ENVIRONMENTAL OFFSETS STRATEGY

VULCAN SOUTH

Tenure number: ML700073

February 2023

Prepared for:	Department of Agriculture, Water and the Environment
Prepared by:	Mining and Energy Technical Services Pty Ltd
EA holder:	Queensland Coking Coal Pty Ltd and QLD Coal Aust. No 1 Pty Ltd
Document ID:	303523
Version:	1.0
Date of Submission:	

+ 61 7 3174 4816 | info@vitrinite.com.au
vitrinite.com.au

PO Box 87, Morningside Q 4170
+ 61 7 3174 4816 | info@vitrinite.com.au

Suite 2, Level 6, Blue Tower
12 Creek Street, Brisbane Q 4000

VITRINITE PTY LTD
ABN 46 167 744 578

Table of Contents

List of Figures

List of Tables

1 Introduction

Vulcan South is an open-cut and highwall coal-mining operation proposed by Vitrinite Pty Ltd between Dysart and Moranbah, in the Bowen Basin of Queensland. It is located on lots 2SP296877, 59SP235297, 72SP137467, 26CNS125 and 2CNS109, and within mining lease ML700073 (**Figure 1-1**). Due to significant residual impacts of Vulcan South on matters of national environmental significance (MNES), the project is being referred to the Department of Climate Change, Energy, the Environment and Water (DCCEEW) for assessment under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). It is anticipated that Vulcan South will be considered a controlled action by DCCEEW and environmental offsets will be required to ensure the project does not result in a net loss to any MNES.

To achieve these environmental offsets, Vitrinite Pty Ltd intends to procure, protect and restore areas of land that support the matters that will be impacted by Vulcan South. Identification of suitable land to achieve these goals is still in progress, so a draft Offset Area Management Plan (OAMP) cannot yet be developed. Instead, Vitrinite Pty Ltd has developed this Environmental Offsets Strategy to articulate and commit to a process that will be undertaken to identify and assess suitable offset sites, and to prepare a draft OAMP for approval prior to the commencement of any disturbance resulting from the amendment.

1.1 Commonwealth Government Requirements

MNES are protected under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Significant impacts to MNES must be compensated through the delivery of environmental offsets in accordance with the *EPBC Act Environmental Offsets Policy* (Department of Sustainability, Environment, Water, Population and Communities 2012). This policy states that an environmental offset must "deliver an overall conservation outcome that improves or maintains the viability of the protected matter as compared to what is likely to have occurred under the status quo".

The Offsets Assessment Guide, an Excel spreadsheet-based calculator, was developed by the Commonwealth Government to assist in the determination of suitable offsets. When assessing impacts of the neighbouring Vulcan Coal Mine (referral 2020/8676), the Commonwealth Government requested that, "to inform the inputs of the Offsets Assessment Guide… [quality is to be assessed] using the *Queensland Guide to Determining Terrestrial Habitat Quality".*

The Species Profile and Threats (SPRAT) database provides ecological information about species and ecological communities listed under the EPBC Act, and impact assessments and offset designs are to consider this information.

Approval for a project under the EPBC Act requires that environmental offsets and the associated Offset Area Management Plan (OAMP) are approved by the Minister for the Environment, and legally secured, prior to the commencement of any disturbance to MNES.

Figure 1-1 Project location

1.2 Queensland Government Requirements

Significant impacts to prescribed environmental matters must be offset in accordance with the *Environmental Offsets Regulation 2014*. Prescribed environmental matters include MNES protected by the EPBC Act, as well as some matters of state and local environmental significance. Matters of state environmental significance that are prescribed environmental matters are listed in Schedule 2 of the *Environmental Offsets Regulation 2014.* This regulation also prescribes the *Queensland Environmental Offsets Policy version 1.9*, which clarifies how environmental offsets should be delivered in Queensland.

As stated in section 1.1.3 of the *Queensland Environmental Offsets Policy version 1.9*, state governments can only impose an offset condition in relation to a prescribed activity if the same or substantially the same impact and the same or substantially the same matter has not been subject to assessment under a Commonwealth Act. Offsets are therefore only required under the Queensland framework in the following two instances:

- when the prescribed environmental matters that experience significant residual impacts are not MNES; and/or
- when the Commonwealth Government decided that the activity was not a controlled action, yet residual impacts to a matter of both state and national environmental significance qualify as significant under Queensland definitions (as defined within the *Queensland Environmental Offsets Policy Significant Residual Impact Guideline*: DEHP 2014).

Some "Of Concern" and watercourse vegetation to be disturbed by Vulcan South are matters of state environmental significance that are not also MNES. Likewise, the impact of Vulcan South on connectivity is a state matter. These will require environmental offsets under the Queensland framework separate to the federal offsets addressed by this Environmental Offsets Strategy.

1.3 Location

1.3.1 Impact Area

Vulcan South lies within the Brigalow Belt Bioregion. Most of the mining lease is located within the Northern Bowen Basin subregion, although the clay plains in the centre of the lease are contained within the Isaac-Comet Downs subregion.

Vulcan South falls within the local government area of the Isaac Regional Council. It lies adjacent to Saraji Road, midway between Moranbah and Dysart. The land tenure is leasehold and has historically been used primarily for cattle grazing. The project area is bounded to the north and east by proposed and existing coal mining operations and existing transport infrastructure (Saraji Road and the Goonyella railway line) run along the eastern edge of the mining lease, within the lease.

The ML 700073 permit application created for Vulcan South covers an area of approximately 3,824 hectares (ha).

1.3.2 Suitable Offset Location

As stated within the *EPBC Act Environmental Offsets Policy*, "*in most cases* [a suitable location for an offset site] *will be as close to the impact site as possible. However, if it can be shown that a greater conservation benefit for the impacted protected matter can be achieved by providing an offset further away, then this will be considered*."

Not only must suitable offset areas be located near the impact area, but the tenure of this land is important, as this affects the risk that habitat will be lost in the future without the additional protection afforded by offsets. Offsets are only suitable for areas of land that are not fully protected from clearing by other laws or legal instruments.

Even though remnant vegetation is protected in Queensland as category B regulated vegetation under the *Vegetation Management Act 1999* (VM Act), a small amount of clearing occurs annually through exempt works and illegal activities. The rate of clearing differs between tenure types (**Table 1-1**). Of the dominant land tenures in Queensland, background clearing rates of remnant vegetation are highest on freehold land, followed by leasehold. These tenures therefore stand to benefit most from the additional protection afforded by offsets. These patterns are reversed for regrowth vegetation; category C and X vegetation under the VM Act has a two to three times higher risk of clearing on leasehold than freehold land (**Table 1-2**).

Offset areas containing large amounts of non-remnant vegetation (category C, R and X vegetation under the VM Act) stand to benefit most from protection, as such vegetation is less fully protected (category C and R) or not protected (category X) under the VM Act, and experience high rates of re-clearing to maintain open landscapes for agriculture. Category C vegetation has, on average, twice the risk of clearing as remnant vegetation (category B), while category X vegetation has, on average, four times the risk (**Table 1-2**).

Table 1-1 *Clearing rates of remnant vegetation per tenure type in the Brigalow Belt Bioregion since the introduction of the* Vegetation Management Act 1999

Tenure	Percent of remnant vegetation that was cleared between 1999 and 2019*					
	Land Zone					Total
	3: Alluvial	4: Clay Plain	5: Sand Plain	9: Siltstone	10: Sandstone	
Freehold	9.40%	18.26%	17.71%	9.52%	6.75%	11.56%
Leasehold	7.02%	14.86%	16.11%	9.05%	4.48%	8.01%
State Forest	0.38%	0.16%	0.18%	0.82%	0.36%	0.30%
National Park	0.00%	0.04%	0.26%	0.18%	0.03%	0.05%

*Values represent the average of the Brigalow Belt Bioregion since the enactment of the *Vegetation Management Act 1999*, as reported by Accad *et al.* (2022).

Table 1-2 *Clearing rates of all vegetation types within the Brigalow Belt Bioregion between 2015 and 2018*

Land zone	Class under the VM Act*	Percent of vegetation class that was cleared between 2015 and 2018†	
		Freehold	Leasehold
3: Alluvial	Category B: Remnant vegetation	1.40%	1.38%
	Category C: High-value regrowth	0.53%	1.61%
	Category X: No protection	1.46%	3.00%
5: Sand Plain	Category B: Remnant vegetation	1.45%	1.16%
	Category C: High-value regrowth	0.62%	2.69%
	Category X: No protection	4.79%	5.08%
10: Sandstone	Category B: Remnant vegetation	1.27%	0.65%
	Category C: High-value regrowth	1.57%	6.08%
	Category X: No protection	4.34%	7.92%

*Category R regulated vegetation (regrowth along watercourses) was not recognised under the VM Act during the period of data collection, so is not included.

†Data was calculated by overlaying the Statewide Landcover and Trees Study (SLATS) clearing data for the periods 2015-2016 and 2016-2017 with version 10 of regional ecosystem mapping, and SLATS data for 2017-2018 with version 11 of regional ecosystem mapping. This ensured that the clearing data corresponded with the vegetation present at the start of each period. This analysis will be repeated for other land zones and to include the latest year of SLATS data, to inform the baseline risk of loss at prospective offset sites.

A suitable offset area for Vulcan South is one that:

- is located within Isaac Regional Council area, the Northern Bowen Basin subregion or Isaac-Comet Downs subregion. If no suitable offset area can be located within these areas, an alternate location will be chosen that lies within the northern half of the Brigalow Belt Bioregion;
- has freehold or leasehold tenure; and
- contains some areas with category C and X vegetation under the VM Act.

1.4 Matters Requiring Offsets

A Terrestrial Ecological Assessment (METServe 2022) has examined the environmental values in and near the project area. The significance of impacts of Vulcan South on MNES was assessed against the *Matters of National Environmental Significance Significant Impact Guidelines 1.1* (Department of the Environment, Water, Heritage and the Arts 2013) within the EPBC Act referral documentation accompanying this Environmental Offsets Strategy. This assessment determined that the following listed threatened species and ecological communities are likely to experience significant residual impacts as a result of Vulcan South:

- Koala (combined populations of Queensland, NSW and the ACT), *Phascolarctos cinereus* (endangered);
- Squatter Pigeon (southern subspecies), *Geophaps scripta scripta* (vulnerable);
- Central Greater Glider, *Petauroides armillatus* (endangered); and
- Brigalow (*Acacia harpophylla* dominant and co-dominant) ecological community.

Negligible residual impacts to other MNES are anticipated.

The three species listed above are also listed as endangered and vulnerable respectively under the *Nature Conservation Act 1992*, while the regional ecosystems that comprise the Brigalow ecological community are listed as endangered under the *Vegetation Management Act 1999.* If Vulcan South is not considered a controlled action under the EPBC Act, offsets may be required within the Queensland framework. As offsets for the same matters and impacts will be a likely condition of approval under the EPBC Act, there are no additional requirements under Queensland legislation regarding offsets for these three species.

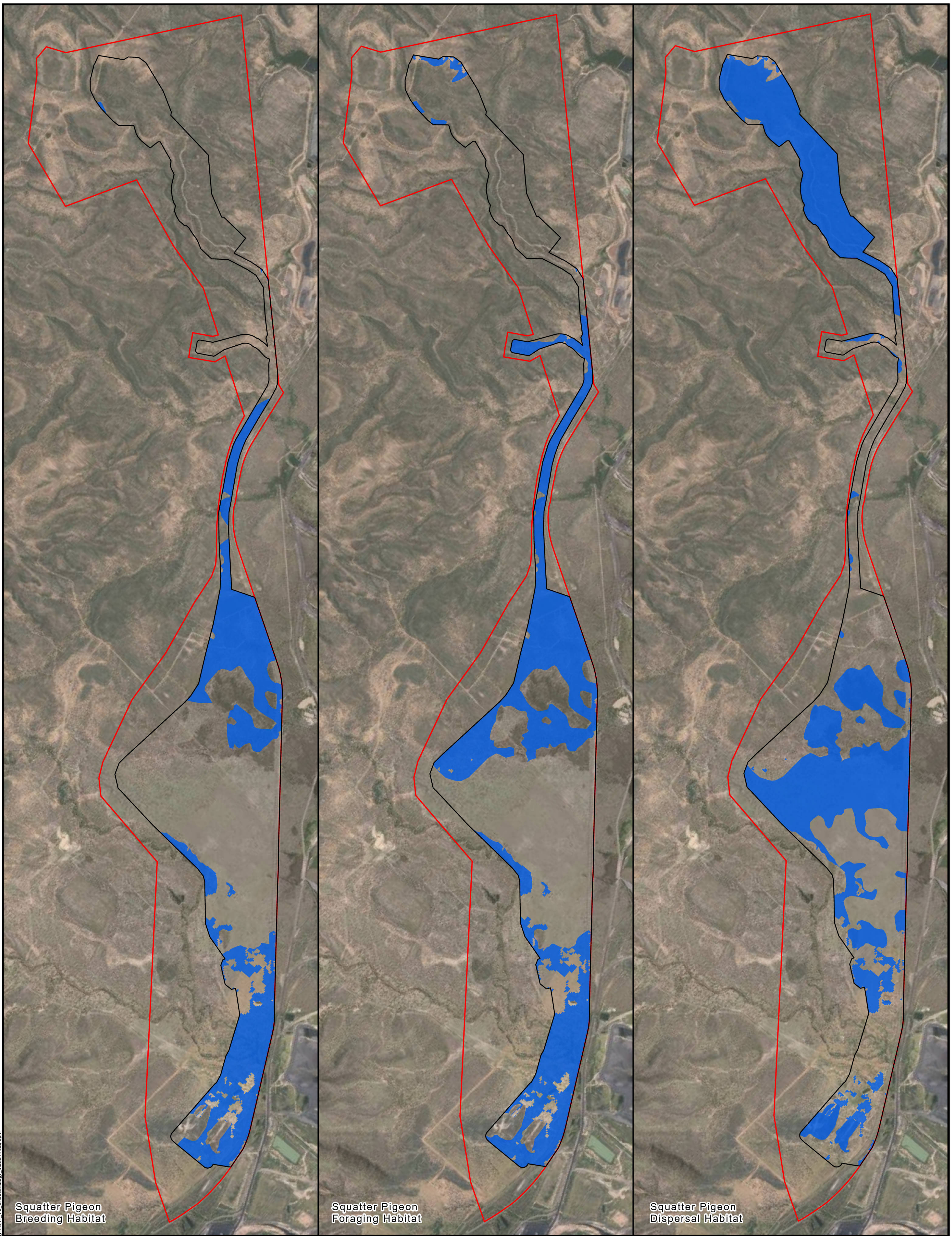
The size of impacts to each matter depends on the amount and quality of habitat for each species that will be disturbed/removed. How quality will be assessed is discussed in **Section 3** of this Environmental Offsets Strategy. The "matter area" for each habitat type is the area that contains or represents the extent of an individual prescribed environmental matter. Matter areas typically comprise a fraction of the total disturbance footprint, and matter areas pertaining to different matters or habitat types can partly or fully overlap. Matter areas are the impact footprints identified in the Terrestrial Ecological Assessment (METServe 2022). The area and location of each matter area is shown on **Table 1-3, Figure 1-2** and **Figure 1-3**.

Vulcan South has a life of nine years, although the duration of impacts (time until habitat has been effectively restored on the rehabilitated mined land) is expected to be 23 years for the Koala, Central Greater Glider and Squatter Pigeon (refer to the referral for details). The Progressive Rehabilitation and Closure Plan (PRCP) for Vulcan South includes rehabilitation completion criteria reflecting habitat for the Koala, Greater Glider and Squatter Pigeon.

Table 1-3 Size of matter areas within the impact site

Prescribed Matter		Size of Matter Area (ha)
Brigalow (*Acacia harpophylla* dominant and co-dominant) ecological community		120.3
Koala		1,023.6
Central Greater Glider		71.1
Squatter Pigeon:	Foraging Habitat	671.2
	Breeding Habitat*	426.8
	Dispersal Habitat	692.9

*All breeding habitat for the Squatter Pigeon overlaps with foraging habitat



Legend

- MLA Area
- Impact Site
- Matter Area

Vulcan South

Squatter Pigeon Matter Areas

0 1 2

Kilometers

Scale: 1:62,000 (A3)

18/08/2022

N

Datum: GDA2020
Projection: MGA55

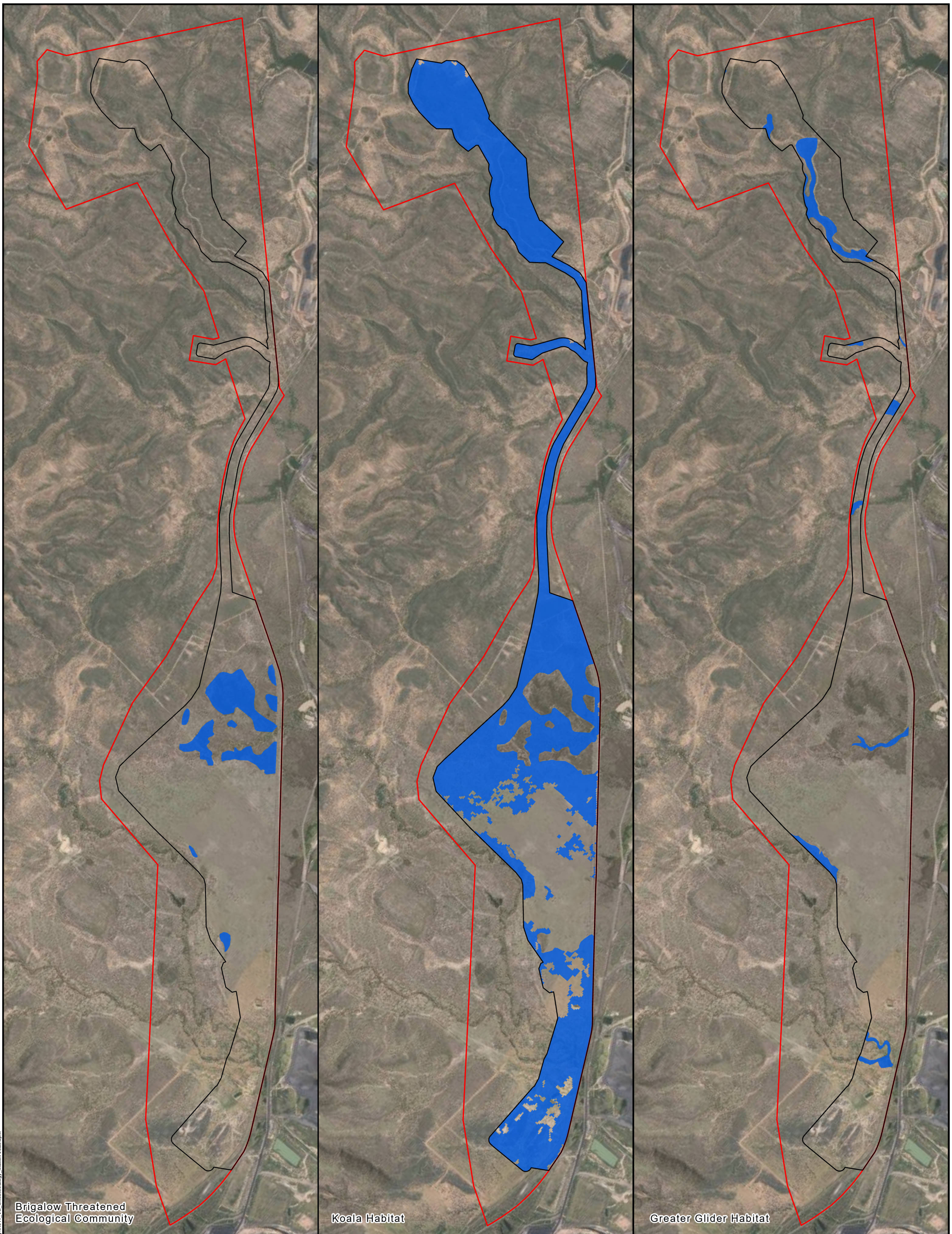
FIGURE 1-2

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Source: Vitrinite 2022, METServe 2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Offset_Strategy\VI011_VS_OffsetStrategy_MatterAreas.aprx



Legend

- MLA Area
- Impact Site
- Matter Area

Source: Vitrinite 2022, METServe 2022, Earthstar Geographics.

