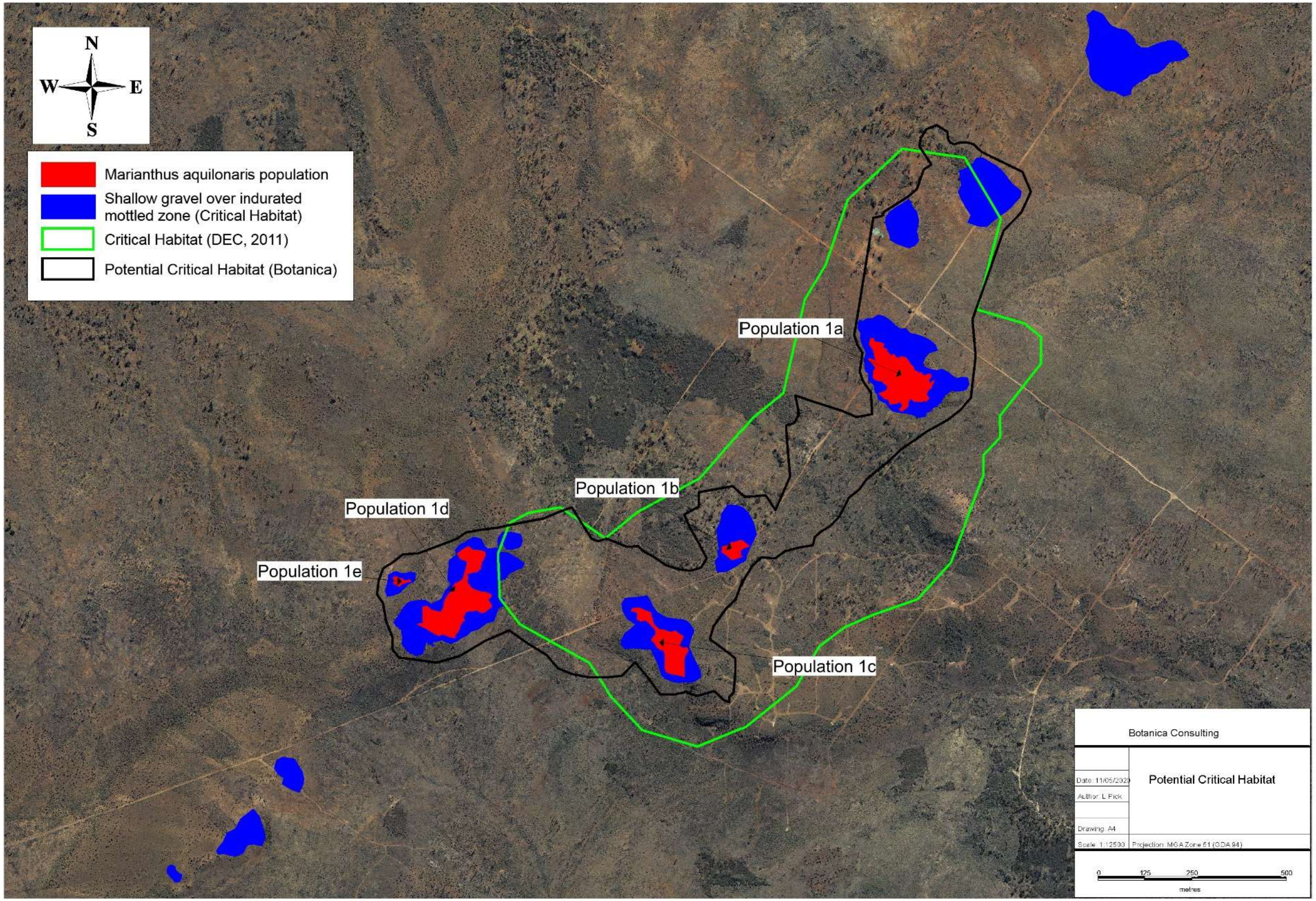



Figure 14: Critical habitat map for *M. aquilonaris* (DEC, 2011 and Botanica)

# 4 SUPPORTING STUDIES

## 4.1 Abiotic factors

Additional studies commissioned by Audalia have contributed new information about what attributes may be most significant in defining 'similar habitat' to those habitats in which *Marianthus aquilonaris* are known to occur.

### 4.1.1 Geomorphological attributes

Field assessments conducted in spring 2018 (Botanica, 2019a) examined a range of biotic and abiotic habitat characteristics within seventy 3 m x 3 m quadrats, distributed along 14 monitoring transects. *Marianthus aquilonaris* was present in 37 of the quadrats. The species was absent the remaining 33 quadrats. Ten landform / substrate attributes and seven biological characteristics were measured at each quadrat (**Table 4**). The key attributes of habitat favourable for *Marianthus aquilonaris* are summarised in **Table 5**. Ranges and means of values recorded in nearby areas where *Marianthus aquilonaris* were not recorded are presented for comparison.

**Table 5** shows that soil depth is generally shallower and there is more bedrock exposed in occupied areas compared to unoccupied areas. This is consistent with the soil observations and mapping of Lantzke (2019). None of the other landform monitoring parameters appear to have a consistent pattern between occupied and unoccupied areas.

**Table 4: Landform monitoring quadrat parameters**

| Landform Properties | Biological Properties |
|---|---|
| Morphological Type | No. *Marianthus aquilonaris* |
| Landform Type | Condition rating of *Marianthus aquilonaris* |
| Substrate type | Dominant species in each stratum |
| Elevation | % cover per each stratum |
| Aspect | Full sun/part sun/shade |
| Loose rocks or gravel: % and size | % cover of bare ground |
| % Bedrock | % cover of plant litter |
| Surface Soil depth | |
| Surface resistance (LFA classification) | |
| Local slope (degrees) | |

**Table 5: *Marianthus aquilonaris* – critical habitat parameters**

| Sub-population | *Marianthus aquilonaris* (Present/ Absent) | | Bedrock % | Surface Soil depth (mm) |
|---|---|---|---|---|
| 1a | P | Range | 0-20% | 5-100 |
| | | Mean | **8%** | **18** |
| | A | Range | 0-10% | 30-140 |
| | | Mean | **2%** | **85** |
| 1b | P | Range | 20-30% | Oct-30 |
| | | Mean | **25%** | **20** |
| | A | Range | 0-30% | 40-110 |

| Sub-population | *Marianthus aquilonaris* (Present/ Absent) | | Bedrock % | Surface Soil depth (mm) |
|---|---|---|---|---|
| | | Mean | **8%** | **67** |
| 1c | P | Range | 0-40% | 15-90 |
| | | Mean | **13%** | **58** |
| | A | Range | 0-60% | 20-110 |
| | | Mean | **11%** | **56** |
| 1d | P | Range | 0-80% | 10-100 |
| | | Mean | **36%** | **32** |
| | A | Range | 0-10% | 10-130 |
| | | Mean | **2%** | **85** |
| 1e | P | Range | 0-20% | 30-60 |
| | | Mean | **19%** | **42** |
| | A | Range | 0% | 40-110 |
| | | Mean | **0%** | **0** |

### 4.1.2 Hydrological and climatic factors

Hydrological and climatic characterisation conducted in 2018 and 2019 (GRM, 2019) reported a correlation between *Marianthus aquilonaris* communities and indicators of geological structures, such as vughs, iron stained fracture surfaces, quartz veining and bleached shearing (suggesting that the *Marianthus aquilonaris* plants potentially take advantage of the recharge process, capturing persistent soil moisture from within weathered and/or fractured bedrock), but overall did not identify any spatially-dependent hydrological or climatic attributes that explain *Marianthus aquilonaris* distribution in the Bremer Range.

The assessment also showed that the hydrological regime downslope of the areas of occupancy was different than upstream due to the areas of occupancy being at or near the catchment divide.

The assessment also showed that the areas of occupancy are all likely to be 40 m or so above a hypersaline groundwater system. Hence there is no groundwater dependency by *Marianthus aquilonaris*.

### 4.1.3 Substrate characteristics

In April and August 2019, soil mapping and testing was conducted to characterise soil chemical and physical attributes in areas where *Marianthus aquilonaris* is known to occur and in other areas where the species has not been observed (Western Horticultural Consulting, 2019). These studies have found that occurrence of *Marianthus aquilonaris* is strongly associated with the presence of soil units described as ‘shallow gravel over indurated mottled zone’. Of the 18 soil sampling locations established in locations where *Marianthus aquilonaris* is known to occur, all but one location had the ‘shallow gravel over indurated mottled zone’ soil type. *Marianthus aquilonaris* is more likely to occur in locations where limonite rock outcrops or is present at shallow depth. A Chi-squared analysis comparing 70 observations recorded in spring 2018 found that *Marianthus aquilonaris* plants were significantly more likely to occur in areas with limonite outcrop ($p < .01$). The soil survey also found that *Marianthus aquilonaris* does not grow on other shallow soils that contain subsoil layers of lateritic duricrust (ferricrete) or decomposing mafic rocks. Other attributes that are typical of areas in which *Marianthus* *aquilonaris* was observed included low to near-neutral soil pH, low soil salinity, large percentage of bare ground

## 4.2 Biotic factors

### 4.2.1 Genetic studies

Genetic studies were carried out by the Department of Biodiversity Conservation and Attractions (DBCA) in 2019, using leaf samples recovered from 30 plants at each of five subpopulations of *Marianthus aquilonaris* (**Figure 15**). Sub-population '1f' was not sampled, as no plants were found at that location at the time of sample collection. More detailed genetic analysis was conducted using 350 leaf samples from sub-population '1b' (representing all individuals present in sub-population 1b).

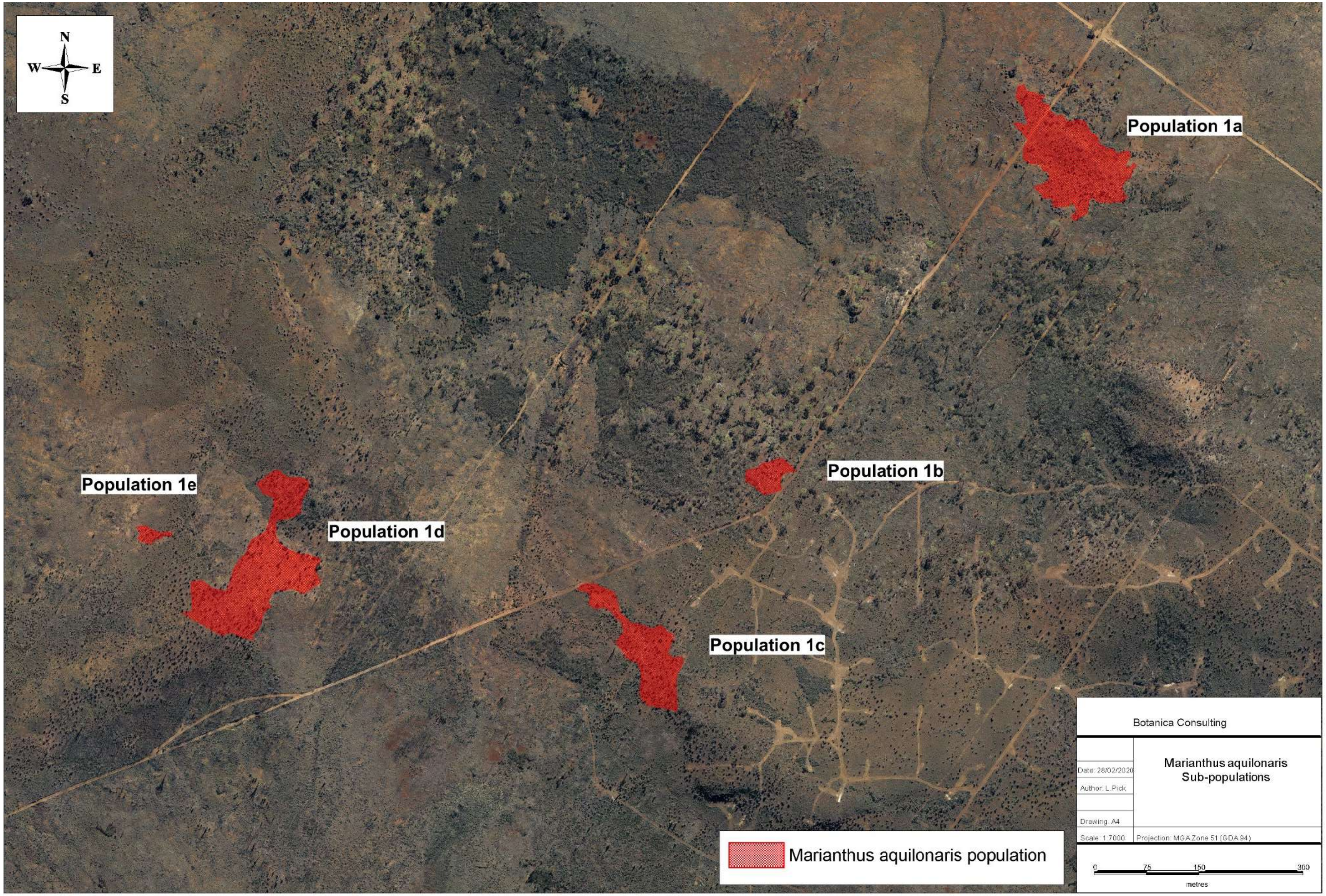



Figure 15: Sub-populations of ***Marianthus aquilonaris***

The genetic research by DBCA made a number of key findings:

- All sub-populations of *Marianthus aquilonaris* showed moderate levels of genetic diversity.
- The level of differentiation among the sub-populations is high given the small geographical distance between them (typically less than 200 m), suggesting that there is limited genetic connectivity.
- Population differentiation analysis showed sub-population 1a to have the greatest differentiation from all other sub-populations, consistent with the greater isolation of this sub-population, approximately 600 m from the nearest sub-population 1b.
- Low levels of differentiation were found amongst sub-populations 1c, 1d and 1e, as expected due to their closer geographic proximity (**Figure 16**).
- Analysis of seed from plants from sub-population 1b showed that pollen dispersal is occurring over distances of approximately 42m.
- Pollen dispersal between sub-population 1b and other populations is low: only 4% of seedlings produced from sub-population 1b were fathered from sub-populations 1c, 1d and 1a, which ranged in distance from 150 m to approximately 465 m away from sub-population 1b.
- The majority of seedlings (96%), were fathered by plants within the sub-population.
- There is a high rate (49%) of self-pollination (where mother plants are also the fathers of the seedlings produced).
- Seed germination was high and while variable among mothers, generally approached 100%. However, seeding survival was low when germinated seeds were planted into a pre-mix soil. This result is consistent with earlier germination trials conducted by Botanica in 2015.

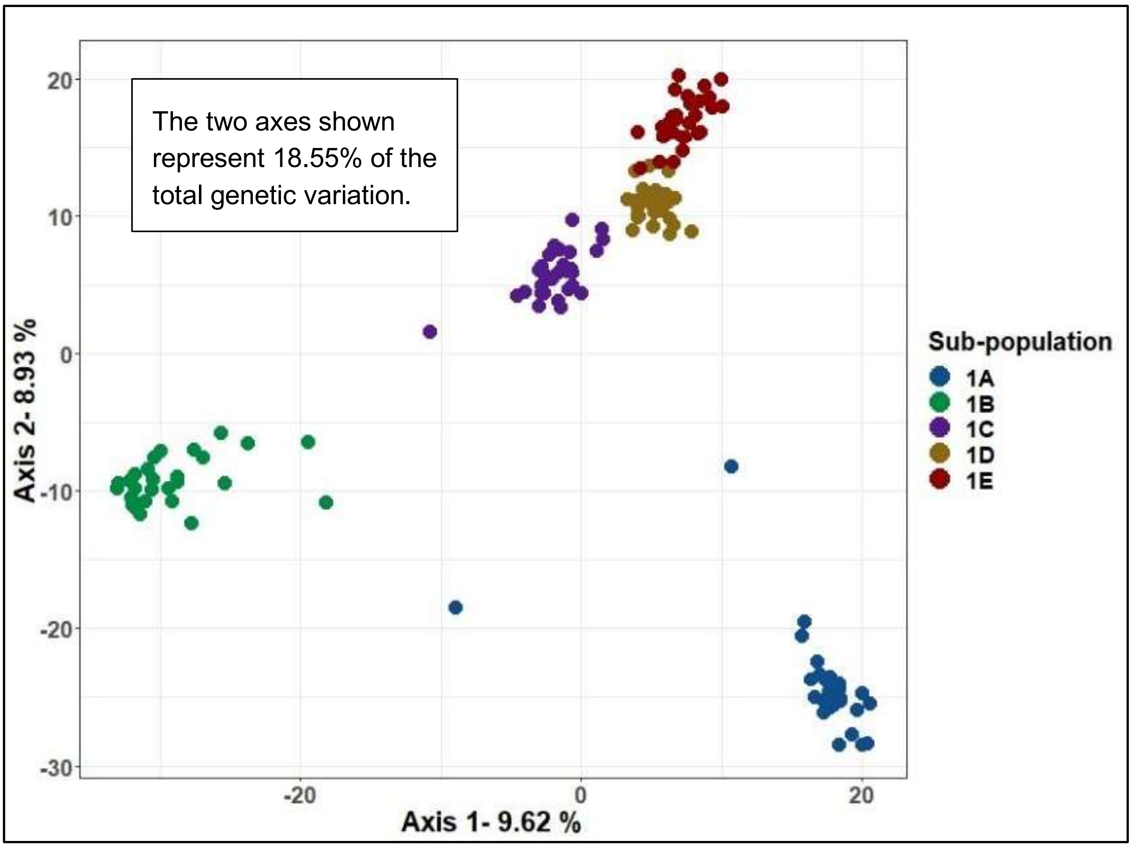



**Figure 16: Principal components analysis of genetic differentiation based on 4017 single nucleotide polymorphisms (DBCA, 2019).**

### 4.2.2 Pollination studies

Surveys of insect visitors to *Marianthus aquilonaris* (including potential pollinators) were carried out in early November 2019. Conditions at the time of the survey were dry and fewer than 50 of the estimated 5,712 *Marianthus aquilonaris* plants in the general project locality were flowering at the time of the survey. Flowering of other native flora in the district was also limited (Prendergast, 2019).

Notwithstanding the sub-optimal seasonal conditions, 15 insect visitors to *Marianthus aquilonaris* were observed during the November 2019 survey. Of these, 11 were native bees belonging to a number of genera. Numerous insect taxa were collected passively in bee bowls installed next to *Marianthus aquilonaris* plants in flower. Insects collected in the bee bowls included native bees that are effective pollinators (Michener, 2007), including the large, mobile *Amegilla* (Houston, 2018). *Amegilla* has been observed to visit another *Marianthus* species (*Marianthus bicolor*) (K. Prendergast, in prep.). However, *Amegilla* were not amongst the bees observed foraging on *Marianthus aquilonaris* during the surveys in early November 2019. Further observations would be recommended to establish which – if any – of the insects collected in bee bowls act as pollinators of *Marianthus aquilonaris*.

Abundant seed set was noted during the November 2019 surveys, evidenced by many seed pods on the plants. This suggest that pollination is occurring, but based on the genetic data, there is little pollen exchange between plants of different sub-populations (Hopley & Byrne 2018a; Hopley & Byrne, 2019b). This suggests that either a) the pollinators of this plant have low vagility and/or small flight ranges, and/or generally forage on flowers in the same plant or between adjacent plants; or b) seed set is mostly a result of selfing and potentially wind pollination resulting in only local pollen transfer (Prendergast, 2019).

If insect pollination is occurring, it may be occurring over short distances. Flight distance of bees is correlated to body size (Gathmann & Tscharntke, 2002; Greenleaf, Williams, Winfree, & Kremen, 2007). Bees are 'central foragers' (Westrich, 1996) and nesting sites and foraging resources must be within the flight range of the species. As *Marianthus aquilonaris* subpopulations are separated by >500 m, it may be that the native bees are rarely flying between subpopulations, thereby explaining the limited pollen exchange (Prendergast, 2019).

## 4.3 Population Viability

If potential direct or indirect impacts to *M. aquilonaris* are proposed, a Population Viability Analysis (PVA) was required by the ESD to model the potential impacts on the long-term viability of *M. aquilonaris* populations. The computer modelling program, VORTEX was chosen to run the analysis. VORTEX is an individual-based simulation model for PVA and is the most widely deployed PVA platform available (Brook *et al.*, 2000). VORTEX models population dynamics as discrete, sequential events that occur according to defined probabilities (Miller & Lacy, 2005). The model is repeated to reveal the distribution of fates that the population might experience under a given set of input conditions (Miller & Lacy, 2005).

Initial analysis was conducted; however, it was evident that PVA software was not suitable to assess *M. aquilonaris* as long-term demographic/census monitoring data is not currently available to inform the attributes of the discrete sequential events, reducing the validity of the modelling predictions. The demographic data acquisition commenced by the Project will be central to completing PVA at a later date, if required. The modelling also did not have the capacity to take into account the re-sprouting capabilities of *M. aquilonaris.* Finally, the PVA is utilised to model different scenarios, with the intent to model the difference between direct impacts to different sub-populations vs no direct impacts and different translocation scenarios, however as no direct impacts from the Project are proposed, there were no scenarios to assess.

Genetic diversity studies have shown that all sub-populations have moderate levels of genetic diversity, with sub-population 1d showing the largest range of genetic diversity, followed by populations 1c and 1e. Populations 1a and 1b are less representative of the gene diversity present than other sub-populations; however, they do contain more than half of the private alleles present. Analysis of the contribution of each sub-population to the total maximal gene diversity found subpopulation 1d to harbor a large proportion of the total gene diversity present across all the subpopulations, followed by sub-population 1c. The impacts on total genetic diversity caused by removing each sub-population showed variable but small outcomes. The gene diversity is slightly increased if sub-populations 1a and 1b are removed, this is likely a reflection of the lower heterozygosity found at these sites. Gene diversity is decreased the most when sub-population 1d is removed (DBCA, 2019).

All sub-populations were found to have negative inbreeding coefficients, suggesting that mating is not occurring between related or genetically similar individuals (DBCA, 2019). Results of pollination studies demonstrate high levels of self-pollination, effective pollen dispersal among plants across the sub-population, and limited pollen immigration between subpopulations (DBCA, 2019).

Given the current absence of inbreeding depression, limited effect on the genetic diversity when removing different sub-populations, limited pollen transfer between populations, no direct impacts are proposed to any of the sub-populations and potential indirect impacts related to dust emissions are anticipated to only occur within sub-population 1b, it is unlikely that mining will reduce the viability of populations.

# 5 SUMMARY

A range of technical studies have been completed by Audalia Resources Limited to seek to understand the occurrence, ecological requirements and population characteristics of *Marianthus aquilonaris* sub-populations in the Bremer Range. The required studies are documented in the Environmental Scoping Document for the Medcalf Project. Studies completed to date indicate that the species' distribution:

- Is positively associated with locations where limonite bedrock is present at very shallow depth.
- Is not highly correlated with chemical characteristics of soil, although low pH and low salinity conditions are generally present where the species has been observed.
- Is not directly affected by altitude or aspect but area of occupancy only occurs on low to mid slopes on northern face of the range.
- Is not conspicuously linked to climatic or hydrological factors, although the occurrence of the plant in areas of very limited soil depth suggests that the species may have a competitive advantage where water availability is limited.

The information from the studies has been considered to enable a reconsideration of critical habitat for the species. The definition from DEC 2011 has been retained.

> *…the area of occupancy of* [known] *populations, areas of similar habitat surrounding and linking populations (these providing potential habitat for population expansion and for pollinators), additional occurrences of similar habitat that may contain undiscovered populations of the species or be suitable for future translocations, and the local catchment for the surface and/or groundwater that maintains the habitat of the species* (DEC, 2011).

The area has been re-mapped based on the above studies to provide a proposed new boundary for critical habitat. The proposed critical habitat boundary is to be used in environmental impact assessment for the Medcalf Project. The differences (and reasons in brackets) between the DEC 2011 mapped critical habitat and proposed critical habitat are due to:

- Inclusion of sub-populations 1d and 1e which were not identified by DEC in 2011 (required update based on newly identified sub-populations);
- Inclusion of areas within direct lines of areas of occupancy (for protection of potential pollinator pathways);
- Inclusion of areas of shallow gravel over indurated mottled zones within close proximity to areas of occupancy (capable of sustaining cross-pollination via linkages to existing sub-populations should plants be established there);
- Refined northern boundary to follow the same vegetation type boundary of the *M aquilonaris* populations (vegetation types often have relationships with fauna, soil type, topography and drainage that make them a logical linkage – therefore direct paths between subpopulations are included where they follow the same vegetation type);
- Refined the southern boundary to exclude the hillcrest areas and the southern faces of the range which were included in the 2011 area mapped by DEC as critical habitat (population extent, upper catchment areas, associated soil types/ landforms and topography has been further defined). Populations, associated mottle zone and upper catchment areas that would drain through the populations and associated mottle zone do not occur on the hill crest/ southern slopes.

In addition, areas of 'optimal habitat' and 'sub-optimal habitat' have been defined to allow for impact assessment.

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**Attachment 1: Images of each *Marianthus aquilonaris* sub-population**

Sub-population 1a

Sub-population 1b

Sub-population 1c

Sub-population 1d

Sub-population 1e

Sub-population 1f

**Attachment 2: *Marianthus aquilonaris* Landform Monitoring: Spring 2018, Memorandum prepared for Audalia Resources Limited by Botanica Consulting, February 2019 Botanica (2019a)**

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**MARIANTHUS AQUILONARIS LANDFORM MONITORING: SPRING 2018**

## 1 Objectives

The objective of the study is to characterize the ecological/edaphic factors of the Bremer Range (*M. aquilonaris* habitat) and classify the habitats of the existing sub-populations. Studies will assist in determining suitable habitat and identifying/ mapping potential direct and indirect impacts on *M. aquilonaris* sub-populations and habitat.

## 2 Methodology

The location of the landform monitoring transect were determined based on:

- Presence of suitable habitat/vegetation for *M. aquilonaris* identified during flora and vegetation surveys (Regrowth mid open mallee woodland *Eucalyptus livida* over mid open shrubland of *Hakea pendens* and open low shrubland of *Goodia medicaginea* on hillslope);
- Presence/ absence of *M. aquilonaris* to ensure at least one transect was established within occupied area of each sub-population[1] and at least one transect was established within un-occupied area for each sub-population to allow for comparison of occupied and un-occupied habitat for each sub-population; and
- Elevation-to ensure at least one transect was located in the upper slope and lower slope of each *M. aquilonaris* sub-population[1];

A total of fourteen monitoring transects (100m length) were established extending down the length of the hillslope:

- six transects outside of the *M. aquilonaris* populations (NMT1-6)
- eight transects within the *M. aquilonaris* populations (Pop 1a-Pop 1e)

At 25m intervals along each landform transect, a 3m X 3m quadrat was established. The parameters measured within each quadrat are listed in Table 1. Location maps of the transects are provided in Figure 1. The location of each transect was recorded using a handheld GPS (Transect coordinates provided in Appendix 1) and the ends of the transect were marked with metal fence droppers. Raw data for the Spring 2018 monitoring is provided in Appendix 2. A photographic record was taken for each transect (Appendix 3). A summary of the range and mean values for each sub-population for each parameter measured (landform and biological properties) is provided in Appendix 4.

Descriptive variables related to landform properties listed in Table 1 (morphological type, landform type, substrate type and loose rocks or gravel size) were assessed using standard techniques described by McDonald *et al*. (1990).

Elevation was measured using hand held GPS, surface soil depth was measured using a ruler (mm) and the local slope was measured using a level. Percentage cover of each stratum was classified in accordance with the NVIS foliage cover categories (DotEE, 2018). Percentage cover of bedrock and bare ground/ plant litter were estimated based on coverage within the 3m X 3m quadrat.

[1] Excluding Population 1f which comprises of a single plant.

**Table 1: Landform Monitoring Quadrat Parameters**

| |
|---|
| **Landform Properties** |
| Morphological Type |
| Landform Type |
| Substrate type |
| Elevation |
| Aspect |
| Loose rocks or gravel: % and size |
| % Bedrock |
| Surface Soil depth |
| Surface resistance (LFA classification) |
| Local slope (degrees) |
| **Biological Properties** |
| No. *Marianthus aquilonaris* |
| Condition rating of *M. aquilonaris* |
| Dominant species per each stratum |
| % cover per each stratum |
| Full sun/part sun/shade |
| % cover of bare ground |
| % cover of plant litter |

Principal Components Analysis (PCA) and factor analysis was conducted using the statistical program PAST3 were conducted to determine the environmental variables which accounted for most of the variance in the set of observed variables (listed in Table 1). The analysis was conducted for all quadrats (total of 70 quadrats; 37 Marianthus absent and 33 Marianthus present). Patterns of dissimilarity among environmental variables (those identified in PCA to account for most the variance) between Marianthus present and Marianthus absent sites were assessed using non-metric multi-dimensional scaling (nMDS). The significance of dissimilarities in the composition of those variables between Marianthus present and Marianthus absent sites was tested using ANOSIM.

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**Figure 1: Location of landform monitoring transects**

## 3 Results

Principal Components Analysis and factor analysis results show that the environmental variables which account for the greatest variability between the Marianthus present and Marianthus absent sites were surface soil depth, percentage cover of bare ground, plant litter and exposed bedrock (Table 2, Figure 2 & 3). The Marianthus present quadrats had shallower surface soils (ranging from 18-58mm), higher percentage bare ground (ranging from 53-72%), higher percentage plant litter (ranging from 21-41%) and higher percentage bedrock (8-36%) compared to the Marianthus absent quadrats.

**Table 2: Dissimilarity and mean values of Marianthus present and Marianthus absent sites for each variable**

| Environmental Variable | Av. dissimilarity | Contribution % | Mean (Marianthus Present) | Mean (Marianthus Absent) |
|---|---|---|---|---|
| Surface Soil depth (mm) | 3228 | 46.75 | 40 | 70.6 |
| % cover of bare ground | 1322 | 19.15 | 63.2 | 57.8 |
| % cover of plant litter | 812.4 | 11.76 | 41 | 29 |
| Bedrock % | 725.1 | 10.5 | 17.5 | 5.28 |
| % Loose rocks/ gravel | 463.4 | 6.71 | 84.7 | 82.8 |
| Elevation (m) | 295.5 | 4.279 | 399 | 403 |
| Local slope (degrees) | 26.08 | 0.3776 | 5.7 | 6.28 |
| Aspect | 7.961 | 0.1153 | 3.38 | 2.69 |
| % Cover-upper stratum | 7.34 | 0.1063 | 2.44 | 2.36 |
| % Cover-lower stratum | 5.418 | 0.07846 | 2.85 | 3.31 |
| % Cover-mid stratum | 4.041 | 0.05851 | 3.29 | 2.92 |
| Morphological Type | 2.121 | 0.03071 | 2.85 | 3.19 |
| Rocky Type | 1.944 | 0.02816 | 1.12 | 1.78 |
| Size Loose rocks/ gravel | 1.717 | 0.02487 | 2 | 2.19 |
| Surface resistance (LFA classification) | 1.212 | 0.01756 | 3.56 | 3.22 |
| Soil Type | 0.7549 | 0.01093 | 2.62 | 2.67 |
| Soil Colour | 0.2647 | 0.003833 | 1.76 | 1.94 |
| Landform Type | 0.0817 | 0.001183 | 1.03 | 1.06 |

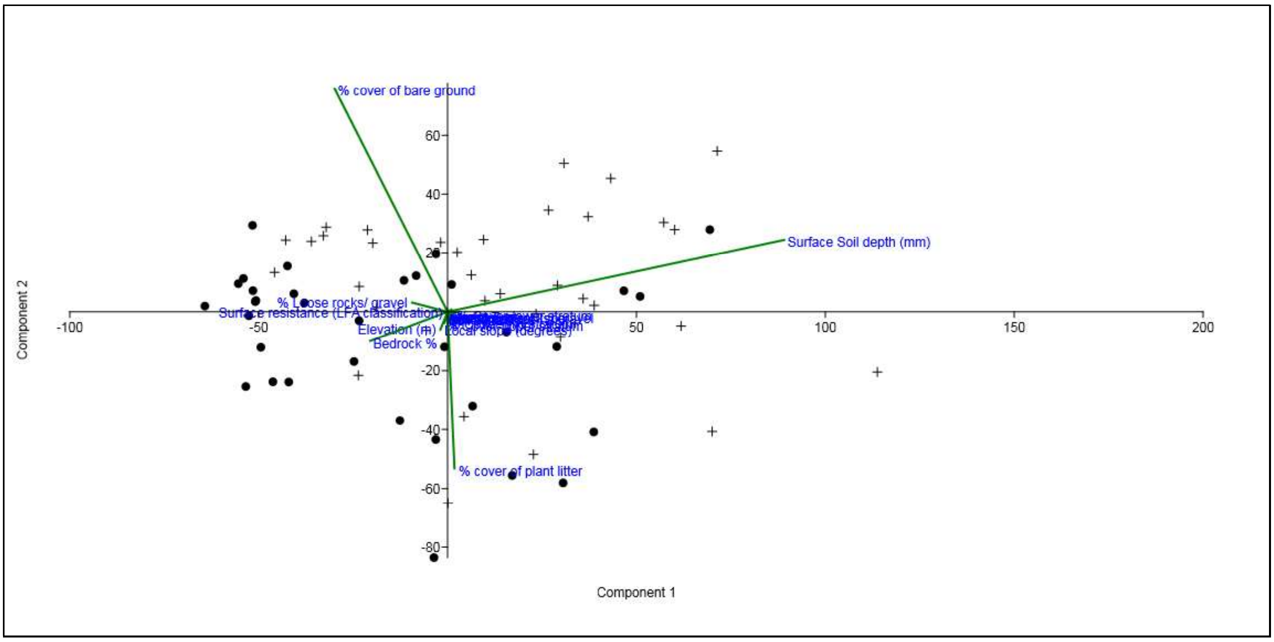



**Figure 2: Principal Component Analysis-Scatterplot**

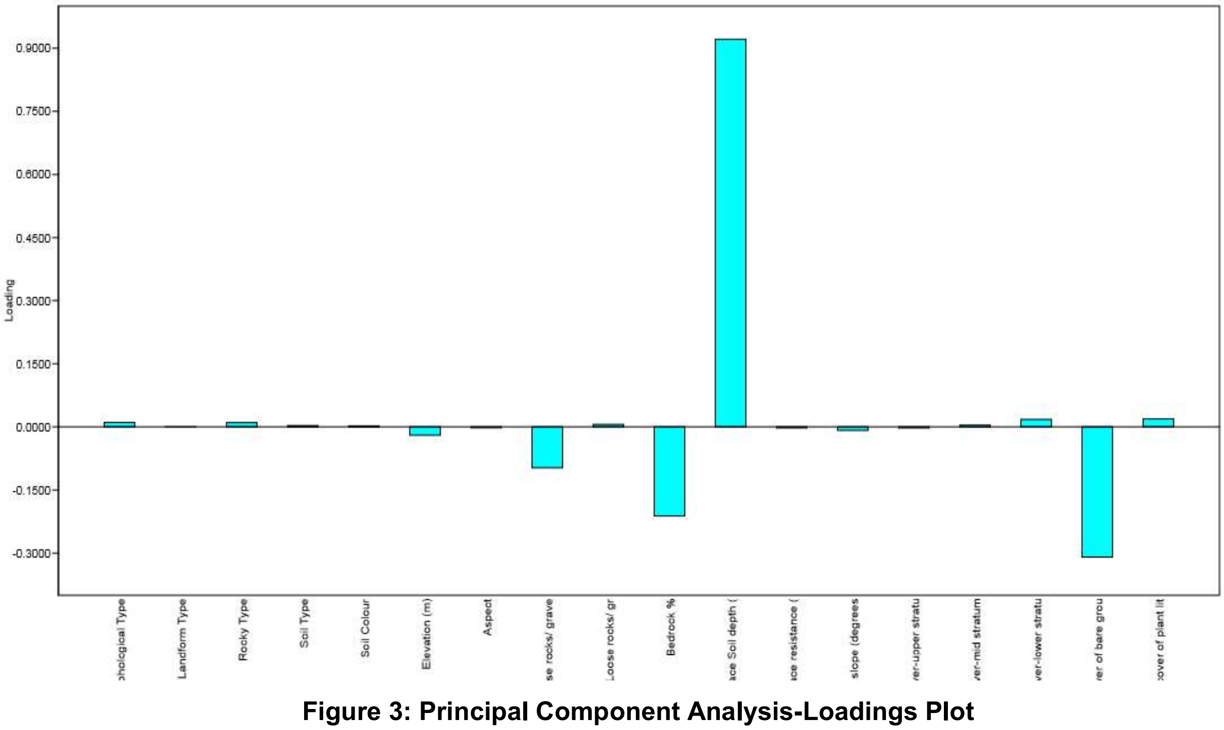
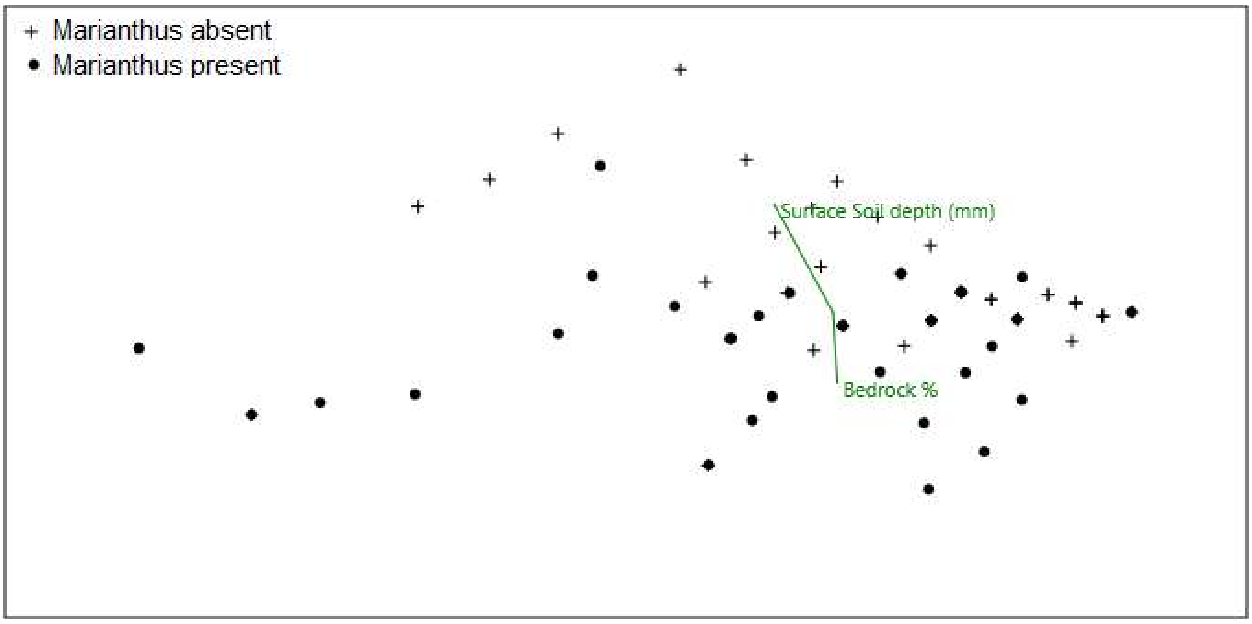



**Figure 3: Principal Component Analysis-Loadings Plot**

The two-dimensional nMDS plots (Figure 3 & 4) shows the Marianthus absent sites generally occur on deeper soils and had lower plant litter. The stress of the ordination for the biological variables (% bare ground and % plant litter) was low 0.02 and moderate for the landform (0.11). The ANOSIM results showed the differentiation in the environmental variables between the Marianthus absent and Marianthus present sites were low (R=0.13; P=0.0003).



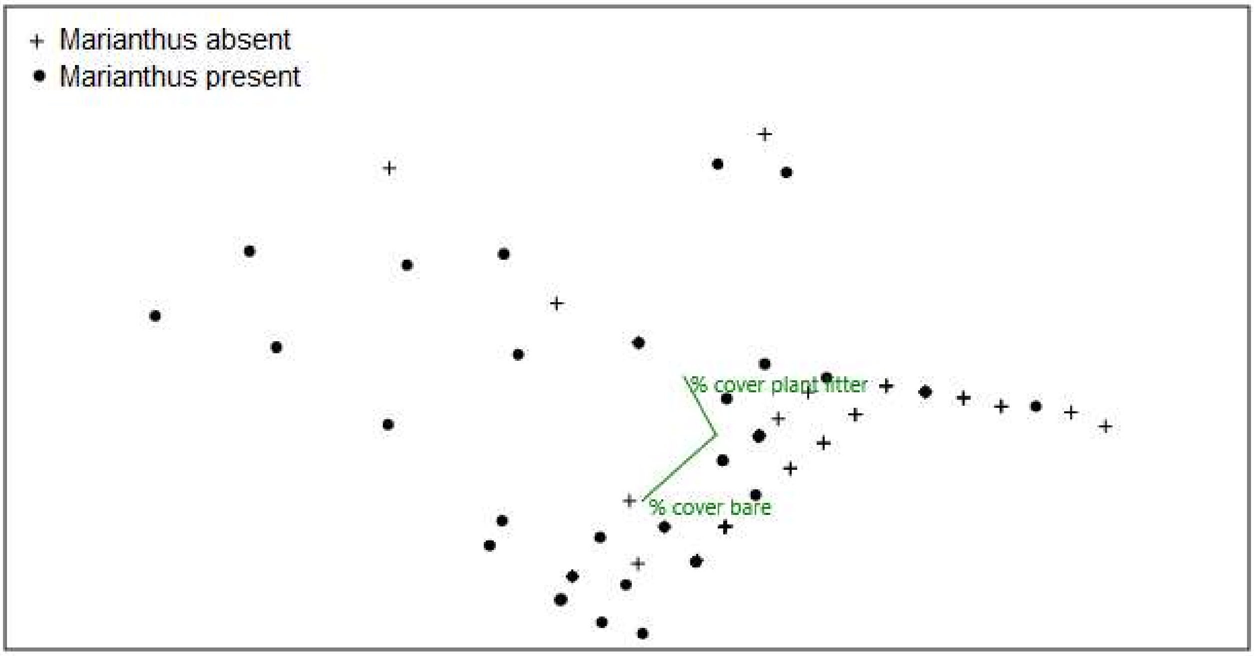




**Figure 4: Non-metric multi-dimensional scaling (nMDS) ordination of the main environmental attributes of the Marianthus absent and Marianthus present quadrats.**

## 4 Discussion

Whilst the differentiation in environmental variables between the Marianthus absent and Marianthus present sites were low, depth of soil, percentage of bedrock, plant litter and bare ground were found to be the main factors contributing to where *Marianthus aquilonaris* occurs. The sites where *M. aquilonaris* was present comprised of low soil surface depth (≤58mm), high percentage plant litter (≥20%), bare ground (≥53%) and exposed bedrock (≥8%). Difference in morphology' landform and elevation had little influence on the habitat preferences for *M. aquilonaris.*

**Appendix 1: Landform Monitoring Transects GPS Coordinates**

| Population | Transect | Zone | Easting | Northing | Elevation (m) |
|---|---|---|---|---|---|
| Population 1a | Pop 1a-T1 | 51 H | [redacted] | | 399 m |
| | Pop 1a-T2 | 51 H | | | 376 m |
| | NM-T1 | 51 H | | | 388 m |
| | NM-T2 | 51 H | | | 419 m |
| Population 1b | Pop 1b-T1 | 51 H | | | 404 m |
| | NM-T3 | 51 H | | | 430 m |
| Population 1c | Pop 1c-T1 | 51 H | | | 417 m |
| | Pop 1c-T2 | 51 H | | | 405 m |
| | NM-T4 | 51 H | | | 405 m |
| Population 1d | Pop1d-T1 | 51 H | | | 402 m |
| | Pop1d-T2 | 51 H | | | 405 m |
| | NM-T5 | 51 H | | | 409 m |
| Population 1e | Pop1e-T1 | 51 H | | | 402 m |
| | NM-T6 | 51 H | | | 405 m |

## Appendix 2: Landform Monitoring Data (Spring 2018)

| **Transect ID:** | Pop 1a - T1 | **Transect WP:** | 2 | **Transect Photo (Start/End):** | 226S/ 239E |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | 2 | 3 | 4 | 5 | 6 |
| **Quadrat Photo:** | 225 | 227 | 228 | 229 | 238 |
| **Morphological Type:** | crest | upper slope | upper slope | mid slope | mid slope |
| **Landform Type:** | hill slope | hill slope | hill slope | hill slope | hill slope |
| **Substrate type (rock):** | Limonite | Limonite | Limonite | Limonite | Limonite |
| **Substrate type (soil):** | clay-sand brown | clay-sand brown | clay-sand brown | clay-sand brown | clay-sand brown |
| **Elevation:** | 399 m | 398 m | 390 m | 386 m | 384 m |
| **Aspect:** | W | W | W | W | W |
| **Loose rocks or gravel: % and size:** | >90% Cobbles | >90% Cobbles | >90% Coarse Gravel | >90% Coarse Gravel | >90% Coarse Gravel |
| **Bedrock %:** | <10% | <10% | <10% | 20% | 5% |
| **Surface Soil depth (mm):** | 5mm | 5mm | 5mm | 5mm | 5mm |
| **Surface resistance (LFA classification):** | 2 | 3 | 2 | 4 | 4 |
| **Local slope (degrees):** | 3.4 | 5.3 | 6.4 | 9.4 | 4.4 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | 2 | 4 | 1 | 7 | 7 |
| **Condition rating of *M. aquilonaris:*** | good | good | good | good | good |
| **Dominant species-upper stratum:** | *Eucalyptus livida* | *Allocasuarina* sp. sterile | *Eucalyptus livida* | *Eucalyptus livida* | *Eucalyptus livida* |
| **% Cover-upper stratum** | 0-5 | 0-1 | 10-30 | 10-30 | 5-10 |
| **Dominant species-mid stratum:** | *Dodonaea viscosa* | *Marianthus aquilonaris* | *Dodonaea viscosa* | *Marianthus aquilonaris* | *Marianthus aquilonaris* |
| **% Cover-mid stratum** | 0-5 | 0-5 | 10-30 | 10-30 | 5-10 |
| **Dominant species-lower stratum:** | *Conospermum* sp. sterile | *Astroloma serratifolium* | *Lepidosperma sanguinolentum* | *Westringia cephalantha* | N/A |
| **% Cover-lower stratum** | 0-1 | 5-10 | 5-10 | 5-10 | 0 |
| **Full sun/part sun/shade:** | Full Sun | Full Sun | Full Sun | Full Sun | Full Sun |
| **% cover of bare ground** | 80% | 70% | 70% | 50% | 90% |
| **% cover of plant litter** | <10% | <10% | <10% | 30% | 30% |

| Transect ID: | Pop 1a - T2 | Transect WP: | 10 S/16 E | Transect Photo (Start/End): | 264 S / |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | 10 | 11 | 13 | 14 | 15 |
| **Quadrat Photo:** | 263 | 266 | 274 | 276 | 278 |
| **Morphological Type:** | Mid slope | Mid slope | Low slope | Low slope | Valley |
| **Landform Type:** | Hill slope | Hill slope | Hill slope | Hill slope | Valley |
| **Substrate type (rock):** | Limonite | Limonite | No bedrock | No bedrock | No bedrock |
| **Substrate type (soil):** | clay-loam brown | clay-loam brown | clay-loam brown | clay-loam brown | clay-loam brown |
| **Elevation:** | 376 m | 378 m | 375 m | 375 m | 371 m |
| **Aspect:** | W | W | W | W | SW |
| **Loose rocks or gravel: % and size:** | >90% Coarse gravel | >90% Coarse gravel | 20-50% Medium gravel | >90% Cobbles | >90% Fine gravel |
| **Bedrock:** | <10% | 0% | 0% | 0% | 0% |
| **Surface Soil depth (mm):** | 10mm | 10mm | 100mm | 140mm | 60mm |
| **Surface resistance (LFA classification):** | 3 | 4 | 4 | 4 | 3 |
| **Local slope (degrees):** | 4.8 | 4.5 | 4.1 | 4.6 | 2 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | 7 | 3 | 4 | 0 | 0 |
| **Condition rating of *M. aquilonaris:*** | good | good | good | N/A | N/A |
| **Dominant species-upper stratum:** | *Eucalyptus livida* | Nil | Nil | Nil | *Eucalyptus* sp. sterile |
| **% Cover-upper stratum** | 10-30 | 0 | 0 | 0 | 0-5 |
| **Dominant species-mid stratum:** | *Marianthus aquilonaris* | *Marianthus aquilonaris* | *Marianthus aquilonaris* | *Santalum acuminatum* | *Davesia argillacea/ Westringia cephalantha* |
| **% Cover-mid stratum** | 30-70 | 0-5 | 30-70 | 0-5 | 5-10 |
| **Dominant species-lower stratum:** | Nil | Nil | Nil | *Wilsonia humilis* | *Wilsonia humilis* |
| **% Cover-lower stratum** | 0 | 0 | 0 | 10-30 | 10-30 |
| **Full sun/part sun/shade:** | Full sun | Full sun | Full sun | Full sun | Full sun |
| **% cover of bare ground** | 60% | 95% | 60% | 85% | 70% |
| **% cover of plant litter** | 50% | <5% | 35% | <5% | 10% |

| Transect ID: | NM-T1 | Transect WP: | 17 S/ 22 E | Transect Photo (Start/End): | 281/287 |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | 17 | 18 | 19 | 20 | 21 |
| **Quadrat Photo:** | 280 | 282 | 283 | 285 | 286 |
| **Morphological Type:** | Upper slope | Upper slope | Mid slope | Mid slope | Mid slope |
| **Landform Type:** | Hill slope | Hill slope | Hill slope | Hill slope | Hill slope |
| **Substrate type (rock):** | No bedrock | Limonite | Limonite | No bedrock | No bedrock |
| **Substrate type (soil):** | clay-loam red-brown | clay-loam red-brown | clay-loam red-brown | clay-loam red-brown | clay-loam red-brown |
| **Elevation:** | 388 m | 387 m | 386 m | 383 m | 383 m |
| **Aspect:** | NE | NE | NW | W | W |
| **Loose rocks or gravel: % and size:** | >90% Coarse gravel | >90% Coarse gravel | 70-90% Cobbles | 20% Fine gravel | 20-50% Fine gravel |
| **Bedrock:** | 0% | 5% | 10% | 0% | 0% |
| **Surface Soil depth (mm):** | 90mm | 66mm | 30mm | 150mm | 60mm |
| **Surface resistance (LFA classification):** | 3 | 4 | 4 | 2 | 2 |
| **Local slope (degrees):** | 0.2 | 8 | 4 | 4.4 | 7 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | Nil | Nil | Nil | Nil | Nil |
| **Condition rating of *M. aquilonaris:*** | Nil | Nil | Nil | Nil | Nil |
| **Dominant species-upper stratum:** | *Eucalyptus ?eremophila* | *Eucalyptus livida* | *Eucalyptus livida* | *Eucalyptus salmonophloia* | *Eucalyptus livida* |
| **% Cover-upper stratum** | 10-30 | 30-70 | 10-30 | 5-10 | 0-5 |
| **Dominant species-mid stratum:** | *Dodonaea stenozyga* | *Trymalium myrtillus* subsp. *myrtillus* | *Nil* | *Santalum acuminatum* | *Melaleuca pauperiflora* |
| **% Cover-mid stratum** | 5-10 | 5-10 | | 10-30 | 10-30 |
| **Dominant species-lower stratum:** | *Acacia erinaceae* | *Acacia erinaceae* | *Westringia cephalantha* | *Dodonaea stenozyga* | *Dodonaea stenozyga* |
| **% Cover-lower stratum** | 0-1 | 0-5 | 0-5 | 70-100 | 0-5 |
| **Full sun/part sun/shade:** | Full sun | Full sun | Full sun | Full sun | Full sun |
| **% cover of bare ground** | 80% | 60% | 90% | 20% | 70% |
| **% cover of plant litter** | 10% | 25% | <10% | 20% | 20% |

