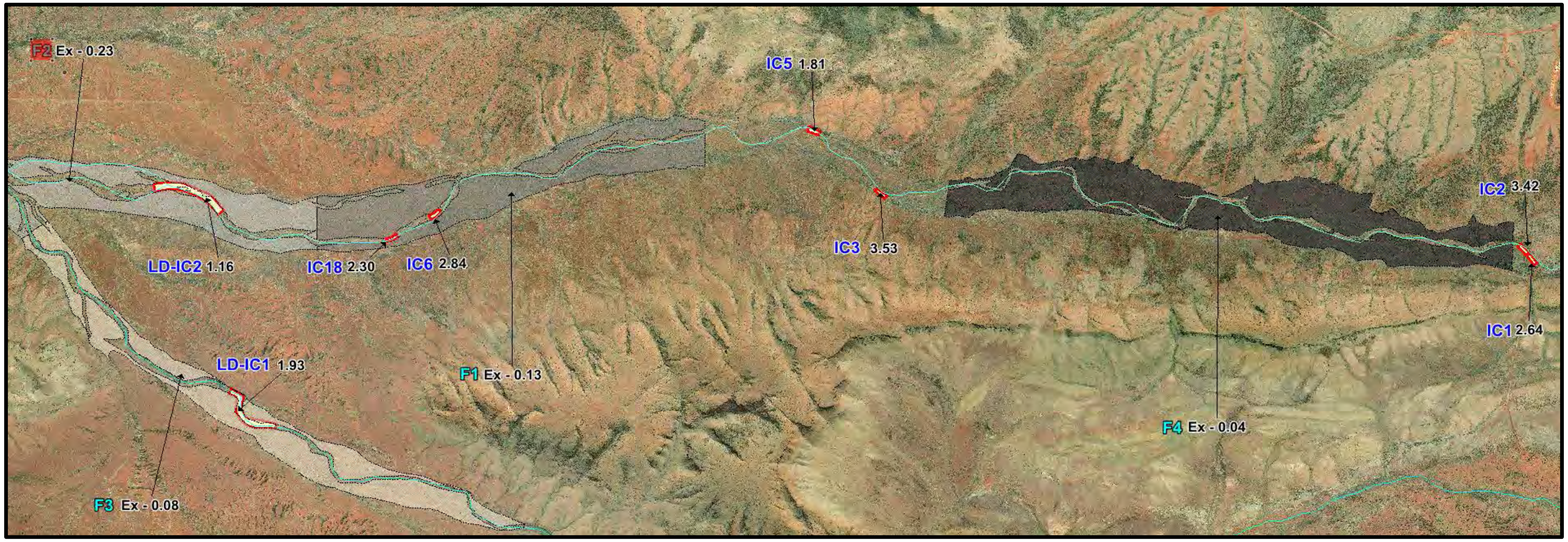
Based on the residual risk results provided in table 5-3 the following risk mapping results have been concluded (based on an interpreted scale of risk due to groundwater dependence of 'significant impact' from groundwater changes):

- Approximately 93% of the study area is represented by riparian vegetation interpreted to possess a "Very Low to Low" residual risk.
- Approximately 6.6 % of riparian vegetation in the study area (the remainder) has been interpreted to possess a residual risk of "low" and greater.
- Of this remaining 6.6% of assessed riparian vegetation; 4% (42 ha) was attributed a residual risk of "low" and 2 % (22 ha) was attributed a residual risk of "Low-Medium".
- Only 0.4% (4.2 ha) of the study area was attributed a "Medium" risk of 'significant impact' due to potential groundwater changes.



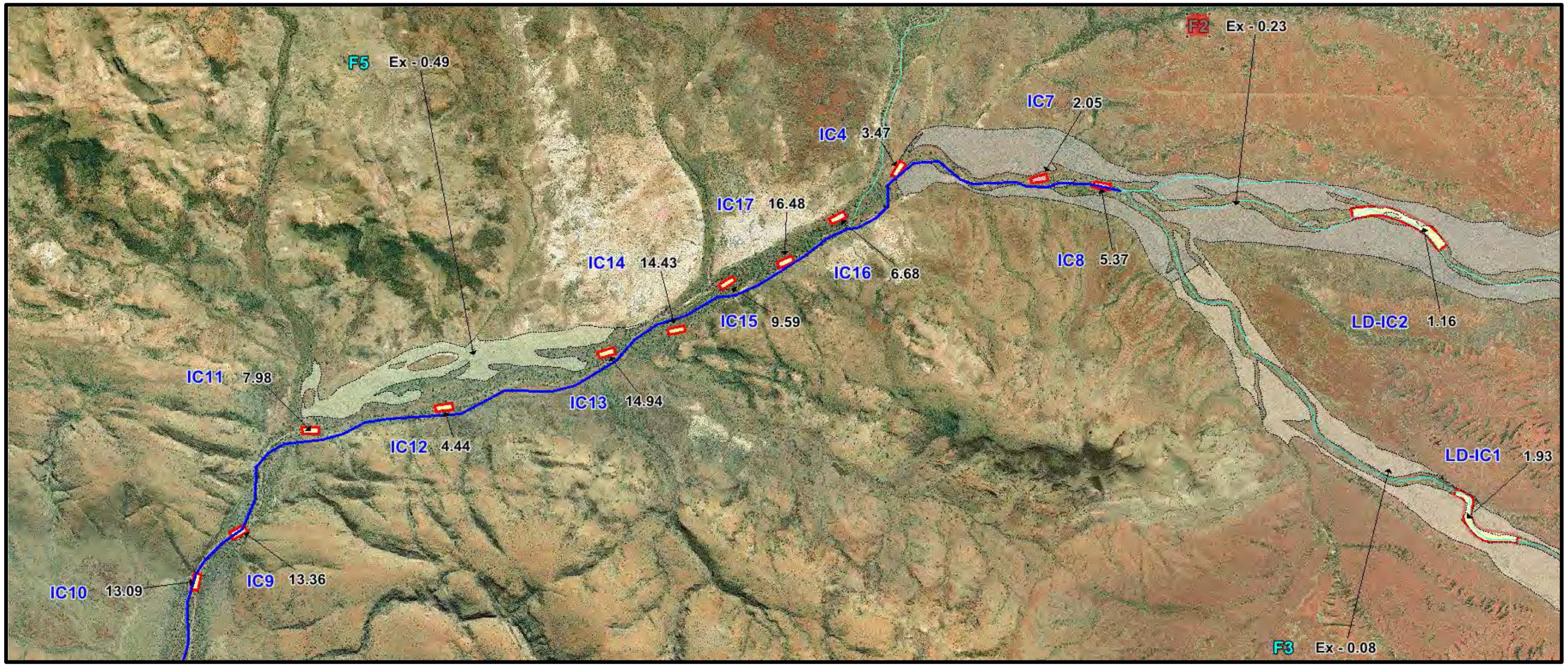


Figure 5-4: Basal area results map, showing the basal area (in m^2 per ha) calculated for each assessment plot (east and west portions of the study area)

Figure 5-5: Aerial photo demonstrating potential inaccuracies with interpreting biomass from aerial photo signatures

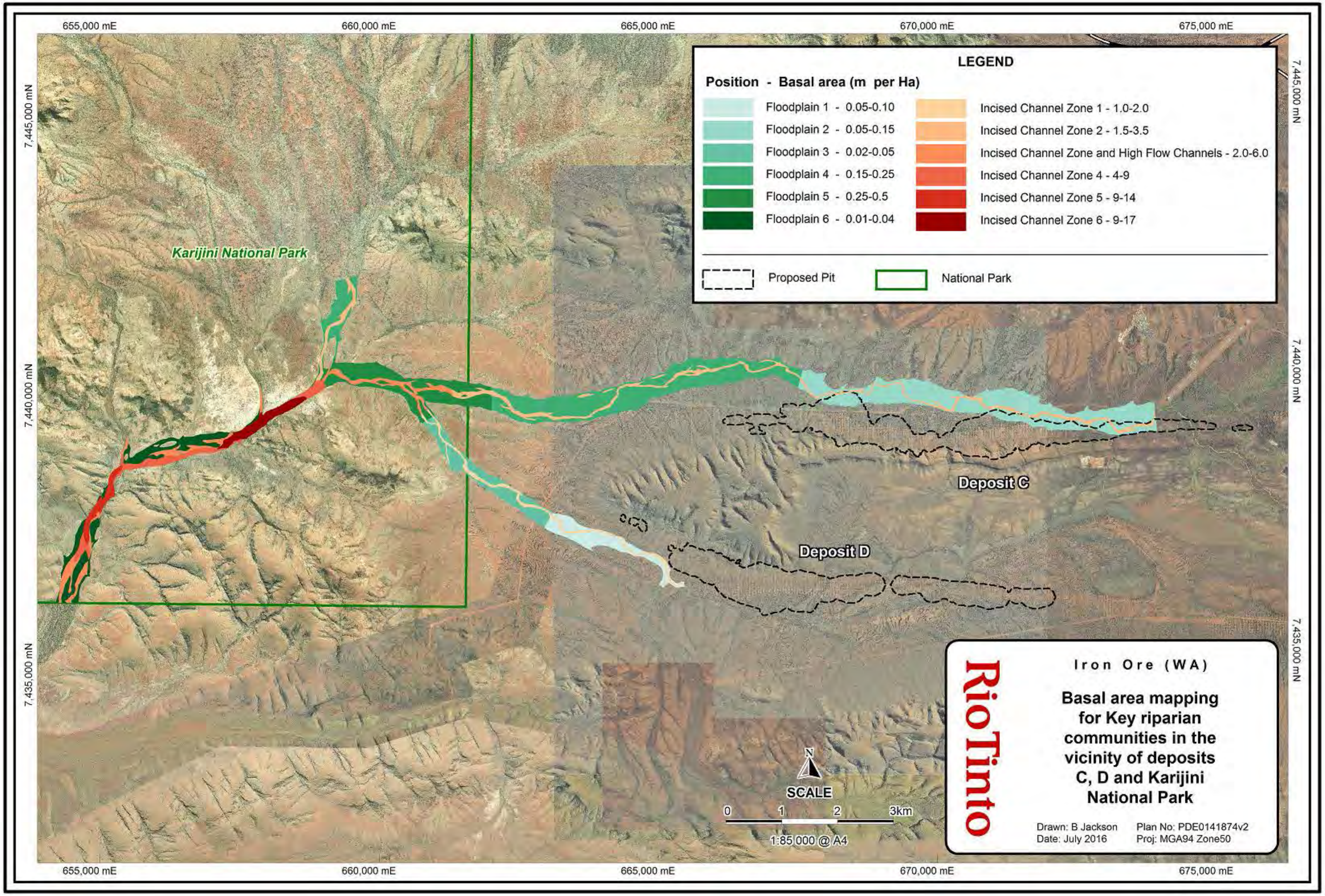


Figure 5-6: **Basal area mapping by zone (Floodplain and Incised channel) and reach (by topography and incremental catchment gain within the study area**

Table 5-3: GDE Risk Matrix

Veg unit	Broad vegetation description	Position	Reach	Basal area (m^2/ha)	Phreatophytic over-storey structural/compositional evidence	Matrix prescribed basal area range	Matrix prescribed risk	Modifying or supporting factors	Interpreted residual risk
F3	**Scattered to isolated *E. victrix* low trees over mixed scattered tall-shrubs/shrubs, over very open tussock/hummock grassland**	**Floodplain**	**1**	**0.01-0.04**	**Isolated to scattered - Low risk facultative phreatophytes present**	**0.01-0.15**	**Negligible**	**Neutral**	**Negligible**
			2	**0.02-0.05**	**Isolated to scattered - Low risk facultative phreatophytes present**			**Neutral**	
			3	**0.05-0.10**	**Isolated to scattered - Low risk facultative phreatophytes present**			**Neutral**	
			4	**0.05-0.15**	**Isolated to scattered - Low risk facultative phreatophytes present**			**Neutral**	
			5	**0.15-0.25**	**Isolated to scattered - Low risk facultative phreatophytes present**	**0.15-1.0**	**Very Low**	**Neutral**	**Very Low**
F2	**Scattered *E. victrix* and *E xerothermica* low trees over mixed tall-open-shrubland/open-shrubland, over mixed very open tussock/hummock grassland**	**Floodplain**	**6**	**0.25-0.5**	**Scattered - Low risk facultative phreatophytes present**	**0.15-1.0**	**Very Low**	**Neutral**	**Very Low**

Veg unit	Broad vegetation description	Position	Reach	Basal area (m^2/ha)	Phreatophytic over-storey structural/compositional evidence	Matrix prescribed basal area range	Matrix prescribed risk	Modifying or supporting factors	Interpreted residual risk
C3C	***E. Victrix* low open woodland over *Acacia citrinoviridis* tall open shrubland, over mixed scattered-shrubs/low-open-shrubland over mixed open tussock grassland**	**Incised Channel Zone**	**7**	**1-2**	**Scattered to low open woodland - Low risk facultative phreatophytes present and co-dominant to dominant**	**1.0-6.0**	**Very Low+**	**(+0.5) - Positioned in the riparian zone where groundwater heights are between 5-10 m bgl; in places vegetation forming a low open woodland.**	**Very Low to Low**
		Incised Channel Zone	**8**	**1.5-3.5**	**Scattered to low open woodland - Low risk facultative phreatophytes present and co-dominant to dominant**			**(+0.5) - Positioned in the riparian zone where groundwater heights are between 5-10 m bgl; at times possessing a basal area approaching the upper limit of the "very low+" class; in the vicinity of creek confluences.**	
					Scattered to low open woodland - Low risk facultative phreatophytes present and co-dominant to dominant			**(-0.5) – Groundwater unlikely to be accessible, facultative phreatophytes more often representing a scattered cover-abundance.**	**Very Low**
		Incised Channel Zone and High Flow Channels	**9**	**2-6**	**Scattered to low open woodland - Low risk facultative phreatophytes present and co-dominant to dominant**			**(-0.5) – Positioned approximately 10km downstream of drawdown source; located in areas downstream of predicted groundwater divides.**	
					Scattered to low open woodland - Low risk facultative phreatophytes present and co-dominant to dominant			**(+0.5) – Positioned in the riparian zone where the creek profile is constricted and alluvial's may be shallow; in places vegetation forming a low open woodland to woodland.**	**Very Low-Low**

Veg unit	Broad vegetation description	Position	Reach	Basal area (m^2/ha)	Phreatophytic over-storey structural/compositional evidence	Matrix prescribed basal area range	Matrix prescribed risk	Modifying or supporting factors	Interpreted residual risk
				3-6	low open woodland to woodland - Low risk facultative phreatophytes dominant	3.0-9.0	Low (-)	(+1) – Possessing patches of generally higher biomass (3-6 m^2/ha); possessing increasing potential for shallow groundwater; within proximity of groundwater impact zone; positioned in the riparian zone where the creek profile is constricted and alluvial's may be shallow.	Low
C3B	*E. victrix* woodland over *A. citrinoviridis* tall open shrubland, over mixed open-shrubland/low-open-shrubland over mixed open tussock grassland	Incised Channel Zone	10	4-9	low open woodland to Woodland - Low risk facultative phreatophytes dominant, potentially isolated medium risk facultative phreatophytes present	3.0-9.0	Low (-)	Neutral	Low (-)
					low open woodland to Woodland - Low risk facultative phreatophytes dominant, potentially isolated medium risk facultative phreatophytes present	3.0-9.0		(+0.5) – Positioned in the riparian zone where the creek profile is constricted and alluvial's may be shallow; in places vegetation forming a woodland; possessing moderate potential for shallow groundwater; still occurring within the potential groundwater impact zone.	Low
					Woodland - Low risk facultative phreatophytes dominant, potentially isolated medium risk facultative phreatophytes	5.0-9.0	Low	(+0.5) - Initially positioned at the start of shallow groundwater heights where potential groundwater changes first become relevant, and in all cases located where the creek profile is constricted and alluvial's may be shallow; moderate potential for shallow groundwater remains in the downstream areas; occurring within the potential groundwater impact zone.	Low (+)

Veg unit	Broad vegetation description	Position	Reach	Basal area (m^2/ha)	Phreatophytic over-storey structural/compositional evidence	Matrix prescribed basal area range	Matrix prescribed risk	Modifying or supporting factors	Interpreted residual risk
			11	9-14	Woodland - Low risk facultative phreatophytes dominant, potentially isolated medium risk facultative phreatophytes present	9.0-13.0	Low+	(-0.5) – Only possesses low risk FPS; initially positioned where a new tributary joins TCEB (additional surface water input lowers reliance on groundwater and risk); positioned either side of a topographically constrained gorge section of the creek where geology suggests a high likelihood of groundwater divides restricting drawdown propagation.	Low
						9.0-13.0	Low+	Neutral	Low+
			12	9-17	Woodland - Low risk facultative phreatophytes dominant, medium risk facultative phreatophytes associated - No specific mesic woody species detected	9.0-18.0	Low-medium	Neutral	Low-medium
C2B	*E. victrix* and *E. camaldulensis* woodland over *Acacia citrinoviridis* tall open shrubland, over mixed open-shrubland/low-open-shrubland over mixed open tussock grassland	Incised Channel Zone	11	9-14	Woodland - Low and moderate risk facultative phreatophytes dominant - No specific mesic woody species detected	9.0-13.0	Low-Medium	(- 0.5) - Highly restricted with very small areal extent; positioned where a new tributary joins TCEB (additional surface water input lowers reliance on groundwater and risk); located within a topographically constrained gorge section of the creek where geology suggests reducing potential for groundwater drawdown propagation.	Low+
			12	9-17	Woodland to open forest - Low and moderate risk facultative phreatophytes dominant - No specific mesic woody species detected	9.0-18.0	Medium	Neutral	Medium

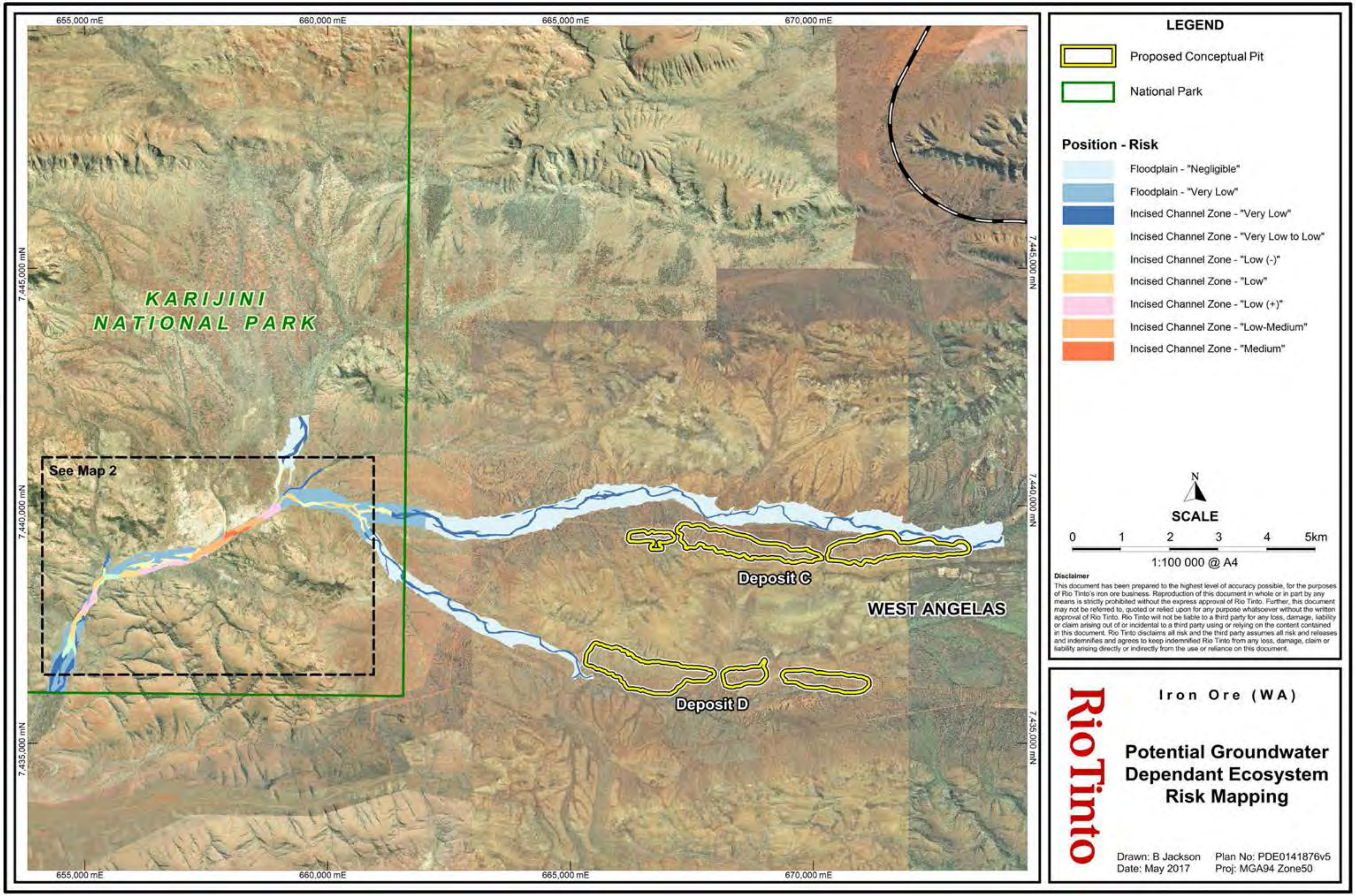


Figure 5-7: GDE Risk Mapping depicting the spatial distribution of risk of 'significant impact' to potentially GDV in the Study Area from changes to groundwater availability associated with the proposed dewatering of Deposits C and D

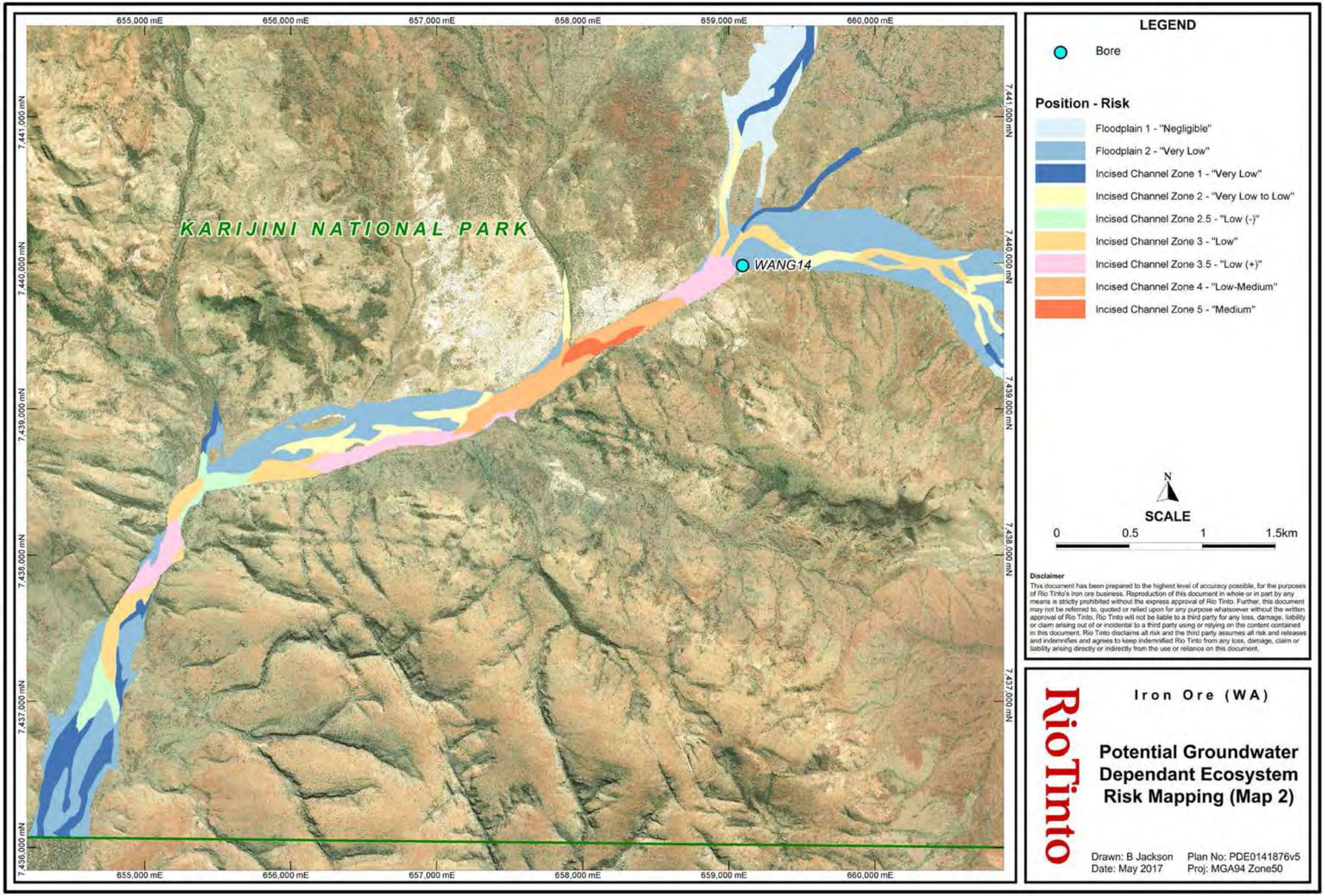


Figure 5-8: GDE Risk Mapping (Map 2) depicting the spatial distribution of risk in the key zone of interest (KNP), and the position of monitoring bore WANG14

6 DISCUSSION

6.1 GROUNDWATER AVAILABILITY/ACCESS

Within the study area and outside of KNP, groundwater below the riparian zone is interpolated to be between 50 m and 70 m bgl (at times as low as 20 m) and is therefore, essentially beyond the reach of local trees. This groundwater depth is based on data from more than 100 monitoring bores throughout the Proposal area.

There is almost no direct information on the depth to groundwater in KNP aside from a single bore (WANG14; see Figure 5-8) which is located approximately 2.5 km inside the KNP boundary at the confluence of two key tributaries (of relevance to the study area) into TCEB.

Given the sensitivities around disturbance within the conservation estate, opportunities to increase our knowledge about the hydrogeology inside the KNP boundary are constrained. Monitoring bores show that groundwater depth decreases from east to west through the study area towards TCEB and the head of the valley (at the KNP boundary). This decreasing groundwater depth from east to west appears to be primarily associated with decreasing elevation in the same direction. Towards the western end of the study area groundwater is within proximity of the surface, as evidenced in the monitoring bore (WANG14) located inside the KNP boundary which indicates that groundwater is approximately 5-6 m bgl. As elevation falls downstream of WANG14, interpolation of the monitoring data indicates that in such areas, and particularly within Riparian Zone C, groundwater is potentially in easily accessible reach of riparian vegetation (i.e. <5 m bgl).

Geophysics work conducted in early 2017 (restricted to Riparian Zone C) interpreted depth to groundwater within Riparian Zone C to be in the vicinity of 3-5 m (1.5-6.5 m range (average 3.5); GBG MAPS 2017) at the time of survey. More detailed consideration of the mapping provided by this work and the actual and average groundwater heights present within two key riparian zones are provided in Table 6-1. This table also presents figures for the predicted groundwater heights (due to drawdown) which result from the combination of baseline heights with predicted magnitudes of drawdown at Riparian Zone C. This detailed consideration estimates that within Riparian Zone C-1 groundwater is on average 2m deep, with an average range of 1.5-2.5 m bgl across this zone. Within the remainder of Riparian Zone C; average depth to groundwater was estimated as 3.5 m, with an average range of 2.5-4.5 m bgl. While groundwater depths of up to 6.5 m were interpreted/inferred from the geophysical investigations, there was actually only a couple of dips recorded in groundwater heights to this level (often only over very short distances in the order of 20-50 m), and for the most part interpretations put groundwater at less than 5 m below the surface.

Once the baseline heights in zone C-1 were considered in relation to worst case modelling of drawdown (Sy1%; predicted at the WANG14 Bore), the maximum depth to groundwater predicted under the most sensitive vegetation type (C2B; that containing *E. camaldulensis*) was determined to be in the order of 10.5 m (with base case being approximately 7 m). Importantly; this worst case prediction clearly maintains groundwater at a depth which will ensure contact is maintained between local tree roots and groundwater. For the remainder of Zone C, where the more resilient *E. victrix* dominated community resides (vegetation type C3B), this same analysis predicts the worst case depth to groundwater to be in the order of 12.5 m; still clearly in reach of resident tree roots.

When groundwater resides 10 m or more below ground level it is acknowledged that groundwater is generally considered to become a more minor component of tree water use. However; when considering a community with a tree strata dominated by facultative phreatophytes, the key concern generally relates to the maintenance of some access to groundwater, so that in dry periods where the vadose soil water resource may not be adequate, groundwater is available to supplement EWR. Alternatively, one concern relates to whether impact might arise if groundwater levels approach or exceed 15 m bgl, and the amount of water which is sourced from groundwater approaches negligible proportions of the EWR of a community.

For Australian systems, evidence suggests that reliance on groundwater by terrestrial vegetation is greatly reduced in areas where the water table exceeds a threshold depth, likely to lie between 7 m and 12 m (Benyon, Theiveyanathan, and Doody 2006; Department of Water 2009; O'Grady, Carter, and Holland 2010; Zolfaghar et al. 2014), with 10 m suggested as a general threshold (Eamus, Froend, et al. 2006). However vegetation may potentially access groundwater when the water table is between 10 m and 20 m depth, although it is thought to be very small in terms of contribution to total plant water use (Zencich et al. 2002), and beyond 20 m depth, the probability of groundwater as a water source for vegetation is regarded as being low. While meta-analyses by Canadell et al. (1996), Schenk & Jackson (2002) and Schenk & Jackson (2005), have shown maximum rooting depths across multiple biomes to extend 20-50 m below ground, significant variation exists. Global scale analysis by Canadell (1996) showed that for tropical grassland/savannah (the included Biome most relevant to our arid-land situation) the average maximum rooting depth from examples in the literature was 15.0+/-5.4.

Models of vertical root resource distribution (and water extraction) and field observations made by Schenk (2008), suggest that the percentage of root resources present below 10 m is likely to be less than 1% of all root resources available. A study by Kath et al, (2014) on groundwater decline and tree change in eastern Australian floodplain landscapes identified groundwater depth thresholds ranging from 12.1 m to 22.6 m for *E. camaldulensis*; beyond which canopy condition declined abruptly. Statistical modelling conducted as part of this study indicated that 27% of variation was explained by survey year, 24% was explained by antecedent groundwater depths, 20% was explained by tree density, and 10% was explained by groundwater decline magnitude. It is hypothesised by Kath et al, (2014) that while maximum rooting depths in *E. camaldulensis* are unknown, critical groundwater depths identified in their study may represent a functional physiological limit to effective root growth and water extraction.

Considering the available literature and experience with facultative phreatophytes within the Pilbara; where groundwater is at 10-15 m bgl, phreatophytic species are likely to have some access to and potential reliance on access to broader groundwater tables. However, this access is unlikely to represent a significant proportion of EWR. For phreatophytes occurring where groundwater is 15-20 m bgl, the likely reliance on access to groundwater is considered negligible and their presence will be more closely linked to surface and soil water regimes, along with shallow groundwater's and fractured rock aquifers present in the creek bed zone. Furthermore; for *E. camaldulensis* which has established under relatively deep groundwater conditions (i.e. 10 m bgl and lower), or where groundwater changes have been slow (and adaptation has been effective); such populations have been observed to exhibit substantial resilience to changes in groundwater access. In such situations, it has been observed that where groundwater depths have surpassed impact thresholds, this has led to canopy decline (without detectable increases in mortality) and removal of selective weaker branches (likely through cavitation and vascular failure), until water demand is reduced to a level where the available root system is better matched to vadose soil resources.

While remote sensing analyses conducted by CSIRO on vegetation cover persistence (via a temporal analysis of NDVI (Normalised Difference Vegetation Index)) across the Pilbara indicate a moderate (to at times slightly higher) degree of persistence in the vicinity of Riparian Zone C-1; greater degrees of NDVI persistence are mapped to occur elsewhere in riparian zones where groundwater is consistently at a similar height. While it's not yet clear how consistent it is, the relatively shallow depth to groundwater interpreted to be present in Riparian Zone C (Figure 4-1) indicates that vegetation is likely to have a reliance on groundwater in this zone to satisfy a portion of its EWR. However; disparity exists between the interpreted likely depth to groundwater within and downstream of Riparian Zone C and the GDS (and associated GDV) present. Initially this was thought to indicate that there is potential for a groundwater divide to occur in this area (with early geological observations supporting this theory), however geophysics work did not interpret there to be any shallow basement material based on the positioning of the Electrical Resistivity Sections. According to GBS MAPS (2017), the degree of confidence in this interpretation is significantly influenced by the degree of basement weathering, and so some caveats are placed in this interpretation.

The data on water table heights provided by the geophysics work is at times potentially variable as within a large proportion of the study area (particularly that area under the C2B community) water table heights were inferred (rather than interpreted) where the shallow subsurface material is interpreted as massive/non-permeable and as such fluid content does not significantly influence the electrical resistivity (GBS MAPS 2017).

Between monitoring bore MB16WAW0005 (approximately 2.7 km upstream) and the WANG14 bore, depth to groundwater appears to reduce proportionately with ground height (i.e. elevation drops by approximately 10 m and depth to groundwater reduces from 15 to 5 m bgl). Similar trends are seen between monitoring bores throughout the valley adjacent to Deposit C. It is therefore assumed that the drop in elevation downstream of WANG14 (approximately 5 m drop in elevation to the start of Zone C-1 (800 m downstream) and approximately 10 m drop in elevation to the end of Zone C-2 (2.3 km downstream)) would likely lead to at least a 2-3 m drop in depth to groundwater within Zone C (i.e. groundwater 2-3 m bgl). Given the geophysics work supports this and interprets similar groundwater proximity in Riparian Zone C, it appears that geophysical interpretations of groundwater height are correct. Despite this fact, the degree of hydraulic connectivity between groundwater in Riparian Zone C and that in the broader upstream valley appears to remain undetermined and an area of interest.