Vulcan South

Matter Areas for Brigalow, the Koala and the Greater Glider

0 1 2
Kilometers
Scale: 1:62,000 (A3)

18/08/2022

N
Datum: GDA2020
Projection: MGA55

FIGURE 1-3

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

2 Habitat Needs of Listed Species

The Offsets Assessment Guide requires evidence-based habitat quality scores for the impact and offset areas. Habitat quality is to consider site condition, site context and species stocking rates, but no federal guidelines or manuals exist that prescribe how habitat quality is to be assessed. During assessment for the neighbouring Vulcan Coal Mine, the Commonwealth Government requested that, "to inform the inputs of the Offsets Assessment Guide… [quality is to be assessed] using the Queensland *Guide to Determining Terrestrial Habitat Quality*". A similar approach will be taken to assess habitat quality of the footprint of Vulcan South.

The *Guide to Determining Terrestrial Habitat Quality version 1.3* (Department of Environment and Science 2020a) recommends undertaking a comprehensive literature review of the species to identify the factors that constitute, and have the ability to affect, the following components of habitat quality:

- Quality and availability of food and habitat required for foraging;
- Quality and availability of habitat required for shelter and breeding;
- Quality and availability of habitat required for mobility; and
- Exposure to threats.

The following subsections summarise key habitat requirements of the Koala, Central Greater Glider and Squatter Pigeon.

2.1 Koala

Koala populations within Queensland, New South Wales and the Australian Capital Territory are listed as endangered under the EPBC Act as of February 2022. Koalas were recorded 11 times within the project area, and three times in areas immediately west in a survey conducted in February 2019. There is no recovery plan in place for the species. However, the Commonwealth Government has provided advice about the species' ecology and priority actions to mitigate key threats within the SPRAT profile for the species (DCCEEW 2022a).

2.1.1 Habitat Requirements

On the western slopes, tablelands and plains in Queensland, Koalas are found in sub-humid *Eucalyptus*-dominated forests and woodlands in riparian and non-riparian environments, and some *Acacia*-dominated forests and woodlands in non-riparian environments (DCCEEW 2022a). The main habitat requirement is availability of suitable food trees and, to a lesser extent, shelter trees, which tend to have shadier foliage, be taller and/or be located in sheltered locations in gullies (Crowther *et al.* 2013).

Food

While Koalas have been observed sitting in or eating up to 120 species of eucalypt (Phillips 1990), the diet of individual Koalas is usually limited to one or a few species (Moore and Foley 2000). Preferences also vary between regions or seasons (Moore and Foley 2000). Chemical anti-feedants, soil nutrients and leaf water content in semi-arid areas may limit or prevent koalas feeding on foliage of individual trees even when the species is considered preferred (Lawler *et al.* 1998; Moore *et al.* 2005). In the northwest of their range in Queensland (including the project area), Koala distribution is limited by heat and water availability, with the highest densities of Koalas occurring along creek lines (Munks *et al.* 1996; Sullivan *et al.* 2003). Variability in leaf nutrition creates patchiness such that species-based assessments of habitat likely overestimate the availability of high-quality habitat (Threatened Species Scientific Committee 2012).

Despite limitations in habitat mapping caused by varying leaf nutrition, a conservative approach to habitat mapping is appropriate, which assumes that any individuals of tree species known to be eaten by Koalas could constitute a potential food tree. Likewise, the SPRAT profile defines Koala habitat as "any forest or woodland containing species that are known Koala food trees, or shrubland with emergent food trees"

(DCCEEW 2022a). These vegetation types need not be defined as remnant vegetation to be used extensively by Koalas (Barth *et al.* 2019). Assessment of habitat quality for Koalas therefore relies on the identification of local preferences for species and the quantification of the availability of those species (DCCEEW 2022a).

The Australian Koala Foundation (2015) maintains a database that lists seven food species used by Koalas within the Isaac Regional Council area. *Eucalyptus camaldulensis* and *Eucalyptus tereticornis* are considered to be the primary food trees. Secondary food trees include *Eucalyptus brownii*, *Eucalyptus coolabah*, *Eucalyptus ochrophloia*, *Eucalyptus orgadophila* and *Eucalyptus populnea*. Of these species, *E. camaldulensis, E. populnea* and *E. orgadophila* are found within the impact area.

The Australian Koala Foundation (2015) acknowledges that *Eucalyptus crebra* can sometimes constitute an additional secondary food species in localised areas with better soils and nutrient availability. Given that this tree species is eaten by Koalas at nearby sites (Ellis *et al.* 2002; Melzer *et al.* 2014), it is conservatively considered a food tree for the purposes of habitat mapping. This species is widespread across the impact area and surrounding region, being a dominant component of most of the ecosystems occurring on site. Given the low fertility of local sandy soils, it is unlikely that most local *E. crebra* is utilised to a significant extent by Koalas. Nevertheless, in accordance with the SPRAT definition of Koala habitat (i.e., any forest or woodland containing species that are known Koala food trees), vegetation containing *E. crebra* is included as potential habitat.

In addition to tree species, tree size is an important factor affecting the quality of foraging habitat (e.g., Callaghan *et al.* 2011; Smith *et al.* 2013), presumably because larger trees possess a greater quantity of food, and individuals feeding in large trees do not need to move between different food trees as often. Trees with a trunk diameter at 1.3 m height of >10 cm are used by Koalas, but trees with a diameter >30 cm are used to a significantly greater extent (Callaghan *et al.* 2011).

Both the quantity and quality of potential food affect Koalas. Directly measuring the amount of food available to Koalas within a habitat patch is onerous and destructive (usually involves the felling and measurement of leaf biomass of whole trees: Burrows *et al*. 2000). However, studies of *E. crebra* and *E. populnea* elsewhere in central Queensland have shown that trunk circumference is highly correlated to leaf biomass in these species (Burrows *et al.* 2000), as it is for other tree species (Catchpole and Wheeler 1992). Furthermore, the relationship is remarkably congruent between eucalypt species (Burrows *et al*. 2000), suggesting that measuring trunk basal areas of food trees within a habitat patch (a simple and widely used technique for assessing vegetation structure) is a valid proxy for the total quantity of food available to Koalas in an area.

The quality of available food is reflected by the proportion of trees that are primary food trees—a strong predictor of Koala presence elsewhere in Queensland (McAlpine *et al.* 2006)—and the density of "large" food trees (as defined by Department of Science, Information Technology, Innovation and the Arts (2015) in the *BioCondition Assessment Manual version 2.2*).

Shelter

Koalas often select non-food trees in which to shelter during the day, especially during hot weather. Shelter trees tend to have shadier foliage, be taller and/or be located in sheltered locations in gullies (Crowther *et al.* 2013). However, the minimum height or shadiness for a tree to be considered a shelter tree has not been published. Definitions of shelter trees (for the purposes of habitat quality assessment) have been developed based on available data, which are discussed below.

The *Queensland Environmental Offsets Policy* considers non-juvenile Koala habitat trees to be those with a height greater than 4 m or a trunk diameter (1.3 m above ground) greater than 10 cm (Department of Environment and Science 2020b). This broadly accords with the findings of Callaghan *et al.* (2011), who found utilisation of trees with a diameter as small as 10-20 cm. However, White (1999) found that trees with a diameter less than 15.5 cm were rarely utilised.

Shelter trees are known to be larger than food trees (Crowther *et al.* 2013; Callaghan *et al.* 2011; Marsh *et al.* 2014), and defining these based on larger minimum sizes is appropriate. Marsh *et al.* (2014) found that shelter trees have trunk diameters that are, on average, 55% larger than feeding trees. Trunk diameter has a roughly linear relationship with tree height for most *Eucalyptus* species (particularly young trees), such that a doubling of diameter is associated with a doubling in height (Bernardo *et al.* 1998). Based on this limited data, for the purposes of habitat assessment at Vulcan South, a potential Koala shelter tree is at least 6 m tall.

Non-food trees used for shelter tend to have dense crowns that cast heavy shade (Ellis *et al.* 2010; Crowther *et al.* 2013). Based on estimates of the typical canopy density of non-food species known to be used by Koalas (e.g., *Casuarina* spp., *Callitris* spp., *Brachychiton populneus, Acacia harpophylla, Endiandra sieberi, Melaleuca* spp.: Ellis *et al.* 2010; Callaghan *et al.* 2011; Crowther *et al.* 2013), shelter trees are defined as having a minimum foliage projective cover of 75%. Given that Koalas prefer to shelter in the largest trees, an abundance of "large" non-food trees (as defined by Department of Science, Information Technology, Innovation and the Arts (2015) in the *BioCondition Assessment Manual version 2.2* is likely to be an additional indicator of the existence of favourable shelter sites.

In addition to the presence of specific trees with physical characteristics that make them valuable as Koala shelter sites during the day, the overall vegetation density reflects a measure of protection, as it is negatively proportional to the distance Koalas must move across the ground (when highly vulnerable to predation) between trees.

Mobility

Koalas have extensively overlapping home ranges. These vary in size from 10-30 ha in coastal areas of New South Wales (Lassau *et al.* 2008) to 100-135 ha at Blair Athol in central Queensland (Ellis *et al.* 2002). Home ranges in the impact and offset areas are likely to be similar in size to that recorded at Blair Athol, given the proximity.

Koalas move an average of 50 m during a single night, and habitat patches separated by gaps narrower than 50 m represent effectively connected habitat units (Rus *et al.* 2020). In fragmented rural landscapes of subcoastal south-eastern Queensland, telemetry records that were at least 30 days apart showed that 50% of movements were between 200 and 500 m, a further 35% were between 500 m and 1 km, and the remainder were less than 5 km (White 1999). This study revealed home ranges up to 94.1 ha in size (White 1999), which are comparable to findings at Blair Athol, suggesting that these movements are likely to be representative of the Vulcan South region. In rural south-eastern Queensland, White (1999) found that Koalas regularly moved between habitat patches separated by up to 2 km of cleared paddocks, such that the spatial configuration and inter-patch distance was of minor importance compared with the total area of habitat. However, in a mixed urban-rural landscape at Noosa, a landscape with more numerous, smaller patches is less likely to be occupied than one with fewer, larger patches (McAlpine *et al.* 2006). This is consistent with a higher risk from domestic dogs and vehicles to dispersing Koalas in urban environments. At Noosa, the amount of forest within 1 km was one of the strongest predictors of habitat use by Koalas (McAlpine *et al.* 2006). Habitat patch size had a moderately positive effect on occupation by Koalas, while forest patch density, mean nearest neighbour distance and road density all had moderate negative effects on the probability of koala occurrence (McAlpine *et al.* 2006).

Dispersing individuals can occasionally cover distances of several kilometres over land with little vegetation; however, this places them at higher risk of predation. The average distance between natal and breeding home ranges is 3.5 km, although maximum dispersal distances of 9-16 km have been recorded (DCCEEW 2022a; White 1999).

In light of the above information, the main factor that affects the ability of Koalas to move within rural landscapes is the existence of large (>2 km) treeless areas through which Koalas are reluctant to move and are vulnerable to predation if they do. Smaller habitat gaps are unlikely to constitute a significant barrier to movement.

Threats

The chief threats to the Koala are habitat clearing, vehicle strike, predation by domestic and feral dogs, drought and disease (DCCEEW 2022a). In rural areas of Queensland with low densities of human habitation (such as the impact site), habitat clearing and drought are the principal threats, with vehicle strikes and dog attacks being localised threats (near roads and human habitation, respectively).

The threat of habitat loss through clearing is accounted for in the Offset Assessment Guide calculator independently of habitat quality. Consequently, only those threats that contribute to habitat quality scores are discussed further.

In rural landscapes on the Sunshine Coast, Queensland, McAlpine *et al.* (2006) found that the density of sealed roads within 1 km was a predictor of Koala presence. Given that a home range of 100 ha (a reasonable expectation at Vulcan South: refer to **Mobility**) has an average diameter of 1.1 km, roads located within 1 km of a nominated location are likely to represent a threat to Koalas inhabiting that location.

The density of dogs is relatively low in sparsely populated areas, such as the impact site, but may be high in potential offset sites if these are located near human habitation. Wild-roaming dogs have home ranges of 10 km^2 to 272 km^2 (radius of 1.8 km to 9.3 km) (Robley *et al.* 2010; McNeill *et al.* 2016). This implies that any site within 18 km of human habitation (or other sources of supplementary food, such as dumps, mine camps, etc) could have elevated dog densities as a result of access to this nearby food. Distance from supplementary food and the existence of current control programs are the principal factors dictating risk from dog attack in rural Queensland. In some parts of southeast Queensland, attacks from wild dogs and dingos are the leading cause of Koala mortality (Beyer *et al.* 2017).

The prevalence of disease in local Koala populations is unknown, but this threat is likely to vary little geographically (*Chlamydia* is thought to be present in all Koala populations on the mainland of the eastern states: DCCEEW 2022a) and little can be done to manage this threat at offset sites. It is therefore not considered important when assessing variation in threat level between different habitat patches.

Drought is an important threat to Koalas in semi-arid regions such as the impact site. Droughts lead to widespread mortality, and the regional persistence of Koalas exposed to regular drought may rely on the protection of refugial habitats around waterholes and creeks, where high leaf moisture levels are maintained during drought (Gordon *et al.* 1988; DCCEEW 2022a). Koalas obtain most of their dietary water from foliage but need to drink in extreme climatic conditions (Mella *et al.* 2019). Proximity to water is therefore important during drought, both as a source of drinking water and because nearby trees have leaves with higher moisture content.

Droughts are forecast to become increasingly frequent and severe with climate change. CSIRO's (2021) Climate Analogues Tool forecasts Moranbah's climate to be analogous to that of Hughenden, QLD by 2050. Hughenden is currently the western limit for the distribution of Koalas, where they are confined to the vicinity of watercourses (Melzer *et al.* 2014). Habitat modelling by Adams-Hosking *et al*. (2011) supports the notion that the Moranbah region will represent the western limit of the species' distribution by 2050 and will be uninhabitable by 2070. If Koalas are to persist locally in the face of climate change, riparian vegetation and access to permanent surface water will become increasingly important.

2.2 Squatter Pigeon

The southern subspecies of the Squatter Pigeon is listed as vulnerable under the EPBC Act. This species was recorded widely within the project's ML and in surrounding areas. There is no recovery plan in place for the species. However, the Commonwealth Government has provided advice about the species' ecology and priority actions to mitigate key threats within the conservation advice (Threatened Species Scientific Committee 2015) and the SPRAT profile for the species (DCCEEW 2022b).

2.2.1 Habitat Requirements

The Squatter Pigeon is a ground-dwelling bird that inhabits the grassy understorey of open eucalypt woodland, and less often savannas. It also inhabits altered landscapes such as improved pastures, beside railway lines and around settlements (Threatened Species Scientific Committee 2015). It often occurs in burnt areas and is sometimes found on tracks and roadsides (Threatened Species Scientific Committee 2015a). It is nearly always found near permanent water such as rivers, creeks and waterholes (Threatened Species Scientific Committee 2015). Sandy areas dissected by gravel ridges, which have open and short grass cover, allowing easy movement, are preferred (Threatened Species Scientific Committee 2015). It is less commonly found on heavier soils with dense grass (Threatened Species Scientific Committee 2015).

Provided land is not overgrazed, Squatter Pigeons coexist readily with cattle grazing; however, the species has largely disappeared from the southern part of its distribution (e.g., New South Wales and southern Queensland), where sheep grazing is widespread and rabbit densities are high (Threatened Species Scientific Committee 2015).

Food

The SPRAT profile defines foraging habitat for the Squatter Pigeon as remnant or regrowth open-forest to sparse, open-woodland or scrub dominated by *Eucalyptus*, *Corymbia*, *Acacia* or *Callitris* species, on sandy or gravelly soils (Queensland land zones 5 and 7), within 3 km of a suitable, permanent or seasonal waterbody (DCCEEW 2022b).

Squatter Pigeons feed on seeds among sparse and low grass (Threatened Species Scientific Committee 2015). Typically, the ground-covering vegetation layer in foraging habitat is considerably patchy, consisting of native, perennial tussock grasses or a mix of perennial tussock grasses and low shrubs or forbs. This patchy, ground layer of vegetation rarely exceeds 33% of the ground area (DCCEEW 2022b). The remaining ground surface consisting of bare patches of gravelly or dusty soil and areas lightly covered in leaf litter and coarse, woody debris. Excessive densities of ground layer vegetation and/or litter reduce the quality of foraging habitat by impeding movement or obscuring fallen seed.

A wide diversity of different seeds are eaten by Squatter Pigeons, with plants in the families Fabaceae (peas) and Poaceae (grasses) being the most important (Crome 1976). Both native and introduced species are consumed, with exotic pasture legumes (especially *Stylosanthes* spp.) comprising 30% of the diet in northern Queensland (Crome 1976). Favourable habitats are those where a broad diversity of grasses and forbs grow in the understorey, providing a year-round supply of seed.