| **Transect ID:** | Pop 1b-T1 | **Transect WP:** | 29 S/34E | **Transect Photo (Start/End):** | 298 S / 308 E |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | 29 | 30 | 31 | 32 | 33 |
| **Quadrat Photo:** | 297 | 299 | 300 | 306 | 307 |
| **Morphological Type:** | Mid slope | Mid slope | Mid slope | Mid slope | Mid slope |
| **Landform Type:** | Hill slope | Hill slope | Hill slope | Hill slope | Hill slope |
| **Substrate type (rock):** | Limonite | Limonite | Limonite | Limonite | Limonite |
| **Substrate type (soil):** | Sandy clay-loam red-brown | Sandy clay-loam red-brown | Sandy clay-loam red-brown | Sandy clay-loam red-brown | Sandy clay-loam red-brown |
| **Elevation:** | 404 m | 404 m | 401 m | 400 m | 397 m |
| **Aspect:** | NW | NW | NW | N | NE |
| **Loose rocks or gravel: % and size:** | >90% Coarse gravel | >90% Coarse gravel | >90% Cobbles | 70-90% Cobbles | 70-90% Coarse gravel |
| **Bedrock %** | 0% | <5% | 20% | 30% | 0% |
| **Surface Soil depth (mm):** | 110mm | 60mm | 10mm | 30mm | 40mm |
| **Surface resistance (LFA classification):** | 4 | 4 | 3 | 4 | 4 |
| **Local slope (degrees):** | 5 | 6.6 | 6.7 | 10.1 | 14.6 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | Nil | Nil | 8 | 9 | Nil |
| **Condition rating of *M. aquilonaris:*** | Nil | Nil | Good | Good | Nil |
| **Dominant species-upper stratum:** | *Eucalyptus livida* | *Eucalyptus livida* | *Eucalyptus livida* | Nil | Nil |
| **% Cover-upper stratum** | 10-30 | 5-10 | 0-5 | 0 | 0 |
| **Dominant species-mid stratum:** | *Westringia cephalantha* | *Davesia* sp. (sterile) | *Mananthus aquilonaris* | *Mananthus aquilonaris* | *Alyxia buxifolia* |
| **% Cover-mid stratum** | 10-30 | 30-70 | 5-10 | 5-10 | 0-5 |
| **Dominant species-lower stratum:** | *Lepidosperma sanguinolentum* | *Gahnia ancistrophylla* | Nil | Nil | Nil |
| **% Cover-lower stratum** | 30-70 | 70-100 | 0 | 0 | 0 |
| **Full sun/part sun/shade:** | Part shade | Full sun | Part Shade | Full sun | Full sun |
| **% cover of bare ground** | 30% | 20% | 85% | 50% | 5% |
| **% cover of plant litter** | 40% | 30% | 40% | 25% | <5% |

| Transect ID: | NM-T2 | Transect WP: | 23 S/ 28 E | Transect Photo (Start/End): | 288 S/ 296 E |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | 23 | 24 | 25 | 26 | 27 |
| **Quadrat Photo:** | 289 | 291 | 293 | 294 | 295 |
| **Morphological Type:** | Upper slope | Upper slope | Upper slope | Mid slope | Mid slope |
| **Landform Type:** | Hill slope | Hill slope | Hill slope | Hill slope | Hill slope |
| **Substrate type (rock):** | Limonite | Limonite | Limonite | Limonite | Limonite |
| **Substrate type (soil):** | clay-loam red-brown | clay-loam red-brown | clay-loam red-brown | clay-loam red-brown | clay-loam red-brown |
| **Elevation:** | 419 m | 418 m | 412 m | 405 m | 400 m |
| **Aspect:** | N | N | N | N | N |
| **Loose rocks or gravel: % and size:** | >90% Coarse gravel | >90% Coarse gravel | >90% Coarse gravel | >90% Coarse gravel | >90% Coarse gravel |
| **Bedrock %** | 0% | <5% | 20% | 30% | 0% |
| **Surface Soil depth (mm):** | 70mm | 75mm | 50mm | 90mm | 40mm |
| **Surface resistance (LFA classification):** | 3 | 3 | 3 | 3 | 3 |
| **Local slope (degrees):** | 6.3 | 10.3 | 22.2 | 15.8 | 14.2 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | Nil | Nil | Nil | Nil | Nil |
| **Condition rating of *M. aquilonaris:*** | Nil | Nil | Nil | Nil | Nil |
| **Dominant species-upper stratum:** | *Melaleuca hamata* | *Melaleuca hamata* | *Eucalyptus* sp. sterile | *Eucalyptus* sp. sterile | *Eucalyptus* sp. sterile |
| **% Cover-upper stratum** | 0-5 | 0-5 | 10-30 | 10-30 | 70-100 |
| **Dominant species-mid stratum:** | *Acacia colletioides* | *Westringia cephalantha* | *Westringia cephalantha* | *Westringia cephalantha* | Nil |
| **% Cover-mid stratum** | 10-30 | 10-30 | 10-30 | 10-30 | 0 |
| **Dominant species-lower stratum:** | *Lepidosperma sanguinolentum* | *Lepidosperma sanguinolentum* | *Gahnia ancistrophylla* | *Gahnia ancistrophylla* | *Gahnia ancistrophylla* |
| **% Cover-lower stratum** | 0-5 | 10-30 | 10-30 | 10-30 | 10-30 |
| **Full sun/part sun/shade:** | full sun | full sun | full sun | full sun | shade |
| **% cover of bare ground** | 60% | 40% | 50% | 50% | 20% |
| **% cover of plant litter** | 20% | 5% | 15% | 5% | 80% |

| Transect ID: | Pop 1c- T1 | Transect WP: | 43 S/48 E | Transect Photo (Start/End): | 324S/332E |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | 43 | 44 | 45 | 46 | 47 |
| **Quadrat Photo:** | 323 | 325 | 326 | 327 | 331 |
| **Morphological Type:** | Mid slope | Mid slope | Mid slope | Mid slope | Mid slope |
| **Landform Type:** | Hill slope | Hill slope | Hill slope | Hill slope | Hill slope |
| **Substrate type (rock):** | Limonite | Limonite | Limonite | Limonite | Limonite |
| **Substrate type (soil):** | Sandy-clay loam red-brown | Sandy-clay loam red-brown | Sandy-clay loam red-brown | Sandy-clay loam red-brown | Sandy-clay loam red-brown |
| **Elevation:** | 417 m | 416 m | 414 m | 410 m | 405 m |
| **Aspect:** | NW | NW | NW | NW | NW |
| **Loose rocks or gravel: % and size:** | >90% Cobbles | >90% Coarse gravel | >90% Coarse gravel | >90% Coarse gravel | >90% Coarse gravel |
| **Bedrock %:** | 0% | 25% | <5% | 30% | 40% |
| **Surface Soil depth (mm):** | 50mm | 90mm | 60mm | 80mm | 40mm |
| **Surface resistance (LFA classification):** | 3 | 4 | 4 | 4 | 4 |
| **Local slope (degrees):** | 10 | 10.5 | 6.7 | 3.3 | 6.8 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | 1 | 16 | 14 | 20 | 12 |
| **Condition rating of *M. aquilonaris:*** | Good | Good | Good | Poor | Good |
| **Dominant species-upper stratum:** | *Eucalyptus livida* | *Eucalyptus livida* | *Eucalyptus livida* | Nil | Nil |
| **% Cover-upper stratum** | 30-70 | 10-30 | 30-70 | 0 | 0 |
| **Dominant species-mid stratum:** | *Beyeria brevifolia* | *Beyeria brevifolia* | *Westringia cephalantha* | *Mananthus aquilonaris* | *Mananthus aquilonaris* |
| **% Cover-mid stratum** | 30-70 | 30-70 | 10-30 | 10-30 | 10-30 |
| **Dominant species-lower stratum:** | *Lepidosperma sanguinolentum* | *Gahnia ancistrophylla* | *Lepidosperma sanguinolentum* | *Lepidosperma sanguinolentum* | *Gahnia ancistrophylla* |
| **% Cover-lower stratum** | 30-70 | 0-5 | 0-5 | 10-30 | 5-10 |
| **Full sun/part sun/shade:** | Part shade | Part shade | Part shade | Full sun | Full sun |
| **% cover of bare ground** | 25% | 25% | 20% | 20% | <5% |
| **% cover of plant litter** | 30% | 60% | 70% | 80% | 85% |

| **Transect ID:** | NM-T3 | **Transect WP:** | 37 S | **Transect Photo (Start/End):** | 317S/322E |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | 37 | 38 | 39 | 40 | 41 |
| **Quadrat Photo:** | 316 | 318 | 319 | 320 | 321 |
| **Morphological Type:** | Upper slope | Upper slope | Upper slope | Upper slope | Upper slope |
| **Landform Type:** | Hill slope | Hill slope | Hill slope | Hill slope | Hill slope |
| **Substrate type (rock):** | Limonite | Limonite | Limonite | Limonite | Limonite |
| **Substrate type (soil):** | Sandy clay-loam red-brown | Sandy clay-loam red-brown | Sandy clay-loam red-brown | Sandy clay-loam red-brown | Sandy clay-loam red-brown |
| **Elevation:** | 430 m | 427 m | 425 m | 424 m | 421 m |
| **Aspect:** | N | NW | NW | NW | NW |
| **Loose rocks or gravel: % and size:** | >90% Cobbles | >90% Coarse gravel | 70-90% Coarse gravel | >90% Cobbles | >90% Cobbles |
| **Bedrock %:** | <5% | <5% | <5% | 60% | 30% |
| **Surface Soil depth (mm):** | 30mm | 20mm | 60mm | 40mm | 40mm |
| **Surface resistance (LFA classification):** | 4 | 3 | 2 | 2 | 3 |
| **Local slope (degrees):** | 4.4 | 5.8 | 6.3 | 5.7 | 8.2 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | Nil | Nil | Nil | Nil | Nil |
| **Condition rating of *M. aquilonaris:*** | Nil | Nil | Nil | Nil | Nil |
| **Dominant species-upper stratum:** | Nil | Nil | *Eucalyptus livida* | *Eucalyptus livida* | *Eucalyptus livida* |
| **% Cover-upper stratum** | 0 | 0 | 30-70 | 0-5 | 0-5 |
| **Dominant species-mid stratum:** | *Westringia cephalantha* | *Melaleuca hamata* | Nil | *Beyeria* sp. (sterile) | *Santalum murrayanum* |
| **% Cover-mid stratum** | 30-70 | 0-5 | 0 | 0-5 | 0-5 |
| **Dominant species-lower stratum:** | *Lepidosperma sanguinolentum* | *Lepidosperma sanguinolentum* | *Lepidosperma sanguinolentum* | *Lepidosperma sanguinolentum* | *Phebalium filifolium* |
| **% Cover-lower stratum** | 10-30 | 10-30 | 10-30 | 10-30 | 30-70 |
| **Full sun/part sun/shade:** | Full sun | Full sun | Shade | Full sun | Full sun |
| **% cover of bare ground** | 70% | 70% | 40% | 50% | 50% |
| **% cover of plant litter** | 15% | 10% | 30% | 30% | 30% |

| Transect ID: | Pop 1c-T2 | Transect WP: | 49 S/55 E | Transect Photo (Start/End): | 334 S/340 E |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | 49 | 50 | 52 | 53 | 54 |
| **Quadrat Photo:** | 333 | 336 | 337 | 338 | 339 |
| **Morphological Type:** | Low slope | Low slope | Low slope | Low slope/ wash out | Low slope/ wash out |
| **Landform Type:** | Hill slope | Hill slope | Hill slope | Hill slope | Hill slope |
| **Substrate type (rock):** | Limonite | Limonite | Limonite | Limonite | Limonite |
| **Substrate type (soil):** | Sandy-clay loam red-brown | Sandy-clay loam red-brown | Sandy-clay loam red-brown | Sandy-clay loam red-brown | Sandy-clay loam red-brown |
| **Elevation:** | 405 m | 404 m | 401 m | 400 m | 399 m |
| **Aspect:** | NW | NW | NW | NW | NW |
| **Loose rocks or gravel: % and size:** | >90% Coarse gravel | >90% Coarse gravel | >90% Coarse gravel | >90% Fine gravel | 70-90% Coarse gravel |
| **Bedrock %:** | <5% | <5% | 5% | 10% | 5% |
| **Surface Soil depth (mm):** | 50mm | 15mm | 80mm | 70mm | 50mm |
| **Surface resistance (LFA classification):** | 3 | 3 | 4 | 4 | 4 |
| **Local slope (degrees):** | 1.3 | 5.1 | 4.1 | 1.5 | 9 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | 11 | 5 | 2 | 9 | 20 |
| **Condition rating of *M. aquilonaris:*** | Good | Good | Good | Good | Good |
| **Dominant species- upper stratum:** | *Eucalyptus livida* | Nil | *Eucalyptus livida* | Nil | *Eucalyptus livida* |
| **% Cover-upper stratum** | 30-70 | 0 | 0-5 | 0 | 30-70 |
| **Dominant species-mid stratum:** | *Mananthus aquilonaris* | *Mananthus aquilonaris* | *Mananthus aquilonaris* | *Mananthus aquilonaris* | *Mananthus aquilonaris* |
| **% Cover-mid stratum** | | 0-5 | 0-5 | 10-30 | 10-30 |
| **Dominant species- lower stratum:** | *Gahnia ancistrophylla* | *Gahnia ancistrophylla* | *Lepidosperma sanguinolentum* | *Lepidosperma sanguinolentum* | Nil |
| **% Cover-lower stratum** | 0-5 | 5-10 | 5-10 | 0-5 | 0 |
| **Full sun/part sun/shade:** | Part shade | Full sun | Full sun | Full sun | Part shade |
| **% cover of bare ground** | 60% | 90% | 80% | 90% | 70% |
| **% cover of plant litter** | 50% | <5% | 10% | <5% | 10% |

| Transect ID: | NM-T4 | Transect WP: | WP56 S/61 E | Transect Photo (Start/End): | 342 S/347 E |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | WP56 | WP57 | WP58 | WP59 | WP60 |
| **Quadrat Photo:** | 341 | 343 | 344 | 345 | 346 |
| **Morphological Type:** | Low slope | Low slope | Low slope | Low slope | Low slope |
| **Landform Type:** | Hill slope | Hill slope | Hill slope | Hill slope | Hill slope |
| **Substrate type (rock):** | Limonite | Limonite | No bedrock | Limonite | Limonite |
| **Substrate type (soil):** | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown |
| **Elevation:** | 405 m | 404 m | 403 m | 402 m | 400 m |
| **Aspect:** | NW | NW | NW | NW | NW |
| **Loose rocks or gravel: % and size:** | >90% Fine gravel | >90% Fine gravel | 50% Fine gravel | 90% Fine gravel | >90% Fine gravel |
| **Bedrock %:** | 0% | 0% | 0% | 0% | 0% |
| **Surface Soil depth (mm):** | 100mm | 30mm | 30mm | 110mm | 100mm |
| **Surface resistance (LFA classification):** | 4 | 4 | 4 | 4 | 3 |
| **Local slope (degrees):** | 5.4 | 6.7 | 2.4 | 4.5 | 4.6 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | Nil | Nil | Nil | Nil | Nil |
| **Condition rating of *M. aquilonaris:*** | Nil | Nil | Nil | Nil | Nil |
| **Dominant species-upper stratum:** | Nil | *Eucalyptus* sp. (Sterile) | Nil | Nil | Nil |
| | 0 | 0-5 | 0 | 0 | 0 |
| **Dominant species-mid stratum:** | Nil | Nil | *Dodonaea stenozyga* | Nil | *Exocarpos aphyllus* |
| | 0 | 0 | 10-30 | 0 | |
| **Dominant species-lower stratum:** | *Wilsonia humilis* | *Acacia erinacea/ Acacia poliochroa* | *Acacia erinacea/ Acacia poliochroa* | *Wilsonia humilis* | *Acacia erinacea/ Acacia poliochroa* |
| | 0-5 | 5-10 | 10-30 | 10-30 | 10-30 |
| **Full sun/part sun/shade:** | Full sun | Full sun | Full sun | Full sun | Full sun |
| **% cover of bare ground** | 95% | 90% | 60% | 85% | 75% |
| **% cover of plant litter** | <5% | <5% | 10% | <5% | 10% |

| **Transect ID:** | Pop1d-T1 | **Transect WP:** | 63 S/ 67 E | **Transect Photo (Start/End):** | 353 S/ 359 E |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | 63 | 64 | 65 | 66 | 67 |
| **Quadrat Photo:** | 352 | 353 | 354 | 356 | 358 |
| **Morphological Type:** | Crest | Crest | Crest | Mid slope | Mid slope |
| **Landform Type:** | Hill slope | Hill slope | Hill slope | Hill slope | Hill slope |
| **Substrate type (rock):** | Limonite | Limonite | Limonite | Limonite | Limonite |
| **Substrate type (soil):** | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown |
| **Elevation:** | 402 m | 402 m | 402 m | 400 m | 399 m |
| **Aspect:** | S | N | N | N | N |
| **Loose rocks or gravel: % and size:** | 90% Coarse gravel | 90% Coarse gravel | 90% Coarse gravel | 90% Coarse gravel | 30% Coarse gravel |
| **Bedrock %:** | 70% | 50% | 40% | 10% | 0% |
| **Surface Soil depth (mm):** | 20mm | 30mm | 10mm | 60mm | 100mm |
| **Surface resistance (LFA classification):** | 4 | 4 | 4 | 4 | 4 |
| **Local slope (degrees):** | 10.7 | 5.8 | 4.5 | 2 | 4.1 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | 16 | 4 | 15 | 3 | 1 |
| **Condition rating of *M. aquilonaris:*** | Good | Good | Good | Good | Good |
| **Dominant species-upper stratum:** | *Eucalyptus livida* | Nil | *Eucalyptus livida* | Nil | *Eucalyptus livida* |
| **% Cover-upper stratum** | 10-30 | 0 | 10-30 | 0 | 10-30 |
| **Dominant species-mid stratum:** | *Mananthus aquilonaris* | *Mananthus aquilonaris* | *Mananthus aquilonaris* | *Dodonaea stenozyga* | *Mananthus aquilonaris* |
| **% Cover-mid stratum** | 10-30 | 5-10 | 10-30 | 5-10 | 0-5 |
| **Dominant species-lower stratum:** | *Gahnia ancistrophylla* | *Lepidosperma sanguinolentum* | *Dampiera angulata* subsp. Peak Charles (K.R. Newbey 5402) | *Gahnia ancistrophylla* | *Dodonaea stenozyga* |
| **% Cover-lower stratum** | 10-30 | 10-30 | 5-10 | 10-30 | 10-30 |
| **Full sun/part sun/shade:** | Full sun | Full sun | Full sun | Full sun | Shade |
| **% cover of bare ground** | 76% | 90% | 60% | 80% | 50% |
| **% cover of plant litter** | 5% | 20% | 20% | 20% | 20% |

| Transect ID: | Pop1d-T2 | Transect WP: | 69 S/ 73 E | Transect Photo (Start/End): | 361 S/ 367 E |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | 69 | 70 | 71 | 72 | 73 |
| **Quadrat Photo:** | 362 | 363 | 364 | 365 | 366 |
| **Morphological Type:** | Crest | Crest | Mid slope | Valley | Low slope |
| **Landform Type:** | Hill slope | Hill slope | Hill slope | Hill slope | Hill slope |
| **Substrate type (rock):** | Limonite | Limonite | Limonite | Limonite | Limonite |
| **Substrate type (soil):** | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown |
| **Elevation:** | 405 m | 404 m | 402 m | 400 m | 403 m |
| **Aspect:** | N | N | N | N | SE |
| **Loose rocks or gravel: % and size:** | 90% Coarse gravel | 90% Coarse gravel | 70% Coarse gravel | 50% Coarse gravel | >90% Coarse gravel |
| **Bedrock %:** | 80% | 60% | 10% | 0% | 0% |
| **Surface Soil depth (mm):** | 10mm | 10mm | 20mm | 30mm | 130mm |
| **Surface resistance (LFA classification):** | 4 | 4 | 4 | 4 | 3 |
| **Local slope (degrees):** | 7.9 | 7.9 | 8.7 | 6.4 | 4.8 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | 12 | 4 | 11 | 15 | Nil |
| **Condition rating of *M. aquilonaris:*** | Good | Good | Good | Good | Nil |
| **Dominant species-upper stratum:** | *Eucalyptus* sp. (sterile) | *Eucalyptus* sp. (sterile) | Nil | *Eucalyptus livida* | Nil |
| **% Cover-upper stratum** | 10-30 | 10-30 | 0 | 30-70 | 0 |
| **Dominant species-mid stratum:** | *Mananthus aquilonaris* | *Mananthus aquilonaris* | *Mananthus aquilonaris* | *Trymalium myrtillus* subsp. *myrtillus* | *Santalum acuminatum* |
| **% Cover-mid stratum** | 5-10 | 5-10 | 5-10 | 5-10 | 5-10 |
| **Dominant species-lower stratum:** | *Dodonaea stenozyga* | Nil | *Leptosema daviesioides* | *Acacia poliochroa* | *Acacia erinacea* |
| **% Cover-lower stratum** | 10-30 | 0 | 10-30 | 10-30 | 5-10 |
| **Full sun/part sun/shade:** | Full sun | Part Sun | Part Sun | Shade | Full sun |
| **% cover of bare ground** | 80% | 60% | 80% | 10% | 60% |
| **% cover of plant litter** | 15% | 40% | 30% | 20% | <10% |

| Transect ID: | NM-T5 | Transect WP: | 75S/ | Transect Photo (Start/End): | 369s/374 |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | 76 | 77 | 78 | 79 | 80 |
| **Quadrat Photo:** | 368 | 371 | 372 | 373 | 375 |
| **Morphological Type:** | Low slope | Low slope | Low slope | Low slope | Low slope |
| **Landform Type:** | Hill slope | Hill slope | Hill slope | Hill slope | Hill slope |
| **Substrate type (rock):** | Limonite | Limonite | Quartz | Ironstone | Ironstone |
| **Substrate type (soil):** | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown |
| **Elevation:** | 409 m | 407 m | 406 m | 403 m | 403 m |
| **Aspect:** | NE | NE | NE | NE | NE |
| **Loose rocks or gravel: % and size:** | 50% Cobbles | >90% Coarse gravel | >90% Coarse gravel | >90% Coarse gravel | >90% Coarse gravel |
| **Bedrock %:** | <10% | 0% | 0% | 0% | 0% |
| **Surface Soil depth (mm):** | 10mm | 40mm | 120mm | 120mm | 90mm |
| **Surface resistance (LFA classification):** | 4 | 4 | 3 | 2 | 2 |
| **Local slope (degrees):** | 2.5 | 4.1 | 2.5 | 4.8 | 2.9 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | Nil | Nil | Nil | Nil | Nil |
| **Condition rating of *M. aquilonaris:*** | Nil | Nil | Nil | Nil | Nil |
| **Dominant species-upper stratum:** | *Eucalyptus* sp. (sterile) | Nil | *Eucalyptus* sp. (sterile) | *Santalum acuminatum* | Nil |
| **% Cover-upper stratum** | 10-30 | 0 | 10-30 | 10-30 | 0 |
| **Dominant species-mid stratum:** | *Trymalium myrtillus* subsp. *myrtillus* | *Davesia argillacea* | *Melaleuca pauperiflora* | *Dodonaea stenozyga* | *Melaleuca pauperiflora* |
| **% Cover-mid stratum** | 5-10 | 5-10 | 10-30 | 10-30 | 5-10 |
| **Dominant species-lower stratum:** | Nil | *Acacia poliochroa* | *Acacia sulcata/ Davesia argillacea* | *Davesia argillacea* | *Acacia sulcata* |
| **% Cover-lower stratum** | 0 | 10-30 | 10-30 | 10-30 | 30-70 |
| **Full sun/part sun/shade:** | Part shade | Full sun | Full sun | Full sun | Full sun |
| **% cover of bare ground** | 80% | 80% | 60% | 70% | 40% |
| **% cover of plant litter** | 5% | <5% | <5% | 15% | 10% |

| Transect ID: | Pop1e-T1 | **Transect WP:** | 81 | **Transect Photo (Start/End):** | 377 |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | 81 | 82 | 83 | 84 | 85 |
| **Quadrat Photo:** | 376 | 379 | 380 | 383 | 384 |
| **Morphological Type:** | Upper slope | Mid slope | Mid slope | Low slope/ Valley | Low slope/ Valley |
| **Landform Type:** | Hill slope | Hill slope | Hill slope | Valley | Valley |
| **Substrate type (rock):** | Limonite | Limonite | Limonite | Ironstone | Ironstone |
| **Substrate type (soil):** | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown |
| **Elevation:** | 402 m | 402 m | 397 m | 396 m | 393 m |
| **Aspect:** | NE | NE | NE | NE | NE |
| **Loose rocks or gravel: % and size:** | >90% Coarse gravel | >90% Coarse gravel | >90% Coarse gravel | >90% Fine gravel | 20-50% Fine gravel |
| **Bedrock %:** | 20% | 5% | >5% | 0% | 0% |
| **Surface Soil depth (mm):** | 50mm | 60mm | 30mm | 30mm | 80mm |
| **Surface resistance (LFA classification):** | 4 | 2 | 4 | 2 | 2 |
| **Local slope (degrees):** | 5.9 | 5 | 1.6 | 1 | 2.4 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | 5 | 12 | 8 | 2 | Nil |
| **Condition rating of *M. aquilonaris:*** | Good | Good | Good | Good | Nil |
| **Dominant species-upper stratum:** | *Eucalyptus livida* | *Eucalyptus livida* | *Eucalyptus livida* | *Eucalyptus livida* | *Eucalyptus transcontinentalis* |
| **% Cover-upper stratum** | 10-30 | 10-30 | 10-30 | 5-10 | 10-30 |
| **Dominant species-mid stratum:** | *Mananthus aquilonaris* | *Mananthus aquilonaris* | *Mananthus aquilonaris* | *Mananthus aquilonaris* | *Melaleuca pauperiflora* |
| **% Cover-mid stratum** | 5-10 | 10-30 | 10-30 | 10-30 | 10-30 |
| **Dominant species-lower stratum:** | *Westringia cephalantha* | *Gahnia ancistrophylla* | *Gahnia ancistrophylla* | *Gahnia ancistrophylla* | *Acacia erinacea* |
| **% Cover-lower stratum** | 5-10 | 5-10 | 10-30 | 70-100 | 30-70 |
| **Full sun/part sun/shade:** | Full sun | Part Sun | Part Sun | Full sun | Full sun |
| **% cover of bare ground** | 70% | 70% | 60% | 30% | 40% |
| **% cover of plant litter** | 15% | 25% | 20% | 40% | 15% |

| Transect ID: | NM-T6 | Transect WP: | 86S/ | Transect Photo (Start/End): | 386S/391 |
|---|---|---|---|---|---|
| **Quadrat ID:** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Quadrat WP:** | 86 | 87 | 88 | 89 | 90 |
| **Quadrat Photo:** | 385 | 387 | 388 | 389 | 390 |
| **Morphological Type:** | Upper slope | Upper slope | Mid slope | Low slope | Low slope |
| **Landform Type:** | Hill slope | Hill slope | Hill slope | Hill slope | Hill slope |
| **Substrate type (rock):** | Ironstone | Ironstone | Ironstone | Ironstone | Ironstone |
| **Substrate type (soil):** | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown | Sandy clay loam red-brown |
| **Elevation:** | 405 m | 402 m | 401 m | 399 m | 397 m |
| **Aspect:** | NE | NE | NE | NE | NE |
| **Loose rocks or gravel: % and size:** | >90% Cobbles | >90% Cobbles | >90% Cobbles | >90% Cobbles | >90% Cobbles |
| **Bedrock %:** | 0% | 0% | 0% | 0% | 0% |
| **Surface Soil depth (mm):** | 110mm | 90mm | 70mm | 80mm | 40mm |
| **Surface resistance (LFA classification):** | 4 | 4 | 3 | 2 | 4 |
| **Local slope (degrees):** | 6.4 | 4.9 | 4.5 | 6.8 | 5 |
| **Biological Properties** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **No. *Marianthus aquilonaris:*** | Nil | Nil | Nil | Nil | Nil |
| **Condition rating of *M. aquilonaris:*** | Nil | Nil | Nil | Nil | Nil |
| **Dominant species-upper stratum:** | Nil | Nil | *Eucalyptus* sp. (sterile) | *Eucalyptus* sp. (sterile) | *Eucalyptus* sp. (sterile) |
| **% Cover-upper stratum** | 0 | 0 | 10-30 | 10-30 | 0-5 |
| **Dominant species-mid stratum:** | *Dodonaea bursariifolia* | *Melaleuca hamata* | *Dodonaea bursariifolia* | *Melaleuca pauperiflora* | *Melaleuca hamata* |
| **% Cover-mid stratum** | 30-70 | 30-70 | 10-30 | 10-30 | 10-30 |
| **Dominant species-lower stratum:** | *Stenanthemum bremerense* | *Gahnia ancistrophylla* | *Westringia cephalantha* | *Westringia cephalantha* | *Westringia cephalantha* |
| **% Cover-lower stratum** | 30-70 | 10-30 | 10-30 | 10-30 | 5-10 |
| **Full sun/part sun/shade:** | Full sun | Full sun | Part shade | Part shade | Full sun |
| **% cover of bare ground** | 25% | 50% | 75% | 40% | 85% |
| **% cover of plant litter** | 10% | 20% | 10% | 25% | 5% |

**Appendix 3: Landform Monitoring-Transect Photographs**

**Pop 1a-T1**

Start

End

**Pop 1a-T2**

Start

End

**NM-T1**

Start

End

**Pop 1b-T1**

Start

End

NM-T2


Start


End

Pop 1c-T1


Start


End

NM-T3


Start


End

Pop 1c-T2


Start


End

NM-T4


Start


End

**Pop 1d-T1**


Start


End

**Pop 1d-T2**


Start


End

**NM-T5**


Start


End

**Pop 1e-T1**


Start


End

**NM-T6**


Start


End

## Appendix 4: Landform Monitoring-Summary Data

| Population | Marianthus (Present/ Absent) | | Morphological Type | Landform Type | Rocky Type | Soil Type | Soil Colour | Elevation (m) | Aspect | % Loose rocks/ gravel | Size Loose rocks/ gravel | Bedrock % | Surface Soil depth (mm) | Surface resistance (LFA classification) | Local slope (degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1a | P | **Range** | Crest-Low Slope | Hill slope | Limonite-No bedrock | Clay-loam | Brown | 375-399 | W | 35-90 | Cobbles-Medium Gravel | 0-20% | 5-100 | 2-4 | 3.4-9.4 |
| | | **Mean** | **Mid slope** | **Hill slope** | **Limonite** | **Clay-loam** | **Brown** | **385** | **W** | **83** | **Coarse Gravel** | **8%** | **18** | **3** | **5.3** |
| | A | **Range** | Upper Slope-Valley | Hill Slope-Valley | Limonite-No bedrock | Clay-loam | Brown-Red brown | 371-388 | SW-NE | 20-90 | Cobbles-Fine Gravel | 0-10% | 30-140 | 2-4 | 0.2-8 |
| | | **Mean** | **Mid slope** | **Hill slope** | **No bedrock** | **Clay-loam** | **Red-Brown** | **381** | **W** | **71** | **Coarse Gravel** | **2%** | **85** | **3** | **4.3** |
| 1b | P | **Range** | Mid slope | Hill slope | Limonite | Sandy-clay loam | Red-Brown | 400-401 | N-NW | 80-90 | Cobbles | 20-30% | 10-30 | 3-4 | 6.7-10.1 |
| | | **Mean** | **Mid slope** | **Hill slope** | **Limonite** | **Sandy-clay loam** | **Red-Brown** | **401** | **N-NW** | **85** | **Cobbles** | **25%** | **20** | **4** | **8.4** |
| | A | **Range** | Upper Slope-Mid Slope | Hill slope | Limonite | Clay loam-Sandy clay loam | Red-Brown | 397-419 | NW-NE | 80-90 | Coarse Gravel | 0-30% | 40-110 | 3-4 | 5-22.2 |
| | | **Mean** | **Mid slope** | **Hill slope** | **Limonite** | **Clay-loam** | **Red-Brown** | **407** | **N** | **89** | **Coarse Gravel** | **8%** | **67** | **3** | **11.8** |
| 1c | P | **Range** | Mid Slope-Low Slope | Hill Slope | Limonite | Sandy clay loam | Red-Brown | 399-417 | NW | 70->90% | Cobbles-Fine Gravel | 0-40% | 15-90 | 3-4 | 1.3-10.5 |
| | | **Mean** | **Mid slope** | **Hill slope** | **Limonite** | **Sandy-clay loam** | **Red-Brown** | **407** | **NW** | **89** | **Coarse Gravel** | **13%** | **58** | **4** | **5.8** |
| | A | **Range** | Upper Slope-Low Slope | Hill Slope | Limonite-No bedrock | Sandy clay loam | Red-Brown | 400-430 | N-NW | 50->90% | Cobbles-Fine Gravel | 0-60% | 20-110 | 2-4 | 2.4-8.2 |
| | | **Mean** | **Upper Slope** | **Hill slope** | **Limonite** | **Sandy-clay loam** | **Red-Brown** | **414** | **NW** | **85** | **Fine Gravel** | **11%** | **56** | **3** | **5.4** |
| 1d | P | **Range** | Crest-Valley | Hill slope | Limonite | Sandy-clay loam | Red-Brown | 399-405 | N-S | 30-90 | Coarse Gravel | 0-80% | 10-100 | 4 | 2-10.7 |
| | | **Mean** | **Crest** | **Hill slope** | **Limonite** | **Sandy-clay loam** | **Red-Brown** | **402** | **N** | **77** | **Coarse Gravel** | **36%** | **32** | **4** | **6.4** |
| | A | **Range** | Low slope | Hill slope | Limonite-Ironstone | Sandy-clay loam | Red-Brown | 403-409 | SE-NE | 50-90 | Cobbles-Coarse Gravel | 0-10% | 10-130 | 2-4 | 2.5-4.8 |
| | | **Mean** | **Low slope** | **Hill slope** | **Limonite** | **Sandy-clay loam** | **Red-Brown** | **405** | **NE** | **83** | **Coarse Gravel** | **2%** | **85** | **3** | **3.6** |
| 1e | P | **Range** | Upper Slope-Low Slope | Hill slope-Valley | Limonite-Ironstone | Sandy-clay loam | Red-Brown | 396-402 | NE | 90 | Coarse Gravel-Fine Gravel | 0-20% | 30-60 | 3-4 | 1-5.9 |
| | | **Mean** | **Mid slope** | **Hill slope** | **Limonite** | **Sandy-clay loam** | **Red-Brown** | **399** | **NE** | **90** | **Coarse Gravel** | **19%** | **42** | **3** | **3.4** |
| | A | **Range** | Upper slope-Low slope | Hill slope | Ironstone | Sandy-clay loam | Red-Brown | 393-405 | NE | 35-90 | Cobbles-Fine gravel | 0% | 40-110 | 3-4 | 2.4-6.8 |
| | | **Mean** | **Low slope** | **Hill slope** | **Ironstone** | **Sandy-clay loam** | **Red-Brown** | **399** | **NE** | **81** | **Cobbles** | **0%** | **78** | **3** | **5** |

| Population | Marianthus (Present/ Absent) | | No. *Marianthus aquilonaris* | % Cover-upper stratum | % Cover-mid stratum | % Cover-lower stratum | % cover of bare ground | % cover of plant litter |
|---|---|---|---|---|---|---|---|---|
| 1a | P | **Range** | 1-7 | 0-30 | 0-70 | 0-10 | 50-90 | <5-50 |
| | | **Mean** | **4** | **9** | **21** | **3** | **72** | **23** |
| | A | **Range** | 0 | 0-70 | 0-30 | 0-100 | 20-90 | <5-25 |
| | | **Mean** | **0** | **15** | **9** | **19** | **68** | **14** |
| 1b | P | **Range** | 8-9 | 0-5 | 5-10 | 0 | 50-85 | 25-40 |
| | | **Mean** | **9** | **1** | **8** | **0** | **68** | **33** |
| | A | **Range** | 0 | 0-100 | 0-70 | 0-100 | 5-60 | <5-80 |
| | | **Mean** | **0** | **20** | **20** | **28** | **34** | **29** |
| 1c | P | **Range** | 1-20 | 0-70 | 0-70 | 0-70 | <5-90 | <5-85 |
| | | **Mean** | **11** | **24** | **22** | **11** | **53** | **41** |
| | A | **Range** | 0 | 0-70 | 0-70 | 5-70 | 40-95 | <5-30 |
| | | **Mean** | **0** | **6** | **8** | **21** | **69** | **15** |
| 1d | P | **Range** | 1-16 | 0-70 | 0-30 | 5-30 | 10-90 | 5-40 |
| | | **Mean** | **9** | **17** | **10** | **16** | **65** | **21** |
| | A | **Range** | 0 | 0-30 | 5-30 | 5-70 | 40-80 | <5-15 |
| | | **Mean** | **0** | **10** | **12** | **20** | **65** | **8** |
| 1e | P | **Range** | 2-12 | 5-30 | 5-30 | 5-100 | 30-70 | 15-40 |
| | | **Mean** | **7** | **17** | **17** | **30** | **58** | **25** |
| | A | **Range** | 0 | 0-30 | 10-70 | 5-70 | 25-85 | 5-25 |
| | | **Mean** | **0** | **10** | **32** | **30** | **53** | **14** |

**Attachment 3: Memorandum: *Marianthus aquilonaris* Demographic monitoring. Botanica (2020)**

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**MARIANTHUS AQUILONARIS DEMOGRAPHIC MONITORING: SPRING 2018-SPRING 2019**

## 1 Objectives

The objective of the study was to establish demographic monitoring of *Marianthus aquilonaris* sub-populations to determine the population structure/ rates of growth/ reproduction and survival in order to conduct future assessments on 'effective population size' (that is plants capable of reproducing), population viability analysis (modelling of probability of plant extinction from direct disturbance) and measure potential indirect impacts to sub-populations.

## 2 Methodology

The location of the demographic monitoring quadrats were determined based on:

- Presence of suitable habitat/vegetation for *M. aquilonaris* identified during flora and vegetation surveys (Regrowth mid open mallee woodland *Eucalyptus livida* over mid open shrubland of *Hakea pendens* (P3) and open low shrubland of *Goodia medicaginea* on hillslope); and
- Elevation-to ensure at least one quadrat was located in the upper slope and lower slope of each *M. aquilonaris* sub-population[1];

A total of twenty-seven monitoring quadrats (10m X 10m) were established within the *M. aquilonaris* sub-populations in September and November 2018 (Figure 1). These quadrats have continued to be assessed biannually (May 2019 and October 2019). Location maps of the quadrats within each sub-population are provided in Appendix 1. The location of each quadrat was recorded using a handheld GPS (Quadrat coordinates provided in Appendix 2) and the boundary of the quadrats were marked with metal fence droppers. A photographic record was taken for each quadrat (Appendix 3). Raw data for the current monitoring period (Spring 2019) is provided in Appendix 3.

The parameters measured within each quadrat are listed in Table 1. Parameters chosen are consistent with previous monitoring established by the Department of Biodiversity, Conservation and Attractions (DBCA) which are detailed in the *Implementing Recovery Actions for Bremer Marianthus,* DEC, 2011) and will enable assessment on the rate of growth, reproduction/ recruitment and survival of each sub-population. Quadrat size was determined to ensure consistency with existing population quadrats established by DBCA and due to the high density of *M. aquilonaris* populations, particularly in areas of regrowth from fire disturbance. Monitoring is to be conducted biannually (Autumn and Spring) throughout the life of the Medcalf Vanadium Project (minimum one year of monitoring pre-mining) which currently undergoing Public Environmental Review under the Part IV of the *Environmental Protection Act 1986*.

[1] Excluding Population 1f which comprises of a single plant.

**Table 1: Demographic Monitoring Quadrat Parameters**

| **Demographic Properties** |
| --- |
| No. mature plants |
| No. juvenile plants |
| No. dead plants |
| No. seedlings |
| No. sprouting plants |
| No. flowering plants |
| No. fruiting plants |
| Height/width of plants |
| No. fruits per plant |
| No. flowers per plant |
| Dominant species |

[redacted]

Figure 1: Location of demographic monitoring quadrats

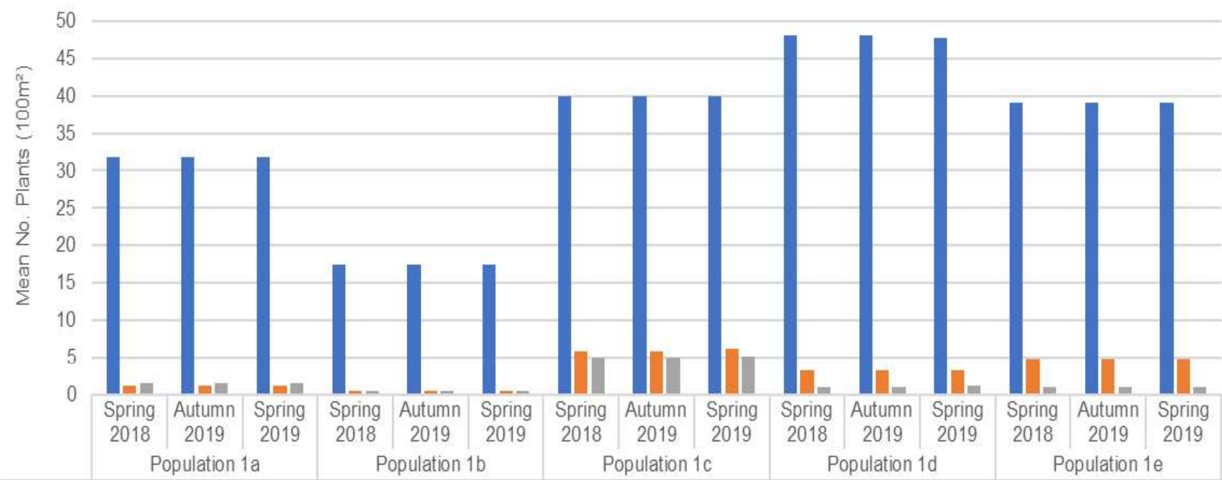
## 3 Results

As shown in Figure 2 below, Population 1d had the highest mean number of mature plants (average of 48 mature plants per 100m²) and Population 1c had the highest mean number of juvenile plants (average of six juvenile plants per 100m²). The highest mean number of dead plants was also recorded in Population 1c (average of five dead plants per 100m²). The mean number of mature, juvenile and dead plants for each population remained relatively constant across each monitoring period.

Flowers were only present during the Spring monitoring periods (2018 and 2019). The mean number of plants with flowers increased for all populations between Spring 2018 and Spring 2019, with Population 1d currently recording the highest mean number of plants in flower (average of ten flowering plants per 100m²) (Figure 3 below).

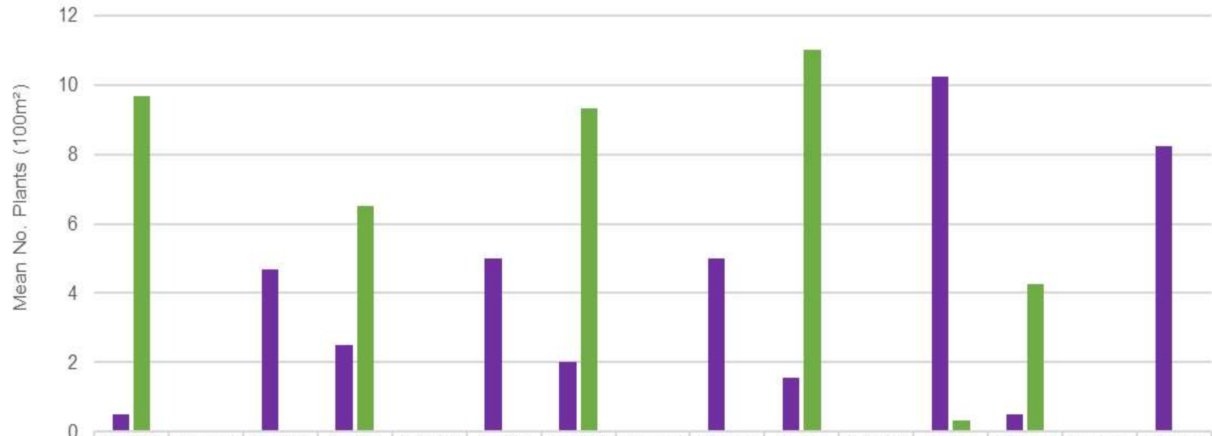
In Spring 2018, the percentage of fruiting plants ranged from 11% (Population 1e) to 38% (Population 1b). In Spring 2019, only one quadrat from Population 1d (Q1-2) has fruits present in the Spring 2019 monitoring period with the percentage of fruiting plants in Population 1e recorded at 1%. In Spring 2018, the percentage of flowering plants ranged from 1% (Population 1e) to 15% (Population 1b) (Figure 4). In Spring 2019, the percentage of flowering plants ranged from 9% (Population 1c) to 29% (Population 1b) (Figure 4).

In Spring 2018, the mean number of flowers per plant ranged from one to three flowers per plant, with the highest number of flowers per plant recorded for Population 1a (Figure 5). In Spring 2019, the mean number of flowers per plant ranged from nine to twenty-three flowers per plant, with the highest number of flowers per plant recorded for Population 1b (Figure 5).



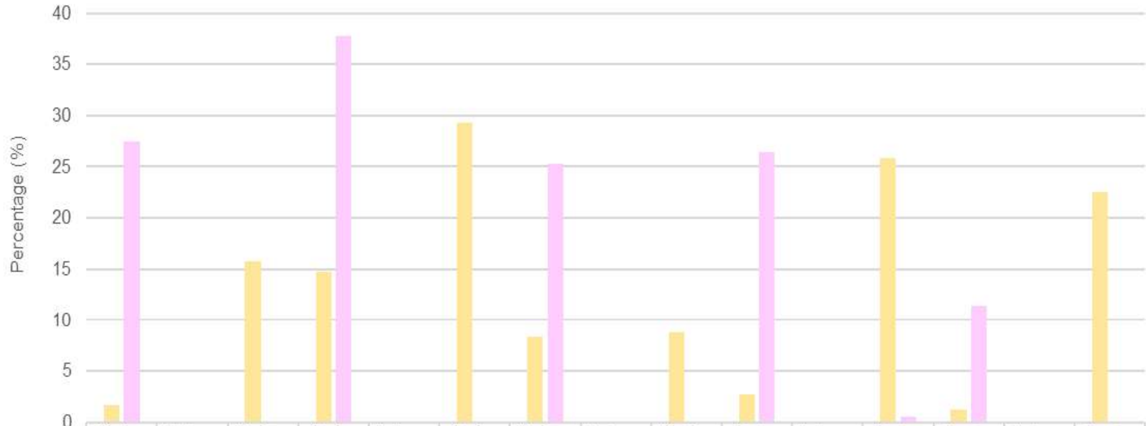

| | Population 1a | | | Population 1b | | | Population 1c | | | Population 1d | | | Population 1e | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 |
| Mature | 32 | 32 | 32 | 18 | 18 | 18 | 40 | 40 | 40 | 48 | 48 | 48 | 39 | 39 | 39 |
| Juvenile | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 6 | 6 | 3 | 3 | 3 | 5 | 5 | 5 |
| Dead | 2 | 2 | 2 | 1 | 1 | 1 | 5 | 5 | 5 | 1 | 1 | 1 | 1 | 1 | 1 |

**Figure 2: Age Structure of each sub-population (Spring 2018-Spring 2019)**



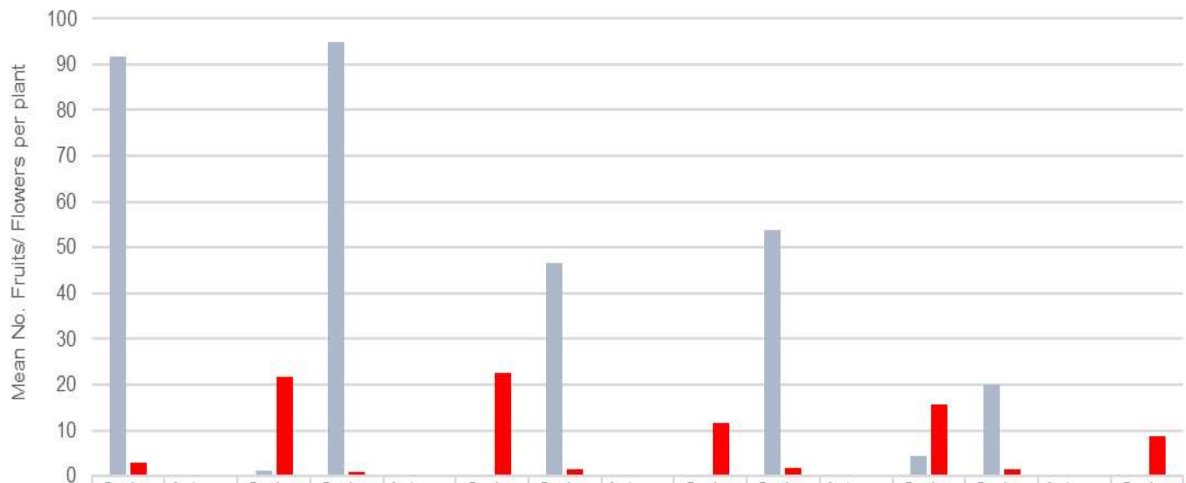

| | Population 1a | | | Population 1b | | | Population 1c | | | Population 1d | | | Population 1e | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 |
| Flowering | 1 | 0 | 5 | 3 | 0 | 5 | 2 | 0 | 5 | 2 | 0 | 10 | 1 | 0 | 8 |
| Fruiting | 10 | 0 | 0 | 7 | 0 | 0 | 9 | 0 | 0 | 11 | 0 | 0 | 4 | 0 | 0 |

**Figure 3: Number of Flowering/Fruiting Plants of each sub-population (Spring 2018-Spring 2019)**




| | Population 1a | | | Population 1b | | | Population 1c | | | Population 1d | | | Population 1e | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 |
| Flowering | 2 | 0 | 16 | 15 | 0 | 29 | 8 | 0 | 9 | 3 | 0 | 26 | 1 | 0 | 23 |
| Fruiting | 27 | 0 | 0 | 38 | 0 | 0 | 25 | 0 | 0 | 26 | 0 | 1 | 11 | 0 | 0 |

**Figure 4: Percentage of Flowering/Fruiting Plants of each sub-population (Spring 2018-Spring 2019)**




| | Population 1a | | | Population 1b | | | Population 1c | | | Population 1d | | | Population 1e | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 | Spring 2018 | Autumn 2019 | Spring 2019 |
| Fruits | 92 | 0 | 1 | 95 | 0 | 0 | 47 | 0 | 0 | 54 | 0 | 4 | 20 | 0 | 0 |
| Flowers | 3 | 0 | 22 | 1 | 0 | 23 | 2 | 0 | 12 | 2 | 0 | 16 | 2 | 0 | 9 |

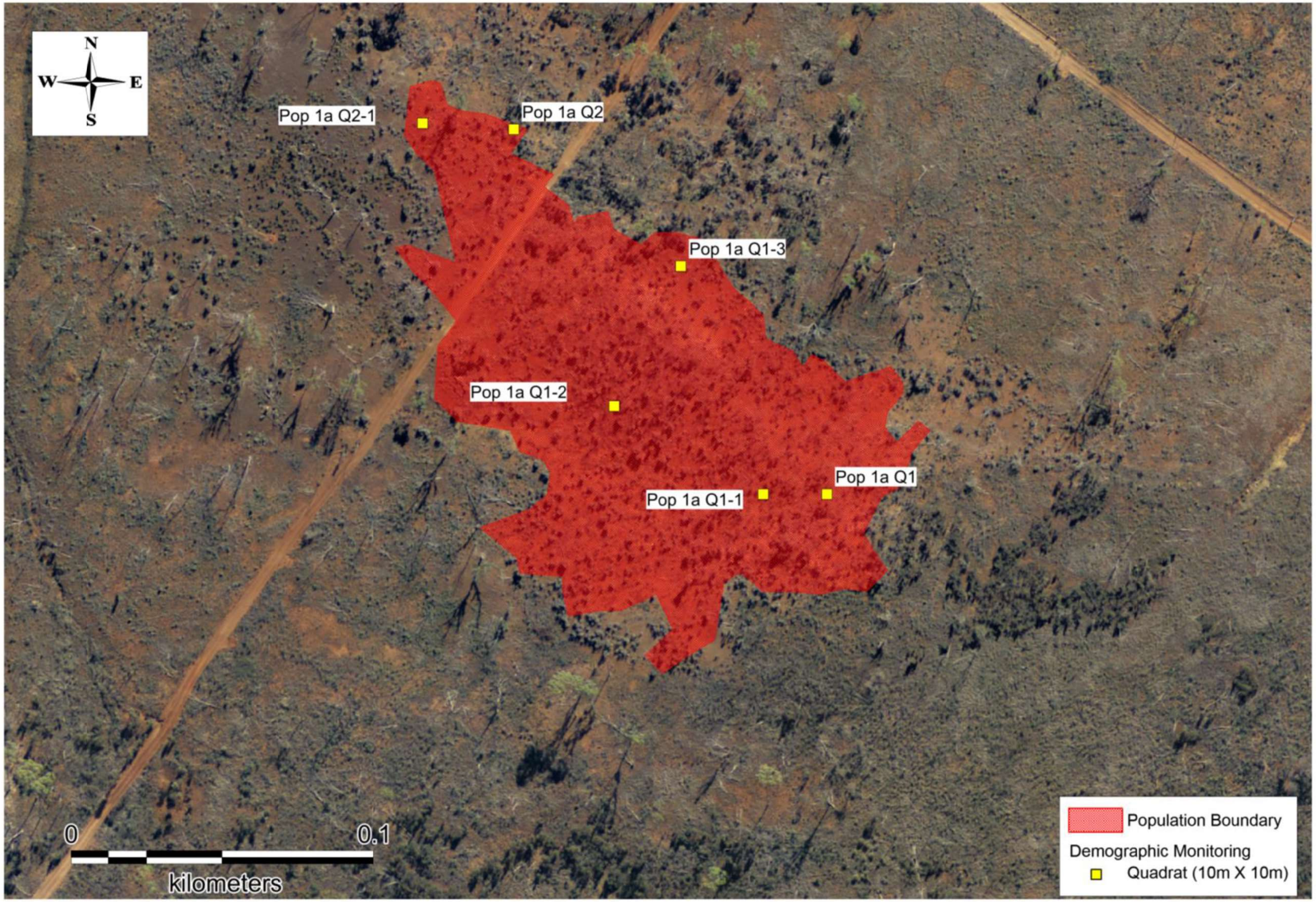
**Figure 5: Mean no. flowers/fruits per plant of each sub-population (Spring 2018-Spring 2019)**