Where depth to groundwater is in the order of 2-4 m bgl, it is typically expected that *E. camaldulensis* would be a consistent co-dominant component of the over-storey and that a number of common mesic indicator species (such as *M. glomerata* and potentially *M. bracteata* and *Acacia ampliceps*) would be present within resident vegetation. However, the vegetation composition in Zone C is not typically representative of a depth to groundwater of 2-4 m bgl. While an impervious layer existing in the vicinity of Zone C, and blocking the downstream continuation of groundwater heights equal to or shallower than that present at WANG14 could explain such disparities between vegetation and groundwater height; this is looking increasingly unlikely.

While vegetation density (and potential for groundwater dependence) increases significantly immediately downstream of WANG14, this is thought to be mostly attributable to increased surface water input and confinement occurring at the beginning of Riparian Zone C. At this point, the confluence of the east and west tributaries into TCEB (represented by the two catchments in Figure 3-3) coincides with the topographic constriction of the creek system (floodplain and incised channel zones) into a single incised channel zone. Upstream, the tributaries are 300-500 m wide each, but at the point of constriction the system is only 150 m wide.

Table 6-1: Key riparian zones within the study area and their relevant average and actual subsurface groundwater heights interpreted from GBS Maps (2017) and considered in respect to modelled groundwater drawdown predictions.

	Average baseline GW height	Average baseline range of GW heights	Absolute baseline range of GW heights
Riparian Zone	In Meters Below Ground Level and Interpreted/inferred from the geophysical mapping conducted by GBS Maps (2017)		
Riparian Zone C-1 (C2B vegetation type)	**2 m bgl**	**1.5-2.5 m bgl**	**1.2-3.3 m bgl**
Riparian Zone C (outside of Zone C-1 (C3B vegetation type))	**3.5 m bgl**	**2.5-4.5 m bgl**	**1.8-6.5 m bgl**

	Maximum depth (In meters below ground level) of Groundwater Following the assumed base case (Sy3%) potential for ~5 m of modelled drawdown (Rio Tinto 2017) and based on:			Maximum depth (In meters below ground level) of Groundwater Following the assumed potential for between 3-8 m of modelled drawdown (Rio Tinto 2017) and based on:		
Riparian Zone	Average baseline GW height	Average range of baseline GW heights	Absolute range of baseline GW heights	Average baseline GW height	Average range of baseline GW heights	Absolute range of baseline GW heights
Riparian Zone C-1 (C2B vegetation type)	**7 m**	**6.5-7.5 m**	**4.2-11.3 m**	**5-10 m**	**4.5-10.5 m**	**4.2-11.3 m**
Riparian Zone C (outside of Zone C-1 (C3B vegetation type))	**8.5 m**	**7.5-9.5 m**	**6.8-11.5 m**	**6.5-11.5 m**	**5.5-12.5 m**	**4.8-14.5 m**

GW = Groundwater, m bgl = meters below ground level

Importantly, occurrences of the Wittenoom Formation along with McRae Shales (both of which can potentially provide impervious lithologies), reside underneath the calcrete formation in the vicinity of Riparian Zone C, and downstream (potentially 100-600 m) of WANG14. The occurrence of these formations has the potential to provide a groundwater divide which, while not supported by the geophysics work, could explain the disparity between interpreted trends in groundwater height and riparian vegetation in this area. The presence of an impervious layer providing a groundwater divide in the vicinity of Riparian Zone C, such that groundwater heights within and downstream of this point are independent of those upstream, could not only provide some explanation of the minimal presence of GDS, but could also prevent potential groundwater drawdown (and associated impacts) from propagating into and downstream of Riparian Zone C. With recent geophysics failing to indicate obvious presence of such features in the upper sediments it has become increasingly evident that other factors are potentially operating in the area to influence the distribution and structure of vegetation present.

Another hypothesis which geophysics work also did not seem to support, was the concept that basement rock (potentially forming part of an aquiclude) may be quite shallow, thus confining the alluvial formations of the creek system in the vicinity of Riparian Zone C. Shallow basement material was not identified in the Electrical Resistivity Sections of the geophysical interpretations (GBS 2017). With geophysical interpretations covering at least 25 m of vertical depth, and with basement expected to be less than 30 m deep in the study area, the absence of basement material in the geophysical interpretations is interesting. In general the ability of ERI geophysical sections to differentiate basement from overlying material, is largely dependent on the degree of weathering present in basement material (i.e. highly weathered basement will not be distinguishable). With drilling at a nearby (2.6km east) bore hole logging highly weathered dolomite and shale just beyond 25 m below ground level, it can be assumed that if this basement follows a similar elevation that highly weathered basement is likely to occur just beyond 15 m bgl or greater in the study area. Combined with the mosaic of clay and detrital formations interpreted to occur in the alluvium of the creek bed, it can be argued that there is high potential for an array of weathered rock formations filled with hydrophilic alluvium lying approximately 20 m bgl. In turn this suggests that there is a high likelihood for such formations to provide a potentially complex suite of small fractured rock aquifers within reach of local tree populations, with the potential to exist relatively independently (from groundwater tables) through regular surface water replenishment events.

Based on the results of the geophysics work, it was noticed that the distribution of the C2B community somewhat aligns with the apparent gaps in the distribution of the relatively impermeable detritals formations (units 4, 5, and 6 outlined in GBS MAPS (2017); present throughout a significant proportion of riparian zone C. These formations are shown on cross section interpretations of subsurface geology under electrical resistivity imaging transect conducted by GBS MAPS (2017). Such formations were visually sighted in abundance in the field as part of the current study; particularly in the northern half of Riparian Zone C and generally more commonly distributed to the North West side of the creek channel in this zone. It is postulated that shallow formations such as this, while apparently acceptable for local *E. victrix* populations, may be unlikely to provide suitable substrate conditions for the proliferation of E. camaldulensis. Furthermore; within the vicinity of the C2B community (and the gaps in the detrital units) and where geophysics data was available, relatively massive interspersed clay formations/lenses were broadly interpreted by geophysics to occur in the zones where *E. camaldulensis* was distributed. It is noted that the West Angelas locality and the catchment in question here has an abundance of local cracking clay formations, and fine apparently clay dominated alluvial sediments were observed to be present within Riparian Zone C; particularly in the vicinity of the C2B community. Preferring deep moist subsoils with clay content (Costermans, 1989), *E. camaldulensis* is likely to find the clay lenses and calcrete/clay units observed/interpreted to occur in Riparian Zone C, as favourable. For this reason the shallow, extensive and relatively impervious detritals formations in the area are considered to provide the most relevant constraint on riparian growth in the area. As a result, the perceived disparities between interpreted groundwater proximity and the GDS and GDV present could be explained by potential constraints on riparian development provided by the poor shallow substrate conditions present through large parts of Riparian Zone C.

6.2 RELATIVE GROUNDWATER DEPENDENCE OF THOSE SPECIES DETERMINED PRESENT

This study has provided an understanding of the distribution of potentially groundwater dependant receptors in the area which suggests that the risk of sensitive GDV being present in the study area is relatively low (but still present as moderate risk GDV in a small number of cases). Furthermore; for the vast majority of riparian vegetation within the study area; low risk FPS (*E. victrix*) dominates the tree strata and moderate risk FPS (*E. camaldulensis*) is generally absent. While there are areas of elevated risk (particularly the 4 ha extent of the C2B vegetation community), the generally 'Low' to 'Very Low' risk posed by potentially GDV (with some examples of 'Low-Medium' risk GDV) present throughout the study area determines that the low level of hydrogeological information within the KNP is unlikely to have a significant influence on the validity of the conclusions made by this study.

Broadly speaking, the dominance of 'low' risk FPS, and the general lack of moderate risk FPS suggests groundwater dependence in the study area is low; however within KNP and starting within Riparian Zone C (the orange and red risk mapping polygons shown in Figure 5-81; where groundwater levels are interpreted as shallow but information is low), over-storey biomass measurements suggest water availability is increasing via either surface water, groundwater, or a combination of both inputs.

Some studies (Stromberg et al. 1993; Lite and Stromberg 2005) have demonstrated relationships which exist between standing biomass within a community and the potential groundwater dependence of that community. In general; consistently shallow groundwater typically allows a much greater biomass to be established. For this reason; throughout the range of riparian habitats known to occur, the upper limit of over-storey biomass able to be supported by vegetation relying on the vadose soil resource alone (given its inherent degree of variability) is well below the upper limit of riparian biomass observed to occur. This is generally because the magnitude and consistency of water availability when groundwater is consistently shallow allows a much greater biomass to be established and maintained.

In some cases where standing riparian biomass is above average, the reduced sensitivity of the resident FPS may determine that, under changing groundwater conditions, composition can be maintained, but structure may vary. In other cases where standing biomass is also above average, the increased sensitivity of resident phreatophytes (such as OPS) may determine that, under changing groundwater conditions, both the structure and composition cannot be maintained. Alternatively; in some cases where the standing biomass and sensitivity of the resident phreatophytes are below a threshold, the composition and structure may be broadly maintained under changing groundwater conditions.

Broadly determining and applying these thresholds is something which this study has tried to explore, as it appears to be important for establishing a more detailed understanding of potential groundwater dependence. While the majority of vegetation (and associated groundwater regimes) present in the study area appears to clearly fall well below such thresholds, some areas of resident vegetation show evidence suggesting they represent vegetation in the vicinity of this threshold, and so provide an interesting case study for establishing and testing such thresholds. Furthermore; making a determination as to which side of such thresholds local vegetation communities reside is quite important as it determines the potential for, and scale of impact likely to result from changing groundwater access.

To explore these thresholds; the study conducted herein has used a combination of structural/compositional phreatophytic evidence along with an over-storey biomass index. This has been done to provide a more measured interpretation of potential groundwater dependence and therefore a more detailed assessment of the risk of compositional and/or structural changes to FPV in the study area due to changing groundwater conditions.

The associated risk matrix (Table 5-3) provides a consistent logic and associated justification for risk values attributed to riparian vegetation throughout the study area.

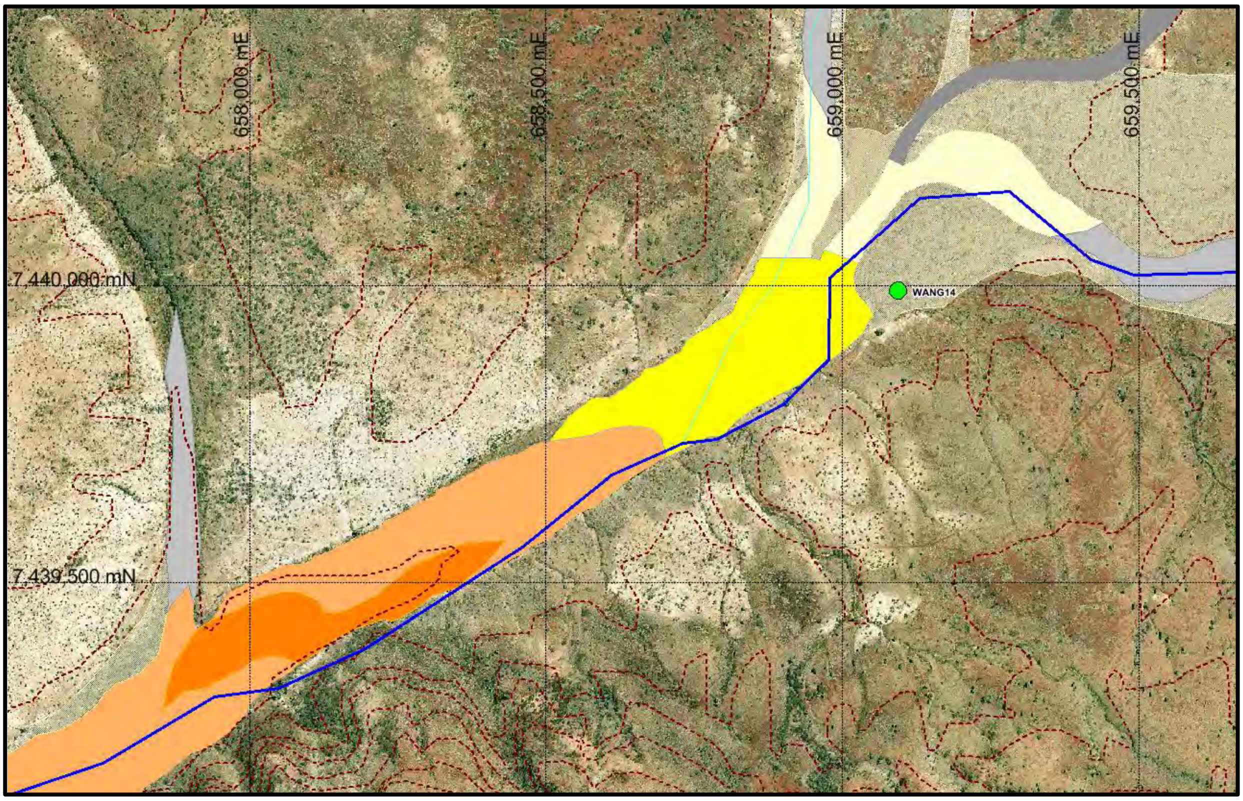


Figure 6-1: Location of monitoring bore WANG14, topographical contours and GDE risk mapping in the vicinity of Riparian Zone C

The interpretation of risk to riparian phreatophytic vegetation made by the study relies on two key evidence based components within the methodology:

1. The degree of groundwater dependence based on; phreatophytic species composition and to a lesser degree phreatophytic species structure/abundance, and the accepted environmental water strategy (EWS) each employs.
2. The standing biomass of over-storey vegetation (i.e. that component of the vegetation more likely to access groundwater), including:
   - the potential associated water demand; and
   - the sub-surface environment and its influence on satisfying water demand.

Given that the resulting interpretations of groundwater dependence of vegetation rely heavily on the degree of influence provided by these key evidence based components, these components are discussed further below.

6.2.1 PHREATOPHYTIC SPECIES IN THE STUDY AREA, ASSOCIATED EWS, AND RELATIVE GROUNDWATER DEPENDENCE

It is generally considered that any vegetation that uses groundwater is potentially at risk of impact if it occurs in a location where the groundwater might be lowered beyond natural groundwater variation. However, the impact on vegetation from lowering the groundwater table is likely to be relative to the species' dependence upon groundwater, and on the alternative sources of water available. For example, phreatophytes, which rely on water sourced directly from the groundwater table are more likely to show signs of decline or mortality than vadophytes that can purely rely on soil moisture from the vadose zone.

Groundwater dependence within phreatophytic species (particularly in arid environments) generally varies along a scale. A scale of groundwater dependence whose potential influence on health and viability varies by species, but also within species due to genetic variability and particularly due to antecedent surface and ground water conditions. An assessment of the groundwater dependence of species present within the study area was informed by a desktop literature review, with specific reference to the previous response of facultative phreatophytes within the Pilbara to changes in groundwater access. As mentioned, not all phreatophytic species display the same degree of dependency on groundwater and the dependency within species has been shown to vary both spatially and temporally (Eamus and Froend 2006). The presence of *E. camaldulensis* subsp. *refulgens* (including subsp. *obtusa*), *E. victrix* and *Melaleuca argentea,* which are the most common phreatophytic tree species within riparian systems of the Pilbara bioregion, are often used to infer the relative presence of a potential GDE. However, these species vary in their degree of dependence on groundwater and this variation has a strong influence on their distribution and abundance within riparian systems.

Vegetation associations occurring along the tributaries and main drainage channel of TCEB (and associated flood plains) within the study area support two key tree species that are considered to be at low to moderate risk of impact from groundwater drawdown: Eucalyptus *camaldulensis* subsp. *obtusa* (moderate risk); and *E. victrix* (low to moderate risk). These tree species are classified as facultative phreatophytes or in some cases, vadophytes. *E. camaldulensis* is the most widespread of Australian Eucalypt species and is known to tolerate an apparently wide range of water regimes (Colloff 2014). Based on work by Wen *et al*. (2009), *E. camaldulensis* obtains its water for transpiration via three main sources: groundwater, river flooding (which over tops creek and river banks thereby replenishing floodplain soil moisture), and rainfall (Wen *et al*. 2009). The degree to which *E. camaldulensis* depends on groundwater and soil moisture has been found to vary both spatially and temporally (Mensforth *et al*. 1994, O'Grady *et al*. 2009, Wen *et al*. 2009, O'Grady *et al*. 2010). Investigations at Marillana Creek in the Pilbara found the vigour of large *E. camaldulensis* trees (>10 m tall) declined in response to lower groundwater levels caused by test pumping of water, while the vigour of smaller *E. camaldulensis* remained unchanged (Onshore Environmental 2013). This observation suggests that the species is capable of being both a vadophyte and a phreatophyte, using the former strategy when young and the latter strategy when mature (Halpern Glink Maunsell 1999). Muir environmental (1995) indicates that *E. camaldulensis* and *E. victrix* are generally not restricted in their occurrences along Marillana Creek and thus given local groundwater height variability cannot be considered as being true phreatophytes, but as vadophytes. In the case of *E. camaldulensis*, general observations in the Pilbara by Rio Tinto suggests that there is some degree of restriction to the distribution of this species along medium to large sized creek systems within the Hamersley's, and so the concept that this species can be both a phreatophyte and a vadophyte (depending on the circumstances) appears most accurate.

Furthermore, from genetic barcoding studies by UWA (UWA 2015) on *E. camaldulensis* and *E. victrix*, it is suggested that *E. victrix* is able to hybridise with other species. Furthermore; within the E. victrix complex, there appears to be high within-population diversity, particularly in the North West, compared with relatively little genetic distinction between populations (Li 2000). Any hybridisation of EV with other eucalypts, as well as high genetic diversity among local EV populations may lead to local individuals displaying intermediate EWR, and therefore intermediate degrees of groundwater dependence. It has also been observed during field surveys by Rio Tinto that in some clearly dry conditions, *E. camaldulensis* individuals can apparently tend morphologically (in a number of traits) towards *E. victrix* and in some clearly wet conditions, *E. victrix* individuals can apparently tend morphologically (in a number of traits) towards *E. camaldulensis*. This observation alludes to the potential that, in hydro-ecotonal situations, where it is advantageous to possess some of the eco-physiological traits of other species (particularly those xerophytic or mesophytic adaptations), hybrid or genetically variable individuals may survive/prosper where other members of the same species cannot. This would in effect provide a greater range of conditions over which individuals of one apparently distinct species could survive. Such potential for variability in environmental responses is important when considering the conclusions of research on the distribution of riparian eucalypts under varying hydrological conditions (such as Loomes (2010)), as the difficulties in discriminating between some species along with hybridisation and genetic variability, has the potential to influence the accuracy of such conclusions.

E. victrix has been shown to access groundwater in areas where the depth to groundwater is low (O'Grady et al. 2009) but in non-riparian habitats, has also been shown to exploit shallow soil water to meet is transpiration needs (Grigg *et al*. 2008). *E. victrix* is generally considered for the most part to be a vadophyte, being relatively drought tolerant but susceptible to decline when groundwater becomes limiting (Muir Environmental 1995). Work by Pfautsch *et al*., (2014) in Weeli Wolli Creek used measurements of foliage density and sap flow to assess the effects of depth to groundwater on *E. victrix*. While foliage density provided partial insight, sapwood-sap-flow was determined to be highly informative, and analyses of various drawdown treatments (falling, rising, and stable groundwater heights) emphasised that water use by *E. victrix* is highly plastic and opportunistic. Such conclusions are in line with observed broad scale responses of riparian *E. victrix* experiencing various drawdown conditions, and also agree with the concept that this species could be considered a vadophyte or a facultative phreatophyte depending on the antecedent conditions.

It is important to note that the definitions attached to classes of groundwater dependence possess some degree of overlap. For example; broadly speaking *E. victrix* is a species typically characterised as being a facultative phreatophyte, relying on groundwater, often via the capillary fringe, to satisfy at least some portion of their environmental water requirement (Eamus & Froend 2006). However; if the vadose resource is adequate and of reduced variability, then such species (i.e. facultative phreatophytes) are also considered capable of inhabiting areas where their water requirements can be met by soil moisture reserves alone. This distinction is not always true, and is importantly related to the water demands associated with resident tree densities, the increased size of the vadose soil water resource often associated with larger sized creek catchments and the inherent frequency of surface water inputs which they typically provide. This essentially determines that while facultative phreatophytes are adapted to riparian habitats where groundwater proximity allows enough access to satisfy some of their water requirements, they have also often evolved to survive on other more variable yet sufficient riparian water resources such as soil moisture in the vadose zone. Vadophytes are also defined as able to inhabit areas where their water requirements can be met by soil moisture reserves alone, but can also occur in areas where groundwater contributes to plant water use. These distinctions determine that some species characterised as being facultative phreatophytes are also able to be accurately characterised as vadophytes under certain conditions.

An illustration of the conceptual overlap in water use strategies (e.g. phreatophyte/vadophyte/xerophyte) and the relevant classes of groundwater dependence used to define each is presented in Figure 6-2. Figure 6-2also gives an interpretation of where some of the most relevant Pilbara species might sit in the spectrum of ground/soil water dependence and the relevant ranges of this dependence which is occupied by defined classes of groundwater dependence. Furthermore Figure 6-2also helps to illustrate the likely water use strategy of *E. victrix* and the increasingly held understanding that *E. victrix* is a relatively drought tolerant riparian species, suggesting that the risk to this species from groundwater drawdown is often much lower than the commonly characterised 'facultative phreatophyte' class of groundwater dependence might advise.

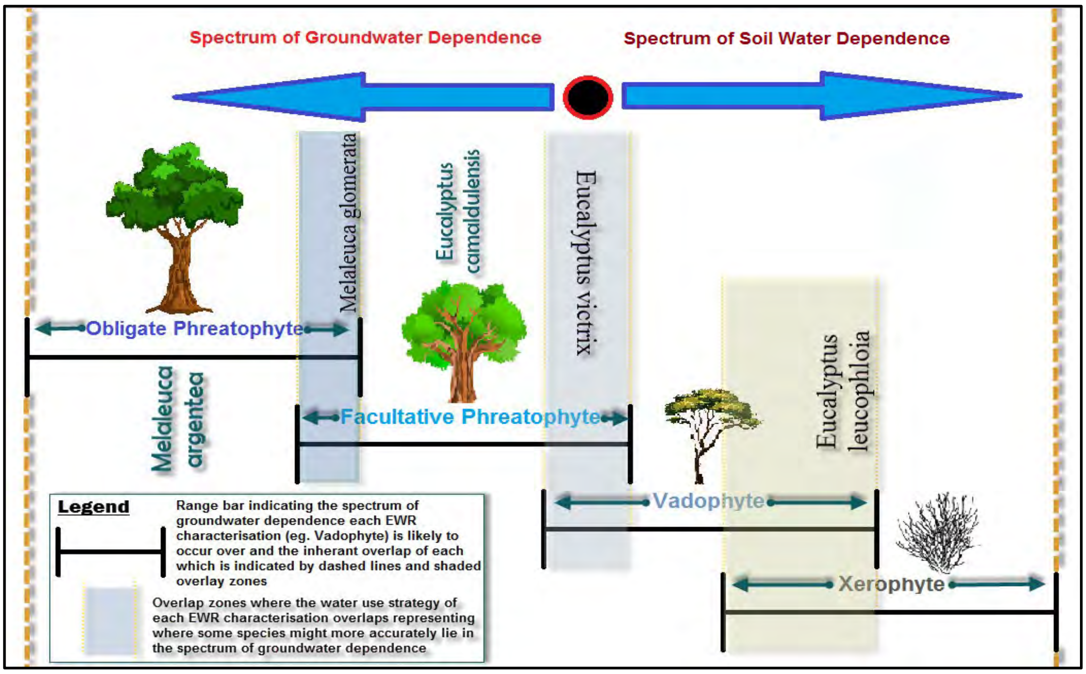


Figure 6-2: Spectrum of groundwater dependence and soil water dependence

The ranges of this spectrum which are likely occupied by the various groundwater dependence classes (water use strategies) used to characterise the environmental water requirements of Pilbara species, the likely zones of overlap in groundwater dependence classes, and the interpreted position on the scale of groundwater dependence of some key Pilbara species.

For the key phreatophytic species within riparian systems of the study area; the broad eco-physiological differences inherent to each have led to the following key conclusions about the degree of dependence of each on groundwater and antecedent conditions, and therefore the risk which groundwater drawdown from the proposed dewatering of Deposits C and D poses on each.

E. victrix is considered to be fairly drought tolerant, and generally capable of successfully transitioning from good to limited moisture availability, without mortality (Pfautsch *et al*. 2014). In riparian habitats within KNP this is complicated by the above average standing biomass recorded (Riparian Zones C & D; Figure 4-1), which may elevate the water demand per unit area to a point where this ability to transition to reduced water availability is reduced. Therefore despite the potential for *E. victrix* to suffer from a decline in health due to changes in depth to groundwater within the incised channel zone, the potential for *E. victrix* dominated communities in the study area (the C3C and C2C communities) to be significantly impacted is determined to be 'very low' to 'low' for the majority of the study area, and slightly elevated for the higher biomass representations (C2C community) present on TCEB (riparian Zones C & D).

Consequently it is predicted that the structure and composition of C3C and C2C communities will likely remain relatively un-changed (while likely exposed to some reduction in health) as a result of potential groundwater drawdown from the proposed dewatering for the Proposal such that the predicted impacts are not considered to represent a 'significant impact'. Therefore, overall the risk to this species and the communities within which it forms the dominant tree species is determined to be 'Low', and at times 'Low-Medium' due to elevated biomass based water demands. *E. camaldulensis*, while considered less drought tolerant than *E. victrix*, is also considered relatively well adapted to the increased variability in access to soil moisture in areas where the water table may regularly be out of reach. While this species is generally known to establish as a dominant/co-dominant species in areas where there is good access (at least a proportion of the time) to the broader groundwater table (or capillary fringe) (Loomes 2010), it also appears capable of establishing in or transitioning to an altered hydrological regime and surviving on the relatively regular surface water inputs and associated vadose soil water resource provided by larger catchment creek systems (Rio Tinto 2016b).

The Department of Water (**DoW**) completed a study to determine the range of groundwater levels which Pilbara riparian species occur over (Loomes 2010). Based on this work it is suggested that *E. camaldulensis* generally occur where average depth to groundwater is less than 5 m and are unlikely to occur beyond an average depth to groundwater of 10 m. As the work of Loomes (2010) focused purely on large river systems of the Pilbara (the De-Gray, Yule, Robe and Fortescue Rivers), it's assumed that it is most relevant to rivers with often shallow water tables, and appears less directly applicable to creek systems of the Hamersley Ranges. In creek systems of the Hamersley's *E. camaldulensis* has been shown to establish in riparian zones where depth to groundwater is >15 m (RTIO 2015b). However, within the study area, the distribution of *E. camaldulensis* in relation to interpolated groundwater heights appears to fit with the results of Loomes (2010). Despite this, the riparian zones in the study area are positioned where the relevant upstream catchment is small to medium in size and where the reduced frequency of surface water inputs (which in turn help replenish the vadose soil resource) would determine that the distribution of *E. camaldulensis* is likely to be more strongly linked to groundwater access.

The publically available report by the DoW titled "Determining water level ranges of Pilbara riparian species" (Loomes 2010) does not provide a clear indication of finer scale field methodologies used (or where to source them), and so direct comment on the applicability of this work to the potentially drier riparian environments of Hamersley Range creeks systems is difficult. While the results of Loomes (2010) was suggested to be inconclusive for E. victrix (*E. victrix* was only recorded in a small number of sites) it is interesting to note that it showed that *E. victrix* was not found in areas where depth to groundwater was greater than 10 m. Within the study area *E. victrix* is shown to consistently establish where depth to groundwater is 20-60 m below ground. Such results may allude to issues with the applicability of the results of Loomes (2010) to Hamersley Creek systems.

6.2.2 Standing biomass

The relationship between vegetation biomass and water demand is well accepted and a logical result of the increased photosynthetic demand and associated water loss per unit of biomass (Salisbury and Ross 1992). Much less well accepted is the how this increasing biomass per unit of area influences the ability of substrates to supply the commensurate water demand. This is most likely a product of two key factors. Firstly; riparian vegetation possessing a high standing biomass is often present as a result of shallow groundwater access. However, the distinction is rarely made when other riparian vegetation zones of moderate to high biomass have in fact established without effective groundwater access (and may represent the upper bounds of biomass capable without groundwater access). Secondly; if groundwater is within proximity, such that a significant proportion of root systems have access to a zone of saturated sediments, then the typical volume of soil (and associated root volume) required to uptake the EWR of a single tree (without interference from others) is significantly lower than a tree relying on pore water sources alone. The same applies for a situation where multiple trees are occupying a shared volume of soil. Therefore, in a riparian situation where groundwater is readily and consistently accessible more trees can satisfy their EWR from a significantly smaller combined soil volume, allowing for much greater biomass per unit of area. If relying on the vadose soil water resource alone, the soil volume required to satisfy EWR is typically much greater than when groundwater is readily accessible.

These distinctions are important where groundwater is readily available (and shallow), high standing biomass is present and a tight mass of roots within a relatively low volume of soil (that soil zone where groundwater is readily accessible) is established. In such a situation, removal of groundwater access would essentially determine that the volume of soil occupied is not adequate to provide all trees with their EWR (from vadose soil water), and significant impacts would be expected. Alternatively; assuming resident phreatophytic species are of no greater than low to moderate groundwater dependence; if the frequency and magnitude of surface water inputs are adequate (for vadose soil resource replenishment), and root systems are well distributed within a substantial soil volume, moderate to high levels of standing biomass have the potential to be supported regardless of access to groundwater. The key determinants to viability of vegetation in such a situation appear to be the influence of antecedent groundwater conditions and available soil volume on root architecture and distribution, as well as the EWS (i.e. groundwater dependence) and dominance of resident phreatophytic species.

As discussed earlier; models developed for some arid-land riparian species (using both hydrological and vegetational datasets) have shown that stand structure is strongly related to water availability and groundwater depth (Stromberg *et al.* 1993). Work by Stromberg *et al* (1993) demonstrated that biomass indices such as basal area and stem density (proxies of stand biomass) can be a useful indicator of groundwater dependence. The theory being; that the survival of vegetation possessing a basal area within a particular lower range was likely, as such a biomass determines that groundwater access is unlikely to be limiting, and that the available vadose water resource is adequate enough to sustain minimum water availability for the resident biomass (through typical periods of climatic variability). This standing biomass concept can also be considered in relation to the height and structure of vegetation in a riparian system. The height and structure of a community also obviously have a relationship with biomass. One of the potential impacts of groundwater drawdown on potentially GDV is that phreatophytic species can no longer maintain previous canopy heights. This is likely a result of differing xylem pressures and susceptibility to cavitation, leading to reductions in stature and horizontal reach within larger more mature trees (through intermittent loss of higher stature canopy components in turn altering canopy architecture to match the changing water availability. Work by Lite & Stromberg (2005) looked at surface water and groundwater thresholds for maintaining Populus–Salix forests in the San Pedro River, Arizona. This research identified hydrologic thresholds above which *Populus fremontii* & *Salix gooddingii* maintain tall dense stands with diverse age classes. This study documented shifts in species composition which corresponded to decreases in maximum canopy height and upper stratum (above 8 m) vegetation volume as site water availability declined. Furthermore the results of this study showed that sites with deeper water tables and more intermittent river flows had greater areal coverage of shrublands and less of woodlands. This study provides further evidence to the concept that changes in groundwater access don't simply lead to phreatophytic species being removed/added, but instead that biomass and structural changes play an important role in matching water demand with availability.

In the study area, the natural distribution of *E. camaldulensis* is highly restricted to a small area (mainly in Riparian Zone C/C1, but including a small pod in Zone D) within the incised channel zone of TCEB (the C2B community). Typically the distribution of *E. camaldulensis* is strongly correlated with the distribution of increased surface water inundation frequencies. Such distribution suggests a greater reliance of *E. camaldulensis* on surface water than groundwater, but this is generally observed in, and most relevant to, areas with a substantial volume of alluvial sediments to support extensive lateral root systems. Within Zones C and D of the study area (and where the C2B community occurs), the incised channel zone is topographically confined resulting in a relatively narrow and potentially shallow (as indicated by exposed bedrock in some places) alluvial zone.

In many cases it is postulated that large alluvial formations and associated vadose soil water resources (within riparian zones) can facilitate a certain degree of resilience within vegetation to groundwater changes which might occur. However, within the study area, resident potentially groundwater dependent riparian communities existing in the confined alluvial Zones C and D, most likely have access to a smaller than typical vadose soil resource available within the alluvial's. Consequently there is potential for increased dependence on groundwater access (in Zone C in particular) due to an apparently reduced alluvial soil volume from which to source soil pore moisture. As such, it is suggested that the increased density riparian communities in Zones C and D of the study area are of increasing potential (given their increased density) to be at least partially dependent on access to groundwater or fractured rock aquifers present in potentially shallow sub-surface bedrock features. If so; *E. camaldulensis,* and to a lesser extent *E. victrix,* in Zones C and D may rely on groundwater to provide a higher proportion of their total EWR than typical, and as such risk of impact from groundwater changes may be commensurately elevated. However; the sub-surface geological cross-sections provided by the recent geophysics work did not directly interpret basement bedrock features to be present below Riparian Zone C (GBS MAPS 2017). From this result it is inferred that such features must be located deeper than the 25 m sub-surface zone of interpretative confidence provided by such geophysical techniques (GBS MAPS 2017). While this work does not conclusively rule out the presence of smaller scale basement lithologies at times restricting root distribution, it does give a reasonable degree of confidence that broadly speaking such features are not significantly limiting the soil volume and resultant vadose soil resource available to resident riparian communities. As well as confining/reducing the alluvial soil resource, topographic confinement of the creekline can have a positive influence on water availability, by funnelling all surface water inputs through the most relevant (to sustaining potentially groundwater dependent communities) riparian zone. This concentration of inputs within a smaller area may help increase the frequency and effectiveness of successive vadose soil resource and minor fractured rock aquifer replenishment events. Furthermore it is postulated that in comparison to broader systems, a more topographically confined riparian environment will likely possess more favourable microclimates, and is likely to more efficiently store/maintain soil pore moisture between surface water input events. Such effects along with the potential accessibility of fractured rock aquifers (associated with topographic confinement features), will likely attenuate, to some degree, the influence of a reduced alluvial soil volume on the potential groundwater dependence of communities present in zones C and D of the study area.