Squatter Pigeons drink at least once a day, and prefer to drink where there is gently sloping, bare ground on which to approach and stand at the water's edge (DCCEEW 2022b). Such habitat may occur in permanent or seasonal rivers, creeks, lakes, ponds, waterholes and artificial dams (DCCEEW 2022b). Squatter Pigeons have also been recorded drinking from raised cattle troughs (Adani and GHD 2015).

Shelter and Nesting

The Squatter Pigeon nests on the ground, usually laying two eggs among or under vegetation (Threatened Species Scientific Committee 2015). Breeding habitat occurs on rises occurring on sandy or gravelly soils, within 1 km of a suitable, permanent waterbody (DCCEEW 2022b). The structure of the vegetation in favourable breeding habitat is as described for foraging habitat.

When disturbed, Squatter Pigeons flush from the ground and land in nearby trees. A minimum density of woody vegetation appears to be required for shelter from predators. DCCEEW (2022b) suggests that a maximum spacing of 100 m between standing trees is required to meet the protective needs of Squatter Pigeons; however, this assertion is not based on any publicly available data.

METServe (2020) used an extensive set of local Squatter Pigeon records (60 individuals recorded in 28 one-hectare cells) to identify minimum woody vegetation density in habitats known to support Squatter Pigeons. The Normalised Difference Vegetation Index (NDVI), as measured during the late dry season, when woody vegetation comprises the sole source of greenness in the landscape, was used as a measure of woody vegetation density. This analysis identified habitat as providing sufficient cover for Squatter Pigeons when the NDVI exceeds 0.125. This corresponds to an approximate spacing of 60 m between large trees or 25 m between smaller shrubs.

Mobility

The size of the average home range of a pair of Squatter Pigeons is not known, but the related Partridge Pigeon (*Geophaps smithii*) is thought to occupy a home range of approximately 8 ha (Fraser *et al.* 2003).

Squatter Pigeons are largely sedentary where permanent water is available but may be locally nomadic if food or water becomes seasonally unavailable (DCCEEW 2022b).

Squatter Pigeons are able to disperse through a wide range of woodland and forest habitats that are unsuitable for feeding or nesting, including those on clay soils, with excessively dense grass cover, or with dense leaf litter instead of bare ground (DCCEEW 2022b). Any habitats with trees closer than 100 m apart are likely to facilitate movement through the landscape (DCCEEW 2022b). Likewise, cleared areas less than 100 m wide constitute dispersal habitat.

No published studies have examined the dispersal ability of Squatter Pigeons or characterised movement barriers. Given their ability to fly, there are likely to be few significant barriers to dispersal, although extensive treeless areas possibly discourage movement.

Threats

Current threats to the Squatter Pigeon include habitat loss and fragmentation, habitat degradation from overgrazing, invasive weeds such as Buffel Grass (*Cenchrus ciliaris*), and introduced predators (DCCEEW 2022b).

The threat of habitat loss through clearing is accounted for in the Offset Assessment Guide calculator independently of habitat quality. Consequently, only those threats that contribute to habitat quality scores are discussed further.

The threat posed to Squatter Pigeons by introduced predators has not been quantified by any studies. The species is eaten by native snakes and other birds, as well as the introduced Dingo (*Canis lupus dingo*), Red Fox (*Vulpes vulpes*) and Feral Cat (*Felis catus*) (DCCEEW 2022b), but the relative importance of each predator is unknown. Foxes and cats are thought to be the principal threats (DCCEEW 2022b), although no data exist to confirm this. The threat posed by these individual predators is further complicated by interactions between them; Dingoes moderate populations of foxes (Johnson and VanDerWal 2009; Letnic *et al.* 2010) and to a lesser extent cats (Allen *et al.* 2014), while foxes also influence cat foraging behaviour (Molsher *et al.* 2017), such that controlling one predator may inadvertently elevate the risks posed by others. The threat posed by predators (e.g. foxes and cats) is likely to be fairly consistent within any one region, except where elevated in the vicinity of urban areas, dumps or other sources of supplementary food supplies for predators. Studies elsewhere suggest that cats typically roam within a radius of up to 1.3 to 2.6 km (Edwards *et al.* 2001; Metsers *et al.* 2010; Bengsen *et al.* 2012), while dogs generally roam within a radius of up to 9.3 km (Robley *et al.* 2010). This implies that elevated predation pressure can be expected within 18 km of a supplementary food source.

Provided land is not overgrazed, Squatter Pigeons coexist readily with cattle grazing; however, the species has largely disappeared from the southern part of its distribution (e.g., New South Wales and southern Queensland), where sheep grazing is widespread and rabbit densities are high (Threatened Species Scientific Committee 2015a). A moderate amount of land modification probably benefits the species, reflected by long-term population increases (between 1934 and 1999) in grazing properties elsewhere in the Brigalow Belt (Woinarski and Catterall 2004). This is also supported by data comparing undisturbed woodlands near Townsville with areas disturbed by grazing or military activities; the latter two land uses supported ten times more Squatter Pigeons (Woinarski and Ash 2002). These patterns are likely to stem from moderate to light grazing by cattle creating favourable open patches of ground for foraging by

Squatter Pigeons. Cattle grazing, in itself, is therefore unlikely to represent an important direct threat to Squatter Pigeons in the Isaac region. Rather, overgrazing affects Squatter Pigeons indirectly via a reduction of grass cover, reducing food supply and protective cover. As the quality of foraging habitat is already assessed in habitat quality assessments, no additional assessment of the threat of "grazing" was deemed necessary.

Density of Buffel Grass is one attribute that varies widely across small scales and, along with habitat loss through clearing, underlies most of the spatial variation in threat level posed to Squatter Pigeons in the Isaac region. Density of Buffel Grass varies widely according to soil type and management history. Invasion by Buffel Grass displaces native species and leads to a reduced diversity of forbs and grasses (Fairfax and Fensham 2000; Franks 2002; Marshall *et al.* 2012). Buffel Grass also forms tall, dense swards that impede the movement and foraging of Squatter Pigeons.

2.3 Central Greater Glider

The Greater Glider (*Petauroides volans*) is listed as endangered under the EPBC Act. Recent studies have suggested that this taxon comprises three genetically distinct species, with the Central Greater Glider (P. *armillatus*) being present in the survey area (McGregor *et al*. 2020). Its taxonomy under the EPBC Act is yet to be revised in accordance with this recent study. Central Greater Gliders were widely recorded within the ML (METServe 2022). There is no recovery plan in place for the species. However, the Commonwealth Government has provided advice about the species' ecology and priority actions to mitigate key threats within the conservation advice (DCCEEW 2022c). Further information about the species' ecology is provided by Eyre *et al.* (2022), in a report commissioned by the Commonwealth Government titled *Guide to Greater Glider Habitat in Queensland.*

2.3.1 Habitat Requirements

The Central Greater Glider typically inhabits tall forests dominated by large, hollow eucalypts (DCCEEW 2022c). Water availability limits populations near the western edge of the species' distribution, such as at Vulcan South (Kearney *et al.* 2010). Local populations are largely restricted to riparian environments, where large, hollow trees are most abundant, and subsoil moisture allows suitable food trees to grow fresh leaves over extended periods of the year.

Food

The Central Greater Glider is primarily folivorous, with a diet consisting of eucalypt leaves and occasional flowers (DCCEEW 2022c). Central Greater Gliders forage on a wide range of *Eucalyptus* and *Corymbia* species, and individuals feed on 1–11 individual trees of 1–6 different species in a single night (Kehl and Borsboom 1984).

Certain tree species contribute the bulk of the diet in any one area (Foley *et al.* 1990; Comport *et al.* 1996). Young foliage is preferred (Comport *et al.* 1996), and dietary preferences vary seasonally, according to which tree species has new growth.

Corymbia citriodora and *Eucalyptus tereticornis* are the most important food species for Central Greater Gliders in southern Queensland, although a large number of other species have been recorded in their diet (Eyre *et al.* 2022). Local tree species known to be eaten by Central Greater Gliders include *Corymbia tessellaris, Eucalyptus crebra* and *Eucalyptus melanophloia. Eucalyptus camaldulensis*, *Corymbia clarksoniana*, *Corymbia trachyphloia* and *Eucalyptus exserta* are also utilised in an unspecified context (food or dens) (Eyre *et al.* 2022). Trunk circumference is highly correlated to leaf biomass in local eucalypts (Burrows *et al.* 2000) and is a valid proxy for the total quantity of food available to Greater Gliders in an area.

Central Greater Gliders preferentially feed in trees with a trunk diameter (at 1.3 m height) larger than 30 cm, although trees as small as 20 cm are occasionally used for foraging (Eyre *et al.* 2022).

Shelter and Nesting

Central Greater Gliders shelter during the day in dens within the hollow branches of live or dead trees. Hollow availability is the habitat feature most likely to limit the distribution of Central Greater Gliders (Andrews *et al.* 1994). Hollow openings greater than 8 cm in diameter are suitable for denning, with trees greater than 50 cm in trunk diameter commonly supporting such hollows (Eyre 2005). Tree trunks wider than 50 cm also provide sufficient buffering and refuge against high daytime temperatures (Kearney *et al.* 2010). Each glider requires at least 2-4 large, hollow-bearing trees within its home range of 1-4 ha in order to inhabit an area of forest (Comport *et al.* 1996).

As a consequence of the high variability and low reliability in determining hollows in trees from the ground, hollow-bearing trees is no longer an assessable attribute in BioCondition assessments in Queensland or New South Wales and has been replaced by a 'large tree' attribute which is determined by a direct measure of tree diameter (Eyre *et al.* 2022). Density of 'large trees' is a more accurate reflection of hollow availability than direct estimates of hollow abundance made from the ground (Eyre *et al.* 2022). What constitutes a 'large tree' varies according to tree species and ecosystem, as different species are variably sensitive to hollow formation. In most of Queensland, 'large trees' are those that exceed 50 cm diameter, while in the Brigalow Belt, 'large trees' exceed 46 cm diameter on average (Eyre *et al.* 2022).

Mobility

Queensland populations of greater gliders (various species) have average home ranges of 5.8 ha and 2.9 ha of males and females, respectively (Eyre *et al.* 2022). The largest home ranges (19.3 ha) have been recorded in the Brigalow Belt bioregion (Smith *et al.* 2007). Home range size is largely determined by hollow density and forest productivity.

Due to their small home ranges and sedentary lifestyle, greater gliders can persist in favourable habitat patches of a remarkably small size, provided the surrounding matrix contains woody vegetation (e.g., regrowth, pine plantations, or burnt forest: Taylor *et al.* 2007; Eyre *et al.* 2022) through which they can disperse. Possingham *et al.* (1994) suggests an average dispersal distance of 8 km to access habitat patches within a matrix of native regrowth, while Taylor and Goldingay (2009) suggest dispersal distances of 1–7 km. Small habitat patches located 1 km from contiguous forest and surrounded by pine plantations had equally high genetic diversity as the source population (Taylor *et al.* 2007), suggesting greater gliders readily disperse through treed landscapes. No published studies have examined the ability of Central Greater Gliders to disperse across treeless expanses. Of greater gliders marked and released during tree felling for forestry operations, half moved less than 0.5 km, while the remainder moved 0.8–2.8 km through the fallen timber to other areas of native forest (Taylor *et al.* 2007). Even small gaps created by major roads (~50 m wide) likely constitute important barriers to dispersal (Taylor and Goldingay 2009).

All gliding possums are limited in their movement by the maximum gliding distance between successive trees. They are thought to be highly sensitive to habitat fragmentation and easily isolated by gaps in their habitat, as they do not readily cross open ground (Jackson 2000; Eyre *et al.* 2022). Other species of gliders (Mahogany Glider, Sugar Glider and Yellow-bellied Glider) achieve a glide angle of 28–31°, which corresponds to a distance of 1.8–1.9 m per 1 m loss in altitude (Jackson 2000). However, Wakefield (1970) suggests a glide angle of only 40° for the greater glider, corresponding to a distance of 1.2 m per 1 m loss in altitude. This suggests that gaps between trees should not exceed the height of those trees, in order to facilitate movement and dispersal. Greater gliders are at high risk of mortality (by feral predators) when they come to ground (Eyre 2005).

Threats

DCCEEW (2022c) identified habitat clearance for agriculture and forestry, fires and climate change as the three most severe threats to all species/populations of the greater glider. Hyper-predation by Powerful Owls can also have moderate localised impacts, although this native predator is largely absent from the Brigalow Belt. The threat of habitat loss through clearing is accounted for in the Offset Assessment Guide calculator independently of habitat quality. Consequently, only those threats that contribute to habitat quality scores are discussed further.

High-intensity fires in Victorian Mountain Ash (*Eucalyptus regnans*) and Alpine Ash (*Eucalyptus delegatensis*) forest during 2009 resulted in a drastic reduction in canopy cover and hollow availability (measured four years after the fires), and the localised extinction of Southern Greater Gliders (*Petauroides volans*) (Berry *et al.* 2015). Studies of wet and dry sclerophyll forests in the Southern Tablelands of New South Wales, which burnt extensively in the mega-fires of 2019-2020, revealed a similar pattern; greater gliders were able to persist at sites that experience low-intensity fire (where the canopy did not burn), but mostly vanished from sites where fires burnt the canopy (May-Stubbles *et al.* 2022). The effects of fires were still evident (burnt sites had half the population density of unburnt sites) after ten years in warm temperate eucalypt forests in north-eastern New South Wales (McLean *et al.* 2018). The Southern Greater Glider not only responds negatively to fire severity at the site level, but also negatively to the amount of forest burned in the surrounding landscape (Lindenmayer *et al.* 2013), presumably a reflection of the extent of local fire refuges. Gullies tend to experience lower fire intensities and may therefore act as fire refuges (Berry *et al.* 2015). Australia-wide, 29% of greater glider (all species) habitat burned in the 2019–2020 mega-fires (Ashman *et al.* 2021).

No studies have examined the impact of fires on Central Greater Gliders in Queensland. The threat posed by fire in Queensland is likely to be much lower than that experienced by gliders in New South Wales and Victoria. Queensland's summer rainfall and less rugged terrain generally produce fires of smaller scale and lower intensity than the devastating bushfires that occur in temperate regions of the country. Most of central Queensland is subject to infrequent to frequent low-intensity grass fires, rather than the shrub and canopy fires that can occur in tall, temperate forests (Murphy *et al.* 2013). During the 2019-2020 mega-fire season, 11.4 % of greater glider habitat in Victoria and New South Wales experienced fires of a "very high" severity, while only 2.7 % of glider habitat in Queensland experienced the same class of fire (Ashman *et al.* 2021). Nevertheless, climate change is worsening fire conditions throughout Australia, including in Queensland (Clarke and Smith 2012).

Climate change is not only expected to impact Central Greater Gliders indirectly (through increasing intensity and frequency of fires), but also directly, through heat stress and drought. Greater gliders are known to be sensitive to temperatures higher than 20°C (Rübsamen *et al.* 1984). Higher temperatures are associated with panting and intense licking of the belly and extremities to facilitate evaporative cooling (Rübsamen *et al.* 1984). Such behaviour is associated with substantial water loss. Greater gliders are thought to obtain their entire water requirements from foliar water content, dew and rain on foliage and water trapped in tree hollows (Kearney *et al.* 2010). Reproduction (milk production) is limited in the northern and inland parts of the species' distribution by water availability (Kearney *et al.* 2010). Increasing temperatures have already been implicated in the contraction of greater glider populations near Sydney towards high altitudes (Smith and Smith 2018). A similar contraction has been observed across Victoria, where aridity and extreme weather conditions, such as number of nights warmer than 20°C, were highly significant predictors of Southern Greater Glider occurrence (Wagner *et al.* 2020). Given that the Bowen Basin lies at the drier, western limit of the species' current distribution, drought and heat stress are likely to be major threats to local populations. In light of the above information, drought is considered a relatively more important risk to Central Greater Gliders in central Queensland than fire, and this is taken into account when developing habitat quality scores (**Section 3.1.5**).

Drought refuges are of great importance to the local persistence of Central Greater Gliders in central Queensland. Drought refuges include areas buffered from climatic extremes due to higher altitudes or protected aspects (shaded gorges and south-facing slopes), as well as forests that maintain a year-round, high foliar water content by accessing groundwater or permanent watercourses. Groundwater-dependent ecosystems and riparian vegetation also tend to support the largest trees in most local landscapes. A study at Townsville found that hollows with larger entrances, hollows highest on trees and hollows in the largest trees (by trunk diameter) had the coolest daytime temperatures, and were favoured by possums (Isaac *et al.* 2008).

3 Habitat Quality

A robust assessment of habitat quality within the impact and proposed offset areas is necessary for confirming the appropriateness of offsets for three reasons:

- The *Offsets Assessment Guide* requires evidence-based quality scores for the impact and offset areas, in order for the Commonwealth Government to assess the offset proposal.
- Improvement in habitat quality over time is one of two means by which conservation gains can be achieved via offsets (the other is via increased levels of habitat protection), and the assessment of baseline habitat quality and improvements over time are important for monitoring the success of offsets.
- In accordance with section 7.1 of the *EPBC Act Environmental Offsets Policy*, an offset area must possess, as a minimum, the quality of the habitat at the impact site, or be managed and resourced over a defined period of time so that its habitat quality is improved to meet the quality of habitat originally impacted.

In its document titled *How to Use the Offset Assessment Guide*, the Australian Government recommends that habitat quality is to consider site condition, site context and species stocking rates, with the weighting given to each component being dependent on the ecological requirements of the impacted species. In response to EPBC referral 2020/8676 (the neighbouring Vulcan Coal Mine), the Australian Government requested that "to inform the inputs of the Offsets Assessment Guide… [quality is to be assessed] using the Queensland *Guide to Determining Terrestrial Habitat Quality*".

The following subsections explain how habitat quality will be assessed within the Vulcan South impact area, and within potential offset areas. The approach adopts methodology prescribed by the *Guide to Determining Terrestrial Habitat Quality.* These scores are weighted and combined to generate a single overall score of habitat quality for each species within the impact (or offset) area.

3.1 Methodology for Assessing Habitat Quality

3.1.1 Assessment Guidelines

The methodology to be adopted when undertaking habitat quality assessments with regard to environmental offsets in Queensland is prescribed by the *Guide to Determining Terrestrial Habitat Quality version 1.3* (Department of Environment and Science 2020a). The Australian Government recommended that this guideline was used to inform habitat quality inputs in the *Offsets Assessment Guide* for the neighbouring Vulcan Coal Mine, and the same approach will be used for Vulcan South.