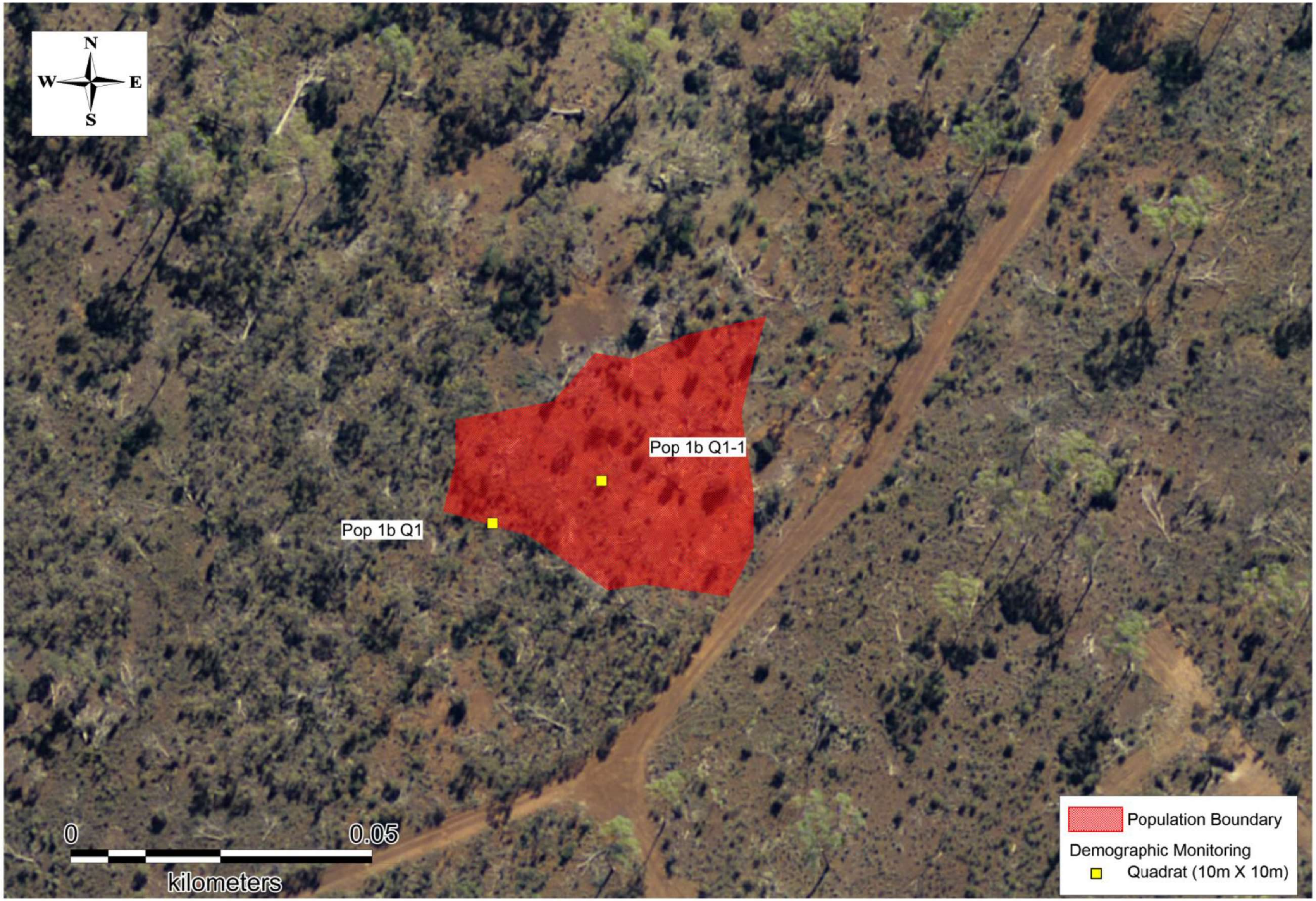
## 4 Discussion

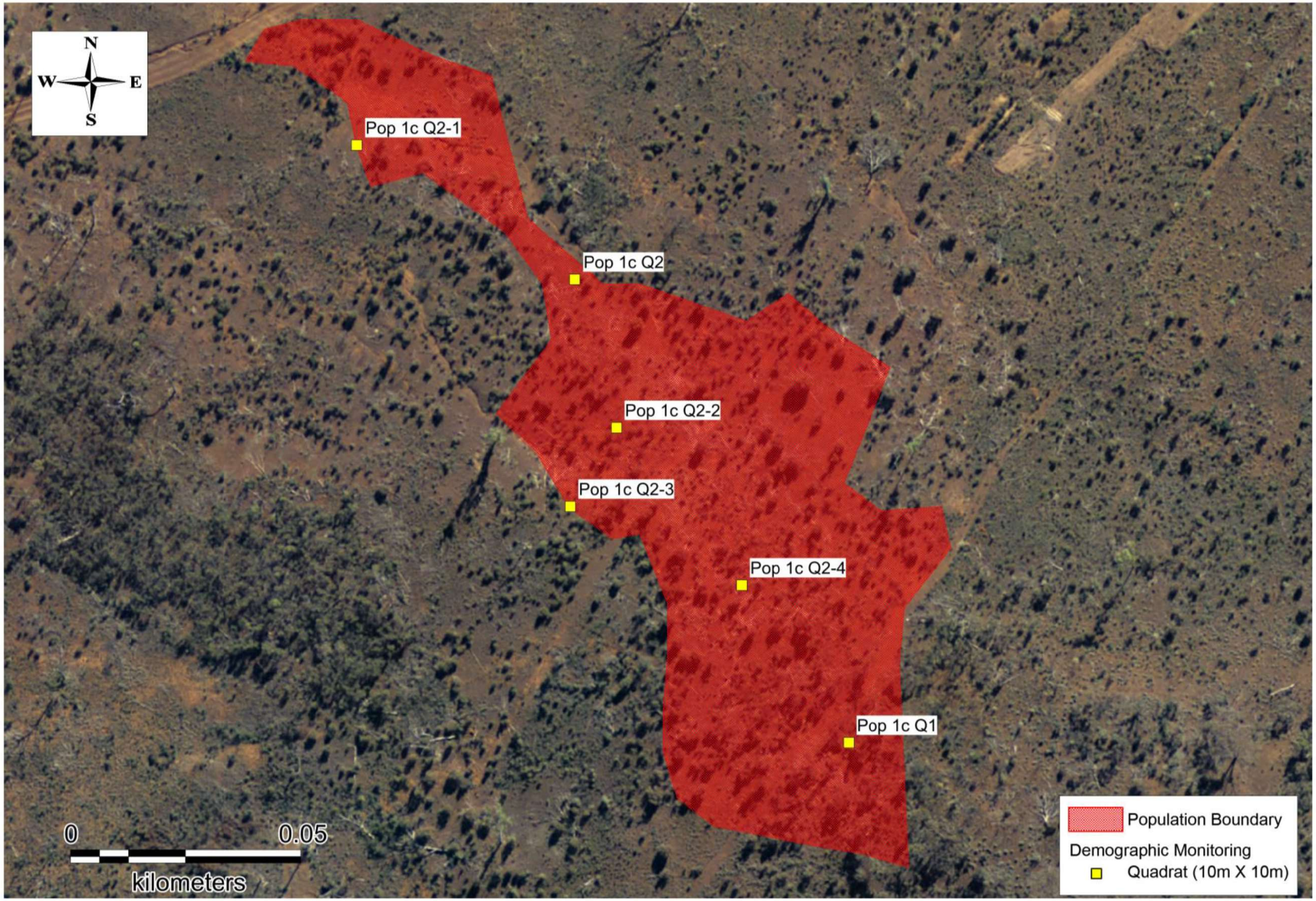
As this is the first year of monitoring, assessments on the reproductive or mortality rates of each population are not possible at this time. The data presented in this report only provides baseline data on the sub-populations (represents the minimum one year of monitoring proposed), with monitoring to continue biannually (autumn and spring) to determine 'effective population size' (that is the proportion of each sub-population that are mature and capable of reproducing), average mortality rates, average reproduction/recruitment rates and age distribution of each sub-population.

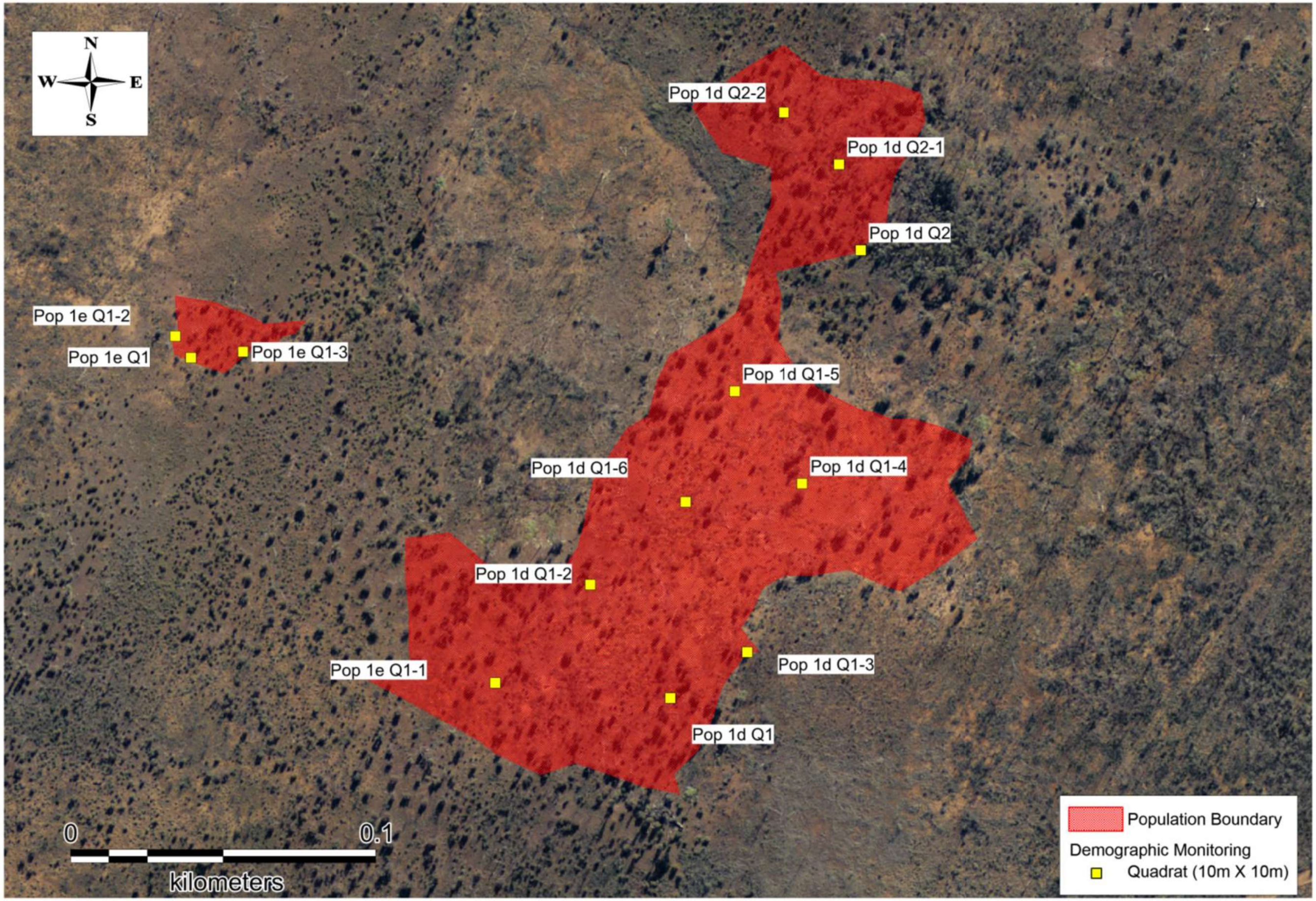
The data obtained from the ongoing monitoring (rates of mortality/ reproduction and age) will be used to conduct Population Viability Analysis modelling (using modelling programs e.g. *Vortex*) to predict the probability of extinction of each sub-population over time. Results of the analysis will assist in determining population structure and stability of the sub-populations and subsequently determine the susceptibility of *Marianthus* to direct/indirect impacts.

## Appendix 1: Demographic Monitoring Location Maps




N
W
E
S
Pop 1b Q1-1
Pop 1b Q1
0
0.05
kilometers
Population Boundary
Demographic Monitoring
Quadrat (10m X 10m)


N
W
E
S
Pop 1c Q2-1
Pop 1c Q2
Pop 1c Q2-2
Pop 1c Q2-3
Pop 1c Q2-4
Pop 1c Q1
0
0.05
kilometers
Population Boundary
Demographic Monitoring
Quadrat (10m X 10m)


N
W
E
S
Pop 1d Q2-2
Pop 1d Q2-1
Pop 1d Q2
Pop 1e Q1-2
Pop 1e Q1
Pop 1e Q1-3
Pop 1d Q1-5
Pop 1d Q1-6
Pop 1d Q1-4
Pop 1d Q1-2
Pop 1e Q1-1
Pop 1d Q1-3
Pop 1d Q1
0
0.1
kilometers
Population Boundary
Demographic Monitoring
Quadrat (10m X 10m)

## Appendix 2: Demographic Monitoring Quadrats GPS Coordinates

| Sub-Population | Quadrat | Zone | Easting | Northing | Elevation (m) |
|---|---|---|---|---|---|
| Population 1a | Pop 1a Q1 | 51 H | [redacted] | [redacted] | 392 m |
| | Pop 1a Q1-1 | 51 H | [redacted] | [redacted] | 401 m |
| | Pop 1a Q1-2 | 51 H | [redacted] | [redacted] | 392 m |
| | Pop 1a Q1-3 | 51 H | [redacted] | [redacted] | 391 m |
| | Pop 1a Q2 | 51 H | [redacted] | [redacted] | 376 m |
| | Pop 1a Q2-1 | 51 H | [redacted] | [redacted] | 383 m |
| Population 1b | Pop 1b Q1 | 51 H | [redacted] | [redacted] | 399 m |
| | Pop 1b Q1-1 | 51 H | [redacted] | [redacted] | 401 m |
| Population 1c | Pop 1c Q1 | 51 H | [redacted] | [redacted] | 417 m |
| | Pop 1c Q2 | 51 H | [redacted] | [redacted] | 404 m |
| | Pop 1c Q2-1 | 51 H | [redacted] | [redacted] | 401 m |
| | Pop 1c Q2-2 | 51 H | [redacted] | [redacted] | 402 m |
| | Pop 1c Q2-3 | 51 H | [redacted] | [redacted] | 400 m |
| | Pop 1c Q2-4 | 51 H | [redacted] | [redacted] | 406 m |
| Population 1d | Pop 1d Q1 | 51 H | [redacted] | [redacted] | 403 m |
| | Pop 1d Q1-2 | 51 H | [redacted] | [redacted] | 409 m |
| | Pop 1d Q1-3 | 51 H | [redacted] | [redacted] | 399 m |
| | Pop 1d Q1-4 | 51 H | [redacted] | [redacted] | 406 m |
| | Pop 1d Q1-5 | 51 H | [redacted] | [redacted] | 403 m |
| | Pop 1d Q1-6 | 51 H | [redacted] | [redacted] | 407 m |
| | Pop 1d Q2 | 51 H | [redacted] | [redacted] | 399 m |
| | Pop 1d Q2-1 | 51 H | [redacted] | [redacted] | 403 m |
| | Pop 1d Q2-2 | 51 H | [redacted] | [redacted] | 397 m |
| Population 1e | Pop 1e Q1 | 51 H | [redacted] | [redacted] | 402 m |
| | Pop 1e Q1-1 | 51 H | [redacted] | [redacted] | 409 m |
| | Pop 1e Q1-2 | 51 H | [redacted] | [redacted] | 400 m |
| | Pop 1e Q1-3 | 51 H | [redacted] | [redacted] | 395 m |

**Appendix 3: Demographic Monitoring Quadrat Data (Spring 2019)**

| | |
|---|---|
| **Population ID:** 1a | **Quadrat ID:** Q1 |
| **WP:** 9 | **Coordinates:**[redacted] |
| **Elevation:** 392 m | **Photo No:** 1 |
| **No. mature plants** | 24 |
| **No. juvenile plants (<30cm)** | 0 |
| **No. dead plants** | 1 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 3 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 76cm x 90cm |
| **Height/width of juvenile plants (average)** | N/A |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 15 |
| **Dominant species** | *Eucalyptus livida, Dodonaea viscosa* subsp. *spatulata, Lepidosperma sanguinolentum, Hakea pendens, Allocasuarina* sp. sterile |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1a | **Quadrat ID:** Q1-1 |
| **WP:** 88-91 | **Coordinates:** [redacted] |
| **Elevation:** 401m | **Photo No:** 288 |
| **No. mature plants** | 47 |
| **No. juvenile plants (<30cm)** | 4 |
| **No. dead plants** | 1 |
| **No. seedlings (single stem)** | 2 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 3 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 80cm x 80cm |
| **Height/width of juvenile plants (average)** | 20cm x 10cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 15 |
| **Dominant species** | *Eucalyptus livida, Dodonaea viscosa* subsp. *spatulata, Lepidosperma sanguinolentum, Hakea pendens, Allocasuarina* sp. sterile |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1a | **Quadrat ID:** Q1-2 |
| **WP:** 92-95 | **Coordinates:** [redacted] |
| **Elevation:** 392m | **Photo No:** 289 |
| **No. mature plants** | 20 |
| **No. juvenile plants (<30cm)** | 0 |
| **No. dead plants** | 0 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 4 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 80cm x 60cm |
| **Height/width of juvenile plants (average)** | N/A |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 20 |
| **Dominant species** | *Eucalyptus livida, Dodonaea viscosa* subsp. *spatulata, Lepidosperma sanguinolentum, Hakea pendens, Allocasuarina* sp. sterile |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1a | **Quadrat ID:** Q1-3 |
| **WP:** 96-099 | **Coordinates:** [redacted] |
| **Elevation:** 391m | **Photo No:** 290 |
| **No. mature plants** | 26 |
| **No. juvenile plants (<30cm)** | 1 |
| **No. dead plants** | 7 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 10 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 80cm x 60cm |
| **Height/width of juvenile plants (average)** | 20cm X 20cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 40 |
| **Dominant species** | *Eucalyptus livida, Dodonaea viscosa* subsp. *spatulata, Lepidosperma sanguinolentum, Hakea pendens, Allocasuarina* sp. sterile |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1a | **Quadrat ID:** Q2 |
| **WP:** 10 | **Coordinates:** [redacted] |
| **Elevation:** 376 m | **Photo No:** 293 |
| **No. mature plants** | 27 |
| **No. juvenile plants (<30cm)** | 0 |
| **No. dead plants** | 0 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 0 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 56cm x 60cm |
| **Height/width of juvenile plants (average)** | N/A |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 0 |
| **Dominant species** | *Eucalyptus livida, Dodonaea bursariifolia, Westringia cephalantha, Eremophila saligna, Trymalium myrtillus subsp. myrtillus, Dodonaea inaequifolia* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1a | **Quadrat ID:** Q2-1 |
| **WP:** 100-103 | **Coordinates:** [redacted] |
| **Elevation:** 383m | **Photo No:** 291 |
| **No. mature plants** | 47 |
| **No. juvenile plants (<30cm)** | 2 |
| **No. dead plants** | 0 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 8 |
| **No. fruiting plants** | 14 |
| **Height/width of mature plants (average)** | 60cm x 60cm |
| **Height/width of juvenile plants (average)** | 25cm x 10cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 40 |
| **Dominant species** | *Eucalyptus livida, Dodonaea bursariifolia, Westringia cephalantha, Eremophila saligna, Trymalium myrtillus subsp. myrtillus, Dodonaea inaequifolia* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| **Population ID:** 1b | **Quadrat ID:** Q1 |
| --- | --- |
| **WP:** 35 | **Coordinates:** [redacted] |
| **Elevation:** 399 m | **Photo No:** 314 |
| **No. mature plants** | 18 |
| **No. juvenile plants (<30cm)** | 1 |
| **No. dead plants** | 1 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 1 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 75cm x 60cm |
| **Height/width of juvenile plants (average)** | 25cm x 10cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 30 |
| **Dominant species** | *Eucalyptus livida, Melaleuca hamata, Westringia cephalantha, Gahnia ancistrophylla* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1b | **Quadrat ID:** Q1-1 |
| **WP:** 121-124 | **Coordinates:** [redacted] |
| **Elevation:** 401m | **Photo No:** 294 |
| **No. mature plants** | 17 |
| **No. juvenile plants (<30cm)** | 0 |
| **No. dead plants** | 0 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 9 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 70cm x 60cm |
| **Height/width of juvenile plants (average)** | N/A |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 15 |
| **Dominant species** | *Eucalyptus livida, Melaleuca hamata, Westringia cephalantha, Gahnia ancistrophylla* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| **Population ID:** 1c | **Quadrat ID:** Q1 |
|---|---|
| **WP:** 36 | **Coordinates:** [redacted] |
| **Elevation:** 417 m | **Photo No:** 315 |
| **No. mature plants** | 17 |
| **No. juvenile plants (<30cm)** | 2 |
| **No. dead plants** | 1 |
| **No. seedlings (single stem)** | 2 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 0 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 70cm x 60cm |
| **Height/width of juvenile plants (average)** | N/A |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 2 |
| **Dominant species** | *Eucalyptus livida, Westringia cephalantha, Beyeria brevifolia, Lepidosperma sanguinolentum* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1c | **Quadrat ID:** Q2 |
| **WP:** 50 | **Coordinates:** [redacted] |
| **Elevation:** 404 m | **Photo No:** 335 |
| **No. mature plants** | 24 |
| **No. juvenile plants (<30cm)** | 3 |
| **No. dead plants** | 2 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 0 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 60cm x 30cm |
| **Height/width of juvenile plants (average)** | 30cm x 8cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 0 |
| **Dominant species** | *Eucalyptus livida, Gahnia ancistrophylla, Eremophila saligna, Trymalium myrtillus subsp. myrtillus* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1c | **Quadrat ID:** Q2-1 |
| **WP:** 165-168 | **Coordinates:** [redacted] |
| **Elevation:** 401m | **Photo No:** 298 |
| **No. mature plants** | 40 |
| **No. juvenile plants (<30cm)** | 3 |
| **No. dead plants** | 1 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 0 |
| **No. fruiting plants** | 3 |
| **Height/width of mature plants (average)** | 60cm x 60cm |
| **Height/width of juvenile plants (average)** | 25cm x 8cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 15 |
| **Dominant species** | *Eucalyptus livida, Gahnia ancistrophylla, Eremophila saligna, Trymalium myrtillus* subsp. *myrtillus* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1c | **Quadrat ID:** Q2-2 |
| **WP:** 169-172 | **Coordinates:** [redacted] |
| **Elevation:** 402m | **Photo No:** 302 |
| **No. mature plants** | 41 |
| **No. juvenile plants (<30cm)** | 0 |
| **No. dead plants** | 5 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 6 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 70cm x 50cm |
| **Height/width of juvenile plants (average)** | N/A |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 15 |
| **Dominant species** | *Eucalyptus livida, Gahnia ancistrophylla, Eremophila saligna, Trymalium myrtillus* subsp. *myrtillus* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1c | **Quadrat ID:** Q2-3 |
| **WP:** 173-176 | **Coordinates:** [redacted] |
| **Elevation:** 400m | **Photo No:** 303 |
| **No. mature plants** | 48 |
| **No. juvenile plants (<30cm)** | 26 |
| **No. dead plants** | 10 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 1 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 80cm x 55cm |
| **Height/width of juvenile plants (average)** | 27cm x 4cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 9 |
| **Dominant species** | *Eucalyptus livida, Gahnia ancistrophylla, Eremophila saligna, Trymalium myrtillus subsp. myrtillus* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1c | **Quadrat ID:** Q2-4 |
| **WP:** 177-180 | **Coordinates:** [redacted] |
| **Elevation:** 406m | **Photo No:** 305 |
| **No. mature plants** | 70 |
| **No. juvenile plants (<30cm)** | 3 |
| **No. dead plants** | 12 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 20 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 90cm x 80cm |
| **Height/width of juvenile plants (average)** | 25cm x 4cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 30 |
| **Dominant species** | *Eucalyptus livida, Gahnia ancistrophylla, Eremophila saligna, Trymalium myrtillus subsp. myrtillus* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1d | **Quadrat ID:** Q1 |
| **WP:** 62 | **Coordinates:** [redacted] |
| **Elevation:** 403 m | **Photo No:** 350 |
| **No. mature plants** | 24 |
| **No. juvenile plants (<30cm)** | 5 |
| **No. dead plants** | 1 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 3 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 70cm x 70cm |
| **Height/width of juvenile plants (average)** | 30cm x 10cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 6 |
| **Dominant species** | *Eucalyptus livida, Dodonaea bursariifolia, Gahnia ancistrophylla* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1d | **Quadrat ID:** Q1-2 |
| **WP:** 282-285 | **Coordinates:** [redacted] |
| **Elevation:** 409m | **Photo No:** 313 |
| **No. mature plants** | 58 |
| **No. juvenile plants (<30cm)** | 2 |
| **No. dead plants** | 0 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 18 |
| **No. fruiting plants** | 3 |
| **Height/width of mature plants (average)** | 90cm x 30cm |
| **Height/width of juvenile plants (average)** | 20cm x 3cm |
| **No. fruits per plant (average)** | 40 |
| **No. flowers per plant (average)** | 20 |
| **Dominant species** | *Eucalyptus livida, Dodonaea bursariifolia, Gahnia ancistrophylla* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1d | **Quadrat ID:** Q1-3 |
| **WP:** 186-189 | **Coordinates:** [redacted] |
| **Elevation:** 399m | **Photo No:** 314 |
| **No. mature plants** | 60 |
| **No. juvenile plants (<30cm)** | 2 |
| **No. dead plants** | 2 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 1 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 60cm x 40cm |
| **Height/width of juvenile plants (average)** | 15cm x 4cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 14 |
| **Dominant species** | *Eucalyptus livida, Dodonaea bursariifolia, Gahnia ancistrophylla* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

<table>
<tr><td>Population ID: 1d</td><td>Quadrat ID: Q1-4</td></tr>
<tr><td>WP: 290-293</td><td>Coordinates: [redacted]</td></tr>
<tr><td>Elevation: 406m</td><td>Photo No: 315</td></tr>
<tr><td>No. mature plants</td><td>31</td></tr>
<tr><td>No. juvenile plants (<30cm)</td><td>0</td></tr>
<tr><td>No. dead plants</td><td>1</td></tr>
<tr><td>No. seedlings (single stem)</td><td>0</td></tr>
<tr><td>No. sprouting plants (multi-stem)</td><td>0</td></tr>
<tr><td>No. flowering plants</td><td>14</td></tr>
<tr><td>No. fruiting plants</td><td>0</td></tr>
<tr><td>Height/width of mature plants (average)</td><td>80cm x 40cm</td></tr>
<tr><td>Height/width of juvenile plants (average)</td><td>N/A</td></tr>
<tr><td>No. fruits per plant (average)</td><td>0</td></tr>
<tr><td>No. flowers per plant (average)</td><td>30</td></tr>
<tr><td>Dominant species</td><td>Eucalyptus livida, Dodonaea bursariifolia, Gahnia ancistrophylla</td></tr>
<tr><td>Spring 2018</td><td>Spring 2019</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Autumn 2019</td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

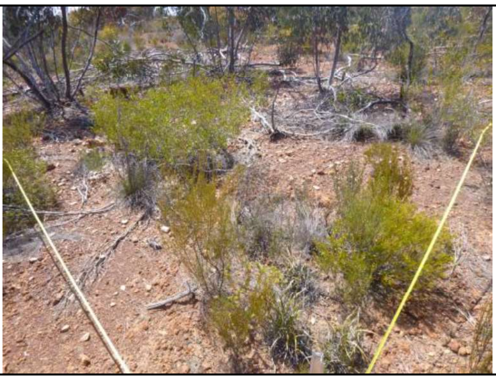
| | |
|---|---|
| **Population ID:**1d | **Quadrat ID:** Q1-5 |
| **WP:** 294-297 | **Coordinates:** [redacted] |
| **Elevation:** 403m | **Photo No:** 316 |
| **No. mature plants** | 15 |
| **No. juvenile plants (<30cm)** | 15 |
| **No. dead plants** | 0 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 8 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 70cm x 40cm |
| **Height/width of juvenile plants (average)** | 10cm x 3cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 15 |
| **Dominant species** | *Eucalyptus livida, Dodonaea bursariifolia, Gahnia ancistrophylla* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

<table>
<tr><td>Population ID: 1d</td><td>Quadrat ID: Q1-6</td></tr>
<tr><td>WP: 307-310</td><td>Coordinates: [redacted]</td></tr>
<tr><td>Elevation: 407m</td><td>Photo No: 320</td></tr>
<tr><td>No. mature plants</td><td>54</td></tr>
<tr><td>No. juvenile plants (<30cm)</td><td>0</td></tr>
<tr><td>No. dead plants</td><td>0</td></tr>
<tr><td>No. seedlings (single stem)</td><td>0</td></tr>
<tr><td>No. sprouting plants (multi-stem)</td><td>0</td></tr>
<tr><td>No. flowering plants</td><td>14</td></tr>
<tr><td>No. fruiting plants</td><td>0</td></tr>
<tr><td>Height/width of mature plants (average)</td><td>90cm x 70cm</td></tr>
<tr><td>Height/width of juvenile plants (average)</td><td>N/A</td></tr>
<tr><td>No. fruits per plant (average)</td><td>0</td></tr>
<tr><td>No. flowers per plant (average)</td><td>25</td></tr>
<tr><td>Dominant species</td><td>Eucalyptus livida, Dodonaea bursariifolia, Gahnia ancistrophylla</td></tr>
<tr><td>Spring 2018</td><td>Spring 2019</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Autumn 2019</td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

| | |
|---|---|
| **Population ID:** 1d | **Quadrat ID:** Q2 |
| **WP:** 68 | **Coordinates:** [redacted] |
| **Elevation:** 399 m | **Photo No:** 360 |
| No. mature plants | 14 |
| No. juvenile plants (<30cm) | 0 |
| No. dead plants | 3 |
| No. seedlings (single stem) | 1 |
| No. sprouting plants (multi-stem) | 0 |
| No. flowering plants | 4 |
| No. fruiting plants | 0 |
| Height/width of mature plants (average) | 60cm x 40cm |
| Height/width of juvenile plants (average) | N/A |
| No. fruits per plant (average) | 0 |
| No. flowers per plant (average) | 5 |
| Dominant species | *Eucalyptus livida, Dodonaea bursariifolia, Gahnia ancistrophylla* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1d | **Quadrat ID:** Q2-1 |
| **WP:** 298-301 | **Coordinates:** [redacted] |
| **Elevation:** 403m | **Photo No:** 318 |
| **No. mature plants** | 89 |
| **No. juvenile plants (<30cm)** | 5 |
| **No. dead plants** | 0 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 15 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 55cm x 40cm |
| **Height/width of juvenile plants (average)** | 15cm x 4cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 12 |
| **Dominant species** | *Eucalyptus livida, Dodonaea bursariifolia, Gahnia ancistrophylla* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1d | **Quadrat ID:** Q2-2 |
| **WP:** 302-305 | **Coordinates:** [redacted] |
| **Elevation:** 397m | **Photo No:** 319 |
| **No. mature plants** | 85 |
| **No. juvenile plants (<30cm)** | 0 |
| **No. dead plants** | 3 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 15 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 60cm x 60cm |
| **Height/width of juvenile plants (average)** | N/A |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 14 |
| **Dominant species** | *Eucalyptus livida, Dodonaea bursariifolia, Gahnia ancistrophylla* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1e | **Quadrat ID:** Q1 |
| **WP:** 81 | **Coordinates:** [redacted] |
| **Elevation:** 402 m | **Photo No:** 378 |
| No. mature plants | 57 |
| No. juvenile plants (<30cm) | 3 |
| No. dead plants | 0 |
| No. seedlings (single stem) | 0 |
| No. sprouting plants (multi-stem) | 0 |
| No. flowering plants | 4 |
| No. fruiting plants | 0 |
| Height/width of mature plants (average) | 55cm x 50cm |
| Height/width of juvenile plants (average) | 30cm x 10cm |
| No. fruits per plant (average) | 0 |
| No. flowers per plant (average) | 5 |
| Dominant species | *Eucalyptus livida, Westringia cephalantha, Lepidosperma sanguinolentum* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1e | **Quadrat ID:** Q1-1 |
| **WP:** 278-281 | **Coordinates:** [redacted] |
| **Elevation:** 409m | **Photo No:** 312 |
| **No. mature plants** | 32 |
| **No. juvenile plants (<30cm)** | 0 |
| **No. dead plants** | 3 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 23 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 80cm x 30cm |
| **Height/width of juvenile plants (average)** | N/A |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 25 |
| **Dominant species** | *Eucalyptus livida, Westringia cephalantha, Lepidosperma sanguinolentum* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1e | **Quadrat ID:** Q1-2 |
| **WP:** 270-273 | **Coordinates:** [redacted] |
| **Elevation:** 400m | **Photo No:** 308 |
| **No. mature plants** | 14 |
| **No. juvenile plants (<30cm)** | 4 |
| **No. dead plants** | 0 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 0 |
| **No. fruiting plants** | 0 |
| **Height/width of mature plants (average)** | 60cm x 30cm |
| **Height/width of juvenile plants (average)** | 10cm x 3cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 0 |
| **Dominant species** | *Eucalyptus livida, Westringia cephalantha, Lepidosperma sanguinolentum* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

| | |
|---|---|
| **Population ID:** 1e | **Quadrat ID:** Q1-3 |
| **WP:** 274-277 | **Coordinates:** [redacted] |
| **Elevation:** 395m | **Photo No:** 309 |
| **No. mature plants** | 53 |
| **No. juvenile plants (<30cm)** | 12 |
| **No. dead plants** | 1 |
| **No. seedlings (single stem)** | 0 |
| **No. sprouting plants (multi-stem)** | 0 |
| **No. flowering plants** | 0 |
| **No. fruiting plants** | 6 |
| **Height/width of mature plants (average)** | 60cm x 60cm |
| **Height/width of juvenile plants (average)** | 20cm x 4cm |
| **No. fruits per plant (average)** | 0 |
| **No. flowers per plant (average)** | 5 |
| **Dominant species** | *Eucalyptus livida, Westringia cephalantha, Lepidosperma sanguinolentum* |
| **Spring 2018** | **Spring 2019** |
|  |  |
| **Autumn 2019** | |
|  | |

**Attachment 4: Component 2 Report Assessment of genetic diversity in sub-populations of *Marianthus aquilonaris.* Prepared by Dr Tara Hopley and Dr Margaret Byrne Biodiversity and Conservation Science, Department of Biodiversity, Conservation and Attractions, for Audalia Resources Limited. DBCA (2019)**

Department of **Biodiversity, Conservation and Attractions**

GOVERNMENT OF WESTERN AUSTRALIA

**Biodiversity** and **Conservation Science**

# Component 2 Report

# Assessment of genetic diversity in sub-populations of *Marianthus aquilonaris*

**Dr Tara Hopley and Dr Margaret Byrne**

Biodiversity and Conservation Science, Department of Biodiversity, Conservation and Attractions

December 2019

Report submitted to Audalia Resources

## Executive Summary

This research is in response to a request from Botanica Consulting for a research project that provides information on the population genetic diversity, structure and connectivity of *Marianthus aquilonaris* to inform management of the population in relation to proposed mining activity. Audalia Resources is seeking more information about the connectivity of plants of *Marianthus aquilonaris* to inform environmental impact assessment and conservation management.

*Marianthus aquilonaris* is declared as Rare Flora under the Biodiversity Conservation Act 2016 and is recorded from six sub-populations in three population clusters at one location in the Bremer Range. Little is known of the genetic diversity and structure of the species, or the connectivity of subpopulations through gene flow. Proposed mining activity in the area may have impacts on two of the six sub-populations. This research aims to determine the genetic diversity and structure of the six subpopulations, the contribution of each population to the total diversity present in the species and the level of genetic connectivity among populations. This can inform management to maximise retention of genetic diversity.

The project addressed the requirement through research into the assessment of the genetic diversity present in each of the five sub-populations currently present (no individuals were found at the sixth sub-population), the spatial genetic structure present among the sub-populations, and assessment of connectivity and gene flow of the five sub-populations. Genetic diversity and structure research was accomplished by sampling 30 individuals from each of the five sub-populations and undertaking genetic assessment using a reduced representation genomic sequencing approach. Several population diversity parameters were measured for each sub-population as well as overall genetic structure and differentiation. The contribution of each sub-population to the total maximal gene diversity was also evaluated. Connectivity assessment was accomplished by undertaking paternity analysis of seed collected from ten mother plants in sub-population 1B to determine the source of the pollen contribution to the seed by identifying whether the pollen is local, from within the sub-population, or from another sub-population.

The main findings include:

- All sub-populations of *Marianthus aquilonaris* were found to have moderate levels of genetic diversity.
- The level of differentiation among the sub-populations is high given the small geographical distance between them, suggesting that there is limited genetic connectivity.
- Population differentiation analysis showed sub-population 1A to have the greatest differentiation from all other sub-populations, consistent with the greater isolation of this subpopulation.
- Analysis of contribution of each sub-population to the total gene diversity found subpopulation 1D, as well as sub-populations 1C and 1E, represent the largest proportion of the gene diversity present across the species.
- Sub-populations 1A and 1B are less representative of the gene diversity present than other sub-populations; however, they do contain more than half of the private alleles present.

- The majority of seedlings from sub-population 1B tested for paternity (96%) were fathered by plants within sub-population 1B.
- There is a high rate (49%) of self-pollination, where mothers are also the fathers of the seedling.
- Every progeny cohort is receiving pollen from multiple fathers, and paternal source plants are often spread throughout the sub-population showing pollen movement is occurring across the sub-population.
- 16% of plants were involved in fathering the outcrossed seedlings that were sampled, suggesting good contribution of plants to reproduction.
- A small number of seedlings are receiving a pollen contribution from other sub-populations, with evidence of contributions from sub-populations, 1A, 1C and 1D.

All sub-populations of *Marianthus aquilonaris* were found to represent unique genetic clusters, indicating that there has been limited historical connectivity and gene flow amongst all subpopulations. All sub-populations were found to harbour private alleles, representing unique diversity present within each sub-population. While sub-populations 1A and 1B represented the highest numbers of private alleles, gene diversity present in sub-populations 1C, 1D and 1E were the most representative of total gene diversity present in the species. Results suggest that while the majority of pollination is by fathers within sub-population 1B, there is a small amount of pollen coming from other sub-populations. A large number of plants within the sub-population are contributing to the reproductive process, of which we only assessed a snapshot. Every progeny cohort assessed had pollen contribution from multiple fathers, indicating mixing of genetic material throughout the sub-population during seed production. There is limited movement of pollen between sub-populations, which is consistent with the high differentiation seen between sub-populations.

## Project Objective and Outcome

The research project shall provide information about the genetic diversity, structure, connectivity and gene flow amongst the sub-populations of *Marianthus aquilonaris*.

## Background Proposed Research

This research is in response to a request from Botanica Consulting for a research project that provides information on the population genetic diversity, structure and connectivity of *Marianthus aquilonaris* to inform management of the population in relation to proposed mining activity. *Marianthus aquilonaris* is a rare species that is currently found in six sub-populations in three populations clusters at one location in the Bremer Range. Little is known of the genetic diversity and structure of the species, or the connectivity of sub-populations through gene flow. Proposed mining activity in the area may have impacts on one of the clusters of sub-populations. Audalia Resources is seeking more information about the population genetic diversity and structure of plants of *Marianthus aquilonaris* to inform environmental impact assessment and conservation management.

## Research Plan

This research will assess genetic structure and estimate connectivity among the sub-populations of *Marianthus aquilonaris*. The genetic analysis will be undertaken with next generation genomic sequencing that provides the greatest power to identify localised genetic structure and evidence of connectivity.

Samples from all sub populations of *Marianthus aquilonaris* will be collected and analysed using DArTseq to determine genetic diversity and genetic structure among the sub populations. DNA samples from up to 30 individuals per subpopulation (all individuals from sub-populations 1e and 1f that have less than 30 individuals) will be sequenced by Diversity Arrays Technology (150 samples in total). Population genetic parameters will be obtained for the species using a range of appropriate population genetics software, using the Pawsey supercomputing facilities where required.

Connectivity will be assessed using paternity analysis of seed collected from sub-population 1B to determine the location of the pollen contribution to the seed and whether the pollen is local or from another sub-population. DNA analysis using DArTseq of seed from collections from 10 plants in populations 1B will be undertaken, as well as all plants from sub-population 1B. This sub-population is smaller than the others and thus all plants in the sub-populations can be genotyped giving power to identify those seed sired by plants from within the sub-population, and those sired from plants in other sub-populations.

## Research Methodology

**Sample Collection**

Leaf samples from 30 individuals at each of the five sub-populations (1A, 1B, 1C, 1D, 1E) were received. No plants were found at sub-populations 1F. The spatial relationships among populations is represented in Figure 1. Seed and leaf were also received for 10 plants (mother plants) and 350 leaf samples representing all individuals present in sub-population 1B. Spatial relationships among individuals in sub-population 1B are represented in Figure 2.

[redacted]

*Figure 1 Spatial relationship among sub-populations of* Marianthus aquilonaris *in the Bremer Range.*

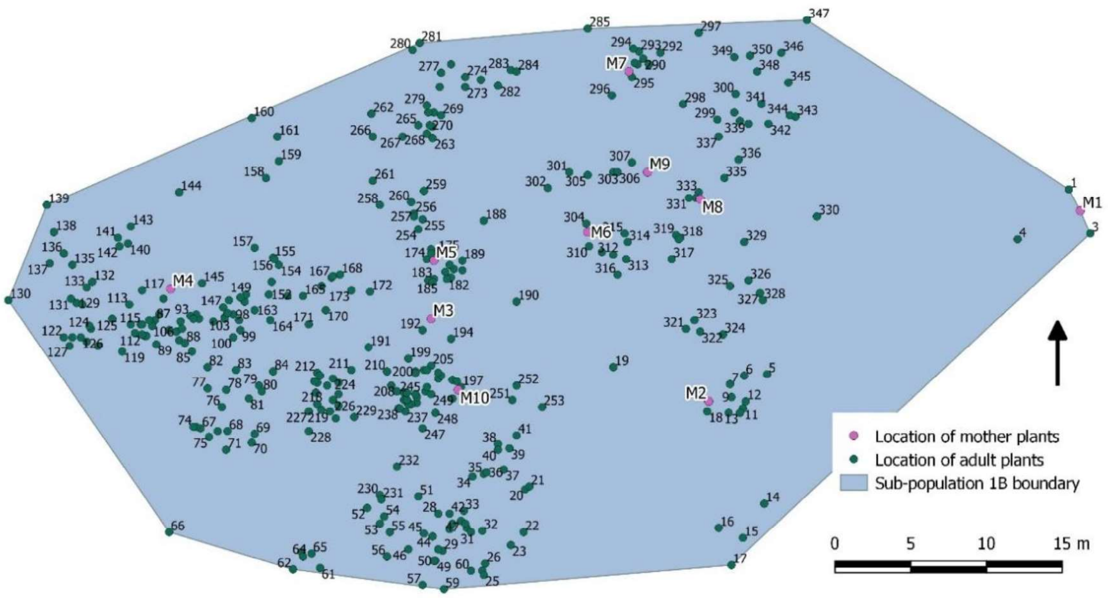



*Figure 2 Spatial relationship among individuals of sub-population 1B of* Marianthus aquilonaris *in the Bremer Range.*

**Laboratory Analysis**

The seed collections of *Marianthus aquilonaris* were cleaned then counted, listed in Table 1 below is the number of seeds received for each mother plant. For germination, 45 seed from each mother had the seed coat nicked with a scalpel blade. Seeds were then soaked in a 10% solution of PPM (Plant Preservative Material supplier, (Plant Cell Technology)) for 15 min before being placed onto agar containing 100 mg/L Gibberellic Acid (GA3). Gibberellic Acid (filter sterilised) was added to autoclaved water agar that had cooled to a temperature of 60°C. Plates were incubated at 15°C with light/dark cycles of 12 hours.

*Table 1: The number of seed received for each mother plant.*

| Mother | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Number of seeds received** | 45 | 110 | 100 | 64 | 30 | 90 | 48 | 90 | 105 | 102 |
| **Number of seedlings successfully grown** | 16 | 12 | 17 | 19 | 7 | 23 | 12 | 24 | 21 | 29 |

Leaf material from adult plants and from the seedlings was freeze-dried before genomic DNA was extracted using a modified CTAB method (Doyle & Doyle 1987), with the addition of 1% w/v PVP (polyvinylpyrrolodine) to the extraction buffer. DNA of samples was checked for quality and the amount of DNA quantified before DNA concentrations were standardised. DNA samples were then sent to Diversity Arrays Technology (DArT) (Canberra) for DArTSeq analysis.

**Data Analysis**

The results received from the DArTSeq analysis were filtered using the R packages dartR (Gruber & Georges 2019), poppr (Kamvar et al. 2014, 2015) and SNPRelate (Zheng et al. 2012) in R (R Core Team 2016). The data were filtered to a loci call rate of 95%, an individual call rate of 95%, a reproducibility score of 1, a hardy-weinberg equilibrium with a 5% level of significance, a minor allele frequency greater than 2%, a linkage disequilibrium threshold of 20%, removal of monomorphic loci, and finally filtered on hamming distance to remove potential paralogues

As the collection of all adult leaf samples at sub-population 1B was undertaken at a separate time to the collection of seed, it included recollection of leaf material form the 10 mother plants. Therefore, the first step was to identify which of the leaf collections was a repeat collection of the mother leaf samples. This was undertaken by creating a distance matrix from the final snp dataset using the dist function in the stats package in R (R Core Team 2016). The repeat samples were removed from the analysis.

*Outlier removal*

Outliers were removed from the filtered SNP dataset as most genetic structure programs used assume neutrality within data. BayPass (Gautier 2015) was used to identify outliers within the SNP datasets. This was done using the XtX differentiation measure, which is analogous to the SNP FST corrected for covariance of population allele frequencies. Initially the core model was run four times with default settings, with a nval of 100,000, burnin of 50,000, npilot of 30, and pilotlength of 5000, results were averaged over runs. Calibration of the XtX statistic was undertaken using the function simulate.baypass() to create a pseudo-observed dataset, and subsequently run using the same settings on the core model to calculate 1% and 99% thresholds to discriminate between neutral and outlier loci. Those SNPs having XtX statistics above the 99% and below the 1% threshold, representing directional and balancing selection respectively, were removed to create a neutral dataset.

*Neutral population structure*

To identify clusters of individuals and visualise the major axes of variation between clusters, principle coordinates analysis (PCO) was undertaken, implemented in the adegenet package (Jombart & Ahmed 2011) in R (R Core Team 2016). Expected and observed heterozygosity, private alleles, inbreeding coefficients and pairwise population differentiation (FST) were assessed using the adegenet (Jombart & Ahmed 2011), hierfstat (Goudet & Jombart 2015) and Poppr (Kamvar et al. 2014) packages in R.
Population genetic structure was explored using Structure 2.3.4 (Pritchard et al. 2000) using the neutral data set obtained after filtering and outlier removal. Analysis using K-values from 2 to 7 were undertaken, with ten independent runs for each K-value with a burnin of 50,000 and 250,000 MCMC iterations. The R package pophelper (Francis 2017) was used to visual results and select the most probable K based on the ΔK metric (Evanno et al. 2005).

Analyses were performed in Metapop 1.0.3 (Pérez-Figueroa et al. 2009) to determine the relative contributions of populations toward overall genetic diversity and to allow an assessment of the impact of their removal.

Adult leaf material representing all individuals in sub-population 1B was used to confirm the relationship between the full samples collection of all individuals in the sub-population with that of analysis using a subsample of 30 plants. Principal coordinates analysis (PCO), expected and observed heterozygosity, private alleles, inbreeding coefficients and pairwise population differentiation (FST) were assessed as described above.

*Paternity analysis*

To ensure a dataset that was informative for paternity analysis, a stringent filtering to loci with a minor allele frequency above 0.4 was undertaken and loci with mismatches between mother and progeny were removed. Paternity analyses were conducted with the SNP genotype data using CERVUS version 3.0, which uses a maximum-likelihood assignment based approach to infer parentage (Marshall *et al.* 1998; Kalinowski *et al.* 2007). CERVUS calculates the natural logarithm of the likelihood ratio (LOD score), which provides the likelihood of paternity of each candidate male relative to a random male in the population for each offspring. CERVUS uses simulations of the allele frequencies of adults in the population to calculate critical differences in LOD scores between the most likely father and all other candidate fathers to assign paternity at either 80% or 95% confidence. Paternity was simulated for 100,000 offspring to determine the critical LOD scores for the assignment of paternity. CERVUS assignments of the most likely fathers were made using Delta scores, Delta is defined as the difference in LOD scores between the most likely candidate parent and the second most likely candidate parent. The advantage of using Delta over LOD is that it guards against potentially incorrect assignment of parentage when two or more candidate parents have similar large positive LOD scores.

For any seedling that was not assigned paternity with at least 95% confidence in CERVUS, a population assignment method was used to predict the most likely sub-population to have produced that seedling. This was implemented in the R package assignPOP v1.1.7 (Chen et al. 2018). The assignPOP process performs population assignment using a machine-learning framework; it employs supervised machine-learning methods to evaluate the discriminatory power the data. It then uses a cross-validation procedure followed by PCA to evaluate assignment accuracy and membership probabilities. First, the data set is partitioned into training (baseline) and test (holdout) data sets using a resampling cross-validation procedure, with the user specifying the number or proportion of individuals from each source to be used in the training data set. Next, the features of the training data sets are reduced in dimensionality using PCA, the output of which is used to build predictive models from user-chosen classification machine-learning functions. Finally, these models are used to estimate membership probabilities of test individuals and assign them to a source population, while also evaluating the baseline data and conducting assignment tests on individuals for which the origin is unknown.

# Research Results

**Genetic diversity and differentiation - 30 individuals per sub-population**

The results from the samples that included 30 individuals from each of the five sub-populations, had a single sample fail sequencing and as such the DArTSeq results contained 149 samples and 9503 loci. After filtering, as outlined above, the filtered SNP dataset set contained 4065 loci and 146 individuals. Outlier detection analysis found 24 loci under directional selection and 24 loci under balancing selection. These outliers were removed from further data analysis of population differentiation and structure as most programs used assume neutrality within data. This resulted in a final dataset of 4017 loci.

Analysis of the samples of *Marianthus aquilonaris* found moderate levels of nuclear genetic diversity across all sub-populations (Table 2, Figure 3). The observed heterozygosity values ranged from 0.239 to 0.321, with sub-population 1D having the highest value and sub-population 1A having the lowest. Sub-population 1D also had the highest mean allelic richness at 1.92, followed by sub-population 1C at 1.87 while the lowest was found at 1B with 1.72. However, sub-population 1A was found to have the highest number of private alleles with 37 alleles unique to the sub-population, followed by sub-population 1C which has 23 private alleles. All sub-populations were found to have negative inbreeding coefficients suggesting that mating is not occurring between related or genetically similar individuals.