Given the transition of TCEB from an open valley to a more topographically confined environment, other important hydrological characteristics are also likely to be in effect in the in the vicinity of riparian Zone C. Based on geological mapping and the fairly evident calcrete sheet formations adjacent to the creek in this area, it appears that sub-surface lithologies (such as members of the Wittenoom geological formation) may be influencing groundwater presence in the vicinity of Riparian Zone C. While conceptual hydrogeological models depict the Wittenoom formation as manipulating or constricting groundwater to within proximity of the surface in the area of interest (Rio Tinto 2017); it's not clear yet as to whether such formations are primarily influencing groundwater trends in the vicinity of Riparian Zones A/B/C. However, it is commonly observed that the majority of the larger carbonate sheet (calcrete) formations in the Hamersley Ranges tend to flank creek or river systems transitioning from a valley or flatter landscape/lithology to different, often more topographically confined circumstances; i.e. passing through a slot in a range formation, or something similar. Such transition zones are thought to trap (or dam-up/funnel) groundwater into sediments close to or on the surface. Fluctuations in groundwater height near the surface then lead to cycles of desiccation and carbonate precipitation which deposit calcrete. The presence of such characteristic calcrete formations tend to be a clear indication that the resident lithology or topography may be manipulating groundwater closer to the surface, and so GDEs may be associated. The calcrete formation present in Zone C hints that groundwater in the vicinity has likely been historically shallow (or even pooling on the surface), and that either topography, confinement by the range or some other product of the lithology there has played a part in this. With available bore data suggesting that groundwater nearby (WANG 14) is becoming shallow (approximately 5 m bgl), geophysics interpreting this trend as being maintained through Zone C, , and standing biomass (basal area) spiking in Zone C, there is mounting supporting evidence that groundwater is and has been historically shallow in the vicinity of Zone C. This would also tend to suggest an increasing likelihood that local riparian communities are groundwater dependent, however the distribution and abundance of FPS in the area does not completely support such an inference. Typically if groundwater was consistently shallow in this area then *E. camaldulensis* and other mesic species would be expected to be more common than has been observed in Riparian Zone C. Geophysical evidence suggesting some degree of constraint to riparian development is provided by extensive shallow calcrete detrital formations and other potential impervious subsurface features (GBS MAPS 2017). Such evidence suggests that the composition and structure of resident riparian vegetation correctly reflects the substrate and moisture conditions present and as such determines that groundwater should continue to be considered as providing an important supporting role.

Beyond the basic compositional and structural evidence present within and downstream of Zone C, there are a number of different site attributes and observations which provide evidence supporting and denying the likely dependence of local riparian vegetation on groundwater access. Despite this; it is becoming increasingly evident that in the area of most concern (the KNP), TCEB is transitioning from a broad valley with deep groundwater conditions to more shallow groundwater conditions as it is constricted by, and forced through, the local range formation. As TCEB is constricted through the range, riparian vegetation structure changes significantly, but species composition does not. As a consequence the interpreted risk to local vegetation of impact from groundwater changes can only be considered moderate (at its highest) and generally low elsewhere. While the combination of elevated standing biomass along with an apparently reduced alluvial volume within Zone C has potential to increase reliance of vegetation on groundwater access, the potential influence of such an effect is unclear. Importantly, geological interpretations continue to maintain the likely presence of an effective groundwater divide (McCrae Shale/Mt. Sylvia Formation based aquiclude) at the downstream end of Riparian Zone C (Rio Tinto 2017). Such a divide should at least determine that the potential for drawdown impacts on riparian groundwater heights within KNP will be confined to areas upstream of this point.

6.3 HOPE DOWNS 1 CASE STUDY

The Hope Downs 1 mining area provides a good case study for understanding how low to moderate risk FPS and FPV might respond to the removal of access to groundwater as a result of dewatering. Since mining has begun in this area, and groundwater heights have fallen, nearby GDV has been without access to groundwater for between 5 and 8 years. A recent riparian Eucalypt health study in the Hope Downs 1 vicinity focused on systematically assessing the current health and historical mortality present in resident vegetation which has been exposed to significant drawdown. Within the Eucalypt genus this assessment had a focus on influences to *E. camaldulensis*; a moderate risk FPS, but also focused on *E. victrix* as a secondary source of information on the response of FPS and associated FPV to groundwater changes. Riparian vegetation health has been monitored since mining began in the area in 2006, so approximately 10 years of canopy cover data exists in this area. The results of the Hope Downs 1 study are summarised below:.

In mid-2015, a systematic Eucalypt health assessment was conducted by Rio Tinto along a 3 km section of Weeli Wolli Creek where consistent drawdown from the nearby mining operation has lead, in some areas, to a 7-8 m per year (at Bore BH31) drop in depth to water table (approximately 20 mm per day) (Rio Tinto 2015b). Dewatering began in 2007, with baseline water tables between 7 and 10 m bgl. This drawdown has translated (depending on location) to a depth to water table in the range of 15-30 m bgl since mid-2009 and has peaked at present in the range of 25-70 m bgl in different parts of the creek. To date (based on an assessment of the time it takes to increase the depth to water table from baseline to 30+m bgl), this represents at least 5-6 years in succession that a portion of the Weeli Wolli creek riparian system, including vegetation within both the incised channel and floodplain zones (likely longer in the floodplain zone), has been without access to groundwater. Importantly, unlike many other areas of known drawdown impact in the Pilbara; this stretch of creek does not receive surplus water discharge from mining.

A health assessment of every Eucalypt with a DBH greater than 10cm in a 3 km stretch (adjacent to the zone of greatest drawdown influence) was undertaken. Of a total of 620 eucalypts recorded, 88% were assessed as being of average and better health. Only 4.5% of *E. camaldulensis* present were assessed as being stressed. Digital multispectral imagery (**DMSI**) interpretation showed that only 2.6% of all eucalypts (16 trees) had died since 2007. The results of the Hope Downs 1 study demonstrated the inherent resilience of moderate risk GDV to significant changes to groundwater access.

The Hope Downs 1 study area is somewhat different from the current study area given the smaller size of the upstream catchment reporting to the current study area. Furthermore, there is evidence that at present (degree of associated historical variability not yet clear) zones within the current study area possess significantly shallower antecedent groundwater conditions. However, the results from Hope Downs 1 study support the suggestion that, in at least the short to medium term, mortality rates (particularly of *E. camaldulensis*) are not significantly increased by a significant change in the availability of groundwater (at vertical change rates in excess of 1-2 cm per day), even in floodplain zones at distance from regular surface water inputs (RTIO 2015b). The results of this work are depicted in Figures A1-A4 within Appendix 4.

7 CONCLUSIONS

The degree of scrutiny applied to the question of groundwater dependence is often a product of the degree of perceived risk associated with the potential impacts and the significance of biological assets subject to those potential impacts. In the case of the study area, the pre-existing evidence suggested that the risk of significant GDE's being present was low. However, the proximity of KNP and presence of moderate interest riparian vegetation signatures inside its boundary indicated that a baseline assessment utilising qualitative (and some quantitative) assessment measures/indicators was most relevant. After considering the limited degree of hydrogeological information available and the current state of knowledge in relation to Pilbara FPS, the level of complexity employed in the current study is considered commensurate with the likely sensitivity of local riparian communities.

Previous GDE studies have generally solely relied upon the structure and composition of baseline riparian communities. While focussing on riparian vegetation within KNP, this study has used a risk based approach to explore the degree to which the data suggests that riparian vegetation in the study area is dependent on groundwater access and additionally, the degree to which potential groundwater changes might impact riparian vegetation if it is dependent on groundwater access.

The risk assessment has combined qualitative and quantitative data to attempt to quantify (in terms of risk) the groundwater dependence of riparian vegetation (and therefore potential GDEs) in the study area. This risk to riparian vegetation is highly dependent upon factors such as;

- Genetic variability within species.
- The influence of sub-surface factors which are inherently difficult to understand (e.g. alluvial characteristics and variability, fine scale antecedent groundwater conditions under GDV, root architecture/distribution of GDS etc.).
- The likelihood of groundwater changes being realised in the vicinity; which is also dependent on subsurface factors such as the interaction of geological and aquifer variability, surface water regimes and groundwater recharge dynamics, the timing and magnitude of abstraction, etc.

The combined influence of these factors on groundwater dependence and the propagation of groundwater drawdown (the last of which is not quantified as part of this study), ultimately determine that the risks presented in this study are relatively conservative. That is; not only is there some conservatism applied to the interpreted risk of groundwater dependence, but there is also compounding conservatism associated with the risk of groundwater changes being realised some 7-10 km from the proposed dewatering. Furthermore; considering the inherent degree of arid adaptation held by local FPS, and the demonstrated ability of moderate risk FPS to adapt and remain viable in the absence of, or with reduced access to groundwater; the likelihood of significant impacts appears to be Low-Medium and highly spatially restricted.

There are however, local observations/characteristics which might support rather than attenuate this risk (particularly in Riparian Zone C); characteristics include the shallow geophysics based groundwater heights interpreted in key riparian zones within KNP, topographically confined channel profiles and low associated alluvial volumes available, and the constraints on riparian development potentially provided by sub-surface lithologies. These characteristics indicate some potential that the risk of groundwater dependence of riparian vegetation is increasing within the KNP and particularly when transitioning from Riparian Zone B into Zone C.

However, it is thought that propagation of groundwater drawdown will likely be somewhat limited downstream of riparian zones A and B (Figure 4-1; beyond which alluvial/colluvial formations are less extensive). Furthermore the potential for groundwater propagation beyond Zone C appears to be increasingly diminished. This can be partially attributed to the geological complexity of subsurface lithologies in the section of TCEB dissecting Riparian Zone D (and parts of Zone E), which includes abundant dolerite dykes mapped running perpendicular to TCEB, and which typically form a barrier to groundwater flow. Furthermore, the continued interpreted presence of an impervious McCrae Shale aquiclude at the southern end of Riparian Zone C (Rio Tinto 2017) determines that drawdown propagation beyond its location is highly unlikely. This determines that only a 4 km stretch of TCEB (and potentially less; which includes Riparian Zone C and the northern section of Riparian Zone E) has potential to be impacted by drawdown if it were to extend into KNP.

Of this 4 km stretch of TCEB which has potential to be impacted by drawdown, only Riparian Zone C (the initial 2 km stretch) possesses vegetation with GDS of sufficient standing biomass to be considered at risk of significant/noticeable impact from drawdown (if drawdown were to be realised). Furthermore, of this 2 km stretch at risk; only a 700 m stretch (Riparian Zone C-1 and the included C2B vegetation unit) possesses GDS (*E. camaldulensis*) of moderate potential groundwater dependence and elevated standing biomass. Therefore; it is this stretch which represents the area of greatest risk of groundwater dependence. Conversely this area coincides with that area of diminishing potential to propagate potential drawdown. However, despite initial hydrogeological investigations indicating that a groundwater divide is likely in the vicinity of Riparian Zone C-1, geophysics did not support this, and confidence in information surrounding this potential for diminished propagation is limited and therefore unable to be considered in detail.

Perceived disparity between the interpreted depth to groundwater within Riparian Zone C (and potentially downstream; based on geophysics and bore data) and the GDS and associated GDV recorded, can potentially be at least partially explained by substrate constraints on riparian growth through Zone C. However, based on observations made in other Hamersley creek systems, the restricted distribution of *E. camaldulensis* and absence of key mesic indicator species is still perceived as somewhat unusual in light of the interpreted 3.5 m average depth to groundwater through this zone (with an average depth of 2 m bgl through Riparian Zone C-1). Therefore, either substrate constraints are playing a bigger role than first conceived, geophysical interpretations are inaccurate (unlikely given bore data), upstream propagule sources of mesic species are extremely limited, and/or historical variability in groundwater height is considerable (downstream of Riparian Zone B) and therefore limiting. Importantly; regardless of whether vegetation present in the area of interest is reflective of the degree of groundwater access present, along with the predicted resilience of the over-storey; understorey vegetation does not show compositional signs of increasing reliance on groundwater, and as such this component of local vegetation is unlikely to see significant impact.

It is maintained, through geological interpretations (Rio Tinto 2017), that drawdown is highly unlikely to propagate beyond the end of Riparian Zone C, due to the presence of a groundwater divide in that vicinity. Therefore, upstream of this point; drawdown as a result of dewatering for the Proposal has the potential to propagate through and impact vegetation within Riparian Zone C. Different modelled scenarios for the magnitude of drawdown experienced at bore WANG14 indicate that drawdown is unlikely to reduce groundwater heights to a point where vegetation in Riparian Zone C no longer has access. Groundwater modelling predicts up to 8 m (worst case) of drawdown will potentially propagate to WANG 14, and within Riparian Zone C-1 this figure is likely to be slightly less due to the extra distance travelled to this point (approximately 1 km further). For the worst case modelling scenario (Sy = 1%), geophysical interpretations combined with drawdown modelling suggests groundwater access would be minimal but acceptable at approximately 5.5-12.5 m bgl within Riparian Zone C (outside of Zone C-1), and approximately 4.5-10.5 within Riparian Zone C-1 (the most sensitive zone; Table 6-1). Under the base case scenario (Sy3%) geophysics combined with drawdown modelling predicts maximum groundwater depth to be approximately 6.5-7.5 m bgl within Riparian Zone C-1 and approximately 7.5-9.5 m bgl within the remainder of Riparian Zone C (Table 6-1), and clearly still accessible to trees. Most importantly (also considering that FPV has the potential to survive with minimal to no groundwater access) the time scales over which this drawdown is modelled to occur indicate that vertical rates of change per year are very small. Based on the various specific yield modelling scenarios, vertical height changes to groundwater potentially experienced within KNP are likely to be in the order of 5-20 cm per year with a base case of 10 cm and worst case scenario of approximately 40cm/yr. This degree of vertical change to groundwater access is thought to be easily in the order of that which local facultative phreatophytes can successfully adapt to (i.e. 1 cm per day; Kranjcec, Mahoney and Rood 1998; Scott, Shafroth, and Auble 1999; Horton and Clark 2001; and Canham 2011). This adaptation is primarily achieved through root systems tracking groundwater down through the soil profile, and via the allocation of increased root resources to vadose soil water sources.

In conclusion, if groundwater drawdown of 3 m to 8 m were to extend beyond the KNP boundary (i.e. 2-4 km), the overall risk of significant impact would likely be considered moderate and would be restricted to Riparian Zone C, particularly Zone C-1.

However, considering the very slow rates of vertical change in groundwater height modelled as reaching KNP, the high potential for local FPV to adapt to such change and the low potential for complete removal of groundwater access, the resultant risk to vegetation in this area is likely lower. Downstream and upstream of this zone, the risk of significant impact is considered low. Ultimately compositional changes in the dominant species present in Riparian Zone C (within KNP) are considered unlikely, while changes in cover/abundance and health are considered the impact of greatest potential; albeit low-to moderate in significance and extent.

Based on consideration of the interacting factors surrounding the potential for groundwater changes to significantly impact potentially groundwater dependant riparian vegetation; it is concluded that overall, the interpreted risks attributed herein are deemed relevant, adequately conservative and therefore the best estimate currently available.

In line with this assessment, it is concluded that monitoring and management efforts should be focussed on the incised channel zone of TCEB, starting approximately 2 km inside the KNP boundary (in the vicinity of the calcrete formations), and further focusing on Riparian Zone C, with some consideration for the northern section of Zone E. Some monitoring of Zone D should also be conducted in order to confirm that impacts downstream are not being realised. Substantial historical tree health monitoring data collected in Riparian Zone C (qualitative reference sites associated with the Turee creek bore field) should form the basis of important baseline data relevant to contextualising the variability in tree health likely to be seen in such a system. Cover indices based on World View or equivalent remote sensing is recommended to form the basis of health monitoring to systematically track the presence/absence of cover change anomalies in the study area.

8 REFERENCES

Antao, M. and Braimbridge, M., (2009), Millstream status report, Department of Water, Government of Western Australia, Environmental water report no. 9.

Barbour, M.G., Burk, J.H., Pitts, W.D. (1987), Terrestrial Plant ecology, 2nd Edition (Ed. J Kranhold), The Benjamin/Cummings Publishing Company, California.

Beard, J. S. (1975). Vegetation Survey of Western Australia 1:1,000,000 Vegetation Series. Map Sheet 5 - Pilbara. University of Western Australia Press, Western Australia.

Benyon, RG, Theiveyanathan, S & Doody, TM (2006), 'Impacts of tree plantations on groundwater in south-eastern Australia', Australian Journal of Botany, vol. 54, no. 2, pp. 181-92.

Bettany, E., Churchward, H.M. and McArthur, W.M. (1967). Atlas of Australian Soils, Sheet 6, Meekatharra - Hamersley Range Area. CSIRO, Melbourne.

Biota (2010). Flora and Vegetation Survey of the Proposed West Angelas Gas-Fired Power Station and Pipeline Corridor. Unpublished report prepared for Hamersley Iron Pty Ltd, Biota Environmental Sciences, Western Australia.

Biota (2013). Statement Addressing the 10 Clearing Principles for West Angelas Deposit C Drill Program. Unpublished report prepared for Hamersley Iron Pty Ltd, Biota Environmental Sciences, Western Australia.

Boulton, A. J., and P. J. Hancock (2006), Rivers as groundwater-dependent ecosystems: A review of degrees of dependency, riverine processes and management implications, Aust. J. Bot., 54, 133–144.

Braimbridge, M (2010), Yule River: ecological values and issues, Department of Water, Perth.

Canham, C (2011), 'The response of Banksia roots to change in water table level in a Mediterranean type environment', PhD Thesis, Edith Cowan University.

CAPON, S. J. and BROCK, M. A. (2006), Flooding, soil seed bank dynamics and vegetation resilience of a hydrologically variable desert floodplain. Freshwater Biology, 51: 206–223. doi:10.1111/j.1365-2427.2005.01484.x

Colloff, M., (2014), Flooded Forest and Desert Creek. CSIRO Publishing. ISBN 9780643109193.

Colloff, M., (2014). Flooded Forest and Desert Creek. CSIRO Publishing. ISBN 9780643109193.

Costermans, L. F. (1989). Native trees and shrubs of south-eastern Australia,Weldon, Sydney.

Department of Water (2009), Environmental considerations for groundwater management in the Northern Perth Basin, Environmental Water Report Series Report No. 8.

DoE (2014), Australian Vegetation Attribute Manual, National Vegetation Information System Version 6, viewed February 2015, http://www.environment.gov.au/erin/nvis/publications/avam/section-2-1.html#table1

Eamus, D., Huete, A., Yu, Q., (2016). Vegetation dynamics: a synthesis of plant ecophysiology, remote sensing and modelling. Cambridge University Press, New York.

Eamus, D. & Froend, R. (2006) Groundwater dependent ecosystems: the where, what and why of GDEs. Australian Journal of Botany 54, 91-96.

Eamus, D., Froend, R., Loomes, R., Hose, G. & Murray, B. (2006). A functional methodology for determining the groundwater regime needed to maintain the health of groundwater-dependent vegetation. Australian Journal of Botany 54, 97-114.

ecologia (2000). Greater West Angelas Vegetation and Flora Assessment. Unpublished report prepared for Hamersley Iron Pty Ltd.

ENV (2011), Flora, Vegetation and Fauna Assessment of the Re-Aligned Gas Pipeline Corridor at West Angelas. Unpublished report prepared for Hamersley Iron Pty Ltd, ENV Environmental Sciences, Western Australia.

ENV (2012), Flora, Vegetation and Fauna Assessment of the West Angelas Gas Pipeline Deviation. Unpublished report prepared for Hamersley Iron Pty Ltd, ENV Environmental Sciences, Western Australia.

Environmental Protection Authority (EPA) (2002), Terrestrial Biological Surveys as an Element of Biodiversity Protection, Position Statement 3, EPA, Perth.

EPA (2004), Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia, Guidance Statement 51, EPA, Perth.

Florabase (2016). Online flora database. Western Australian Herbarium. Department of Environment and Conservation. http://florabase.dec.wa.gov.au/

Florentine S. K. (1999) Ecology of Eucalyptus victrix in grassland in the floodplain of the Fortescue River. In: School of Environmental Biology. Curtin University of Technology, Perth.

Florentine, S & Fox, J (2002a), 'Morphological and physiological adaptations to waterlogging by Eucalyptus seedlings from the semi-arid Pilbara, Western Australia', Journal of the Royal Society of Western Australia, vol. 85, pp. 61-70.

Florentine, S & Fox, J (2002b), 'Seed longevity of Eucalyptus victrix in grassland in the floodplain of the Fortescue River, Pilbara, Western Australia', Biologia Plantarum, vol. 45, no. 3, pp. 477-9.

GBS MAPS (2017) Turee Creek East Geophysical Investigation, Karijini National Park, Pilbara WA. Unpublished report prepared for Rio Tinto by GBG MAPS Pty Ltd, WA.

Gibson, AC, Bachelard, EP & Hubick, KT (1994), 'Growth strategies of Eucalyptus camaldulensis Dehnh. at three sites in northern Australia', Australian Journal of Plant Physiology, vol. 21, pp. 653-62.

Graham, J., Landman, P.A., Adams, M.A. & Grierson, P.F. (2003) Root hydraulic architecture and water use by the by the riparian species Melaleuca argentea W. Fitz in the rangelands of north Western Australia. Proceedings VII International Rangeland Conference, Durban South Africa, CD-ROM.

Grigg, A. M., Veneklaas, E.J. & Lambers, H. (2008) Water relations and mineral nutrition of closely related woody plant species on desert dunes and interdunes. Australian Journal of Botany 56, 27-43.

Halpern, Glick Maunsell (1999), Marillana Creek Western Access Corridor – Biological Assessment. Unpublished Report for BHPIO.

Hill KD, Johnson LAS (1994), Systematic studies in the eucalypts. 6. A revision of the coolibahs, Eucalyptus subgenus Symphyomyrtus section Adnataria series Oliganthae subseries Microthecosae (Myrtaceae). Telopea 5: 743–771.

Horton, J & Clark, J (2001), 'Water table decline alters growth and survival of Salix gooddingii and Tamarix chinensis seedlings', Forest Ecology and Management, vol. 140, pp. 239-47.

Humphreys WF (2006), 'Aquifers: the ultimate groundwater-dependent ecosystems', Australian Journal of Botany 54:115−132.

Jackson, RB, Canadell, J, Ehleringer, JR, Mooney, HA, Sala, OE & Schulze, ED (1996), 'A global analysis of root distributions for terrestrial biomes.', Oecologia, vol. 108, pp. 389-411.

Keighery, BJ (1994), Bushland Plant Survey. A Guide to Plant Community Survey for the Community. Wildflower Society of WA (Inc.), Western Australia.

Kranjcec, J, Mahoney, JM & Rood, SB (1998), 'The responses of three riparian cottonwood species to water table decline', Forest Ecology and Management, vol. 110, pp. 77-87.

Lamontagne, S., Cook, P.G., O'Grady, A. & Eamus, D. (2005) Groundwater use by vegetation in a tropical savannah zone (Daly River, Australia). Journal of Hydrology 310, 280-293.

Landman P. (2001) The ecology and physiology of acacias and eucalypts in the Pilbara region of Western Australia. In: Department of Botany. University of Western Australia, Nedlands.

Landman, P.A., Grierson, P.F. & Adams M.A. (2003) A landscape approach to understanding water use by trees in the Pilbara region of north Western Australia. Proceedings VII International Rangeland Conference, Durban South Africa, CD-ROM.

Li C., (2000), RAPD analysis of genetic variation in Eucalyptus microtheca F. Muell. populations. Hereditas 132: 151-156.Loomes (2010), Determining water level ranges of Pilbara riparian species, Department of Water; Environmental water report series, Report no.17, Viewed January 2016, https://www.water.wa.gov.au/__data/assets/pdf_file/0019/4429/95314.pdf

Lite, S. J. and J. C. Stromberg (2005), Surface water and ground-water thresholds for maintaining Populus−Salix forests, San Pedro River, Arizona. Biological Conservation 125 (2005) 153–167

Loomes, R (2010), Determining water level ranges of Pilbara riparian species, Environmental report no. 17, Department of Water, Government of Western Australia, Perth.

Marcam Environmental (1998), Water use by creekline eucalypts (Eucalyptus camaldulensis and E. victrix) near Newman, East Pilbara. BHP Orebody 23 tree monitoring programme Report No 98/5, unpublished report to BHP Billiton Iron Ore Pty Ltd.

Marshall, JK, Morgan, AL, Akilan, K, Farrell, RCC & Bell, DT (1997), 'Water uptake by two river red gum (Eucalyptus camaldulensis) clones in a discharge site plantation in the Western Australian wheatbelt', Journal of Hydrology, vol. 200, pp. 136-48.

Mensforth, L.J., Thorburn, P.J., Tyerman, S.D. & Walker, G.R. (1994), Sources of water used by riparian Eucalyptus camaldulensis overlying highly saline groundwater. Oecologia 100:21-28.

Morris, JD & Collopy, JJ (1999), 'Water use and salt accumulation by Eucalyptus camaldulensis and Casuarina cunninghamiana on a site with shallow saline groundwater', Agricultural Water Management, vol. 39, pp. 205-27.

Muir Environmental (1995), Possible Long Term Impacts of the Yandicoogina Iron Ore Project on Riverine Species along Marillana Creek. Report for BHPIO.

Murray BR, Hose GC, Eamus D and D Licari (2006), 'Valuation of groundwater-dependent ecosystems: a functional methodology incorporating ecosystem services', Australian Journal of Botany 54:221−229.

Naumburg, E, Mata-gonzalez, R, Hunter, RG, McLendon, T & Martin, DW (2005), 'Phreatophytic vegetation and groundwater fluctuations: A review of current research and application ofecosystem response modeling with an emphasis on Great Basin vegetation', Environmental Management, vol. 35, no. 6, pp. 726-40.

O'Grady, A. Carter, J. & Holland, K. (2010) Review of Australian groundwater discharge studies of terrestrial systems. CSIRO: Water for a Healthy Country National Research Flagship. 60pp.

O'Grady, A.P., Cook, P.G., Eamus, D., Duguid, A., Wischusen, J.D.H., Fass, T. & Wordege, D. (2009) Convergence of tree water use within an arid-zone woodland. Oecologia 160:643-655.

O'Grady, A.P., Eamus, D., Cook, P.G. & Lamontagne, S. (2006) Groundwater use by riparian vegetation in the wet-dry tropics of northern Australia. Australian Journal of Botany 54, 145-154.

Onshore Environmental (2013), Orebody (OB) 29, 30, 35, Groundwater Dependent Vegetation Impact Assessment, unpublished report prepared for BHPBIO, Onshore Environmental, Perth.

Orellana, F, Verma, P, Loheide II, S & Daly, E (2012), 'Monitoring and modelling water-vegetation interactions in groundwater-dependent ecosystems', Reviews of Geophysics, vol. 50, pp. RG3003, doi:10.1029/2011RG000383.

Pfautch, S., Dodson, W., Madden, S., & Adama, M.A. (2014). Assessing the impact of large-scale water table modifications on riparian trees: a case study from Australia. Ecohydrol., 8, 640–649. doi: 10.1002/eco.1531.

Pfautsch, S, Keitel, C, Turnbull, TL, Braimbridge, MJ, Wright, TE, Simpson, RR, O'Brien, JA & Adams, MA (2011), 'Diurnal patterns in water use of Eucalyptus victrix indicate pronounced desiccation-rehydration cycles despite unlimited water supply', Tree Physiology, vol. 31, pp. 1041-51.

Rio Tinto (2009) Flora and Vegetation Assessment of the Proposed West Angelas Discharge Creekline Corridor (WADCC). Unpublished internal report, June 2009.

Rio Tinto (2011) Marandoo Phase II – Coolibah Soil Moisture Investigation. Resource Development Technical Projects. Unpublished internal report, June 2011.

Rio Tinto (2015a), West Angelas Deposits C, D, and G, Order of Magnitude Study; Water management, Unpublished internal report, Rio Tinto Iron Ore, Perth.

Rio Tinto (2015b), Hope Downs One Systematic Eucalypt health assessment; Weeli Wolli Creek ephemeral drawdown zone, unpublished internal study conducted by Rio Tinto Iron Ore, Perth.

Rio Tinto (2015c), Riparian Vegetation of Marillana and Weeli Wolli Creeks; Mapping Refinement and Assessment of Values and Significance, published report, Rio Tinto Iron Ore, Perth.

Rio Tinto (2016), Monitoring Bore water level database, unpublished internal data recorded by Rio Tinto Iron Ore, Perth.

Rio Tinto (2016b). Yandicoogina Pockets and Billiards South; detailed responses to public submissions in relation to flora and vegetation. Published report, Rio Tinto Iron Ore, Perth.

Rio Tinto (2017). West Angelas Deposits C and D; Hydrogeological Numerical Modelling Report. Unpublished internal report, Orebody Knowledge & Planning; Water Resource Evaluation, Rio Tinto, Perth WA.

Salisbury, F.B., Ross, C.W., (1992), Plant Physiology, 4th Edition (Ed. J.C. Carey), Wadsworth Publishing Company, California.

Scott, ML, Shafroth, PB & Auble, GT (1999), 'Responses of riparian cottonwoods to alluvial water table declines', Environmental Management, vol. 23, pp. 347-58.

Stromberg, J. C., Wilkins, S. D., & Tress, J. A., (1993), Vegetation-Hydrology Models: Implications for Management of Prosopis Velutina (Velvet Mesquite) Riparian Ecosystems. Ecological Applications, 3(2), 307–314. http://doi.org/10.2307/1941833

Thorne, A.M. and A.F. Trendall (2001). Geology of the Fortescue Group, Pilbara Craton, Western Australia. Geological Survey of Western Australia, Bulletin 144.

Thurgate M. E., Gough J. S., Clarke A. K., Serov P. and Spate A. (2001), Stygofauna diversity and distribution in Eastern Australian cave andkarst areas. Records of the Western Australian Museum 64 (Suppl.),49–62.

Trudgen, M. and Casson, N. (1998) Flora and Vegetation surveys of Deposit A and Deposit B in the West Angela Hill area, an area surrounding them, and of rail route options considered to link them to the existing Robe River Iron Associates rail line. Report prepared for Robe River Iron Associates, March, 1998.

Tyler, I.M., Hunter, W.M. and Williams, I.R. (1990). Newman, Western Australia, sheet SF50-16. 1:250 000 Geological Series Explanatory Notes (2nd edition). Australian Government Publishing Service: Canberra.

UWA (2015), Feasibility of genetic fingerprinting of riparian eucalypts at Rio Tinto monitoring sites, Unpublished report prepared for Rio Tinto Iron Ore, Ecosystems Research Group; University of Western Australia, Perth.

Wen, L., Ling, J., Saintilan, N. & Rogers, K. (2009) An investigation of the hydrological requirements of River Red Gum (Eucalyptus camaldulensis) Forest, using Classification and Regression Tree modelling. Ecohydrology 2, 143-155.

Western Australian Herbarium (2016), FloraBase – the Western Australian Flora, viewed May 2016, http://florabase.Parks and Wildlife.wa.gov.au/search/advanced

Zencich, SJ, Froend, RH, Turner, JV & Gailitis, V (2002), 'Influence of groundwater depth on the seasonal sources of water accessed by Banksia tree species on a shallow sandy coastal aquifer', Oecologia, vol. 131, pp. 8-19.

Zolfaghar, S, Villalobos-Vega, R, Cleverly, J, Zeppel, M, Rumman, R & Eamus, D (2014), 'The influence of depth-to-groundwater on structure and productivity of Eucalyptus woodlands', Australian Journal of Botany, vol. 62, pp. 428-37.

9 APPENDICES

Appendix 1: Flora sampling sites recorded during historical surveys and utilised in the current study for the purpose of vegetation mapping

ID	Type	Phase	Survey	Author	Year	Easting	Northing	Document control Number
FS-2010-736	Quadrat	Phase 1	A Flora and Vegetation Survey of the Proposed West Angelas Gas-Fired Power Station and Pipeline Corridor	Biota Environmental Sciences	2010	670209.4	7439566	RTIO-HSE-0103735
FS-2010-3252	Quadrat	Phase 2				673488.9	7439510.5	RTIO-HSE-0103735
FS-2011-3450	Quadrat	Phase 2	Flora, Vegetation and Fauna Assessment of the Re-Aligned Gas Pipeline Corridor at West Angelas	ENV. Australia	2011	671202	7439469.05	RTIO-HSE-0131727
FS-2012-5518	Relevé	Phase 1	Flora, vegetation and fauna assessment of the West Angelas gas pipeline deviation		2012	663074	7437471.06	RTIO-HSE-0156742
FS-2012-5510	Quadrat	Phase 2				663089	7437588.05	RTIO-HSE-0156742
FS-2012-6230	Quadrat	Phase 1	Rio Tinto Greater West Angelas Vegetation and Flora Assessment	ecologia Environment	2012	672580	7439183	RTIO-HSE-0185831
FS-2012-6137	Quadrat	Phase 1				669629.99	7439904.14	RTIO-HSE-0185831
FS-2012-6208	Quadrat	Phase 1				667450.17	7440007.34	RTIO-HSE-0185831
FS-2012-6204	Quadrat	Phase 1				662935.63	7437760.12	RTIO-HSE-0185831
FS-2012-6228	Quadrat	Phase 1				662967	7439466	RTIO-HSE-0185831
FS-2012-6143	Quadrat	Phase 1				672930.07	7439386.28	RTIO-HSE-0185831
FS-2012-6176	Quadrat	Phase 1				673420	7439350	RTIO-HSE-0185831
FS-2012-6203	Quadrat	Phase 1				671233.1	7439484.48	RTIO-HSE-0185831
FS-2012-6207	Quadrat	Phase 1				672023.59	7439634.47	RTIO-HSE-0185831
FS-2014-11331	Relevé	Single Phase	Western Hill Native Vegetation Clearing Permit Report	Biota Environmental Sciences	2014	661777.95	7439934	RTIO-HSE-0235895

Appendix 2: Flora sampling sites recorded within the study area as part of the current survey

ID	Type	Survey	Date	Easting	Northing
WAR-1	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	12/03/2016	673124.49	7439264
WAR-2	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	12/03/2016	667782.49	7439782
WAR-3	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	13/03/2016	667232.95	7440319
WAR-4	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	13/03/2016	664101.95	7439601
WAR-5	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	13/03/2016	662109.04	7439794
WAR-6	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	660286.97	7440006
WAR-7	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	659889.12	7440048
WAR-8	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	16/03/2016	662539.85	7437855
WAR-9	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	659033.31	7440108
WAR-10	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	658672.48	7439812
WAR-11	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	658353.28	7439534
WAR-12	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	658001.71	7439395
WAR-13	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	657682.51	7439104
WAR-14	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	657266.16	7438960
WAR-15	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	656280.82	7438618
WAR-16	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	655480.51	7438484
WAR-17	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	655059.54	7437850
WAR-18	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	654781.98	7437531
WAR-19	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	654675.57	7437018
WAR-20	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	13/03/2016	663975.94	7439675
WAR-21	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	16/03/2016	663294.03	7437543
WAR-22	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	660529.13	7439721
WAR-23	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	660266.38	7440137

Appendix 3: Vegetation structural classification used to describe vegetation

Stratum	Canopy Cover (%)				
	70-100%	30-70%	10-30%	2-10%	<2%
Trees over 30 m	Tall closed forest	Tall open forest	Tall woodland	Tall open woodland	Scattered tall trees
Trees 10-30 m	Closed forest	Open forest	Woodland	Open woodland	Scattered trees
Trees under 10 m	Low closed forest	Low open forest	Low woodland	Low open woodland	Scattered low trees
Shrubs over 2 m	Tall closed scrub	Tall open scrub	Tall shrubland	Tall open shrubland	Scattered tall shrubs
Shrubs 1-2 m	Closed heath	Open heath	Shrubland	Open shrubland	Scattered shrubs
Shrubs under 1 m	Low closed heath	Low open heath	Low shrubland	Low open shrubland	Scattered low shrubs
Hummock grasses	Closed hummock grassland	Hummock grassland	Open hummock grassland	Very open hummock grassland	Scattered hummock grasses
Grasses, Sedges, Herbs	Closed tussock grassland / sedgeland / herbland	Tussock grassland / sedgeland / herbland	Open tussock grassland / sedgeland / herbland	Very open tussock grassland / sedgeland / herbland	Scattered tussock grasses / sedges / herbs

*Based on Keighery (1994), adapted from Muir (1977), and Aplin's (1979) modification of the vegetation classification system of Specht (1970):

Aplin T.E.H. (1979). The Flora. Chapter 3 *In* O'Brien, B.J. (ed.) (1979). *Environment and Science.* University of Western Australia Press;

Muir B.G. (1977). Biological Survey of the Western Australian Wheatbelt. Part II: Vegetation and habitat of Bendering Reserve. *Records*

of the Western Australian Museum, Suppl. No. 3;

Specht R.L. (1970). Vegetation. *In The Australian Environment.* 4th edn (Ed. G.W. Leeper). Melbourne.