This guideline proposes two methodologies for assessing habitat quality:

- BioCondition assessments conducted in accordance with the *BioCondition Assessment Manual version 2.2* (Department of Science, Information Technology, Innovation and the Arts 2015); and
- Specially tailored, species-specific habitat quality scores developed by considering the foraging, breeding, sheltering and dispersal requirements of each species, along with local threat levels.

The former provides a general assessment of the overall state of the vegetation community. BioCondition assesses both site-specific habitat quality attributes, as well as landscape-scale attributes such as connectivity, size of habitat patch and regional context. The site-specific component of BioCondition is broadly analogous to the "site condition" score suggested within *How to Use the Offset Assessment Guide.* The landscape-scale component is broadly analogous to "site context" score. Meanwhile, the species-specific habitat quality scores indirectly reflects the potential stocking rate of the listed species that the habitat is able to support, by specifically targeting habitat features that are likely to be limiting local populations.

3.1.2 Sampling Design

The impact and offset sites are to be assessed using identical methodology and sampling designs. Each will be assessed using the sampling design framework described by the *Guide to determining terrestrial habitat quality version 1.3*. This defines a 'matter area' for each prescribed environmental matter requiring offsets as the area that contains or represents the extent of an individual prescribed environmental matter. The matter areas for the impact site are described in **Section 1.4.** A habitat quality score will be assigned to each separate matter area within the impact and offset sites.

Matter areas will be divided into assessment units. An assessment unit is a defined area or group of areas of at least 1 ha in total size within the matter area that is relatively homogenous in that it contains only one regional ecosystem type that is of a reasonably consistent broad condition state (i.e., remnant, high-value regrowth or non-remnant). Assessment units should also consider variation that exists within each broad condition state. For example, non-remnant pastures can have no woody vegetation or dense, young regrowth.

The assessment units assigned to the impact site will be based upon field-verified regional ecosystem mapping undertaken as part of the Terrestrial Ecological Assessment (METServe 2022). Within each regional ecosystem, the high-value regrowth and remnant broad condition states are expected to be sufficiently homogenous and should not warrant further division of these assessment units. However, the non-remnant broad condition state is expected to vary from completely disturbed sealed roads and railway lines to thinned forest with a mostly native pasture and scattered young trees. Hence, non-remnant states will be divided into three condition classes: non-habitat (existing sealed roads, railways, buildings and car parks), highly disturbed habitat (extensively cleared pasture that no longer qualifies as woody vegetation due to the canopy cover being less than 5%) and moderately disturbed habitat (woody vegetation is present with >5% canopy cover, but doesn't meet the definition of high-value regrowth or remnants).

Field assessments of condition are not considered necessary for the highly disturbed class of non-remnant land, as this is not considered part of any matter area.

Sampling will cover the entire footprint of the impact site, and habitat scores for each of the prescribed matters will be based on the relative proportions of the different assessment units within each respective matter area.

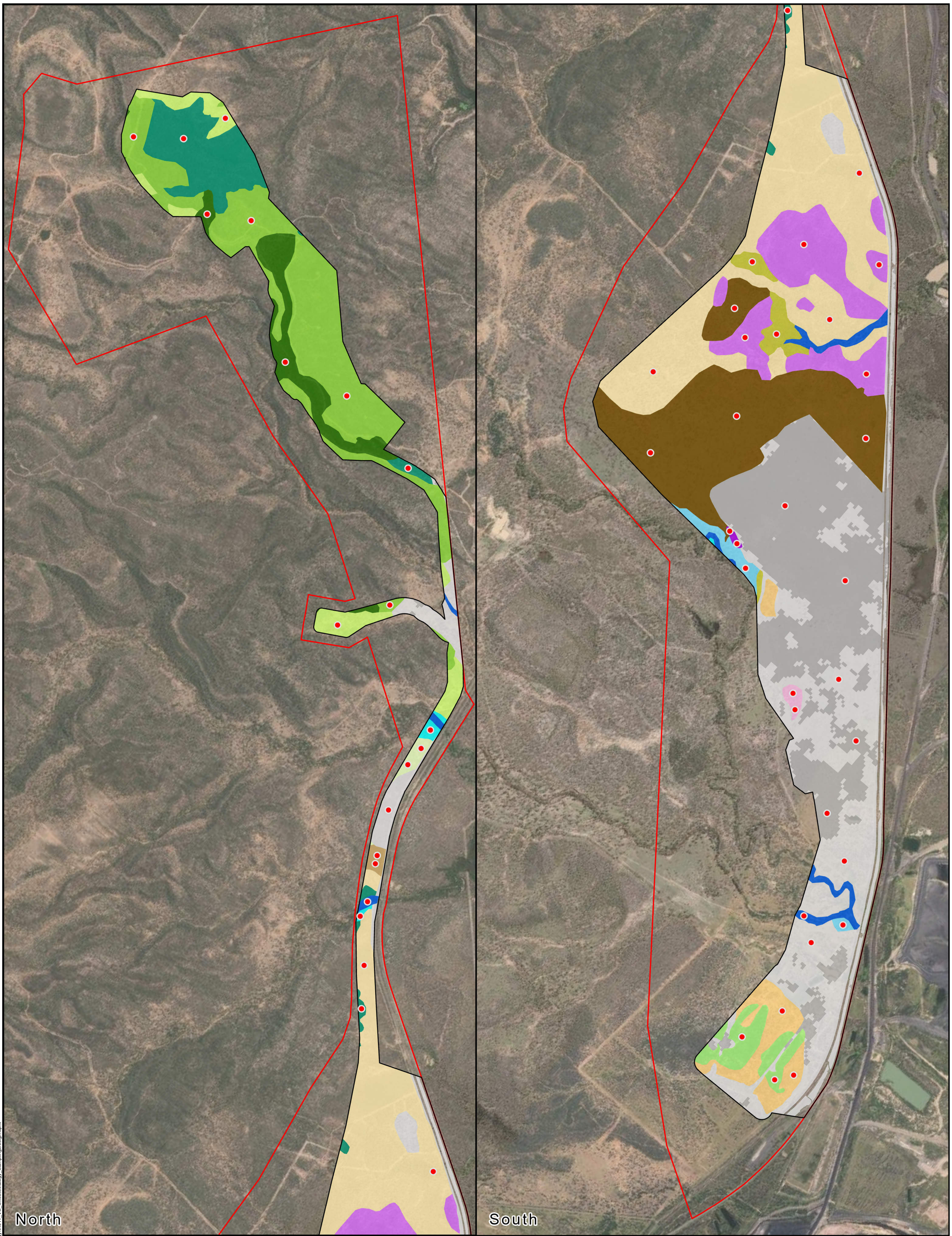
Each assessment unit will be surveyed at multiple sampling sites. The number of sampling sites per assessment unit is based on the density suggested by the *Guide to determining terrestrial habitat quality version 1.3* (**Table 3-1**). 19 assessment units are contained within the Vulcan South impact site, requiring 51 sampling sites (**Table 3-2**). Sampling sites will be selected at random prior to arriving at the sites, in order to avoid biases in their placement and ensure that they were representative of their respective assessment unit.

Table 3-1 Recommended number of sampling sites per assessment unit

Assessment unit size	Number of sampling sites
1-50 ha	At least two
50-100 ha	Three
100-500 ha	Four
500-1,000 ha	Five
More than 1,000 ha	Six

Table 3-2 Assessment units within the impact site

Assessment Unit	Description	Area (ha)	$N_{sampling\ locations}$
AU1	Remnant 11.3.2	12.4	2
AU2	Remnant 11.3.7	4.1	2
AU3	Remnant 11.3.25	21.3	2
AU4	Remnant 11.4.8	114.9	4
AU5	Remnant 11.4.9	1.3	2
AU6	Remnant 11.5.3	20.6	2
AU7	Remnant 11.5.9	282.9	4
AU8	Remnant 11.9.2	227.7	4
AU9	Remnant 11.10.1	47.9	2
AU10	Remnant 11.10.1x1	73.9	3
AU11	Remnant 11.10.3	182.3	4
AU12	Remnant 11.10.7	38.1	2
AU13	Regrowth 11.4.8	4.0	2
AU14	Regrowth 11.5.3	43.6	2
AU15	Regrowth 11.5.9	3.8	2
AU16	Regrowth 11.10.3	30.1	2
AU17	Regrowth 11.10.7	5.4	2
AU18	Woody (>5% canopy cover) non-remnant	296.9	4
AU19	Non-woody (<5% canopy cover) non-remnant	301.4	4
n/a	Vegetation absent	44.2	0
	Total	**1,756.7**	**51**



Legend

- Sampling Site
- MLA Area
- Impact Site

Assessment Units

AU1	AU3	AU9	AU15
AU2	AU4	AU10	AU16
	AU5	AU11	AU17
	AU6	AU12	AU18
	AU7	AU13	AU19
	AU8	AU14	

Source: Vitrinite 2022, METServe 2022, Maxar.

Vulcan South

Proposed Sampling Design within the Impact Site

0 0.5 1
Kilometers

Scale: 1:34,000 (A3)

19/08/2022

N

Datum: GDA2020
Projection: MGA55

FIGURE 3-1

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

3.1.3 Proposed Offset Site

The approach used to sample the offset site will be similar to that for the impact site. However, prior to stratifying the proposed offset site into assessment units, ground-truthing of the certified regional ecosystem mapping will be required. To achieve this, the methodology described by Neldner *et al.* (2020) will be adopted to produce a field-verified regional ecosystem map of the proposed offset site.

Matter areas within the proposed offset site will be defined using the same habitat definitions as applied to the impact area. The only exception is that cleared, non-remnant vegetation that may not currently qualify as habitat for a matter may be included within the matter area at the offset site if it has potential to develop into habitat for the matter in the next 20 years, contingent on the proposed management measures.

3.1.4 Landscape-scale Assessments

For fragmented landscapes, such as those containing the impact site, the following landscape-scale attributes will be assessed:

- Size of patch (area in hectares of any remnant or regrowth vegetation, irrespective of regional ecosystem or tenure, that is connected to the site via corridors wider than 200 m);
- Context (proportion of local region that comprises remnant or regrowth vegetation); and
- Connectivity (the proportion of a site's perimeter that is connected to remnant or regrowth vegetation).

The same attributes will be assessed for the offset site, once its location has been confirmed.

The methodology used for generating a score out of 20 for the impact site is described in the *BioCondition Assessment Manual version 2.2* (Department of Science, Information Technology, Innovation and the Arts 2015). The landscape-scale attributes will be calculated using data stored in Geographical Information Systems (GIS). Regional ecosystem mapping (remnant) and regrowth (non-remnant) vegetation mapping will be used to assess landscape-scale attributes. Field-verified mapping (surrounding the impact site) is planned to be used in the assessment where it is available. For the remaining portions of the landscape lacking field-verified mapping, certified mapping (version 12.2) downloaded from the Queensland Government QSpatial website will be used.

The methodology used for calculating scores for size of patch and connectivity will follow the *BioCondition Assessment Manual version 2.2* (Department of Science, Information Technology, Innovation and the Arts 2015). However, the methodology for assessing context is expected to require some adjustment. According to the *Guide to determining terrestrial habitat quality version 1.3* (Department of Environment and Science 2020a), landscape-scale attributes should be assessed "at the overall site level, rather than at the matter area level". Furthermore, these assessments are intended as a description of "the landscape surrounding the offset site" not within it. These intentions conflict with the methodology proposed in the *BioCondition Assessment Manual version 2.2* (Department of Science, Information Technology, Innovation and the Arts 2015), which nominates a 1 km radius circle around the midpoint of a single sampling location as the zone in which context should be measured. As the impact site exceeds 19 km in length, the 1-km-radius-circle approach largely characterises the extent of vegetation within the impact site, rather than surrounding it. As a compromise between the intentions of the *BioCondition Assessment Manual version 2.2* and the *Guide to determining terrestrial habitat quality version 1.3*, context will be assessed by calculating the proportion of the land that comprises remnant or regrowth vegetation contained within a 1 km buffer around the boundaries of the site.

3.1.5 Site-based Assessments

Site-based attributes will be assessed at all sampling locations within the impact site. In accordance with the *Guide to determining terrestrial habitat quality version 1.3* (Department of Environment and Science 2020a), two approaches for assessing site-based attributes will be adopted:

- BioCondition scores; and
- Specially tailored, species-specific, fauna habitat quality scores.

Both approaches will be used to assess different aspects of habitat quality for the three listed species. BioCondition scores alone will be used to assess the quality of the Brigalow (*Acacia harpophylla* dominant and co-dominant) ecological community. Site-based assessments of the impact and offset sites (once selected) will be assessed during a similar time of year, to ensure impact and offset sites can be directly comparable.

BioCondition

BioCondition will be assessed following the methodology prescribed by the *BioCondition Assessment Manual version 2.2* (Department of Science, Information Technology, Innovation and the Arts 2015). This methodology uses quadrat sampling to generate measurements of native plant richness, recruitment, shrub and tree cover, native perennial grass cover, litter cover, amount of coarse woody debris, non-native plant cover, tree height and number of large trees. These measurements are then compared to benchmarks published by the Queensland Herbarium compiled from various reference sites. The most recent revision (version 3.2) of these the benchmarks will be used.

The scoring system prescribed by the *BioCondition Assessment Manual version 2.2* (Department of Science, Information Technology, Innovation and the Arts 2015) results in a score out of 80, while the *Guide to determining terrestrial habitat quality version 1.3* (Department of Environment and Science 2020a) requires that this score is out of 100. To achieve this conversion, the original score will be multiplied by 1.25.

Species Habitat Quality

In addition to BioCondition, which assesses the overall quality of the vegetation within the impact and offset sites, species-specific habitat attributes will also be assessed at each sampling location. As prescribed by the *Guide to determining terrestrial habitat quality version 1.3* (Department of Environment and Science 2020a), habitat attributes must include indicators for food availability, suitability for breeding and shelter, suitability for mobility and level of ongoing threats. These four habitat attributes are to have equal weighting when generating overall scores for habitat quality for any one species.

Based on the literature reviewed in **Section 2**, a project-specific set of indicators and a scoring system has been devised in order to assess habitat quality for the Koala, Central Greater Glider and Squatter Pigeon (**Table 3-4**). Some of the species-specific habitat attributes may overlap with the BioCondition assessment (e.g., number of large trees for the Koala and Central Greater Glider, and understorey richness for the Squatter Pigeon). The following attributes are additional assessments to be undertaken at sampling locations:

- Basal area per hectare of Koala food trees (*Eucalyptus camaldulensis, Eucalyptus populnea and Eucalyptus crebra*) and Central Greater Glider food trees (most *Eucalyptus* and *Corymbia* species) will be assessed via 360° sweeps with a Bitterlich gauge at the 0 m, 50 m and 100 m marks of the transect used to assess canopy cover for BioCondition. The mean of the three estimates will be used to represent the amount of food available at the site for Koalas and Central Greater Gliders.
- Canopy cover (based on the vertical projection of crowns) of trees taller than 4 m (the minimum height likely to be used by Koalas) will be assessed as for total canopy cover for BioCondition, except only trees taller than 4 m are included in the estimate. This reflects the density of trees tall enough for Koalas to climb to escape predators.
- The presence/absence of at least one dense shade tree (at least 6 m tall with >75% foliage projective cover within the crown) within the 100 m × 50 m quadrat used for BioCondition will be recorded. This indicates whether favourable shelter trees are available to Koalas at the site.

- The proportion of trees that are within gliding distance of other trees (i.e., with spacing ≤ tree height) will be estimated in each 100 m × 50 m quadrat used for BioCondition.
- Elevated fine fuel hazard will be estimated based on the methodology and hazard classes described in the *Overall fuel hazard assessment guide* (Department of Sustainability and Environment 2012). A summary of the classification system is provided in **Table 3-3**. The elevated fine fuel hazard largely determines if a fire will spread to the forest canopy or be maintained at ground level, where it is of little threat to Central Greater Gliders. Elevated fine fuel hazards that are high, very high or extreme have the potential to cause canopy fires.

Table 3-3 Elevated fine fuel hazard classes.

Key attributes					Fuel hazard rating	Effect on fire behaviour (at FFDI 25)[4]
Plant Cover	% dead	Vertical continuity	Vegetation density	Thickness of fuel pieces		
<20% or low flammability species	<20%		Easy to walk in any direction without needing to choose a path between shrubs.		Low	Little or no effect.
20–30%	<20%	Most of the fine fuel is at the top of the layer.	Easy to choose a path through but brush against vegetation occasionally.		Moderate	Does not sustain flames readily.
30–50%	<20%	Most of the fine fuel is at the top of the layer.	Moderately easy to choose a path through, but brush against vegetation most of the time.		High	Causes some patchy increases in the flame height and/or rate of spread of a fire.
50–80%	20–30%	Continuous fine fuel from the bottom to the top of the layer.	Need to carefully select path through.	Mostly less than 1–2mm thick.	Very High	Elevated fuels mostly dictate flame height and rate of spread of a fire.
>70%	>30%	Continuous fine fuel from the bottom to the top of the layer.	Very difficult to select a path through. Need to push through vegetation.	Large amounts of fuel <2mm thick.	Extreme	Elevated fuels almost entirely determine the flame height and rate of spread of a fire.

- The percentage cover of Buffel Grass will be estimated by dividing the 50 m × 10 m quadrat used for BioCondition into 1/8s, visually estimating the percentage cover of Buffel Grass in each 1/8, then calculating the mean of the eight estimates. This reflects the threat posed by the weed on foraging habitat for the Squatter Pigeon.
- The percentage of bare ground will be estimated at five 1 m × 1 m quadrats used for BioCondition, and the mean of the five estimates is calculated. Bare ground is an important feature of foraging habitat for the Squatter Pigeon.

In addition to these field-measured attributes, the following suite of spatial attributes are planned to be measured using GIS tools:

- Distance from the assessment unit boundary to the nearest watercourse (refuge from drought for Koalas and Central Greater Glider) and road (vehicle threat to Koalas).
- Proportion of the assessment unit that overlaps with groundwater-dependent ecosystems (GDEs) mapped in the National GDE Atlas (Bureau of Meteorology 2022) (drought refuge for the Central Greater Glider).
- Maximum altitude (based on the Australian Height Datum) of the assessment unit. Temperature decreases linearly with altitude (6.5°C for every 1,000 m), so assessment units higher than 450 m are buffered from an increase in global temperatures of 3°C (such sites are forecast to have the same temperatures as nearby sites at sea level currently have).

- Size of the habitat patch connected to the assessment unit, and distance to large habitat patches will be used to assess habitat for all three species.
- The percentage of the assessment unit that comprises one-hectare cells with an NDVI > 0.125, when assessed in the dry season (a measure of the extent of woody vegetation cover for Squatter Pigeons).