*Table 2: Genetic diversity characteristics of the five sub-populations of* Marianthus aquilonaris.

| Sub-population | Number of individuals | Mean allelic richness | Private alleles | Expected heterozygosity | Observed heterozygosity | Inbreeding coefficient | Population size estimate* |
|---|---|---|---|---|---|---|---|
| **1A** | 30 | 1.74 | 37 | 0.227 (0.003) | 0.239 (0.003) | -0.051 | 260/2259 |
| **1B** | 28 | 1.72 | 17 | 0.220 (0.003) | 0.246 (0.004) | -0.121 | 138/247 |
| **1C** | 29 | 1.87 | 23 | 0.279 (0.003) | 0.297 (0.003) | -0.065 | 1142/3205 |
| **1D** | 30 | 1.92 | 12 | 0.300 (0.003) | 0.321 (0.003) | -0.071 | 2090/NA |
| **1E** | 29 | 1.85 | 11 | 0.273 (0.003) | 0.281 (0.003) | -0.030 | 1029/NA |

*Population size estimates taken from counts by Botanica Consulting in 2013-2014 and DBCA in 2015.

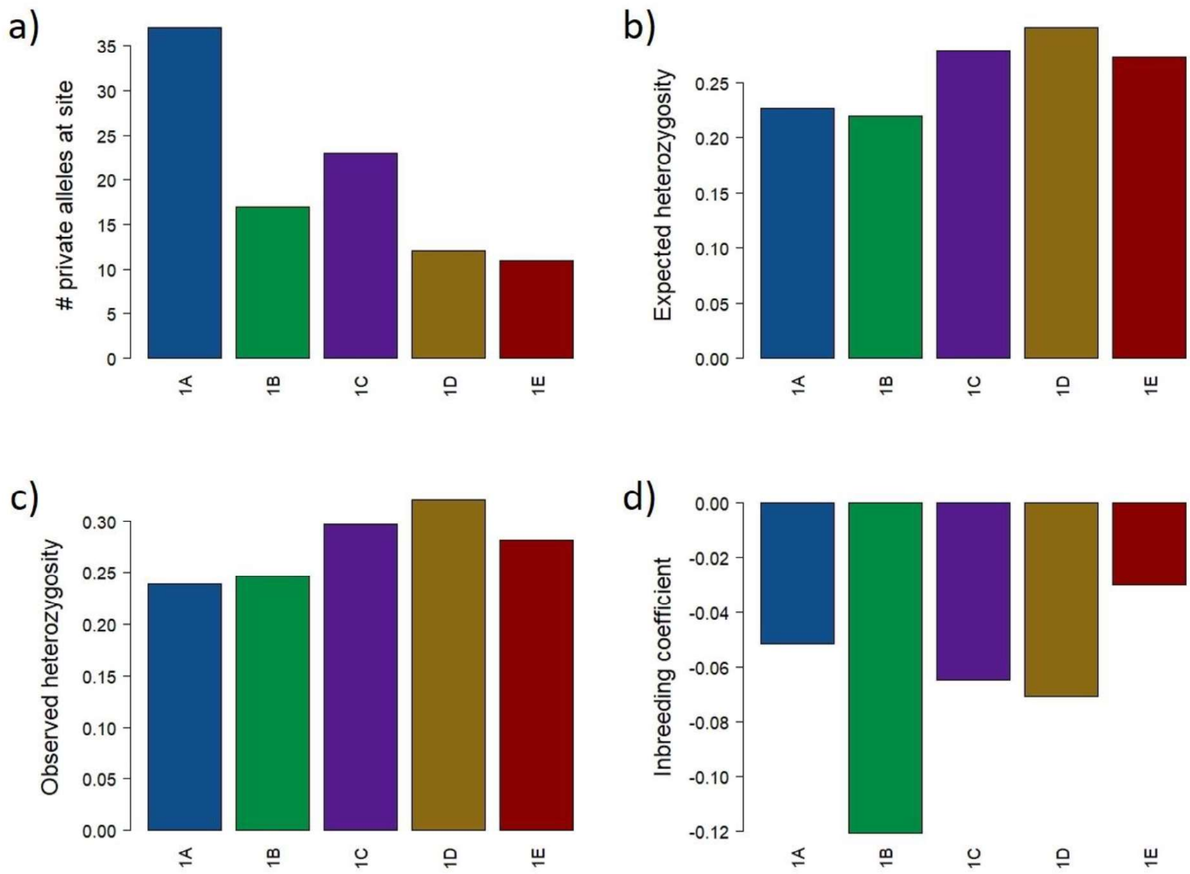



*Figure 3 Visual representation for comparison of genetic diversity characteristics, a) number of private alleles, b) expected heterozygosity, c) observed heterozygosity and d) inbreeding coefficient for each of the five sub-populations.*

Measures of genetic differentiation ($F_{ST}$) found a range of values from a low of 0.042 to a high of 0.235 (Table 3). The highest differentiation was between sub-populations 1A and 1B and the lowest differentiation was found between sub-populations 1D and 1E. Sub-populations 1A and 1B showed moderate differentiation from all sub-populations. Supporting the results of the principal coordinate analysis sub-populations 1C, 1D and 1E were found to have low levels of genetic differentiation. Principal components analysis also highlighted the highest differentiation amongst sub-populations to be between sub-populations 1A and 1B, separated along the first axis and the closer grouping of sub-populations 1C, 1D and 1E (Figure 4). With the second axis differentiating sub-population 1A from the grouping of sub-populations 1C, 1D and 1E. The principal components analysis also shows overlap between individuals in sub-population 1D and 1E.

*Table 3 Pairwise FST comparison amongst sub-populations of* Marianthus aquilonaris.

| Sub-population | 1A | 1B | 1C | 1D | 1E |
|---|---|---|---|---|---|
| **1A** | - | | | | |
| **1B** | 0.235 | - | | | |
| **1C** | 0.164 | 0.156 | - | | |
| **1D** | 0.141 | 0.159 | 0.067 | - | |
| **1E** | 0.181 | 0.197 | 0.106 | 0.042 | - |

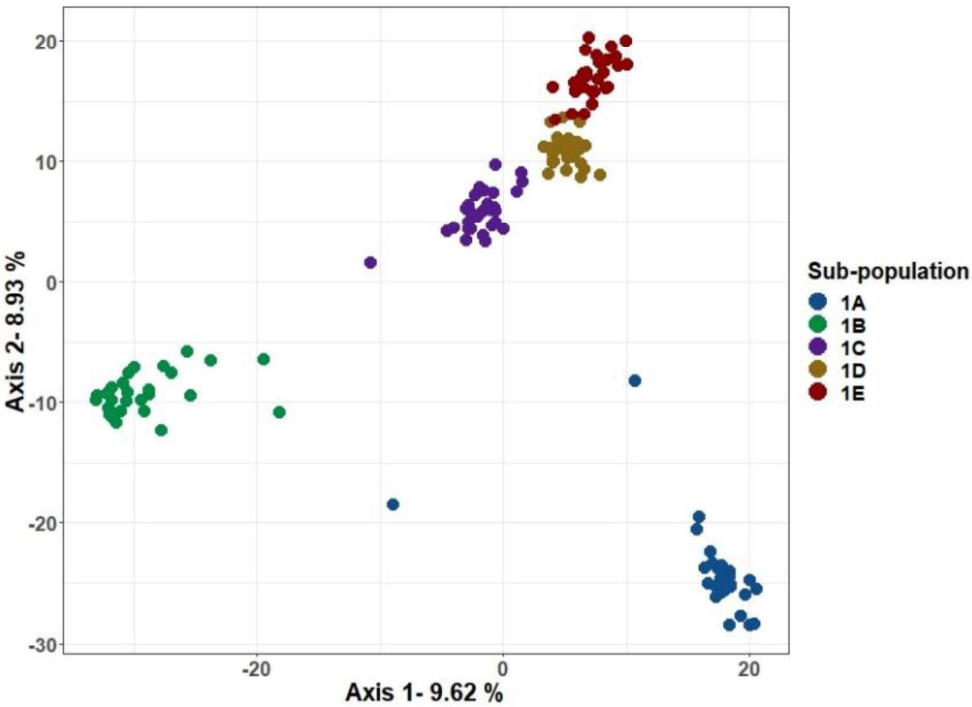



*Figure 4 Principal coordinates analysis of genetic differentiation based on 4017 single nucleotide polymorphisms. The first two axis shown represent 18.55% of the total genetic variation.*

Population genetic structure, assessed in Structure, identified five genetic clusters present, generally representing each of the five sub-populations (Figure 5). Sub-population 1D was found to be represented by a mixture of two genetic clusters, its own unique cluster and that genetic cluster represented by sub-population 1E. This shows that these two sub-populations have some connectivity, supporting the results found in the measures of genetic differentiation discussed above. The Structure results also highlight that several individuals in all populations are represented to some degree by their home sub-population genetic cluster and that of a different sub-population, generally neighbouring sub-populations. This indicates that some mating is occurring between sub-populations facilitating gene flow amongst sub-populations.

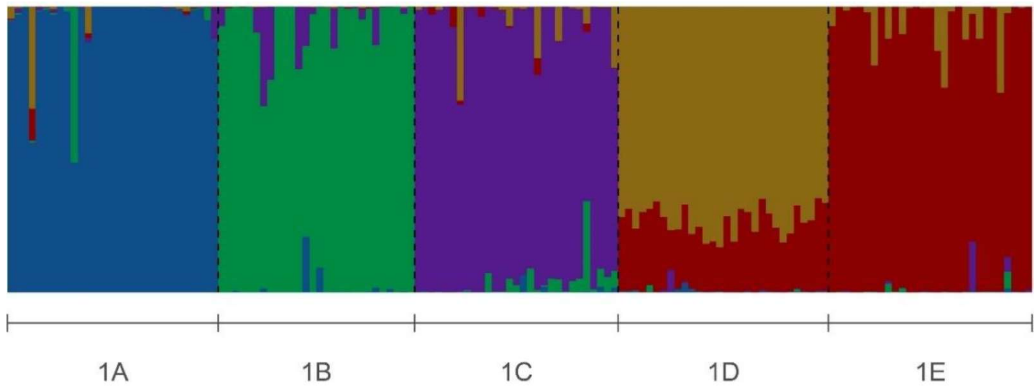



*Figure 5 Structure results showing the five identified genetic clusters present, each individual is represented by a vertical bar which is apportioned into its kinship to each of the identified genetic clusters.*

*Sub-population contributions*

Analysis of the contribution of each sub-population to the total maximal gene diversity found sub-population 1D to harbor a large proportion of the total gene diversity present across all the sub-populations, followed by sub-population 1C (Figure 6a). The impacts on total genetic diversity caused by removing each sub-population showed variable but small outcomes (Figure 6b). The gene diversity is slightly increased if sub-populations 1A and 1B are removed, this is likely a reflection of the lower heterozygosity found at these sites. Gene diversity is decreased the most when sub-population 1D is removed, with similar impacts when removing sub-populations 1C and 1E.

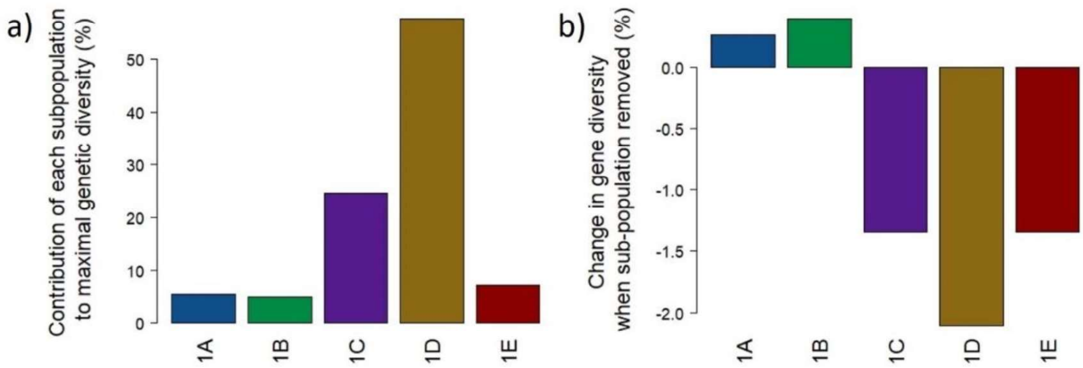



*Figure 6 Influence of sub-populations to a) proportional contribution of each subpopulation to a pool with maximal genetic diversity (%) and b) impacts of removing each sub-population on total gene diversity.*

**Genetic diversity and differentiation including all adult samples from sub-population 1B**

The genetic diversity and differentiation estimates from sub-population 1B with all individuals sampled were consistent with previous results, confirming that the sub-sampling provided a reliable sample of the genetic diversity in the sub-population. However, there was a slight reduction in diversity estimates for the second dataset between the smaller original sample of 30 individuals and that estimated from the whole sub-population sampling (Table 4). This may be due to more samples likely being related as all individuals were sampled whereas original sampling of a smaller number of plants would have been spread out across the sub-population in order to avoid sampling of related individuals. This is also likely reflected in the inbreeding coefficient, which shows a positive value for the whole population sampling, while all values are negative for those with only 30 representative samples from a sub-population.

*Table 4: Genetic diversity characteristics of the five sub-populations with 30 samples (1A-1E) and sub-population labelled M1BA which has all individuals of sub-population 1B represented.*

| Sub-population | Number of individuals | Mean allelic richness | Private alleles | Expected heterozygosity | Observed heterozygosity | Inbreeding coefficient |
|---|---|---|---|---|---|---|
| 1A | 30 | 1.768 | 0 | 0.261 (0.003) | 0.276 (0.004) | -0.056 |
| 1B | 30 | 1.799 | 0 | 0.251 (0.003) | 0.282 (0.004) | -0.122 |
| 1C | 30 | 1.888 | 0 | 0.314 (0.003) | 0.341 (0.003) | -0.088 |
| 1D | 30 | 1.904 | 0 | 0.326 (0.003) | 0.350 (0.003) | -0.074 |
| 1E | 30 | 1.849 | 0 | 0.301 (0.003) | 0.309 (0.003) | -0.026 |
| M1BA | 344 | 1.786 | 1 | 0.244 (0.003) | 0.223 (0.003) | 0.086 |

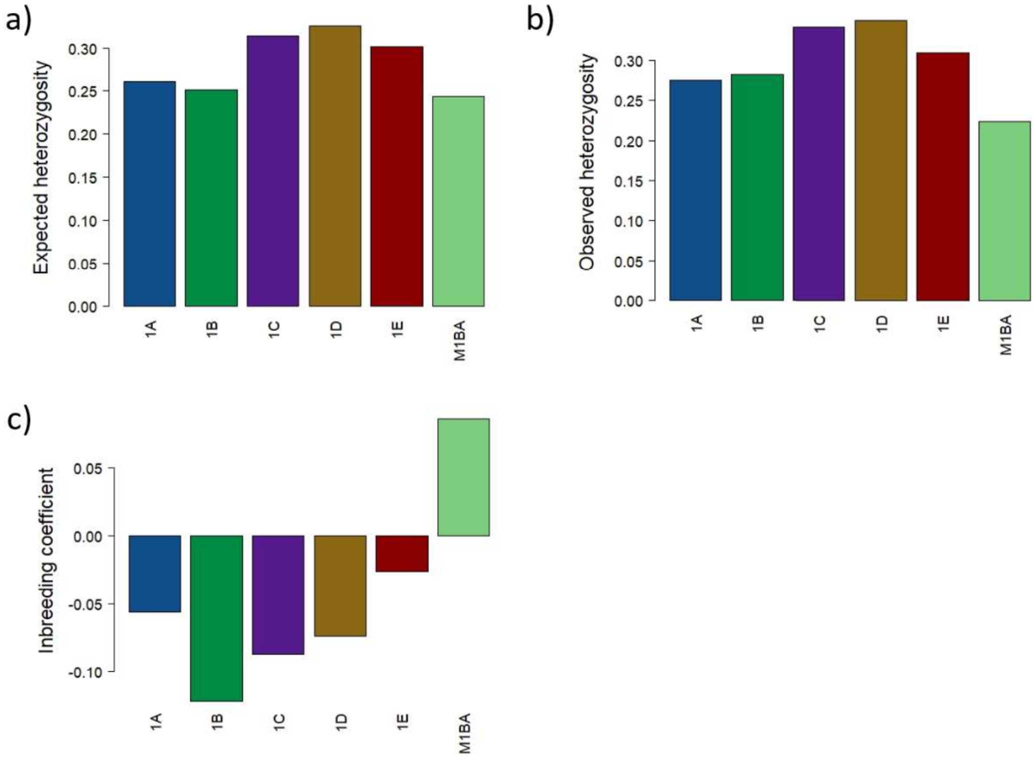



*Figure 7 Visual representation for comparison of genetic diversity characteristics, a) expected heterozygosity, b) observed heterozygosity and c) inbreeding coefficient for each of the five sub-populations and the whole populations sampling of sub-population 1B (M1BA).*

Measures of genetic differentiation among sub-populations ($F_{ST}$) reflected earlier work with estimates of differentiation from sub-population 1B with all individuals sampled slightly higher with the sub-sample (Table 5). The two sub-population 1B samples showed little differentiation (-0.002) as would be expected if the sub-sample was an accurate representation of the whole population. Principal components analysis showed the reduced sample of 30 individuals were clustered with the 350 individual samples from across the whole population (Figure 8).

*Table 5: Pairwise FST comparison amongst sub-populations of* Marianthus aquilonaris.

| **Sub-population** | **1A** | 1B | 1C | 1D | 1E | M1BA |
|---|---|---|---|---|---|---|
| 1A | - | | | | | |
| 1B | 0.234 | - | | | | |
| 1C | 0.157 | 0.156 | - | | | |
| 1D | 0.143 | 0.161 | 0.066 | - | | |
| 1E | 0.18 | 0.194 | 0.103 | 0.041 | - | |
| M1BA | 0.246 | -0.002 | 0.184 | 0.192 | 0.223 | - |

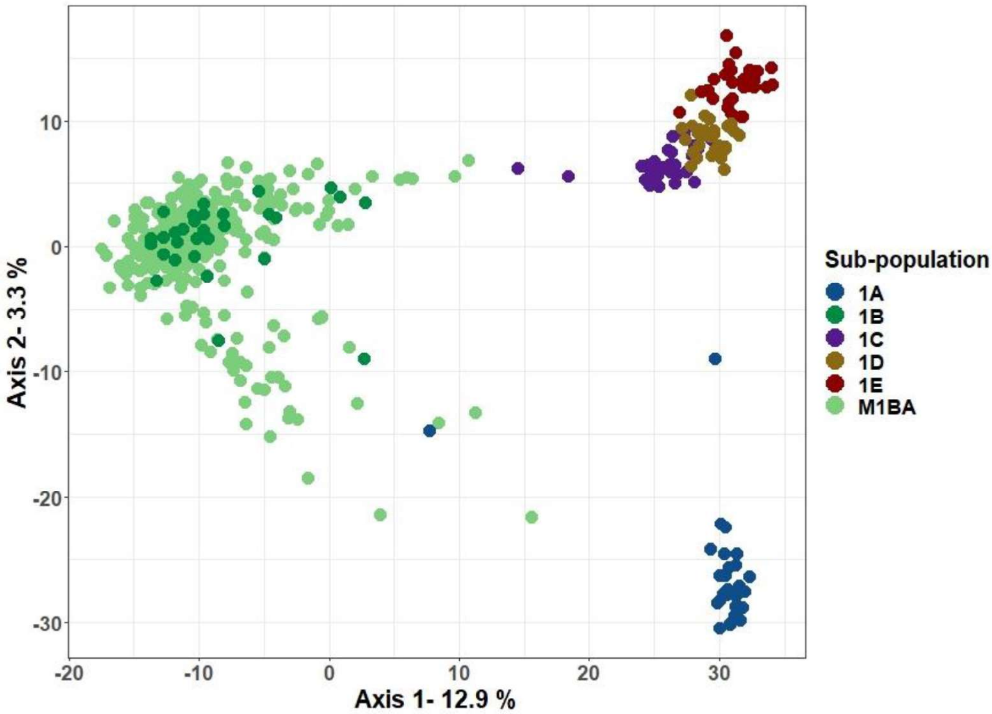



*Figure 8 Principal coordinates analysis of genetic differentiation based on 3499 single nucleotide polymorphisms. The first two axis shown represent 16.26% of the total genetic variation.*

**Paternity analysis**

Seed gemination was high and while variable among mothers, generally approached 100%. Seed germinates were planted into a pre-mix soil and seedling survival was low. Those mothers with low initial numbers of seed generally had lower germination and seedling survival. Seedlings were harvested once they reached about 5cm tall and DNA extraction was undertaken. A total of 180 seedlings were harvested and DNA extracted (The numbers of seedlings per mother are listed in Table 6).

The 350 adult DNA samples including the 10 mother DNA samples and the 180 seedling DNA samples were sequenced. Of the samples, 3 adult samples and 8 seedling samples failed sequencing, consequently DArTSeq results contained 347 adults and 172 seedlings sequenced at 9967 loci. After filtering, as outlined above, the filtered SNP dataset set contained 3548 loci across 344 adults and 165 seedlings. Outlier identification analysis found 28 loci under directional selection and 21 loci under balancing selection. These outliers were removed from further data analysis of population statistics and differentiation as programs used assume neutrality within data. This resulted in a final dataset of 3499 loci. This dataset was used to for confirming genetic diversity and differentiation and for population assignment.

The stringent filtering to create the most informative set of loci for paternity analysis resulted in 116 loci. These were used to assign paternity in CERVUS. While all seedlings were assigned paternity within sub-population 1B, not all of these were with a high confidence. Those seedlings with a trio Delta score correlating to a 95% confidence were considered as known paternity. Of the 165 seedlings genotyped, 148 were assigned paternity with 95% confidence, the numbers of seedlings for each mother with assigned paternity is shown in Table 4. The remaining 17 individuals were not able to be assigned to a specific father and may represent pollen from outside the sub-population or may represent paternity from a father with very close relatives that can't be differentiated. The proportion of seedlings from each mother assigned paternity varied from 75% in Mother 4 to 100% in three mothers. Of the 148 seedlings with known paternity, 75 (46%) were assigned as selfed seed, where the mother plant is also the father. The selfing rate (the proportion of seedlings that were selfed) varied between mothers, with no seedlings produced by selfing in Mother 6 to 87% (13) in Mother 1 (Table 4). This may be due to the Mother 1 plant being more isolated with a lower density of plants surrounding in the vicinity and on the edge of the sub-population boundary (Figure 1). However, Mother 10 had an 82% selfing rate and is in the middle of the sub-population and surrounded by other plants. There may be a combined effect of phenology (flowering timing) and density that influences the rate of outcrossing.

Of the 343 adult plants tested for paternity, 11% (39) contributed to the outcrossed (not selfed) seedlings assigned paternity. Each mother plant had multiple fathers contributing pollen to seedling cohort (Table 6). As the number of outcrossed seedlings per mother varied greatly so did the numbers of fathers contributing per seedlings cohort. Only 8 (21%) of the fathers contributed to three or more seedlings, the majority (79%) fathering only one or two seedlings. Of the 39 fathers, 8 (21%) contributed to more than one mother's seedling cohort. Figure 9-18 show the number of fathers, the location of fathers and the number of seedlings they fathered for each mother. While some mothers (M3, M5 and M7) show more localised pollen contributions, most mothers have pollen contributions from a broader area. There are a small number of mother-father pairs that produce a large number of offspring, mother 8 and father A333 with 11 progeny (Figure 16) and mother 6 and father A295 with seven progeny (Figure 14), although this will be biased by the number of seedling in each cohort. However, most mothers had seed with multiple fathers. There didn't seem to be an impact of location of mother plants on the proportion of progeny assigned paternity, even though it might be expected that mothers on the edge of the sub-population would be more likely to receive pollen from outside the population.

*Table 6: The number of seedlings successfully grown for each mother plant, the number of seedlings per mother after sequencing and filtering of data, the number of seedlings assigned paternity with 95% confidence in CERVUS and the numbers of fathers contributing to the seedling cohort for each mother plant.*

| **Mother** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Number of seedlings in final filtered sequencing dataset** | 15 | 12 | 16 | 16 | 4 | 23 | 9 | 21 | 21 | 28 |
| **Number of seedlings assigned paternity with 95% confidence** | 15 | 11 | 14 | 12 | 4 | 19 | 8 | 20 | 17 | 28 |
| **Number of seedlings that were selfed** | 13 | 4 | 11 | 10 | 2 | 0 | 3 | 3 | 6 | 23 |
| **Numbers of fathers contributing to non-selfed seedlings** | 2 | 6 | 3 | 2 | 2 | 11 | 5 | 6 | 10 | 4 |

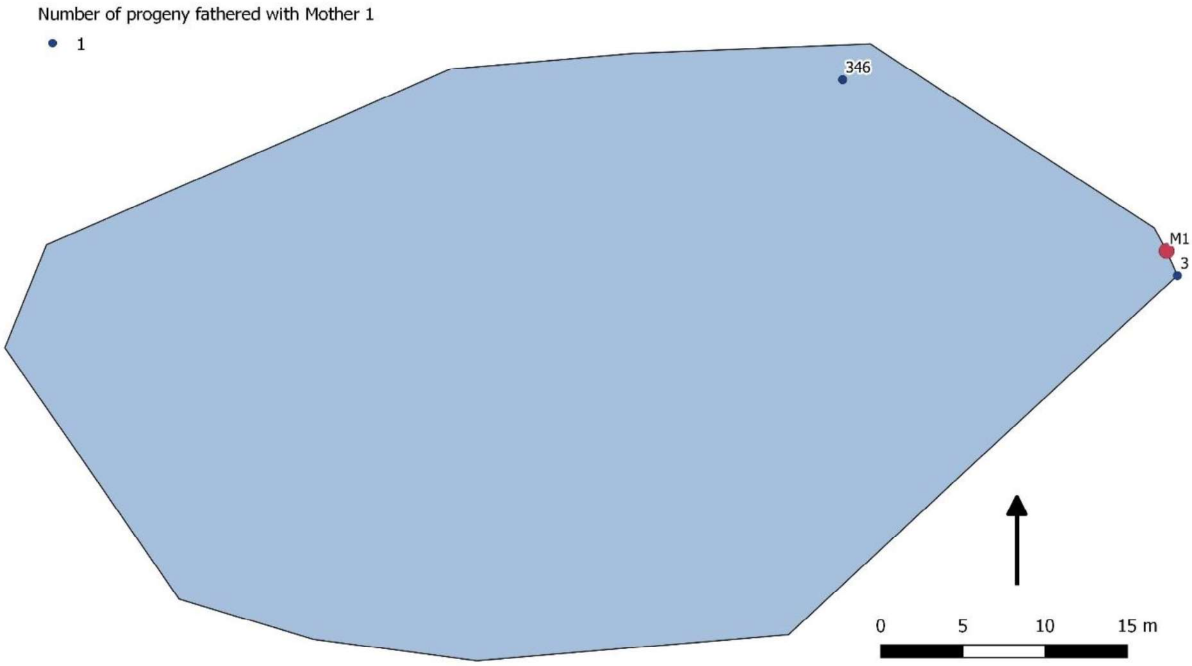



*Figure 9 Spatial relationship among Mother plant 1 and the fathers of seedlings assigned with 95% confidence in CERVUS, shaded area shows boundary of sub-population 1B of* Marianthus aquilonaris*.*

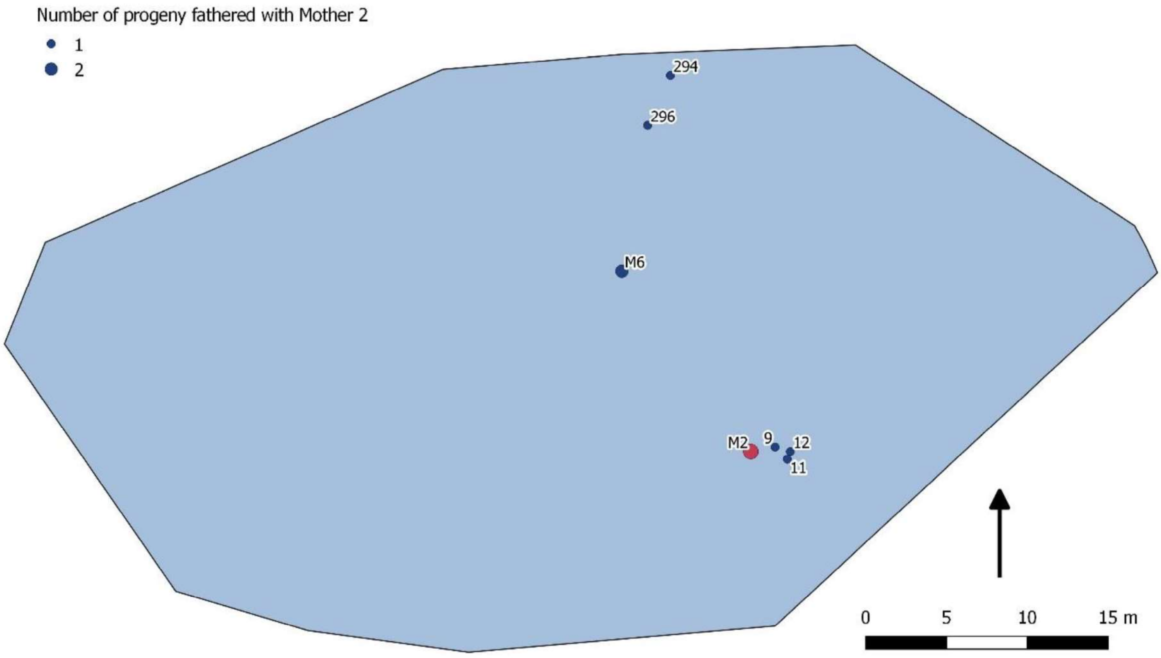



*Figure 10 Spatial relationship among Mother plant 2 and the fathers of seedlings assigned with 95% confidence in CERVUS, shaded area shows boundary of sub-population 1B of* Marianthus aquilonaris.

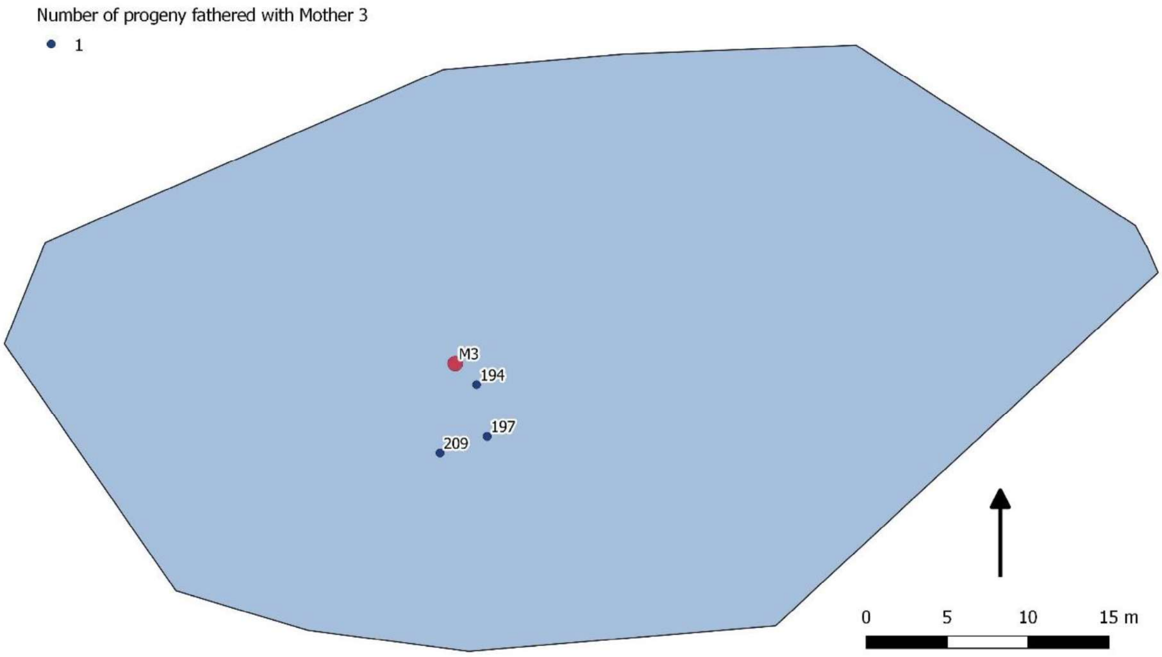



*Figure 11 Spatial relationship among Mother plant 3 and the fathers of seedlings assigned with 95% confidence in CERVUS, shaded area shows boundary of sub-population 1B of* Marianthus aquilonaris.

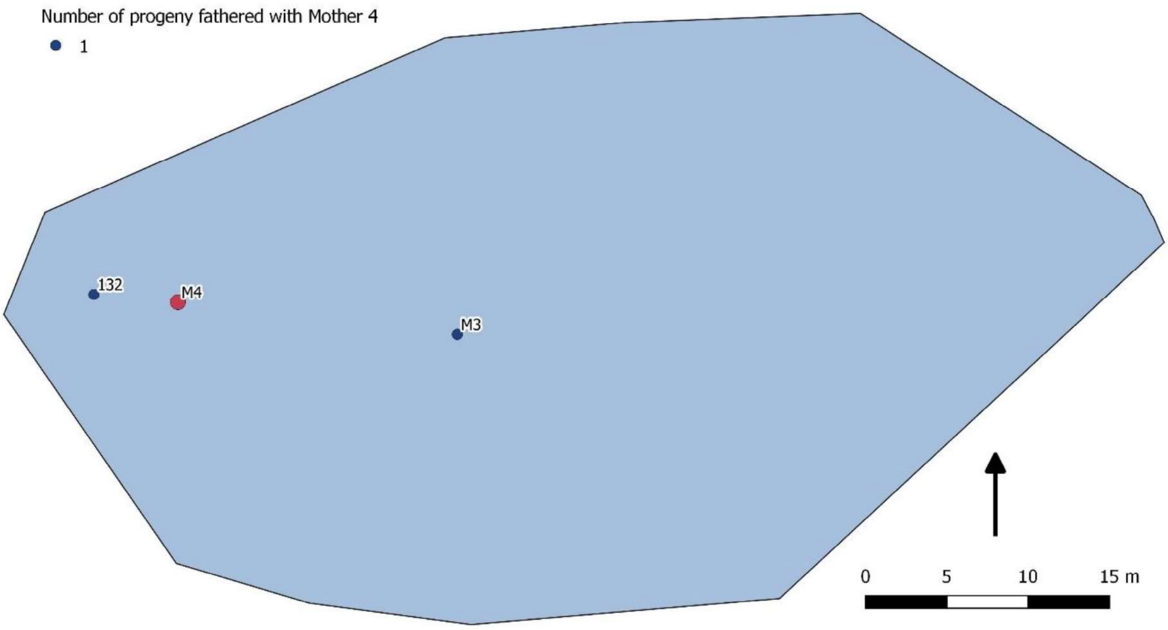



*Figure 12 Spatial relationship among Mother plant 4 and the fathers of seedlings assigned with 95% confidence in CERVUS, shaded area shows boundary of sub-population 1B of* Marianthus aquilonaris.

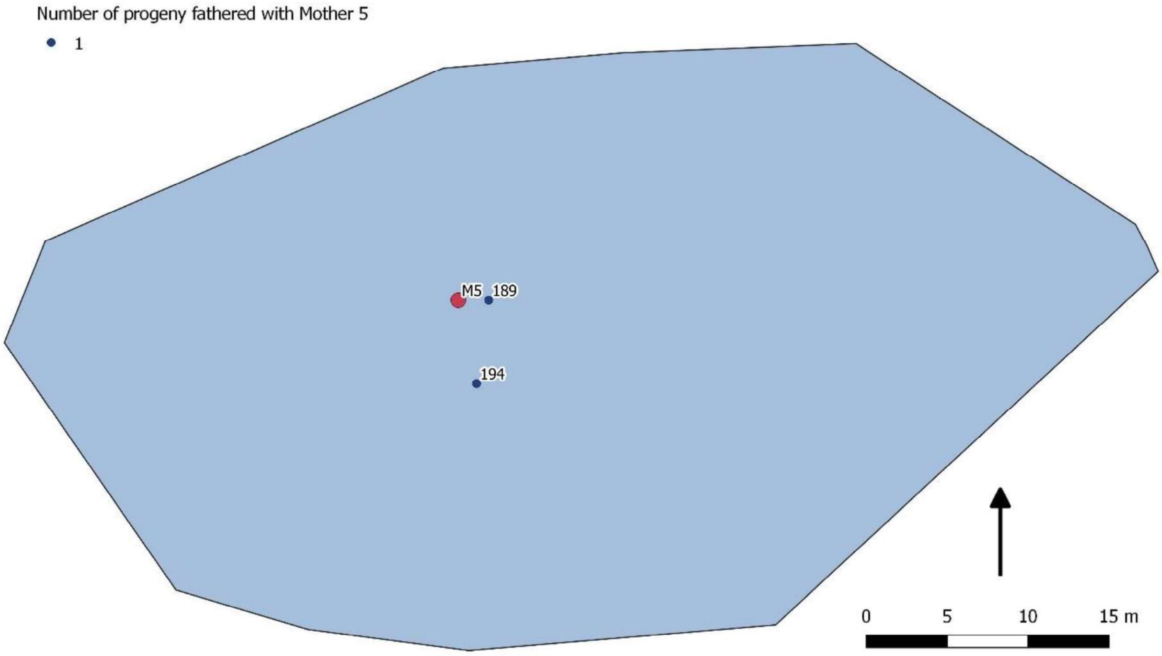



*Figure 13 Spatial relationship among Mother plant 5 and the fathers of seedlings assigned with 95% confidence in CERVUS, shaded area shows boundary of sub-population 1B of* Marianthus aquilonaris.

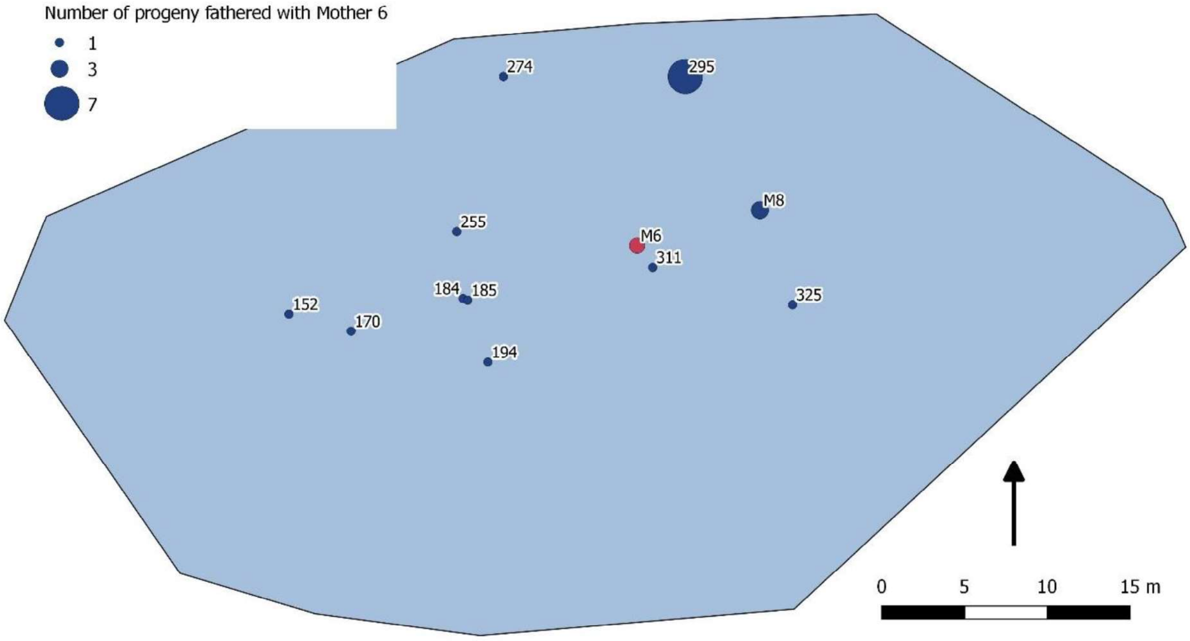



*Figure 14 Spatial relationship among Mother plant 6 and the fathers of seedlings assigned with 95% confidence in CERVUS, shaded area shows boundary of sub-population 1B of* Marianthus aquilonaris.

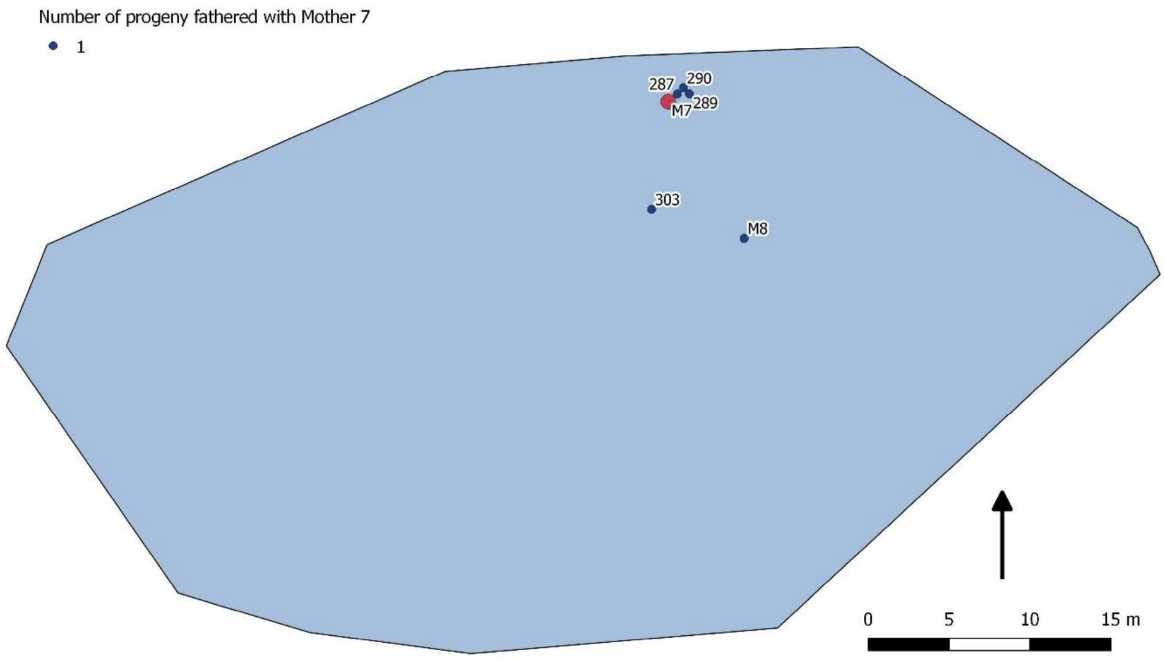



*Figure 15 Spatial relationship among Mother plant 7 and the fathers of seedlings assigned with 95% confidence in CERVUS, shaded area shows boundary of sub-population 1B of* Marianthus aquilonaris.

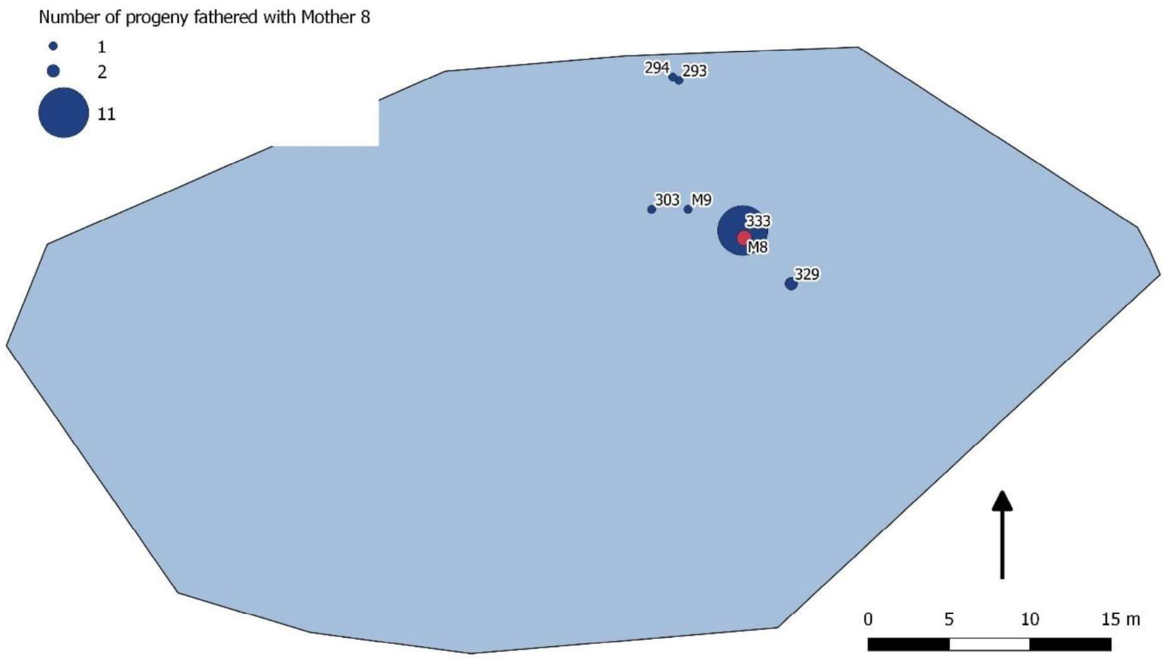



*Figure 16 Spatial relationship among Mother plant 8 and the fathers of seedlings assigned with 95% confidence in CERVUS, shaded area shows boundary of sub-population 1B of* Marianthus aquilonaris.

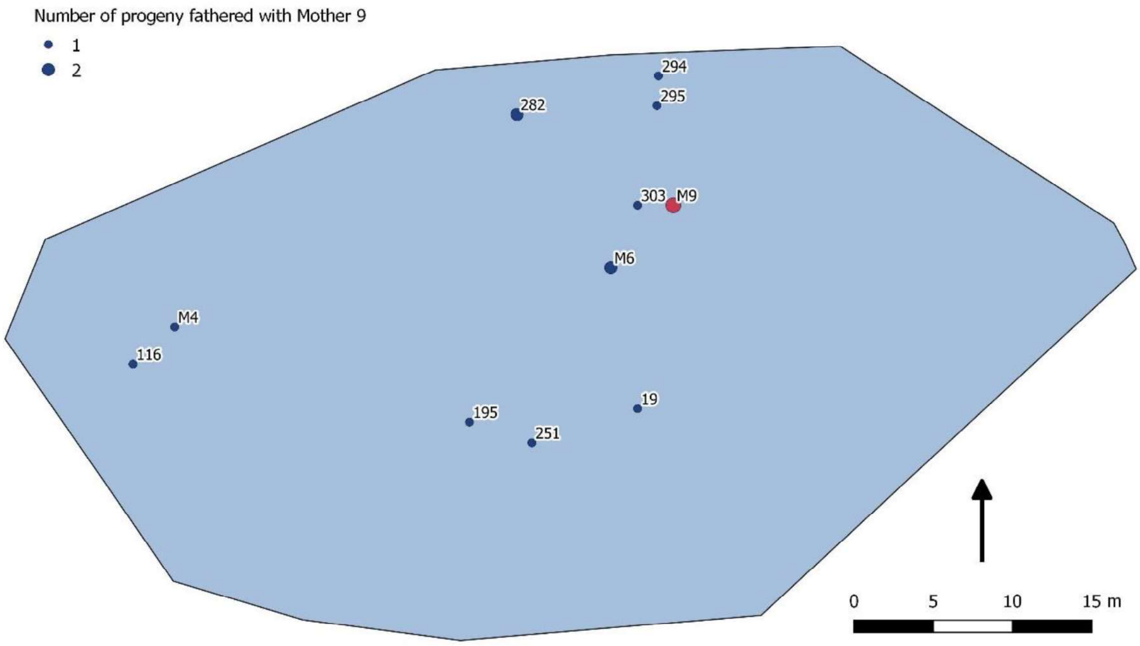



*Figure 17 Spatial relationship among Mother plant 9 and the fathers of seedlings assigned with 95% confidence in CERVUS, shaded area shows boundary of sub-population 1B of* Marianthus aquilonaris.

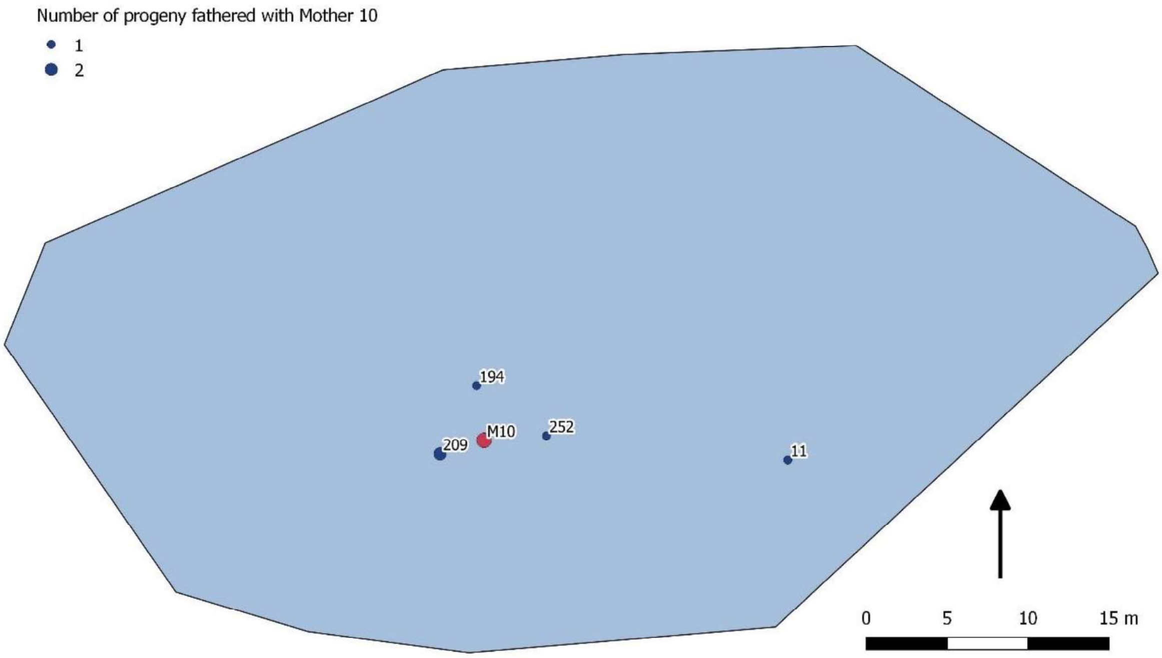



*Figure 18 Spatial relationship among Mother plant 10 and the fathers of seedlings assigned with 95% confidence in CERVUS, shaded area shows boundary of sub-population 1B of* Marianthus aquilonaris.

**Population assignment**

For those 17 seedlings that were not assigned paternity with a 95% confidence a population assignment approach was used to determine whether they are more likely to have been produced by pollen from another sub-population. The original 30 samples from each sub-population were used for the population assignment as this will not bias the results due to variation in sampling size.

To check the reliability of the assignment method we also examined the population assignment of the 148 seedlings that were assigned paternity with 95% confidence. For each of the seedlings being assessed, a probability of membership to each reference population was generated. Figure 19 shows these membership probabilities for each seedling, with a separate colour representing the proportional contribution to each of the sub-populations. All seedlings showed the majority assignment to sub-population 1B confirming the paternity assignment.