Appendix 4: Hope Downs 1 Case study

Systematic Eucalypt health assessment to demonstrate the response of riparian eucalypts to drawdown within the incised channel & floodplain zones of Weeli Wolli Creek in the Hope Downs 1 area (without the influence of artificial perennial flows).

Figures A1-A4, illustrating the results of the systematic eucalypt health assessment at HD 1

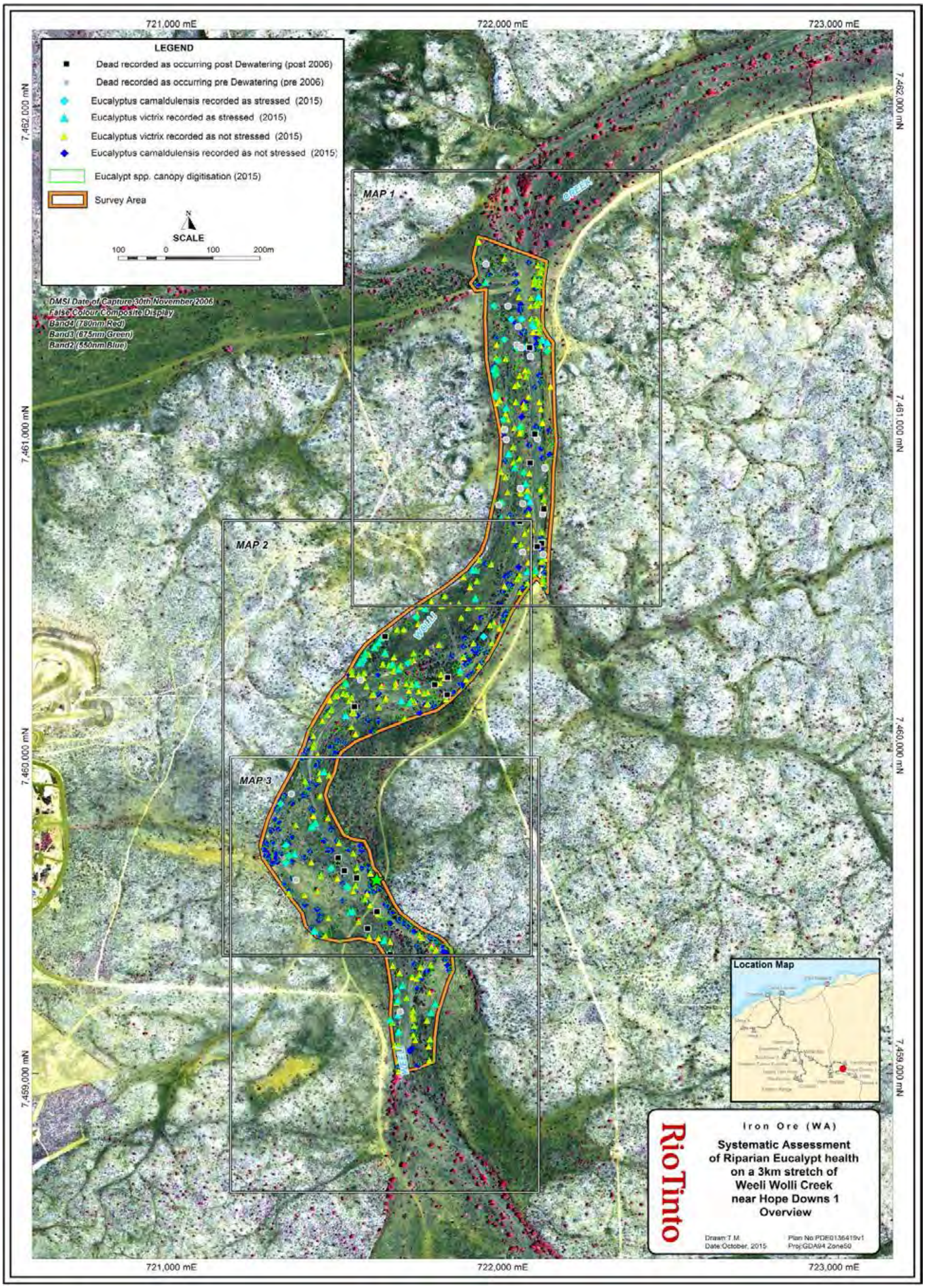


Figure A1: Systematic Assessment of Riparian Eucalypt health on a 3 km stretch of Weeli Wolli Creek near Hope Downs 1 and centred on the zone of most significant drawdown from the adjacent Hope downs 1 mining pits; - Overview map

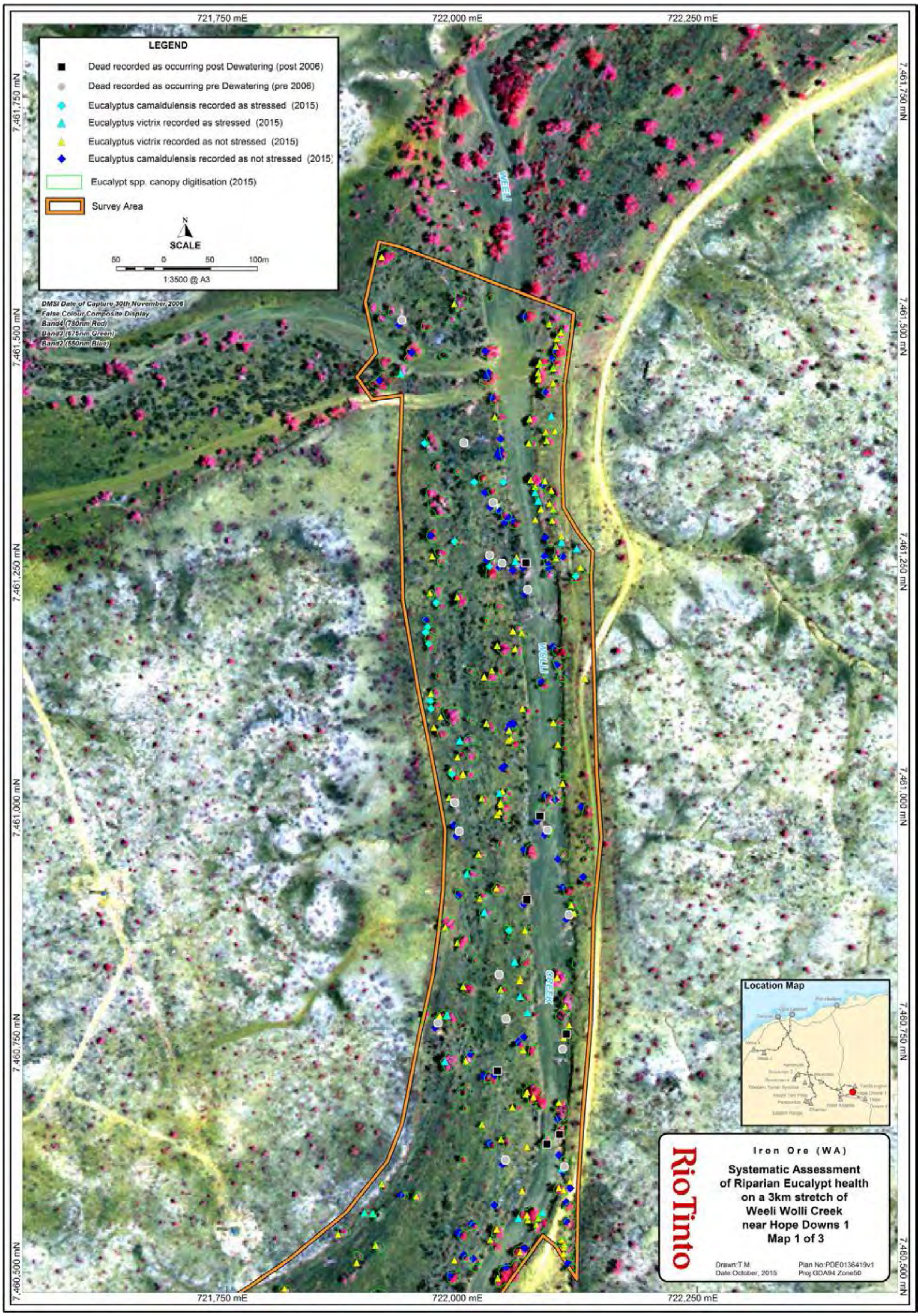


Figure A2: Systematic assessment of riparian eucalypt health on a 3 km stretch of Weeli Wolli Creek: Map 1 of 3

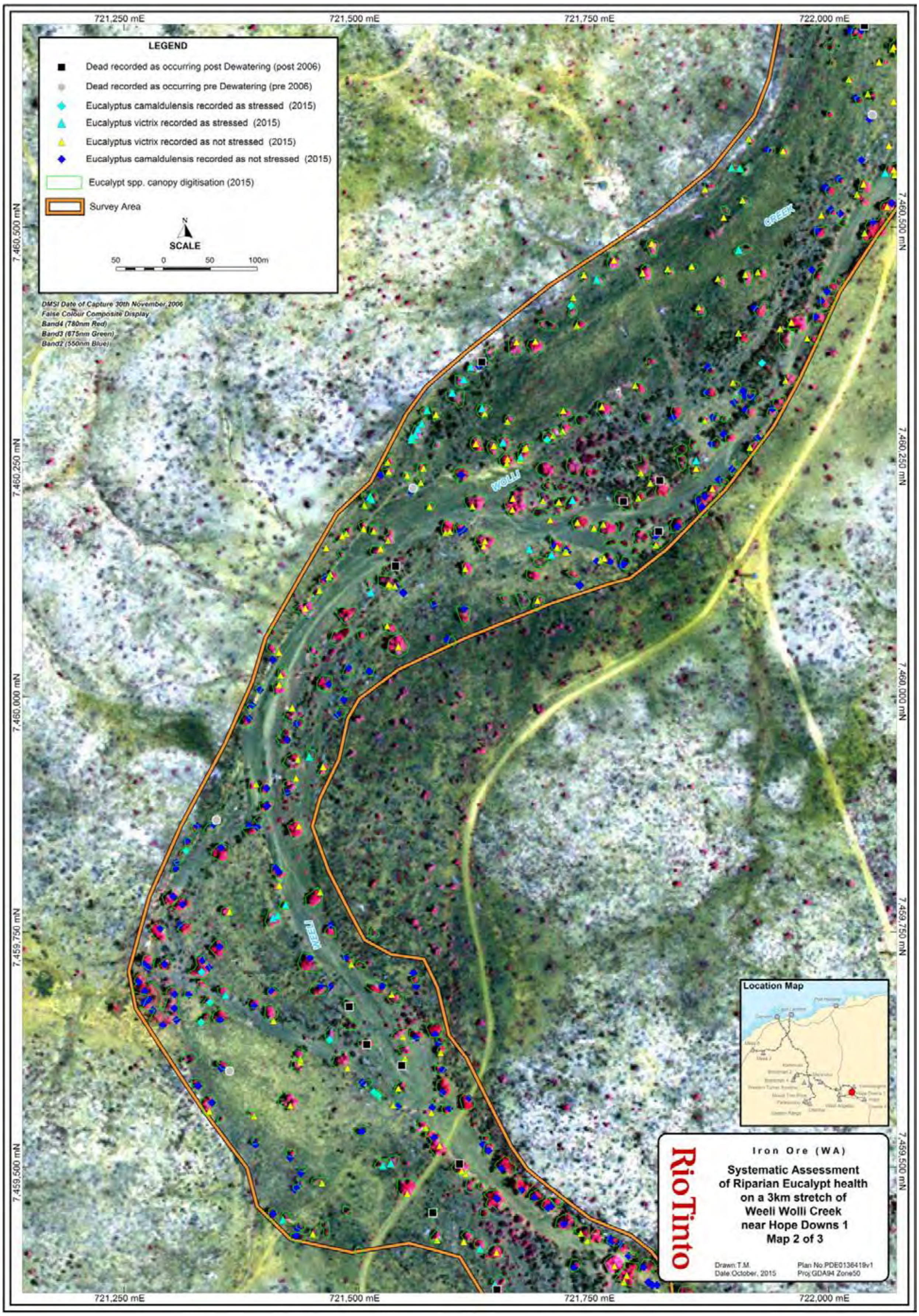


Figure A3: Systematic assessment of riparian eucalypt health on a 3 km stretch of Weeli Wolli Creek; Map 2 of 3

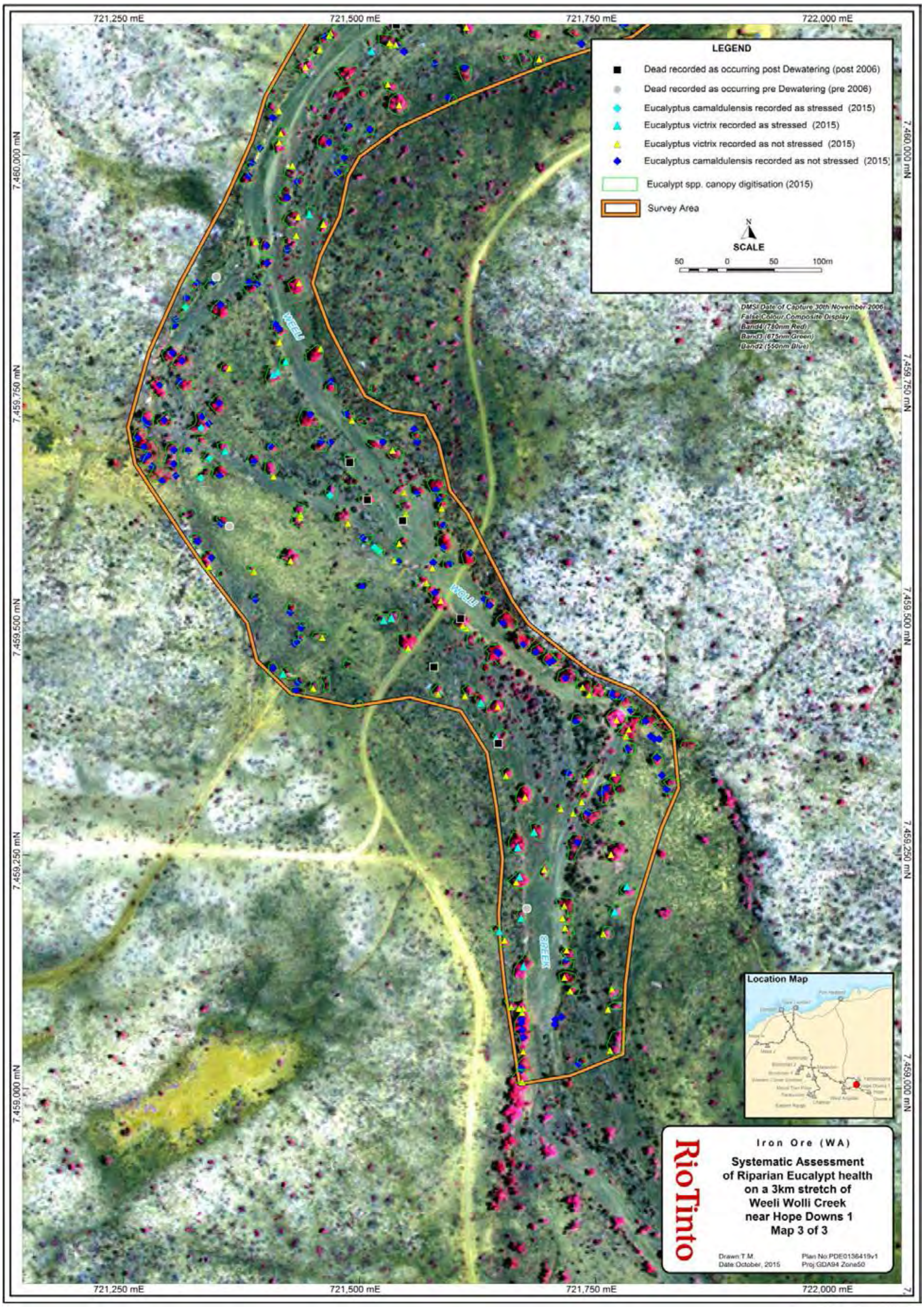


Figure A4: Systematic assessment of riparian eucalypt health on a 3 km stretch of Weeli Wolli Creek; Map 3 of 3

JANUARY 2014

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ACRONYMS

ARI	Ashburton Regional Inventory
BoM	Bureau of Meteorology
CAMBA	China-Australia Migratory Bird Agreement
DEC	Department of Environment and Conservation
DSEWPaC	Department of Sustainability, Environment, Water, Population and Communities
DPaW	Department of Parks and Wildlife
EIA	Environmental Impact Assessment
EPA	Environmental Protection Authority
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
JAMBA	Japan-Australian Migratory Bird Agreement
NHMRC	National Health and Medical Research Centre
PRI	Pilbara Regional Inventory
SAC	Species Accumulation Curve
SM2BAT	SM2BAT+ 384 kHz ultrasonic acoustic recorder
SRE	Short Range Endemic
WAM	Western Australia Museum
WC Act	*Wildlife Conservation Act 1950*

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EXECUTIVE SUMMARY

Rio Tinto Iron Ore is currently conducting preliminary feasibility studies for the development of ore deposits C, D, D extension, G, F, H and Mt Ella, collectively termed the Greater West Angelas study area, located approximately 105 km north west of Newman. As part of these investigations, *ecologia* Environment was commissioned to conduct a two-phase vertebrate fauna and terrestrial invertebrate short-range endemic (SRE) survey of the study area. This survey will provide baseline data which may be supplemented with additional studies should approval to mine deposits be sought in the future.

The literature review identified that the potential vertebrate fauna assemblage consists of a total of 38 native and nine introduced mammal species, 129 bird species, 103 reptile species and eight amphibian species. Of these potential species, six mammal species, 12 bird species and three reptile species are listed as conservation significant. The literature review also identified 32 SRE species that have been previously recorded in the region surrounding the study area.

The survey was undertaken using a variety of sampling techniques, both systematic and opportunistic, in accordance with relevant guidelines. A summary of the vertebrate fauna survey effort consisted of;

- 12 trapping sites were open for 14 nights over two seasons, totalling 7,056 trapnights;
- 53.8 hours spent surveying for birds;
- 51.6 hours spent conducting diurnal searches;
- 25 hours spent conducting nocturnal searches;
- 576 hours of motion camera trapping; and,
- 340 hours of bat call recording analysis.

A summary of the invertebrate fauna survey effort consisted of:

- 12 sites consisting of dry pitfall and funnel traps were open for 14 nights, totalling 5,040 trapnights;
- 51.6 hours spent actively foraging (looking through leaf litter, under bark and stones etc); and
- A total of 60 leaf litter collections (1m^2 quadrat) taken from 18 locations.

A total of nine broad-scale habitat types have been identified within the study area; 'footslope or plain', 'hilltop, hillslope, ridge or cliff', 'mixed Acacia woodland', 'mesa top', 'cracking clay', 'major gorge and gully', 'major drainage', 'mulga woodland' and 'cleared area'. No habitats recorded were regarded as rare or unique to the study area.

A one-way ANOSIM test and MDS plot of the trapping sites within the different habitat types was completed for data collected systematically for both avifauna and terrestrial trapped fauna. The results from the one-way ANOSIM test suggested a slight difference between the habitats. The results of the MDS plot did not display visually a clear difference in habitat types for both avifauna and terrestrial trapped fauna. Overall, the results from the statistical habitat assessment suggested little difference in fauna assemblages between the different habitat types within the study area. This is likely due to the presence of a number of habitat generalist species recorded at many sites and in many habitats.

A total of 23 species of native mammal, two species of introduced mammal, 80 species of bird and 64 species of reptile were recorded during this survey. No species of amphibian were recorded.

The literature review identified 21 vertebrate fauna species of conservation significance as potentially occurring; six mammal species, 12 bird species and three reptile species. A total of six conservation significant species were recorded from the current survey, additionally, four species were assessed as having a high likelihood of occurrence with a further four species assessed as having a medium likelihood of occurrence. The remaining seven species were considered to have a low likelihood of occurrence.

The six species of conservation significance recorded from the study area consisted of; Pilbara Leaf-nosed Bat (Pilbara form) (EPBC VU, WC Act S1, DEC VU), Western Pebble-mound Mouse (secondary evidence only) (DEC P4), Fork-tailed Swift (EPBC M, WC Act S3), Australian Bustard (DEC P4), Bush Stone-curlew (signs only) (DEC P4) and Pilbara Barking Gecko (DEC P1).

A total of 33 invertebrate species from six different Orders were submitted for identification and SRE status assessment. Fifteen of these species were identified as potential SREs; two species of spider, one species of scorpion, six species of isopod, four species of pseudoscorpion and two species of centipede.

Systematically obtained data was assessed to determine survey adequacy through SACs. Extrapolation of the Michaelis-Menten (MM) curve suggested that 96.1% of trappable mammals, 92.1% of trappable reptiles, 98.5% of avifauna and 71.2% of SRE fauna had been recorded, indicating that the majority of fauna was recorded in all fauna groups.

When compared with previous surveys identified during the literature review, the current assessment recorded the highest number of mammal, bird and reptile species for the region. This is likely due to the size of the study area, variety of habitat types present and survey effort expended.

No significant limitations were experienced during the assessment. Given the minimal limitations experienced during the surveys and the fact that the majority of fauna species were recorded, the current assessment is considered adequate to allow assessment of impacts from future projects.

1 INTRODUCTION

1.1 PROJECT OVERVIEW

Rio Tinto Iron Ore (Rio Tinto) required biological surveys to be undertaken, in order to support a strategic assessment of the Greater West Angelas Project (the Project). The Project includes a series of iron ore deposits in the Pilbara region of Western Australia.

Rio Tinto is currently conducting preliminary feasibility studies for the development of ore deposits C, D, D extension, G, F, H and Mt Ella, collectively termed the Greater West Angelas study area (the study area) located approximately 105 km north-west of Newman (Figure 1.1). The study area comprises three separated areas covering a total of 175.65 km^2. The study area is situated on Rio Tinto exploration leases and encompasses the borefield supplying water to West Angelas mine. No pastoral leases intersect the study area.

As part of these investigations, *ecologia* Environment (*ecologia*) was commissioned to conduct a two-phase vertebrate fauna and terrestrial invertebrate short-range endemic (SRE) assessment of the study area. This survey will provide baseline data which may be supplemented with additional studies should approval to mine deposits be sought in the future.

1.2 LEGISLATIVE FRAMEWORK

The *Environmental Protection Act 1986* (EPBC Act) is "an Act to provide for an Environmental Protection Authority, for the prevention, control and abatement of environmental pollution, for the conservation, preservation, protection, enhancement and management of the environment and for matters incidental to or connected with the foregoing." Section 4A of this Act outlines five principles that are required to be addressed to ensure that the objectives of the Act are addressed. Three of these principles are relevant to native fauna and flora:

The Precautionary Principle

> Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

The Principle of Intergenerational Equity

> The present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.

The Principle of the Conservation of Biological Diversity and Ecological Integrity

> Conservation of biological diversity and ecological integrity should be a fundamental consideration.

In addition to these principles, projects undertaken as part of the Environmental Impact Assessment (EIA) process are required to address guidelines produced by the Environmental Protection Authority (EPA), in this case Guidance Statement No. 56: *Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia* (EPA 2004), principles outlined in EPA Position Statement No. 3: *Terrestrial Biological Surveys as an Element of Biodiversity Protection*(EPA 2002) and the *Technical Guide – Terrestrial Vertebrate Fauna Surveys for Environmental Impact Assessment, Guidance Statement 20: Sampling of Short Range Endemic Invertebrate Fauna for Environmental Impact Assessment in Western Australia* (EPA 2009).

In relation to terrestrial short range endemic (SRE) fauna, the EPA Guidance Statement *No. 56* states that:

> *"Comprehensive systematic reviews of different faunal groups often reveal the presence of short range endemic species (Harvey 2002). Among the terrestrial fauna there are numerous regions that possess short range endemics. Mountainous terrains and freshwater habitats often harbour short range endemics, but the widespread aridification and forest contraction that have occurred since the Miocene has resulted in the fragmentation of populations and the evolution of many new species. Particular attention should be given to these types of species in environmental impact assessment because habitat loss and degradation will further decrease their prospects for long-term survival."*

Harvey (2002) considered that although there were occasional SREs among the vertebrates and insects, there were much higher numbers among the molluscs, earthworms, some spider groups (especially the mygalomorphae), millipedes and some groups of crustaceans. SREs generally possessed similar ecological and life history characteristics, especially poor powers of dispersal, confinement to discontinuous habitats, slow growth, and low fecundity.

The State is committed to the principles and objectives for the protection of biodiversity as outlined in *The National Strategy for the Conservation of Australia's Biological Diversity* (Commonwealth Government 1996).

Native flora and fauna in Western Australia that are formally recognised as rare, threatened with extinction, or as having high conservation value are protected at a federal level under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and at a state level under the *Wildlife Conservation Act 1950* (WC Act).

The EPBC Act also takes into consideration four international agreements related to migratory species, which include the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention), the Japan-Australian Migratory Bird Agreement, the China-Australia Migratory Bird Agreement and the Republic of Korea-Australian Migratory Bird Agreement.

The EPBC Act was developed to provide for the protection of the environment, especially those aspects of the environment that are matters of national environmental significance, to promote ecologically sustainable development through the conservation and ecologically sustainable use of natural resources, and to promote the conservation of biodiversity. The EPBC Act includes provisions to protect native species (and in particular to prevent the extinction and promote the recovery of threatened species) and to ensure the conservation of migratory species. In addition to the principles outlined in Section 4A of the EPBC Act, Section 3A of the EPBC Act includes a principle of ecologically sustainable development dictating that decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equitable considerations. Schedule 1 of the EPBC Act contains a list of species that are considered Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable and Conservation Dependent. Definitions of categories relevant to fauna occurring or potentially occurring in the project area are provided in Appendix A.

The Western Australian *Wildlife Conservation Act 1950* (WC Act) provides for the conservation and protection of wildlife in Western Australia. Under Section 14 of this Act, all flora and fauna within Western Australia is protected; however, the Minister may, via a notice published in the *Government Gazette*, declare a list of fauna identified as rare, likely to become extinct, or otherwise in need of special protection (Appendix A). These species are considered Threatened Fauna. The current listing was gazetted in September 2013.

In addition, the Department of Parks and Wildlife (DPaW – formerly DEC) maintains a ranked list of specially protected fauna, which includes Threatened Fauna and Priority Fauna. These rankings dictate which species should receive the highest priority for conservation management. Threatened fauna that are listed as Schedule 1 under the WC Act are further ranked by the DPaW according to their level of threat using IUCN Red List categories and criteria. Schedule 1 species can be ranked as Critically Endangered (CR), Endangered (EN) or Vulnerable (VU).

Priority Fauna are placed into five categories. The first three Priority Fauna categories are species that have not yet been adequately surveyed to be listed under Schedule 1 or 2, and are ranked in order of priority for survey and evaluation of conservation status so that consideration can be given to their declaration as threatened fauna. Species that are adequately known and are rare but not threatened, meet IUCN criteria for Near Threatened, or that have been recently removed from the threatened list for other than taxonomic reasons, are placed in Priority 4. These species require regular monitoring. Species meeting criteria for the IUCN category of Conservation Dependent are placed in Priority 5. The three Threatened Fauna codes and five Priority codes are also summarised in Appendix A.

Some better known SRE species have been listed as threatened or endangered under State or Commonwealth legislation in the WC Act and/or EPBC Act, but the majority have not. Often the lack of knowledge about these species precludes their consideration for listing as threatened or endangered. Listing under legislation should therefore not be the only conservation consideration in environmental impact assessment.

1.3 SURVEY OBJECTIVES

Rio Tinto commissioned *ecologia* Environment (*ecologia*) to undertake a comprehensive biological survey of the terrestrial vertebrate and invertebrate SRE fauna of the study area. This study will aid in supporting EIA of the project for future development.

The EPA's objectives with regards to fauna management are to:

- maintain the abundance, species diversity and geographical distribution of terrestrial fauna; and
- protect specially protected (Threatened) fauna, consistent with the provisions of the WC Act.

The aim of this study was to provide information to Rio Tinto and the EPA to assess the impact of the project on the fauna populations that occur in the regional areas associated with the project, thereby ensuring that these objectives will be upheld.

This report satisfies the requirements documented in relevant EPA guidelines, by providing:

- a review of background information (including literature and database searches);
- an inventory of vertebrate and invertebrate fauna species occurring in the study area, incorporating recent published and unpublished records;
- a discussion related to the species of biological and conservation significance recorded or likely to occur within the study area and the surrounding region;
- a description of fauna habitats occurring in the study area;
- a description of the characteristics of the faunal assemblage;
- an appraisal of the current knowledge base for the area, including a review of previous surveys conducted in the area that are relevant to the current study; and
- a review of regional and biogeographical significance, including the conservation status of species recorded in the study area.

1.4 BACKGROUND SUMMARY OF FAUNA GROUPS

1.4.1 Vertebrate Conservation Significant Species

Australia's vertebrate fauna, in particular mammal and bird species, have experienced a high rate of decline and extinction over the last two hundred years (Johnson 2006), with approximately thirty species of mammals and birds becoming extinct and a further 57 species of mammals, birds, reptiles, frogs and fish, many hundreds of species of invertebrate considered endangered and likely to become extinct in near future.

Changes in fire regime and the introduction of feral animals, such as the Fox and the Cat resulted in a decrease and the extinction of several species. A number of ground dwelling birds, such as the Night Parrot and the Ground Parrot, and small to medium sized mammals (Lesser Bilby and Greater Stick-nest Rat) have reduced drastically in numbers or even became extinct. With the onset of progressively more impact by human activity, already rare fauna species that are generally restricted to a particular habitat or microhabitat, are identified and protected to preserve the existing populations within their habitat.

1.4.2 Terrestrial Invertebrate Short Range Endemics

The decline in biodiversity of terrestrial communities has already been observed both nationally and state-wide (CALM 2004). There is also an increasing shift in environmental protection from species based conservation to biodiversity based conservation (Chessman 1995; Burbidge *et al.* 2000; McKenzie *et al.* 2000) and one of the important considerations involved in this is the presence of endemic species.

Endemism refers to the restriction of species to a particular area, whether it is at the continental, national or local level (Allen *et al.* 2002). This review focuses on SREs, outlines the major paths to short range endemism, the current knowledge of short range endemism in Australia and the conservation significance of such species. It is important to note that the individual taxa and broader groups discussed are not an exhaustive list of all SREs. This is due to the fact that SRE are dominated by invertebrate species, which are historically understudied and in many cases lack formal descriptions. An extensive, reliable taxonomic evaluation of these species has begun only relatively recently and thus the availability of literature relevant to SREs is relatively scarce.

1.4.3 Processes Promoting Short Range Endemism

Short range endemism is influenced by numerous processes, which generally contribute to the isolation of a species. A number of factors, including the ability and opportunity to disperse, life history, physiology, habitat requirements, habitat availability, biotic and abiotic interactions, and historical conditions, influence not only the distribution of a taxon, but also the tendency for differentiation and speciation (Ponder and Colgan 2002).

Isolated populations of plants and animals tend to differentiate both morphologically and genetically as they are influenced by different selective pressures over time. Additionally, a combination of novel mutations and genetic drift promote the accumulation of genetic differences between isolated populations. Conversely, the maintenance of genetic similarity is promoted by a lack of isolation through migration between the populations, repeated mutation and balancing selection (Wright 1943). The level of differentiation and speciation between populations is determined by the relative magnitude of these factors, with the extent of migration generally being the strongest determinant. Migration is hindered by the poor dispersal ability of the taxon as well as geographical barriers to impede dispersal. In summary, those taxa that exhibit short range endemism are generally characterised by poor dispersal, low growth rates, low fecundity and reliance on habitat types that are discontinuous (Harvey 2002).

The historical connections between habitats are also important in determining species distributions and often explain patterns that are otherwise inexplicable by current conditions. Many SREs are considered to be relictual taxa (remnants of species that have become extinct elsewhere) and are confined to certain habitats, and in some cases, single geographic areas (Main 1996). Relictual taxa include extremely old species that can be traced back to the Gondwanan periods (180-65 million years ago) and have a very restrictive biology (Harvey 2002).