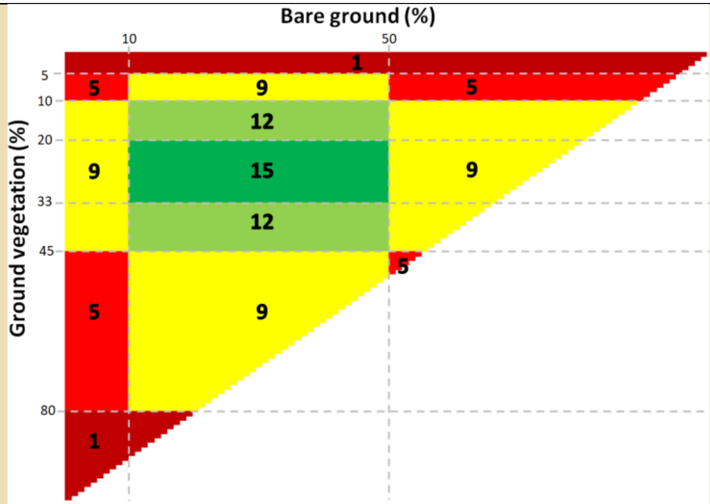
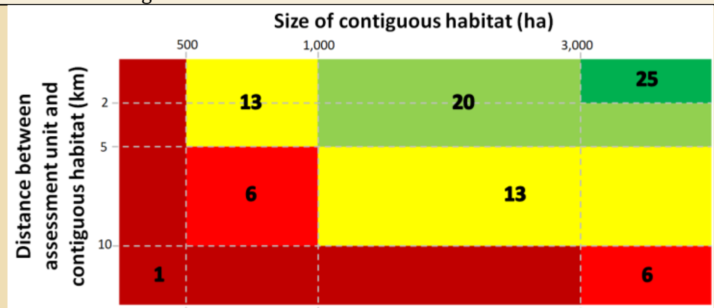
Table 3-4 Species-specific habitat quality scoring system proposed for the impact and offset sites

Koala	**1 Threats to species**	Score	0	3	6	8	
		Risk of road-based mortality	High: Assessment unit borders a public road with 100 kph speed limit.	Moderate: Assessment unit is within 1 km of a public road with 100 kph speed limit, OR borders a public road with 60-100 kph speed limit.	Low: Assessment unit lies 1-2 km from public roads, AND any private tracks through or near the unit are used infrequently at night (less than once per week) and at low speeds (less than 50 kph).	Nil: Assessment unit lies >2 km from a public road, AND any private tracks through or near the unit are used infrequently at night (less than once per week) and at low speeds (less than 50 kph).	
		Score	0	5	8		
		Risk of dog attack	High: Assessment unit is within 18 km of a town, dump or other source of supplementary food for dogs, and no control programs are in place.	Moderate: Assessment unit is within 18 km of a town, dump or other source of supplementary food for dogs, but active control measures (baiting, trapping or shooting) occur within the assessment unit and effectively reduce dog densities (as shown by monitoring).	Low: Assessment unit is further than 18 km from a town, dump or other source of supplementary food for dogs.		
		Score	0	5	9		
		Importance as a drought refuge	**Low:** The assessment unit is further than 2 km from a watercourse or source of surface water, OR is 1-2 km from a watercourse, but no vegetation occurs along the watercourse.	**Medium:** The assessment unit is 1-2 km from a watercourse or source of surface water and is connected to vegetation along the watercourse.	**High:** The assessment unit is within 1 km of a watercourse or source of surface water.		
	2 Quantity and quality of food	Score	Scores are assigned based on combination of basal area and proportion of primary food trees, as shown in the below table				
		Density and quality of food trees	(see table below)				

Combined basal area of all food trees (m²/ha)	Percentage of total food tree basal area that comprises primary food trees (*E. camaldulensis* or *E. tereticornis*): 0	<10	10-40	40-70	70-100
0	0	0	0	0	0
<2	1	2	3	4	5
2-5	2	3	5	7	8
5-8	3	5	7	10	12
8-10	4	7	10	13	16
>10	5	8	12	16	20

Koala	**2 Quantity and quality of food**	Score	1	2	3	4	5
		Number of large food trees	**None:** No large food trees	**Poor:** 1 or 2 large food trees per 0.5 ha	**Moderate:** 3 to 6 large food trees per 0.5 ha	**High:** 7 to 10 large food trees per 0.5 ha	**Very high:** >10 large food trees
	3 Quality and availability of shelter	Score	1	2	4	7	10
		Canopy cover of trees taller than	**None:** No trees taller than 4 m.	**Poor:** <10% cover.	**Moderate:** 10-30% cover.	**High:** 30-60% cover.	**Very high:** >60% cover.

		4 m.					
		Score	0	2	4	7	10
		Number of large non-food trees	0	1	2-4	5-10	>10
		Score	0	5			
		Presence of dense shade trees	Trees taller than 6 m and with a crown that has >75% cover are absent	Trees taller than 6 m and with a crown that has >75% cover are present			
	4 Species mobility capacity	Score	1	5	10	17	25
		Extent of contiguous habitat.	**Very poor:** Assessment unit is further than 5 km from contiguous habitat larger than 200 ha.	**Poor:** Assessment unit is 2-5 km from contiguous habitat larger than 200 ha	**Moderate:** Assessment unit is connected to, or within 2 km of, a contiguous landscape that is 200-500 ha.	**Good:** Assessment unit is within 2 km of a contiguous landscape that is 500-1,000 ha.	**Very good:** Assessment unit is connected to or within 2 km of a contiguous landscape that is >1,000 ha.
Squatter Pigeon	**1 Threats to species**	Score	1	6	11	16	
		Invasion by Buffel Grass	**High:** Buffel Grass has a ground cover >40%	**Moderate:** Buffel Grass has a ground cover of 10-40%.	**Low:** Buffel Grass has a ground cover of 0.1-9.9%.	**None:** Buffel Grass is absent.	
		Score	0	3	7	9	
		Predation by feral predators	**Very High:** Assessment unit is within 5 km of a town, dump or other source of supplementary food for dogs and cats, and no control programs are in place.	**High:** Assessment unit is within 18 km of a town, dump or other source of supplementary food for dogs, and no control programs are in place.	**Moderate:** Assessment unit is within 18 km of a town, dump or other source of supplementary food for dogs and cats, but active control measures (baiting, trapping or shooting) occur within the assessment unit and effectively reduce cat and dog densities (as shown by monitoring).	**Low:** Assessment unit is further than 18 km from a town, dump or other source of supplementary food for dogs and cats.	
	2 Quality and availability of food and foraging	Score	**0**	**1**	*Unlike for other habitat attributes and species, the score for distance to water is multiplied by the sum of the other foraging scores to generate an overall foraging habitat score for Squatter Pigeons.		
		Distance to water*	**High:** Assessment unit is >3 km from water.	**Low:** Assessment unit is within 3 km of water.			
		Score	Scores (1-15) are assigned based on the percentage of ground covered by low vegetation (<1 m) and bare ground, as shown in the below table				

	habitat	Ground cover	 				
		Score	1	3	5	8	10
		Understorey richness	**Very low:** <5 species of grasses and forbs.	**Low:** 5-14 species of grasses and forbs.	**Moderate:** 15-24 species of grasses and forbs.	**High:** 25-29 species of grasses and forbs.	**Very high:** >30 species of grasses and forbs.
	3 Quality and availability of habitat for shelter and breeding	Score	0	1	*Unlike for most other habitat attributes and species, the score for distance to water is multiplied by the other breeding habitat score below to generate an overall breeding habitat score for Squatter Pigeons.		
		Distance to water*	**High:** Assessment unit is >1 km from permanent water	**Low:** Assessment unit is within 1 km of permanent water.			
		Score	1	4	11	18	25
		Normalised Difference Vegetation Index (NDVI)	**Very poor:** the assessment unit does not contain any 1-ha cells with a mean NDVI > 0.125.	**Poor:** <30% of the assessment unit has NDVI > 0.125.	**Moderate:** 30-60% of the assessment unit has NDVI > 0.125.	**Good:** 60-80% of the assessment unit has NDVI > 0.125.	**Very good**: >80% of the assessment unit has NDVI > 0.125.
	4 Species mobility capacity	Score	Scores are assigned based on the below table				
		Extent of, and distance to, large patches of contiguous habitat	 				
Central	**1 Threats to**	Score	Scores are assigned based on the below table				

Greater Glider	**species**	Threat of intense canopy fires					

		Position in landscape		
		Valley	**Midslope**	**Crest**
Elevated Fine Fuel Hazard	**Low**	10	9	8
	Moderate	7	5	4
	High to extreme	5	2	1

		Score	0	5	10	13	15
		Importance as a climate change refuge	**None:** Assessment unit is further than 1 km from a drought refuge OR occurs within 1 km of a drought refuge but there is a vegetation gap > 0.5 km between the unit and the drought refuge.	**Low:** Assessment unit is <1 km from a permanent watercourse or an area mapped as a 'moderate' or 'high' potential groundwater-dependent ecosystem in the National GDE Atlas AND is connected to these drought refuges by woody vegetation.	**Moderate:** Assessment unit is within 100 m of a farm dam or other water impoundment, OR overlaps with a 'low' potential groundwater-dependent ecosystem in the National GDE Atlas.	**High:** Assessment unit is adjacent to a permanent watercourse or overlaps with a 'moderate' or 'high' potential groundwater-dependent ecosystem in the National GDE Atlas.	**Very high:** Assessment unit is above 450 m in altitude.
	2 Quality and availability of food	Score	Scores are assigned based on combination of basal area and proportion of primary food trees, as shown in the below table				
		Density and quality of food trees					

		Species richness of *Eucalyptus* and *Corymbia* in 0.5 ha				
		1	**2**	**3**	**4**	**5+**
Total basal area of food trees (m^2/ha)	**0**	0	0	0	0	0
	<2	1	2	3	4	5
	2-5	2	3	5	7	8
	5-8	3	5	7	10	12
	8-10	4	7	10	13	16
	>10	5	8	12	16	20

		Score	1	2	3	4	5
		Number of large food trees (>30 cm DBH)	**None:** No large food trees	**Poor:** 1 or 2 large food trees per 0.5 ha	**Moderate:** 3 to 6 large food trees per 0.5 ha	**High:** 7 to 10 large food trees per 0.5 ha	**Very high:** >10 large food trees
	3 Quality and availability of shelter	Score	0	5	12	18	**25**
		Number of large shelter trees (>50 cm DBH).	**None:** No eucalypt trees with >50cm DBH.	**Poor:** 1 or 2 eucalypt trees with >50cm DBH.	**Moderate:** 3 to 5 eucalypt trees with >50cm DBH.	**High:** 6 to 8 eucalypt trees with >50cm DBH.	**Very high:** > 8 eucalypt trees with >50 cm DBH
	4 Species	Score	Scores are assigned based on a combination of size of the habitat patch and connectivity to other patches, as shown in the below table.				

	mobility capacity	Size and connectivity of habitat patch	

		Connectivity to nearest patch					
		Patches <1 km apart and connected by woody vegetation*	**Patches 1-8 km apart and connected by woody vegetation***	**Patches >8 km apart and connected by woody vegetation***	**Patches <0.5 km apart and separated by open areas***	**Patches 0.5-3 km apart and separated by open areas***	**Patches >3 km apart and separated by open areas***
Size of habitat patch†	**>300 ha**	25	23	21	20	18	15
	100-300 ha	24	20	17	15	12	10
	50-100 ha	23	17	10	8	6	4
	<50 ha	22	14	8	6	3	1

*Distinction between open areas versus wooded vegetation is defined by the gliding distance of Greater Gliders (i.e., average spaces between trees should not exceed the height of trees in wooded vegetation).

†Habitat patch size classes are based on ability of the patch to support a viable population of 100 Greater Gliders, assuming a mean home range size of 3 ha.

3.2 Offset Starting Quality

In accordance with section 7.1 of the *EPBC Act Environmental Offsets Policy,* any direct offset must meet, as a minimum, the quality of the habitat at the impact site, or its habitat quality is to be improved so that it meets the quality of habitat originally impacted. Consequently, the minimum starting quality of a suitable offset site is contingent on the potential for this value to be improved via management measures. This potential improvement is discussed in the following subsections.

3.2.1 Koala

Management measures have the potential to improve habitat quality for Koalas in offset areas by improving the following components of the species-specific habitat quality score (refer to **Table 3-4**):

- Risk of dog attack;
- Vegetation connectivity with watercourses;
- Basal area of food trees;
- Number of large food trees (only likely to be improved when there are numerous trees marginally smaller than the "large size" when offsets commence);
- Canopy cover of trees taller than 4 m;
- Number of large non-food trees (only likely to be improved when there are numerous trees marginally smaller than the "large size" when offsets commence); and
- Presence of dense shade trees.

Collectively, these components comprise approximately half of the total species-specific habitat quality score (setting a maximum possible improvement of 5/10). However, a more realistic improvement of 1/10 to 2/10 is achievable across most starting values. To maximise the habitat gains that can be reasonably achieved, a suitable offset site for the Koala should have the following attributes as a foundation:

- High starting scores for attributes that cannot be improved via management (e.g., small distance to watercourses, large distance to roads, extensive contiguous habitat);
- A starting habitat quality score that is close to, or greater than, the impact site, such that a likely gain of 1 or 2 will result in a total that exceeds the impact site;
- A dense cover of trees less than 4 m tall, but few trees taller than 4 m (i.e., a very low current canopy cover, but a high cover can be expected within 5-10 years);
- Areas containing regrowth of primary food trees (*Eucalyptus camaldulensis* and/or *Eucalyptus tereticornis*); and
- Low levels of current vegetation protection.

3.2.2 Squatter Pigeon

Through management measures to improve habitat quality for the Squatter Pigeon, offsets have the potential to improve the following components of the species-specific habitat quality score:

- The density of feral predators;
- Extent of protective cover provided by woody vegetation;
- Density of Buffel Grass (possible, but logistically difficult, to improve);
- Ground cover composition (cover of low vegetation and bare ground); and
- Distance to water.

There is potential for management measures to contribute towards habitat gains through the removal of Buffel Grass from infested offset sites (maximum gain of ~1/10). However, such measures are only feasible on small scales, due to the very high demands on time and money required for this to be successful. Consequently, this is considered to be an inefficient means to achieve conservation gains for Squatter Pigeons.

The single component with the greatest effect on habitat score, as well as the potential to be rapidly improved, is distance to water. The installation of artificial water points within landscapes that otherwise constitute optimal habitat for the Squatter Pigeon, but that are further than 1 km (for breeding habitat) or 3 km (for foraging habitat) from existing water, has the potential to immediately improve habitat scores by up to 5/10 within the first year of offsets. Even at sites with existing water, there is the potential for management measures (e.g., grazing intensity, managing density of woody regrowth) to improve ground cover composition and woody vegetation density to improve within a reasonable timeframe (10-20 years).

To maximise the habitat gains that can be reasonably achieved, a suitable offset site for the Squatter Pigeon should otherwise meet the ecological needs of Squatter Pigeons, but be located more than 3 km from fresh water. Alternatively, a suitable offset site should possess as many of the following attributes as possible:

- Located within 1 km of fresh water and have a dense regrowth of young trees and shrubs that produces an NDVI that is slightly under 0.125; and
- Dense grass and other ground vegetation that exceeds 45% cover;
- Little existing management of feral predators;
- High starting scores for attributes than cannot be improved via management (e.g., high understorey richness, high connectivity to contiguous habitat and low densities of Buffel Grass);
- Starting habitat quality score that is close to, or greater than, the impact site, such that a likely gain of 1 or 2 will result in a total that exceeds the impact site (lower scores are suitable if the addition of water to the landscape will result in immediate gains); and
- Low levels of current vegetation protection.

3.2.3 Central Greater Glider

Through management measures to improve habitat quality for the Central Greater Glider, offsets have the potential to improve the following components of the species-specific habitat quality:

- The elevated fine fuel hazard;
- Vegetation connectivity with drought refuges;
- Basal area and species richness of food trees;
- Number of large food trees and large shelter trees (only likely to be improved when there are numerous trees marginally smaller than the “large size” when offsets commence); and
- Habitat patch size and connectivity.

As for the Koala, an improvement in habitat quality of 1/10 to 2/10 is potentially achievable across most starting values. To maximise the habitat gains that can be reasonably achieved, a suitable offset site for the Central Greater Glider should have the following attributes as a foundation:

- High starting scores for attributes than cannot readily be improved via management (e.g., presence of drought refugia, abundant large trees, presence of nearby tracts of habitat to which the offset site can be connected);
- Numerous trees slightly smaller than the threshold for large trees; and
- Areas containing regrowth of food trees; and
- Low levels of current vegetation protection.

3.2.4 Brigalow Threatened Ecological Community

The quality improvements that can potentially be achieved within Brigalow ecological communities over a 20-year period depend greatly on the starting state. Peeters and Butler (2014) list the following four alternate condition states into which mature Brigalow has often been converted:

- Mature Brigalow that is disturbed and where exotic grasses have invaded, creating a grassy open forest or woodland that is fire-prone.
- Widespread clearing and/or damage causes suckering, which produces “Sucker Brigalow” (multi-stemmed, highly branched and generally less than 4 m in height) in areas typically mapped in Queensland as non-remnant category X vegetation. This may ultimately form into “Whipstick Brigalow” (Johnson 1964), which typically consists of high densities of many straight, slender stems about 4 to 8 m tall, with spindly or dead lower branches. Such areas are often mapped as category C regulated vegetation (regrowth) in Queensland.
- If clearing was done with blade ploughs or herbicides, the resulting grassland or cropland usually lacks any woody vegetation.
- Brigalow where native rainforest species have invaded can transition into dry rainforest communities.

Mature Brigalow can be restored if the damaging processes cease, and their effects are counteracted by managing fire and grazing, controlling weeds, promoting Brigalow suckering, and in some cases reintroducing native woody plants (Peeters and Butler 2014). Biomass accumulation rates of Brigalow regrowth ranges from 1.3 to 4.6 t ha^{-1} yr^{-1} for living biomass, whereas mature Brigalow possess approximately 100 t ha^{-1} of above-ground live biomass (Peeters and Butler 2014). In Brigalow regrowth, species richness and other diversity indices (primary driven by the species-rich herbaceous layer) increase rapidly to a maximum after 2–4 years, decline until the 30th year when they again increase (Johnson *et al.* 2016). This suggests that offset sites containing regrowth younger than 30 years may experience short-term declines in species richness as the canopy thickens and shades out the understorey. At least 90 years of recovery is required post-clearing, before regrowth woodlands regain 90% of the species richness and structural characteristics of mature woodlands (Bradley *et al.* 2010). Plant species richness returns to that of remnant Brigalow woodlands within 30–40 years of regrowth, but the floristic composition of older regrowth remains distinct from remnant Brigalow (Le Brocque and Wagner 2018).