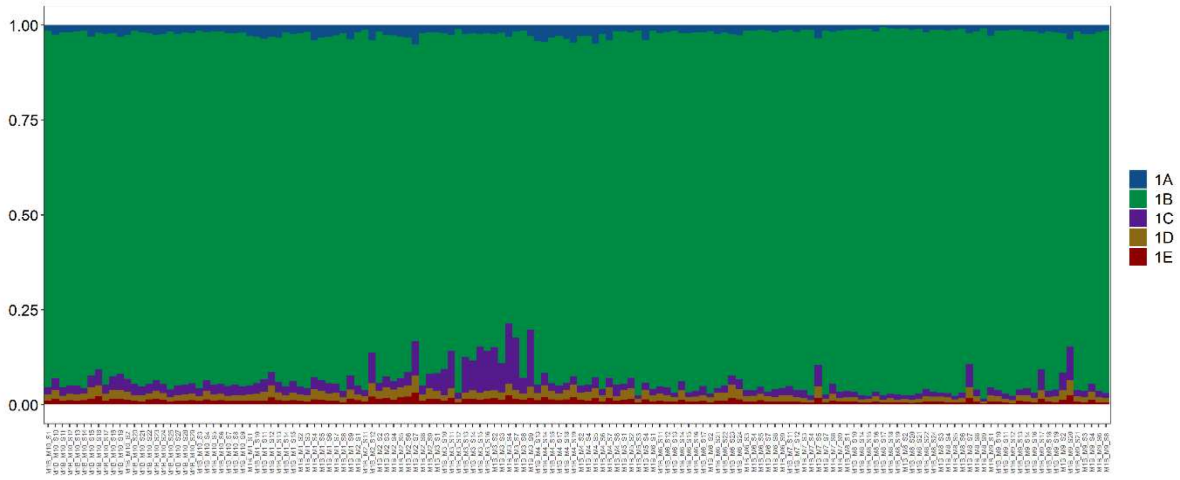



*Figure 19 Probability of membership for the 148 seedlings assigned paternity with 95% confidence, to the five sub-populations of* Marianthus aquilonaris*. Results estimated based on 3548 loci.*

For each of the 17 seedlings being assessed, a probability of membership to each reference population was generated. Figure 20 shows these membership probabilities for each seedling, with a separate colour representing the proportional contribution to each of the sub-populations. Of the 17 seedlings, 10 showed the majority assignment to sub-population 1B suggesting they have been fathered by plants within this sub-population. The other seven seedlings showed assignment to multiple sub-populations. Of these, four had majority assignment to sub-population 1C and 1B as expected from a seedling from sub-population 1B with pollen from sub-population 1C. A single seedling showed roughly 50% assignment to sub-population 1A along with some assignment to sub-populations 1C, 1D and 1B, and likely originated from pollen from sub-population 1A. The other two seedlings showed majority assignment to sub-population 1D with some assignment to 1B but also 1C, and it is likely that these three seedlings were fathered with pollen from sub population 1D. The two seedlings are from Mother 3 and seedlings from this mother also showed greater level of membership to sub-population 1C (Figure 19). This suggests that Mother 3 is a progeny of an earlier pollen migration event from sub-population 1C and this explains the mixed membership of the two seedlings fathered by pollen from sub-population 1D. Thus, the results suggest seven seedlings likely received pollen from outside sub-population 1B, from sub-populations 1C, 1D and 1A.

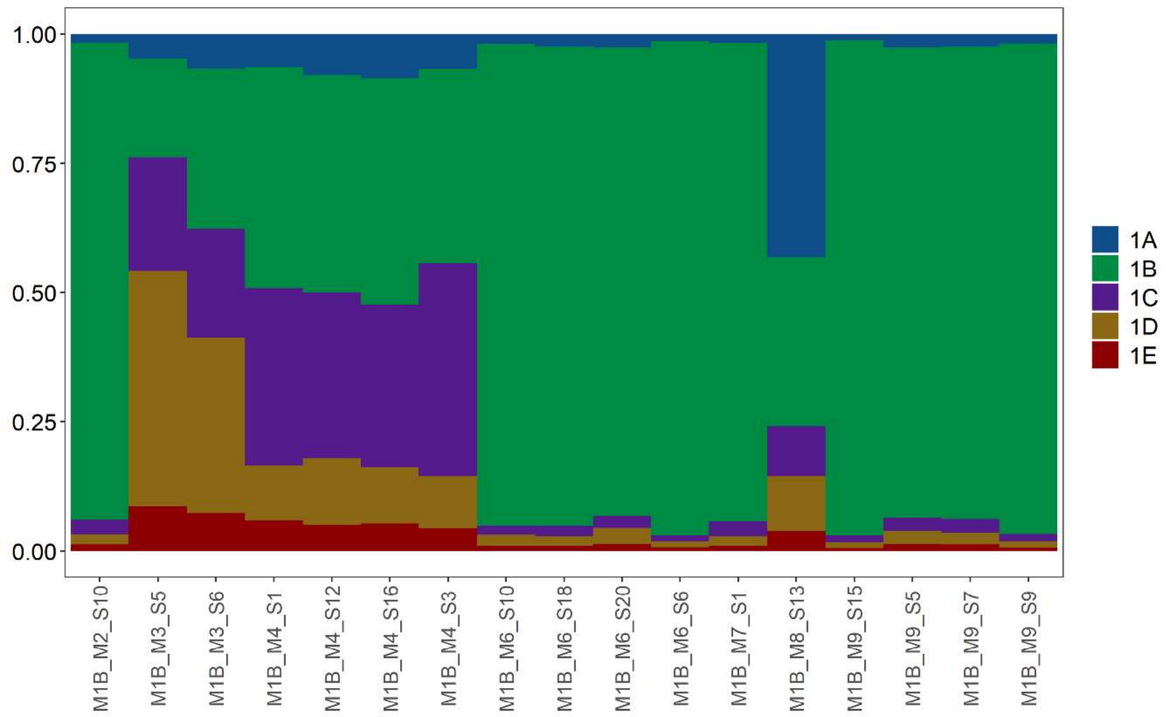



*Figure 20 Probability of membership for the 17 seedlings not assigned paternity with 95% confidence, to the five sub-populations of* Marianthus aquilonaris*. Results estimated based on 3548 loci.*

## Summary

Genetic analysis of all sub-populations of *Marianthus aquilonaris* showed moderate levels of genetic diversity. Sub-population 1D was found to have the highest heterozygosity and allelic richness levels, with sub-population 1C had the second highest heterozygosity, mean allelic richness and number of private alleles, while sub-population 1A had the lowest levels of heterozygosity. However, sub-population 1A was found to have the highest number of private alleles suggesting that this sub-population harbours the highest levels of genetic diversity that is unique from the other sub-populations. This is consistent with the greater isolation of this sub-population.

Population differentiation analysis showed sub-population 1A to have the greatest differentiation from all other sub-populations, consistent with the greater isolation of this sub-population, approximately 600 m from the nearest sub-population 1B. Sub-population 1B also showed high levels of differentiation from other sub-populations even though it is separated from sub-population 1C by only approximately 250m. Low levels of differentiation were found amongst sub-populations 1C, 1D and 1E. Sub-populations 1D and 1E appear to be genetically connected with a lower differentiation and some admixture between genetic clusters, as expected due to their closer geographic relationship. The level of differentiation among the sub-populations is high given the small geographical distance between them. This suggests that there is limited genetic connectivity among the sub-populations, except for 1D and 1E.

Analysis of contribution of each sub-population to the total gene diversity found sub-population 1D, as well as sub-populations 1C and 1E, contain the largest proportion of the gene diversity present across the species. Sub-populations 1A and 1B have less genetic diversity present, although these two sub-populations contain more than half of the private alleles present and removing these would likely result in a loss of allelic diversity.

The genetic diversity and differentiation estimates from sub-population 1B with genotypes of all individuals were consistent with the results from 30 samples from each sub-population, confirming that sub-sampling for genetic analysis was a reliable estimate of genetic relationships among sub-populations. The full sampling of sub-population 1B showed a slightly higher inbreeding coefficient and slightly lower heterozygosity estimates. This is likely due to more related individuals being included in the whole population sampling whereas the original sampling of a smaller number of plants would have been carried out across the sub-population to avoid sampling of related individuals.

Successful germination and growth of seedlings was variable between the seed cohorts, ranging from 5-29. Of the 180 seedlings sampled for analysis, 165 were successfully sequenced and passed quality and filtering checks. Of the 165 seedlings, 148 were assigned paternity to a sampled plant in sub-population 1B with 95% confidence. Of these 148 seedlings assigned paternity, 75 were assessed as arising from self-pollination where the mother is also the father. Of the outcrossed progeny, the numbers of seedlings assigned paternity per mother was variable, with every cohort receiving pollen from multiple fathers. The plants contributing pollen were spread throughout the sub-population showing pollen dispersal is occurring across the sub-population. Overall 11% of plants were involved in fathering the portion of seedlings that we sampled, suggesting good representation of plants involved with reproduction. Phenology has a strong influence on the plants involved in producing seed at any point in time. Generally, not all plants in a population will be flowering at the same time, as such only those flowering synchronously will be captured in a seedling cohort. It is therefore likely that plants in the population not represented in the current paternity analysis are also involved in reproduction across the sub-population.

Population assignment showed that seven seedlings, or 4% of all seedlings assessed, likely received pollen from outside sub-population 1B. While this amount is small, it is consistent with the high differentiation seen among sub-populations.

Analysis of seed has shown that pollen dispersal is occurring across sub-populations 1B over distances of approximately 42m. Pollen dispersal between sub-population 1B and other populations is low with only 4% of seedlings fathered from sub-populations 1C, 1D and 1A, that range from 150-465m away from sub-population 1B. The assignment of these seedlings confirms the power of this approach to detect pollen immigration. It may be that pollen immigration between closer population is greater.

Overall, the results demonstrate high levels of self-pollination, effective pollen dispersal among plants across the sub-population, and limited pollen immigration into the sub-population from other sub-populations.

## Acknowledgements

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**Attachment 5: Lake Medcalf Hydrogeological and Hydrological Study Characterisation of *Marianthus aquilonaris Habitat.* Prepared by Groundwater Resource Management. GRM (2020)**

GROUNDWATER RESOURCE MANAGEMENT

# Medcalf Hydrogeological and Hydrological Study

# Characterisation of *Marianthus* Habitat

Prepared for

**Audalia Resources Limited**

**Level 1, 1139 Hay Street**

**WEST PERTH WA 6005**

Report Distribution

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Report J1843R02b May 2020

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Audalia Resources Limited (Audalia) is developing the Medcalf Vanadium/Titanium Project. The site is located in the Bremer Range, some 470 km east of Perth and 100 km south west of Norseman, near Lake Johnson.

A threatened species under Part 2 of the Biodiversity Conservation Act 2016 (*Marianthus aquilonaris*) has been identified in the project area. Ecological assessment of the mine site has identified six sub-populations with the extent of the plant mapped. Further work is underway to determine critical habitat for the species. The Environmental Scoping Document (ESD) for the Project identifies a series of study requirements; the part relevant to this hydrology study is item 6:

> "Hydrological assessments of surface water flows/hydrological regimes of the Bremer Range and influence of ironstone ridge microhabitats."

This study characterises the surface water hydrology of the project area to assist in understanding the microhabitat of the species current area of occupancy. The study focuses on areas of soil mapped as 'shallow gravel over indurated mottled zone' as the plants appear to be associated with this soil type. The results will be used to help identify any unique characteristics of the area of occupancy that contribute to the existence of the community and to provide guidance for other areas in the region that may be able to support *Marianthus aquilonaris* communities.

The mine site is located in an arid area with low, variable rainfall and high evaporation. Average annual rainfall is approximately 294 mm/year. Evaporation exceeds rainfall in every month of the year. Rainfall occurs all year round, but more rain tends to be received during winter (May to September). Large events tend to occur in summer, mainly from January to March.

Drainage through the area of the *Marianthus aquilonaris* communities is defined by a line of low hills trending in an east-west direction. Drainage from the hills is generally either toward the north or south in a number of small catchments.

Soil mapping in other studies indicates that all the *Marianthus aquilonaris* populations occur on soils referred to as shallow gravel over indurated mottled zone. Of 13 discrete areas of the soil type identified, five contain *Marianthus aquilonaris* populations. The areas that contain *Marianthus aquilonaris* populations all lie across a ridge line and down north east or north west trending slopes. Of the areas without *Marianthus aquilonaris* populations, most lie on ridgelines and on slopes with aspects ranging from northerly to southerly. One lies mid-slope. One lies in the upper reaches of a small drainage line.

The area of catchment above the mapped soils that contain *Marianthus aquilonaris* populations is smaller than the soil area in all catchments and smaller than most of the population areas. The area of catchment above the populations is smaller than the population area in Catchments 3, 4 and 6 and marginally larger in Catchment 5. The area of soils containing *Marianthus aquilonaris* populations is a small proportion of the total catchment area, varying from 1-7%.

Modelling indicates that all of the mapped soil areas have a high runoff rate, which is consistent with their shallow soil profile and rocky surface. All of the areas receive some runoff from upslope; the amount varies depending on the location of the area in the landscape, local topography and surrounding soils. The water balance for the soil areas is dominated by evapotranspiration, which accounts for 60-80% of rainfall. This means that most of the rainfall is taken up by plants and transpired or evaporated from soil, rock and vegetation surfaces.

For the whole project area, the amount of runoff reduces from that predicted for the soil areas, consistent with the effects of higher rates of infiltration into the deeper red and gravely loams. While runoff from upper rocky areas can be high, much of this is infiltrated in the colluvial zone downslope. Runoff is predicted to account for 3% of rainfall over the project area.

Total seepage below the root zone, which could recharge groundwater, is low relative to the other components of the water balance. Recharge is likely to be highly episodic, with much occurring during extended wet periods. Evaporation still dominates the water balance at the site scale.

Regional groundwater level in the area is typically greater than 45 m below surface and the groundwater is hypersaline. Consequently the *Marianthus aquilonaris* plants are unlikely to have direct interaction with the regional groundwater table. *Marianthus aquilonaris* plants may benefit from underlying geological structures, such as vughs, iron stained fracture surfaces, quartz veining and bleached shearing, in terms of persistent soil moisture.

There are two larger rock holes in the area of the mapped *Marianthus aquilonaris* community. Both are small, shallow irregular depressions located on low ridgelines in exposed rock. The rock holes pond water for relatively short periods after larger rainfall events. Water in the holes is probably sourced from direct rainfall and runoff from a small catchment and lost mainly to evaporation.

# GLOSSARY OF HYDROLOGICAL TERMS

**Annual Exceedance Probability (AEP)**

The probability of an event being equalled or exceeded within a year. For rainfall, an event is a total accumulated over a given duration. For floods, an event is typically the annual maximum flow rate. The relationships in terminology between AEP and ARI for specific event probabilities are (Ball *et al.* 2016):

| Frequency descriptor | AEP %) | ARI (1 in *x*) |
|---|---|---|
| Frequent | 63.21 | 1 |
| Frequent | 50 | 1.44 |
| Frequent | 20 | 4.48 |
| Frequent | 18.13 | 5 |
| Rare | 10 | 9.49 |
| Rare | 5 | 20 |
| Rare | 2 | 50 |
| Rare | 1 | 100 |

**Antecedent Soil Moisture**

Water present in the soil prior to a rainfall event.

**Average Recurrence Interval (ARI)**

The average time period between occurrences of an event equalling or exceeding a given value.

**Australian Rainfall and Runoff (ARR)**

National guideline document, data and software suite that can be used for the estimation of design flood characteristics in Australia. Currently in its 4th edition it is commonly referred to as ARR2016.

**Australian Hydrological Geospatial Fabric (AHGF)**

The Australian Hydrological Geospatial Fabric (Geofabric) is a specialised Geographic Information System (GIS). It identifies and registers the spatial relationships between important hydrological features such as watercourses, water bodies, canals, aquifers, monitoring points and catchments.

**Backwater**

Water backed-up or retarded in its course as compared with its normal or natural condition of flow.

**Baseflow**

The component of streamflow supplied by groundwater discharge.

**Basin**

A tract of country, generally larger catchment areas, drained by a river and its tributaries.

**Catchment**

The land area draining to a point of interest, such as a water storage or monitoring site on a watercourse.

**Channel**

An artificial or constructed waterway designed to convey water. Often described as open channels to distinguish them from pipes.

**Control**

Physical properties of a cross-section or a reach of an open channel, either natural or artificial, which govern the relation between stage and discharge at a location in the open channel.

**Dead Storage**

In a water storage, the volume of water stored below the level of the lowest outlet (the minimum supply level). This water cannot be accessed under normal operating conditions.

**Discharge**

Volume of liquid flowing through a cross-section in a unit time.

**Drainage Division**

Representation of the catchments of the 12-major surface water drainage systems across Australia, generally comprising a number of river basins.

**Endorheic Basin**

A closed surface water drainage basin that retains water and has no outflow to the sea.

**Environmental Flow**

The streamflow required to maintain appropriate environmental conditions in a waterway or water body.

| | |
|---|---|
| **Ephemeral** | Something which only lasts for a short time. Typically used to describe rivers, lakes and wetlands that are intermittently dry. |
| **Evapotranspiration (ET)** | The sum of evaporation and plant transpiration from the earth's land surface to the atmosphere. |
| **Evaporation** | A process that occurs at a liquid surface, resulting in a change of state from liquid to vapour. |
| **Floodplain** | Flat or nearly flat land adjacent to a stream or river that experiences occasional or periodic flooding. |
| **Flood Risk** | The combination of the probability (likelihood or chance) of a flood event happening and the consequences (impact) if it occurred. Flood risk is dependent on there being a source of flooding, such as a sufficiently large upstream catchment, and something that is affected by the flood, such as a mine pit. |
| **Full Supply Level (FSL)** | The normal maximum operating water level of a water storage when not affected by floods. This water level corresponds to 100% capacity. |
| **Generalised Short-Duration Method (GSDM)** | Appropriate for estimating probable maximum precipitation for durations up to six hours and for an area of less than 1000 square kilometres. |
| **Generalised Tropical Storm Method – Revised (GTSMR)** | Appropriate for estimating probable maximum precipitation in regions of Australia affected by tropical storms. |
| **Intensity-Frequency-Duration (IFD)** | Design rainfall intensities (mm/h) or design rainfall depths (mm) corresponding to selected standard probabilities, based on the statistical analysis of historical rainfall. |
| **Minimum Supply Level (MSL)** | The lowest water level to which a water storage can be drawn down (0% full) with existing outlet infrastructure; typically, equal to the level of the lowest outlet, the lower limit of accessible storage capacity. |
| **Precipitation** | All forms in which water falls on the land surface and open water bodies as rain, sleet, snow, hail, or drizzle. |
| **Probable Maximum Flood (PMF)** | The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation (PMP, and coupled with the worst flood producing catchment conditions. |
| **Probable Maximum Precipitation (PMP)** | The theoretically greatest depth of precipitation for a given duration under modern meteorological conditions for a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends. |
| **Rainfall** | The total liquid product of precipitation or condensation from the atmosphere, as received and measured in a rain gauge. |
| **Riparian** | An area or zone within or along the banks of a stream or adjacent to a watercourse or wetland; relating to a riverbank and its environment, particularly to the vegetation. |
| **Stage** | Water level relative to a datum, typically measured at a water monitoring site. |
| **Storage** | A pond, lake or basin, whether natural or artificial, for the storage, regulation and control of water. |
| **Surface Runoff** | Water from precipitation or other sources that flows over the land surface. Surface runoff is the fraction of precipitation that does not infiltrate at the land surface and may be retained at the surface or result in overland flow toward depressions, streams and other surface water bodies. |
| **Sustainable Yield** | The level of water extraction from a particular system that would compromise key environmental assets, or ecosystem functions and the productive base of the resource, if it were exceeded. |
| **Total Suspended Solids (TSS)** | The sum of all particulate material suspended (i.e. not dissolved) in water. Usually expressed in terms of milligrams per litre (mg/L). It can be measured by filtering and comparing the filter weight before and after filtration. |

| | |
|---|---|
| **Transpiration** | Evaporative loss of water from the leaves of plants through the stomata; the flow of water through plants from soil to atmosphere. |
| **Watercourse** | A river, creek or other natural watercourse (whether modified or not) in which water is contained or flows (whether permanently or from time to time). |
| **Wind Run** | The product of the average wind speed and the period over which that average speed was measured. |

Terms referenced from BoM (2018a).

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# 1.0 INTRODUCTION

## 1.1 BACKGROUND

Audalia Resources Limited (Audalia) is proposing to develop their Medcalf Vanadium/Titanium Project. The site is located some 470 km east of Perth and 50 km south west of Norseman, near Lake Johnson. The site is located in the Bremer Range.

The site location and overall project layout is shown on Figure 1. Proposed preliminary and indicative mine site layout is given in Figure 2.

Shallow open pit mining for vanadium and titanium is planned from three separate open pits - Vesuvius, Fuji and Egmont. Site infrastructure includes waste rock dumps, tailings storage facility, beneficiation plant, administration and camp. A 73 km haul road will be constructed connecting the site to the Esperance Highway to the east. A transfer depot will be built near the highway.

The ore production rate is likely to be in the order of 1.5 Mtpa over a 13 year life of mine with beneficiation processing at the mine site. The concentrate will be transported by haul trucks along the haul road to the transfer depot. The concentrate will then be transferred to smaller road trains for transport to the Esperance Port.

Audalia has been granted mining lease M63/656, and have submitted an Environmental Scoping Document (ESD, Audalia 2019) that defines the required studies for impact assessment. Item 6 of the ESD defines the study requirements relevant to hydrology:

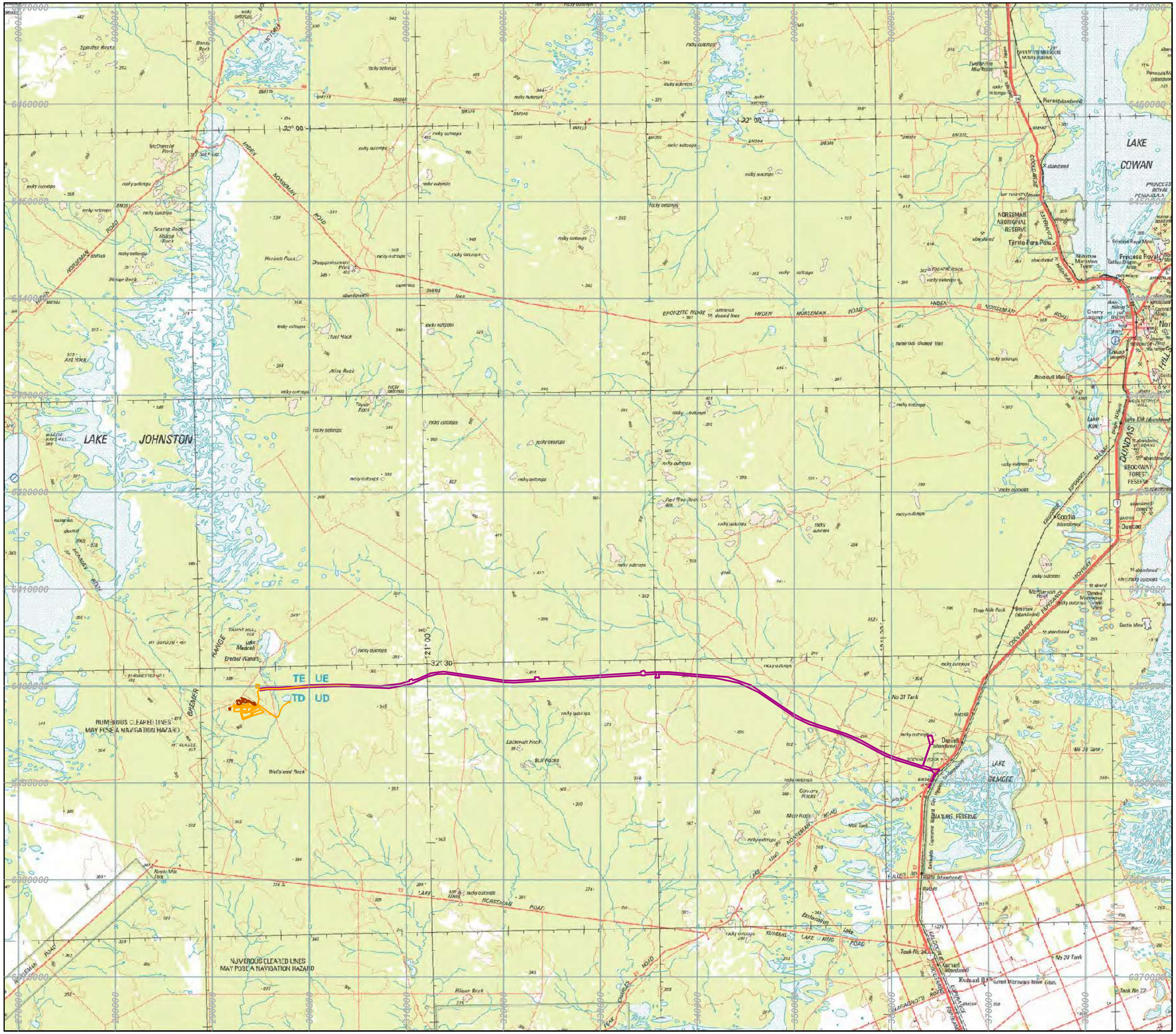
> "Hydrological assessments of surface water flows/hydrological regimes of the Bremer Range and influence of ironstone ridge microhabitats."

A rare flora (*Marianthus aquilonaris*) has been identified in the project area which will require further assessment to understand the habitat of the species. *Marianthus aquilonaris* was declared as Threatened under the WC Act in 2002 and is currently listed as 'critically endangered' under the World Conservation Union (IUCN) criteria.

Substantial ecological and landform assessment of the community at the mine site has already been undertaken. Four communities have been identified and a general extent of the plant at the mine site mapped (Botanica, 2017a, 2018). A soil investigation (Lantzke 2019) mapped a soil type (Shallow gravel over indurated mottled zone) that consistently occurs where *Marianthus aquilonaris* has been observed to occur. Lantzke (2019) suggests that the location of these soils may assist in determining the boundaries of critical *Marianthus aquilonaris* habitat. Accordingly, the location and characteristics of these soils are a focus for this hydrologic investigation.

Characterisation of surface water hydrology for the area of *Marianthus aquilonaris* is required to satisfy the ESD requirements for hydrological assessments. This study will be used to help identify any unique characteristics of this site that contribute to the existence of the community and to provide guidance for other areas in the region that may be able to support *Marianthus aquilonaris* communities.

This report presents the results of the hydrological study. The work presented here includes a review of the plant's characteristics, description of the physical environment as related to surface water and groundwater hydrology, and water balance modelling.

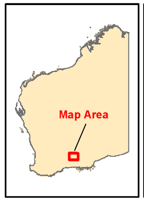



## Legend

- Pits
- Project Disturbance Footprint
- Transport Development Envelope

Data Sources:
Project Disturbance Footprint, Transport Development Envelope, Pits - Audalia Resources Limited
250K topography - Geoscience Australia

Location




1:100 000 Map Sheet Location

| | | | |
|---|---|---|---|
| Lake Percy 2934 | Diamond Rock 3034 | Cave Hill 3134 | Cowan 3234 |
| Roundtop 2933 | Johnston 3033 | Bronzite Ridge 3133 | Norseman 3233 |
| Hope 2932 | Tay 3032 | Peak Charles 3132 | Dundas 3232 |

N

SCALE 1:400,000

0 2.5 5 10 15 20 Km

GDA 1994 MGA Zone 51

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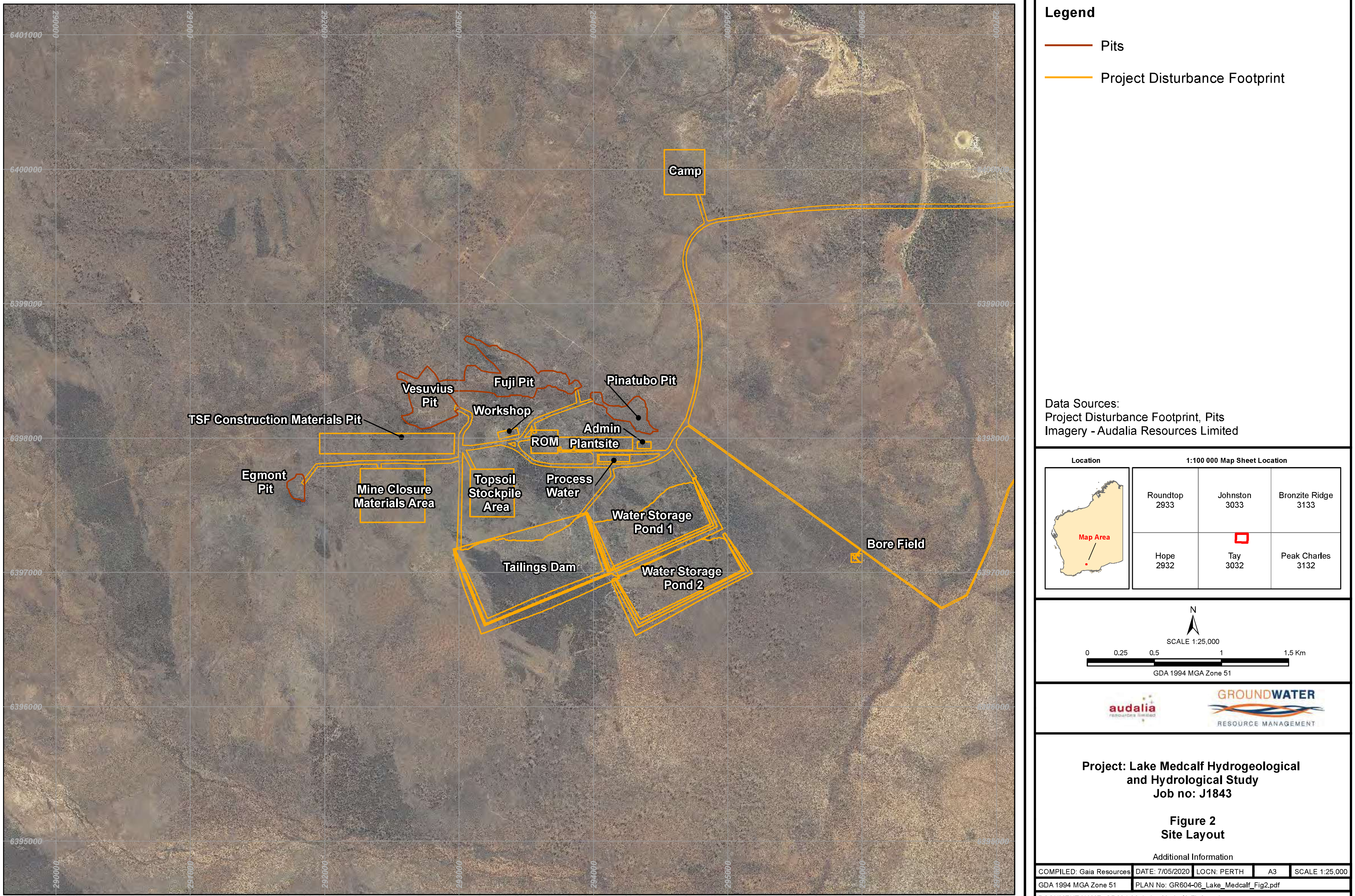
GROUNDWATER RESOURCE MANAGEMENT

**Project: Lake Medcalf Hydrogeological and Hydrological Study**
**Job no: J1843**

**Figure 1**
**Project Location**

Additional Information

| | | | | |
|---|---|---|---|---|
| COMPILED: Gaia Resources | DATE: 5/03/2020 | LOCN: PERTH | A3 | SCALE 1:400,000 |
| GDA 1994 MGA Zone 51 | PLAN No: GR604-06_Lake_Medcalf_Fig1.pdf | | | |
| DOCUMENT NAME: GR604-06_Lake_Medcalf_Fig1.mxd | | | | |




**Legend**

- Pits
- Project Disturbance Footprint

Data Sources:
Project Disturbance Footprint, Pits
Imagery - Audalia Resources Limited

audalia resources limited

GROUNDWATER RESOURCE MANAGEMENT

**Project: Lake Medcalf Hydrogeological and Hydrological Study**
**Job no: J1843**

**Figure 2**
**Site Layout**

Additional Information

| | | | | |
|---|---|---|---|---|
| COMPILED: Gaia Resources | DATE: 7/05/2020 | LOCN: PERTH | A3 | SCALE 1:25,000 |
| GDA 1994 MGA Zone 51 | PLAN No: GR604-06_Lake_Medcalf_Fig2.pdf | | | |
| DOCUMENT NAME: GR604-06_Lake_Medcalf_Fig2.mxd | | | | |

## 1.2 Scope of Work

The scope of work is to undertake a hydrological assessment of surface water flows and hydrological regimes of the *Marianthus aquilonaris* communities at the Medcalf Project site.

The deliverable is this report.

## 1.3 Summary of Methodology

The work was undertaken in the following stages:

- Data collation and review;
- Site visits;
- Characterisation of the hydrology of the area supporting *Marianthus aquilonaris* communities; and
- Reporting.

### 1.3.1 Data Review

The data review involved sourcing available data and undertaking a preliminary review of local and catchment conditions.

The following information was used in this study:

- 1 m contour data and high resolution aerial imagery across the site, supplied by Audalia;
- Proposed indicative site layout across the mine site, supplied by Audalia;
- Mapping of *Marianthus aquilonaris* communities, supplied by Audalia;
- Site weather station data (incomplete record for the period 4 April 2014 to 12 June 2018), supplied by Audalia;
- Regional topographic and satellite imagery data, supplied by Geoscience Australia;
- Regional weather and design rainfall data, supplied by the Bureau of Meteorology; and
- Reports as referenced throughout the report.

### 1.3.2 Site Visit

A site visit was undertaken on 29-30 November 2018 by R. Connolly (Principal Hydrologist). During the visit the landscape and drainage through the areas of *Marianthus aquilonaris* habitat were inspected. Drainage lines crossing the haul road alignment were inspected.

An assessment of the hydrogeological conditions associated with the plant communities was undertaken in September 2019 by R. Toll (Senior Hydrogeologist), as part of the project's water supply investigations.

### 1.3.3 Characterise Hydrology of *Marianthus aquilonaris* Communities

The microclimate of the communities was described using a combination of data analysis and modelling. This included:

- Characterisation of the climate of the area, using site and regional weather records;

- Identifying catchments and topographic, terrain and soil features for the area;
- Modelling the water balance of the community area, including identifying major flow pathways and sources of water that may influence the presence of communities; and
- Interpreting possible relationships relevant to the presence of *Marianthus aquilonaris* communities.

Stations recording long term weather in the area are sparse, so it is difficult to determine reliable averages at the site. Also, the site weather station data is not a continuous record. Accordingly the data used for analysis of site climate and for input into the water balance model data were derived from a number of sources and should be considered to be indicative but sufficient to characterise the environment.

Daily weather data from the site station and generated data using the Bureau of Meteorology's (BoM's) Data Drill (Queensland Government 2018) were used. The site rainfall data covered the period 2014-2018 with a 0.5 or 1 h time step but is not complete. The Data Drill data for a number of locations was tested and it was found that data generated at the location of the BoM Salmon Gums Station, located some 90 km to the southeast of the mine site, gave the best overall representation of weather at the site compared with BoM stations in the area. Design rainfall was also derived for the site using the BoM's online data tool (BoM 2018b). These data were used in the assessment of site climate and in the water balance modelling.

Surface water catchments and drainage lines through the community area were defined using the 1 m contour data sourced from Audalia.

A catchment water balance model was setup using the Mike SHE software (DHI 2018). MIKE SHE is an advanced, flexible framework for modelling major processes in the hydrologic cycle. It includes process models for evapotranspiration, overland flow, unsaturated flow, groundwater flow, channel flow and their interactions. Each of these processes can be represented at different levels of spatial distribution and complexity, according to the goals of the modelling study, the availability of field data and the modeller's choices.

The Mike SHE model was used to help assess the water balance for the catchments through the *Marianthus aquilonaris* community area and for the rock holes. The water balance is predicted for the root zone for the period 2014-2017, which is the period of site rainfall monitoring.

The model was parameterised using the available data. Site rainfall data and daily Data Drill rainfall and evaporation data were used in the model for different model scenarios. Topography was represented in the model as a rectangular grid (5 m by 5 m cell), derived from the contour data. Soil information was based on observations made during the site visit and using information in Lantzke (2019). No mapping of soils across the site, other than for the shallow gravel over indurated mottled zone soil group, was available. The distribution of soils other than the shallow gravel over indurated mottled zone soil group was assumed. Based on site observations at the areas occupied by *Marianthus aquilonaris* and the soil type shallow gravel over indurated mottled zone, the modelling assumes hard rock occurs below the soil profile.

Vegetation characteristics were varied spatially across the site approximately based on soil type and from interpretation of topography and aerial imagery.

Two scenarios were modelled:

- Rainfall events, using the site data; and
- Catchment and rock hole water balance, 2014-2017, using daily weather data.

The catchment and rock hole model was set up with minimal data and run for a short period (four years), so the results should be considered indicative but sufficient to characterise the microhydrological environment where *Marianthus aquilonaris* grows. The site data indicates that a number of heavy rainfall events were received during the 2014-2017 period, which may not be representative of a longer term record. The water balance was calculated for the soil area that falls within the model domain and for the total domain. The total domain represents the main catchments through the project area.

Two rock holes (east and west) were included in the water balance model. Rock holes were represented by lowering the elevation of a single cell at each site by 0.5 m below ground surface. This gave an effective depth of 0.26 m for the western and 0.12 m for the eastern rock hole. This is an approximation, as the model grid size (5 by 5 m) is larger than the size of the actual rock holes and shape of the rock holes is not represented in detail. The model represents overland flow into the rock hole and evaporation and seepage. There may be other losses (such as animal use) and local factors (such as variable runoff patterns at the micro scale or variable vegetation use) that are not included in the model and could affect the actual water balance of the rock holes. Nevertheless the model helps characterise the rock hole water balance, including the contributing catchment and likely rate and mechanisms of loss of water ponded in the holes.

## 1.4 Limitations

This report has been prepared by Groundwater Resource Management Pty Ltd (GRM) for Audalia and may only be used and relied on by Audalia for the purpose agreed between GRM and Audalia as set out in Section 1.2 of this report.

GRM otherwise disclaims responsibility to any person other than Audalia arising in connection with this report. GRM also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GRM in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GRM has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GRM described in this report (refer Section 1.3 of this report). GRM disclaims liability arising from any of the assumptions being incorrect.

GRM has prepared this report on the basis of information provided by Audalia and others who provided information to GRM (including Government authorities), which GRM has not independently verified or checked beyond the agreed scope of work. GRM does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

# 2.0 DESCRIPTION OF THE *MARIANTHUS AQUILONARIS* ENVIRONMENT

## 2.1 REVIEW OF HABITAT REQUIREMENTS

A number of comprehensive studies of the distribution and characteristics of the *Marianthus aquilonaris* populations through the project area have been undertaken by Audalia. Detailed flora and vegetation survey for the mining area and haul road, including a comprehensive regional description and landform assessment, has been undertaken (Botanica 2017a, 2018, 2019). A detailed soil investigation has also been recently undertaken (Lantzke 2019).

Typical habitat for *Marianthus aquilonaris* has been defined by DEC (2011) as: "Ironstone ridges (ca. 400 m above sea level) with a laterite capping and exposed iron oxide (commonly referred to as limonite). Plants tend to be located within shallow drainage lines on the ridge, on rocky red-orange sandy loam. Habitat is Open Low Woodland dominated by *Eucalyptus livida* over Dwarf Scrub dominated by *Eremophila clavata*, *Pultenaea arida*, *Acacia erinacea*, *Westringia cephalantha* var. *caterva*, *Waitzia fitzgibbonii*, *Asteridea athrixioides* and *Lepidosperma* sp."

Botanica Consulting (Botanica 2017b) conducted regional targeted searches for *Marianthus aquilonaris* populations in areas of similar topography/geology outside of the Medcalf area but to date have not identified regional populations.

Based on a number of studies, Botanica (2019) describe the following habitat preferences for *Marianthus aquilonaris*:

- Low salinity soils (<200 mS/m);
- Shallow brown to orange/ red-brown sandy-clay loam soils/ loamy earths (≤58 mm depth);
- Areas of exposed bedrock (predominately limonite ≥8%) with high percentage plant litter (≥20%) and bare ground (≥53%);
- Elevations ranging from 380 to 425 m with the north-eastern populations (Population 1a and 1b) occurring lower in the landscape of the Bremer Range (380-405 m) and the north-western populations (Population 1c, 1d and 1e) occurring higher in the landscape (400 to 425 m);
- North-eastern and north-western face of rocky slopes which is likely associated with the surface drainage of the hills which generally drains toward the north.

A typical plant is shown in Photo 1 and landscape in Photo 2.

**Photo 1** ***Marianthus aquilonaris*** **Plant**

**Photo 2** ***Marianthus aquilonaris*** **Community Landscape**

Source: Botanica (2017a).

A detailed soil investigation for the Medcalf site was undertaken by Western Horticultural Consulting (Lantzke 2019). This study indicated that all the *Marianthus aquilonaris* communities at the site occur on 'Shallow gravel over indurated mottled zone' soils. Surrounding soils have different properties – they tend to be deeper colluvial soils, do not contain limonite outcrops and are neutral to alkaline. Lantzke (2019) suggests that the location of the 'shallow gravel over indurated mottled zone' soils may assist in determining the boundaries of critical *Marianthus aquilonaris* habitat. More details of soil types are given in 2.3.

## 2.2 CLIMATE

The site is located in an arid area with low and variable rainfall year round and with high evaporation. The climate is classified by the modified Köppen system (BoM 2018c) as Grassland, warm (persistently dry). Summers are warm to hot and winters mild.

Key aspects of the climate that affect the hydrology of the *Marianthus aquilonaris* communities are rainfall and evaporation. The timing and magnitude of rainfall affects infiltration of rainfall into the soil and availability for uptake by plants, as well rates of runoff. Evaporation from the soil and transpiration by plants affects the rate that the soils dry out.

A summary of rainfall statistics derived for the site is given in Figure 3. A summary of larger events observed at site is given in Table 1.

Observed annual rainfall at Norseman (BoM station 012009 Norseman Aero, data from 1999-2020) is 294 mm/year. Annual rainfall has varied during the observation period between 183 and 454 mm/year. Rainfall occurs all year round, but more rain tends to be received, on average, during winter (May to September). However, rainfall is variable and large rainfall events can occur. Large events tend to occur in summer, mainly January to March. However large events have occurred in September to December and in June.

Rainfall in the period before large events is variable. Table 1 shows data for the 10 days prior, with totals tending to vary from almost no rain to around 30 mm, but sometimes much more.

Rainfall at the site occurs generally as a result of regional rain-bearing depressions in winter, or in summer from thunderstorms and occasionally as a result of tropical cyclones that track far enough south (BoM 2018d). The influence of cyclones, though, is weak and generally results in only small rainfall events.

Mean annual pan evaporation is some 1,500 mm/year with little variation from year-to-year. Mean monthly evaporation exceeds mean rainfall in every month of the year. Evaporation rates are much lower in winter than in summer. This pattern of variation in evaporation combined with rainfall distributed during the year in variable falls suggests that the soil profile prior to larger events is likely to be relatively dry in summer but could be moist to saturated in winter.

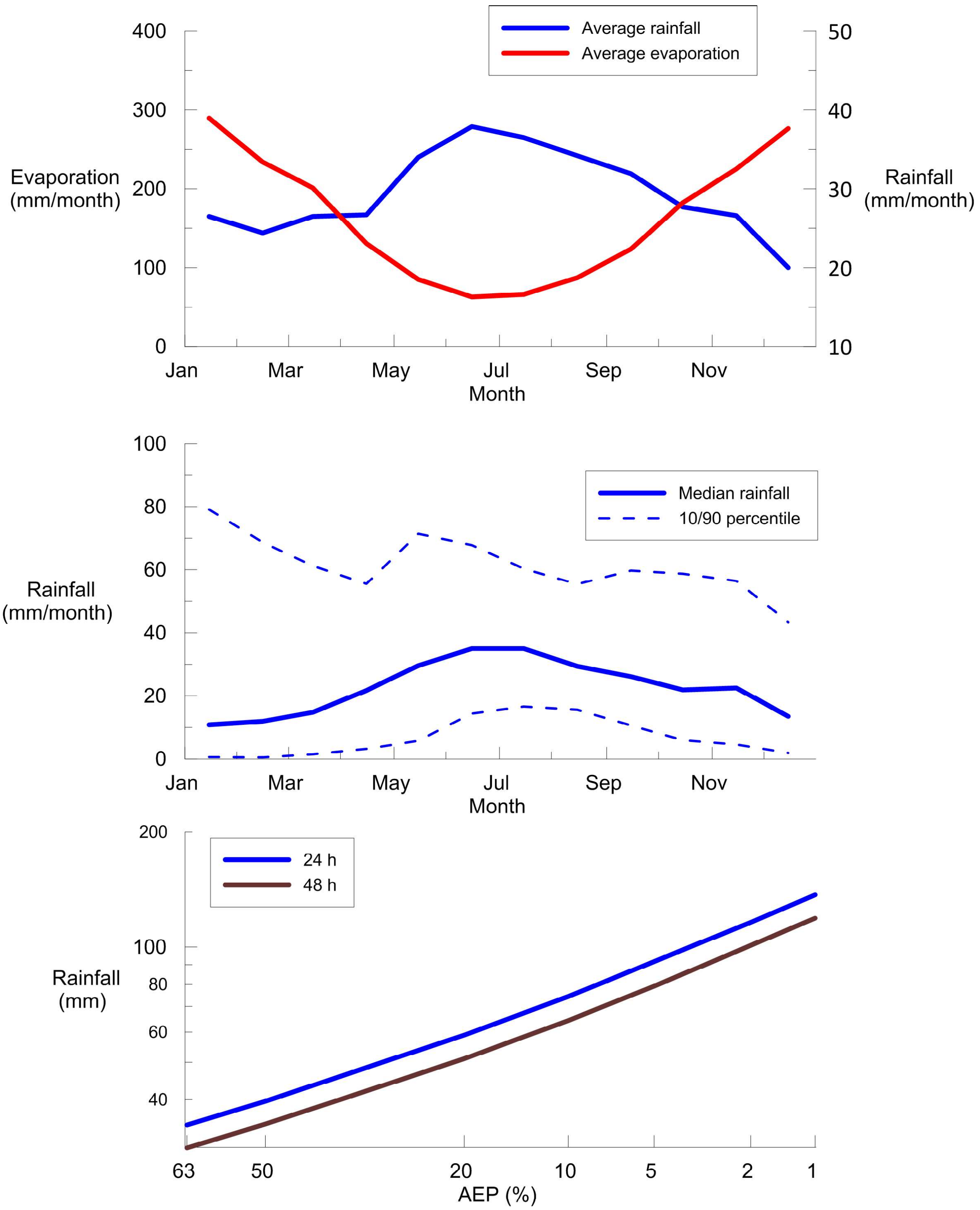



**Figure 3** **Site Climate Details**

**Table 1 Site Rainfall Events**

| Date | Duration (h) | Rainfall (mm) | Average rainfall intensity (mm/h) | Rain in previous 10 days (mm) | AEP |
|---|---|---|---|---|---|
| 21/09/2017 | 9.5 | 97.5 | 10.3 | 1.2 | 1 in 200 |
| 7-8/02/2017 | 10.0 | 78.3 | 7.8 | 24.6 | 2% |
| 26/10/2017 | 6.0 | 59.4 | 9.9 | 9.9 | 2% |
| 10/06/2018 | 5.0 | 49.2 | 9.8 | 5.1 | 5% |
| 18/12/2017 | 5.0 | 24.9 | 5.0 | 31.2 | 50% |
| 18/02/2018 | 1.0 | 23.1 | 23.1 | 11.4 | 10% |

Data are observed at the site, 0.5 h or 1 h time step. AEP is approximate.

## 2.3 LAND SYSTEMS AND SOILS

Land systems, soils and geology through the project area have been mapped by a number of agencies. Most though, are at regional scales, which are hard to interpret at the scale of the project footprint. The Lanktze (2019) study is the only report specific to the Medcalf site.

One regional dataset, surface geology (GA 2018) has sufficient resolution to provide some background to the soils and landscape that occurs through the area of the mine site. The surface geology mapping shows a band of rock corresponding to the low hills and mine resource areas. Off the hills to the north and south is mapped as colluvium.

The Lantzke study undertook field investigations at the project site in April and August 2019. The aim of the study was to determine the range of soil types on which *Marianthus aquilonaris* and other selected species grow. Because of difficulties with access, a limited area of the site was surveyed directly.

Five main soil groups were identified:

1. Alkaline red shallow loamy duplex;
2. Loamy gravel;
3. Shallow gravel over indurated mottled zone;
4. Stony soils; and
5. Shallow gravel.

This study indicates that *Marianthus aquilonaris* grows on gravelly, shallow loamy soils with an indurated, mottled zone layer that occurs within 30 cm of the soil surface (soil type 3). The occurrence of the shallow gravel over indurated mottled zone and *Marianthus aquilonaris* populations are mapped in Figure 4.

The shallow gravel over indurated mottled zone soils are acidic, occurring on low ridges that typically have outcrops of limonite. It is a minor soil type in the district. Between 70 and 90% of the surface is covered with a scree of dark lateritic gravels and fragments of limonite rock. Limonite outcrops are common and in areas may compose up to 50 % of the soils surface. The subsoil is impermeable. As a result, infiltration rates of rainfall for these soils are low and runoff rates will be high. Topsoil is prone to erosion by shallow overland flow. Plant available water holding capacity (the water holding capacity of the soil that is available to plants) is low.

The alkaline red shallow loamy duplex soil is a major soil group in the project area. This group includes a range of red coloured, loamy duplex soils. These soils occur below the gravelly lateritic plateau and extend towards the valley floor. It can be found on the upper, mid and lower slopes. The soil profile can contain up to 60 % gravel and rocks. Soils typically have a 0.1-0.15 m thick topsoil and a deep subsoil. Plant roots can extract water to some 1 m deep and the plant available water holding capacity of the soil is relatively high.

The loamy gravel is also a major soil group. It occurs on the lateritic plateau at the top of the landscape, and on the upper, mid and lower slopes. The soil surface contains gravel that can cover up to 70 % of the soils surface. A 0.1-0.15 m deep topsoil grades into a subsoil to a depth of 1 m. Plant water holding capacity is reduced by the presence of gravels and is considered to be moderate.

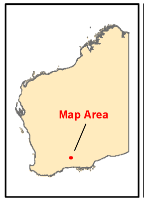
The stony sols and shallow gravels are minor soil groupings. Both occur at the top of the landscape in association with rock outcrops and breakaway faces. Up to 90 % of the soil surface can be covered by rocks and gravel. The topsoil is 0.1 to 0.25 m deep with an effective plant rooting depth of approximately 0.3 m and low plant available water holding capacity. Rainfall-runoff from these areas would be high.

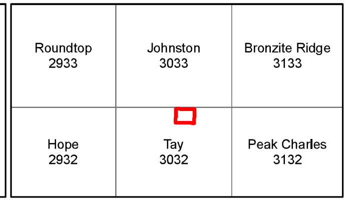
[redacted]

**Legend**

- Marianthus Locations
- Pits
- Project Disturbance Footprint
- Mapped soils

Data Sources:
Project Disturbance Footprint, Marianthus Locations, Imagery, Mapped Soils, Pits - Audalia Resources Limited

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GDA 1994 MGA Zone 51

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**Project: Lake Medcalf Hydrogeological and Hydrological Study**
**Job no: J1843**

**Figure 4**
**Shallow gravel over indurated mottled zone soils**

Additional Information

| | | | | |
|---|---|---|---|---|
| COMPILED: Gaia Resources | DATE: 11/05/2020 | LOCN: PERTH | A3 | SCALE 1:25,000 |
| GDA 1994 MGA Zone 51 | PLAN No: GR604-06_Lake_Medcalf_Fig4.pdf | | | |
| DOCUMENT NAME: GR604-06_Lake_Medcalf_Fig4.mxd | | | | |

## 2.4 VEGETATION AND LAND USE

Vegetation through the area of the *Marianthus aquilonaris* is generally Eucalypt and Mallee woodlands and shrublands (Botanica 2017a).

Land use is native vegetation on unallocated crown land overlain with Mining Act tenements.

## 2.5 DRAINAGE AND TOPOGRAPHY

Topography, drainage lines and catchments are shown in Figure 5. Note that the available topographic data does not cover the area of *Marianthus aquilonaris* Population 1e nor the area of shallow gravel over indurated mottled zone soils are acidic referred to as Site 8. The area of Population 1c is truncated by the boundary of the available topographic data.

Drainage around the area of the *Marianthus aquilonaris* communities is defined by a line of low hills trending in an east-west direction. Drainage from the hills is generally either toward the north or south. The *Marianthus aquilonaris* communities tend to extend mainly from the top of the hills toward the north (i.e. on north-facing slopes).

Rock is generally exposed on the top of the hills and there is little vegetation cover, litter or dead timber in contact with the ground surface (Photo 3). These areas include the shallow gravel over indurated mottled zone, stony soils, and shallow gravels mapped by Lantzke (2019). See Section 2.3 for a description of these soils.

These areas are likely to be high runoff zones as infiltration into the rock and rocky soil will be low and there is little impediment to stormwater moving across the ground surface. Runoff from even small rainfall events would occur as shallow overland flow.

In smaller events, most runoff would reinfiltrate in areas downstream with a deeper soil profile.

**Photo 3 Overland Flow Area on Hills**

Moving downslope below the areas of occupancy, a soil profile gradually forms, either as alkaline red shallow loamy duplex or loamy gravels (Lantzke 2019). The soil profile increases in depth with distance downstream and the infiltration capacity of the soil profile increases. Occasional small erosion gullies tend to form about mid-slope and then dissipate (Photo 4).

**Photo 4 Mid-Slope Erosion Gully**

Defined streamlines form toward the bottom of the catchments – well below the zone of occupancy (Photo 5). Runoff from the deeper soil areas would occur in more intense events and move as overland flow concentrating into drainage lines then defined streams as flow rates increase with distance downstream. Vegetation density increases as the soil profile increases and in proximity to drainage lines. The larger drainage lines tend to have heavy vegetation growth and fallen debris that restricts stormwater flow.