In Western Australia, relictual taxa generally occur in fragmented populations, from lineages reaching back to historically wetter periods. For example, during the Miocene period (from 25 million to 13 million years ago), the aridification of Australia resulted in the contraction of many areas of moist habitat and the fragmentation of populations of fauna occurring in these areas (Hill 1994). With the onset of progressively dryer and more seasonal climatic conditions since this time, suitable habitats have become increasingly fragmented. Relictual species now generally persist in habitats characterised by permanent moisture and shade, maintained by high rainfall and/or prevalence of fog. This may be induced by topography or coastal proximity, or areas associated with freshwater courses (e.g. swamps or swampy headwaters of river systems), caves or microhabitats associated with southern slopes of hills and ranges, rocky outcrops, deep litter beds or various combinations of these features (Main 1996; Main 1999). As a result, these habitats support only small, spatially isolated populations, which are further restricted by their low dispersal powers typical for all SRE species.

1.4.4 Taxonomic Groups Likely to Support Short Range Endemism

Arachnids (Phylum: Arthropoda, Sub Class: Arachnida)

Four orders of arachnids can exhibit short range endemism: Pseudoscorpiones (false scorpions), Scorpiones (true scorpions), Schizomida (short-tailed whip spiders) and Araneae (i.e. infraorder: Mygalomorphae or trap-door spiders). Many mygalomorph trap-door spider species are vulnerable to disturbance and exhibit short range endemism due to their limited ability to disperse. These spiders also have extreme longevity and the long-term persistence of females in a single burrow (Raven 1982). Mygalomorph spiders are largely considered ‘old world’ spiders and, as such, are generally adapted to past climatic regimes making them vulnerable to desiccation in arid environments. They use a variety of behavioural techniques to avoid desiccation, the most obvious of which is their burrow, which may reach up to 70 cm in depth (Main 1982). Mygalomorph groups are thus capable of surviving on the periphery of the great central desert region and minor habitats within the general arid regions of the continent. Many mygalomorph spider species are known from the Pilbara region with representatives of the families Nemesiidae, Barychelidae, Actinopidae, Idiopidae, Dipluridae and Ctenizidae and several potential SRE mygalomorph species known from nearby locations to the study area.

Another member of the arachnid class, the Schizomida, is comprised entirely of SREs, with most recorded from single localities (Harvey 2002).Forty-six schizomid species have been described in northern Australia. Most are known to occur in the entrances to and inside caves, while the remainder occur in nearby habitats (Harvey 2002). No epigean schizomids are known from the Pilbara region (Harvey *et al.* 2008).

Scorpions and pseudoscorpions also exhibit high degrees of endemism (Koch 1981; Harvey 1996). Scorpions are popularly thought of as desert animals although they can be found in most of Australia’s climatic zones. Several SRE scorpions and pseudoscorpions are known from the Pilbara region including species from the scorpion genera *Lychas* and *Urodacus* and the pseudoscorpion species *Synsphyronus gracilis*.

Millipedes and Centipedes (Phylum Arthropoda, Class Myriapoda)

Despite millipedes being highly abundant in soil and leaf litter and highly diverse at the order level, they are inadequately studied and relatively little is known of their biogeography (Harvey 2002). SRE millipedes known to occur in the Goldfields include species from the genus *Antichiropus*. All species from this genus are known to be short range endemics with the exception of two species *Antichiropis variabilis* and *Antichiropus*'PM1', from the jarrah forests and northern Wheatbelt respectively. This genus extends from the Nullarbor Plain to the Pilbara region.

Centipedes are not listed by Harvey (2002) as SRE species; however they have been shown to be endemic to small areas on the east coast (Edgecombe *et al.* 2002). Examination of the distributions of species featured in the CSIRO centipede webpage also reveals disjunct and isolated occurrences of many species. A number of genera have Pangaean and Gondwanan affinities (Edgecombe *et al.* 2002). In general, these animals have a relatively cryptic biology, preferring moist habitats in deep litter accumulations, under rocks and in rotting logs, and they have relatively poor dispersal abilities (Lewis 1981). This suggests that they are potential candidates for designation as SREs.

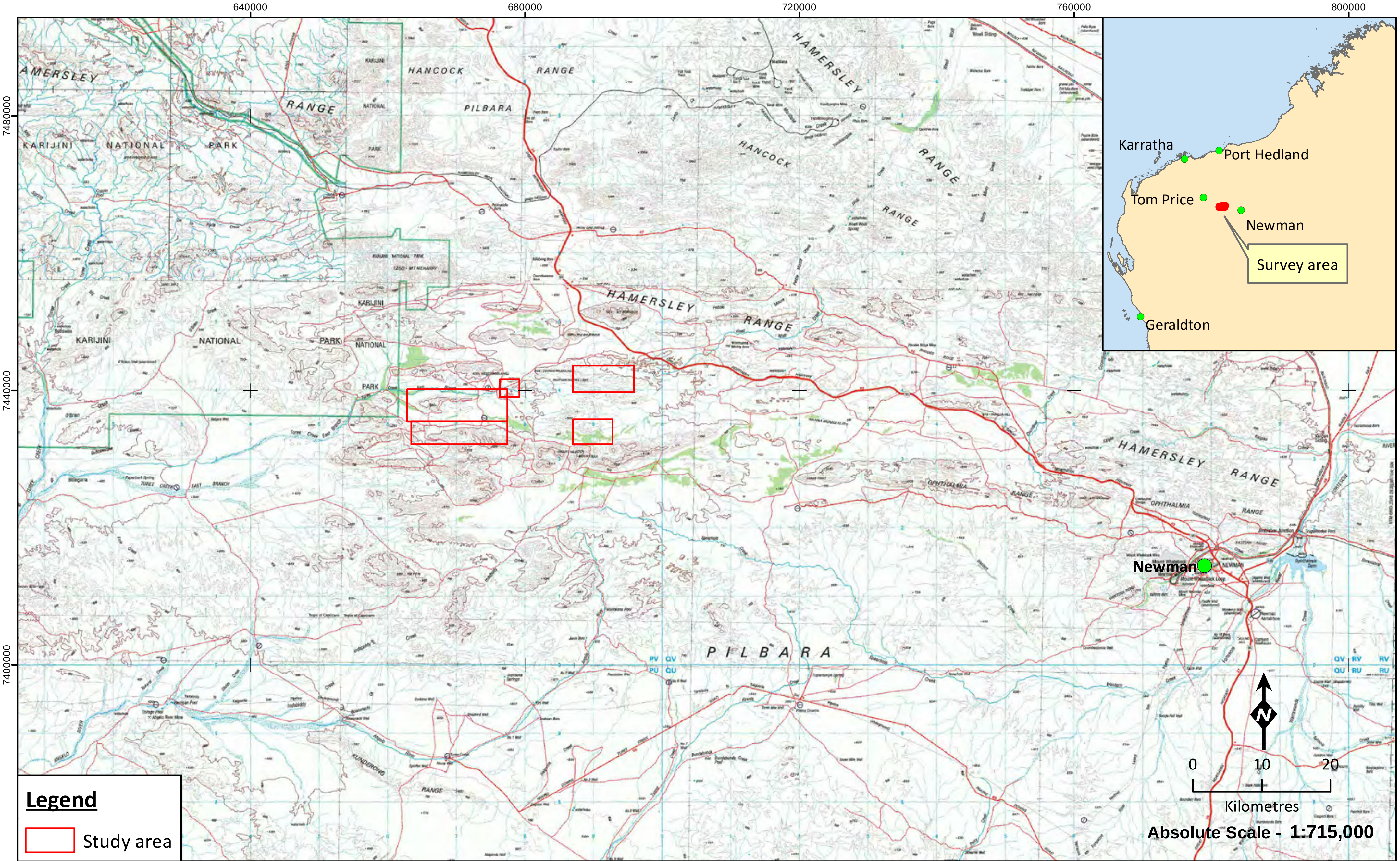
Molluscs (Phylum: Mollusca)

Numerous species of freshwater and terrestrial molluscs belonging to many genera have been identified in Australia, with most being SREs (Harvey 2002). Restricted ranges of the terrestrial molluscs of the drier northern and western Australia were noted for a vast number of species (Solem 1997). Among these were seven endemic species of *Rhagada* from the Dampier Archipelago, five of which were found to occur sympatrically on one island. However, in a recent genetic study conducted on *Rhagada* (Johnson *et al.* 2004), allozyme analysis revealed little variation between taxa. Such a finding could indicate that there is merely high morphological diversity within one or a few species. It is also possible however, that there is a number of highly endemic species and that morphological diversity has taken place rapidly with little genetic change (Johnson *et al.* 2004).

Some species of the terrestrial snail genera *Bothriembryon* are known to be SREs. Species of these genera have been recorded within the Pilbara region with some occurring in areas close to the study area.

Worms (Phylum: Annelida & Onychophora)

The taxonomic status of the earthworm family, Megascolecidae, in Western Australia was revised by Jamieson in 1971. As a result of this study, it was concluded that most of the earthworm genera are made up almost entirely of SREs (Harvey 2002). This is also the case with the velvet worms (Onychophorans). Due to several taxonomic revisions that have been conducted (see references within Harvey, 2002), the number of onychophoran species has expanded from six to over 70 species, and a number of species still remain undescribed (Harvey 2002). Very few of these species exceed ranges of 200 km^2 and some are restricted to single localities and have high genetic differentiation, indicating very little mobility and dependence on their permanently moist habitats (Harvey 2002). No terrestrial SRE worms are known from the Pilbara region.



ecologia ENVIRONMENT

Location of Study area

Figure: 1.1
Project ID: 1458

Drawn:BG
Date: 13/02/2013

Coordinate System
Name: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Unique Map ID: BG309

A4

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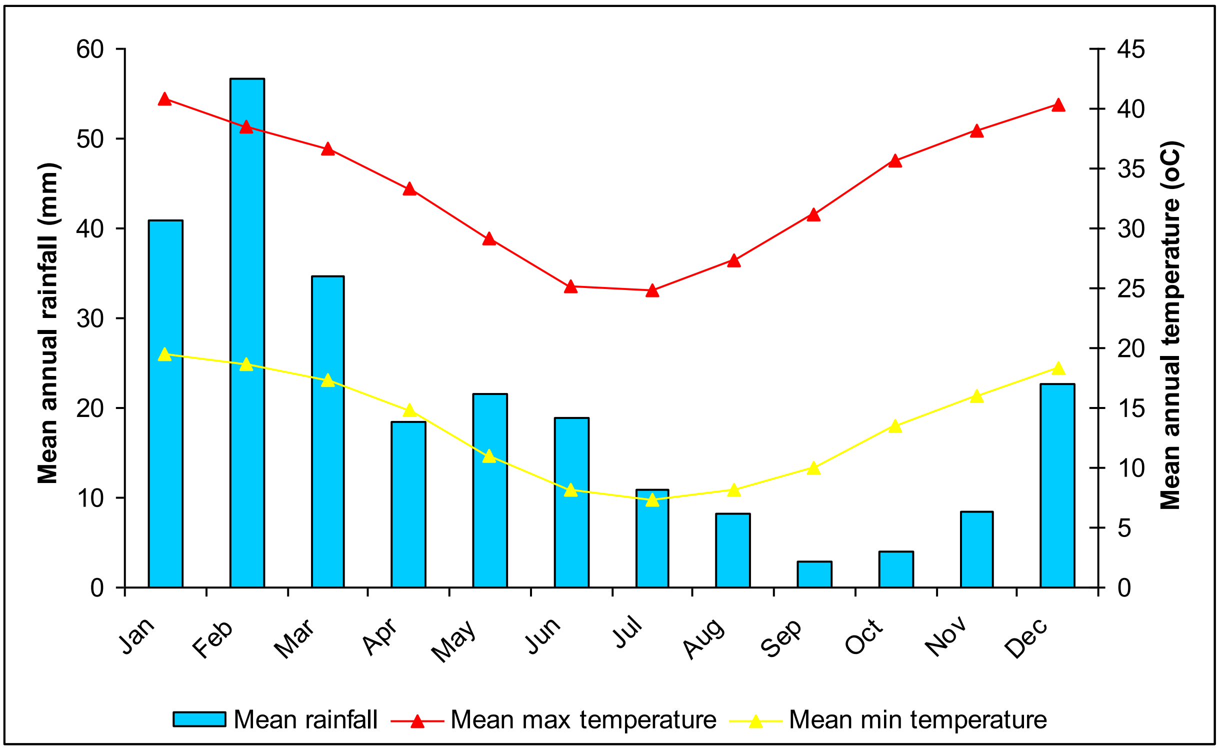
2 EXISTING ENVIRONMENT

2.1 CLIMATE AND WEATHER

The study area is located in the Pilbara region of WA. The Pilbara experiences an arid-tropical climate with two distinct seasons; a hot summer from October to April and a mild winter from May to September. Temperatures are generally high, with summer temperatures frequently exceeding 40°C. Light frosts occasionally occur inland during July and August.

Rainfall is generally localised and unpredictable (some years have recorded zero rainfall), and temperatures are high, resulting in annual evaporation exceeding rainfall by as much as 500 mm per year. The majority of the Pilbara has a bimodal rainfall distribution; from December to March rains result from tropical storms producing sporadic thunderstorms. Tropical cyclones moving south also bring heavy rains. From May to June, cold fronts move eastwards across the state and occasionally reach the Pilbara. These fronts usually produce only light rains. Surface water can be found in some pools and springs in the Pilbara all year round, although watercourses generally flow intermittently due to the short wet season (Beard 1975).

The nearest Bureau of Meteorology (BOM) station that has current temperature data is Paraburdoo Aero (Site No. 007185), 85 km west from the western boundary of the study area. Rainfall data is available from Turee Creek Station (Site No 007083) located 45.5 km south of the southern boundary of the study area. The study area location has a typical Pilbara climate of hot summers with sporadic summer storms and warm dry winters (BoM 2013). Figure 2.1 displays monthly rainfall and temperature averages with temperatures obtained from Paraburdoo Aero, rainfall obtained from Turee Creek Station.



Source: BOM (2013)

Figure 2.1 – Mean monthly climate data

An indication of weather experienced during the survey is shown in Appendix B. Phase 1 experienced typical early spring conditions, with daily maximum temperatures ranging from 28.2°C to 38.1°C (average 34.1°C) and daily minimums ranging from 11.4°C to 20.2°C (average 16.4°C). No rainfall was received during the survey.

Phase 2 experienced warmer conditions, with above average rainfall for the region experienced leading up to Phase 2. During the months of December 2012 and January 2013, a total of 185.2 mm of rain were received at Turee Creek Station (Site No 007083, (BoM 2013). No rainfall was recorded from Turee Creek Station during the survey period (Appendix B). Localised thunderstorms and associated heavy rainfall occurred on a number of days within the study area. The maximum temperature reached 43.1°C on the second day of surveying with an average of 39.6°C. The daily mimimum temperature ranged from 18.7°C to 31.4°C, averaging 24.5°C (BoM 2013, Appendix B).

2.2 BIOGEOGRAPHY

The Interim Biogeographic Regionalisation for Australia (IBRA) classifies the Australian continent into regions (bioregions) of similar geology, landform, vegetation, fauna and climate characteristics (DEWHA 2004). According to IBRA Version 7 (DSEWPaC 2012), the study area lies within the Pilbara Bioregion which comprises four subregions: Hamersley, Fortescue Plains, Chichester and Roebourne.

The study area lies within the Hamersley subregion (Figure 2.2) which in turn encompasses 6,215,092 ha of the southern section of the Pilbara Craton. It is composed of mountainous areas of Proterozoic sedimentary ranges and plateaus, dissected by gorges (basalt, shale and dolerite). General vegetation types include Mulga low woodland over bunch grasses on fine textured soils in valley floors, and *Eucalyptus leucophloia* over *Triodia brizoides* occur on the skeletal soils of the ranges. The climate is Semi-desert tropical, with an average 300 mm rainfall, usually in summer cyclonic or thunderstorm events. Winter rain is not uncommon. Drainage flows into either the Fortescue (to the north), the Ashburton to the south, or the Robe to the west (Kendrick and McKenzie 2001).

2.3 LAND SYSTEMS

The study area crosses the northern boundary of the area surveyed by Payne *et al* (1982) in the Regional Inventory of the Ashburton Rangelands and into the area surveyed by Van Vreeswyk *et al*. (2004) in the Regional Inventory of the Pilbara Rangelands. Both surveys documented the land systems present and their condition. Because the study area intersects the two regional surveys, they are discussed collectively for the purpose of the report. The Ashburton Regional Inventory (ARI) and Pilbara Regional Inventory (PRI) cover an area of approximately 275,323 km^2, encompassing the Ashburton River and Rous Creek, part of the Yannarie River catchment, as well as the coastal strip from and including Marrilla Station in the south, extending to Broome in the north-east.

Seven land systems mapped by Payne *et al* (1982) within the ARI and by Van Vreeswyk *et al*. (2004) in the PRI are present within the study area, each of which has been further classified by landform, soil, vegetation and drainage patterns. The seven land systems within the study area include Boolgeeda, Egerton, Elimunna, Newman, Platform, Rocklea and Wannamunna, with the Newman (71.4 km^2) and Boolgeeda (56.2 km^2) land systems being the most extensive. Summary descriptions of the characteristics of each land system are provided in Table 2.1, with land systems of the study area mapped in Figure 2.3.

The condition of the vegetation of each land system within the ARI and PRI has also been assessed. Regionally the majority of the area within each of these land systems has been determined to be in very good condition due to inaccessibility and lack of palatable vegetation. The Elimunna and

Wannamunna Land Systems are the exception, with only 39% and 44%, respectively characterised to be in good or very good condition. The remaining 17% has been determined to be in fair, poor or very poor condition. The condition of both land systems is due to the presence of vegetation that is attractive to grazing animals and prone to degradation if grazing pressure is excessive. The Wannamunna Land System is regionally restricted, comprising only 0.22% of the combined ARI and PRI areas surveyed by Payne *et al* (1982) and Van Vreeswyk *et al*. (2004). Within the study area it is also restricted, comprising only 0.3% of the total area. The area of each land system within the study area represents less than one percent of their individual regional distribution.

Given the aim of assessing the pastoral value of rangelands, the presence of the introduced grass **Cenchrus ciliaris* (Buffel grass) was not considered a negative indicator of condition, due to its perceived foraging value to pastoralists. However, this species is regarded as a serious environmental weed and the proportion of land systems in poor condition in an environmental context is therefore likely to be significantly higher, particularly for those land systems that support extensive stands of this species. Conversely the value of areas in which this species is not widespread is likely to be higher.

Table 2.1 – Land System information from the study area

Land System (% of study area)	Area (% of PRI and ARI combined)	Area within study area (% of Land System)	Description	Vegetation Condition Assessment	Landform (and % of Land System)	Vegetation Community
Boolgeeda (32.01%)	10337 km^2 (3.8%)	56.2 km^2 (0.54%)	Stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and mulga shrublands.	Very good 82%, good 13%, fair 4%, poor 1%. Hard spinifex grasslands not preferred by livestock.	Low hill and rises (4%)	Hummock grasslands of *T. wiseana* and other *Triodia* spp. with very scattered *Acacia* spp. shrubs.
					Stony slope and upper plain (20%)	Hummock grasslands of *T. lanigera*, *T. wiseana* or scattered tall shrublands of *A. aneura*, *A. ancistrocarpa*, *A. atkinsiana* and other *Acacia* spp., with occasional *Eucalyptus* trees.
					Stony lower plain (65%)	Hummock grasslands of *T. wiseana*, *T. lanigera* or *T. pungens*. Also scattered to moderately close tall shrublands of *A. aneura* and other *Acacia* spp. with hard and soft *Triodia* spp. ground layer.
					Grove (small drainage foci) (1%)	Moderately closed woodlands or tall shrublands of *A. aneura* with sparse low shrubs and tussock or hummock grasses.
					Narrow drainage floor and channel (10%)	Scattered to closed tall shrublands or woodlands of *A. aneura*, *A. atkinsiana* and *C. hamersleyana* with sparse low shrubs and hummock and tussock grasses. Occasionally hummock grasslands of *T. pungens*.
Egerton (2.52%)	3868 km^2 (1.40%)	4.4 km^2 (0.11%)	Dissected hardpan plains supporting mulga shrublands and hard spinifex hummock grasslands.	Very good 89%, good 11%. Vegetation not preferred by livestock.	Hardpan plains (10%)	Very scattered to scattered tall shrublands of *Acacia aneura* and other *Acacia* spp. with prominent ground layer of *Triodia* spp.
					Dissected slopes (75%)	Hummock grasslands of *Triodia brizoides*, *T. wiseana* with isolated *Acacia* shrubs and *Eucalypts*.
					Calcrete drainage margins (6%)	Hummock grasslands of *T. wiseana* with sparse *Eucalyptus socialis* trees or mallees and isolated low shrubs.
					Drainage floors and channels (9%)	Moderately close woodlands/tall shrublands of *A. aneura* with other shrubs including *Senna* spp., *Ptilotus obovatus* and *Eremophila forrestii* with *Triodia* spp. ground layer.

Land System (% of study area)	Area (% of PRI and ARI combined)	Area within study area (% of Land System)	Description	Vegetation Condition Assessment	Landform (and % of Land System)	Vegetation Community
Elimunna (1.15%)	656.6 km^2 (0.24%)	2.0 km2 (0.30%)	Stony plains on basalts supporting sparse *Acacia* and cassia shrublands and patchy tussock grasslands.	Very good 14%, good 25%, fair 35%, poor 21%., very poor, 5% Vegetation attractive to grazing animals and prone to degradation if grazing pressure is excessive.	Hills and low rises (10%)	Hummock grasslands of *Triodia wiseana* (hard spinifex) or very scattered shrublands of *Acacia* and *Senna* spp.
					Stony plains (45%)	Very scattered to scattered mixed height shrublands with *Acacia aneura* (mulga) other *Acacia*s, *Senna* spp. (cassias) and *Eremophila* spp. occasionally with patchy *Triodia* spp. (hard spinifex) understorey.
					Gilgai plains (26%)	Patchy tussock grasslands with *Eragrostis xerophila* (Roebourne Plains grass), *E. setifolia* (neverfail), *Astrebla pectinata* (barley Mitchell grass) with isolated shrubs mainly *Eremophila* and *Senna* spp.
					Hardpan plains (6%)	Very scattered tall shrublands of *A. aneura* and other *Acacia*s.
					Groves (1%)	Moderately close to close tall shrublands of *A. aneura* with numerous other shrubs and patchy perennial grasses.
					Drainage floors (12%)	Tussock grasslands with *Astrebla* and *Eragrostis* spp. Or very scattered to moderately close tall shrublands of *Acacia* spp. With various low shrubs and patchy tussock and/or hummock grasses.
Newman (40.66%)	21109 km^2 (7.7%)	71.4 km^2 (0.34%)	Rugged jaspilite plateaux, ridges and mountains supporting hard.	Very good 91%, good 7%, fair 1%, poor 1%. Inaccessible or poorly accessible and is unsuitable for pastoral purposes.	Plateaux, ridges, mountains and hills (70%)	Hummock grasslands of *Triodia wiseana*, *T. brizoides*, *T. plurinervata* with very scattered to scattered shrubs and trees including *Acacia* and *Senna* spp., *Grevillea wickhamii*, *Eucalyptus leucophloia* and other eucalypts. Occasionally hummock grass is *Triodia biflora*.
					Lower slopes (20%)	Similar to the vegetation community above.
					Stony plains (5%)	Hummock grasslands of *Triodia wiseana*, *T.* spp. (hard spinifex) with isolated to very scattered shrubs of *Acacia* and *Senna* spp. And occasional eucalypt trees. Occasionally hummock grasslands of *Triodia pungens* (soft spinifex).
					Narrow drainage floors with channels (5%)	Smaller floors support hummock grassland of *Triodia pungens* with very scattered shrubs. Larger floors and channel support tall shrublands/woodlands of *Acacia* spp. And *Eucalyptus victrix* with tussock grass or hummock grass understoreys.

Land System (% of study area)	Area (% of PRI and ARI combined)	Area within study area (% of Land System)	Description	Vegetation Condition Assessment	Landform (and % of Land System)	Vegetation Community
Platform (9.75%)	2552 km^2 (0.9%)	17.1 km^2 (0.67%)	Dissected slopes and raised plains supporting hard spinifex grasslands.	Very good 97%, good 3%. Vegetation on this system is not preferred by livestock and is of Very little use for pastoralism. The system is not susceptible to erosion.	Stony upper plains (25%)	Hummock grasslands of *Triodia wiseana* and other *Triodia* spp. (hard Spinifex) with isolated to very scattered *Acacia* spp. Shrubs
					Dissected slopes (60%)	Hummock grasslands of *Triodia wiseana*, *T. plurinervata* (hard Spinifex) with isolated to very scattered *Acacia* spp. Shrubs or *Eucalyptus leucophloia* (snappy gum)
					Drainage floors (15%)	Scattered to close tall shrublands/woodlands with *Acacia citrinoviridis* (black mulga), *A. tumida* (pindan wattle) and other *Acacia*s, occasional eucalypt trees, numerous low shrubs including *Senna* spp. (cassias), *Ptilotus obovatus* (cotton bush), *Corchorus walcottii* (grey Corchorus) and *Triodia pungens* (soft spinifex)
Rocklea (13.89%)	31089 km^2 (11.3%)	24.4 km^2 (0.08%)	Basalt hills, plateaux, lowers slopes and minor stony plains supporting hard spinifex (and occasionally soft spinifex) grasslands.	Very good 89%, good 7%, fair 2%, poor 2% Spinifex grasslands inaccessible and not preferred by livestock.	Hills, ridges, plateaux and upper slopes (65%)	Hummock grasslands of *T. wiseana*, *Triodia* spp. Or less frequently, of *T. pungens* with isolated to very scattered shrubs such as *A. inaequilatera* and *Senna* spp.
					Lower slopes (15%)	Hummock grasslands of *T. wiseana*, *Triodia* spp. Or less frequently, of *T. pungens* with isolated to very scattered shrubs such as *A. inaequilatera* and *Senna* spp.
					Stony plains and interfluves (10%)	Hummock grasslands of *T. wiseana* or less frequently *T. pungens* with isolated to very scattered shrubs such as *A. inaequilatera*. Occasionally grassy shrublands with *Acacia*, *Senna* and *Eremophila* spp.
					Gilgai plains (1%)	Tussock grasslands with *Astrebla pectinata*, *E. xerophila* and other perennial grasses.
					Upper drainage lines (4%)	Hummock grasslands of *T. wiseana* or *T. pungens* with very scattered to scattered *Acacia* shrubs and occasional *C. hamersleyana* trees.
					Drainage floors and channels (5%)	Scattered to moderately close tall shrublands or woodlands of *Acacia* and *Eucalyptus* spp. With numerous undershrubs and hummock grass understoreys or tussock grass understoreys.

2.4 VEGETATION

The vegetation of Western Australia was originally mapped at the 1:1,000,000 scale by Beard (1979), and was subsequently reinterpreted and updated to reflect the National Vegetation Information System standards (Shepherd *et al.* 2002). The study area lies within the Eremaean Botanical Province (Beard 1975). Two vegetation associations occur in the study area (Shepherd *et al.* 2001), and are described in Table 2.2 and displayed in Figure 2.4.

Table 2.2 – Vegetation associations of the study area

Shepherd Unit	Structure	Vegetation Description	Species	Area within the study area (km^2)	Percentage of the study area (%)
18	Low woodland; mulga (*Acacia aneura*)	*Acacia* open shrubland / *Ptilotus* mixed open forbland	*Acacia aneura*, *Acacia pruinocarpa*, *Acacia aneura* var. *Aneura, Eremophila fraseri*, *Eremophila foliosissima*, *Eremophila exilifolia, Senna* sp., *Solanum lasiophyllum*, *Ptilotus obovatus*.	89.5	51
82	Open hummock grassland	Hummock grasslands, low tree steppe; snappy gum over *Triodia wiseana*	*Eucalyptus leucophloia*, *Eucalyptus gamophylla*, *Senna artemisioides subsp.* x *sturtii*, *Dodonaea viscosa*, *Grevillea wickhamii*, *Triodia wiseana*, *Ptilotus rotundifolius*, *Acacia lycopodiifolia* and *Triodia wiseana*.	86.2	49

2.5 GEOLOGY

The majority of the Pilbara is composed of the granite terrain of the Pilbara Block in the north with the rugged sedimentary Hamersley Basin in the south and the sedimentary rocks overlain by Aeolian sands of the Canning Basin to the east. Drainage is mostly via major river catchments of the De Grey, Turner and Yule rivers in the north, and the Fortescue and Robe rivers in the west. All rivers are exoreic (i.e. flow into the ocean) with the exception of Savory Creek, which drains eastwards into Lake Disappointment (Van Vreeswyk *et al.* 2004). The geological stratigraphy in the Pilbara region of WA is relatively continuous, with similar geological processes occurring across the region, resulting in the enrichment of the iron deposits.

The main source of the magnetic mineralization in the Pilbara is the Pincunah Formation, which is one of the prominent Banded Ironstone Formations (BIF) within the greenstone belts of the Pilbara Craton. The study area is intersected by three different geological formations: Mafic volcanics, Sedimentary Rocks and Dolerites and gabbros from the Archaean to Palaeoproterozoic era. The study area and local geology is presented in Figure 2.5. Definitions of the geological unit codes are provided in Table 2.3 (Hickman and Kranendonk 2008). Geology of the study area comprises 12.4% mafic volcanics, 66.4% sedimentary rock and 21.1% dolerites and gabbros geological units (Hickman and Kranendonk 2008).

Table 2.3 – Geology of the study area

Geological Code	Lith Association	Area within study area (km^2)	Definition of code
A4 - -Pp	Mafic volcanics	21.7	Archaean period
A3b	Sedimentary rocks	116.9	Archaean – palaeoproterozoic period
A2d	Dolerites and gabbros	37.0	Archaean period

2.6 SOILS

Twenty-one broad soil groups have been identified by Van Vreeswyk *et al*. (2004) as part of their study defining land systems within the Pilbara. Soils are predominantly red and shallow with stony mantles.

The most extensive soils in the Pilbara are shallow, stony soils on hills and ranges and sands on sandplains. In the south, the soils are predominantly red earths overlying hardpan on level to gently inclined plains. Lower flood plains have cracking and non-cracking clay soils. Duplex (texture-contrast) soils occur in localised areas on saline alluvial plains and elsewhere. These soils support the most preferentially grazed vegetation and are highly susceptible to erosion (Van Vreeswyk *et al.* 2004).

Within the study area, three soil units as classified by Bettenay *et al.* occur (Figure 2.6). These units are described below:

Fa13: Ranges of banded jaspilite and chert along with shales, dolomites, and iron ore formations; some areas of ferruginous duricrust as well as occasional narrow winding valley plains and steeply dissected pediments. This unit is largely associated with the Hamersley and Ophthalmia Ranges. The soils are frequently stony and shallow and there are extensive areas without soil cover: chief soils are shallow stony earthy loams (Um5.51) along with some soils on the steeper slopes (Uc5.11). Associated are soils on the limited areas of dissected pediments, while (Um5.52) and (Uf6.71) soils occur on the valley plains;

Fa14: Steep hills and steeply dissected pediments on areas of banded jaspilite and chert along with shales, dolomite, and iron ore formations; some narrow winding valley plains: chief soils are shallow stony earthy loams (Um5.51) along with some (Uc5.11) soils on the steeper slopes. (Dr2.33 and Dr2.32) soils whish occur on the pediments are more extensive than unit Fa13, while (Um5.52) and (Uf6.71) soils occur on the valley plains; and

Fb3: High-level valley plains set in extensive areas of unit Fa13. There are extensive areas of pisolitic limonite deposits: principal soils are deep earthy loams (Um5.52) along with small areas of Gn2.12) soils.

2.7 LITERATURE REVIEW

Several databases were consulted in the preparation of potential fauna (and conservation significant fauna) lists (Table 2.4). In addition, ecologia has conducted 18 surveys within 70 km of the study area, with a further eight publications, reporting on fauna surveys conducted in the same region, also consulted (Table 2.5). The location of previous surveys in relation to the study area is shown in Figure 2.7. The results of database searches and previous surveys for vertebrate and SRE fauna are presented in Appendix E. The online NatureMap database encompasses several datasets which include the WA Museum (WAM), DEC threatened fauna database and DEC survey return database.

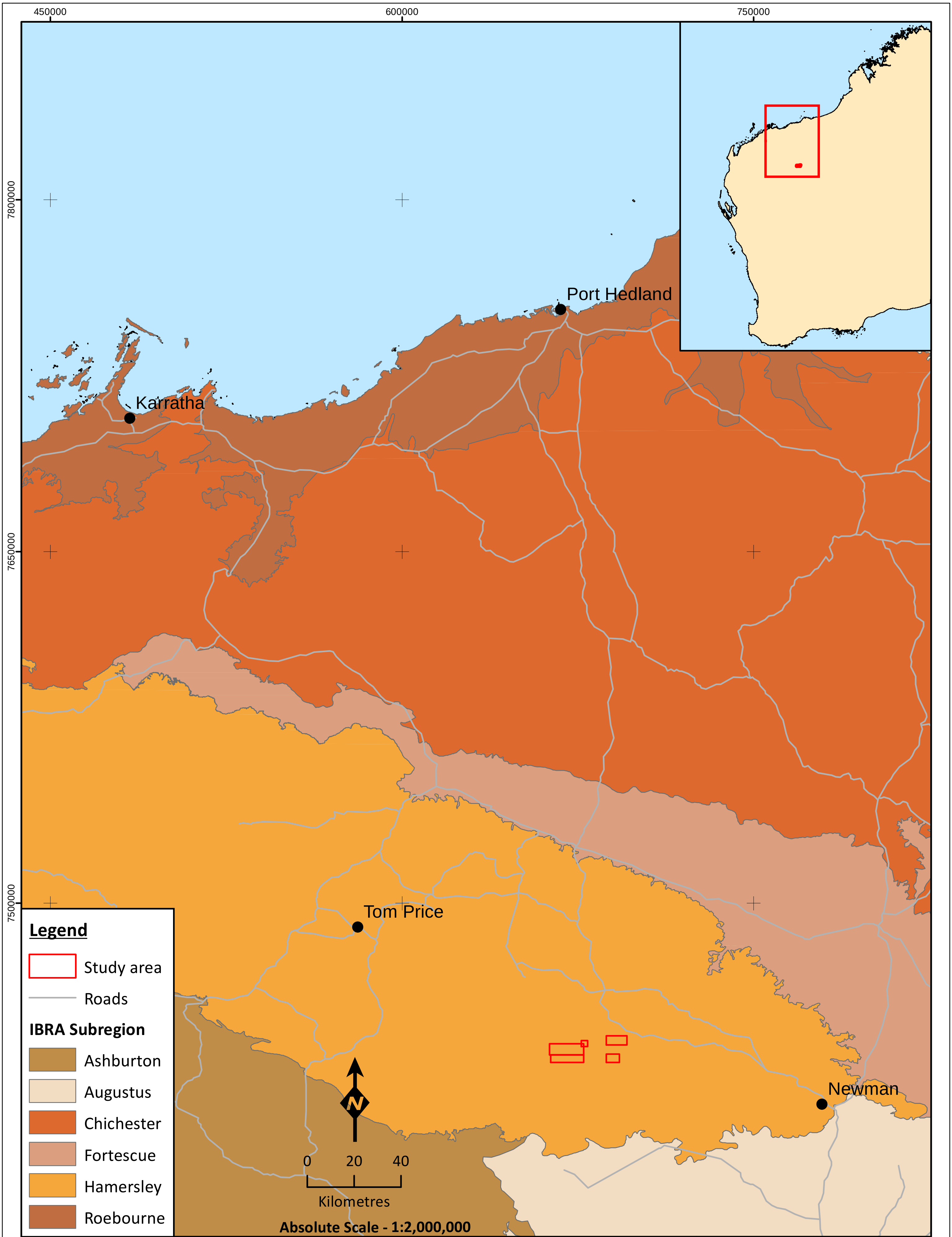
The literature review has revealed that the potential vertebrate fauna assemblage consists of a total of 38 native and nine introduced mammal species, 129 bird species, 103 reptile species and eight amphibian species have the potential to occur within the study area (Appendix F). Of these potential species, six mammal species, 12 bird species and three reptile species are listed as conservation significant. These are discussed in detail in section 5.3. The literature review revealed 32 SRE species have been previously recorded in the region (Appendix F).