As the Brigalow contained within the impact site mostly comprises grazed, remnant woodlands, these are expected to achieve relatively high quality scores. In order for Brigalow within an offset site to achieve equivalent scores within a 20-year period, it is anticipated that the starting scores at the offset site should be within 1 or 2 points (out of 10) of the score at the impact site.

3.2.5 Ecological Corridors

The impact site is not connected to any state-wide terrestrial or riparian ecological corridors as shown on the “Queensland biodiversity and vegetation offsets special features” map. The impact site is 20 km from the nearest riparian corridor and 2.5 km from the nearest terrestrial corridor. In order to achieve a similar value as an ecological corridor as the impact site, there is no requirement for a suitable offset site to be within or connected to a state-wide terrestrial or riparian ecological corridor as shown on the “Queensland biodiversity and vegetation offsets special features” map. Nevertheless, such a location would be desirable if it were available.

3.2.6 Presence of Species

In accordance with the *EPBC Act Environmental Offsets Policy,* assessment of potential offsets must consider level of certainty that the proposed offset will be successful. Offset sites that already support the Koala, Central Greater Glider and Squatter Pigeon, or that are located close to known populations, have a lower risk of failure than sites that require colonisation from distant source populations. For this reason, the presence of each species within the proposed offset site, or within approximately 8 km of the proposed offset site, is to be confirmed through field observations during habitat quality assessment.

Likewise, the presence of the Brigalow ecological community is to be confirmed through field observations.

4 Proposed Management of Offsets

While the primary consideration in determining suitable offsets is delivering a conservation gain for the impacted protected matter, the delivery of offsets that establish positive social or economic co-benefits is encouraged by the *EPBC Act Environmental Offsets Policy.* Three examples provided within the policy include an offset:

- Contributing to an area recognised as important to increasing landscape connectivity, above and beyond what is required by the impacted protected matter;
- That employs local Indigenous rangers to undertake management actions; and
- Delivered by paying rural landholders to protect and manage land for conservation purposes.

The approach to be taken for Vulcan South is one based on one or more of the above social benefits listed above.

Several options are currently being investigated through a broker to identify an offset site that supports the Brigalow ecological community, meets the habitat needs of the Koala, Central Greater Glider and Squatter Pigeon (refer to **Section 2**), and possesses attributes that allow offsets to achieve substantial conservation gains for the four matters (refer to **Section 3.2**). As the proposed management of an offset site is contingent on the starting quality and attributes that are most sensitive to improvement, specific management measures cannot be prescribed until a final site has been chosen. Nevertheless, a range of management options are presented in **Table 4-1** and **Table 4-2**, as examples of the types of actions that will be considered for improving habitat attributes that are deficient at the offset site at the time of acquisition.

The principal means through which offsets will achieve environmental gains for the Koala and Squatter Pigeon is expected to be through the protection of regrowth vegetation that otherwise has a high risk of repeated clearing. This vegetation may already qualify as habitat for these two species at the procurement of the offset(s) or be expected to develop into suitable habitat in the near future. If required, supplementary water points will be installed in the offset area to maximise the amount of foraging and breeding habitat for the Squatter Pigeon and offer drinking sites for Koalas during droughts. As young regrowth is unable to support Central Greater Gliders unless mature, hollow trees were left standing during clearing, suitable offset sites must also contain ample remnant vegetation to provide a source of den sites. Nevertheless, protection of regrowth will have the benefit of increasing connectivity between habitat patches for Central Greater Gliders. Regrowth adjacent to existing den sites also increases food availability for gliders.

It is expected that offsets for the Koala, Central Greater Glider and Squatter Pigeon are not mutually exclusive of cattle grazing, provided the stocking rates are sustainable. All three species coexist readily with cattle, and some amount of grazing is probably beneficial (Woinarski and Ash 2002). Grazing promotes bare ground required by the Squatter Pigeon for foraging and reduces the density of grass swards that may otherwise hinder the movement of Koalas between trees. By reducing grass density, grazing also facilitates movement between trees by arboreal marsupials (Neilly and Schwarzkopf 2017) and decreases the risk posed by uncontrolled fires, which is a major threat of both the Koala and Central Greater Glider (DCCEEW 2022a, 2022c).

On the other hand, cattle grazing may pose a risk to the success of offsets if it leads to heavy browsing of regenerating trees, insufficient grass cover for Squatter Pigeons, or depleted understorey richness. Furthermore, grazing typically results in reduced condition of the Brigalow ecological community (Le Brocque and Wagner 2018). Regular monitoring of the offset site (every five years) will identify whether such damage is likely to threaten the achievement of the projected conservation goals and, in such an event, stocking densities would be modified accordingly. Cattle-exclusion fencing around patches of the Brigalow ecological community may also be warranted in some circumstances. Furthermore, as Squatter Pigeons nest on the ground, their nests may be susceptible to trampling by cattle, such that removal of cattle from the offset site during breeding periods may be prudent.

Other management measures may be adopted (**Table 4-1** and **Table 4-2**), contingent on the specific attributes of the final offset site(s), and the site-specific potential for improving habitat quality. Further details of the management measures to be adopted within the final offset site(s) will be provided in a draft Offset Area Management Plan (OAMP), to be submitted for approval prior to implementation (**Section 8**).

Table 4-1 Potential management options for improving Koala habitat quality within an offset site

Potential Scenario	Habitat Deficiency	Management Measures	Expected Improvements
K1	A low level of pre-existing vegetation protection places this at a high risk of future loss through clearing for agriculture.	Habitat within the offset area is to be protected and will retain this protection at least for the duration of impacts arising from Vulcan South.	The benefits of additional habitat protection depend on the pre-existing risk of loss, which is to be determined based on recent historical clearing patterns associated with the tenure, land zone and level of protection under the VM Act within the offset site (see **Section 1.3.2**). This data is available from Accad *et al.* (2022) and the Statewide Landcover and Trees Study datasets published by the Queensland Government. Protecting regrowth and allowing it to develop will improve the habitat quality for Koalas by increasing the basal area of food trees, increasing the canopy cover of trees taller than 4 m, and allowing dense shade trees to form.
K2	Low cover of trees taller than 4 m (large enough to be used by Koalas)	Allowing the passive regeneration of woody vegetation.	Seedlings and suckers of canopy trees that are <1 m tall are expected to reach ≥4 m within five years in central Queensland. Regrowth as young as four to seven years is regularly used by Koalas (Kavanagh and Stanton 2012; Rhind *et al.* 2014). The success of passive regeneration depends on the clearing methods originally used at the offset site, with pulled vegetation recovering faster than that killed with herbicide (Back *et al.* 2009a). Recruitment is also stronger when clumps of standing trees have been retained in the cleared landscape (Back *et al.* 2009a). In most grazed areas of central Queensland, a moderate to high amount of natural recruitment is expected, and the amount can be anticipated at the start of offsets (by observing the presence of seedlings or suckers).
K3	Lack of access to surface water during drought	Installation of tanks and troughs at 1.4 km intervals (so that no areas fail to fall within 1 km of water). Tanks are to be regularly refilled, and troughs are to be checked and maintained at regular intervals.	Sites that lack nearby surface water are unlikely to be suitable as offsets for the Koala and Squatter Pigeon, as they will not meet the definition of suitable habitat for the latter. Koalas readily and frequently drink from artificial water placed on the ground (Mella *et al.* 2019) and are expected to make use of water provided for Squatter Pigeons, provided the design of the troughs allows access by Koalas. Use of supplementary water by Koalas is highest during hot, dry weather (Mella *et al.* 2019), indicating that it can be important for sustaining Koala populations during drought.
K4	Lack of connectivity between surface water and Koala habitats located 1-2 km away.	Allowing the passive regeneration of woody vegetation surrounding water sources.	Regrowth as young as four to seven years is regularly used by Koalas (Kavanagh and Stanton 2012; Rhind *et al.* 2014), and there is therefore a high likelihood that connectivity would be restored within 10 years.
K5	Absence of trees and natural recruitment	Direct seeding and/or tubestock planting of food and shelter tree species	Expansive treeless areas will not constitute suitable offset sites on their own, as these are unlikely to achieve habitat scores comparable to the impact site in a reasonable timeframe (e.g., 20 years). Nevertheless, if small, treeless areas form a minor subset of the total offset site, high habitat scores within the remaining forested subset of the offset site could deliver average habitat scores across the offset site that meet targets set by the impact site. Generally, such small treeless areas experience natural recruitment via seed blown from nearby forest. In the event that this does not occur, active planting of Koala food trees is a highly successful means of introducing these to the site (Kavanagh and Stanton 2012;

Potential Scenario	Habitat Deficiency	Management Measures	Expected Improvements
			Rhind *et al.* 2014). Planted trees as young as four to seven years old are used by Koalas (Kavanagh and Stanton 2012; Rhind *et al.* 2014).
K6	Deficiency of large trees and dense regrowth of small trees (many of which are non-food trees), inhibiting their development into "large trees".	Thinning of midstorey non-food and non-shelter tree species, so that these constitute less than half of the total woody vegetation basal area.	The rate at which trees develop into "large trees" depends on their initial size and extent of competition with other trees. In forested areas, *Eucalyptus crebra* and *Eucalyptus melanophloia* generally increase in trunk diameter by 0.16 to 0.22 cm per year in the 600-800 mm annual rainfall regions of Queensland (Ngugi *et al.* 2015). This implies that only those trees with a diameter within 3.5 cm of the "large tree" threshold (as per BioCondition) are likely to develop into large trees within a 20-year timeframe. Growth rates can be accelerated by thinning dense regrowth (Back *et al.* 2009b). Over a 20-year period at Dingo, Queensland, *E. populnea* trees in unthinned plots increased in circumference by 20%, while those in thinned plots increased by 50% (Back *et al.* 2009b). The extent of thinning used in this study was much higher (80% of trees removed) than would be considered appropriate within an offset site, and the relative benefits of thinning an offset site would be accordingly lower.
K7	Elevated risk of dog attack within 18 km of supplementary food sources (towns, dumps, mine camps)	Where practicable, exclusion fencing around supplementary food sources to be installed.	Preventing access by wild-roaming dogs and dingoes to nearby supplementary food sources would limit their local population densities (and associated risk to Koalas) to background levels. Such measures are only feasible in specific circumstances (e.g., fencing off waste storage areas at a nearby mine camp, or fencing off a public landfill), but would not be employed for isolating whole towns.
		Implementation of a wild dog control program, involving baiting, trapping and shooting.	Dog control programs in south-eastern Queensland, where dogs constitute a major cause of death, successfully reduced mortality rates of adult Koalas by 85-92% (Beyer *et al.* 2017). Any improvements in Koala survivorship are expected to be short-lived, however, due to ongoing recolonisation of the site by new dogs. Consequently, such a control program would need to continue throughout the life of the offsets (at a minimum, for the duration of the impact at Vulcan South).

Table 4-2 Potential management options for improving Squatter Pigeon habitat quality within an offset site

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
S1	A low level of pre-existing vegetation protection places this at a high risk of future loss through clearing for agriculture.	Habitat within the offset area is to be protected and will retain this protection for the duration of impacts arising from Vulcan South.	The benefits of additional habitat protection depend on the pre-existing risk of loss, which is to be determined based on recent historical clearing patterns associated with the tenure, land zone and pre-existing level of protection under the VM Act within the offset site. This data is available from Accad *et al.* (2022) and the Statewide Landcover and Trees Study datasets published by the Queensland Government (see **Section 1.3.2**).

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
S2	Low woody vegetation cover providing inadequate protection (based on NDVI)	Allowing the passive regeneration of woody vegetation.	Protecting regrowth and allowing it to develop will improve the habitat quality for Squatter Pigeons via increasing the NDVI (protective woody vegetation cover) at sites where this is initially deficient.
S3	High density of grass swards limiting the extent of bare ground required for foraging.	Allowing the passive regeneration of woody vegetation.	Density of grass in *E. populnea* and *E. crebra* woodlands in Queensland has a strong negative association with the basal area of trees and shrubs (Scanlon and Burrows 1990). As regrowth is allowed to grow, overly dense groundcover vegetation is expected to naturally thin to provide more favourable foraging habitat for Squatter Pigeons.
		Modifying cattle grazing intensities to reduce overall grass biomass and provide open areas for foraging.	Grazing management generally has a more pronounced effect on ground-storey composition of plant communities than tree density (Jones *et al.* 2009; Good *et al.* 2012). These effects are also more immediate, compared to those achieved through passive regeneration of trees. Grazing can be an effective conservation tool for managing excessive pasture densities in Queensland, although secondary invasion by the exotic grass Indian Couch (*Bothriochloa pertusa*) may undermine the biodiversity benefits gained by grazing in conservation areas (Lebbink *et al.* 2021).
S4	Insufficient amount of ground -storey vegetation due to shading and litter fall beneath overly dense woody vegetation.	Thinning of the midstorey and/or trees (of species not used by Koalas or Central Greater Gliders for food or shelter).	Woody regrowth is commonly much denser than undisturbed forest, leading to a suppression of ground-storey vegetation and diversity (Jones *et al.* 2014). Thinning has been demonstrated to restore the ground-storey vegetation to a state similar to remnant forest (Jones *et al.* 2014). Reducing the cover of overly dense woody vegetation leads to the (mostly) rapid expansion of grass cover, and greater representation within the understorey community of large-seeded, perennial grasses such as *Themeda triandra* and *Heteropogon contortus* (Scanlon and Burrows 1990). Effectiveness of thinning varies with vegetation community, with the understorey being less responsive to the removal of *Eucalyptus melanophloia* than *Eucalyptus populnea* (Hall *et al.* 2016). Thinning only successfully restores ground-storey vegetation communities at sites with few weeds; otherwise, thinning can promote the proliferation of weeds (Jones *et al.* 2014).
		Controlled burning designed to reduce biomass within the midstorey.	Regular fires encourage the growth of grasses, forbs and sub-shrubs, at the expense of sapling trees (Williams *et al.* 2003). However, unlike targeted thinning, burning is expected to have some collateral damage on Koala and glider food and shelter tree species. Furthermore, areas with too little ground-storey vegetation may have insufficient fuel to initiate or support a sufficient burn (MacLeod *et al.* 2014). Prescribed burns are therefore likely to be more valuable for maintaining a favourable understorey composition, once established, than for converting areas of dense regrowth to an open, patchy forest favourable for Squatter Pigeons.
S5	Insufficient amount of ground-storey	Reduction in grazing intensity.	Grazing management generally has a more pronounced effect on ground-storey

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
	vegetation due to overgrazing		composition of plant communities than tree density (Jones *et al.* 2009; Good *et al.* 2012). On average, heavily degraded pastures (>60% bare ground, erosion visible and/or few palatable perennial grasses) need to be "rested" for approximately four years to recover their condition (Hunt *et al.* 2014).
S6	Low species richness of grasses and forbs in the ground-storey	Modifying cattle grazing intensity to improve species diversity.	Generally, the composition of ground-storey vegetation is slow to respond to changes in grazing intensity, compared to the density of this vegetation (Grice and Barchia 1995). However, de-stocking heavily grazed sites in northern Queensland resulted in a 19% to 37% increase in native species richness (measured within 10 m^2 per site) within ten years (Kemp and Kutt 2020). In some locations, namely those dominated by palatable, perennial grasses such as *Themeda triandra* and *Heteropogon contortus*, intermediate levels of grazing results in an increase in diversity, as grazing releases other plant species from competition (Calvert 2001). These studies indicate that modest improvements to understorey diversity may be achieved over medium timeframes by optimising grazing intensities.
S7	Lack of nearby water	Installation of tanks and troughs at 1.4 km intervals (so that no areas fail to fall within 1 km of water). Tanks are to be regularly refilled, and troughs are to be checked and maintained at regular intervals.	Squatter Pigeons readily use artificial water sources. The provision of artificial water points rapidly increased the numbers and diversity of birds inhabiting semi-arid woodlands in Victoria (Starks 2015). The installation of permanent water points within habitat that otherwise provides favourable foraging and breeding habitat for Squatter Pigeons would have large, immediate benefits.
S8	Elevated risk of predation by cats and dogs within 18 km of supplementary food sources (towns, dumps, mine camps)	Where practicable, exclusion fencing around supplementary food sources to be installed.	Preventing access by wild-roaming dogs and cats to nearby supplementary food sources would limit their local population densities (and associated risk to Squatter Pigeons) to background levels. Such measures are only feasible in specific circumstances (e.g., fencing off waste storage areas at a nearby mine camp, or fencing off a public landfill), but would not be suitable for isolating whole towns.
		Implementation of a wild dog and cat control program, involving baiting, trapping and shooting.	There is no available data on the effects of predator-control programs on the Squatter Pigeon, but this ground-nesting species is expected to benefit from measures implemented for the Koala. Due to ongoing colonisation of the site by new individual cats and dogs, any control program would need to continue throughout the life of the offsets (at a minimum, for the duration of the impact at Vulcan South).