**Photo 5 Streamline in the Lower Catchment**

Flow in drainage lines through the site is generally relatively shallow (less than 0.3 m deep) and there are few depressions or pools. Large, incised drainage lines do not form until some distance downstream of the site.

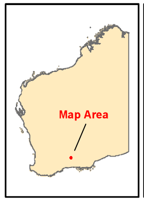
[redacted]

## Legend

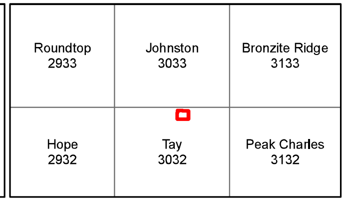
- Rock Holes
- Critical Habitat
- Drainage Lines
- Pits
- Project Disturbance Footprint
- Contours (1m)
- Mapped soils
- Catchments

Data Sources:
Pits, Mapped Soils, Critical Habitat,
Project Disturbance Footprint,
Marianthus Locations - Audalia Resources Limited
Rock Holes, Drainage Lines, Catchments,
Contours - GRM

Location




1:100 000 Map Sheet Location

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GDA 1994 MGA Zone 51

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**Job no: J1843**

**Figure 5**
**Drainage and topography**

Additional Information

| | | | | |
|---|---|---|---|---|
| COMPILED: Gaia Resources | DATE: 11/05/2020 | LOCN: PERTH | A3 | SCALE 1:15,000 |
| GDA 1994 MGA Zone 51 | PLAN No: GR604-06_Lake_Medcalf_Fig5.pdf | | | |
| DOCUMENT NAME: GR604-06_Lake_Medcalf_Fig5.mxd | | | | |

## 2.6 Groundwater

The description of the hydrogeological conditions, with respect to the *Marianthus aquilonaris* communities is provided in the following sections, and is based on information obtained during the recent water supply investigation (GRM 2019).

### 2.6.1 Regional Hydrogeology

The project area is located on the western flank of a northerly draining palaeotributary of the regionally extensive Lefroy Palaeodrainage system. The main hydrogeological sequences within the project tenements are shown in Figure 6 and comprise a palaeochannel sand aquifer in the east of the project area, and fractured bedrock aquifers in the western portion of the tenements, away from the palaeochannel. The identified *Marianthus aquilonaris* communities are located within the fractured bedrock domain.

The palaeochannel and bedrock sequences are overlain by a veneer of Quaternary deposits comprising lacustrine deposits, aeolian deposits, alluvium, colluvium and laterite. The water supply investigations indicate that these units are unsaturated in the project area. However, more regionally, the Quaternary cover may be partially saturated in the larger drainage lines and the small playa lakes.

Rainfall recharge to the fractured rock and palaeochannel aquifers is low, and is via direct rainfall infiltration through the soil profile or by stream flow (in the drainage lines) during episodic rainfall events.

### 2.6.2 Groundwater Levels

Groundwater level measurements collected during the water supply investigations are provided in Figure 6 and indicate that the depth to groundwater ranges from around 6 m below ground level in the low-lying eastern portion of the site (MWH003 and MWH008) to 45 m below ground level in the central portion of the site (MWH011). The groundwater flow direction is expected to be towards the north east, i.e. towards the palaeochannel.

The closest monitoring bores to the identified *Marianthus* communities is MWH010 and MWH010. The measured groundwater level in MWH011 is 45 m below ground level. Monitoring bore MWH010 was constructed to 66 m below ground level and remained dry after construction, indicating that either the water level in this area is greater than 66 m below surface, or that the permeability is so low that the bore did not recover within the timeframe of the field investigations. It is considered more likely that the groundwater level is greater than 66 m below surface, given that MWH010 is located at approximately 50 m higher elevation than MWH011. However, ongoing water level measurements of this bore will be necessary to confirm this.

### 2.6.3 Groundwater Quality

The water supply investigations indicate that the groundwater is hypersaline, ranging from 54,000 to 170,000 mg/L total dissolved solids (TDS). The pH of the groundwater is circum neutral in the fractured bedrock aquifer and acidic (3.7) in the palaeochannel aquifer.

### 2.6.4 Site Visit

A site inspection of the hydrogeological conditions associated with a selection of the *Marianthus aquilonaris* plants was conducted by Mr Richard Toll (GRM Senior Hydrogeologist) during the water supply investigations.

The *Marianthus aquilonaris* plants visited and a description of observations is provided in Table 2 below, and the locations shown in Figure 6.

The site inspection identified indicators of underlying geological structures, such as vughs, iron stained fracture surfaces, quartz veining and bleached shearing in outcrops adjacent to *Marianthus aquilonaris* communities, which may be of benefit to the *Marianthus aquilonaris* plants, in terms of persistent soil moisture from within discrete fractured bedrock zones underlying the indurated mottled zone soils.

**Table 2 *Marianthus Aquilonaris* Plants Visited**

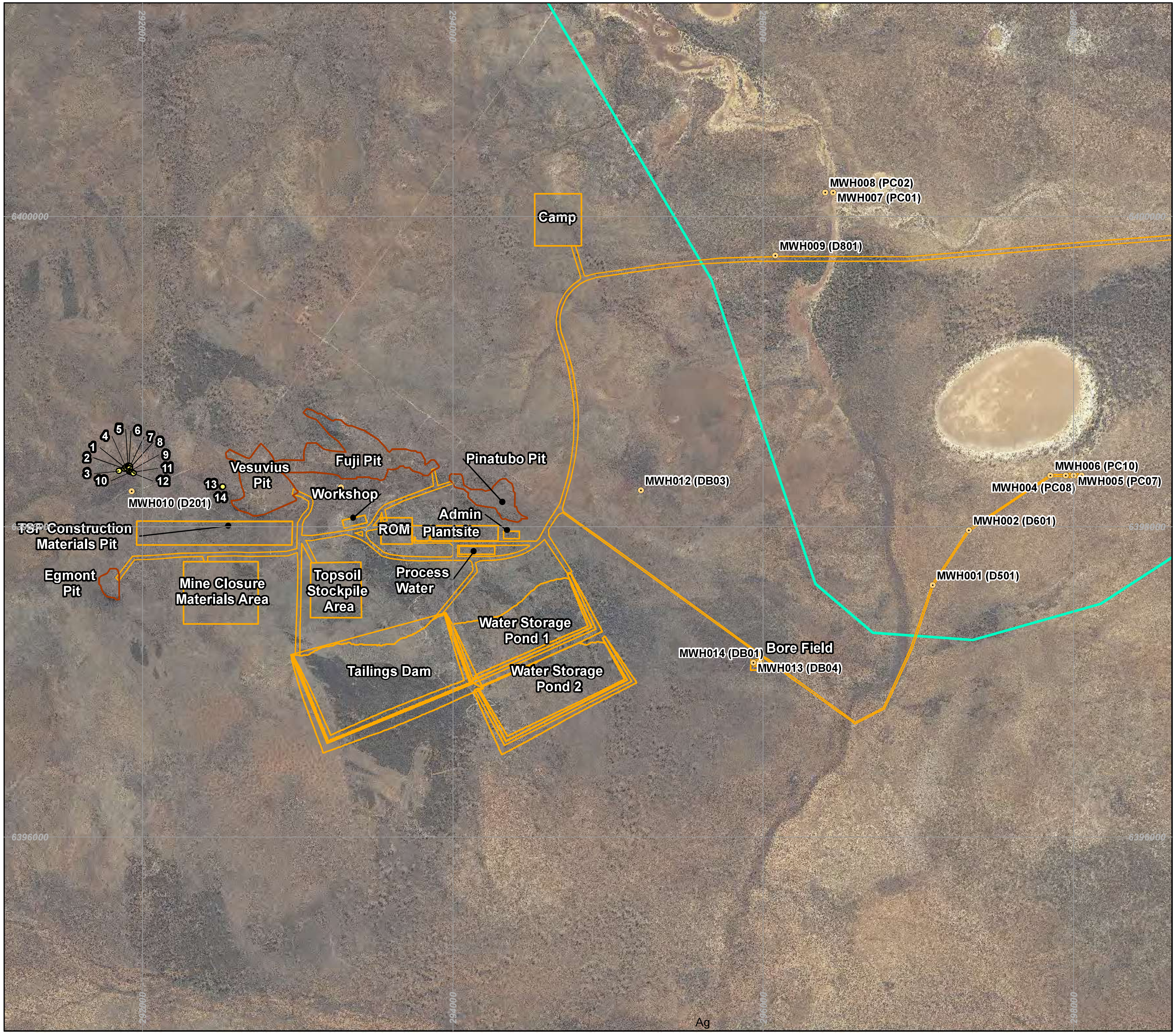
[redacted]

### 2.6.5 Marianthus Relationship with Groundwater

The information collected to date indicates that the *Marianthus aquilonaris* plants rely on rain water within the soil profile, and not the regional groundwater table, given that the groundwater is hypersaline and that the depth to groundwater is in excess of 45 m.

Consequently, groundwater drawdown associated with the projects proposed water supply bores is unlikely to impact the *Marianthus aquilonaris* communities. Similarly, the proposed mine pits do not extend below the water table, hence mining will not impact the groundwater environment.

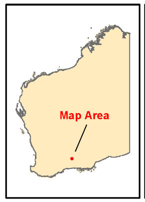
The *Marianthus aquilonaris* plants may benefit from underlying geological structures, such as vughs, iron stained fracture surfaces, quartz veining and bleached shearing, in terms of persistent soil moisture.




**Legend**

- Drill Holes
- Geological Structures
- Pits
- Project Disturbance Footprint
- Palaeovalley

Data Sources:
Project Disturbance Footprint, Imagery,
Pits - Audalia Resources Limited
Geological Structures, Drill Holes, Palaeovalley - GRM




1:100 000 Map Sheet Location

| | | |
|---|---|---|
| Roundtop 2933 | Johnston 3033 | Bronzite Ridge 3133 |
| Hope 2932 | Tay 3032 | Peak Charles 3132 |

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SCALE 1:25,000
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GDA 1994 MGA Zone 51

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**Project: Lake Medcalf Hydrogeological and Hydrological Study**
**Job no: J1843**

**Figure 6**
**Geological Structures**

Additional Information

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|---|---|---|---|---|
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| GDA 1994 MGA Zone 51 | PLAN No: GR604-06_Lake_Medcalf_Fig6.pdf | | | |
| DOCUMENT NAME: GR604-06_Lake_Medcalf_Fig6.mxd | | | | |

## 2.7 CHARACTERISTICS OF THE SHALLOW GRAVEL OVER INDURATED MOTTLED ZONE SOILS

The mapped areas of shallow gravel over indurated mottled zone extend from the south west of the site to the north. These areas are mapped in Figure 4. Characteristics of each area are summarised in Table 3. The mapped soils have highly variable areas but are all small compared to even the size of local catchments. The areas generally lie close to or across low ridgelines, which is consistent with characteristics of this soil grouping.

The areas that contain *Marianthus aquilonaris* populations all lie across a ridge line and down north east or north west trending slopes.

Of the areas without *Marianthus aquilonaris* populations, most lie on ridgelines and on slopes with aspects ranging from northerly to southerly. One lies mid-slope (Site 1). One lies in the upper reaches of a small drainage line (Site 3).

**Table 3 Soil Area Characteristics**

| Name | Area ($m^2$) | Description |
|---|---|---|
| Population 1a | 43,470 | Contains a large *Marianthus aquilonaris* population. Lies across a ridge line and on the north west slopes. Level 378-397 m AHD. |
| Population 1b | 13,556 | Contains a smaller *Marianthus aquilonaris* population. Lies across a ridge line and on the north east slopes. Level 411-397 m AHD. Includes the eastern rock hole. |
| Population 1c | 27,597 | Contains a large *Marianthus aquilonaris* population. Lies across a ridge line and on the north west slopes. Level 401-425 m AHD. |
| Population 1d | 52,340 | Contains a large *Marianthus aquilonaris* population. Lies across a ridge line and on the north east slopes. Includes the western rock hole. Level 406-416 m AHD. |
| Population 1e | 3,461 | Outside of topographical data. Contains a small *Marianthus aquilonaris* population. Lies in what appears to be the upper reaches of a northerly trending drainage valley. |
| Site 1 | 8,160 | Lies mid-slope with a north west aspect. Level 372-382 m AHD. |
| Site 2 | 19,814 | Lies across a ridge line and on the northern slopes. Level 373-383 m AHD. |
| Site 3 | 31,184 | Lies in the upper reaches of a small drainage line. Easterly aspect. Level 347-366 m AHD. |
| Site 4 | 346 | Small area on a north-south ridgeline. Level 361 m AHD. |
| Site 5 | 4,802 | Small area to the south that lies across a ridgeline, near of Sites 7 and 8. Level 410-413 m AHD. Easterly and westerly aspect. |
| Site 6 | 8,730 | Small area to the south on a low ridgeline, upslope of Site 8. Level 405-411 m AHD. South westerly aspect. |
| Site 7 | 1,106 | Small area to the south on a low ridgeline. Level 397-399 m AHD. South westerly aspect. |
| Site 8 | 2,786 | Lies outside of the topographic data. |

A predicted water balance for all of the soil areas through the *Marianthus aquilonaris* area and for the whole area is given in Table 4.

The soil areas have a high runoff fraction of the water balance, which is consistent with their shallow soil profile and rocky surface. All of the areas receive some runoff from upslope; the amount varies depending on the location of the area in the landscape, local topography and the assumed surrounding soils.

However, the predicted water balance for the soil areas is still dominated by evapotranspiration, which accounts for 60-80% of rainfall. This means that most of rainfall is taken up by plants and transpired or evaporated from soil, rock and vegetation surfaces.

For the whole project area, the amount of runoff reduces, consistent with the effects of higher rates of infiltration into the deeper red and gravely loams. While runoff from upper rocky areas can be high, much of this is infiltrated in the colluvial zone downslope. Runoff is predicted to account for 3% of rainfall over the project area.

Total seepage below the root zone, which could recharge groundwater, is low relative to the other components of the water balance. Recharge is likely to be highly episodic, with much occurring during extended wet periods. Accordingly, wetter periods than observed during the simulation period (2014-2017) may have higher seepage rates. Presence of deeper soil profiles could also affect rates of seepage to and from the plant root zone.

Evapotranspiration still dominates the water balance at the project scale (96%).

**Table 4 Predicted Soil Area Water Balance**

| Area | Inflows (mm/year) | | Area water balance (mm/year) | | | Area water balance (% of rainfall + runoff inflow) | | |
|---|---|---|---|---|---|---|---|---|
| | Rainfall | Runoff from upslope | Evapo-transpiration | Runoff leaving the area | Seepage below the root zone | Evapo-transpiration | Runoff leaving the area | Seepage below the root zone |
| Population 1a | 390 | 10 | 321 | 74 | 0 | 81% | 19% | 0% |
| Population 1b | 390 | 34 | 322 | 97 | 0 | 76% | 24% | 0% |
| Population 1c | 390 | 84 | 322 | 147 | 0 | 63% | 37% | 0% |
| Population 1e | 390 | 7 | 321 | 71 | 0 | 82% | 18% | 0% |
| Site 1 | 390 | 63 | 327 | 121 | 0 | 70% | 30% | 0% |
| Site 2 | 390 | 17 | 321 | 81 | 0 | 80% | 20% | 0% |
| Site 3 | 390 | 86 | 322 | 150 | 0 | 63% | 37% | 0% |
| Site 4 | 390 | 39 | 367 | 68 | 0 | 83% | 17% | 0% |
| Site 5 | 390 | 10 | 331 | 66 | 0 | 84% | 16% | 0% |
| Site 6 | 390 | 14 | 331 | 71 | 0 | 82% | 18% | 0% |
| Site 7 | 390 | 52 | 336 | 104 | 0 | 74% | 26% | 0% |
| All catchments | 390 | 0 | 375 | 12 | 0 | 96% | 3% | 0% |

Water balance is presented for the unsaturated zone (root zone). Simulation period – 2014-2017. Rainfall and evaporation data are for the location of the BoM Salmon Gums station, derived using BoM data drill. Areas are shown on Figure 5.

## 2.8 AREAS TO CATCHMENT DIVIDE

An assessment of the location of the *Marianthus aquilonaris* communities in the catchments across the site was made by considering the area of catchment above the communities (i.e. the catchment area that would drain through the actual area occupied by *Marianthus aquilonaris*), and also the mapped shallow gravel over indurated mottled zone soils and the catchment area above this soil type (i.e. the catchment area that would drain through the shallow gravel over indurated mottled zone soil type). A summary of these areas is given in Table 5 and mapped in Figure 7. Site drainage and the overall catchments are described in Section 2.5. Mapped soil areas without *Marianthus* *aquilonaris* populations are not considered in this assessment. Catchments 1, 2 and 7 do not contain populations.

The analysis shows that most of the communities and soils lie across or close to ridge lines. The populations in Catchment 5 have the largest upslope area of all the catchments at the site. The area of catchment above the mapped soil is smaller than the soils area in all catchments and smaller than most of the population areas. The area of catchment above the populations is smaller than the population area in Catchments 3, 4 and 6 and marginally larger in Catchment 5.

The area of soils containing *Marianthus aquilonaris* populations is a small proportion of the total catchment area, varying from 1-7%.

**Table 5 Areas to Catchment Divide**

| Catchment | Catchment area ($m^2$) | Soils area ($m^2$) b | Area above soils to ridge ($m^2$)[a] | Population area of occupancy ($m^2$)[c] | Area above population to ridge ($m^2$) | Area below population ($m^2$)[d] |
|---|---|---|---|---|---|---|
| 1 | 93,377 | - | - | - | - | - |
| 2 | 151,262 | - | - | - | - | - |
| 3 | 748,565 | 10,307 | 0 | 1,975 | 974 | 749,567 |
| 4 | 1,217,245 | 46,718 | 1,690 | 17,126 | 7,139 | 1,227,231 |
| 5 | 947,938 | 67,813 | 16,735 | 12,788 | 15,421 | 945,305 |
| 6 | 653,620 | 15,625 | 1,864 | 2,966 | 2,041 | 654,545 |
| 7 | 630,950 | - | - | - | - | - |

a = area of mapped shallow gravel over indurated mottled zone soils; b = catchment soils to ridge - soils; c = area of *Marianthus aquilonaris* population; and d = catchment area - catchment population to ridge. Analysis is given for mapped soils areas that contain *Marianthus aquilonaris*.

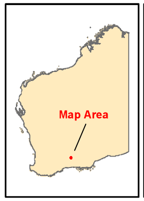
[redacted]

## Legend

- Marianthus Locations
- Rock Holes
- Critical Habitat
- Drainage Lines
- Pits
- Project Disturbance Footprint
- Mapped soils
- Catchments
- Area Above Soils to Ridge
- Area Above Population to Ridge

Data Sources:
Pits, Mapped Soils, Critical Habitat,
Project Disturbance Footprint,
Marianthus Locations - Audalia Resources Limited
Rock Holes, Drainage Lines, Catchments,
Contours, Area Above Soils to Ridge,
Area Above Population to Ridge - GRM

**Location**




**1:100 000 Map Sheet Location**

| | | |
|---|---|---|
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| Hope 2932 | Tay 3032 | Peak Charles 3132 |

N

SCALE 1:8,000

0 50 100 200 300 m

GDA 1994 MGA Zone 51

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**Project: Lake Medcalf Hydrogeological and Hydrological Study**
**Job no: J1843**

**Figure 7**
**Areas to catchment divide**

Additional Information

| | | | | |
|---|---|---|---|---|
| COMPILED: Gaia Resources | DATE: 11/05/2020 | LOCN: PERTH | A3 | SCALE 1:8,000 |
| GDA 1994 MGA Zone 51 | PLAN No: GR604-06_Lake_Medcalf_Fig5.pdf | | | |
| DOCUMENT NAME: GR604-06_Lake_Medcalf_Fig7.mxd | | | | |

## 2.9 Rock Hole Water Balance

A number of rock holes occur in the area. The two largest occur in the west (Photos 6 and 7) and east (Photo 8) of the site. Both are located on low ridgelines in exposed rock. The holes have been observed to hold water and have also been seen dry.

**Photo 6 Western Rock Hole – No Ponded Water**


**Photo 7 Western Rock Hole – With Ponded Water**


**Photo 8 Eastern Rock Hole**

The two rock holes were included in the water balance model, as summarised in Table 6. Figure 8 shows variation in predicted depth of water in the two rock holes.

The modelling indicates that inflow to the rock holes comes from direct rainfall and variable overland flow from a small catchment. The eastern rock hole appears to have a larger catchment than the western rock hole. Both holes readily fill and then overflow in larger events. Water is then lost mainly to evaporation over the following one to two months.

**Table 6 Predicted Rock Hole Water Balance**

| Catchment | Inflow to rock hole (mm/year) | | Water balance (mm/year) | | | Water balance (% of inflows) | | |
|---|---|---|---|---|---|---|---|---|
| | Rainfall | Runoff inflow from catchment | Evapo-transpiration | Overflow from the rock hole | Seepage below the root zone | Evapo-transpiration | Runoff leaving the catchment | Seepage below the root zone |
| Rock hole W | 390 | 341 | 318 | 411 | 0 | 44% | 56% | 0% |
| Rock hole E | 390 | 811 | 318 | 881 | 0 | 27% | 73% | 0% |

Water balance is presented for the rock hole pond. Simulation period – 2014-2017. Rainfall and evaporation data are for the BoM Salmon Gums station, derived using BoM data drill. Pond representation in the model is approximate. Location of the rock holes is shown on Figure 5.

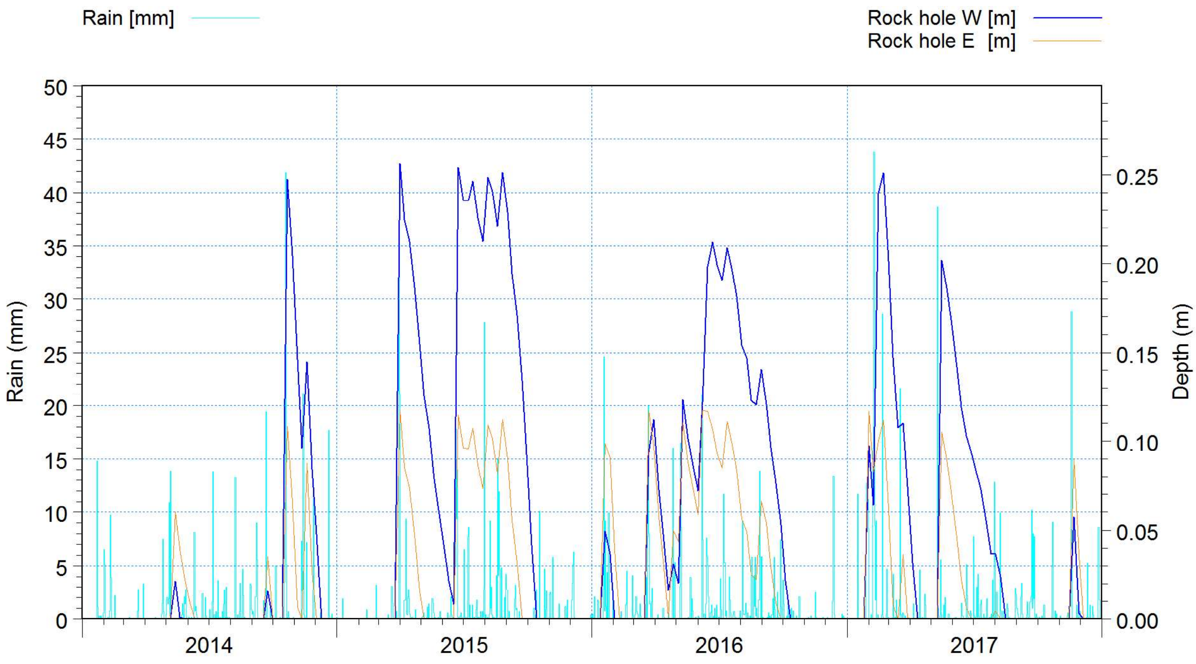


**Figure 8** **Predicted Depth of Water in the Rock Holes**

# 3.0 SUMMARY AND CONCLUSIONS

The landscape through the area of the *Marianthus aquilonaris* community is characterised by low hills with exposed rock at the surface changing to deeper sandy and loamy soils with distance downslope. A number of small catchments drain to the north and south from a central, east-west trending line of hills.

There are occasional, discontinuous erosion gullies in the mid slopes. Broad, heavily vegetated drainage lines with no defined channel tend to form in the mid to lower parts of the local catchments.

Of 13 discrete areas of the soil shallow gravel over indurated mottled zone, five contain *Marianthus aquilonaris* populations. The areas that contain *Marianthus aquilonaris* populations all lie across a ridge line and down north east or north west trending slopes. Of the areas without *Marianthus aquilonaris* populations, most lie on ridgelines and on slopes with aspects ranging from northerly to southerly. One lies mid-slope. One lies in the upper reaches of a small drainage line.

Modelling indicates that all of the mapped soil areas have a high runoff rate, which is consistent with their shallow soil profile and rocky surface. All of the areas receive some runoff from upslope; the amount varies depending on the location of the area in the landscape, local topography and surrounding soils. The water balance for the soil areas is dominated by evapotranspiration, which accounts for 60-80% of rainfall. This means that most of the rainfall is taken up by plants and transpired or evaporated from soil, rock and vegetation surfaces.

As modelled, the catchment water balance is dominated by evapotranspiration, with a small proportion of rainfall reporting to the catchment outlet as runoff in the drainage lines. Total seepage below the root zone, which could recharge groundwater, is generally low. Any significant groundwater recharge is likely to occur in very wet years.

The current understanding of the hydrogeological conditions indicate that the *Marianthus aquilonaris* plants are very unlikely to draw water from the regional groundwater table, given that the groundwater is hypersaline and the depth to groundwater is in excess of 45 m (the plant roots are thought to only extend 1 m). Similarly groundwater drawdown associated with the projects proposed water supply bores is unlikely to impact the plant communities. *Marianthus aquilonaris* plants may benefit from underlying geological structures, such as vughs, iron stained fracture surfaces, quartz veining and bleached shearing, in terms of persistent soil moisture.

The two larger rock holes in the area pond water for relatively short periods after larger rainfall events. Water in the holes is probably sourced from direct rainfall and runoff from a small catchment and probably lost mainly to evaporation.

Groundwater Resource Management Pty Ltd

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PRINCIPAL HYDROLOGIST

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Doc Ref: J1843R02b.doc

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**Attachment 6: Report: Insect visitors to *Marianthus aquilonaris* and surrounding flora Nov 2-4, 2019. Prepared by Kit Prendergast for Audalia Resources Limited. Prendergast (2019)**

# REPORT: Insect visitors to *Marianthus aquilonaris* and surrounding flora Nov 2-4, 2019

**Kit Prendergast, Native bee scientist**
**BSc First Class Honours, PhD researcher and Forrest Scholar**
**On behalf of Botanica Consulting**

**REPORT: Insect visitors to *Marianthus aquilonaris* and surrounding flora Nov 2-4 2019**

**Kit Prendergast, Native bee scientist**

## Background

*Marianthus aquilonaris* (Fig. 1) was declared as Rare Flora under the Western Australian *Wildlife Conservation Act 1950* in 2002 under the name *Marianthus* sp. Bremer, and is ranked as Critically Endangered (CR) under the International Union for Conservation of Nature (IUCN 2001) criteria B1ab(iii,v)+2ab(iii,v); C2a(ii) due to its extent of occurrence being less than 100 km$^2$, its area of occupancy being less than 10 km$^2$, a continuing decline in the area, extent and/or quality of its habitat and number of mature individuals and there being less than 250 mature individuals known at the time of ranking (Appendix A). However, it no longer meets these criteria as more plants have been found, and a recommendation has been proposed to be made by DBCA to the Threatened Species Scientific Committee (TSSC) to change its conservation status to CR B1ab(iii,v)+2ab(iii,v) (Appendix A), but this recommendation has not gone ahead (DEC, 2010). Despite its listing as CR under the Western Australian *Biodiversity Conservation Act 2016,* the species is not currently listed under the *Environment Protection and Biodiversity Conservation Act 1999*. The main threats to the species are mining/exploration, track maintenance and inappropriate fire regimes (DEC, 2010).

**Fig. 1. *Marianthus aquilonaris,* showing flower, buds and leaves. Photo: Kit Prendergast Oct 2019**

*Marianthus aquilonaris* is known to occur only in the Bremer Range, which is listed as a Priority 1 Ecological Community (PEC), located approximately 100 km west, south-west of Norseman, Western Australia (Fig. 2, from Botanica Consulting, 2017). The extent of occurrence for this taxon is likely to be less than 0.5 km$^2$ (DEC, 2010). Subpopulation information is listed in Table 1 in Botanica

Consulting (2017) (refer to Appendix B), however subpopulation updates are forthcoming. Genetic studies suggest limited gene flow between subpopulations (Hopley & Byrne, 2018).

[redacted]

**Fig. 2. Map of Bremer Range and *Marianthus aquilonaris* subpopulations.**

The aims of this study were to identify the insect visitors to *Marianthus aquilonaris,* and thus establish if it is receiving visits from insects that serve as pollinators, and the identity of these species. Knowledge of the pollinators of this plant can then be used to identify management actions to conserve these floral visitors. Conservation of pollinators is vital if this species is to persist (Prendergast, 2010; Kearns, Inouye & Waser, 1998). This addresses Item 13 in the Environmental Scoping Document (ESD) prepared by Audalia/Preston for assessment of the Project by EPA under the EP Act:

> "Item 13: If potential direct or indirect impacts to *M. aquilonaris* are proposed, identifying potential pollinators for *M. aquilonaris*, including changes to pollinator subpopulations or behaviour, changes to linkages between sub-subpopulations of species pollinated by vectors with short ranges, causing interruptions to gene flow within and between sub-subpopulations." (Preston Consulting Pty Ltd., 2019)

Pollinators are a critical part in the conservation of most angiosperms. The pollination biology of *Marianthus aquilonaris* is unknown, and indeed that of the genus *Marianthus* as a whole is poorly understood, however the small size of the flower and its floral features suggest this genus insect pollinated (Armstrong, 1979). Of all insects, bees tend to be the most effective of pollinators (Willmer et al., 2017). Australia has an estimated 2,000 species of native bees, however a large number of these are undescribed, and the habitat and resource requirements of a large proportion of species are unknown (Batley & Hogendoorn, 2009).

There have been no previous surveys on the insect visitors to *Marianthus aquilonaris.* Other studies by K. Prendergast (Prendergast, in prep.)(Prendergast, 2018a) and records in Houston (2018) on other *Marianthus* species have documented the native bee genera *Amegilla* and *Leioproctus,* as well as the introduced European honeybee *Apis mellifera,* as visitors.

## Methodology

The *Marianthus aquilonaris* subpopulations (A – E) at the Audalia Resource Ltd Medcalf Site (Fig. 2, Fig. 3) were surveyed by Kit Prendergast for their insect visitors. In addition, insects were collected in bee bowls and on surrounding flowering vegetation to further investigate potential pollinator species that may also visit *Marianthus aquilonaris.* Collection of insect visitors to *Marianthus aquilonaris,* and bees on surrounding flowering plant species, involved active sampling by K. Prendergast with an entomological sweepnet. In addition, potential insect visitors were also sampled passively using bee bowls.

[redacted]

**Fig. 3. Map of *Marianthus aquilonaris* subsubpopulations.**

On Nov 2nd 2019, all *Marianthus aquilonaris* subpopulations were visited between 1400h and 1630h to identify *Marianthus aquilonaris* plants in flower to target during the surveys the following two days. Subpopulation E had no plants in flower and so subsequent insect visitor surveys were conducted at *Marianthus aquilonaris* subpopulations A-D.

Each *Marianthus aquilonaris* subpopulation that had plants blooming was visited for 1-2 hrs to undertake insect collections by Kit Prendergast on Nov 3 and Nov 4 2019 between 0830h and 1530h.

During each survey any *M. aquilonaris* plants in flower were observed for half of the time, and flowering plants surrounding the subpopulation were surveyed for the remainder. Insects were collected with an entomological sweepnet (the most effective method for sampling native bees (Prendergast et al., 2020) and transferred to vials, labelled with the date, subpopulation and plant species and stored in a freezer. All insect taxa visiting *M. aquilonaris* were collected, whereas on plants other than *M. aquilonaris* only bees were collected.

In addition to the active collecting, insects were collected passively using bee bowls (also known as pan traps), which comprised 12 oz. plastic bowls filled with water and a few drops of detergent which acted as a surfactant, lowering the surface tension of the water to prevent insects caught in the bowls from flying out. At each subpopulation in the morning one fluoro yellow and one fluoro blue bowl (colours attractive to bees (Prendergast et al., 2020)) were placed near *Marianthus aquilonaris* plants with the most flowers, and were checked in the afternoon to collect any bees that had been captured in the bowls (Fig. 4, see also Appendix C). The bowls were also left overnight on Nov 3 2019 and checked for specimens the following morning to account for the potential to collect nocturnal pollinators or taxa that continued to forage after active surveys had concluded for the day.


**Fig. 4. Yellow (a) and blue (b) bee bowls. Note *Lasioglossum (Chilalictus)* bees (a, b, c) and *Amegilla chlorocyanea* bee (b, d). Photos: Kit Prendergast**

Insects were later thawed, pinned, labelled, and identified to the lowest taxonomic level possible by K. Prendergast using keys, published descriptions, and with reference to the WA Museum entomological collection.

## Results and Discussion

A number of potential pollinating insect species were collected visiting *Marianthus aquilonaris*, and in addition, a high diversity of native bee species were recorded in the area. However more work on the biology and ecology of the species visiting the plants is required, and further pollinator surveys are required due to the current surveys being conducted outside of the peak bloom period of *M. aquilonaris.*

During the surveys, a total of 317 native bees belonging to 47 species were collected (Appendix D, Table D1). However, only a small fraction of these native bees (15 individuals belonging to six species) were visitors to *Marianthus aquilonaris* (Table 1). The vast majority of individuals and species were collected on *Eucalyptus livida*, which hosted a prolific number of native bees as well as other insects (Appendix D, Table D1).

**Table 1. Insect visitors collected on *Marianthus aquilonaris* flowers.**

| Species | Total no. recorded visiting *Marianthus aquilonaris* | Sex | Number of individuals | *Marianthus aquilonaris* subpopulation | Date of collection |
|---|---|---|---|---|---|
| **Bees** | | | | | |
| *Lasioglossum (Chilalictus) florale* | 2 | M | 1 | D | 3/11/2019 |
| | | F | 1 | D | 3/11/2019 |
| *Xanthesma sp* | 1 | M | 1 | A | 4/11/2019 |
| *Lasioglossum (Chilalictus) castor* | 1 | F | 1 | A | 4/11/2019 |
| *Megachile 66 "shelf clypeus"* | 1 | F | 1 | A | 4/11/2019 |
| *Megachile maculosipes* | 1 | M | 1 | A | 4/11/2019 |
| *Megachile 65 "prongs"* | 1 | F | 1 | C | 4/11/2019 |
| **Flies** | | | | | |
| Syrphidae Sp.1 | 1 | | | A | 4/11/2019 |
| Bombyliidae *Geron* sp.1 | 2 | | | A | 4/11/2019 |

There were very few *Marianthus aquilonaris* plants in flower – they had largely ceased flowering. Of the 5,712 live plants (DBCA Live Total Count (2015), from Botanica Consulting, 2017), less than fifty were in flower, and of those that were, the number of flowers on the plants ranged from 1 – 10, typically four (see Appendix C, Figs C1-C4). Peak flowering occurred late Sept/early Oct (DEC 2010) (initial proposed survey date was planned for this time period but was delayed). This would have affected the outcome of this study, in that due to the survey period falling outside of peak bloom, it is likely that the results here are a conservative picture of the insect visitors to *M. aquilonaris*, and when in peak bloom a greater number of individuals, and potentially other species, would be collected.

Conditions were quite dry (Bureau of Meteorology, 2020), and there were few other plant species in flower. The plants species besides *Marianthus aquilonaris* in bloom were: *Eremophila caperata* (common but only a few flowers per plant); Solanaceae sp. (only four plants, but with numerous flowers, on the track away from the *M. aquilonaris*); *Halgania lavandulacea* (common but only a few flowers per plant); *Eucalyptus livida* (a number of trees near *Marianthus aquilonaris* with 5-50 blossoms, but still not flowering profusely across the landscape); *Asteridea athrixioides* (one plant, but many flowers, near subpopulation D); *Scaevola spinescens* (fairly common, approx. 20 flowers per plant); *Waitzia fitzgibbonii* (relatively abundant at subpopulation D); native Hibiscus (*Alyogyne ?hakeifolia*) (some distance from subpopulation A) (see Appendix E, Table E1).

***Visitors to Marianthus aquilonaris***

Native bee taxa visiting *Marianthus aquilonaris* included a tiny species of native bee (Colletidae: Euryglossinae, *Xanthesma* undescribed sp. 60, male), two *Lasioglossum* species (*Lasioglossum (Chilalictus) castor*, female, and *Lasioglossum (Chilalictus) florale*, male and female) (Appendix F, Fig. F1), two *Megachile* species (*Megachile maculosipes*, male and an undescribed species, *Megachile* 66 F "shelf clypeus", female), and one undescribed *Megachile* (*Megachile* 65 F "prongs", female) (Appendix F, Fig. F2d) (Table 1, see also Appendix D, Table D1).

In addition, three flies (Diptera) were observed visiting *Marianthus aquilonaris*: two tiny flies (*Geron* sp., Bombyliidae) were collected on the flowers in the afternoon on 3 Nov 2019 at Subpopulation A and a hoverfly (Syrphidae) at Subpopulation D on 4 Nov 2019 (Table 1). Whether these fly taxa serve as pollinators is unknown, as although flies can be pollinators (Inouye, Larson, Ssymank, & Kevan, 2015), they can also be nectar thieves and are generally less effective at pollinating than bees (Willmer, Cunnold, & Ballantyne, 2017).

With three of the native bee species collected foraging on *Marianthus aquilonaris* being undescribed, and potentially even new to science, their range and potential conservation status is entirely unknown. A similar situation exists for *Megachile maculosipes* is not officially recognised, having been named and published in a thesis (King, 1986). Further studies and surveys to determine the range of these species, identify their habitat requirements, and food and nesting resource requirements are therefore required.

For the three megeachilid species (genus *Megachile*) however it is likely that, like most species in this genus, that they rely on old, large trees that contain small cavities created by wood-boring beetles for nesting substrates (Morato & Martins, 2006; Sydenham et al., 2016). Therefore any activity that removes trees or impacts the beetles they rely on for cavities represents a threat to these bees, which are generally the most effective of pollinators due to the scopae being located on the underside of the abdomen.

The sole euryglossine bee that was collected on *M. aquilonaris* was an undescribed *Xanthesma* species; consequently whilst this species specific range and habitat requirements are unknown, this genus is known to nest in soil (Houston, 1969).

The two halictids collected - *Lasioglossum (Chilalictus) florale* and *Lasioglossum (Chilalictus) castor* - are both described and published information on their biology exists. Both species have a wide range: *L. castor* occurs throughout southwest Western Australia (Walker, 1995), and can be locally abundant and is a common component of bee assemblages (K. Prendergast, unpublished data). The

geographic range of *Lasioglossum (Chilalictus) florale* encompasses most of mid-west, south-west and southern Australia, and it is known to be locally abundant in some locations (Walker, 1995). Interestingly, both species have yet to be collected on a plant species within the family Pittosporaceae, however they are both polylectic species, visiting a high taxonomic diversity of plant species (Walker, 1995; K. Prendergast, unpublished data). *Lasioglossum (Chilalictus)* species nest in the ground (Walker, 1995).
For the ground-nesting bee species, any activities that disturb suitable nesting substrate (e.g. earthworks, road construction, mining) would harm these pollinators.

***Taxa caught in bee bowls***

165 insects were captured in the bee bowls (68 in the blue bowls and 97 in the yellow bowls); of these 127 were native bees (44 captured in the blue bowls and 83 in the yellow bowls) (Table 2). The higher catch rates of native bees in the blue bowls than yellow are consistent with previous studies by K. Prendergast (Prendergast et al., 2020). Bees collected passively in the bee bowls next to *Marianthus aquilonaris* included species that are effective pollinators (Michener, 2007), including the large, mobile *Amegilla* (Houston, 2018). Morever *Amegilla* has been observed to visit another *Marianthus* species (*M. bicolor*) (K. Prendergast, in prep.). Whilst this establishes that native bee taxa occur in the close vicinity of *M. aquilonaris,* the lack of observations of these taxa visiting the plants combined with the genetic data (Botanica Consulting, pers. comm., 2019) suggest that they seldom if at all visit the target plant species, however studies when *M. aquilonaris* is in peak flower would be required to establish this.
The numbers of bees collected in bee bowls next to *M. aquilonaris* far exceeded the number actually foraging on the plants. This highlights a pitfall of bee bowls in that they cannot demonstrate bees actually foraging on the plants (Prendergast et al., 2020). Metabarcoding studies of the bees collected however would reveal if pollen in the gut contents of bees in the bee bowls contained sequences matching *M. aquilonaris*. Although bee bowls collected more bees than sweepnetting from *M. aquilonaris*, overall the number and diversity collected by sweepnetting overall far exceeded that collected by sweepnetting, in line with previous studies by K. Prendergast in the urbanised region of southwest Western Australia (Prendergast et al., 2020).

**Table 2. Bee and fly taxa collected in bee bowls near *Marianthus aquilonaris***

| Bee Bowl colour | Species | Date collected | *Marianthus aquilonaris* Sub-population | Sex | No. collected | Total No. |
|---|---|---|---|---|---|---|
| **Blue** | *Amegilla (Notomegilla) chlorocyanea* | 3/11/2019 | A | F | 1 | 3 |
| | | 4/11/2019 | A | F | 1 | |
| | | 4/11/2019 | B | F | 1 | |
| | *Megachile 65 "prongs"* | 3/11/2019 | B | F | 1 | 5 |
| | | 4/11/2019 | B | F | 1 | |
| | | 4/11/2019 | D | F | 3 | |
| | *Megachile carnaua* | 4/11/2019 | D | F | 1 | 1 |
| | *Lasioglossum (Chilalictus) castor* | 3/11/2019 | C | F | 1 | 20 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 4/11/2019 | A | F | 1 | |
| | | 4/11/2019 | B | F | 5 | |
| | | 4/11/2019 | C | F | 8 | |
| | | 4/11/2019 | C | M | 1 | |
| | | 4/11/2019 | D | F | 4 | |
| | *Lasioglossum (Chilalictus) erythrurum spp-group* | 4/11/2019 | C | F | 3 | 4 |
| | | 4/11/2019 | D | F | 1 | |
| | *Lasioglossum (Chilalictus) cf. sexsetum* | 4/11/2019 | C | F | 1 | 2 |
| | | 4/11/2019 | D | F | 1 | |
| | *Lasioglossum (Chilalictus) cf. victoriellum* | 4/11/2019 | D | F | 1 | 1 |
| | *Lasioglossum (Chilalictus) cf. greavesi* | 4/11/2019 | D | F | 1 | 1 |
| | *Lipotriches (Austronomia) hippophila* | 4/11/2019 | D | F | 1 | 1 |
| | *Lipotriches (Austronomia) flavovridis spp-group* | 4/11/2019 | D | F | 1 | 1 |
| | Diptera: Syrphidae sp.1 | 4/11/2019 | D | | 1 | 1 |
| **Yellow** | *Amegilla (Notomegilla) chlorocyanea* | 3/11/2019 | A | F | 1 | 1 |
| | *Homalictus (Homalictus) cf. urbanus* | 3/11/2019 | A | F | 1 | 2 |
| | | 3/11/2019 | A | M | 1 | |
| | *Lasioglossum (Chilalictus) castor* | 3/11/2019 | A | F | 1 | 40 |
| | | 4/11/2019 | A | F | 13 | |
| | | 4/11/2019 | B | F | 2 | |
| | | 4/11/2019 | C | F | 10 | |
| | | 4/11/2019 | D | F | 14 | |
| | *Lasioglossum (Chilalictus) cf. occiduum* | 4/11/2019 | C | F | 1 | 1 |
| | *Lasioglossum (Chilalictus) cf. instabilis* | 4/11/2019 | C | F | 1 | 5 |
| | | 4/11/2019 | A | F | 4 | |
| | *Euhesma (Euhesma) balladonia/walkeri* | 4/11/2019 | A | F | 1 | 2 |
| | | 4/11/2019 | B | F | 1 | |
| | *Euhesma (Euhesma) inconspicua* | 4/11/2019 | B | F | 1 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| *Lasioglossum (Chilalictus) cf. ptyon* | 4/11/2019 | A | F | 2 | 2 |
| *Lasioglossum (Chilalictus) cf. sexsetum* | 4/11/2019 | A | F | 2 | 2 |
| *Megachile 65 "prongs"* | 4/11/2019 | B | F | 2 | 9 |
| | 4/11/2019 | C | F | 1 | |
| | 4/11/2019 | D | F | 6 | |
| *Megachile clypeata* | 4/11/2019 | B | F | 1 | 1 |
| *Megachile 66 "shelf clypeus"* | 4/11/2019 | D | F | 1 | 1 |
| *Megachile 68* | 4/11/2019 | D | M | 1 | 1 |
| Diptera: Syrphidae sp.1 | 4/11/2019 | A | | 1 | 5 |
| | 4/11/2019 | D | | 4 | |

***Implications for Marianthus aquilonaris pollination***

The relative paucity of insect visitors to *Marianthus aquilonaris* observed during these surveys cannot be taken as conclusive evidence that few insects visit this species. Due to visiting well after peak flowering, the few scattered flowers did not represent an attractive foraging resource for bees, which are known to target larger, clumped patches of flowers (Cresswell & Osborne, 2004; Sih & Baltus, 1987). Nevertheless, despite being well after peak bloom, over the two days of surveys, K. Prendergast collected a total of 15 insect visitors to *M. aquilonaris*, of which 11 were native bees belonging to a number of genera. It is evident therefore that *M. aquilonaris* is not experiencing pollinator deficits, and it is highly likely that a far greater abundance and diversity of pollinators would visit the plants during peak bloom.

*Megachile* and *Lasioglossum* are both effective pollinators of many taxa (Michener, 2007). *Megachile* in particular are highly effective as pollinators, as the scopae are located on the underside of the abdomen, in a prime location for transferring pollen to the stigma of flowers (Michener, 2007). The Euryglossinae are unlikely to be effective pollinators (in terms of cross-pollination), due to their small size (with larger bees being better pollinators (Willmer & Finlayson, 2014)) and how they swallow pollen and are relatively hairless (Michener, 2007). Nevertheless, euryglossines are known to be pollinators of native flora, and have evolved many specialised, co-evolutionary specialised relationships (e.g. Exley, 1998; Houston, 1983). Euryglossinae are a key part of Australia’s bee biodiversity, being the most species-rich of all subfamilies, and are largely endemic to Australia (Houston, 2018). New species are continually being discovered and described (Hogendoorn, Stevens, & Leijs, 2015).

There was abundant seedset during the current surveys, evidenced by many seed pods on the plants. This suggest that pollination is occurring, but based on the genetic data, there is little pollen exchange between plants of different sub-populations (Hopley & Byrne 2018a; Hopley & Byrne, 2019b). This suggests that either a) the pollinators of this plant have low vagility and/or small flight ranges, and/or generally forage on flowers in the same plant or between adjacent plants; or b) seed set is mostly a result of selfing and potentially wind pollination resulting in only local pollen transfer. Therefore, whilst the genetic data do suggest that visitation is rare, or only by insects with low vagility, further pollination studies to determine the contribution of insects to seed production are required, which would involve:

a) surveys of insect visitors to the plants during peak bloom;
b) investigation of pollen loads on insect visitors;
c) pollination studies involving bagging some flowers on multiple plants (thereby excluding insect visitors) and comparing seed set between bagged and open (control) flowers;
d) hand pollination trials to determine whether pollen transferred from stamens of the same flower, same plant, plants in the same subpopulation, and plants in other subpopulations, all result in the production of seedpods.

The small body size of some of the insects observed foraging on *Marianthus aquilonaris* is in line with the genetic data (Hopley & Byrne 2018a; Hopley & Byrne, 2019b): flight distance is directly related to body size (Gathmann & Tscharntke, 2002; Greenleaf, Williams, Winfree, & Kremen, 2007). With bees being central place forages (Westrich, 1996), nesting sites and foraging resources must be within the flight range of the species. As *M. aquilonaris* subpopulations are separated by >500 m, it may be that the native bees are rarely flying between subpopulations, thereby explaining the limited pollen exchange.

Few young *M. aquilonaris* plants were observed during the surveys (K. Prendergast, pers. obs., 2019). These observations, together with genetic data showing little pollen exchange between subpopulations, and no to very poor germination (Botanica Consulting, 2017) suggest that *M. aquilonaris* is suffering from inbreeding depression (Harmon & Braude, 2010). The current surveys established that *M. aquilonaris* is pollinated by bees, including those that are effective pollinators. It appears therefore that the lack of pollen exchange between subpopulations may be due to the subpopulations being fragmented and exceeding the flight range of the bees (Aizen & Feinsinger, 1994; Brosi, Daily, Shih, Oviedo, & Durán, 2008; Donaldson, Nänni, Zachariades, & Kemper, 2002; González-Varo, Arroyo, & Aparicio, 2009; Hunter, 2002; Murren, 2002; Newman, Ladd, Brundrett, & Dixon, 2013).

The current surveys did establish that an incredibly abundant and diverse native bee assemblage are present in the vicinity of *Marianthus aquilonaris*, largely foraging on *Eucalyptus livida* (Appendix F, Fig. F2, Appendix G). With such a high diversity and abundance of native bees, this rules out the hypothesis that the low genetic variation between subpopulations (Hopley & Byrne 2018a; Hopley & Byrne, 2019b) is due to an absence of bees – the primary and most effective pollinators for most angiosperms (Willmer et al., 2017).

Many of the bee species were collected on *Eucalyptus livida*, and some of these taxa (Hylaeinae, Euryglossinae) are known to specialise on Myrtaceae. However, specialisation in bees is considered in terms of pollen resources, not nectar, and therefore these bees may forage on other taxa, including *Marianthus aquilonaris*, for nectar. This would be likely when the *M. aquilonaris* was in peak bloom, representing a readily-available nectar resource.

Very few European honeybees (*Apis mellifera*) were observed, and none were observed foraging on any of the flora, with all observations occurring of honeybees around tiny depressions containing water. The relative paucity of honeybees may be due to the scarcity of water, and the large distances from domesticated hives, given that domestic hives represent both a source from which domesticated honeybee foragers can come from, as well as a source from which feral honeybee colonies can establish from when a colony swarms. The relative scarcity of honeybees may in fact play a role in the abundance and diversity of native bee taxa, given there is some evidence that this introduced species may be having detrimental impacts on wild indigenous bees, including Australian bees (Prendergast, 2018b; Prendergast et al., in prep).

**Conclusion**

These surveys have established that the region supports a rich diversity of native bees, and thus is of high conservation value for native bee biodiversity. Of sites previously surveyed by K. Prendergast across Western Australia, this level of native bee biodiversity has yet to be recorded in a given season at a single site (K. Prendergast, unpublished data).

Despite the limitations of surveys being conducted outside of peak flowering time of *Marianthus aquilonaris,* the surveys fulfilled the aims of this project with respect to the EOD:

> "Item 13: If potential direct or indirect impacts to *M. aquilonaris* are proposed, identifying potential pollinators for *M. aquilonaris*, including changes to pollinator subpopulations or behaviour, changes to linkages between sub-subpopulations of species pollinated by vectors with short ranges, causing interruptions to gene flow within and between sub-subpopulations" (Preston Consulting Pty Ltd., 2019)

Six species of native bees were collected on *Marianthus aquilonaris*: an undescribed *Xanthesma* sp. 60 (family Colletidae), *Lasioglossum (Chilalictus) castor* (family Halictidae), *Lasioglossum (Chilalictus) florale* (family Halictidae), *Megachile maculosipes* (family Megachilidae), undescribed *Megachile* 66 F "shelf clypeus" (family Megachilidae), undescribed *Megachile* 65 F "prongs" (family Megachilidae). In addition, two fly species, in the family Syrphidae and Bombyliidae, were also recorded.

Only two of the native bee species have published information about their biology, and hence further studies on the remaining species is warranted, including identifying how restricted in distribution the undescribed species collected at this locality are. Knowledge on the biology of these species based on their generic classification however indicates that undisturbed soil and mature trees are required to support their nesting and therefore reproductive activities. The native bee taxa were small to medium-sized, and therefore have limited flight ranges (Zurbuchen et al., 2010). As bees are central-place foragers, their foraging and nesting resources must be within flight range (Michener, 2007). With genetic data on *Marianthus aquilonaris* suggesting limited pollen exchange between the sub-populations, it appears that the sub-populations are isolated from the perspective of these pollen vectors. Any activity that may further isolate the sub-populations through destruction of nesting resources, or a shrinking of the area of occupancy of the *Marianthus aquilonaris* plants, may further impede pollen flow between the sub-populations.