Table 2.4 – Fauna databases searched to determine the potential vertebrate fauna assemblage

Database	Custodian	Search Details
NatureMap	DEC	Records within 40 km of study area
Threatened fauna search	DEC	Records within 40 km of study area
Protected Matters Search Tool	Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC)	Records within 40 km of study area
Birdata	BirdLife Australia	Records within 100 km of the study area
Arachnid database	WAM	Records within 50 km of study area
Crustacea database	WAM	Records within 50 km of study area
Molluscs database	WAM	Records within 50 km of study area

Table 2.5 – Previous biological survey reports within 70 km of the study area

Survey Location and Author(s)	Distance to Project Area (km)	Comments
Vertebrate fauna		
ecologia internal database	0 – 50	Total of 14 surveys consisting of seven Level 2 surveys and seven Level 1 surveys
A vertebrate fauna survey of the proposed Hope Downs 4 Option 6 infrastructure corridor (Ninox 2009b)	30	Level 2 survey
Vertebrate fauna of the northern transport corridor option (Ninox 1995)	35	Level 1 survey
Marillana Creek Western Access Corridor - Biological Assessment (HGM 1999b)	35	Level 1 survey
Marillana Creek Iron Ore Project - Review of Biological Reporting (HGM 1999a)	45	Level 1 survey
Yandi Life of Mine Flora and Fauna (Maunsell 2003)	45	Level 1 survey
A fauna survey of the proposed Hope Downs 4 mining area (Ninox 2009a)	65	Level 2 survey
Vertebrate fauna of the proposed Junction Deposit mine and the central Pilbara transport corridor (Ninox 1994)	50	Level 1 survey
Yandicoogina Junction South West and Oxbow Fauna Survey (Biota 2010)	50	Level 2 survey
Invertebrate fauna		
ecologia internal database	30 - 70	Total of four surveys
Yandicoogina Junction South West and Oxbow Fauna Survey (Biota 2010)	50	Pitfall traps and foraging
A fauna survey of the proposed Hope Downs 4 mining area (Ninox 2009a)	65	Foraging and leaf litter sorting



ecologia ENVIRONMENT

IBRA sub-regions of the study area

Figure: 2.2
Project ID: 1458

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Date:13/02/2013

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Projection: Transverse Mercator
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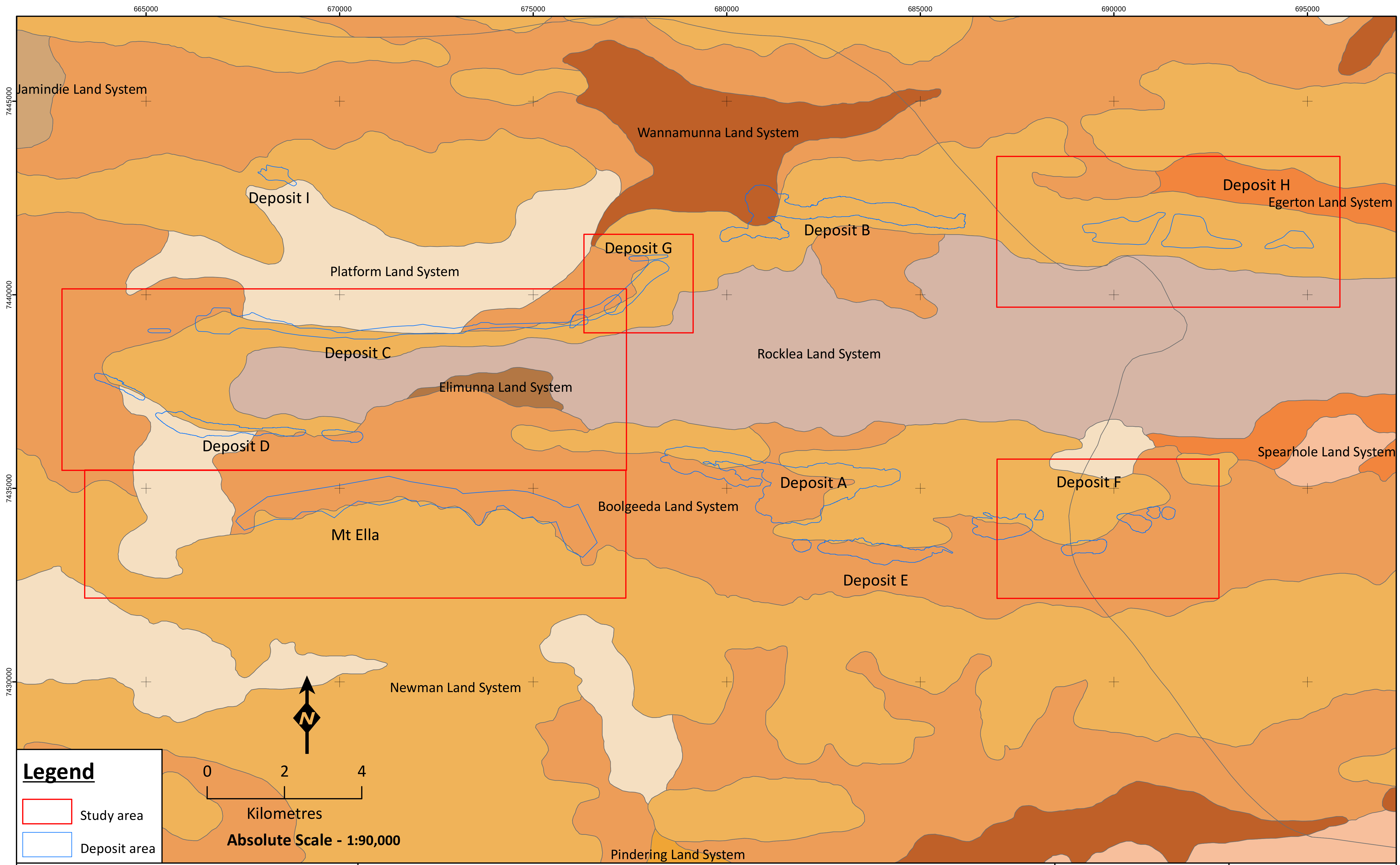

Landsystems of the study area

Figure: 2.3
Project ID: 1458

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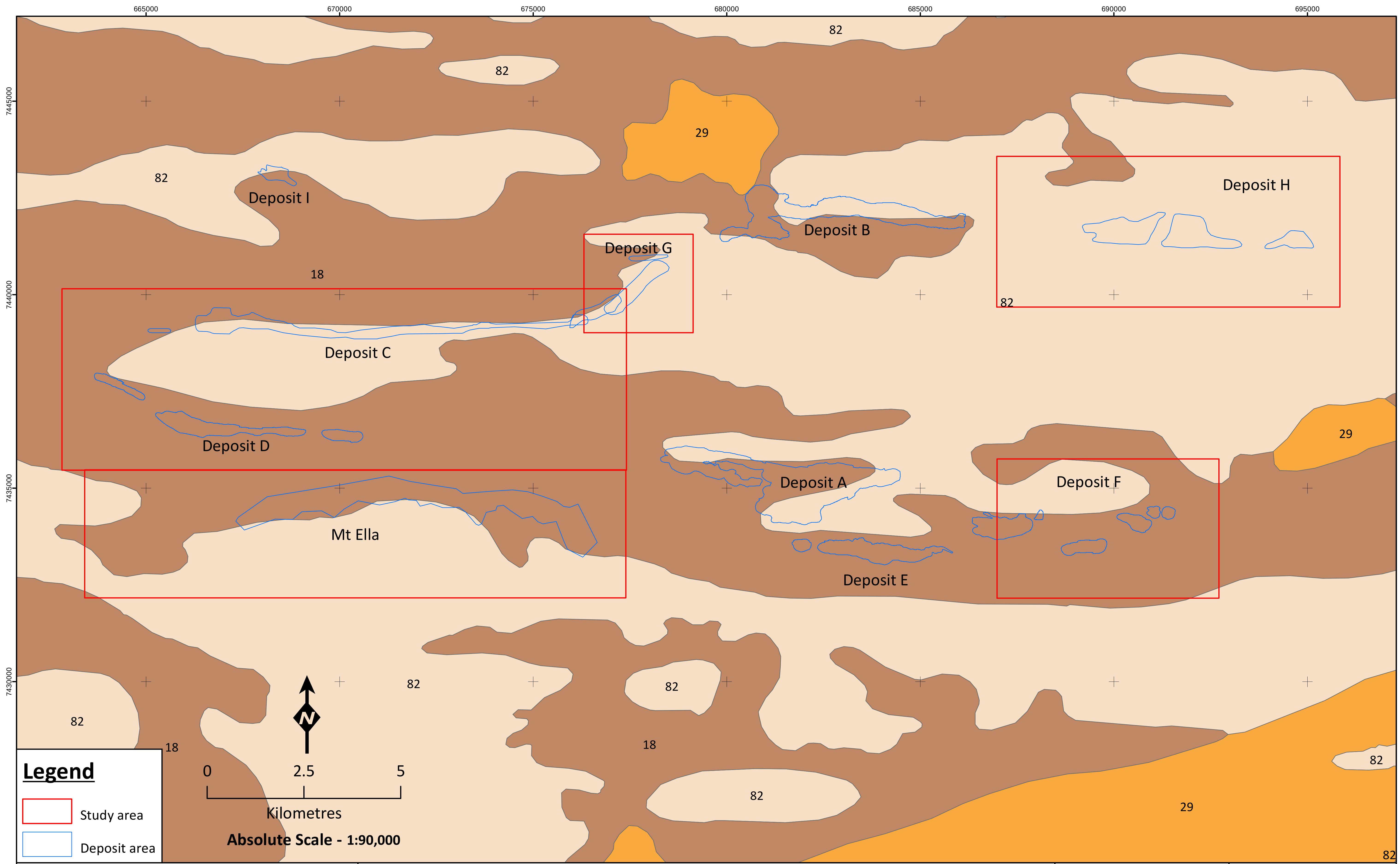

ecologia ENVIRONMENT

Vegetation units of the study area

Figure: 2.4
Project ID: 1458

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Date: 12/2/2013

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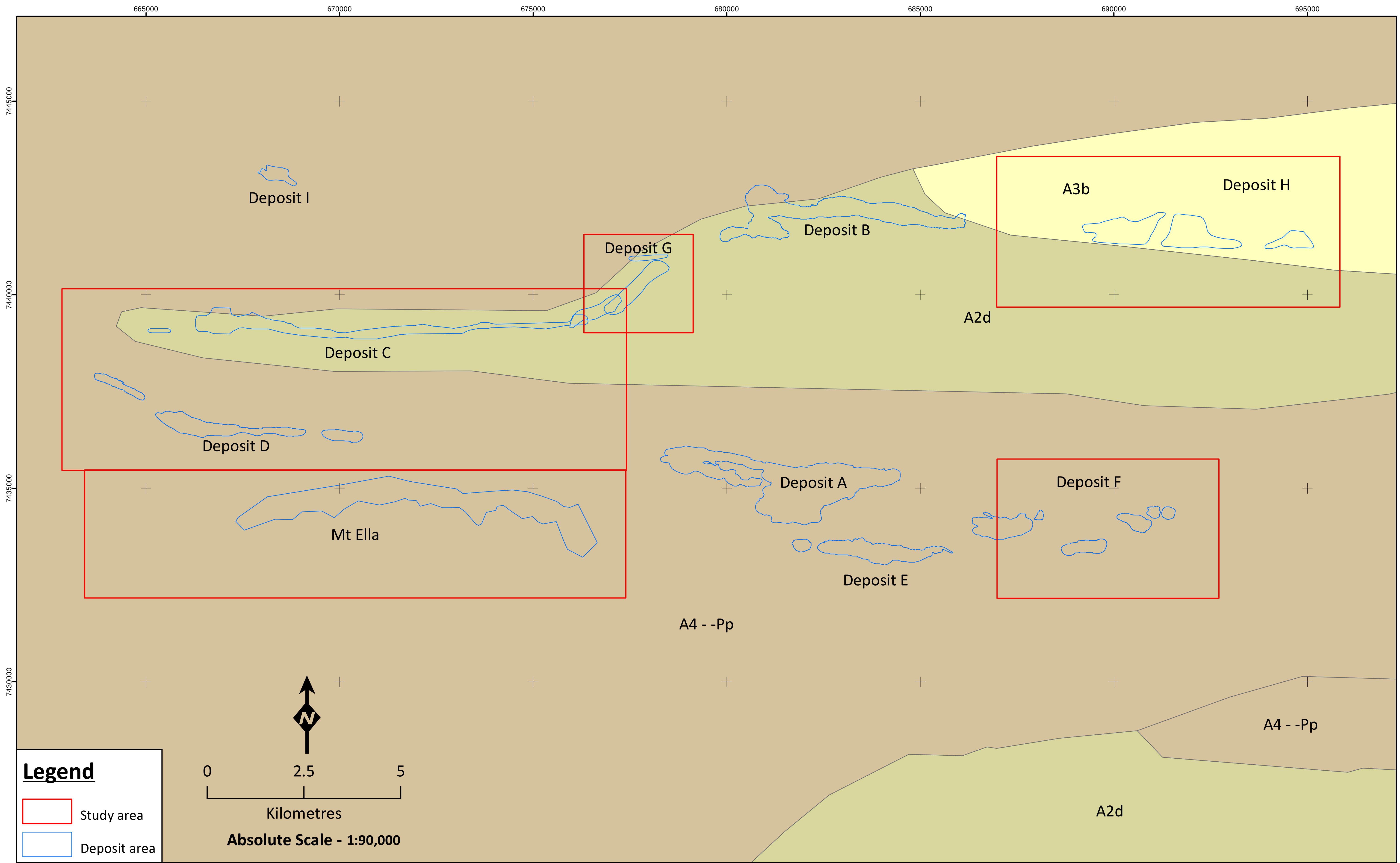

Geology of the study area

Figure: 2.5
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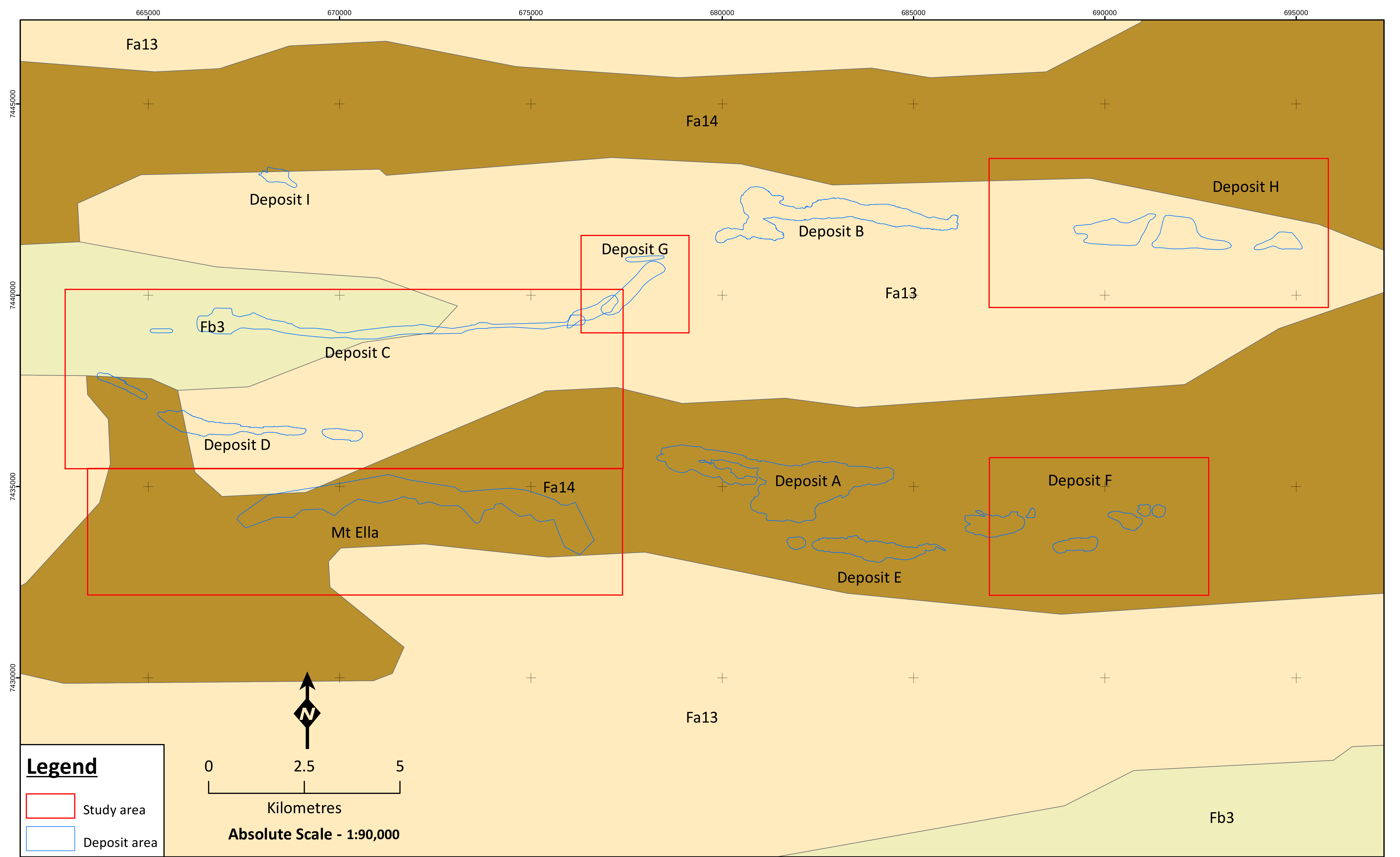

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Soils of the study area

Figure: 2.6
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ecologia ENVIRONMENT

Previous survey locations

Figure: 2.7
Project ID: 1458

Drawn: BG
Date: 26/2/2013

Coordinate System
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Unique Map ID: BG287

A3

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3 METHODOLOGY

3.1 DETERMINATION OF SURVEY SAMPLING DESIGN AND INTENSITY

Prior to the development of field survey methodologies, a review was undertaken of factors likely to influence survey design and intensity (EPA 2004) (Table 3.1). Based on this review, it was deemed necessary for a Level 2 survey to be conducted within the study area.

Table 3.1 – Factors likely to influence survey design

Factor	Relevance
Bioregion – level of existing survey-knowledge of the region and associated ability to predict accurately.	A sound level of previous survey effort and knowledge exists. A total of 26 previous surveys within 70 km have been reviewed. The Hamersley sub-region of the Pilbara has been relatively well studied.
Landform special characteristics/specific fauna/specific context of the landform characteristics and their distribution and rarity in the region.	The study area lies within the Hamersley sub-region and contains typical habitat of the surrounding region. A large area of Mulga woodland habitat type occurs in the south-east of the study area.
Lifeforms, life cycles, types of assemblages and seasonality (e.g. migration) of species likely to be present.	A two-phase survey during spring and autumn with survey timing consistent with survey guidelines.
Level of existing knowledge and results of previous regional sampling (e.g. species accumulation curves, species/area curves).	A large number of previous surveys in the region, with a total of 26 previous surveys within 70 km have been reviewed.
Number of different habitats or degree of similarity between habitats within a study area.	Nine broad-scale habitats have been assessed as occurring within the study area. The Cracking Clay habitat associated with Elimunna landsystem is a restricted habitat type of the region. All other habitats occur broadly in the surrounding region. The Mulga woodland habitat is of high quality.
Climatic constraints (e.g. temperature or rainfall that preclude certain sampling methods).	Climatic conditions were typical for the time of year.
Sensitivity of the environment to the proposed activities.	The Cracking Clay habitat associated with Elimunna landsystem has been previously assessed as environmentally sensitive to degradation. The Mulga woodland habitat is of high quality. Other habitats are widespread in the surrounding region.
Size, shape and location of the proposed activities.	The study area comprises three separated areas covering a total of 175.65 km^2
Scale and impact of the proposal.	Not applicable as no assessment can be made at this stage as no defined impact areas are determined as yet.

3.2 SURVEY TIMING

The two phase Level 2 survey was conducted during spring 2012 and autumn 2013 (Table 3.2). Survey timing was determined as per guidelines (EPA 2004; EPA and DEC 2010).

Table 3.2 – Summary of survey timing and duration

Survey	Timing	Duration (days)	Person Days
Phase 1	26/09/2012 – 06/10/2012	11	74
Phase 2	18/03/2013 – 27/03/2013	10	60
Total		**21**	**134**

3.3 SITE SELECTION

Terrestrial fauna survey sites were selected to provide a good geographic spread over the study area and to be representative of the habitat types in the study area, with location of currently identified deposits taken into consideration. Habitat types occurring over a larger proportion of the study area were sampled using a larger number of trapping sites than less represented habitat types. Habitat types poorly represented by systematic sampling sites were further surveyed using opportunistic searches, targeting potentially sensitive habitats and habitats likely to support conservation significant species. Locations and details of all fauna survey sites are listed in Table 3.3 and mapped in Figure 3.1.

Descriptions and photographs of the systematic fauna trapping sites can be found in Appendix C.

Table 3.3 – Survey site locations

Site	Location	
	Easting	Northing
Systematic trap site		
GWA S1	690650	7441655
GWA S2	691892	7441631
GWA S3	687325	7432923
GWA S4	690271	7434157
GWA S5	675012	7434694
GWA S6	668071	7434246
GWA S7	666240	7436475
GWA S8	673177	7437814
GWA S9	688109	7440440
GWA S10	671504	7435248
GWA S11	673158	7438238
GWA S12	667740	7439331
Opportunistic search site		
GWA Opp S1	666513	7436849
GWA Opp S2	672777	7433992
GWA Opp S3	668377	7434089
GWA Opp S4	673142	7439083
GWA Opp S5	666358	7432530
GWA Opp S6	672027	7439426
GWA Opp S7	673911	7433876
GWA Opp S8	687382	7434157
GWA Opp S9	690830	7441558
GWA Opp S10	690386	7434554
GWA Opp S11	662985	7439744
GWA Opp S12	669725	7439306
GWA Opp S13	688095	7440343
GWA Opp S14	672883	7439043
GWA Opp S15	689013	7434085
GWA Opp S16	669913	7434817
GWA Opp S17	673195	7439118

Site	Location	
	Easting	**Northing**
GWA Opp S18	691928	7441786
GWA Opp S19	686882	7434209
GWA Opp S20	686848	7434423
GWA Opp S21	687482	7434412
GWA Opp S22	677757	7440130
GWA Opp S23	668089	7434460
GWA Opp S24	690500	7441055
Targeted SRE leaf litter collection site		
Forage Site 1	677545	7440245
Forage Site 2	688983	7433331
Forage Site 3	670572	7438925
Forage Site 4	663923	7437791
Forage Site 5	687086	7434227
Forage Site 6	689590	7433600
Forage Site 7	689663	7441394
Forage Site 8	693088	7441312

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Zone: 50

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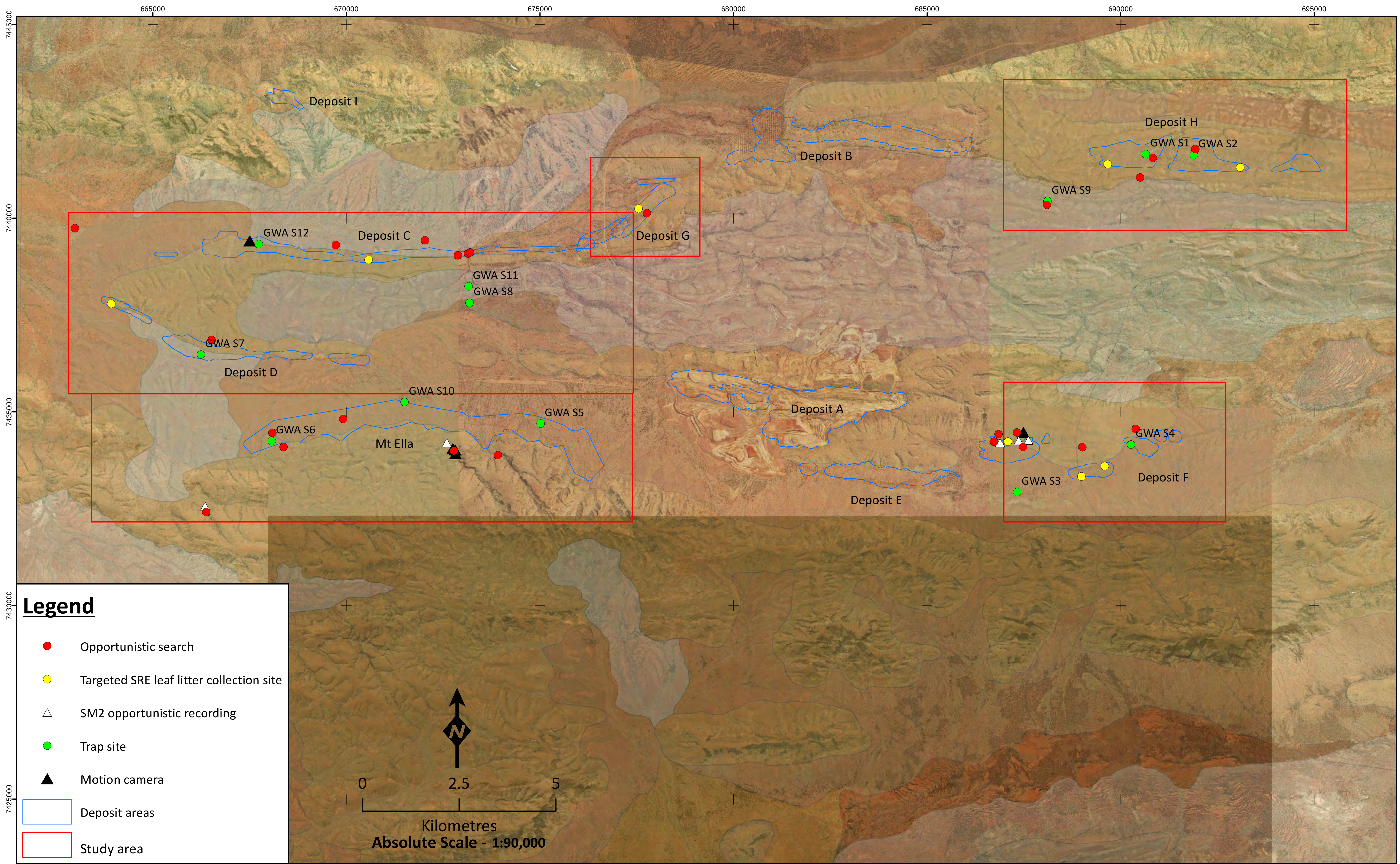

Location of fauna sites

Figure: 3.1
Project ID: 1458

Drawn: BG
Date: 24/9/2013

Coordinate System
Name: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

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3.4 POTENTIAL CONSERVATION SIGNIFICANT VERTEBRATE FAUNA

After the results of the literature review, database searches and survey results were compiled, fauna species that are listed under current legislative frameworks were identified. Three conservation lists have been developed at national (EPBC Act) and state level (WC Act and DPaW priority list).

The likelihood of a conservation significant species being present within the study area was determined by examining the following:

- fauna habitats and their condition known to exist within the study area;
- distance of previously recorded conservation significant species from the study area;
- frequency of occurrence of conservation significant species records in the region; and
- time passed since conservation significant species were recorded within, or surrounding, the study area.

Each conservation or biologically significant species potentially occurring in the study area, was assigned a likelihood of occurrence based on the below category (Table 3.4). The level of available information for each species was also taken into consideration so that species are not allocated a low likelihood of occurrence because of insufficient survey information or cryptic behaviours and ecology.

Table 3.4 – Likelihood of occurrence categories

RECORDED	Species recorded during current survey
HIGH	Species recorded within, or in proximity to, the study area within 20 years; suitable habitat occurs in the study area
MEDIUM	Species recorded within, or in proximity to, the study area more than 20 years ago. Species recorded outside study area, but within 50 km; suitable habitat occurs in the study area
LOW	Species rarely, or not recorded, within 50 km, and/or suitable habitat does not occur in the study area

3.5 SRE STATUS

SRE status is based on the newly released 2013 WAM SRE categories which have been developed to describe the SRE status of WA taxa using: (a) unambiguous categories; and (b) explanations of uncertainty. This has been accomplished using a two-tier classification system. In the first tier of classification, geographic distribution and taxonomic certainty are the variables used to split taxa into "Confirmed SREs", "Widespread (not SREs)", and "Potential SREs". In the second tier of classification, "Potential SREs" are categorised according to the reasons they have been placed into this category and the presence of proxy-indicators for Confirmed SRE or Widespread status (Table 3.5).

Table 3.5 – Western Australian Museum SRE categories (2013)

<table>
<tr><th></th><th>Taxonomic Certainty</th><th>Taxonomic Uncertainty</th></tr>
<tr><td>Distribution < 10 000km^2</td><td>Confirmed SRE
A known distribution of <10 00km^2.
The taxonomy is well known.
The group is well represented in collections and/ or via comprehensive sampling.</td><td rowspan="2">Potential SRE
Patchy sampling has resulted in incomplete knowledge of the geographic distribution of the group.
We have incomplete taxonomic knowledge.
The group is not well represented in collections.
This category is most applicable to situations where there are gaps in our knowledge of the taxon.
Sub-categories for this SRE designation are outlined below</td></tr>
<tr><td>Distribution > 10 000km^2</td><td>Widespread (not an SRE)
A known distribution of >10 000km^2.
The taxonomy is well known.
The group is well represented in collections and/ or via comprehensive sampling.</td></tr>
</table>

SRE SUB-CATEGORIES

If a taxon is determined to be a “Potential SRE”, the following sub-categories will further elucidate this status.

A. Data Deficient:

- There is insufficient data available to determine SRE status.
- Factors that fall under this category include:
    - Lack of geographic information
    - Lack of taxonomic information
    - The group may be poorly represented in collections
    - The individuals sampled (e.g. juveniles) may prevent identification to species level.

B. Habitat Indicators:

- It is becoming increasingly clear that habitat data can elucidate SRE status.
- Where habitat is known to be associated with SRE taxa and vice versa, it will be noted here.

C. Morphology Indicators:

- A suite of morphological characters are characteristic of SRE taxa.
- Where morphological characters are known to be associated with SRE taxa and vice- versa, it will be noted here.

D. Molecular Evidence:

- If molecular work has been done on this taxon (or a close relative), it may reveal patterns congruent or incongruent with SRE status.

E. Research & Expertise:

- Previous research and/or WAM expertise elucidates taxon SRE status.
- This category takes into account the expert knowledge held within the WAM taxonomy and nomenclature

All Likely, Potential and Unknown SREs should be treated as Confirmed SREs in accordance with the precautionary principle (Section 4A of the EP Act).

3.6 SAMPLING METHODS

The survey methods adopted by *ecologia* were aligned with relevant guidelines as identified in Section 1.2.

The survey was undertaken using a variety of sampling techniques, both systematic and opportunistic. Systematic sampling refers to data methodically collected over a fixed time period in a discrete habitat type, using an equal or standardised sampling effort. The resulting information can be analysed statistically, facilitating comparisons. Opportunistic sampling includes data collected non-systematically from both fixed sampling sites and as opportunistic records from chance encounters with fauna.

3.6.1 Systematic Sampling

3.6.1.1 Terrestrial Mammals, Herpetofauna and Invertebrates

Trapping for terrestrial mammals, herpetofauna and invertebrates was undertaken using a standardised trapping format comprising a combination of pit-fall traps, Elliott box traps, funnel traps and cage traps.

Each trapping site consisted of the following (Figure 3.2):

- Pit-trap and drift fence: Five PVC pipe (16 x 50 cm) and five 20 L plastic buckets (30 x 40 cm) were established at each site. A 10 metre flywire drift fence (30 cm high) bisected the pits, directing fauna into the traps.
- Elliott box traps: Ten medium sized Elliott box traps (9 x 9 x 32 cm) were placed at each site, and baited with Universal Bait (a mixture of peanut butter, rolled oats and sardines). Each Elliott trap was placed between the pit trap setups. Elliott traps were shaded using Air Cell roof insulation.
- Funnel traps: Funnel traps (Ecosystematica Type III) were placed in association with drift fences. Twenty funnel traps were used per site, with a trap being placed at each end of the drift fence. Funnel traps were shaded using Air Cell roof insulation.
- Cage traps: Two Sheffield small animal traps (22 cm x 22 cm x 55 cm) were used per site with one trap placed at each end of the trap line. Traps were baited with Universal Bait.