Table 4-3 Potential management options for improving Central Greater Glider habitat quality within an offset site

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
G1	A low level of pre-existing vegetation protection places this at a high risk of	Habitat within the offset area is to be protected and will retain this	The benefits of additional habitat protection depend on the pre-existing risk of loss, which is to be determined based on recent historical clearing patterns associated with

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
	future loss through clearing for agriculture.	protection for at least for the duration of impacts arising from Vulcan South.	the tenure, land zone and pre-existing level of protection under the VM Act within the offset site. This data is available from Accad *et al.* (2022) and the Statewide Landcover and Trees Study datasets published by the Queensland Government (see **Section 1.3.2**).
G2	High elevated fine fuel hazard, leading to a high risk of canopy fires.	Implementation of a controlled fire regime, reducing midstorey fuel load.	Semi-frequent, low intensity burns of open eucalypt forests are a well-recognised tool for reducing their fuel load and the intensity of wildfires they experience (Fernandes 2015). As the midstorey shrubs and saplings removed by prescribed burns are not utilised by Central Greater Gliders for shelter or food (Eyre 2002), risk of fire can be reduced without compromising habitat quality.
		Thinning of midstorey non-food trees, and either lying felled debris flat or piling it in forest gaps, so it does not act as a ladder for fire to reach the canopy.	Mechanical fuel load reduction is a relatively new approach in Australia (Ximenes *et al.* 2017). Only a small number of trials have been undertaken to date. Eucalypt forests burnt after experimental thinning experienced lower-severity fires than un-thinned forest, due to the reduction in elevated fuel (Volkova and Weston 2019). However, thinned debris left on the ground can fuel intense fires during severe fire weather (Weston *et al.* 2022), suggesting that the value of thinning versus prescribed burning as a means of fuel reduction should be ascertained on a case-by-case basis.
		Installation of fire breaks around or within the offset area.	Firebreaks (e.g., cleared tracks) are a useful tool for stopping the spread of low-intensity grass fires, but are ineffective at stopping larger fires (Price *et al.* 2007). They are primarily useful for containing low-intensity prescribed burns.
		Reducing risk of ignition, by limiting public access to the offset area and implementing rules for land managers pertaining to the lighting of fires or use of machinery that could generate sparks during risky weather conditions.	In Australia, most bushfires are initiated by humans, whether intentionally, accidentally or through negligence (Ganteaume and Syphard 2017). Natural causes (of which lightening is the most frequent) ignite less than one-quarter of Australian bushfires (Ganteaume and Syphard 2017). By reducing the risk of local ignition through human actions, the overall chance of fire is substantially reduced.
G3	Deficiency of large trees and dense regrowth of small trees, inhibiting their development into “large trees” and shelter for Central Greater Glider.	Thinning of midstorey non-food tree species, so that these constitute less than half of the total woody vegetation basal area.	The rate at which trees develop into “large trees” depends on their initial size and extent of competition with other trees. In forested areas, *Eucalyptus crebra* and *Eucalyptus melanophloia* generally increase in trunk diameter by 0.16 to 0.22 cm per year in the 600-800 mm annual rainfall regions of Queensland (Ngugi *et al.* 2015). This implies that only those trees with a diameter within 3.5 cm of the “large tree” threshold (as per BioCondition) are likely to develop into large trees within a 20-year timeframe. Growth rates can be accelerated by thinning dense regrowth (Back *et al.* 2009b). Over a 20-year period at Dingo, Queensland, *E. populnea* trees in un-thinned plots increased in circumference by 20%, while those in thinned plots increased by 50% (Back *et al.* 2009b). The extent of thinning used in this study was much higher (80% of trees removed) than would be considered appropriate within an offset site, and the relative benefits of thinning an offset site would be accordingly lower.

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
G4	Lack of connectivity between drought refuges (groundwater-dependent ecosystems and riverine forests) and Central Greater Glider habitat located less than 1 km away.	Allowing the passive regeneration of woody vegetation surrounding drought refuges.	While regrowth will not provide hollows for Central Greater Gliders in the timeframe of offset management, it will allow Central Greater Gliders the opportunity to more effectively move through the landscape without having to go to the ground. This will not only improve the "mobility" component of habitat quality, but also an offset area's value as a refuge against drought.
G5	Protection of hollow-bearing trees providing shelter habitat for the Central Greater Glider from forestry.	No food or shelter trees for Central Greater Gliders will be removed when constructing tracks or undertaking thinning within the offset site.	Queensland landholders are legally allowed to remove otherwise protected vegetation on their land if this is to be used as construction timber to maintain existing buildings and structures (e.g., sheds, stockyards and fences) on the land. This constitutes a type of exempt clearing work under the VM Act. Selective harvesting of eucalypts for construction is a common practice on grazing properties throughout central Queensland. By explicitly protecting trees of value to the Central Greater Glider from harvest, the offset will maintain existing sources of food and dens.

Table 4-4 Potential management options for improving Brigalow ecological community quality within an offset site

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
B1	A low level of pre-existing vegetation protection places this at a high risk of future loss through clearing for agriculture.	Habitat within the offset area is to be protected and will retain this protection for at least for the duration of impacts arising from Vulcan South.	The benefits of additional habitat protection depend on the pre-existing risk of loss, which is to be determined based on recent historical clearing patterns associated with the tenure, land zone and pre-existing level of protection under the VM Act within the offset site. This data is available from Accad *et al.* (2022) and the Statewide Landcover and Trees Study datasets published by the Queensland Government (see **Section 1.3.2**).
B2	High density of exotic grasses, such as Buffel Grass, elevates the risk of fire damaging or killing mature Brigalow trees.	Periodic intense grazing to reduce grass fuel loads	Brigalow is fire-sensitive, but intact Brigalow communities rarely burn due to a lack of fine grass fuels within the ground layer. Fire within Brigalow invaded by Buffel Grass results in widespread tree death and exacerbation of weed infestations (Butler and Fairfax 2003). The risks associated with grazing (extinction of grazing sensitive species, spread of weed seeds and trampling) may be lower than those posed by fire (Butler and Fairfax 2003).
		Removal of Buffel Grass using herbicides	Removal of large Buffel Grass infestations is likely to be costly, and result in substantial collateral damage to native understorey plants. However, the targeted removal of small, newly establishing infestations may be prudent. Furthermore, removal of Buffel Grass within an outer ring can act as a firebreak for the interior of the Brigalow patch. Herbicide treatments are known to be effective and more efficient than manual removal (Dixon *et al.* 2002).
		Enhancement of crown cover around the edges of the Brigalow patch, by ripping strips around the edges of Brigalow remnants to	This approach was proposed by Butler and Fairfax (2003), but has not been subject to widespread testing. Dense clusters of Brigalow are known to impair grass growth underneath (Scanlon 1991), so this measure may prove effective.

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
		encourage sucker growth dense enough to shade out grass.	
		Installation of fire breaks around or within the offset area.	Firebreaks (e.g., cleared tracks) are a useful tool for stopping the spread of low-intensity grass fires, but are ineffective at stopping larger fires (Price *et al.* 2007). They are primarily useful for preventing low-intensity prescribed burns ignited in neighbouring eucalypt woodlands from entering patches of Brigalow.
		Reducing risk of ignition, by limiting public access to the offset area and implementing rules for land managers pertaining to the lighting of fires or use of machinery that could generate sparks during risky weather conditions.	In Australia, most bushfires are initiated by humans, whether intentionally, accidentally or through negligence (Ganteaume and Syphard 2017). Natural causes (of which lightening is the most frequent) ignite less than one-quarter of Australian bushfires (Ganteaume and Syphard 2017). By reducing the risk of local ignition through human actions, the overall chance of fire is substantially reduced.
B3	High density of Buffel Grass reduces species richness of ground vegetation.	Removal of Buffel Grass using herbicides	Managing Buffel Grass infestations through heavy grazing is the cheapest option for reducing cover of this invasive weed, but can have substantial negative effects, such as elevated soil erosion and water runoff (Thornton and Elledge 2021). Removal via herbicide treatment retains dead clumps as soil protection. Herbicide treatments are known to be effective and more efficient than manual removal (Dixon *et al.* 2002). Buffel Grass removal resulted in substantial improvements to the richness and quantity of native forbs and annual grasses near Alice Springs (Wright *et al.* 2020). Due to feasibility, removal of Buffel Grass using herbicides is only feasible over small scales (Lebbink *et al.* 2021).
		Periodic intense grazing to reduce Buffel Grass cover	Pulse grazing implemented at the end of the summer growing season results in an increase in native grasses and herbs in pastures containing Buffel Grass (Lebbink *et al.* 2021). This approach is only appropriate where Indian Couch (*Bothriochloa pertusa*) is absent; otherwise, the gaps will be filled by this other invasive species (Lebbink *et al.* 2021).
B4	High stem density of small trees, inhibiting the growth rates of trees and slowing development into mature Brigalow woodland.	Selective thinning to achieve a target stem density that maximises structural development of the ecological community.	Experimental thinning trials and simulation models revealed that thinning Brigalow to 6,000 stems ha^{-1} (the density of mature Brigalow forest is usually 1,250–2,070 stems ha^{-1}: Ngugi *et al.* 2011) is optimal for expediting development of a regrowth ecosystem towards the structure of mature reference forest over a 20-year period (Dwyer *et al.* 2010). Plots with high initial stem densities accumulate less aboveground biomass over the subsequent 45 years, compared to those that have lower stem densities (Ngugi *et al.* 2011). Thinning is not recommended in areas containing Buffel Grass, as this flammable species will invade the gaps created by thinning and the increased fire risk surpasses the potential gains from improved growth rates of unthinned trees (Dwyer and Mason 2017).
B5	Excessive dominance of rainforest species	None advised	While the identity of the Brigalow (*Acacia harpophylla* dominant and co-dominant) ecological community could be maintained through the selective removal of rainforest

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
			species, this is not justified. The types of rainforest communities into which Brigalow is most likely to transition belong to another endangered community (Semi-evergreen vine thickets of the Brigalow Belt and Nandewar Bioregions), and are therefore protected. Careful selection of offset sites that are sufficiently dominated by *Acacia harpophylla* is important to avoid this issue.
B6	Absence of grazing-sensitive plant species	Excluding cattle or reducing grazing pressure	Exclusion of grazing from *Acacia* shrubland in New South Wales improved the species richness of ground vegetation by 19% over 18 years (Daryanto and Eldridge 2010). Decreased grazing pressure will only improve ground vegetation diversity in the absence of Buffel Grass, which otherwise spreads and excludes native species (Clarke *et al.* 2005). The presence of Indian Couch also reduces the ability of native perennial grasses to colonise and spread, although over extended periods of low grazing pressure (>10 years) native species do increase in dominance in pastures dominated by Indian Couch (Bartley *et al.* 2014).
B7	Deficiency of coarse woody debris	Thinning excessively dense Brigalow regrowth and leaving dead stems as debris for fauna habitat.	Improvements will be immediate at sites with dense regrowth and little existing woody debris. This approach is only suitable at sites with stem densities exceeding 6,000 stems ha^{-1} (Dwyer *et al.* 2010), or else thinning existing vegetation will jeopardise other ecosystem structural traits (e.g., canopy cover, basal area, etc).

5 Monitoring

Permanent monitoring locations will be installed within the offset site, coinciding with the locations to be used in the initial habitat quality assessments. The start and end points of each transect will be marked with star pickets.

The offset site will be monitored in the late wet season (February-April) every five years by qualified ecologists.

The methodology to be adopted is to be consistent with that used for assessing habitat quality at the impact site (see **Section 3**), so that data is directly comparable. The only exceptions are additional pieces of information to be collected at the offset site, including:

- (if a pest animal control program is implemented at the offset site), records are to be kept of all measures implemented, and surveys are to be conducted every five years to determine the effectiveness of this program, based on detection rates of cats, foxes and dogs;
- (if surface water is absent in part or all of the offset site), regular (e.g., weekly) monitoring of the functioning of tanks and troughs, with records to be kept of each inspection and any maintenance required;
- records are to be kept of grazing regimes (what stocking rate and over which period) implemented annually within the offset site, to allow for modifications of this regime should milestone monitoring indicate this is required;
- records are to be kept of any targeted thinning that takes place in the offset area, noting the date and number of stems per hectare removed; and
- records are to be kept of all fires within the offset site (both controlled burns and bushfires), which includes their date, the approximate boundaries of the burn scar and approximate scorch height (if known).

The success criterion to be adopted for each protected matter is that, after 20 years, the offset site achieves the improvement in habitat quality forecast within the Offset Assessment Guide, which is to be detailed within an Offset Area Management Plan (OAMP), once an offset site has been located.

Interim criteria (for each five years, coinciding with each round of monitoring) will also be developed within the OAMP. Interim criteria will not necessarily be based on incremental improvements of exactly one quarter of the total based on the success criteria. Instead, they will consider the shapes of expected improvement curves for each attribute potentially improving with offset management.

Some habitat quality attributes (e.g., availability of surface water, structure of the ground cover, predator control) are expected to show rapid early improvements, followed by negligible change after the first five years. Other attributes (e.g., species richness of understorey vegetation, BioCondition of Brigalow, and basal area of Koala and Central Greater Glider food trees) are expected to show a gradual, linear improvement over time. Others may not display any detectable improvement until considerable time has elapsed (e.g., number of large shelter trees for the Central Greater Glider).

Both the final and interim success criteria are site-specific and cannot be developed until an offset site has been chosen.

6 Protection Measures

Once an offset site has been approved by the Commonwealth and Queensland Governments, it is to be legally secured through a voluntary declaration under the *Vegetation Management Act 1999* (VM Act). Once a declaration is made, it is registered in title and is binding on all current and future owners of the land until the intent and outcomes of an associated Offset Area Management Plan have been achieved. The offset site is to remain protected until all impacts of Vulcan South on the Brigalow ecological community, Koala, Greater Glider and Squatter Pigeon have ceased (i.e., until habitat has been returned to the rehabilitated mine). Declared areas under the VM Act are displayed as category A vegetation on a property map of assessable vegetation (PMAV).

The environmental gains that will be achieved through this additional protection depend on the risk that the habitat would otherwise have been cleared in the absence of offset declaration. This risk varies according to landform, tenure and vegetation category under the VM Act. For remnant vegetation (i.e., category B regulated vegetation under the VM Act), risk of loss at the offset site in the absence of offsets will be inferred from recent historical clearing patterns in the bioregion (data published by Accad *et al.* 2022; refer to **Table 1-1**). Recent historical clearing patterns for category C (high-value regrowth), and X (other non-remnant) regulated vegetation will be inferred from the Statewide Landcover and Trees Study spatial data published by the Queensland Department of Environment and Science (2020c) (refer to **Table 1-2**). With the added protection of offset declaration, it will be assumed that the offset area will have a similarly low risk of clearing as a National Park or State Forest.

7 Offset Suitability

Once a suitable offset site has been located and has undergone the necessary habitat quality assessments (refer to **Section 3.1.3**), the Commonwealth Government's Offset Assessment Guide will be used to confirm the suitability of the proposed offset. Habitat quality assessments will be undertaken using the same methodology as will be used for the impact site. All other inputs to the Offset Assessment Guide will be informed, wherever available, by published data on land-clearing rates, rates of vegetation regrowth in nearby areas, and effectiveness of management measures. To maintain a high confidence in the output of this calculator, conservative values will be used whenever there is uncertainty in inputs. An offset area that possesses the qualities described in **Section 1.3.2** and **Section 3.2** is likely to meet the requirements of the *EPBC Act Environmental Offsets Policy* (**Table 7-1**).

Table 7-1 Accordance with the EPBC Act Environmental Offsets Policy

Principles of the EPBC Act Environmental Offsets Policy	How this will be achieved by Vulcan South
1. Deliver an overall conservation outcome that improves or maintains the viability of the protected matter	• By proposing an offset site and management strategy that, when assessed using the Offset Assessment Guide, indicates No Net Loss or a Net Gain for the Brigalow ecological community, Koala, Greater Glider and Squatter Pigeon; • By achieving a positive conservation outcome for the same protected matters as being impacted (i.e., the Brigalow ecological community, Koala, Central Greater Glider and Squatter Pigeon) and the same attributes (i.e., foraging, breeding and dispersal habitat for the Squatter Pigeon will be assessed separately); • By providing evidence that the Brigalow ecological community, Koala, Greater Glider and Squatter Pigeon are either on the offset site, or are nearby (with connecting habitat) and likely to inhabit the offset site once management makes it suitable; • By implementing the offset for the duration of the impact (at least 20 years), not just the action itself (9 years) • By recreating native vegetation communities and ecosystems, rather than non-native ones; • By committing to a future quality that is equal to, or greater than, the quality of the impact site, and which is to be attained by the nominated time until ecological benefit and then maintained for the duration of the impact;
2. Be built around direct offsets but can include other compensatory measures	• By being a 100% direct offset, which provides a measurable conservation gain for the impacted protected matters; • By acknowledging and managing key threats to the Brigalow ecological community, Koala, Central Greater Glider and Squatter Pigeon; • By being secured for conservation purposes for at least the duration of the impact, as there is a risk of loss or degradation of the site without offset;
3. Be in proportion to the level of statutory protection that applies to the protected matter	• By considering the level of statutory protection (vulnerable, endangered or critically endangered) for the Brigalow ecological community, Koala, Central Greater Glider and Squatter Pigeon when applying the Offset Assessment Guide;
4. Be of a size and scale proportionate to the	• By describing the attributes of the protected matters being impacted, the quality and importance of those attributes, the nature of the impact (e.g. permanent or temporary), the level of threat applicable to the offset site, the time it will take to achieve a

Principles of the EPBC Act Environmental Offsets Policy	How this will be achieved by Vulcan South
residual impacts on the protected matter	conservation gain for the protected matter, and risk of the conservation gain not being realised; • By ensuring that offsets calculations are as accurate as possible and implementing the Precautionary Principle where there is scientific uncertainty;
5. Effectively account for and manage the risks of the offset not succeeding	• By using direct offsets instead of other compensatory measures; • By including a risk analysis within the draft OAMP, which considers factors that could affect the success of the offset (i.e. attain the completion criteria by the nominated time until ecological benefit and maintain this for the duration of the impact), with input from multiple environmental specialists; • By proposing compensatory measures within the draft OAMP for if the offset fails, such as additional offsets to compensate for both the impact and failed offset; • By detailing within the draft OAMP how and when the Precautionary Principle has been applied;
6. Be additional to what is already required, determined by law or planning regulations, or agreed to under other schemes or programs	• By detailing the duty of care requirements applicable to the offset site within a draft OAMP, such as the landowner's responsibility to control certain weeds and feral animals, and managing stocking rates and maintain water troughs; • By calculating the risk of loss based on existing environmental planning laws (e.g., *Vegetation Management Act 1999*) that apply to the offset site; • By delivering conservation gains that have not been paid for, or achieved, while participating in other schemes (e.g. carbon offset scheme); • By providing conservation gains that are in addition to duty of care or environmental planning laws;
7. Be efficient, effective, timely, transparent, scientifically robust and reasonable	• By allocating resources, including any required for management and monitoring, in an efficient manner that maintains or improves the viability of the Brigalow ecological community, Koala, Central Greater Glider and Squatter Pigeon; • By implementing offsets before, or at the same time as, the impact occurring; • By being based on scientifically robust and verifiable information, including published peer-reviewed studies, the Australian Government's Species Profile and Threats Database, expert opinion, and field-collected data from the local area; • By implementing the Precautionary Principle if there is not scientific certainty; • By using scientifically robust and peer-reviewed methods for collecting and analysing environmental data; • By having realistic offset commitments and completion criteria that are likely to be achieved despite any potential threats or risks;
8. Have transparent governance arrangements	• By detailing governance of the offset site within a draft OAMP, including ensuring that offset actions are fully funded for the required timeframe; • By committing to measure and monitor the performance of the offset, and reporting on this every five years to the Department;

Principles of the EPBC Act Environmental Offsets Policy	How this will be achieved by Vulcan South
including being able to be readily measured, monitored, audited and enforced	• As appropriate, by delivering the offset through contractual arrangements with a third party (e.g., local landholder or Aboriginal ranger group); and • By ensuring that offset commitments are measurable and specific so that they can be audited and enforced.