The limitations in few *Marianthus aquilonaris* plants being in flower means that the full suite of insect visitors could not be established, however K. Prendergast was able to reveal that a range of insect taxa, including species of native bees that are effective pollinators, visited this species.

These surveys also clearly demonstrated the importance of *Eucalyptus livida* as a foraging resource for supporting native bee biodiversity in the vicinity of *Marianthus aquilonaris.* Representing a rich supply of nectar and pollen visited by a diverse taxa, these trees represent important foraging resources for native bees, including the pollinators of *Marianthus aquilonaris.*

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## Appendix A: International Union for Conservation of Nature (IUCN) Threatened Species categories

Species are assigned the following categories: Extinct, EX Near Threatened, NT Extinct in the Wild, EW Least Concern, LC Critically Endangered, CR Data Deficient, DD Endangered, EN Not Evaluated, NE Vulnerable, VU. For the criteria for Critically Endangered, Endangered and Vulnerable there is a hierarchical alphanumeric numbering system of criteria and subcriteria. These criteria and subcriteria form an integral part of the Red List assessment and all those that result in the assignment of a threatened category must be specified after the category.

SUMMARY OF THE FIVE CRITERIA (A-E) USED TO EVALUATE IF A TAXON BELONGS IN AN IUCN RED LIST THREATENED CATEGORY (CRITICALLY ENDANGERED, ENDANGERED OR VULNERABLE).[1]

**A. Population size reduction.** Population reduction (measured over the longer of 10 years or 3 generations) based on any of A1 to A4

| | Critically Endangered | Endangered | Vulnerable |
|---|---|---|---|
| A1 | ≥ 90% | ≥ 70% | ≥ 50% |
| A2, A3 & A4 | ≥ 80% | ≥ 50% | ≥ 30% |

- **A1** Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND have ceased.
- **A2** Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.
- **A3** Population reduction projected, inferred or suspected to be met in the future (up to a maximum of 100 years) *[(a) cannot be used for A3].*
- **A4** An observed, estimated, inferred, projected or suspected population reduction where the time period must include both the past and the future (up to a max. of 100 years in future), and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

*based on any of the following:*

- **(a)** direct observation *[except A3]*
- **(b)** an index of abundance appropriate to the taxon
- **(c)** a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality
- **(d)** actual or potential levels of exploitation
- **(e)** effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

**B. Geographic range in the form of either B1 (extent of occurrence) AND/OR B2 (area of occupancy)**

| | Critically Endangered | Endangered | Vulnerable |
|---|---|---|---|
| **B1.** Extent of occurrence (EOO) | < 100 km² | < 5,000 km² | < 20,000 km² |
| **B2.** Area of occupancy (AOO) | < 10 km² | < 500 km² | < 2,000 km² |
| **AND at least 2 of the following 3 conditions:** | | | |
| **(a)** Severely fragmented **OR** Number of locations | = 1 | ≤ 5 | ≤ 10 |

**(b)** Continuing decline observed, estimated, inferred or projected in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** area, extent and/or quality of habitat; **(iv)** number of locations or subpopulations; **(v)** number of mature individuals

**(c)** Extreme fluctuations in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** number of locations or subpopulations; **(iv)** number of mature individuals

**C. Small population size and decline**

| | Critically Endangered | Endangered | Vulnerable |
|---|---|---|---|
| **Number of mature individuals** | < 250 | < 2,500 | < 10,000 |
| **AND at least one of C1 or C2** | | | |
| **C1.** An observed, estimated or projected continuing decline of at least (up to a max. of 100 years in future): | 25% in 3 years or 1 generation (whichever is longer) | 20% in 5 years or 2 generations (whichever is longer) | 10% in 10 years or 3 generations (whichever is longer) |
| **C2.** An observed, estimated, projected or inferred continuing decline AND at least 1 of the following 3 conditions: | | | |
| **(a)** **(i)** Number of mature individuals in each subpopulation | ≤ 50 | ≤ 250 | ≤ 1,000 |
| **(a)** **(ii)** % of mature individuals in one subpopulation = | 90–100% | 95–100% | 100% |
| **(b)** Extreme fluctuations in the number of mature individuals | | | |

**D. Very small or restricted population**

| | Critically Endangered | Endangered | Vulnerable |
|---|---|---|---|
| **D.** Number of mature individuals | < 50 | < 250 | **D1.** < 1,000 |
| **D2.** *Only applies to the VU category* Restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time. | - | - | **D2.** typically: AOO < 20 km² or number of locations ≤ 5 |

**E. Quantitative Analysis**

| | Critically Endangered | Endangered | Vulnerable |
|---|---|---|---|
| **Indicating the probability of extinction in the wild to be:** | ≥ 50% in 10 years or 3 generations, whichever is longer (100 years max.) | ≥ 20% in 20 years or 5 generations, whichever is longer (100 years max.) | ≥ 10% in 100 years |

1 Use of this summary sheet requires full understanding of the *IUCN Red List Categories and Criteria* and *Guidelines for Using the IUCN Red List Categories and Criteria.* Please refer to both documents for explanations of terms and concepts used here.

Source: IUCN. (2012). IUCN Red List Categories and Criteria: Version 3.1. Second edition.Gland, Switzerland and Cambridge, UK: IUCN. iv + 32pp. Available to download: https://www.iucnredlist.org/resources/summary-sheet

**Appendix B: Summary of *Marianthus aquilonaris* sub-populations**

**Table 1: Summary of *Marianthus aquilonaris* sub-populations**

| Population No. | DBCA Live Total Count (2011)[1] | Botanica Live Total Count (2013/2014)[2] | DBCA Live Total Count (2015)[3] | Area Occupied ($m^2$)[4] | Population Condition[4] |
|---|---|---|---|---|---|
| 1a | 9820 | 260** | 2259 | 25,288 | Moderate |
| 1b | 787 | 138** | 247 | 5,645.5 | Moderate |
| 1c | 7091 | 1142** | 3205 | 16,719 | Healthy |
| 1d | N/A* | 2090 | NOT COUNTED | 25,400 | Healthy |
| 1e | N/A* | 1029 | NOT COUNTED | 2,200 | Healthy |
| 1f | N/A* | | 1 | 11 | Healthy |
| **TOTAL** | **17,698** | **4,659** | **5,712** | **75,263.5** | |

[1] Population monitoring conducted by DBCA in October 2011.
[2] simple plant count conducted by Botanica 2013-2014 (yellow shading=2013; orange shading=2014)
[3] simple plant count conducted by DBCA 29th September 2015 (listed on the TPFL database).
[4] area occupied/ population condition as listed on DBCA TPFL database based on assessments conducted by Botanica and DBCA.
*N/A-Sub-populations were not identified during the 2011 count conducted by DBCA
**Simple count of mature plants only not full record of all plants present.

Source: Botanica Consulting (2017). Memorandum: *Marianthus aquilonaris* to Geoffrey Hann (Audalia Resources Limited). Botanica Consulting, Western Australia, p.3.

**Appendix C: *Marianthus aquilonaris* subpopulations**

**Fig. C1: Subpopulation A**

**Fig. C2: Subpopulation B**

**Fig. C3: Subpopulation C**

**Fig. C4: Subpopulation D**

**Fig. C5: Landscape in which the *Marianthus aquilonaris* subpopulations occur; note *M. aquilonaris* plants in the foreground, lacking flowers.**

**Appendix D: Specimens collected**

**Table D1. Total number of potential pollinator taxa collected during the surveys of *Marianthus aquilonaris* by K.S. Prendergast, Nov 2 – Nov 4, 2019.**

| Date | Population (Way Point) | [redacted] | Host | Family | Species Code | Species | no. female | no. male | no. per bee species |
|---|---|---|---|---|---|---|---|---|---|
| 2.Nov. 2019 | A (35, 36) | | *Eucalyptus livida* | Colletidae | Euryglossinae 63 M | *Callohesma lucida* | | 1 | 1 |
| | | | | Halictidae | Lasioglossum 27 F | *Lasioglossum (Chilalictus) mediopolitum* | 1 | 1 | 2 |
| | C (33) | | *Eucalyptus livida* | Colletidae | Euryglossinae 61 F | *Xanthesma (Argohesma) nukarnensis* | 1 | | 1 |
| | D (32, 41) | | *Eucalyptus livida* | Colletidae | Hylaeus 13 F | *Hylaeus (Prosopisteron) chlorosoma* | 1 | 1 | 2 |
| | | | ***Marianthus aquilonaris*** | **Halictidae** | **Lasioglossum 35 F** | ***Lasioglossum (Chilalictus) florale*** | **1** | **1** | **2** |
| 3.Nov. 2019 | A (35, 36) | | BlueBeeBowl | Apidae | Amegilla 1 F | *Amegilla (Notomegilla) chlorocyanea* | 1 | | 1 |
| | | | *Eucalyptus livida* | Colletidae | Euryglossinae 61 F | *Xanthesma (Argohesma) nukarnensis* | 4 | 21 | 25 |
| | | | | Colletidae | Hylaeus 13 F | *Hylaeus (Prosopisteron) chlorosoma* | 2 | 3 | 5 |
| | | | | Colletidae | Hylaeus 16 F | *Hylaeus (Gnathoprosopis) amiculus* | 4 | 1 | 5 |
| | | | | Colletidae | Hylaeus 62 F | *Hylaeus (Rhodohylaeus) lateralis* | 2 | 3 | 5 |
| | | | | Colletidae | Euryglossinae 4F | *Euryglossula sp. 4 F* | 2 | | 2 |
| | | | | Colletidae | Euryglossinae 5 F | *Hyphesma astronomicans* | 2 | | 2 |
| | | | | Colletidae | Hylaeus 6 F | *Hylaeus (Rhodohylaeus) proximus* | 2 | | 2 |
| | | | | Colletidae | Hylaeus 13 F | *Hylaeus (Prosopisteron) chlorosoma* | 2 | | 2 |
| | | | | Colletidae | Euryglossinae 17 F | *Euryglossina (Turnerella) argocephala* | 1 | | 1 |
| | | | | Colletidae | Euryglossinae 58 M | *Brachyhesma (Brachyhesma) wyndhami* | | 1 | 1 |
| | | | | Colletidae | Euryglossinae 59 F | *Pachyprosopis (Parapachyprosopis) eucyrta* | 1 | | 1 |
| | | | | Colletidae | Euryglossinae 64 M | *Callohesma sinapipes* | | 1 | 1 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Colletidae | Hylaeus 64 M | *Hylaeus (Euprosopis) honestus* | | 1 | 1 |
| | | | | Colletidae | Hylaeus 65 M | *Hylaeus (Rhodohylaeus) "crassigenatus* | | 1 | 1 |
| | | | | Colletidae | Euryglossinae 53 M | *Pachyprosopis (Pachyprosopis) haematostoma* | | 1 | 1 |
| | | | | Colletidae | Euryglossinae 54 F | *Euhesma (Euhesma) cf. nitidifrons* | 1 | | 1 |
| | | | | Colletidae | Leioproctus 9 M | *Leioproctus (Leioproctus) clarki* | | 1 | 1 |
| | | | | Halictidae | Lasioglossum 32? M | *Lasioglossum (Chilalictus) cf. occiduum* | | 2 | 2 |
| | | | | Halictidae | Lasioglossum 28 F | *Lasioglossum (Chilalictus) cf. greavesi* | 2 | | 2 |
| | | | | Halictidae | Homalictus 6 F | *Homalictus 6* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 30 M | *Lasioglossum (Chilalictus) erythrurum spp-group* | | 1 | 1 |
| | | | | Halictidae | Lasioglossum 37 M | *Lasioglossum (Chilalictus) cf. ebeneum* | | 1 | 1 |
| | | | | Halictidae | Lipotriches 7 M | *Lipotriches (Austronomia) hippophila* | | 1 | 1 |
| | | | | Halictidae | Lasioglossum 27 M | *Lasioglossum (Chilalictus) mediopolitum* | | 1 | 1 |
| | | | YellowBeeBowl | Apidae | Amegilla 1 F | *Amegilla (Notomegilla) chlorocyanea* | 1 | | 1 |
| | | | | Halictidae | Homalictus 7 F | *Homalictus (Homalictus) cf. urbanus* | 1 | 1 | 2 |
| | | | | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 1 | | 1 |
| | B (34) | [redacted] | BlueBeeBowl | Megachilidae | Megachile 65 F | *Megachile 65 "prongs"* | 4 | | 4 |
| | | | *Eucalyptus livida* | Colletidae | Euryglossinae 61 F | *Xanthesma (Argohesma) nukarnensis* | 2 | 16 | 18 |
| | | | | Colletidae | Hylaeus 62 F | *Hylaeus (Rhodohylaeus) lateralis* | 4 | 7 | 11 |
| | | | | Colletidae | Hylaeus 16 F | *Hylaeus (Gnathoprosopis) amiculus* | 3 | 2 | 5 |
| | | | | Colletidae | Hylaeus 6 F | *Hylaeus (Rhodohylaeus) proximus* | 1 | 3 | 4 |
| | | | | Colletidae | Hylaeus 65 M | *Hylaeus (Rhodohylaeus) "crassigenatus* | | 4 | 4 |
| | | | | Colletidae | Hylaeus 30 M | *Hylaeus (Euprosopis) elegans* | | 2 | 2 |
| | | | | Colletidae | Euryglossinae 53 M | *Pachyprosopis (Pachyprosopis) haematostoma* | | 1 | 1 |
| | | | | Colletidae | Euryglossinae 58 F | *Brachyhesma (Brachyhesma) wyndhami* | 1 | | 1 |
| | | | | Colletidae | Hylaeus 13 M | *Hylaeus (Prosopisteron) chlorosoma* | | 1 | 1 |
| | | | | Colletidae | Leioproctus 9 M | *Leioproctus (Leioproctus) clarki* | | 1 | 1 |
| | | | | Halictidae | Lasioglossum 30 F | *Lasioglossum (Chilalictus) erythrurum spp-group* | 1 | | 1 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | C (33) | [redacted] | BlueBeeBowl | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 1 | | 1 |
| | D (32, 41) | [redacted] | *Eucalyptus livida* | Halictidae | Lasioglossum 27 F | *Lasioglossum (Chilalictus) mediopolitum* | 2 | | 2 |
| | | | | Halictidae | Homalictus 6 F | *Homalictus 6* | 1 | | 1 |
| 4.Nov. 2019 | A (35, 36) | [redacted] | BlueBeeBowl_am | Apidae | Amegilla 1 F | *Amegilla (Notomegilla) chlorocyanea* | 1 | | 1 |
| | | | BlueBeeBowl_pm | Coleoptera | Buprestidae sp.1 | *Buprestidae sp.1* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 2 | | 2 |
| | | | *Eucalyptus livida* | Apidae | Exoneura 9 F | *Exoneura 9* | 1 | | 1 |
| | | | | Colletidae | Euryglossinae 61 F | *Xanthesma (Argohesma) nukarnensis* | 4 | 23 | 27 |
| | | | | Colletidae | Hylaeus 16 F | *Hylaeus (Gnathoprosopis) amiculus* | 10 | 1 | 11 |
| | | | | Colletidae | Euryglossinae 58 F | *Brachyhesma (Brachyhesma) wyndhami* | 1 | 2 | 3 |
| | | | | Colletidae | Hylaeus 6 F | *Hylaeus (Rhodohylaeus) proximus* | 3 | | 3 |
| | | | | Colletidae | Hylaeus 62 F | *Hylaeus (Rhodohylaeus) lateralis* | 1 | 1 | 2 |
| | | | | Colletidae | Hylaeus 13 M | *Hylaeus (Prosopisteron) chlorosoma* | | 1 | 1 |
| | | | | Halictidae | Lasioglossum 36 F | *Lasioglossum (Chilalictus) cf. sexsetum* | 1 | | 1 |
| | | | YellowBeeBowl_am | Diptera: Syrphidae | Syrphidae Sp.1 | *Syrphidae Sp.1* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 11 | | 11 |
| | | | YellowBeeBowl_pm | Colletidae | Euryglossinae 56 F | *Euhesma (Euhesma) balladonia/walkeri* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 2 | | 2 |
| | | | | Halictidae | Lasioglossum 33 F | *Lasioglossum (Chilalictus) cf. instabilis* | 2 | | 2 |
| | | | | Halictidae | Lasioglossum 34 F | *Lasioglossum (Chilalictus) cf. ptyon* | 2 | | 2 |
| | | | | Halictidae | Lasioglossum 36 F | *Lasioglossum (Chilalictus) cf. sexsetum* | 2 | | 2 |
| | B (34) | [redacted] | BlueBeeBowl_am | Apidae | Amegilla 1 F | *Amegilla (Notomegilla) chlorocyanea* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 5 | | 5 |
| | | | | Megachilidae | Megachile 65 F | *Megachile 65 "prongs"* | 1 | | 1 |

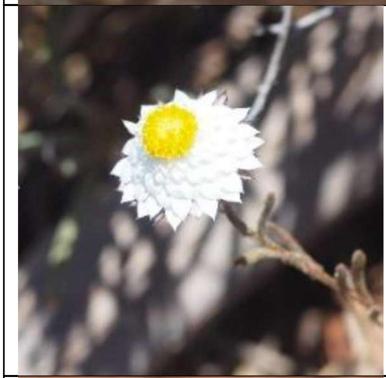
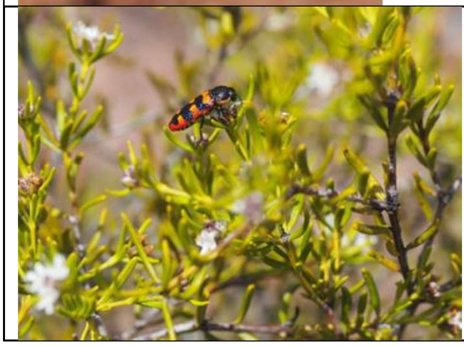
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | YellowBeeBowl_am | Colletidae | Euryglossinae 55 F | *Euhesma (Euhesma) inconspicua* | 1 | | 1 |
| | | | | Colletidae | Euryglossinae 56 F | *Euhesma (Euhesma) balladonia/walkeri* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 1 | | 1 |
| | | | | Megachilidae | Megachile 65 F | *Megachile 65 "prongs"* | 1 | | 1 |
| | | | | Megachilidae | Megachile 69 F | *Megachile clypeata* | 1 | | 1 |
| | | | YellowBeeBowl_pm | Coleoptera | Buprestidae sp.1 | *Buprestidae sp.1* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 4 | | 4 |
| | | | | Megachilidae | Megachile 65 F | *Megachile 65 "prongs"* | 2 | | 2 |
| | C (33) | [redacted] | BlueBeeBowl_am | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 3 | 1 | 4 |
| | | | BlueBeeBowl_pm | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 5 | | 5 |
| | | | | Halictidae | Lasioglossum 30 F | *Lasioglossum (Chilalictus) erythrurum spp-group* | 3 | | 3 |
| | | | | Halictidae | Lasioglossum 36 F | *Lasioglossum (Chilalictus) cf. sexsetum* | 1 | | 1 |
| | | | ***Marianthus aquilonaris*** | **Megachilidae** | **Megachile 65 F** | ***Megachile 65 "prongs"*** | **1** | | **1** |
| | | | YellowBeeBowl_am | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 10 | | 10 |
| | | | | Halictidae | Lasioglossum 32 F | *Lasioglossum (Chilalictus) cf. occiduum* | 1 | | 1 |
| | | | YellowBeeBowl_pm | Halictidae | Lasioglossum 33 F | *Lasioglossum (Chilalictus) cf. instabilis* | 1 | | 1 |
| | | | | Megachilidae | Megachile 65 F | *Megachile 65 "prongs"* | 1 | | 1 |
| | D (32, 41) | [redacted] | BlueBeeBowl_am | Diptera: Syrphidae | Syrphidae Sp.1 | *Syrphidae Sp.1* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 4 | | 4 |
| | | | | Halictidae | Lasioglossum 26 F | *Lasioglossum (Chilalictus) cf. victoriellum* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 28 F | *Lasioglossum (Chilalictus) cf. greavesi* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 30 F | *Lasioglossum (Chilalictus) erythrurum spp-group* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 36 F | *Lasioglossum (Chilalictus) cf. sexsetum* | 1 | | 1 |
| | | | | Halictidae | Lipotriches 7 F | *Lipotriches (Austronomia) hippophila* | 1 | | 1 |
| | | | | Megachilidae | Megachile 65 F | *Megachile 65 "prongs"* | 3 | | 3 |

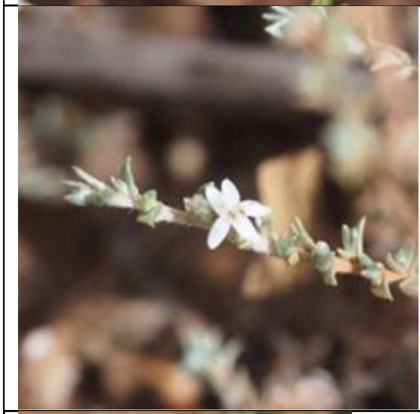
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Megachilidae | Megachile 67 F | *Megachile carnaua* | 1 | | 1 |
| | | | BlueBeeBowl_pm | Coleoptera | Buprestidae sp.1 | *Buprestidae sp.1* | 1 | | 1 |
| | | | | Halictidae | Lipotriches 2 F | *Lipotriches (Austronomia) flavovridis spp-group* | 1 | | 1 |
| | | | *Eucalyptus livida* | Colletidae | Euryglossinae 61 F | *Xanthesma (Argohesma) nukarnensis* | 1 | 11 | 12 |
| | | | | Colletidae | Hylaeus 13 F | *Hylaeus (Prosopisteron) chlorosoma* | 1 | 1 | 2 |
| | | | | Colletidae | Euryglossinae 57 M | *Euhesma 57* | | 1 | 1 |
| | | | | Colletidae | Euryglossinae 62 F | *Indeterminate genus (undescribed, genus nov.) sp. nov.* | 1 | | 1 |
| | | | | Colletidae | Hylaeus 6 F | *Hylaeus (Rhodohylaeus) proximus* | 1 | | 1 |
| | | | | Colletidae | Hylaeus 62 F | *Hylaeus (Rhodohylaeus) lateralis* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 28 F | *Lasioglossum (Chilalictus) cf. greavesi* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 36 M | *Lasioglossum (Chilalictus) cf. sexsetum* | 1 | | 1 |
| | | | | Halictidae | Lasioglossum 36? F | *Lasioglossum (Chilalictus) cf. calophyllae* | 1 | | 1 |
| | | | | Halictidae | Lipotriches (Austronomia) australica F | *Lipotriches (Austronomia) australica* | 1 | | 1 |
| | | | ***Marianthus aquilonaris*** | **Colletidae** | **Euryglossinae 60 M** | ***Xanthesma sp*** | | **1** | 1 |
| | | | ***Marianthus aquilonaris*** | **Diptera: Syrphidae** | **Syrphidae Sp.1** | ***Syrphidae Sp.1*** | **1** | | 1 |
| | | | ***Marianthus aquilonaris*** | **Halictidae** | **Lasioglossum 1 F** | ***Lasioglossum (Chilalictus) castor*** | **1** | | 1 |
| | | | ***Marianthus aquilonaris*** | **Megachilidae** | **Megachile 66 F** | ***Megachile 66 "shelf clypeus"*** | **1** | | 1 |
| | | | ***Marianthus aquilonaris*** | **Megachilidae** | **Megachile 70 M** | ***Megachile maculosipes (WAM code 329)*** | | **1** | 1 |
| | | | ***Marianthus aquilonaris*** | **Diptera: Bombyliidae** | **Geron sp.1** | ***Geron sp.1*** | **2** | | 2 |
| | | | YellowBeeBowl_am | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 5 | | 5 |
| | | | | Megachilidae | Megachile 65 F | *Megachile 65 "prongs"* | 1 | | 1 |
| | | | | Megachilidae | Megachile 66 F | *Megachile 66 "shelf clypeus"* | 1 | | 1 |
| | | | | Megachilidae | Megachile 68 M | *Megachile 68* | | 1 | 1 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | YellowBeeBowl_pm | Diptera: Syrphidae | Syrphidae Sp.1 | *Syrphidae Sp.1* | 4 | | 4 |
| | | | | Halictidae | Lasioglossum 1 F | *Lasioglossum (Chilalictus) castor* | 9 | | 9 |
| | | | | Megachilidae | Megachile 65 F | *Megachile 65 "prongs"* | 5 | | 5 |

**Appendix E: Other plant species in flower**

**Table E1: Photos and species names of some of the plants in bloom**

| Image | ID |
| --- | --- |
|  | *Scaevola spinescens* |
|  | *Eremophila caperata* |
|  | *Waitzia fitzgibbonii* |
|  | *Asteridea athrixioides* |
|  | *Westringia cephalantha* |

| | |
|---|---|
|  | *Halgania lavandulacea* |
|  | *Leptospermum incanum* |
|  | *Alyogyne ?hakeifolia* |

**Appendix F: Native bee species photographs**

**Fig. F1: Male (above) and female (below) *Lasioglossum (Chilalictus) florale* visitors to *Marianthus aquilonaris*.**

**Fig. F2. Examples of native bee taxa sweepnetted from *Eucalyptus livida* (a-c) flowering in the vicinity of *Marianthus aquilonaris* a) *Xanthesma (Argohesma) nukarnensis*, female, b) *Brachyhesma (Brachyhesma) wyndhami*, female c) *Hylaues (Gnathopsis) amiculus*, female, and d) an undescribed *Megachile* collected in the bee bowls and from *Marianthus aquilonaris.***

**Appendix G: Video file of native bees and other insects visiting *Eucalyptus livida* en masse**

**PB040044.MOV : https://drive.google.com/file/d/1sVFuR2lrh3WTbaSbZL95kfH-8gyf2Ys7/view?usp=sharing**

**Attachment 7: Soils of the Audalia Medcalf area. Prepared by Neil Lantzke for Audalia Resources Limited. Western Horticultural Consulting (2019)**

# Soils of the Audalia Medcalf area

Investigations into the soils on which *Marianthus aquilonaris*, *Eucalyptus rhomboidea* and *Stenanthemum bremerense* grow - for use in defining critical habitats


**Neil Lantzke**

**Western Horticultural Consulting**


**December 2019**

# Summary

Soil investigations were conducted in April and August 2019 within and around the Medcalf Project mining tenement (M63/656) to determine the range of soil types on which *Marianthus aquilonaris* (MA), *Eucalyptus rhomboidea* (ER) and *Stenanthemum bremerense* (SB) grow. Seventy four soil profiles located both within and outside populations of MA, ER and SB were described and samples were taken from representative soil horizons for laboratory analysis.

Five main soil groups were identified:

1. Alkaline red shallow loamy duplex
2. Loamy gravel
3. Shallow gravel over indurated mottled zone
4. Stony soils
5. Shallow gravel

A large number of soil observation sites were dug within and surrounding the populations of MA that had been mapped by Botanica Consulting. The soil survey showed that MA grows on gravelly, shallow loamy soils with an indurated, mottled zone layer that occurs within 30 cm of the soil surface ('Shallow gravel over indurated mottled zone' soil). These soils are almost always located on a low ridge that typically have outcrops of limonite. The soil pH is acidic. The soils in the areas that surround these ridges of shallow soils are quite different. They are deeper colluvial soils, do not contain outcrops of limonite and typically have a neutral or alkaline pH. The 'Shallow gravel over indurated mottled zone' soil is a very minor soil type in the district.

Areas of 'Shallow gravel over indurated mottled zone' soil were mapped. The MA populations that were mapped independently by Botanica Consulting occur within this soil map unit. Areas of 'Shallow gravel over indurated mottled zone' soil were found in areas away from the MA populations. The map of the 'Shallow gravel over indurated mottled zone' soils may assist in determining the boundaries of the critical habitat for MA.

The soils on which *Eucalyptus rhomboidea* was growing were examined and described at twenty one sites. This species grows on a range of soil groups at a range of positions in the landscape. This species was found growing on 'Alkaline red shallow loamy duplex' soils that occur on the lower, mid and upper slopes. It was found growing on 'Loamy gravel' soils on the lateritic plateau at the top of the landscape and on the mid slopes. It was also found growing on 'Shallow gravel' soils, below a breakaway. The 'Alkaline red shallow loamy duplex' and 'Loamy duplex' soils are common soil groups in the district.

The soils on which *Stenanthemum bremerense* was growing were examined and described at twenty sites. All sites contained a high percentage of ironstone gravels and were classified as the 'Loamy gravel' soil group. SB was found on the lateritic plateau at the top of the landscape and

on areas of gravelly rises on the mid to lower slopes. The 'Loamy gravel' soil is a common soil group in the district

# Aim

Soil information is required to support the Environmental Impact Assessment for the proposed Medcalf Project. In particular, soil data is required to assist with defining the habitat of *Marianthus aquilonaris* (MA), *Eucalyptus rhomboidea* (ER) and *Stenanthemum bremerense* (SB).

The four aims of this study are to:

1. Describe the major soil types that occur in the Medcalf Project tenement area.
2. Determine and describe the soil types on which MA, ER and SB grow.
3. Accurately map the extent of the 'Shallow gravel over indurated mottled zone' soils that are associated with the MA populations.
4. Survey readily accessible areas of the tenement and adjacent regional land for other areas of 'Shallow gravel over indurated mottled zone.' Map these areas.

# Method

**Defining the properties of the soils on which MA, ER and SB grow**

The soils, landform type and vegetation were described at seventy four sites that were located within and adjacent to the populations of MA, ER and SB.

The GPS coordinates from the Botanica Consulting vegetation survey were used to locate populations of the three species. A subset of these coordinates was selected for conducting the soil descriptions. Sites were chosen to sample the full range of soils present across all populations and landscape types.

A spade, pick and hand auger were used to excavate the soil (rather than a backhoe) to prevent damage to the vegetation.

Soil parameters that were described at each site included; the depth of each soil horizon, soil texture (hand assessment), soil structure, colour, percentage of coarse fragments including gravel (field sieving), field pH and electrical conductivity. The soil profiles were described using the terminology of McDonald et al (1990). Soil colours were described according to standard Munsell colour chart notation. Estimates of plant available water of representative sites were calculated based on soil texture, percentage of coarse fragments and estimated rooting depth.

Eighty one soil samples of the different soil horizons from 38 sites that represented the range of soil groups encountered in the soil survey were sent to the Chem Centre for physical and chemical analysis. These samples were analysed for:

- Percentage of stones
- pH $_{water}$
- pH $_{CaCl}$
- EC

A sub set of samples from each soil group were submitted to a more comprehensive suite of analysis which is listed below:

- ESP
- BSP
- Ca, K, Mg and Na
- CEC
- Organic carbon
- N
- % of clay, silt and sand
- Mehlich suite (Al, P, K, Ca, Na, Mg, B, S, Cu, Fe, Mn, Mo, Cd, Ni, Pb, Zn, Se)

**Mapping areas of 'Shallow gravel over indurated mottled zone' soils on which the populations of MA occur**

East west lines at intervals of 30 metres were drawn on aerial photographs over areas within and adjacent to the MA populations. Initially the soil surveyor walked along these transects digging holes until the boundary of the 'Shallow gravel over indurated mottled zone' soil was identified. It was found that it was quicker and of similar accuracy for the soil surveyor to map the boundary on the 'Shallow gravel over indurated mottled zone' soil by using the presence of outcrops of mottled zone (limonite), so this approach was used instead. Way points were entered into the GPS at distances of approximately 20 metres as the surveyor walked around the areas of 'Shallow gravel over indurated mottled zone' soils. The boundaries were checked against the soil profile descriptions, and by digging observation sites to confirm the soil type.

**Mapping of other areas of 'Shallow gravel over indurated mottled zone' in and adjacent to the tenement area on which no MA has been found**

Access to much of the tenement area is limited due to the lack of tracks and the long distances that have to be covered by walking through bushland. There are four roads that radiate from the camp (SE road, SW road, NE road and NW road). The soil surveyors searched on foot for approximately 250 metres on either side of these roads looking for outcrops of limonite that indicate the presence of the 'Shallow gravel over indurated mottled zone' soil. When areas of 'Shallow gravel over indurated mottled zone' soils were found the soil surveyors used a GPS to mark way points around the soil boundary.

Because of difficulties with access only a small percentage of the area in and around the tenement was searched for the presence of the 'Shallow gravel over indurated mottled zone' soil.

# Background information

## Existing broadscale soil mapping

The following link shows soils and landform information that is available for Western Australia on the DPIRD website. [https://www.agric.wa.gov.au/resource-assessment/nrinfo-western-australia](https://www.agric.wa.gov.au/resource-assessment/nrinfo-western-australia)

The only information that is available for the Lake Metcalf area is the Atlas of Australian Soils mapping that was completed at the very broad scale (1:3000000). The whole of the Audalia tenement area is shown as one soil/landscape unit (266DD13) with the major WA soil groups being listed as 'Calcareous loamy earths', 'Red deep loamy duplex', 'Red shallow loamy duplex' and 'Loamy gravel'.

This information is of too broad a nature to be of use in identifying the soils that the three plant species (MA, ER and SB) grow on.

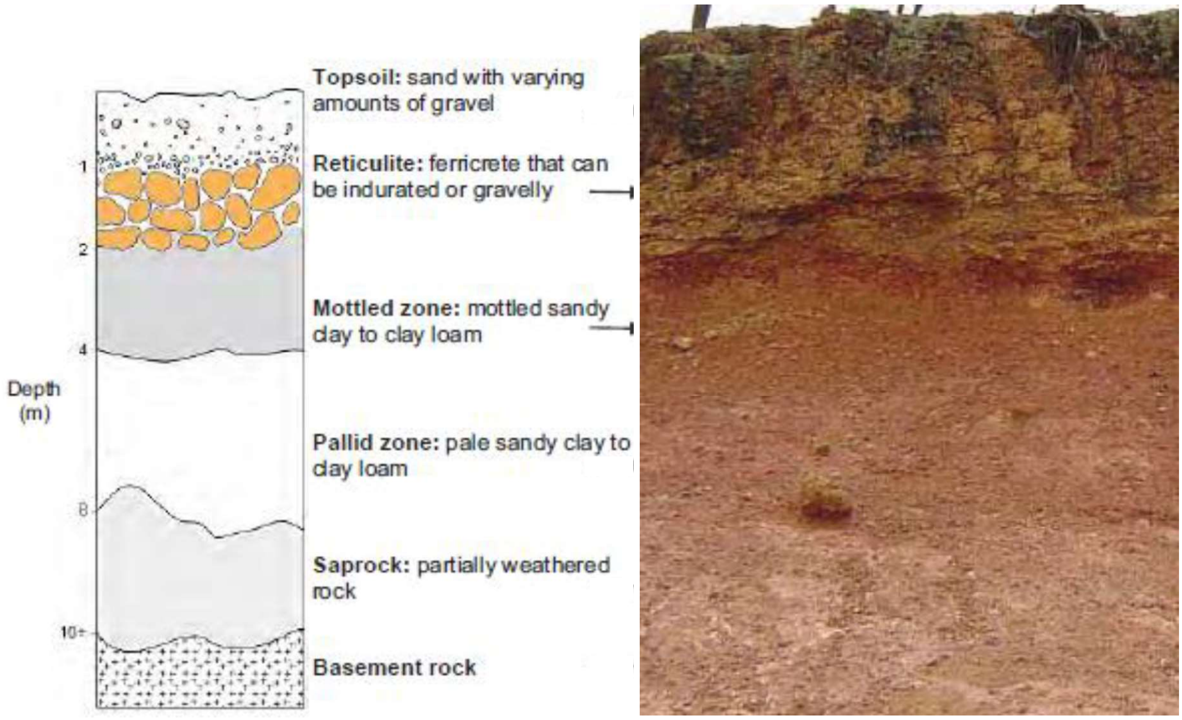
## Geology and physiography

The Medcalf deposit is located on the Lake Johnston Greenstone Belt area. The Medcalf layered sill, which is comprised of gabbro, pyroxenite and amphibolite has intruded into the enclosing basalt.

The upper surface of these rocks has undergone laterization. The lateritic profile can be seen at the top of the landscape at Medcalf. It consists of a gravelly sandy loam overlying ferricrete (duricrust) and lateritic boulders. Beneath the ferricrete layer is the mottled zone, which in turn overlies saprolite and then sap rock.

Figure 1 shows a diagram of a typical lateritic profile (left) and a photograph of the ferricrete layer and underlying mottled zone (right). The parent material at Medcalf is mafic rock which results in a darker red, more loamy topsoil than indicated in the diagram in Figure 1, and the pallid zone was absent or not seen.

**Figure 1. Typical lateritic profile in the south west of Western Australia (from Moore, 2011 (left) and Sawkins, 2011 (right)).**




The lateritic material and the underlying mafic rock provide the parent material for the soils at the Medcalf site. The extent of dissection of the lateritic profile has a large influence on what soils are formed. Different soils develop in different parts of the landscape. Soil types follow a sequence down the slope (catena) with:

- Gravelly lateritic soils developing over ferricrete or ironstone boulders at the top of the landscape.
- Below the breakaway face shallow gravelly soils develop over the mottled zone.
- Where the underlying mafic rocks have been exposed on the upper and mid slopes these rocks generally weather to form loam over clay (duplex) soils.
- Deeper loamy surfaced duplex soils develop as a result of colluvial movement on the mid and lower slopes.
- Salt lakes occur at the bottom of the landscape.

# Results

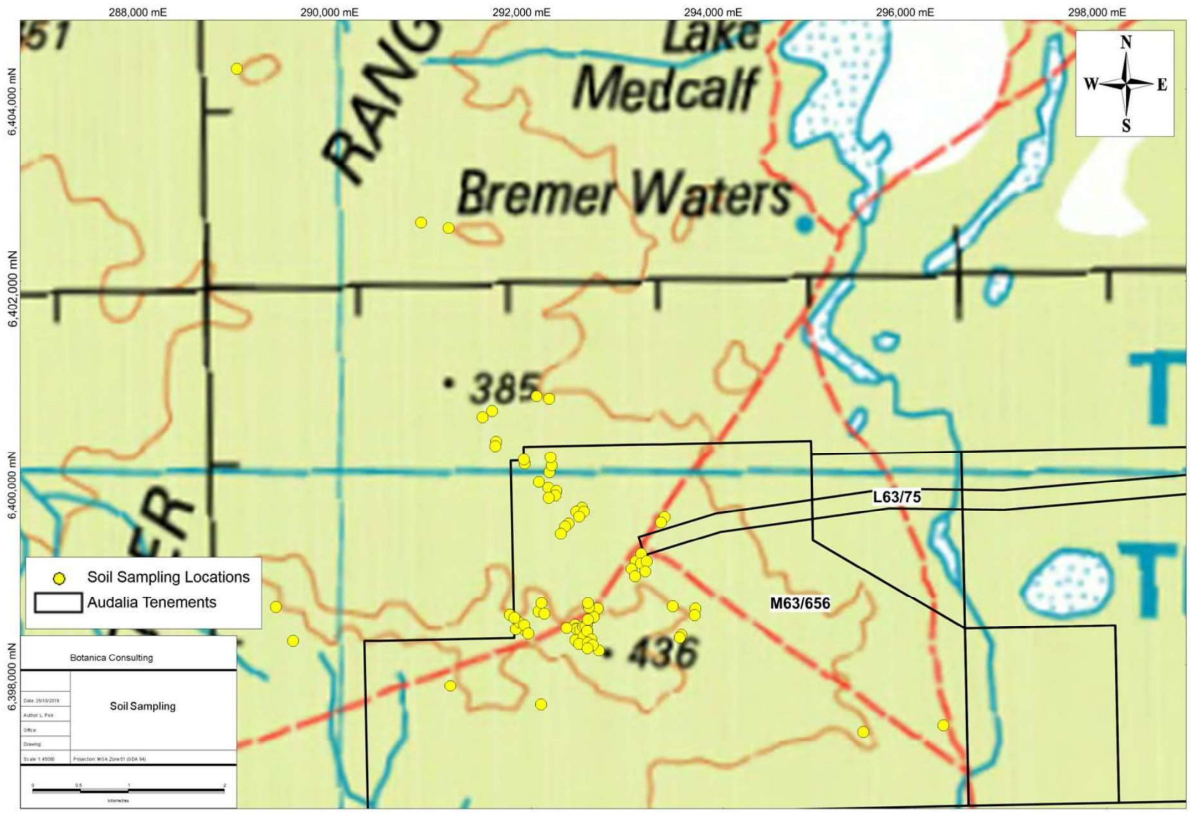
## Soil descriptions

Seventy four soil profiles were sampled and described in and adjacent to the MA, ER and SB populations. The location of the soil profiles is shown in Figure 2. Additional observations sites of the surface soil texture and vegetation type were also made at locations outside of the Medcalf mining tenement to gain an understanding of the regional distribution of the soils.

The soils at these sites can be classified into five soil groups:

1. Alkaline red shallow loamy duplex
2. Loamy gravel
3. Shallow gravel over indurated mottled zone
4. Stony soils
5. Shallow gravel

**Figure 2. Location of the soil profile description sites and the Medcalf mining tenement.**



## Alkaline red shallow loamy duplex

### Location and position in the landscape

This is a major soil group within the Medcalf mining tenement and surrounding areas. In the sequence of soils in the landscape (catena) this soil group occurs below the gravelly lateritic plateau and extends towards the valley floor. It can be found on the upper, mid and lower slopes.

The soil surface usually contains a scree of dark lateritic gravels, particularly on the upper slopes where they may cover up to 70 % of the soils surface. Outcropping of mafic rocks is not common but can occur particularly on the upper slopes where the depth to bedrock is often shallower.

### Soil description

This soil group contains a range of red coloured, loamy duplex soils with the soil properties at each site being influenced by the geology of the parent material and position in the landscape.

The topsoil is generally about 10 to 15 cm thick and is a dark reddish brown sandy loam. A dark reddish brown or dark red clay sub soil generally occurs within 40 cm. In some examples of this soil there is an intermediate sandy clay loam layer between the topsoil and the clay.

The soil has a moderate, sub angular blocky structure.

The soil profile contains between 0 and 60 % dark angular ironstone gravel and rocks. In some profiles, fragments of the underlying mafic rocks are found in the subsoil. When these soils occur on the mid and lower slopes they generally contain less rock.

The topsoils have a neutral to alkaline pH ($pH_{water}$ = 7 to 8.5). The subsoil is alkaline ($pH_{water}$ = 8.5 to 9) and often contains lime nodules.

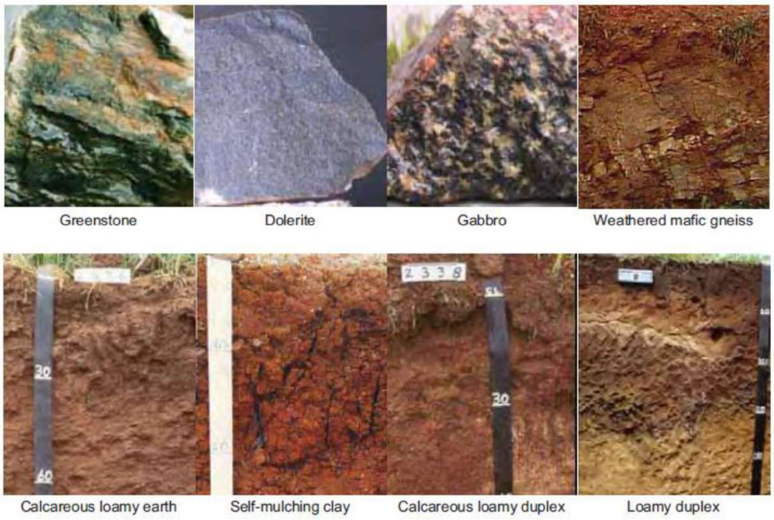
The salinity of this soil is generally low. However, the sub soil can be saline, particularly on sites that are located lower in the landscape.

Areas of similar soil with a greater depth to the clay subsoil ('Alkaline red deep loamy duplex') and similar soils with a more brown or grey colour or with a deeper loamy topsoil ('Calcareous loamy earths') can also be found. These soils are less common than the 'Alkaline red shallow loamy duplex' and all have similar chemical and physical properties so they have not been separated in this study.

#### *Plant growth considerations*

Plant roots can grow deep into the subsoil as this soil has no impeding layers and is moderately well structured. The water holding capacity of this soil is high due to the loamy to clay textures. The plant available water in the effective root zone of this soil group is high, however on examples of this soil with a high percentage of gravels, the water holding capacity is reduced.

**Figure 3. Photographs of an 'Alkaline red shallow loamy duplex' soil at Medcalf showing roots of the native Eucalyptus species growing into the clay subsoil (left and below). Photographs showing a range of soils formed from different mafic rocks (right from Sawkins, 2011)**


## 2. Loamy gravel

**Location and position in the landscape**

This is a major soil group within the Medcalf mining tenement and surrounding areas and it is found at many positions in the landscape. It occurs on the lateritic plateau at the top of the landscape, and on the upper, mid and lower slopes.

The soil surface contains a scree of dark lateritic gravels and they may cover up to 70 % of the soils surface. Ironstone rocks often occur on the soil surface, particularly on the upper slopes.

**Soil description**

The topsoil is generally about 10 to 15 cm thick and is a dark reddish brown, gravelly loamy sand to sandy loam. This surface horizon grades into a dark reddish brown sandy loam to sandy clay loam which extends to depths of greater than 50 to 80 cm. The percentage of gravels generally increases from about 20 to 50 % in the topsoil to over 60 % in the subsoil. A clay layer may be encountered at depth.

The pH throughout the soil profile is close to neutral ($pH_{water}$ = 6.5 to 7.5).

This soil is not saline.

***Plant growth considerations***

This soil has no impeding layers that limit root growth. The water holding capacity of this soil is reduced by the high percentage of gravels. The plant available water in the effective root zone of this soil group is moderate.

**Figure 4. A photograph of a 'Loamy gravel' soil at Medcalf.**

## 3. Shallow gravel over indurated mottled zone

The soil investigation showed that MA grows only on this soil type. 'Soil groups of Western Australia: a simple guide to the main soil groups of Western Australia' Schoknecht and Pathan (2013) contains a general soil group called 'Shallow gravel'. As the soil requirements of MA are so specific it was necessary in this study to subdivide this soil group and create a separate soil type for those soils that contain shallow indurated mottled zone in the sub soil.

The mottled zone in these soils has been hardened by the addition of iron and it is referred to by geologists as limonite. Limonite is an iron ore consisting of a mixture of hydrated iron (III) oxide-hydroxides. The limonite at Medcalf is believed to have formed from weathered basalt. In this report I refer to the soil layer as the 'indurated mottled zone'.

**Figure 5. A photograph of the surface of this soil group showing the high percentage of limonite rock on the surface (left) and the shallow depth to the indurated mottled zone (right).**

**Location and position in the landscape**

This soil is a minor soil group within and on the land surrounding the Medcalf mining tenement area. It occurs on the upper slopes below the lateritic plateau. It is usually found on ridges that are often only one to two metres higher than the surrounding area. It can occur on spurs that lead down from the lateritic plateau.

**Figure 6. A photograph showing MA vegetation in the foreground growing on a rocky ridge of 'Shallow gravel over shallow mottled zone' soil, and in the background Eucalyptus species growing on the deeper soil that occurs off the ridge.**

Between 70 and 90 % of the soil surface is covered with a scree of dark lateritic gravels and fragments of limonite rock. Limonite outcrops are common and in areas may compose up to 50 % of the soils surface.

This soil group can contain areas where water erosion has removed some of the topsoil to expose the underlying indurated mottled zone. The impermeable subsoil and limited plant growth make this soil more prone to erosion by water.

**Soil description**

The topsoil is generally about 10 to 15 cm thick and is a dark reddish brown sandy loam. In most examples the dense, indurated mottled zone occurs directly below the topsoil (at less than 15 cm deep). In some cases, a sandy clay loam subsoil layer can occur below the topsoil, with the indurated mottled zone occurring at depths of no greater than 30 cm.

The soil contains between 10 and 50 % dark angular ironstone gravel.

Topsoils and subsoils are generally acidic, with a $pH_{water}$ between 4.5 and 7.

The salinity of this soil is generally low.

**Figure 7. A photograph of a 'Shallow gravel over indurated mottled zone' soil at Medcalf showing the shallow loamy topsoil and an indurated mottled zone occurring at 15 cm deep. The pick had difficulty penetrating the indurated mottled zone.**

***Plant growth considerations***

No plant roots were seen penetrating the indurated mottled zone. This layer appears to be continuous, which is quite different to the 'Shallow gravel' soil group where ironstone rocks and boulders are found within a soil matrix.

The effective rooting depth of plants is likely to be limited to the soil above the indurated mottled zone. The plant available water in the effective root zone of this soil group is likely to be very low. The acidity of the soil may limit the growth of some species.

**Figure 8. A photograph of a track showing the continuous nature of the mottled zone that occurs below the topsoil. *E. livida* which grows on this soil can be seen in the background.**

## 4. Stony soils

**Location and position in the landscape**

This is a minor soil group within the Audalia tenement that is found in association with outcrops of mafic rocks. It usually occurs higher in the landscape.

The soil surface contains rocks that may cover up to 90 % of the soils surface. The bedrock may outcrop in places.

**Soil description**

The topsoil is generally about 10 to 25 cm thick and is a dark reddish brown, rocky loamy sand to sandy loam. The percentage of gravels and rocks in the topsoil can be as high as 90%. This topsoil overlays bedrock.

The pH is close to neutral ($pH_{water}$ = 7 to 7.5).

This soil is not saline.

***Plant growth considerations***

The water holding capacity of this soil is greatly reduced by the very high percentage of gravels and rocks. However, plant roots can explore the soil matrix between the rocks in the subsoil. The plant available water in the effective root zone of this soil group is low.

**Figure 9. A photograph of a 'Stony soil' at Medcalf.**

## 5. Shallow gravel

**Location and position in the landscape**

This is a minor soil group within the Audalia tenement. This soil is often found at the top of the landscape adjacent to the breakaway face.

The soil surface contains a scree of dark lateritic gravels and rocks that may cover up to 90 % of the soils surface. Ironstone cap rock (ferricrete) may outcrop in places.

**Soil description**

The topsoil is generally about 10 to 25 cm thick and is a dark reddish brown, gravelly loamy sand to sandy loam. The percentage of gravels and rocks in the soil can be as high as 90%. This topsoil overlays ironstone boulders or lateritic cap rock.

The pH is close to neutral ($pH_{water}$ = 7 to 7.5).

This soil is not saline.

***Plant growth considerations***

The water holding capacity of this soil is greatly reduced by the very high percentage of gravels and rocks. However, plant roots can explore the soil matrix between the ironstone rocks in the subsoil. The plant available water in the effective root zone of this soil group is low.

**Figure 10. A photograph of a 'Shallow gravel' soil at Medcalf.**

# Laboratory analysis

The results of the laboratory analysis are shown in Attachments 1 and 2.

## Summary of significant results

### Percentage of stones (> 2mm)

All the soils generally contained a high percentage of stones in the topsoil (between 20 and 50 %), with some soils containing up to 80 % stones. The clayey subsoil layers typically contained less than 25 % stones.

### pH

The 'Alkaline red shallow loamy duplex' typically had neutral soil pH's in the topsoil and were strongly alkaline in the subsoil with the $pH_{water}$ ranging from 8.0 to 9.3.

The 'Loamy gravel' and 'Shallow gravel' soils had pH's that were close to neutral throughout the soil profile (the $pH_{water}$ ranged from 6.3 to 7.6).

The 'Shallow gravel over indurated lateritic zone' soil had an acidic to neutral pH (the $pH_{water}$ of this soil ranged from 4.0 to 6.9).

### Electrical conductivity

Electrical conductivity is a measure of the salinity of the soil. The laboratory analysis showed that a number of the sites contained soil that had a high salinity.

The sub soils of 'Alkaline red loamy shallow duplex' soils which were located lower in the landscape often had elevated salinities (100 to >300 mS/m). It is likely at these locations that the regional saline groundwater table was influencing the salinity of the subsoil.

One 'Shallow gravel over indurated lateritic zone' soil (Site 16) had an elevated salinity (230 mS/m) in the topsoil. This site was located immediately below a small breakaway and the area was bare of vegetation.

### Percentage of clay, silt and sand

The particle size analysis conducted by the laboratory (shown in Attachments 1 and 2) agreed well with the hand textures described in the field during the soil survey (see Appendix 1). The topsoil of all soil groups contained a similar percentage of each particle size fraction and generally had a sandy loam texture.

### Organic carbon

The topsoil of all soil groups contained moderate to high levels of organic carbon (1.2 to 2.8 %).