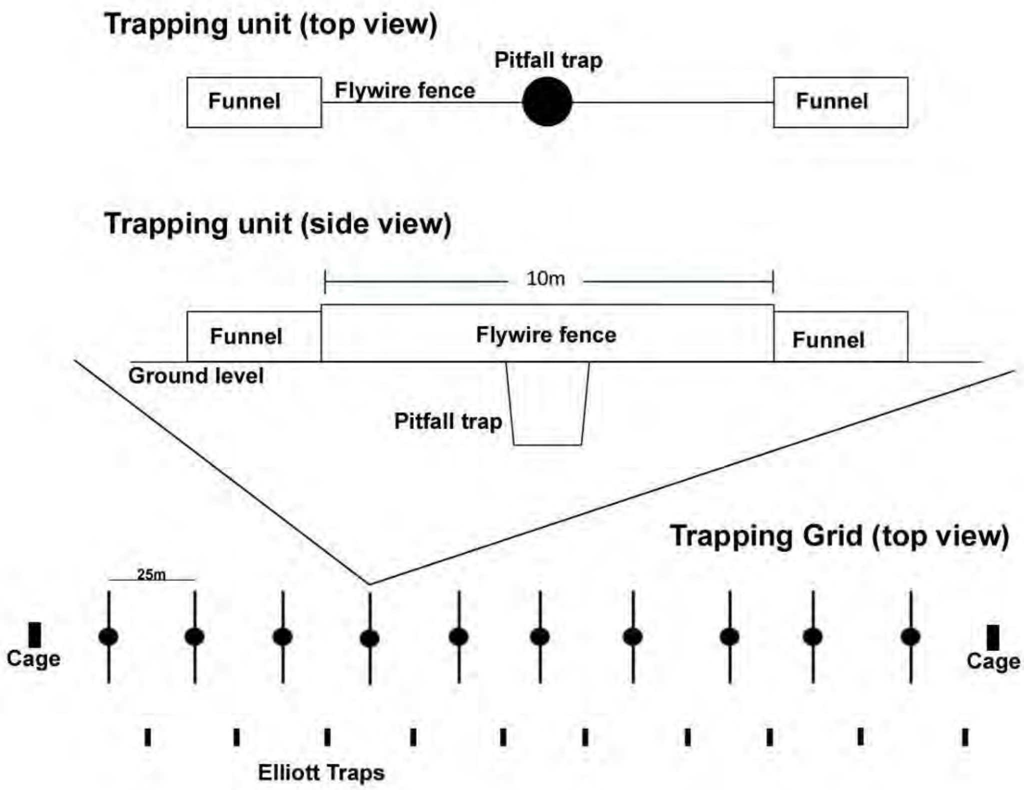


Figure 3.2 – Diagram of the systematic sampling trap arrangement

Figure 3.3 – Image of single *ecologia* trap point

3.6.1.2 Avifauna

Four 30 minute set-time surveys were used to document the avifauna present at each of the fauna sites for each phase of surveying. This totals two hours of systematic surveying per site per phase. During each set-time survey an ornithologist recorded the number of individuals of each species seen while actively searching similar habitat within 500 m of the survey site. This is aligned with survey methodology for the ongoing Birds Australia *Atlas of Australian Birds* project.

Survey effort was concentrated at survey sites within three hours of dawn, as this time is deemed to be the optimal times to record most bird species. Opportunistic surveys during the day and near dusk were also conducted, as they may yield species less frequently observed in the early morning, e.g. diurnal raptors.

3.6.1.3 Bats

Bat echolocation calls were recorded using SM2BAT+ 384 kHz ultrasonic acoustic recorders (SM2BAT). The SM2BAT has a high sampling frequency, enabling the full spectrum of the calls to be recorded without being transformed allowing greater accuracy and sensitivity. The SM2BAT was programmed to record from dusk to dawn for each night surveyed. Each systematic survey site was surveyed for one night per phase. Opportunistic sites were surveyed in areas which represented particularly good bat roosting and foraging habitat, such as rocky gorges.

3.6.1.4 SRE Leaf Litter Collection

At each site, three 1 m^2 quadrats (totalling 3 m^2) of leaf litter were collected and placed into a leaf-litter reducer separately (Figure 3.4). An additional eight opportunistic sites were also sampled. The contents from each collection was placed into a paper bag inside a zip-lock bag and kept separate. A small amount of wet tissue paper was placed into each sample to keep humid. Samples were then transported back to Perth in a cool, dark container where they were placed on Tullgren funnels to extract any specimens.

Figure 3.4 – Example of the leaf litter reducer and Tullgren funnels

3.6.1.5 SRE Extraction Methods and Lab Sorting

Tullgren funnels were used to extract any animals from the collected leaf litter samples (Figure 3.4). The general principle of Tullgren funnels is that a sample of leaf litter is suspended below an incandescent lamp or heat source. Animals inhabiting the sample are forced downwards by the progressive drying of the sample and ultimately fall into the collecting vessel which is located below the sample. Samples are preserved in ethanol to allow DNA extraction if required.

After the leaf litter samples were processed on the Tullgren funnels, each sample was examined for any other animals that were not collected during Tullgren funnel extraction. Each sample was emptied into a tray and examined using a light magnifier. Any animals found were collected and immediately preserved in ethanol.

All specimens collected were examined under a Stereo microscope and sorted into related groups. These specimens were labelled with the Project name, site number and coordinates, the trap number or leaf-litter sift number and the collectors, and were sent to the relevant taxonomic experts for further identification. Table 3.6 shows the list of taxonomic specialists used for identification and relevant experience.

Table 3.6 – Taxonomic specialists used for invertebrate identification

External Consultant	Institution	Relevant Experience
Dr Mark Harvey	Western Australian Museum	Taxonomic specialist in arachnids and millipedes
Dr Amber Beavis	Western Australian Museum	Taxonomic specialist in pseudoscorpions
Corey Whisson	Western Australian Museum	Taxonomic specialist in molluscs
Dr Bill Humphreys	Western Australian Museum	Taxonomic specialist in subterranean fauna
Dr Erich Volschenk	Private consultant	Taxonomic specialist in scorpions
Dr Simon Judd	Private consultant	Taxonomic specialist in isopods
Dr Volker Framenau	Private consultant	Taxonomic specialist in spiders

3.6.2 Opportunistic Data

3.6.2.1 Nocturnal Searching

The study area was searched at night using a combination of road transects and opportunistic ground searches using head torches and hand held spotlights to uncover nocturnal species, including geckos, snakes, frogs, birds and invertebrates.

Each systematic trapping site was surveyed by spotlight for at least 60 minutes for each phase. Sites GWA S1, 2 and 9 did not have nocturnal surveys completed due the long travel times required to reach these sites and the associated health and safety implications.

3.6.2.2 Diurnal Searching

Both trapping and opportunistic sites were searched by hand for both vertebrate and invertebrate cryptic species, which comprised searching beneath the bark of dead trees, breaking open old logs, stumps and dead free-standing trees, investigating burrows and over-turning logs and stones. Sites were selected on the basis of fauna habitat (targeting uncommon habitats or habitats poorly represented by trapping sites) and the possibility of their harbouring conservation significant fauna.

Fauna were also recorded while searching, travelling and during trap establishment within the study area during the day and night. Tracks, diggings, scats, burrows and nests were recorded where possible.

A total of 24 opportunistic survey sites were established during this survey, totalling 47.2 hours of diurnal searching.

3.6.2.3 Motion Camera Trapping

Motion sensor cameras were used in areas with a high likelihood of animal activity such as water sources to detect fauna species. The Bushnell Trophy Cam, model number 119415 was used. The camera is triggered by movement by a highly sensitive Passive Infra-Red motion sensor and functions day and night taking either video footage or photos (Bushnell Outdoor Products 2009).

A total of five motion cameras were set up at five sites for a total of 576 hours.

3.6.2.4 Invertebrate foraging

Opportunistic foraging involved physically searching through microhabitats for SREs. The underside of rocks and logs were closely investigated for SRE invertebrates. Snail shells were collected and trapdoor spiders excavated from their burrows, with their location and date of collection documented.

3.7 SURVEY EFFORT

Survey effort expended within the study area is shown in Table 3.7 and is summarised in the following sections.

3.7.1 Vertebrate Fauna

- 12 trapping sites were open for 14 nights, totalling 7,056 trapnights;
- 53.8 hours spent surveying for birds;
- 51.6 hours spent conducting diurnal searches;
- 25 hours spent conducting nocturnal searches;
- 576 hours of motion camera trapping; and
- 340 hours of bat call recordings analysis.

3.7.2 Conservation Significant Terrestrial Vertebrate Fauna

Excluding systematic trapping effort, targeted potential conservation significant vertebrate fauna were searched for opportunistically using the following methods:

- approximately 28 hours of opportunistic searches and 461 camera trap hours for evidence of Northern Quolls and Pilbara Olive Python;
- a total of 340 hours of bat call recordings were analysed for Ghost Bat and Pilbara Leaf-nosed Bat;
- approximately 12 hours of diurnal searches for Western Pebble-mound Mouse mounds;
- approximately six hours of bird surveys for Rainbow Bee-eater;
- five hours of spotlighting for the Pilbara Barking Gecko; and
- four hours of nocturnal call playback was performed for Bush Stone-curlew.

Other potential conservation significant species were not targeted specifically during searches due to their ability to occur within a variety of habitats (Peregrine Falcon, Grey Falcon, Australian Bustard) and difficulty in detection (*Ramphotyphlops ganei*), however all zoologists conducting the assessment were training in the identification and recognition of these species.

3.7.3 SRE Invertebrates

- Twelve sites consisting of dry pitfall and funnel traps were open for 14 nights, totalling 5,040 trapnights;
- 51.6 hours were spent actively foraging (looking through leaf litter, under bark and stones etc); and
- A total of 60 leaf litter collections (1m^2 quadrat) were taken from 18 locations.

Table 3.7 – Survey effort

Site	Pit Traps (trap nights)		Funnels (trap nights)		Elliotts (trap nights)		Cages (trap nights)		Bird Survey (min)		Leaf litter collection (1m^{2}quadrat)	Diurnal Opp Search (min)		Bat Recording (hour)		Nocturnal Search (min)		Camera Trapping (hour)	
	Ph1	**Ph2**	**Ph1**	**Ph2**	**Ph1**	**Ph2**	**Ph1**	**Ph2**	**Ph1**	**Ph2**		**Ph1**	**Ph2**	**Ph1**	**Ph2**	**Ph1**	**Ph2**	**Ph1**	**Ph2**
GWA S1	70	70	140	140	70	70	14	14	120	120	3	60	-	12	12	-	-	-	-
GWA S2	70	70	140	140	70	70	14	14	120	120	3	-	-	12	12	-	-	-	-
GWA S3	70	70	140	140	70	70	14	14	120	120	3	60	-	12	12	80	60	-	-
GWA S4	70	70	140	140	70	70	14	14	120	120	3	60	-	12	12	80	60	-	-
GWA S5	70	70	140	140	70	70	14	14	120	120	3	60	-	12	12	80	60	-	-
GWA S6	70	70	140	140	70	70	14	14	120	120	3	-	30	12	12	60	60	-	-
GWA S7	70	70	140	140	70	70	14	14	120	120	3	120	30	12	12	60	-	-	-
GWA S8	70	70	140	140	70	70	14	14	120	120	3	-	20	12	12	60	60	-	-
GWA S9	70	70	140	140	70	70	14	14	120	120	3	60	-	12	12	-	-	-	-
GWA S10	70	70	140	140	70	70	14	14	120	120	3	-	30	4	12	60	60	-	-
GWA S11	70	70	140	140	70	70	14	14	120	120	3	-	60	12	12	80	60	-	-
GWA S12	70	70	140	140	70	70	14	14	120	120	3	-	-	12	12	60	120	-	-
Opportunistic	-	-	-	-	-	-	-	-	320	30	24	1240	1270	24	36	340	-	432	144
Phase Total	**840**	**840**	**1680**	**1680**	**840**	**840**	**168**	**168**	**1760**	**1470**	**60**	**1660**	**1440**	**160**	**180**	**960**	**540**	**432**	**144**
Total	**1,680**		**3,360**		**1,680**		**336**		**3,230**		**60**	**3,100**		**340**		**1,500**		**576**	

3.8 FAUNA BROAD-SCALE HABITAT MAPPING

A fauna habitat type broadly describes an area of habitat that is distinguishable in its vegetation and land features from its surroundings, and that is likely to support fauna assemblages which are different to those in other fauna habitats. Fauna habitat types were identified, described and mapped taking in to consideration the following existing information:

- Vegetation associations (Beard 1981; Shepherd et al. 2002);
- IBRA subregions;
- Aerial photography; and
- On ground observations.

To aid in determining the fauna habitat type and its characteristics, the following on ground parameters were taken into consideration:

- Vegetation type and structure;
- Soil characteristics (soil structure and substrate);
- Landscape and landform features; and
- Composition of terrestrial fauna species.

3.9 DATA ANALYSIS

3.9.1 Survey Adequacy

There are three general methods of estimating species richness from sample data: extrapolating species-accumulation curves (SACs), fitting parametric models of relative abundance, and using non-parametric estimators (Bunge and Fitzpatrick 1993; Colwell and Coddington 1994; Gaston 1996). In this report, the level of survey adequacy was estimated using SACs, which graphically illustrate the accumulation of new species as more individuals are recorded. Ultimately, the asymptote is reached at the level at which no new species are present. To eliminate features caused by random or periodic temporal variation, the sample order was randomised 1,000 times using EstimateS (version 8, Colwell 2009). In order to estimate the theoretical maximum for each fauna group, a Michaelis-Menten enzyme kinetic curve was calculated and used as a stopping rule technique.

Only the results of systematic surveys were included in SAC analysis, as this form of analysis assumes a standard sampling effort. Therefore, species recorded through opportunistic methods are not included. Separate analyses were carried out for each species group (mammal, reptile, bird, invertebrates).

3.9.2 Habitat Assessment

Habitat types have been established in the literature as playing an important role in SRE invertebrate and vertebrate fauna diversity. Variability of habitats has been strongly linked with invertebrate and vertebrate species richness and composition. The expectation of this study was to find a relationship between species richness and habitat type, with higher species richness in moister habitats and less in drier habitats.

Statistical analyses were carried out on the complete data set from the 12 sites sampled during the survey. The primary aim of the statistical analysis was to determine whether the vertebrate and invertebrate assemblages (containing SRE invertebrate groups) recorded from the study area differ in terms of richness (number of taxa present) and structure (relative abundance of taxa).

Differences between habitat types and species richness were tested with a one-way ANOVA. Prior to running the ANOVA, a test of normality (Anderson –Darling) and Homogeneity (Barlett's and Levene) was performed in order test if the data set complies with the ANOVA assumptions.

To analyse differences in species diversity between habitats, a Bray Curtis similarity index was calculated for each pairwise site comparison followed by a non-metric multidimensional scaling (MDS) of similarity matrix. Stress values below 0.20 were considered to indicate a good fit of the scaling to the matrix. The dimensions that reduced the majority of the "raw stress" were chosen for the final scaling. In addition, to test whether the differences in species diversity between habitat types were significant, analyses of similarity (ANOSIM) (Clarke 1993) comparisons were made using the one-way ANOSIM function in the PAST software package (Hammer *et al.* 2001). ANOSIM was calculated using the Bray-Curtis Similarity Index with 999 permutations. Bray Curtis is a widely used and well-tested index for incidence data. The analysis was run without the inclusion of rare species, to avoid potential bias. "Rare" species were defined as those species found in only one sample, based on visual inspection of a histogram of species abundances.

Analysis of the fauna survey data was undertaken to determine the similarities in fauna communities and identify any unique fauna habitats. Separate analyses were carried out for terrestrial fauna (mammal and reptile) and avifauna.

3.10 TAXONOMY AND NOMENCLATURE

Nomenclature for mammals, reptiles and amphibians within this report is as per *Western Australian Museum Checklist of the Vertebrates of Western Australia*, birds according to Christidis and Boles (2008). References used for fauna identification are listed in Table 3.8.

All invertebrate specimens collected during the SRE trapping have been lodged with the WA Museum and identified by external experts (Table 3.6).

Table 3.8 – References used for identification

Fauna Group	Reference
Mammals	Menkhorst and Knight (2011), Van Dyck and Strahan (2008)
Bats	Churchill (1998), Menkhorst and Knight (2011)
Birds	Simpson and Day (2004)
Reptiles	Cogger (2000), Wilson and Swan (2010)
Geckos	Storr *et al*. (1990), Wilson and Swan (2010)
Skinks	Storr *et al*. (1999), Wilson and Swan (2010)
Dragons	Storr *et al*. (1983), Wilson and Swan (2010)
Varanids	Storr *et al*. (1983), Wilson and Swan (2010)
Legless Lizards	Storr *et al*. (1990), Wilson and Swan (2010)
Snakes	Storr *et al*. (2002), Wilson and Swan (2010)
Amphibians	Tyler and Doughty (2009), Cogger (2000)

3.11 ANIMAL ETHICS

Surveying was conducted as per *ecologia*'s Animal Ethics Code of Practice, which conforms to Section 5 of the *Australian code of practice for the care and use of animals for scientific purposes* (NHMRC 2004).

In most cases, fauna were identified in the field and released at the point of capture. Where the taxonomy of specimens was not clearly discernible, or when species were collected that are known to exhibit significant morphological variation or are not yet fully described, vouchers specimens were lodged with the W.A. Museum (Appendix D). Voucher specimens were maintained according to WA Museum guidelines to ensure minimum stress to captured animals.

3.12 SURVEY TEAM AND LICENCES

Field survey team members are listed in Table 3.9. The survey was conducted under DEC Regulation 17 Licence SF008716.

Table 3.9 – Field survey personnel

Survey Member	Expertise	Qualification	Experience
Phase 1			
Astrid Heidrich	Herpetology	M.Sc.	7 years
Sean White	Invertebrate Zoology	B.Sc.	7 years
Nigel Jackett	Ornithology	B.Sc. (Hons)	7 years
Bruce Greatwich	Ornithology	B.Sc.	5 years
Leigh Smith	Herpetology	-	5 years
Farhan Bokhari	Invertebrate Zoology	B.Sc. (Hons)	5 years
Anna Nowicki	Zoology	B.Sc. (Hons)	3 years
Jesse Forbes-Harper	Zoology	B.A B.Sc. (Hons)	3 years
Phase 2			
Sean White	Invertebrate Zoology	B.Sc.	7 years
Mei Chen Leng	Invertebrate Zoology	B.Sc. (Hons)	7 years
Mariana de Campos	Botany	Ph.D.	7 years
Bruce Greatwich	Ornithology	B.Sc.	5 years
Anna Nowicki	Zoology	B.Sc. (Hons)	3 years
Jesse Forbes-Harper	Zoology	B.A B.Sc. (Hons)	3 years
External consultant			
Bob Bullen	Bat call analysis	-	15 years

4 RESULTS

4.1 BROAD-SCALE HABITATS

A total of nine broad-scale habitat types have been assessed as existing within the study area; 'footslope or plain', 'hilltop, hillslope, ridge or cliff', 'mixed Acacia woodland', 'mesa top', 'cracking clay', 'major gorge and gully', 'major drainage', 'mulga woodland' and 'cleared area'. Table 4.1 displays the area each habitat type occupied at the time of surveying, and the percentage of this occupancy compared to the other habitat types, within the study area. The fauna habitats are mapped in Figure 4.1 and described in greater detail in section 4.1.2 to 4.1.10. No habitats were recorded that are regarded as rare or unique to the study area.

Table 4.1 – Summary of fauna habitat type areas

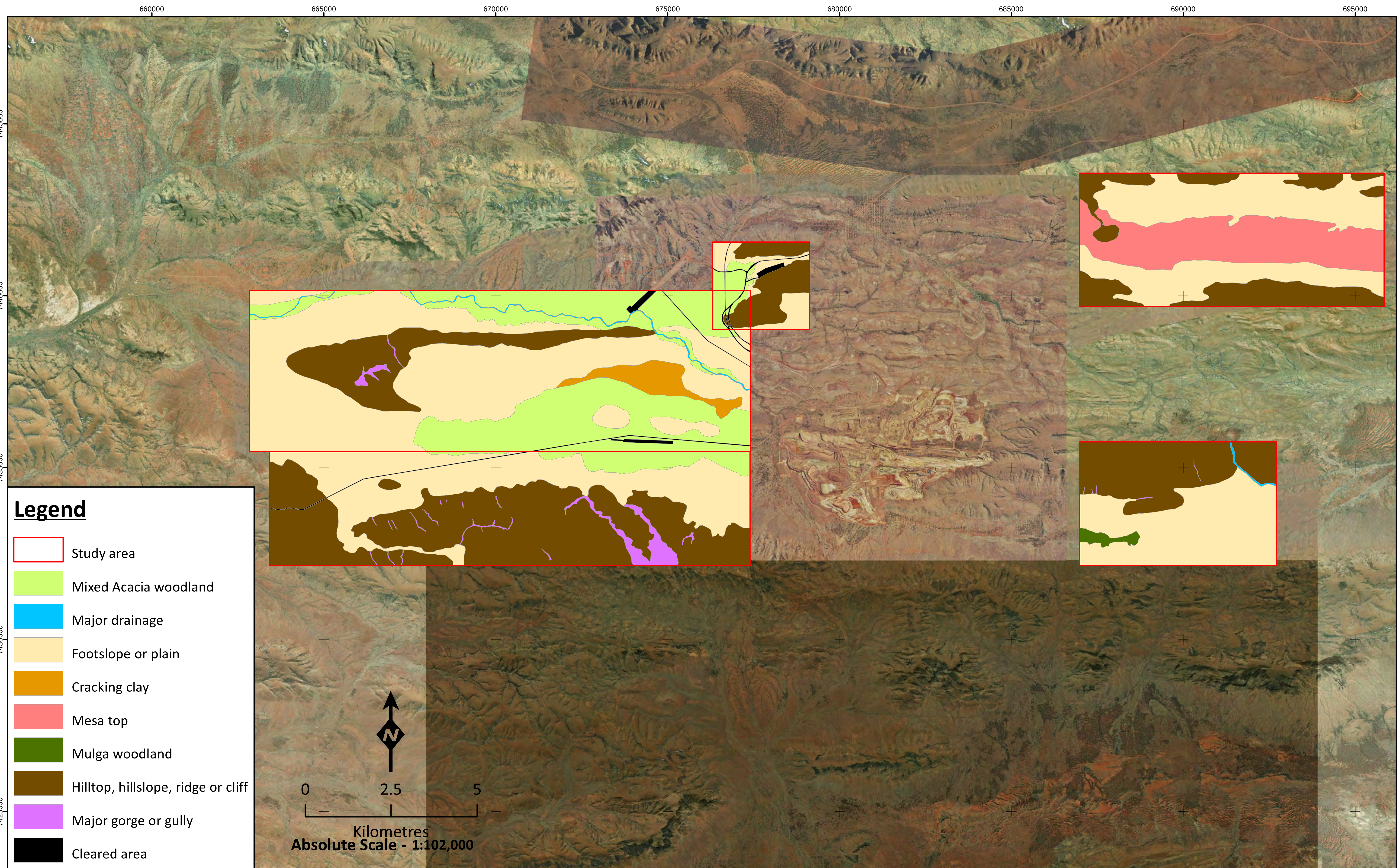
Fauna Habitat	Area inside study area (km^2)	Percentage of total study area (%)
Footslope or plain	80.37	45.76
Hilltop, hillslope, ridge or cliff	51.95	29.58
Mixed Acacia woodland	26.15	14.89
Mesa top	11	6.26
Cracking clay	2.42	1.38
Major gorge and gully	1.70	0.97
Major drainage	0.51	0.29
Mulga woodland	0.49	0.28
Cleared area	1.06	0.60
Total	**175.65**	**100**

4.1.1 Broad-scale habitat survey effort

When survey effort in Table 3.7 is assessed against the corresponding habitats present, survey effort per habitat type can be seen. These results are shown in Table 4.2.

Table 4.2 – Survey effort per habitat type

Survey effort	Habitat Type								
	Footslope or plain	Hilltop, hillslope, ridge or cliff	Mixed Acacia woodland	Mesa top	Cracking clay	Major gorge and gully	Major drainage system	Mulga woodland	Cleared area
Systematic trap sites	GWA S4, S5, S7, S9, S11	GWA S6	GWA S10	GWA S1, S2	GWA S8	GWA S12	-	GWA S3	-
Pit traps (nights)	350	70	70	140	70	70	-	70	-
Funnels (nights)	700	140	140	280	140	140	-	140	-
Elliotts (nights)	350	70	70	140	70	70	-	70	-
Cages (nights)	70	14	14	28	14	14	-	14	-
Bird surveys (min)	1,200	240	240	480	240	240	350	240	-
Leaf litter collection ($1m^2$ quadrat)	27	6	3	9	3	6	-	3	-
Diurnal Opp Search (min)	360	380	180	100	20	1,540	280	240	-
Bat Recording (hour)	112	48	24	48	24	60	-	24	-
Nocturnal Search (min)	460	120	140	-	120	180	-	140	-
Camera Trapping (hour)	115	-	-	-	-	461	-	-	-



ecologia ENVIRONMENT

Fauna habitats

Figure: 4.1
Project ID: 1458

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Date: 15/4/2013

Coordinate System
Name: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
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4.1.2 Footslope or plain

Footslope or plain was the most abundant habitat type and occupied 45.76% of the study area (Table 4.1). The vegetation cover on this habitat is typically comprised of *Eucalyptus leucophloia, E. gamophylla, Corymbia hamersleyana, A. pruinocarpa, A inaequilatera* and species in the *A. aneura* complex open woodland to sparse trees over *Acacia* spp*., Eremophila* spp., *Ptilotus* spp., *Senna* spp. and *Solanum lasiophyllum* open shrubland over *Triodia* spp. open hummock grassland Figure 4.2.

Due to the large area that this habitat type covers, a wider range of plant taxa are associated with it, particularly in the shrub and grass strata. The most abundant shrubs observed were *Acacia bivenosa, A. colei, A. acradenia, A. tetragonophylla, Eremophila fraseri, E. forrestii, E. caespitosa, E. latrobei, Ptilotus calostachyus, P. nobilis* subsp. *nobilis, Senna artemisioides* (various subspecies and varieties) and *Senna glutinosa* (various subspecies and varieties). The hummock grasses present in this vegetation type were *Triodia wiseana, T. basedowii, T. longifolia* and *T. pungens*. The footslope or plain habitat type included minor drainage lines, where *T. longifolia, Gossypium robinsonii and Acacia ancistrocarpa* were characteristic.

This habitat type was associated mostly with orange sandy-clay soils on flat ground. The soil was recorded as loose, a crust or rocky, with few to common ironstone rock, gravel and pebble cover. Common disturbances observed in this habitat type include introduced flora species and animal tracks.

Figure 4.2 – Footslope or plain habitat type

4.1.3 Hilltop, hillslope, ridge or cliff

The hilltop, hillslope, ridge or cliff habitat type was recorded from 29.58% of the surveyed area and was therefore the second most common habitat within the study area (Table 4.1). The vegetation of this fauna habitat typically includes *Eucalyptus leucophloia* and mulga (*Acacia aneura* complex) isolated trees over sparse shrubland of a combination or selection of *Senna artemisioides* subsp. *artemisioides, S. artemisioides* subsp. *filifolia, Ptilotus rotundifolius, Tribulus suberosus, Eremophila fraseri* and *Acacia ancistrocarpa* sparse shrubland to isolated shrubs over *Triodia pungens* hummock grassland (Figure 4.3). In general this habitat type has a predominantly open character with very little vegetation cover.

In some areas, there was also the presence of *Acacia pruinocarpa, A. maitlandii, Acacia synchronicia,* different varieties and subspecies of *Senna artenisioides* and *Senna glutinosa*, as well as sparse herbs. Variations in the lower stratum include the presence of *Triodia wiseana, Eriachne* spp. and *Cymbopogon obtectus.*

Some variation was observed in the landforms, soil composition and rock abundance in this habitat type. The most commonly observed characteristics were soils of sandy-clay texture, ranging from orange to brown in colour and with abundant ironstone rocks, boulders and/or surface plates. The slope ranged from minor to very steep, with smaller vegetation cover in the steeper areas.

Figure 4.3 – Hilltop, hillslope, ridge or cliff habitat type

4.1.4 Mixed *Acacia* woodland

This habitat type occupied 14.89% of the study area (Table 4.1). Vegetation included open to medium dense woodland with a tree stratum of mulga (*Acacia aneura* complex) and scattered *Acacia pruinocarpa*, over *Acacia maitlandii* and *Ptilotus* sp. sparse shrubland, over *Triodia wiseana* and *T. pungens* open hummock grassland dominated the mixed *Acacia* woodland habitat type (Figure 4.4).

Many other *Acacia* species were present in this habitat type, including *A. bivenosa, A. ayersiana, A. pyrifolia, A. sibirica;* as well as *Senna* shrubs (mainly varieties and subspecies of *S. artemisioides* and *S. glutinosa*).

The soils consisted of loam clay with continuous layers of small ironstone pebbles on the surface. The habitat was mostly flat with no or very small drainage channels.

Figure 4.4 – Mixed Acacia woodland habitat type

4.1.5 Mesa top

The mesa top habitat type is located in the north-east corner of the study area, in Deposit H. Although similar to the hilltop, hillslope, ridge or cliff habitat type, it differs in that it is an elevated plateau, and supports dense vegetation in patches (Figure 4.5). The mesa top habitat type occupied 6.26% of the study area at the time of surveying (Table 4.1).

Mesa tops within the study area held an *Eucalyptus leucophloia, E. gamophylla, Acacia pruinocarpa* and mulga (*A. aneura* complex) open woodland to sparse trees, over *A. maitlandii, A. hamersleyensis, Keraudrenia velutina* and *Senna glutinosa* subsp. *glutinosa* open shrubland, over *Triodia pungens, T. longifolia* and/or *T. wiseana* open hummock grassland.

This habitat type included minor drainage lines, where *Gossypium robinsonii* was also present, as well as sparsely vegetated rocky outcrops. The geology of this habitat type is also notably different. Figure 2.5 shows the geology of the mesa top habitat type as unit A3b, which is described as sedimentary rocks. This geology differs from the mafic volcanic and dolerite and gabbros geology of the remaining area of the study area (Table 2.3).

Figure 4.5 – Mesa top habitat type

4.1.6 Cracking clay

The cracking clay habitat type was recorded from one location within the study area and occupied 1.38% of the total study area (Table 4.1). The cracking clay habitat type supported very few trees and tall shrubs and is characterised by open and sparse low vegetation with approximately half of its area being bare ground (Figure 4.6).

Isolated shrubs of *Salsola australis, Boerhavia paludosa* and *Ptilotus nobilis* subsp. *nobilis* were present over open tussock grassland of *Aristida* sp., *Brachyachne* sp. and *Astrebla pectinata.* The soil was recorded as dark orange sand-clay to clay with an undulating surface caused by crabholes and gilgai. Rocks and pebbles were very rare and when present, the rock type was consistently ironstone.

Although no signs of fire were evident, parts of the vegetation on the cracking clay habitat type were desiccated, leaving some areas completely bare.

Figure 4.6 – Cracking clay habitat type

4.1.7 Major gorge and gully

The major gorge and gully habitat type was recorded from sections within the hilltop, hillslope, ridge or cliff habitat type and occupies 0.97% of the study area (Table 4.1). The vegetation recorded commonly included *Acacia aptaneura* open woodland over *Ptilotus obovatus* isolated shrubs over *Themeda triandra* and *Eriachne* sp. open tussock grassland and *Triodia pungens* isolated hummock grasses.

Astrotricha hamptonii, Ficus brachyopoda and *Cyperus cunninghamii* were species found only in the major gorge and gully habitat, and are considered descriptive of this habitat type, although not dominant.

Major gorge and gully were frequently very steep and with an irregular surface, formed by surface plates and boulders of ironstone and with little exposed soil. The soil, when available, was described as orange-brown and sandy to sandy-clay (Figure 4.7).

Figure 4.7 – Major gorge or gully habitat type

4.1.8 Major drainage

The major drainage habitat type occupies only 0.29% of the study area (Table 4.1). The major drainage systems were characterised by open woodland of *Eucalypts victrix, Acacia citrinoviridis* and *Acacia aptaneura*, over *Senna artemisioides* subsp. *oligophylla*, *Rhagodia eremaea*, *Ptilotus obovatus*, *Tephrosia rosea* and Malvaceae spp. shrubland over *Themeda triandra* and *Bothriochloa* sp. sparse tussock grasses and/or *Triodia pungens* sparse hummock grasses (Figure 4.8).

Some variation in the vegetation composition was observed between the different major drainage systems, with varying prevalence of the taxa above mentioned, and in some cases, increased dominance of other species, such as *Pterocaulon sphacelatum, Gossypium robinsonii* or *Evolvulus alsinoides* var. *villisocalyx*.

This habitat occurred mostly on soils of sandy-clay texture that ranged from orange - red to brown in colour and with few to many rocks, pebbles and gravel. The soils were well drained and the rock type present in the major drainage systems was ironstone.

Figure 4.8 – Major drainage habitat type

4.1.9 Mulga woodland

Mulga woodland was recorded from one location and occupied 0.28% of the study area. The mulga woodland habitat type consists of both groved and banded mulga, where different species of the *Acacia aneura* complex were present in a closed woodland, over *Ptilotus obovatus* and juvenile mulga trees sparse shrubland, over *Maireana* sp. and *Salsola australis* isolated herbs and *Aristida* sp. and *Cymbopogon obtectus* isolated tussock grasses (Figure 4.9) creating distinct micro-habitats that include dense leaf litter and shaded zones.

The mulga complex was formed by a group of closely related species, formerly different varieties of *Acacia aneura* and currently split into different species. The most common species in the "mulga woodland" habitat type was *Acacia aptaneura* and *A. pteraneura*.

The soils of this habitat type were orange to red and sandy-clay with no rocks. The slope was negligible and this area of habitat was very consistent and with little variation.

Figure 4.9 – Mulga woodland habitat type

4.1.10 Cleared area

Some areas within the study area were cleared for infrastructure such as major roads (e.g. Borefields road) and airstrips. These areas are unique as they support very little vegetation, and have therefore been separated from the remaining habitat types. A total of 0.60% of the study area was recorded as being cleared.

4.1.11 Fauna habitat analysis

Common habitat types were sampled by a larger number of systematic trapping sites than less common habitat types. Six of the nine fauna habitats within the study area were sampled with systematic trapping sites during the Level 2 fauna assessment. Five trapping sites (GWA S4, S7, S8 S9 and S11) were installed in the dominant habitat type, footslope or plain. Two trap sites were installed within the Mesa top with dense shrubs habitat type (GWA S1 and S2). One trap site was installed within the Mulga woodland (GWA S3), Hilltop, hillslope, ridge or cliff (GWA S6), mixed Acacia woodland (GWA S10) and cracking clay (GWA S12).

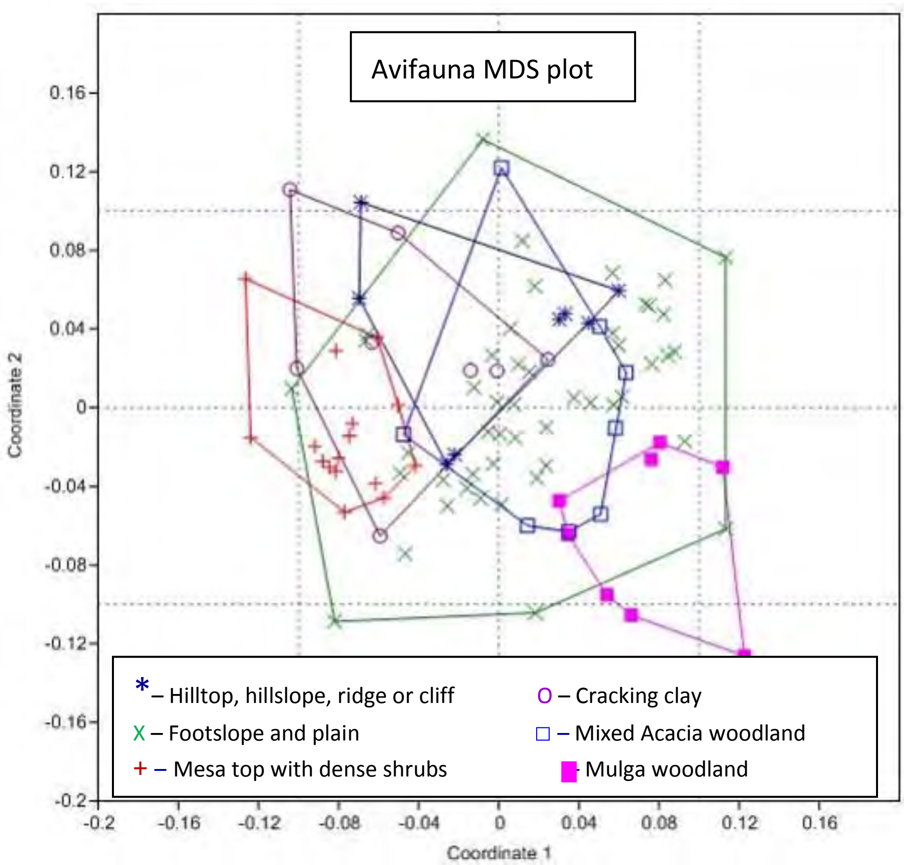
No trapping sites were installed within the gorge and gully, cleared area or major drainage line habitat types. However, these habitat types were targeted with greater opportunistic survey effort to ensure adequate sampling of each habitat type across the study area.

A one-way ANOSIM test and MDS plot of the trapping sites within the different habitat types was completed for data collected systematically for both avifauna and trapped terrestrial fauna. The results from the one-way ANOSIM test suggest a difference between the habitats. Trapped terrestrial fauna results for the R value was 0.1473 (R value ranges from -1 to 1, with 1 indicating that the groups are dissimilar and -1 indicating that the groups are similar) and a p-value of 0.0027 (p-value of <0.05 indicating a significant difference). From Avifauna results,the R value was 0.3133 and a p-value of 0.0001. Both the results from the one-way ANOSIM test for systematically collected data suggest a difference between habitat types.

The results of the MDS plot visually do not display a clear difference in habitat types (Figure 4.10). The avifauna MDS plot shows a slight difference in birds recorded between mesa top with dense shrubs, cracking clay, hilltop, hillslope, ridge or cliff and mixed acacia woodland habitat types. The mulga woodland habitat, based on avifauna assemblage, visually appears to be the most distinct. The differences observed in the analysis of the above habitats, may be a result of reduced survey effort with one or two sites located in these habitats only. It is observed the dominate habitat type, footslope or plain overlaps the majority of all other habitats sampled. This is likely due to the increased survey effort (five systematic trap sites) in this habitat, resulting in the detection of more bird species.

As with the avifauna MDS plot, the trappable fauna MDS plot does not provide a clear difference in habitat types (Figure 4.10). The mulga woodland habitat type shows a tight cluster of similar species records, which is consistent with the avifauna results suggesting that this habitat type is most disjunct in its fauna assemblage, when compared to the other habitats. All other habitats appear to have significant overlap and similarity in the fauna assemblages recorded. This is likely due to a number of habitat generalist species which were recorded regularly. An example of this is the recording of the Sandy Inland Mouse (*Pseudomys hermmanbergensis*) and skink *Ctenotus pantherinus* at 12 of the 12 and 10 of the 12 systematic trapping sites respectively (Appendix F).

Overall, the results from the statistical habitat assessment suggest little difference in fauna assemblages between the different habitat types within the study area. These results are likely to be influenced by the presence of a number of habitat generalists recorded at many sites and in many habitats.



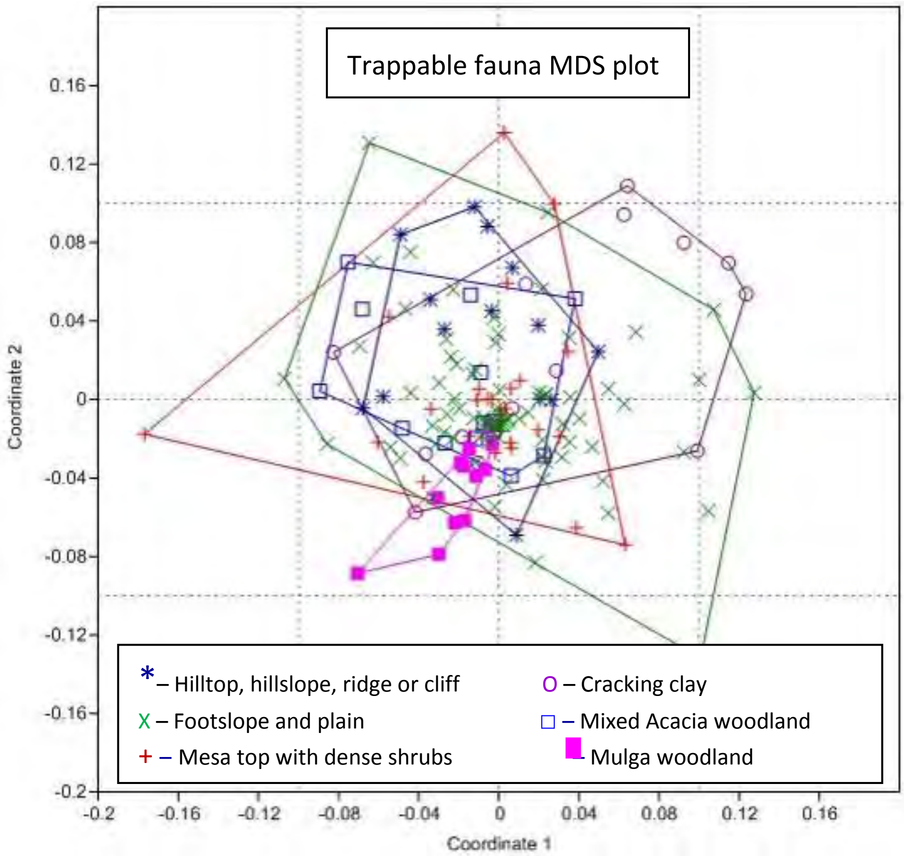


Figure 4.10 – Fauna habitat MDS plot analysis

4.2 VERTEBRATE FAUNA ASSEMBLAGE

A total of 23 species of native mammals, two species of introduced mammal, 80 species of bird and 64 species of reptile were recorded during this survey. No species of amphibian were recorded. Of the species recorded, six species were of conservation significance. The site by species matrix of species recorded during the Level 2 vertebrate fauna assessment is presented in Appendix F.

4.2.1 Mammals

A total of 23 native and two introduced mammals were recorded during this survey. This includes five dasyurids (small, carnivorous marsupials), three macropods (kangaroos), nine species of bat, five murids (mice), one species of canine (the dingo) and two species of introduced mammals (House Mouse and Rabbit) (Appendix F). The majority of species were recorded during both phases of surveying with the exception of the Delicate Mouse (*Pseudomys delicatulus*) which was only recorded during Phase 1 of surveying (Appendix F). Murids and dasyurids were captured in pitfall and Elliott traps at systematic trapping sites. Macropods were observed during diurnal and nocturnal opportunistic searches and nocturnal road spotting. Bats were identified from calls recorded on SM2BAT recorders.

There were a relatively large number of individuals of some murids and some dasyurid species recorded. The most frequently trapped species being the Sandy Inland Mouse (*Pseudomys hermannsburgensis*) with 73 records, the Common Rock-rat (*Zyzomys argurus*) with 52 records, the Pilbara Ningaui (*Ningaui timealeyi*) and the Stripe-faced Dunnart (*Sminthopsis macroura*) with 35 records each. Other abundant mammal species included Little Red Kaluta (*Dasykaluta rosamondae*; 34 records) and Desert Mouse (*Pseudomys desertor*; 29 records).

4.2.2 Birds

In total, 80 species of bird were recorded from the study area. The family Meliphagidae was the most diverse group recorded during this survey, comprising nine species of honeyeaters. The second most diverse group was the family Accipitridae which comprised seven species of birds of prey.

A large number of bird species were recorded during this survey when compared to other surveys conducted in the region (Appendix E). Several species were recorded in high numbers and from many of the sites, and can be considered to represent the common bird species of the study area; Budgerigar (1,010 records), Zebra Finch (840 records), Fork-tailed Swift (553 records), Weebill (411 records), Singing Honeyeater (288 records), Black-faced Woodswallow (182 records) and Yellow-throated Miner (152 records). Several of these species, such as Budgerigar, Black-faced Woodswallow and Fork-tailed Swift, are nomadic and appear in areas after high rainfall when food resources are high, or in the case of the Fork-tailed Swift are associated with thunderstorms.

4.2.3 Herpetofauna

In total, 64 species of reptiles were recorded during this survey. This included 21 skinks, 13 geckos (eight diplodactylid species, four gekkonid species and two carphodactylid species), 11 elapids (venomous snakes), six pygopods (legless lizards), five dragon species, six varanid (monitor lizard) species and one python. The activity of reptiles during the survey was moderate to high and resulted in good diversity of species recorded (Appendix E).

The most common species trapped were *Ctenophorus caudicinctus* (121 records*), Ctenotus pantherinus* (114 records), *Heteronotia binoei* (72 records), *Ctenotus helenae* (68 records), *Gehyra variegata and Ctenotus saxatilis* (61 records each), and *Carlia munda* (48 records), all of which are common species throughout the Pilbara region.

As typical for hot weather conditions, the activity of reptiles was recorded to be high and there was also a relatively large number of elapids recorded (11 species). Noteworthy is the record of the Pilbara Bandy Bandy (*Vermicella snelli*) which is rarely caught or observed due to its secretive nature.

No amphibian species were recorded.

Figure 4.11 – Photo of captured Pilbara Bandy Bandy

4.2.4 Vertebrate endemic species and species of biological significance

Species endemic to the Pilbara, recorded during the survey include: the Pilbara Ningaui (*Ningaui timealeyi*), Pilbara Leaf-nosed Bat (*Rhinonicteris aurantia* (Pilbara form)), Banded Knob-tailed Gecko (*Nephrurus wheeleri cinctus*), *Underwoodisaurus seorsus*, *Delma pax, Ctenotus rubicundus, C. rutilans*, Pilbara Rock Monitor (*Varanus pilbarensis*), *V. bushi* and Rufous Whipsnake (*Demansia rufescens*).

One individual of the small skink, *Ctenotus rutilans* was vouchered during phase 1 as field identification of morphology was not consistent with information in identification guides (Storr *et al.* 1999; Cogger 2000). Subsequent genetic analysis by the WAM confirmed the specimen as *Ctenotus rutilans*, despite a number of morphological characteristics not being typical of this species. Further taxonomic work is being carried out on this species complex to resolve current identification uncertainties (pers. comm. P. Doughty).

Figure 4.12 – Photo of vouchered *Ctenotus rutilans* indvidual from survey

A total of four individuals of the skink *Ctenotus robustus* (Figure 4.13) were recorded from site GWA S8 during phase 2 only (Appendix F). Based on previous records shown on NatureMap, these records represent an approximately 120 km range extension to the south for this species (DPaW 2013).

Figure 4.13 – Photo of *Ctenotus robustus* recorded from survey

4.3 POTENTIAL CONSERVATION SIGNIFICANT VERTEBRATE FAUNA

The literature review revealed a potential 21 vertebrate fauna species of conservation significance; six mammal species, 12 bird species and three reptile species (Appendix E). An assessment of their likelihood of occurrence was completed, based on the categories outlined in section 3.4, with the results summarised in Table 4.3. Regional records of conservation significant vertebrate fauna where point locations exist, have been mapped to aid in the assessment of likelihood of occurrence (Figure 4.14).

A total of six conservation significant species were recorded during the current survey (section 4.4). A further four species are assessed as having a high likelihood of occurrence and four species as having a medium likelihood of occurrence. The remaining seven species are considered to have a low likelihood of occurrence (Table 4.3).

Species that were recorded or assessed as having a high or medium likelihood of occurrence are discussed in further detail in section 5.3. Species assessed as low likelihood of occurrence are not discussed further.

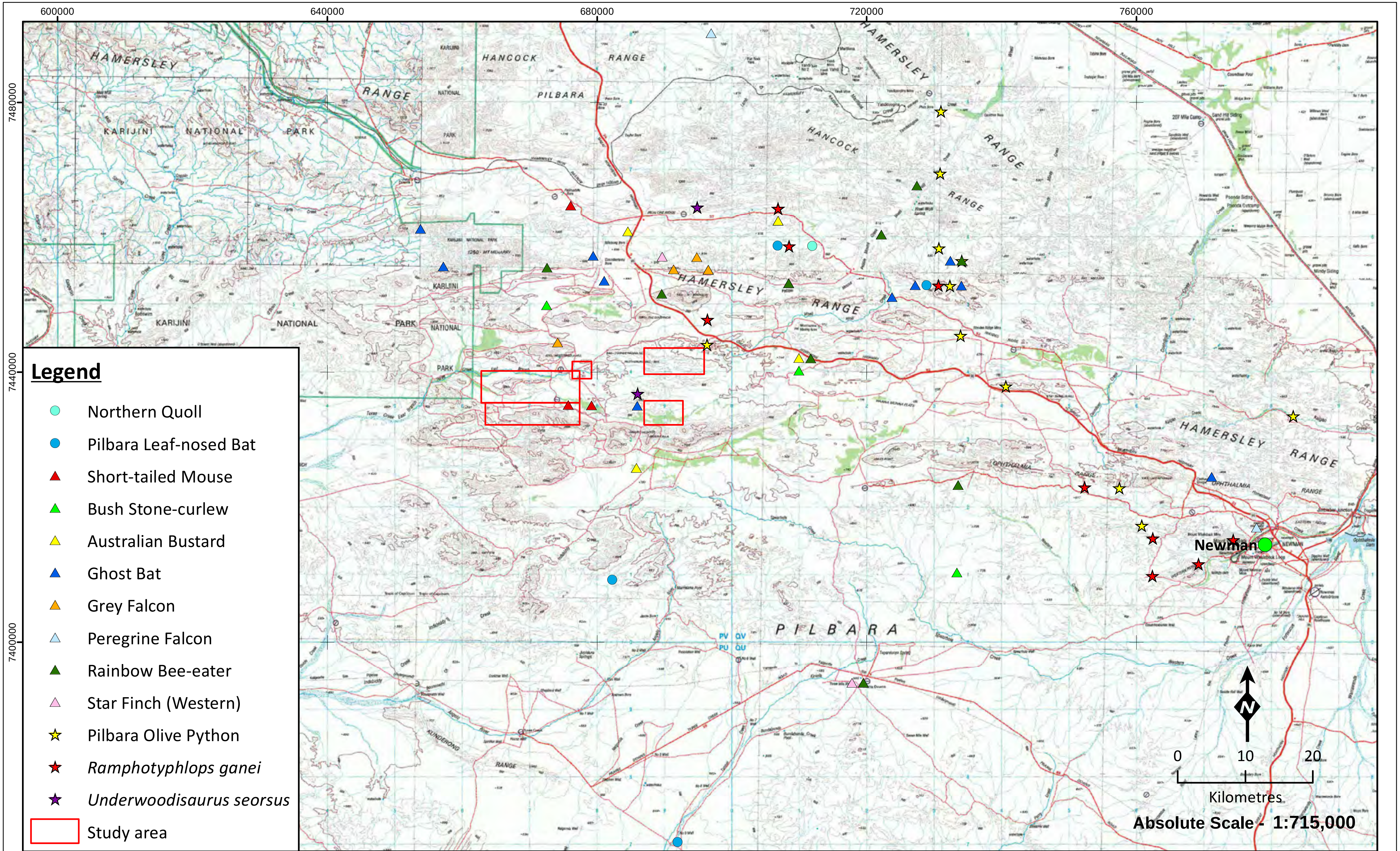
Table 4.3 – Likelihood of occurrence status of potential conservation significant vertebrate fauna

Species	Conservation Significance			Habitat	Previous Records	Likelihood of Occurrence
	EPBC Act	WC Act	DEC			
Mammals						
Northern Quoll *Dasyurus hallucatus*	EN	S1	EN	In the Pilbara, most common on dissected rocky escarpments, but also found in eucalypt forest and woodland. Typically rocky areas with suitable denning sites and access to surface water.	Three records from one location approx. 20 km north-east of study area from 2010 (DEC 2013).	**MEDIUM** Some suitable habitat present within the study area and recent record within 20 km.
Greater Bilby *Macrotis lagotis*	VU	S1	VU	Variety of habitats on soft soil including spinifex hummock grassland, acacia shrubland, open woodland and cracking clays.	Secondary evidence recorded during two previous surveys within 30 km (ecologia internal database, Ninox 1995). Not recorded on NatureMap within 100 km (DEC 2013).	**LOW** Low quality habitat present with lack of confirmed records close by.
Pilbara Leaf-nosed Bat *Rhinonicteris aurantia* (Pilbara form)	VU	S1	VU	Roost in caves with high humidity (95%) and temperature (32°C). Forage along water bodies with fringing vegetation.	Previous records from three locations within 30 km of the study area (DEC 2013).	**RECORDED** Foraging individuals recorded during this survey, no roost cave recorded.
Ghost Bat *Macroderma gigas*			P4	Roost in caves, rock piles and abandoned mines. Will travel 2 km from roost to hunt.	Calls and potential roost caves were previously recorded in close proximity to the study area (*ecologia* internal database).	**HIGH** Suitable hunting and roosting habitat is present within the study area. Species has been recorded previously.
Short-tailed Mouse *Leggadina lakedownensis*			P4	Spinifex and tussock grassland on cracking clays. Also acacia shrubland, samphire, woodlands, and stony ranges.	One previous record from within the study area from 1997 and three additional records from within 80 km area (DEC 2013).	**HIGH** Species was recorded from within the study area in 1997 (DEC 2013). Not recorded during this survey. Suitable habitat present.
Western Pebble-mound Mouse *Pseudomys chapmani*			P4	Footslopes of rocky ranges and rocky hills where the ground has continuous small pebbles and vegetated by spinifex.	Previously recorded throughout the region (DEC 2013) and during 12 surveys in the region (Ninox 1994; HGM 1999a, ecologia internal database, Ninox 2009a, 2009b, Biota 2010; 1999b; Maunsell 2003).	**RECORDED** Numerous active and inactive mounds were recorded within the study area during the survey.

Species	Conservation Significance			Habitat	Previous Records	Likelihood of Occurrence
	EPBC Act	WC Act	DEC			
Birds						
Night Parrot *Pezoporus occidentalis*	EN	S1	CR	Mostly ground-dwelling; spinifex grasslands or samphire and chenopod shrublands near water bodies.	Recorded from Protected Matters Search only with no specific record information. .	**LOW** Ecology poorly known and rarely recorded.
Fork-tailed Swift *Apus pacificus*	M	S3		Nomadic, almost entirely aerial lifestyle over a variety of habitats; associated with storm fronts.	Recorded during one survey within 40 km of the study area (*ecologia* internal database).	**RECORDED** Recorded during the survey.
Rainbow Bee-eater *Merops ornatus*	M	S3		Open country, most vegetation types, dunes, banks; prefer lightly wooded, preferably sandy, country near water.	Recorded during the majority of previous surveys within 50 km of the study area (Biota 2010,Ninox 1994; HGM 1999a, b; Maunsell 2003)	**HIGH** Suitable habitat present within study area. Numerous previous records.
Eastern Great Egret *Ardea modesta*	M	S3		Wide range of wetland habitats, including floodwaters, rivers, shallows of wetlands, intertidal mudflats.	One location record within vicinity of study area (Maunsell 2003).	**LOW** Typical wetland habitat absent within study area.
Cattle Egret Ardea ibis	M	S3		Grassy habitats, shallow wetlands and water bodies, particularly damp pastures.	Recorded from Protected Matters Search only with no specific record information.	**LOW** Typical wetland habitat absent within study area.
Oriental Plover *Charadrius veredus*	M	S3		Open plains, including samphire; bare rolling country; bare claypans; open ground near inland swamps.	Recorded from Protected Matters Search only with no specific record information.	**LOW** Suitable habitat exists but no previous records.
Common Sandpiper *Actitis hypoleucos*	M	S3		Coastal and inland wetlands, with varying levels of salinity; mostly found on muddy margins or rocky shores; rarely mudflats.	One location record within vicinity of study area (Maunsell 2003).	**LOW** Typical wetland habitat absent within study area.
Grey Falcon *Falco hypoleucos*		S1	VU	Lightly wooded coastal and riverine plains.	Previously recorded close by (*ecologia* internal database) and four recent records close by (DEC 2013).	**MEDIUM** Suitable foraging habitat present within study area but infrequently recorded species.

Species	Conservation Significance			Habitat	Previous Records	Likelihood of Occurrence
	EPBC Act	WC Act	DEC			
Peregrine Falcon *Falco peregrinus*		S4	Other	Widespread; coastal cliffs, riverine gorges and wooded watercourses.	Recorded during two previous surveys within 50 km of the study area (ecologia internal database, Ninox 1994). Three additional records on NatureMap within 100 km (DEC 2013).	**MEDIUM** Suitable foraging and nesting habitat present within study area.
Australian Bustard *Ardeotis australis*			P4	Open grasslands, chenopod flats and low heathland.	Recorded during seven previous surveys within 50 km of the study area (Ninox 1994, 1995; HGM 1999a, 2009a, 2009b, ecologia internal database; 1999b).	**RECORDED** Recorded during this survey.
Bush Stone-curlew *Burhinus grallarius*			P4	Lightly wooded country next to daytime shelter of thickets or long grass.	Three records within 50 km of the study area (DEC 2013).	**RECORDED** Tracks recorded during this survey.
Star Finch (western) *Neochmia ruficauda clarescens*			P4	Vegetation around watercourses, particularly thick reed beds.	A few previous records (Biota2010, ecologia internal database).	**LOW** Typical wetland habitat absent within study area.
Reptiles						
Pilbara Olive Python *Liasis olivaceus barroni*	VU	S1	VU	Watercourses and areas of permanent water in rocky gorges, escarpments and gullies.	Eight records within 50 km with the closest one within 1 km to the north-east of the study area (DEC 2013). Recorded during three previous surveys in the local region (ecologia internal database,HGM 1999b; Maunsell 2003)	**HIGH** Some suitable habitat present and some previous records close by.
Ramphotyphlops ganei			P1	Variety of habitats; thought to prefer moist gorges.	Eleven records within 100 km, recent and historic (DEC 2013).	**MEDIUM** Suitable habitat present and some previous records close by.
Pilbara Barking Gecko *Underwoodisaurus seorsus*			P1	Rocky gorges and rock piles.	Type locality close by, two records within 20 km of the study area (DEC 2013).	**RECORDED** Recorded during this survey

Note: Description of conservation significant codes provided in Appendix A.



ecologia ENVIRONMENT

Regional conservation significant vertebrate fauna records

Figure: 4.14
Project ID: 1458

Drawn: BG
Date: 26/04/2013

Coordinate System
Name: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Unique Map ID: BG311

A4

4.4 CONSERVATION SIGNIFICANT VERTEBRATE FAUNA RECORDED

Based on database searches and the results of previous biological surveys in the surrounding region, 6 mammal, 12 bird and 3 reptile species of conservation significance could potentially occur in the study area. Six species of conservation significance (two mammal, three bird and one reptile species) were recorded from within the study area, these records are summarised in Table 4.4 and mapped in Figure 4.15 and Figure 4.15.

Table 4.4 – Conservation significant fauna recorded during the survey

Species	Location			Comments*
	Easting	Northing	Site	
Mammals				
Pilbara Leaf-nosed Bat	671504	7435248	GWA S10	Single call on the 23/3/13 in middle of night indicating foraging individual.
Pilbara Leaf-nosed Bat	666240	7436475	GWA S7	Four calls on the 24/3/13 at different times of night indicating possibly more than one foraging individual.
Pilbara Leaf-nosed Bat	667740	7439331	GWA S12	Single call on the 23/3/13 in middle of night indicating foraging individual.
Western Pebble-mound Mouse	673665	7434462	Opportunistic	Active mound
Western Pebble-mound Mouse	672596	7434480	Opportunistic	Active mound
Western Pebble-mound Mouse	668157	7434280	Opportunistic	Active mound
Western Pebble-mound Mouse	672684	7434543	Opportunistic	Active mound
Western Pebble-mound Mouse	667710	7439402	Opportunistic	Active mound
Western Pebble-mound Mouse	675011	7434825	Opportunistic	Active mound
Western Pebble-mound Mouse	667803	7439414	Opportunistic	Active mound
Western Pebble-mound Mouse	666190	7436653	Opportunistic	Active mound
Western Pebble-mound Mouse	669120	7434586	Opportunistic	Active mound
Western Pebble-mound Mouse	669037	7434650	Opportunistic	Active mound
Western Pebble-mound Mouse	668923	7437248	Opportunistic	Active mound
Western Pebble-mound Mouse	668627	7434577	Opportunistic	Active mound
Western Pebble-mound Mouse	689675	7442560	Opportunistic	Active mound
Western Pebble-mound Mouse	677258	7438166	Opportunistic	Active mound
Western Pebble-mound Mouse	668967	7438036	Opportunistic	Active mound
Western Pebble-mound Mouse	666396	7434452	Opportunistic	Active mound
Western Pebble-mound Mouse	677714	7440975	Opportunistic	Active mound
Western Pebble-mound Mouse	690176	7440478	Opportunistic	Active mound
Western Pebble-mound Mouse	671568	7435429	Opportunistic	Active mound
Western Pebble-mound Mouse	671561	7435088	Opportunistic	Active mound
Western Pebble-mound Mouse	671480	7435074	Opportunistic	Inactive mound
Western Pebble-mound Mouse	668034	7434428	Opportunistic	Inactive mound
Western Pebble-mound Mouse	666413	7434675	Opportunistic	Inactive mound
Western Pebble-mound Mouse	670747	7436275	Opportunistic	Inactive mound
Western Pebble-mound Mouse	671842	7434792	Opportunistic	Inactive mound
Western Pebble-mound Mouse	687618	7441807	Opportunistic	Inactive mound

Species	Location			Comments*
	Easting	Northing	Site	
Western Pebble-mound Mouse	676489	7433398	Opportunistic	Inactive mound
Western Pebble-mound Mouse	676600	7433391	Opportunistic	Inactive mound
Western Pebble-mound Mouse	664911	7437248	Opportunistic	Inactive mound
Western Pebble-mound Mouse	690846	7442070	Opportunistic	Inactive mound
Birds				
Fork-tailed Swift	666240	7436475	GWA S7	Large flock of 400 individuals
Fork-tailed Swift	666240	7436475	GWA S7	40 individuals
Fork-tailed Swift	687325	7432923	GWA S3	10 individuals
Fork-tailed Swift	690270	7434157	GWA S4	70 individuals
Fork-tailed Swift	678869	7433283	Opportunistic	Eight individuals
Fork-tailed Swift	673382	7440840	Opportunistic	15 individuals
Fork-tailed Swift	687325	7432923	GWA S3	10 individuals
Australian Bustard	683491	7441236	Opportunistic	1 individual
Australian Bustard	673255	7440353	Opportunistic	1 individual
Australian Bustard	671862	7439462	Opportunistic	1 individual
Bush Stone-curlew	687166	7433154	GWA S3	Tracks only
Reptiles				
Underwoodisaurus seorsus	690650	7441655	GWA S1	One individual captured

Zone 50K;

Datum WGS 84

*Individuals = animals seen at the same time and, therefore, numbers are confirmed. Records = may be separate bird surveys or different days at a trap site and, therefore, some individuals may have been observed multiple times.

4.5 INVERTEBRATE SHORT RANGE ENDEMIC FAUNA RECORDED

A total of 33 species from six different Orders were submitted for identification and for SRE status assessment. A total of 15 species were identified as potential SRE species. The results and SRE status of submitted specimens are summarised in Table 4.5, with the location of potential SRE species mapped in Figure 4.16.

The results of potential SRE specimens submitted comprised the following: four species from two families of spiders (two potential SRE), six species from two families of scorpions (one potential SRE), 10 species from two families of isopods (six potential SRE), five species from three families of snails (no SRE), five species from one family of pseudoscorpions (four potential SRE) and three species from three families of millipedes and centipedes (two potential SRE).

Table 4.5 – SRE fauna results

Higher Taxon	Species	SRE status	Individuals (M/F/J)*	Method	Site^
Mygalomorphae (trapdoor spiders)					
Barychelidae	*Aurecocrypta* sp. indet.	Potential	0/0/1	Opportunistic capture	GWA S11
	Synothele 'MYG127'	Not SRE	1/0/0	Dry pitfall	GWA S2
Nemesiidae	*Aname mellosa*	Not SRE	2/0/0	Dry pitfall	GWA S10
	Yilgarnia 'MYG197'	Potential	1/0/0	Dry pitfall	GWA S7
Scorpiones (scorpions)					
Buthidae	*Lychas* sp. 'harveyi'	Not SRE	7/1/0	Dry pitfall	GWA S3, S4 ,S5, S10, S11, S12
	Lychas sp. 'pilbara1'	Not SRE	15/1/1	Dry pitfall	GWA S1, S2, S4, S5, S9
	Lychas bituberculatus	Not SRE	0/2/0	Dry pitfall	GWA S7
	Lychas sp. 'hairy tail'	Not SRE	1/0/0	Dry pitfall	GWA S2
	Isometroides 'pilbara1'	Not SRE	1/0/0	Dry pitfall	GWA S8
Urodacidae	*Urodacus* sp. indet.	Potential	0/0/10	Targeted dry pitfall	GWA Opp, S3
Isopoda (Isopods)					
Armadillidae	*Buddelundia* sp. nov. '10 1458A'	Potential	33/35/2	Dry pitfall	GWA S1, S2, S3, S4, S5, S6, S7, S9, S10, S12
	Buddelundia sp. nov. '10 1458B'	Potential	5/4/0	Dry pitfall	GWA S1, S5, S10, S11
	Buddelundia sp. nov. '10 1458C'	Potential	0/1/0	Dry pitfall	GWA S1
	Buddelundia sp. nov. '10 1458D'	Potential	3/1/0	Dry pitfall	GWA S2
	Buddelundia sp. nov. '15'	Not SRE	2/1/0	Dry pitfall	GWA S3, S4, S7
	Buddelundia sp. nov. '16'	Not SRE	5/7/2	Dry pitfall, forage	GWA S1, S2, S6, S7, Opp
	Buddelundia sp. nov. '68WA'	Potential	1/1/0	Dry pitfall, forage	GWA S5, FS1
	Buddelundinae genus ident. Buddelundinae 'PES999'	Not SRE	1/5/0	Dry pitfall	GWA FS4, S4, S6
	New genus. (close to *Buddelundia*) sp. nov. '1'	Not SRE	1/3/0	Dry pitfall	GWA S5, S8, S10

Higher Taxon	Species	SRE status	Individuals (M/F/J)*	Method	Site^
Unknown	Genus indet. sp. indet.	Potential	1/0/0	Dry pitfall	GWA S5
Molluscs (Snails)					
Bothriembryontidae	*Bothriembryon* sp. nov. 'Pilbara'	Not SRE	4	Leaf litter	GWA FS4
Pupilidae	*Gastrocopta mussoni*	Not SRE	12	Leaf litter	GWA FS3, FS4
	Gastrocopta cf. *hedleyi*	Not SRE	12	Leaf litter	GWA S1
	Pupoides cf. *pacificus*	Not SRE	11	Leaf litter	GWA FS4, S9, S12
Subulinidae	*Eremopeas interioris*	Not SRE	15	Leaf litter	GWA S1, S2
Pseudoscorpiones (Pseudoscorpions)					
Olpiidae	*Beierolpium* sp. indet.	Potential	0/0/1	Leaf litter	GWA S1
	Euryolpium sp. indet.	Potential	0/0/1	Leaf litter	GWA S3
	Indolpium sp. indet.	Unlikely	1/0/0	Leaf litter	GWA S11
	Xenolpium sp. indet.	Potential	5/4/1	Dry pitfall, Leaf litter	GWA S1, S2, S5, S7, S9, S11, FS4
	Genus indet. sp. indet.	Potential	0/0/3	Dry pitfall, forage	GWA Opp, S1, S6
Diplopoda (Millipedes and centipedes)					
Trigoniulidae	*Austrostrophus stictopygus*	Not SRE	3/3/3	Forage	GWA Opp, S2
Geophilidae	Genus ident. sp. indet.	Potential	0/0/1	Forage	GWA S2
Chilenophilidae	Genus ident. sp. indet.	Potential	0/0/1	Forage	GWA S2

*M=Male, F=Female, J=Juvenile

^Site FS = Forage Site

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