**Exchangeable sodium percentage (ESP)**

Sodic soils are prone to dispersion which can reduce water infiltration and root penetration. A soil with an ESP of greater than 6 is regarded as sodic and if the ESP is greater than 15 is regarded as strongly sodic.

None of the topsoils of the soils that were analysed were sodic. However, all of the sub soils were sodic or strongly sodic. The two samples of indurated mottled zone (sample 10 C and sample R) were sodic or strongly sodic.

**Composition of the indurated mottled zone (limonite)**

A sample of the indurated mottled zone which occurs in the subsoil of the 'Shallow gravel over indurated mottled zone' soil was analyzed for its composition. The results are shown in Table 1.

**Table 1. Composition of the indurated mottled zone (limonite)**

| Composition | Percentage |
|---|---|
| $SiO_2$ | 45 |
| $Fe_2O_3$ | 17 |
| $Al_2O_3$ | 12 |
| CaO | 11 |
| MgO | 7 |
| $TiO_2$ | 3 |
| $Na_2O$ | 1.8 |
| $K_2O$ | 1.1 |

# Soil and vegetation relationships

In the south of Western Australia there is often a close relationship between the soil type and the native vegetation. Farmers use vegetation as a method of describing soil types, for example, Salmon gum clay, York gum/Jam loams, Morrel loams and Banksia sands. Soil types (and vegetation) vary over short distances and often there is an intergrade of soils (and vegetation) at the margins.

Many species grow on a range of different soil types, but some species grow only on a specific soil type and are good 'indicator species' for that soil type. The information in this section demonstrates that there is a very good correlation between soil type and the presence of MA and SB. On the other hand, ER grows three soil groups that occur at three locations in the landscape.

Appendix 1 gives a summary of soil, landform and vegetation descriptions at the 74 sites.

**Moisture holding characteristics**

The moisture holding capacity of a soil depends on soil depth, soil texture and the percentage of inert material such as gravel. Deep, well-structured soils allow roots to access water at greater depths in the soil profile. Loams hold more water than sands. Gravels do not hold moisture and a high percentage of this material will limit the soils water holding capacity.

Table 2 gives estimates of plant available water stored over the depth of the effective root zone for a typical example of each soil group. The figures are derived from a soil moisture calculating spreadsheet developed by Department of Primary Industries and Regional Development staff.

It can be seen that the 'Alkaline red shallow loamy duplex' has the highest plant available water within the root zone while the 'Shallow gravel over indurated mottled zone' has a very low plant available water.

**Table 2. The estimated effective rooting depth and plant available water for typical examples of the five soil groups.**

| Soil group | Estimated effective rooting depth (cm) | Plant available water (mm) |
|---|---|---|
| 'Alkaline red shallow loamy duplex' | 100 | 80 |
| 'Loamy gravel' | 100 | 40 |
| 'Shallow gravel over indurated mottled zone' | 15 | 6 |
| 'Shallow gravel' | 30 | 10 |
| 'Stony soils' | 30 | 10 |

## *Marianthus aquilonaris (MA)*

MA grows on the 'Shallow gravel over indurated mottled zone' soils. Of the 18 sites that were described adjacent to MA populations, 17 of these were 'Shallow gravel over indurated mottled zone' soils and one location had a soil type that was borderline in being classified as this soil.

The areas of the MA populations are superimposed on top of the map of the 'Shallow gravel over indurated mottled zone' soil in Figure 11. It can be seen that MA was only found on this 'Shallow gravel over indurated mottled zone' soil type.

**Figure 11. Areas of 'Shallow gravel over indurated mottled zone' soils and the MA populations as mapped by Botanica Consulting**

[redacted]

Appendix 1 shows that depth to the indurated mottled zone, presence of limonite outcrop and low soil pH are very well correlated with the presence of MA.

The soil survey indicated that MA does not grow on other shallow soils that contain subsoil layers of lateritic duricrust (ferricrete) or decomposing mafic rocks.

The indurated mottled zone appears to be continuous, with no cracks (Figure 8) and plant roots may not be able to penetrate this layer. On areas of 'Shallow gravel' soils that have ferricrete in the subsoil, and on soils with decomposing igneous rock in the subsoil there are usually gaps between the rocks which contain soil into which plant roots can grow.

At the Medcalf mining tenement, the only place in the landscape where water holes were found was on soils with an indurated mottled zone, indicating that this layer is probably quite impermeable. However, the presence of water pools was rare and the excavated soil profiles did not show subsoil moisture above the indurated mottled zone. It is likely that following rainfall water flows sideways off these ridges along the top of the shallow indurated mottled zone and into the deeper soils on the margins of this soil type. This is supported by the evidence of water erosion in some areas.

There was no difference in the soil properties between the different MA populations (Populations 1a, 1b, 1c, 1d and 1e).

Plants, such as MA, which grow on the 'Shallow gravel over indurated mottled zone' soils must be well adapted to long periods of low water availability. MA does not grow in the areas of deeper soils that have a higher water holding capacity, possibly because it is outcompeted by other species.

There is a strong relationship between soil pH and the presence of MA. Appendix 1 shows the field pH measurements and Attachment 1 shows the pH of the soil samples submitted to the laboratory. The $pH_{CaCl}$ of the 'Shallow gravel over indurated lateritic zone' is acid ($pH_{CaCl}$ = 3.8 to 6.3). Many of these soils had a $pH_{CaCl}$ of less than 4.5.

The pH of the soil affects the availability of nutrients. Phosphorus, molybdenum, magnesium and calcium become less available to plants at a low soil pH. Aluminum and manganese may reach levels that become toxic to plants. Aluminum concentrations increase rapidly and become toxic for most crop and pasture species at a soil $pH_{CaCl}$ of less than 4.5.

It is possible that the low soil pH of the 'Shallow gravel over indurated mottled zone' is a determinant of what species grows on the soil. MA is obviously tolerant of low soil pH. The tolerance of native species to aluminum toxicity has not been well researched.

Microbial activity in the soil is affected by soil pH with most activity occurring in soils with a pH of 5 to 7.

The areas of 'Alkaline red shallow loamy duplex' soils and 'Loamy gravels' that surround the MA populations have very different soil characteristics.

Factors other than soil type (such as pollinator species, surface drainage and aspect) may determine the critical habitat. However, in this case it appears that soil, and in particular the presence of a shallow indurated mottled zone layer, is a dominant consideration.

## *Eucalyptus rhomboidea (ER)*

ER was found growing on three soil groups. The largest population of ER is on the 'Alkaline Red Shallow Loamy Duplex' soils. These soils can be found on the lower slopes near the creek lines and on the mid and upper slopes. ER was also found on the plateau surface growing on the 'Loamy Gravels' and just below the breakaway face growing on the 'Shallow gravels'. The 'Alkaline Red Shallow Loamy Duplex' and 'Loamy Gravels' are common soil groups in the district.

All 27 soil profiles that were excavated at ER populations occurred on these three soil groups.

**Figure 12. A photograph of *E. rhomboidea* growing with other eucalyptus species on an 'Alkaline red shallow loamy duplex' adjacent to a creek line on the lower slope**

## *Stenanthemum bremerense (SB)*

SB grows on 'Loamy gravels'. All the 26 sites that were dug adjacent to the SB plants were located on 'Loamy gravels'. The 'Loamy gravel' soil is a common soil group in the district.

**Figure 13. *Stenanthemum bremerense* growing on a deep 'Loamy gravel'**

# Mapping areas of the 'Shallow gravel over indurated mottled zone' soil

A map of areas of the 'Shallow gravel over indurated mottled zone' soil was produced (Figure 14). The areas of this soil type that contained MA populations were accurately mapped (Populations 1a to 1e), while areas of this soil that contained no MA populations (Sites 1 to 8) were mapped with less accuracy.

There could be other areas of 'Shallow gravel over indurated mottled zone' soil within the Audalia tenement and in the surrounding area. Only land within 250 metres of these four roads, and the tracks within the proposed mine site, was surveyed due to difficulties with accessing other areas.

**Figure 14. A map showing locations of the 'Shallow gravel over indurated mottled zone' soil in an around the Metcalf mining tenement.**

[redacted]

The number of hectares in each area identified in Figure 14 is given in Table 4. There are 14.4 hectares of 'Shallow gravel over indurated mottled zone' soil that contain MA populations and 7.7 hectares of 'Shallow gravel over indurated mottled zone' soil that have no MA present. The currently identified areas of the 'Shallow gravel over indurated mottled zone' soil type make up about 1% of the total land area within the Medcalf mining tenement.

**Table 4. Number of hectares in each area of the 'Shallow gravel over indurated mottled zone' soil in and adjacent to the Metcalf tenement**

| Feature | Area (ha) |
|---|---|
| Population 1a | 4.35 |
| Population 1b | 1.36 |
| Population 1c | 2.76 |
| Population 1d | 5.24 |
| Population 1e | 0.35 |
| **Area of 'Shallow gravel over indurated mottled zone' with MA populations** | **14.4** |
| Site 1 | 0.82 |
| Site 2 | 1.98 |
| Site 3 | 3.12 |
| Site 4 | 0.03 |
| Site 5 | 0.48 |
| Site 6 | 0.87 |
| Site 7 | 0.11 |
| Site 8 | 0.28 |
| **Area of 'Shallow gravel over indurated mottled zone' with no MA populations** | **7.7** |
| Audalia Tenement M63/656 | 1853.9 |

## Areas of 'Shallow gravel over indurated mottled zone' soils near Maggie Hayes

A significant area of 'Shallow gravel over indurated mottled zone' soil was found about 10 kilometers south of the Maggie Hayes mine site. The soils occurred in an area near the salt lakes where erosion of the lateritic profile had resulted in breakaways and areas of exposed mottled zone. A GPS coordinate within this area is 51H Easting 269035 and Northing 6426661. This area of 'Shallow gravel over indurated mottled zone' soil was not mapped.

**Figure 15. A photograph of a 'Shallow gravel over indurated mottled zone' soil in the Maggie Hayes area.**

# Sites identified by DBCA as possible potential habitat for *Marianthus aquilonaris*

The Department of Environment and Conservation Interim Recovery Plan 303 for *Marianthus aquilonaris* identified six sites in the Bremer Range where the species might occur. The sites were identified from a desk top assessment using geology maps.

The GPS coordinates of the six sites are:

| | |
|---|---|
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |

In October 2019 soil was collected from the six sites and the samples and submitted to the Chem Centre for laboratory analysis. The results from the laboratory analysis are shown in Attachment 3.

None of the six sites contained 'Shallow gravel over indurated mottled zone' soils. The soil survey of the existing MA populations has shown the excellent correlation between this soil type and the presence of MA. The was no outcropping of limonite at the six sites. It is therefore unlikely that these locations are critical habitat for the species.

Maps of the underlying geology are generally of limited value in predicting soil type in the south west of Western Australia.

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# Acknowledgements

Many thanks to Botanica Consulting for assistance in the field and for preparation of the maps in this report.

# Appendices

## Appendix 1. Summary of soil properties for the 74 sites

Sites highlighted in yellow are 'Shallow gravel over indurated mottled zone' soils.

Sites highlighted in red are 'Alkaline red shallow loamy duplex' soils.

Sites highlighted in green are 'Loamy gravel' soils.

Sites highlighted in grey are 'Stony soils'.

Sites highlighted in brown are 'Shallow gravels'.

| Site No. | Landform | Soil Group | Depth to indurated layer | Limonite outcrop | pH of topsoil | MA, SB or ER present? |
|---|---|---|---|---|---|---|
| 1 | Ridge below plateau surface | Shallow gravel over indurated mottled zone | 15 cm | Yes | 6 | MA |
| 2 | Edge of ridge on upper slope | Alkaline red shallow loamy duplex | Not encountered | No | 7 | |
| 3 | Ridge below plateau surface | Shallow gravel over indurated mottled zone | 30 cm | Yes | 6.5 | MA |
| 4 | Ridge below plateau surface | Shallow gravel over indurated mottled zone | 12 cm | Yes | 6 | MA |
| 5 | Ridge below plateau surface | Shallow gravel over indurated mottled zone | 10 cm | Yes | 6 | MA |
| 6 | Edge of ridge on upper slope | Loamy gravel | Not encountered | No | 7 | |
| 7 | Upper slope | Alkaline red shallow loamy duplex | Not encountered | No | 7.5 | |
| 8 | Upper slope | Alkaline red shallow loamy duplex | Not encountered | No | 7 | |

| Site ID | Landform | Soil group | Depth to indurated layer | Limonite outcrop | pH of topsoil | MA, SB or ER present? |
|---|---|---|---|---|---|---|
| 9 | Upper slope | Alkaline red shallow loamy duplex | Not encountered | No | 8 | |
| 10 | Ridge below plateau surface | Shallow gravel over indurated mottled zone | 15 cm | Yes | 7 | MA |
| 11 | Upper slope | Alkaline red shallow loamy duplex | Not encountered | No | 7.5 | |
| 12 | Upper slope near ridge | Loamy gravel | Gravel stops digging at 20 cm | No | 6.5 | |
| 13 | Mid slope | Shallow gravel over indurated mottled zone | 12 cm | Yes | 5.5 | MA |
| 14 | Mid slope | Alkaline red shallow loamy duplex | Not encountered | No | 8.5 | |
| 15 | Mid slope | Stony soil | Not encountered | No | 7.5 | |
| 16 | Upper slope. Next to breakaway | Shallow gravel over indurated mottled zone | 25 cm | Yes | 4.5 | MA |
| 17 | Mid slope. Off ridge | Alkaline red shallow loamy duplex | Not encountered | No | 6.5 | |
| 18 | Crest | Shallow gravel over indurated mottled zone | 5 cm | Yes | 6 | MA |
| 19 | Mid slope. Off ridge | Alkaline red shallow loamy duplex | Not encountered | No | 8.5 | |
| 20 | Adjacent to crest | Shallow gravel over indurated mottled zone | 30 cm | Yes | 7 | MA |
| 21 | Crest | Shallow gravel (over duricrust) | 25 cm | No | 7 | |
| 22 | Mid slope. Off ridge. | Loamy gravel | Not encountered | No | 7.5 | |

| Site ID | Landform | Soil group | Depth to indurated layer | Limonite outcrop | pH (field) topsoil | MA, SB or ER present? |
|---|---|---|---|---|---|---|
| 23 | Edge of ridge on mid slope | Shallow gravel over indurated mottled zone | 20 cm | No | 6 | MA |
| 24 | Mid slope | Alkaline red shallow loamy duplex | Not encountered | No | 8 | |
| 25 | Plateau surface | Loamy gravel | Not encountered | No | 7 | ER |
| 26 | Plateau surface | Loamy gravel | Not encountered | No | 6.5 | |
| 27 | Plateau surface | Loamy gravel | Not encountered | No | 7 | ER and SB |
| 28 | Plateau surface | Loamy gravel | Not encountered | No | 7 | ER |
| 29 | Upper slope | Loamy gravel | Not encountered | No | 7 | |
| 30 | Mid slope ridge | Shallow gravel over indurated mottled zone | 5 cm | Yes | 6 | MA |
| 31 | Mid slope ridge | Alkaline red shallow loamy duplex | Not encountered | No | 7 | |
| 32 | Mid slope | Alkaline red shallow loamy duplex | Not encountered | No | 8 | |
| 33 | Lower slope | Alkaline red shallow loamy duplex | Not encountered | No | 8 | ER |
| 34 | Lower slope | Alkaline red shallow loamy duplex | Not encountered | No | 8.5 | ER |
| 35 | Lower slope | Loamy gravel | Not encountered | No | 7 | SB |
| 36 | Lower slope | Loamy gravel | Not encountered | No | 7 | SB |
| 37 | Upper slope | Alkaline red shallow loamy duplex | Not encountered | No | 8 | ER |

| Site ID | Landform | Soil group | Depth to indurated layer | Limonite outcrop | pH (field) topsoil | MA, SB or ER present? |
|---|---|---|---|---|---|---|
| 38 | Upper slope. 20 m below Breakaway | Shallow gravel | Not encountered | No | 7.5 | ER |
| 39 | Mid slope ridge | Shallow gravel over indurated mottled zone | 10 cm | Yes | 7 | |
| 40 | Mid slope ridge | Shallow gravel over indurated mottled zone | 10 cm | Yes | 6 | |
| 41 | Mid slope ridge | Shallow gravel over indurated mottled zone | 10 cm | Yes | 5.5 | MA |
| 42 | Mid slope | Loamy gravel | Not encountered | No | 7.0 | SB |
| 43 | Gravelly rise on mid slope | Loamy gravel | Not encountered | No | 7.0 | SB |
| 44 | Mid slope | Loamy gravel | Not encountered | No | 7.0 | SB and ER |
| 45 | Top of a drainage line in mid slope | Alkaline red shallow loamy duplex | Not encountered | No | 8.5 | ER |
| 46 | Lower slope | Alkaline red shallow loamy duplex | Not encountered | No | 7 | ER |
| 47 | Crest on mid slope | Loamy gravel | Not encountered | No | 7.0 | SB |
| 48 | Crest on mid slope | Loamy gravel | Not encountered | No | 7.0 | SB |
| 49 | Upper slope | Alkaline red shallow loamy duplex | Not encountered | No | 6.5 | ER |
| 50 | Upper slope | Loamy gravel | Not encountered | No | 7.0 | SB |
| 51 | Upper slope | Loamy gravel | Not encountered | No | 7.0 | SB |
| 52 | Upper slope | Loamy gravel | Not encountered | No | 7.0 | SB |

| Site ID | Landform | Soil group | Depth to indurated layer | Limonite outcrop | pH (field) topsoil | MA, SB or ER present? |
|---|---|---|---|---|---|---|
| 53 | Upper slope | Loamy gravel | Not encountered | No | 7.0 | SB |
| 54 | Mid slope | Loamy gravel | Not encountered | No | 6.0 | SB |
| 55 | Below breakaway | Alkaline red shallow loamy duplex | Not encountered | No | 7.0 | ER |
| 56 | Mid slope | Loamy gravel | Not encountered | No | 7.0 | SB |
| 57 | Rise on mid slope | Loamy gravel | Not encountered | No | 7.0 | SB |
| 58 | Mid slope | Alkaline red shallow loamy duplex | Not encountered | No | 7.0 | ER |
| 59 | Mid slope | Alkaline red shallow loamy duplex | Not encountered | No | 8.0 | ER |
| 60 | Upper slope | Shallow gravel over indurated mottled zone | Not encountered | Yes | 7.0 | MA |
| 61 | Mid slope | Alkaline red shallow loamy duplex | Not encountered | No | 8.0 | |
| 62 | Mid slope | Shallow gravel over indurated mottled zone | 10 cm | Yes | 6.5 | MA |
| 63 | Mid slope | Shallow gravel over indurated mottled zone | 10 cm | Yes | 6.5 | MA |
| 64 | Lower slope | Alkaline red shallow loamy duplex | Not encountered | No | 8.0 | ER |
| 65 | Lower slope | Alkaline red shallow loamy duplex | Not encountered | No | 8.0 | ER |
| 66 | Lower slope | Alkaline red shallow loamy duplex | Not encountered | No | 7.5 | ER |

| Site ID | Landform | Soil group | Depth to indurated layer | Limonite outcrop | pH (field) topsoil | MA, SB or ER present? |
|---|---|---|---|---|---|---|
| 67 | Lower slope | Alkaline red shallow loamy duplex | Not encountered | No | 7.5 | ER |
| 68 | Lower slope | Alkaline red shallow loamy duplex | Not encountered | No | 8.0 | ER |
| 69 | Lower slope | Alkaline red shallow loamy duplex | Not encountered | No | 7.0 | ER |
| 70 | Mid slope crest | Loamy gravel | Not encountered | No | 6.0 | SB |
| 71 | Mid slope crest | Loamy gravel | Not encountered | No | 6.5 | SB |
| 72 | Mid slope crest | Loamy gravel | Not encountered | No | 7.0 | SB |
| 73 | Lower slope | Loamy gravel | Not encountered | No | 7.0 | SB |
| 74 | Lower slope | Alkaline red shallow loamy duplex | Not encountered | No | 7.0 | ER |

**Attachment 8: Geomorphology of The *Marianthus aquilonaris* Sub-Populations Bremer Range West Australia. Word Technical Services Group Pty Limited (2019)**

# AUDALIA RESOURCES LIMITED

# MEDCALF PROJECT

# GEOMORPHOLOGY OF THE

# MARIANTHUS AQUILONARIS SUB-POPULATIONS

# BREMER RANGE

# WEST AUSTRALIA

**Prepared by:**

**Word Technical Services Group Pty Limited**

**December 2019**

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### Terry Taylor (now retired)

Mr. Taylor is a geologist who brings over 40 years geological mapping, prospecting and associated drilling programs over greenfield and brownfield areas

Mr Taylor was employed for 30 years with Carpentaria Exploration / MIM Exploration and then since has contracted for Lynas Gold, Titan Resources, Red Back Mining, Cullen Resources, MIM Exploration, Gullewa Gold, Kinross Gold Australia, Sipa Resources, ATW Gold, Thundelara and Audalia Resources.

Mr Taylor has mapped in Western Australia's Yilgarn Craton, Pilbara Craton and Proterozoic basins, Queensland's Mt Isa Inlier and Townsville hinterland and Northern Territories Pine Creek Geosyncline.

Mr Taylor was the Audalia consulting Geologist from 2011 to 2018 and has extensively mapped Mining lease M63/656. He has also mapped the regional areas of Exploration licences E63/1133 and E63/1134 to the east of M63/656.

Mr Taylor holds Master of Science from the University of Western Australia (1984), A Bachelor of Science from Melbourne University (1984) and Diploma of Civil Engineering, Swinburne Technical College, Melbourne (1962).

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## TABLES



## FIGURES

## 1. INTRODUCTION

World Technical Services Group Pty Ltd (WTSG) was commissioned by Audalia Resources Limited (proponent) to complete a baseline Geomorphology Report for their Medcalf vanadium titanium and iron project located in the Lake Johnson area of West Australia.

A Threatened species listed under Part 2 of the *Biodiversity Conservation Act 2016* (*Marianthus aquilonaris*) has been identified in the project area. Ecological assessments of the mine site have identified four sub-populations (1a – 1d) with the project area located on M63/656.

*Marianthus aquilonaris* was first found in the Bremer Range, Lake Johnson by Gilbert and Tobin during 1960's.

*Marianthus aquilonaris* is described as an erect, straggly shrub to 1.6 m high with hairy stems, alternate, elliptic to oblong leaves, a glabrous calyx and a pale blue and white corolla. Flowers appear between September and October (Figure 1).

This report forms part of the Audalia Public Environmental Review Document that will be submitted to the Environmental Protection Authority (EPA) to seek environmental approvals for the project.

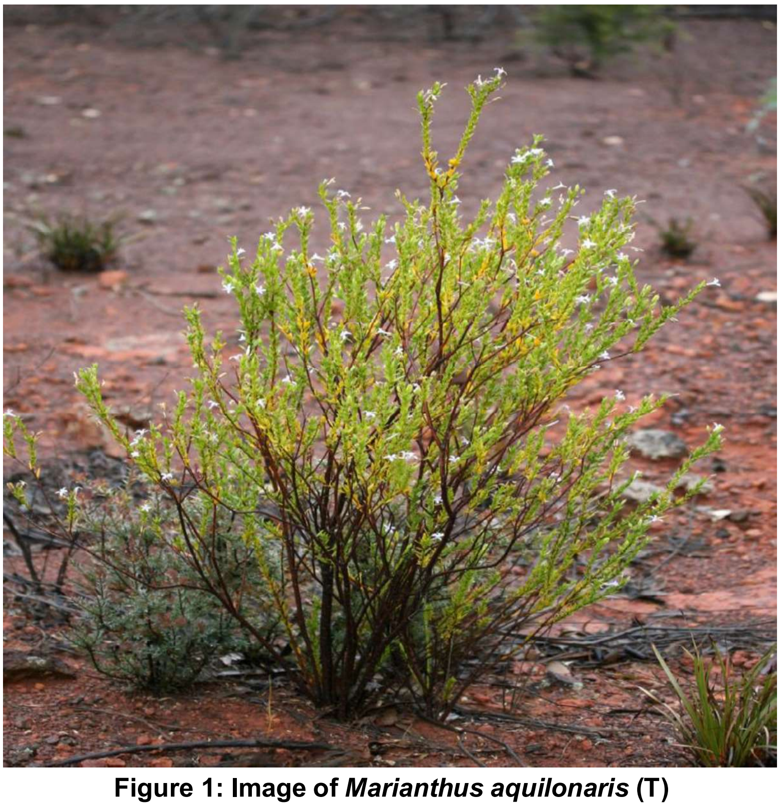

**Figure 1: Image of *Marianthus aquilonaris* (T)**

## 2. LOCATION

The Medcalf Project is located 470km east of Perth, West Australia (Figure 2). Access to the project is via the Coolgardie Esperance Highway some 54km south of Norseman via a 4m wide access track. The project is reached after travelling west 83.6km along this track (Figure 3).

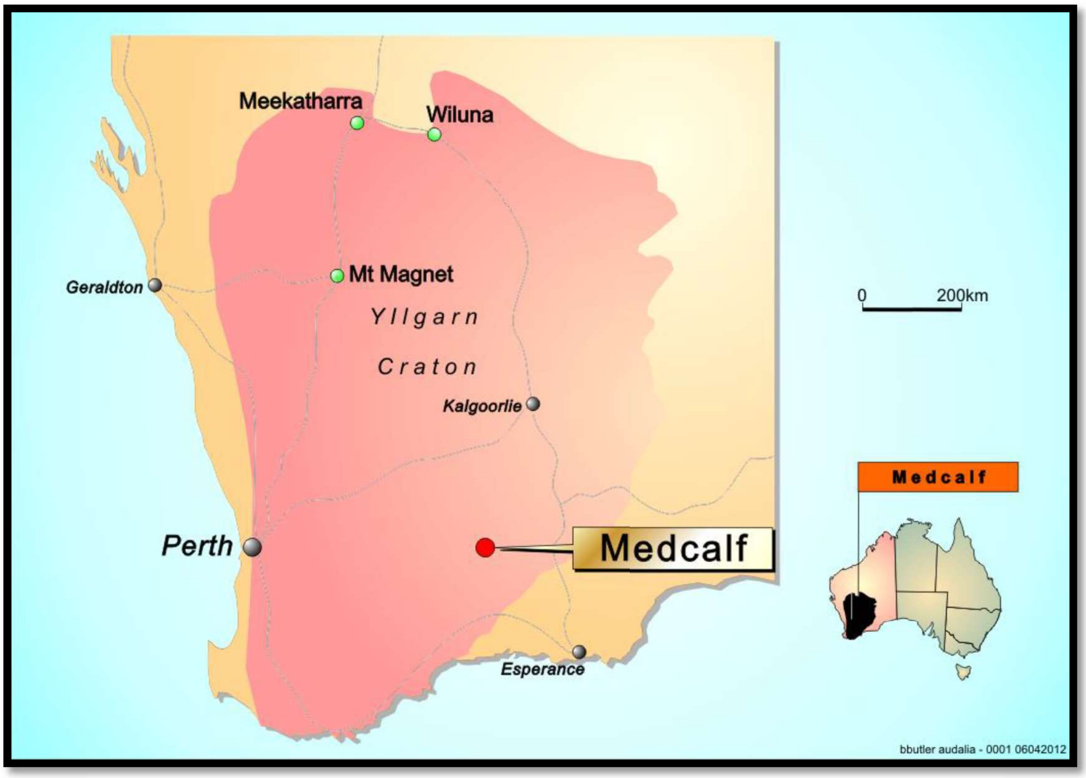


**Figure 2 – Regional Location Map**

## 3. PROJECT LOCATION AND PROPOSAL DESCRIPTION

The proposed mining Project lies within granted Mining Lease M63/656 located approximately 100 kilometres southwest of the township of Norseman, West Australia (Figure 3).

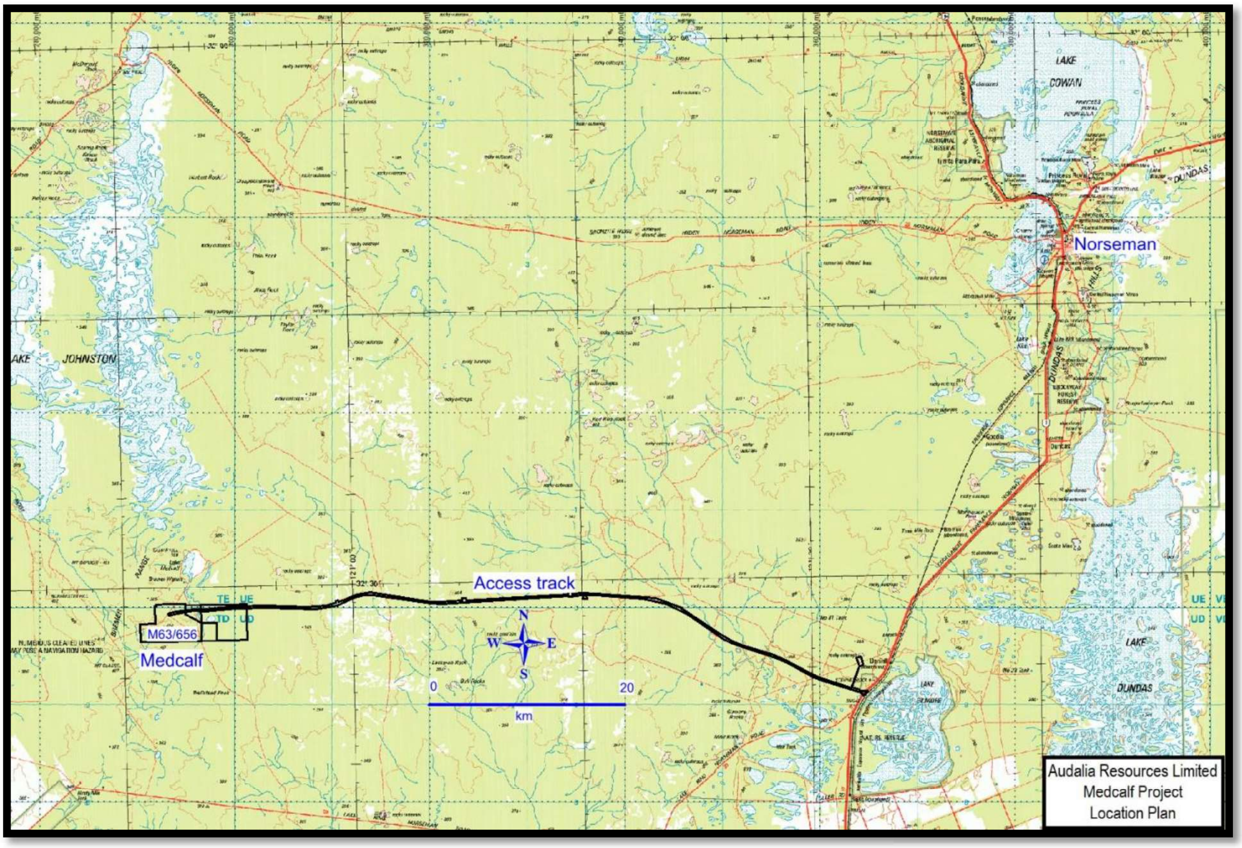


**Figure 3 – Project Location Map**

The Medcalf Project is in an arid area with low, variable rainfall and high evaporation. Average annual rainfall is approximately 360 mm/year. Evaporation exceeds rainfall in every month of the year. Rainfall occurs all year round, but more rain tends to be received during winter (May to September). Large events tend to occur in summer, mainly from January to March.

The area is prone to bush fires of which there have been 12 since 1991. The project area was completely burnt out during 2010 and the most recent fire this year (2019) was 4km west of the project and burnt over a distance of 60km north and south of the project (Figure 4).

*Marianthus aquilonaris* experienced a mass germination event after the 2010 fires. *Marianthus aquilonaris* could be a nursing plant for soil conditioning and appears to excel after major fire events with the competition wiped out for several years.

As years go by post-fire, and more plants begin to grow in the area, the *Marianthus aquilonaris* becomes challenged with competing plants (Figures 5 and 6).

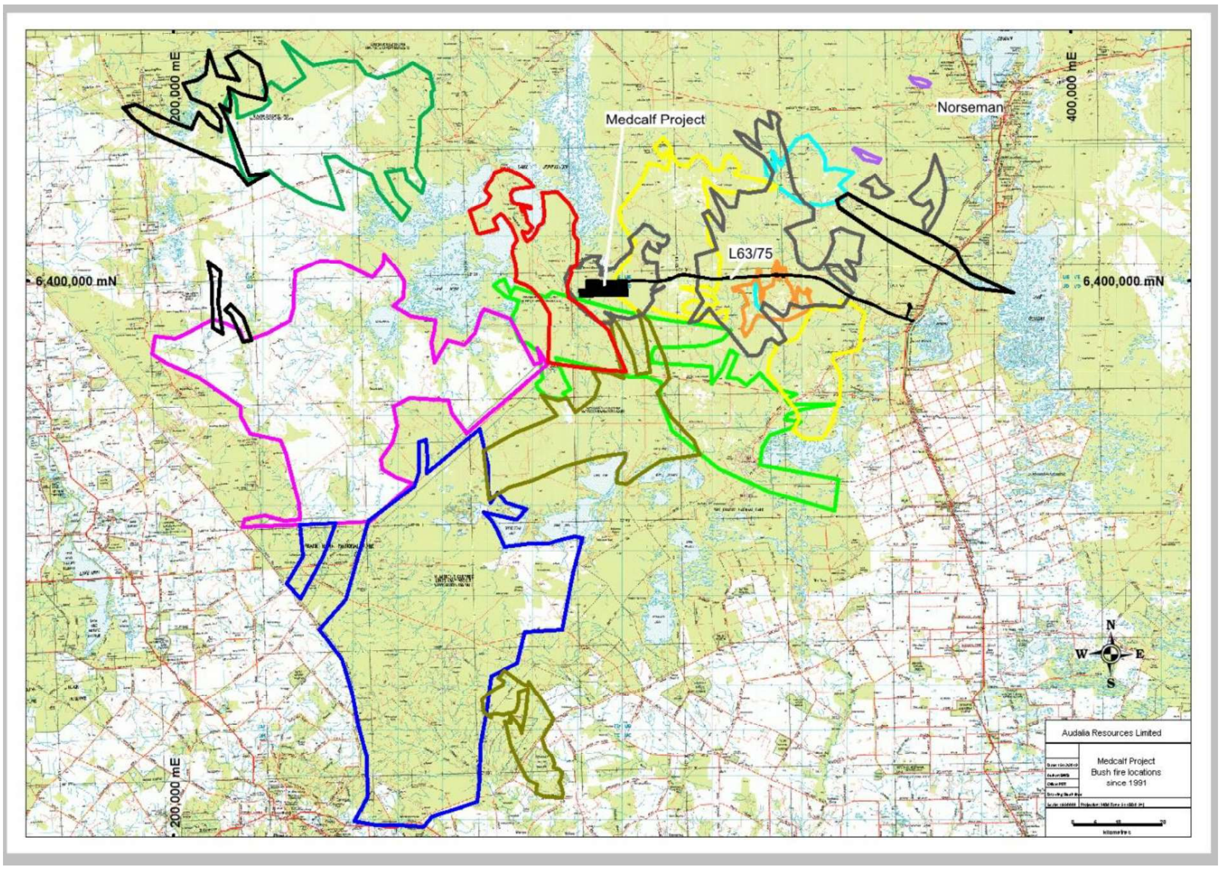


**Figure 4 – Bush fires since 1991**

**Figure 5 – Competing plants**

**Figure 6 – Competing plants**

The Proponent has completed their Prefeasibility Study in 2016 and have since completed additional drilling, metallurgy, flora and fauna and hydrological studies along with a mining study.

From this study, the mining proposal is to mine at a rate of 1.5Mtpa from 3 pits Vesuvius, Fuji and Egmont open cut down to a maximum depth of 50m over a mine life of 13 years (Figure 7).

[redacted]

**Figure 7 – Proposed minesite layout**

## 4. TOPOGRAPHY

The Medcalf Project takes its name from Lake Medcalf located 7 kilometres northeast of the mine (Figure 8). Medcalf lies within the undulating hills of the Bremer Range with Mt Gordon being the tallest elevation of 451m. The general elevation in the area is approximately 350m.

The Medcalf Project has three deposit that lie in an east west direction being Egmont, Vesuvius and Fuji all above 400m elevation with the tallest being Vesuvius peaking at

436m (Figure 9). Drainage is internal with widely spaced ephemeral watercourse draining into the playa lakes Lake Hope and Johnson to the north.

Runoff is high from the hilly areas due to the presence of exposed rocky and shallow rocky soil, with shallow sheet flow occurring from relatively small rainfall events. This sheet flow could transport loose Marianthus seeds on the ground surface downslope. Much of this runoff would infiltrate in the deeper soils downslope (Groundwater Resource Management, 2019).

This would be consistent with the mapped plant locations appearing to extend from the catchment divide downstream. Only in larger rainfall events, often during wetter periods, does runoff reach the catchment outlets via the drainage lines.

Regional groundwater level in the area is typically greater than 45 m below surface and the groundwater is hypersaline. Consequently, the *Marianthus aquilonaris* plants are unlikely to have direct interaction with the regional groundwater table (Groundwater Resource Management, 2019).

The *Marianthus aquilonaris* plants appear to have a correlation to geological structures, which indicates that the plants potentially take advantage of the aquifer recharge process, capturing persistent soil moisture from within weathered and/or fractured bedrock.

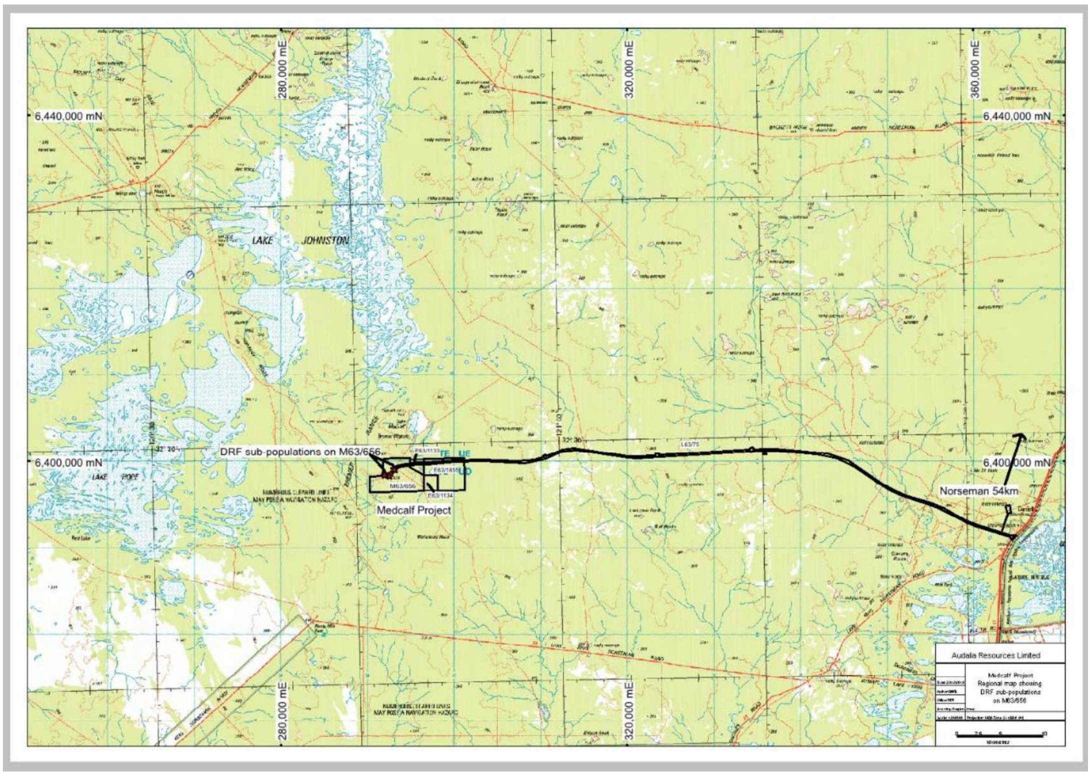

**Figure 8 – Regional map showing location of the *Marianthus aquilonaris* sub-populations**

A total of four *Marianthus aquilonaris* sub-populations (Fig 7 & 9: pop 1a-e) are located on the northern slope of Vesuvius (436mRL) over a NE-SW distance of 1.4km. The elevation of these sub-populations is listed in Table 1 below and are shown in Figure 9.

| Population | Elevation (m) | Distance between pop. |
|---|---|---|
| 1a | 385 | a to b 640m |
| 1b | 400 | b to c 320m |
| 1c | 410 | c to d 515m |
| 1d | 405 | d to e 225m |

**Table 1 – *Marianthus aquilonaris* sub-population elevations**

[redacted]

**Figure 9 – Elevations of *Marianthus aquilonaris* sub-populations**

## 5. GEOLOGY

### 5.1. Regional Geology

The Medcalf deposit is located in the Archaean Aged Lake Johnson Greenstone Belt in the southern portion of the Youanmi Terrane, part of the Yilgarn Craton (Figure 10).

This belt is a narrow north-northwest trending belt, approximately 110 km in length. It is located near the south margin of the Yilgarn Craton, midway between the southern ends of Norseman-Wiluna and the Forrestania-Southern Cross Greenstone Belts.

The eastern and northern limits of the Lake Johnston Greenstone Belt are defined by the large northwest-trending Koolyanobbing Shear Zone. To the west, the Greenstones are bound by Grantoids and Gneissic rocks which extend some 70 km west to the Forrestania-Southern Cross Greenstone Belts. To the south, the Greenstones appear to pinch out in Granites.

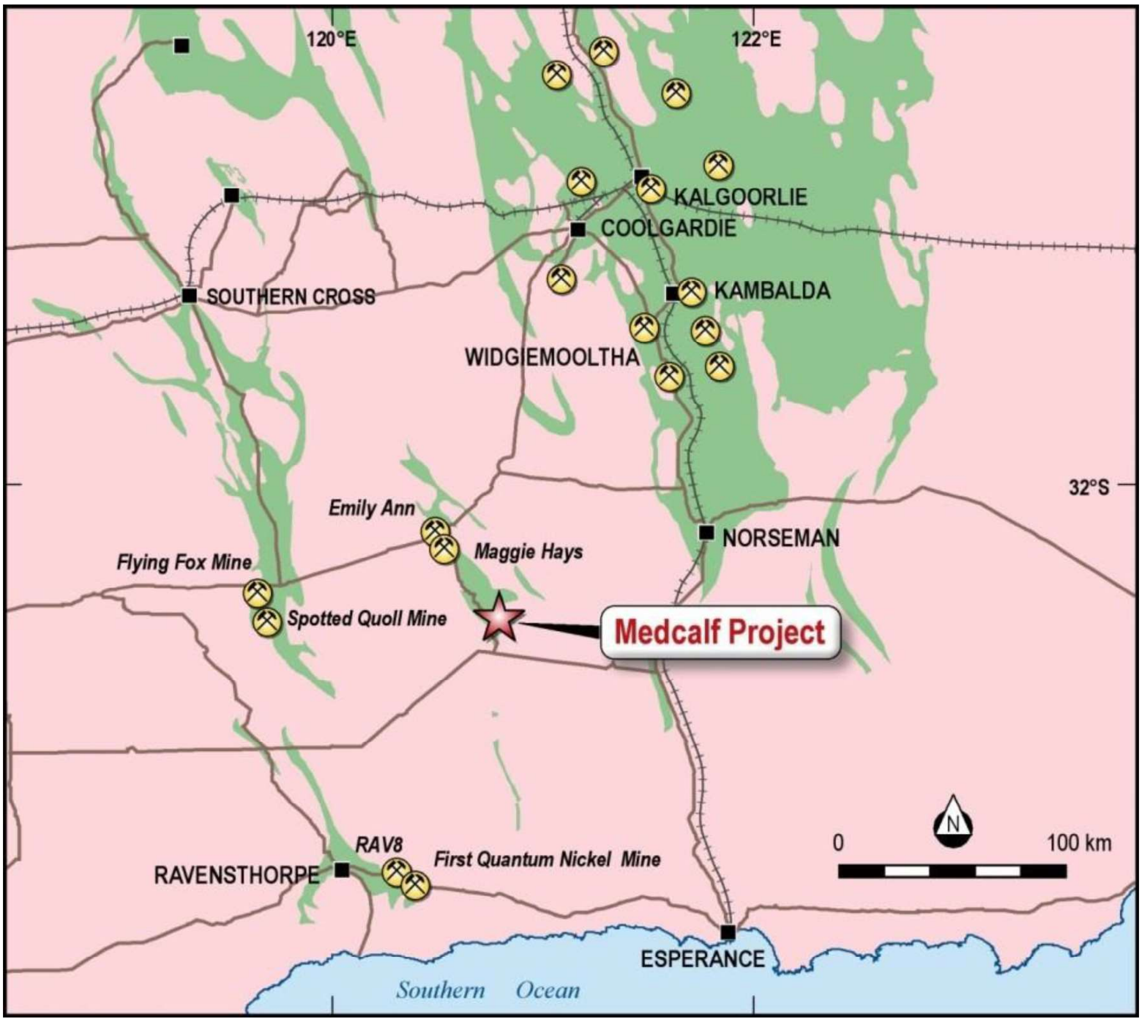


**Figure 10 – Lake Johnson Greenstone belt**

## 5.2. Local Geology

The Medcalf Project lies within the Medcalf layered sill, which is a flat lying igneous body up to 150m thick which has intruded parallel to the enclosing volcanic strata basalt, prior to regional metamorphism (Figure 11). It is a layered basic sill of the gravity differentiated type.

[redacted]

**Figure 11 – Geological plan showing *Marianthus aquilonaris* ~~locations~~ sub-populations on M63/656 and favourable soil boundaries**

The sill is comprised of an upper gabbroic zone, a middle pyroxenite zone, with a lower amphibolite zone in the footwall. Three separate zones of vanadium & titanium mineralisation have been identified within the project area and named the Vesuvius, Fiji and Egmont prospects.

In the Medcalf deposit vanadium, titanium and iron have been concentrated in a pyroxenite unit, which has subsequently been enriched in these metals through weathering and regolith formation.

In the mineralised area, the magnetite-rich sequence is deeply weathered, with +60m of saprolite showing vertical zonation of weathering minerals due to progressive weathering.

The fully developed lateritic weathering profile is divisible into four zones. Starting from the top, they are lateritic residuum, mottled zone (habitat for *Marianthus aquilonaris*), saprolite and saprock. All the vanadium, titanium and iron mineralisation lies within the saprolitic zone.

### 5.2.1. Stratigraphic Column

The stratigraphic column for the Medcalf sill is shown below in Table 2.

| Medcalf Stratigraphic Column | | | |
|---|---|---|---|
| | Colour | Rock type | Thickness |
| | | Basalt | na |
| | | | |
| Medcalf Sill | | Gabbro | ~50m |
| | | | |
| | | Pyroxenite | ~50m |
| | | | |
| | | Ultramafic | ~50m |

**Table 2 – Stratigraphic column of Medcalf sill**

### 5.2.2. Geological cross section

The Vesuvius cross section show that the favourable environment for the Marianthus to thrive is with the in the mottled zone over the weathered basalt on the northern slope for maximum sun.

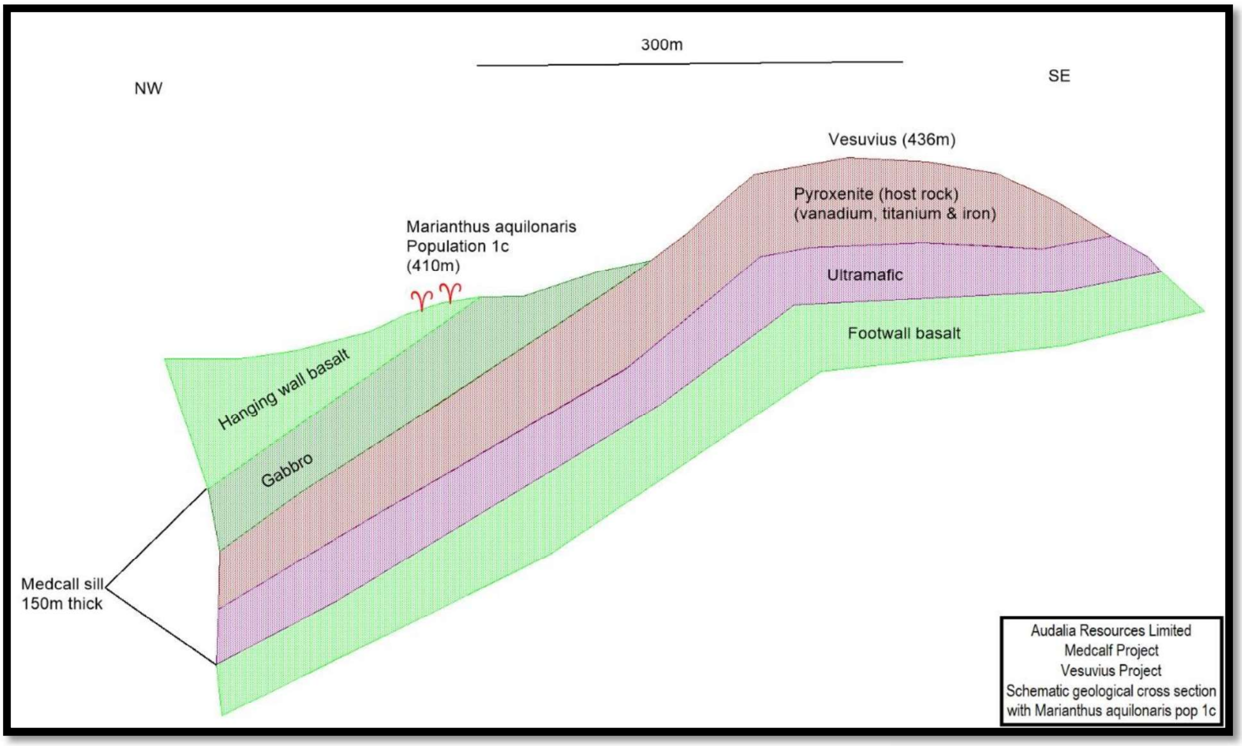


**Figure 12 – Vesuvius schematic geological cross section**

## 6. MARIANTHUS GEOLOGY AND SOIL TYPE

All four *Marianthus aquilonaris* sub-populations (1a-d) grow in the same rock type. (Figure 11) Originally the rock type was basalt which is now heavily weathered to a state of residual iron rich rock (Figures 13 – 16).

The soil type is described by Western Horticultural Consulting (2019) who inspected and sampled all four *Marianthus aquilonaris* sub-populations on M63/656, as shallow gravels over indurated mottled zone. The mottled zone in these soils (see soil boundaries in Figure 11) has been hardened by the addition of iron and it is known as limonite.

Limonite is an iron ore consisting of a mixture of hydrated iron (III) oxide-hydroxides. Between 70 and 90 % of the soil surface is covered with a scree of dark lateritic gravels and fragments of limonite rock. Limonite outcrops are common and in areas may compose up to 50 % of the soils surface.

The topsoil is generally about 10 to 15 cm thick and is a dark reddish-brown sandy loam. Topsoils and subsoils are generally acidic, with a pH(water) between 4.5 and 7. The salinity of this soil is generally low.

### 6.1. POPULATION 1d

7. Population 1d (Figure 13) is the most western population on M63/656 and is the furthest away from the populations (Table 1).

**Figure 13 – Population 1d** [redacted]

The plant is growing within the fractures of the mottled rock. There is a thin layer of transported spoil over the area.

### 7.1. POPULATION 1c

This population (Figure 14) lies within the western edge of the Vesuvius mineralised footprint. This is a northern facing slope and the plant grows in the mottled zone with minor transported soil.

**Figure 14 - Population 1c** [redacted]

## 7.2. POPULATION 1b

This population (Figure 15) lies within the northern edge of the Vesuvius mineralised footprint. This is a northern face slope and the plant grows in the fractures of the mottled zone and downstream in a historic costean where a family now occurs, mature to juvenile.

**Figure 15 - Population 1b** [redacted]

.

### 7.3. POPULATION 1a

This population lies outside the northern edge of the Vesuvius mineralised footprint. This is a northern face slope and the plant grows in the fractures of the mottled zone (Figure 16).

**Figure 16 - Population 1a** [redacted]

## 8. CONCLUSIONS

It is very evident from the geological mapping, flora, fauna, micro hydrology and soil surveys that the *Marianthus aquilonaris* plants require the following conditions for its survival:

- Appropriate fire events;
- Open space;
- Shallow gravels over limonitic mottled zone;
- Acidic soils;
- Low salinity soils;
- Structural settings;
- Fractures to grow in;
- Presence of *Eucalyptus livida* to support pollination (refer to Pollinator study prepared by Kit Prenergast);
- Full sun (north facing slopes);
- Elevation between 380m-425m;
- Rain events for survival.

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