8 Documents to be Prepared

A draft Offset Area Management Plan (OAMP) is to be prepared and submitted for assessment and approval by DCCEEW. The draft OAMP is to be prepared by a suitably qualified ecologist and in accordance with the Department's *Environmental Management Plan Guidelines* (Department of the Environment 2014).

The draft OAMP is to provide the following:

- details to demonstrate how the environmental offset compensates for residual significant impacts of the project on the Brigalow (*Acacia harpophylla* dominant and co-dominant) ecological community and habitat for the Koala, Central Greater Glider and Squatter Pigeon, in accordance with the principles of the *EPBC Act Environmental Offsets Policy* and all requirements of the Offsets Assessment Guide;
- a description of the environmental offset, including location, size, condition, environmental values present and surrounding land uses;
- baseline data, including from field validation surveys, and other supporting evidence that documents the presence of the relevant listed threatened species, and the quality of their habitat within the environmental offset area;
- an assessment of the offset site habitat quality using the *Guide to Determining Terrestrial Habitat Quality version 1.3* (Department of Environment and Science 2020a);
- details of how the environmental offset will provide connectivity with other habitats and biodiversity corridors and/or will contribute to a larger strategic offset for the relevant listed threatened species;
- maps and shapefiles to clearly define the location and boundaries of the offset area, accompanied by the offset attributes (e.g. physical address of the offset area, coordinates of the boundary points in decimal degrees, the listed threatened species that the environmental offset compensates for, and the size of the environmental offset area in hectares);
- specific offset success criteria derived from the site's habitat quality to demonstrate the improvement in the quality of habitat in the environmental offset area over an appropriate period;
- details of the management actions, and timeframes for implementation, to be carried out to meet the offset completion criteria;
- interim milestones that set targets at 5-yearly intervals for progress towards achieving the offset completion criteria;
- details of the nature, timing and frequency of monitoring to inform progress against achieving the 5-yearly interim milestones (the frequency of monitoring must be sufficient to track progress towards each set of milestones, and sufficient to determine whether the environmental offsets are likely to achieve the completion success criteria in adequate time to implement all necessary corrective actions);
- proposed timing for the completion of internal monitoring reports which provide evidence demonstrating whether the interim milestones have been achieved;
- timing for the implementation of corrective actions if monitoring activities indicate the interim milestones have not been achieved;
- risk analysis and a risk management and mitigation strategy for all risks to the successful implementation of the OAMP and timely achievement of the offset completion criteria, including a rating of all initial and post-mitigation residual risks in accordance with a risk assessment matrix;
- evidence of how the management actions and corrective actions take into account relevant approved conservation advices and are consistent with relevant recovery plans and threat abatement plans; and

- details of the legal mechanism for legally securing the environmental offset, such that legal security remains in force for at least 20 years to provide enduring protection for the environmental offset area against development incompatible with conservation.

9 Timeframes

Offsets for Vulcan South are to be legally secured within 12 months of any disturbance to the Brigalow ecological community or a matter area for the Koala, Central Greater Glider and/or Squatter Pigeon. In order for Vulcan South to be approved in time for a commencement date in Q3 2023, an approximate timeline as described in **Table 9-1** will be followed.

Table 9-1 Timeframe for delivering offsets

Date	Tasks to be completed
Q4 2022	Identification of a suitable offset area and undertaking of habitat quality assessments
Q4 2022	Preparation of a draft OAMP and submission to DCCEEW for approval
Q2 2023	Anticipated approval of the OAMP
Q2 2023	Signed agreement with landholder and implementation of the OAMP

10 References Cited

Accad, A. J.A.R. Kelley, D. Richter, V.J. Neldner and J. Li (2022). Remnant Regional Ecosystem Vegetation in Queensland (Version 12.2), Analysis 1997–2019. Queensland Department of Environment and Science: Brisbane.

Adams-Hosking, C., H.S. Grantham, J.R. Rhodes, C. McAlpine and P.T. Moss (2011). Modelling climate-change-induced shifts in the distribution of the koala. *Wildlife Research* **38,** 122-130.

Adani and GHD (2015). Carmichael Coal Mine and Rail Project EIS (Volume 1 Section 11 Matters of NES). Accessed at: http://eisdocs.dsdip.qld.gov.au/Carmichael%20Coal%20Mine%20and%20Rail/EIS/EIS/Project%20Wide/11-mnes-project-wide.pdf.

Allen, B., L. Allen and L. Leung (2014). Interaction between two naturalised invasive predators in Australia: are feral cats suppressed by dingoes? *Biological Invasions* **17**, 1-17.

Andrews, S.P., G.G Gration, D.D. Quin and A.P. Smith (1994). Description and assessment of forestry impacts on fauna of the Urbenville Forestry Management Area. Report for State Forests of New South Wales Austeco Environmental Consultants, Armidale.

Ashman, K.R., D.J. Watchorn, D.B. Lindenmayer and M.F.J. Taylor (2021). Is Australia's environmental legislation protecting threatened species? A case study of the national listing of the greater glider. *Pacific Conservation Biology* **28,** 277-289.

Australian Koala Foundation (2015). *National Koala Tree Planting List.* Available online at: https://www.savethekoala.com/about-koalas/trees-koalas.

Back, P.V., E.R. Anderson, W.H. Burrows and C. Playford (2009a). Woody plant response to various clearing strategies imposed on a poplar box (*Eucalyptus populnea*) community at Dingo in central Queensland. *Tropical Grasslands* **43,** 37-52.

Back, P.V., E.R. Anderson, W.H. Burrows and C. Playford (2009b). Popular box (*Eucalyptus populnea*) growth rates in thinned and intact woodlands in central Queensland. *Tropical Grasslands* **43,** 188-190.

Barth, B.J., S.I. FitzGibbon, A. Gillett, R.S. Wilson, B. Moffitt, G.W. Pye, D. Adam, H. Preece and W.A. Ellis (2019). Scattered paddock trees and roadside vegetation can provide important habitat for koalas (*Phascolarctos cinereus*) in an agricultural landscape. *Australian Mammalogy* **42,** 194-203.

Bartley, R., J.P. Corfield, A.A. Hawdon, A.E. Kinsey-Henderson, B.N. Abbott, S.N. Wilkinson and R.J. Keen (2014). Can changes to pasture management reduce runoff and sediment loss to the Great Barrier Reef? The results of a 10-year study in the Burdekin catchment, Australia. *The Rangeland Journal* **36,** 67-84.

Bengsen, A.J., J.A. Butler and P. Masters (2012). Applying home-range and landscape-use data to design effective feral-cat control programs. *Wildlife Research* **39,** 258-265.

Bernardo, A.L., M.G.F. Reis, G.G. Reis, R.B. Harrison and D.J. Firme (1998). Effect of spacing on growth and biomass distribution in *Eucalyptus camaldulensis, E. pellita* and *E. urophylla* plantations in southeastern Brazil. *Forest Ecology and Management* **104,** 1-13.

Berry, L.E., D.A. Driscoll, S.C. Banks and D.B. Lindenmayer (2015). The use of topographic fire refuges by the greater glider (*Petauroides volans*) and the mountain brushtail possum (*Trichosurus cunninghami*) following a landscape-scale fire. *Australian Mammalogy* **37,** 39-45.

Beyer, H.L., D. de Villiers, J. Loader, A. Robbins, M. Stigner, N. Forbes and J. Hanger (2017). Management of multiple threats achieves meaningful koala conservation outcomes. *Journal of Applied Ecology* **55,** 1966-1975.

Bradley, M., A. House, M. Robertson and C. Wild (2010). Vegetation succession and recovery of ecological values in the southern Queensland Brigalow Belt. *Ecological Management & Restoration* **11,** 113-118.

Bureau of Meteorology (2022). Groundwater Dependent Ecosystems Atlas website. Bureau of Meteorology. Accessed at: http://www.bom.gov.au/water/groundwater/gde/

Burrows, W.H., M.B. Hoffmann, J.F. Compton, P.V. Back and L.J. Tait (2000). Allometric relationships and community biomass estimates for some dominant eucalypts in Central Queensland woodlands. *Australian Journal of Botany* **48,** 707-714.

Butler, D.W., and R.J. Fairfax (2003). Buffel Grass and fire in a Gidgee and Brigalow woodland: A case study from central Queensland. *Ecological Management & Restoration* **4,** 120-125.

Callaghan, J., C. McAlpine, D. Mitchell, J. Thompson, M. Bowen, J. Rhodes, C. de Jong, R. Domalewski and A. Scott (2011). Ranking and mapping koala habitat quality for conservation planning on the basis of indirect evidence of tree-species use: a case study of Noosa Shire, south-eastern Queensland. *Wildlife Research* **38,** 89-102.

Calvert, G.A. (2001). The effects of cattle grazing on vegetation diversity and structural characteristics in the semi-arid rangelands of North Queensland. PhD thesis, James Cook University, Townsville.

Catchpole, W.R. and C.J. Wheeler (1992). Estimating plant biomass: A review of techniques. *Australian Journal of Ecology* **17,** 121-131.

Clarke, H., C. Lucas and P. Smith (2012). Changes in Australian fire weather between 1973 and 2010. *International Journal of Climatology* **33,** 931-944.

Clarke, P.J., P.K. Latz and D.E. Albrecht (2005). Long-term changes in semi-arid vegetation: Invasion of an exotic perennial grass has larger effects than rainfall variability. *Journal of Vegetation Science* **16,** 237-248.

Comport, S.S, S.J. Ward and W.J. Foley (1996). Home ranges, time budgets and food tree use in a high density tropical population of greater gliders, Petauroides volans minor (Pseudocheiridae: Marsupialia). *Wildlife Research* **23**, 401-419.

Crome, F.H.J. (1976). Breeding, moult and food of the Squatter Pigeon in north-eastern Queensland. *Australian Wildlife Research* **3,** 45-59.

Crowther, M.S., D. Lunney, L. Lemon, E. Stalenberg, R. Wheeler, G. Madani, K.A. Ross and M. Ellis (2013). Climate-mediated habitat selection in an arboreal foliovore. *Ecography* **37,** 336-343.

CSIRO (2021). Climate Change in Australia website. Commonwealth Scientific and Industrial Research Organisation and Bureau of Meteorology. Accessed at: https://www.climatechangeinaustralia.gov.au/en/

Daryanto, S. and D.J. Eldridge (2010). Plant and soil surface responses to a combination of shrub removal and grazing in a shrub-encroached woodland. *Journal of Environmental Management* **91,** 2639-2648.

DCCEEW (2022a). *Phascolarctos cinereus* (combined populations of Qld, NSW and the ACT) in Species Profile and Threats Database, Department of Climate Change, Energy, the Environment and Water, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed 22 Feb 2021.

DCCEEW (2022b). *Geophaps scripta scripta* in Species Profile and Threats Database, Department of of Climate Change, Energy, the Environment and Water, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed 22 Feb 2021.

DCCEEW (2022c). Conservation Advice for *Petauroides volans (*greater glider (southern and central)), Department of Agriculture, Water and the Environment, Canberra. Available from: http://www.environment.gov.au/biodiversity/threatened/species/pubs/254-conservation-advice-05072022.pdf. Accessed 23 August 2022.

DEHP (2014). *Queensland Environmental Offsets Policy Significant Residual Impact Guideline*. Department of Environment and Heritage Protection, Queensland Government, Brisbane.

Department of the Environment (2014). *Environment Management Plan Guidelines.* Australian Government, Canberra.

Department of Environment and Science (2020a). *Guide to determining terrestrial habitat quality: Methods for assessing habitat quality under the Queensland Environmental Offsets Policy version 1.3*. Queensland Government, Brisbane.

Department of Environment and Science (2020b). *Queensland Environmental Offsets Policy version 1.9.*Queensland Government, Brisbane.

Department of Environment and Science (2020c). Statewide Landcover and Trees Study (SLATS) spatial data. Downloaded from: https://www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/slats.

Department of the Environment, Water, Heritage and the Arts (2013). *Significant Impact Guidelines 1.1 – Matters of National Environmental Significance*. Australian Government, Canberra.

Department of Science, Information Technology, Innovation and the Arts (2015). *BioCondition Assessment Manual. A Condition Assessment Framework for Terrestrial Biodiversity in Queensland version 2.2*. Queensland Government, Brisbane.

Department of Sustainability and the Environment (2012). *Overall Fuel hazard Assessment Guide 4th ed.* Fire and adaptive management, report no. 82, Victorian Government, Melbourne.

Department of Sustainability, Environment, Water, Population and Communities (2012). *Environment Protection and Biodiversity Conservation Act 1999 Environmental Offsets Policy.*Australian Government, Canberra.

Dixon, I.R., K.W. Dixon and M. Barrett (2002). Eradication of buffel grass (*Cenchrus ciliaris*) on Airlie Island, Pilbara Coast, Western Australia. Pp 92-101 in: Veitch, C.R. and M.N. Clout (eds), *Turning the tide: the eradication of invasive species.* IUCN SSC Invasive Species Specialist Group, Cambridge, UK.

Dwyer, J.M., and R. Mason (2017). Plant community responses to thinning in densely regeneration *Acacia harpophylla* forest. *Restoration Ecology* **26,** 97-105.

Dwyer, J.M., R. Fensham and Y.M. Buckley (2010). Restoration thinning accelerates structural development and carbon sequestration in an endangered Australian ecosystem. *Journal of Applied Ecology* **47,** 681-691.

Edwards, G.P., N. De Preu, B.J. Shakeshaft, I.V. Crealy and R.M. Paltridge (2001). Home range and movements of male feral cats (*Felis catus*) in a semiarid woodland environment in central Australia. *Austral Ecology* **26,** 93-101.

Ellis, W.A.H., A. Melzer, F.N. Carrick and M. Hasegawa (2002). Tree use, diet and home range of the koala (*Phascolarctos cinereus*) at Blair Athol, central Queensland. *Wildlife Research* **29,** 303-311.

Ellis, W., A. Melzer, I.D. Clifton and F. Carrick (2010). Climate change and the koala *Phascolarctos cinereus*: water and energy. *Australian Zoologist* **35,** 369-377.

Eyre, T.J. (2002). Habitat preferences and management of large gliding possums in southern Queensland. Ph.D. thesis, Southern Cross University, Lismore.

Eyre, T.J. (2005). Hollow-bearing trees in a coastal forest in south-east Queensland, Australia: Abundance, spatial distribution and management. *Pacific Conservation Biology* **11**, 23-37.

Eyre, T.J., G.C. Smith, M.F. Venz, M.T. Mathieson, L.D. Hogan, C. Starr, J. Winter and K. McDonald (2022). Guide to greater glider habitat in Queensland. *Department of Environment and Science*, *Queensland Government* **4,** 1-59.

Fairfax, R.J. and R.J. Fensham (2000). The effect of exotic pasture development on floristic diversity in central Queensland, Australia. *Biological Conservation* **94,** 11-21.

Fernandes, P.M. (2015). Empirical support for the use of prescribed burning as a fuel treatment. *Current Forestry Reports* **1,** 118-127.

Foley, W.J., J.C. Kehl, K.A Nagy, I.R. Kaplan and A.C. Borsboom (1990). Energy and water metabolism in free-living greater gliders, P*etauroides volans*. *Australian Journal of Zoology* **38,** 1-9.

Franks, A.J. (2002). The ecological consequences of Buffel Grass *Cenchrus ciliaris* establishment within remnant vegetation of Queensland. *Pacific Conservation Biology* **8,** 99-107.

Fraser, F., V. Lawson, S. Morrison, P. Christophersen, S. McGreggor and M. Rawlinson (2003). Fire management experiment for the declining Partridge Pigeon, Kakadu National Park. *Ecological Management and Restoration* **4,** 94-102.

Ganteaume, A. and A.D. Syphard (2017). Ignition Sources. In: S.L. Manzello (ed.), *Encyclopedia of Wildfires and Wildland-Urban Interface (WUI) Fires*, Springer International Publishing.

Good, M.K., J.N. Price, P.J. Clarke and N. Reid (2012). Dense regeneration of floodplain *Eucalyptus coolabah*: invasive scrub or passive restoration of an endangered woodland community? *The Rangeland Journal* **34,** 219-230.

Gordon, G., A.S. Brown and T. Pulsford (1988). A koala (*Phascolarctos cinereus* Goldfuss) population crash during drought and heatwave conditions in south-western Queensland. *Australian Journal of Ecology* **13,** 451-462.

Grice, A.C. and I. Barchia (1995). Changes in grass density in Australian semi-arid woodlands. *The Rangeland Journal* **17,** 26-36.

Hall, T.J., P. Jones, R.G. Silcock and P.G. Fliet (2016). Pasture production and composition response after killing Eucalypt trees with herbicides in central Queensland. *The Rangeland Journal* **38,** 427-441.

Hunt, L.P., J.G. McIvor, A.C. Grice and S.G. Bray (2014). Principles and guidelines for managing cattle grazing in the grazing lands of northern Australia: stocking rates, pasture resting, prescribed fire, paddock size and water points – a review. *The Rangeland Journal* **36,** 105-119.

Isaac, J.L., J.L. De Gabriel and B.A. Goodman (2008). Microclimate of daytime den sites in a tropical possum: implications for the conservation of tropical arboreal marsupials. *Animal Conservation* **11,** 281-287.

Jackson, S.M. (2000). Glide angle in the genus *Petaurus* and a review of gliding in mammals. *Mammal Review* **30,** 9-30.

Johnson, R.W. (1964). *Ecology and control of Brigalow in Queensland*. Queensland Department of Primary Industries, pp 1-92

Johnson, C.N. and J. VanDerWal (2009). Evidence that dingoes limit abundance of a mesopredator in eastern Australian forests. *Journal of Applied Ecology* **46,** 641-646.

Johnson, R.W., W.J. McDonald, R.J. Fensham, C.A. McAlpine and M.J. Lawes (2016). Changes over 46 years in plant community structure in a cleared brigalow (*Acacia harpophylla*) forest. *Austral Ecology* **41,** 644-656.

Jones, P., P. Filet and D.M. Orr (2009). Demography of three perennial grasses in a central Queensland eucalypt woodland. *The Rangeland Journal* **31,** 427-437.

Jones, C.S., D.H. Duncan, L.Rumpff, F.M. Thomas, W.K. Morris and P.A. Vesk (2014). Empirically validating a dense woody regrowth 'problem' and thinning 'solution' for understorey vegetation. *Forest Ecology and Management* **340,** 153-162.

Kavanagh, R.P. and M.A. Stanton (2012). Koalas use young *Eucalyptus* plantations in an agricultural landscape on the Liverpool Plains, New South Wales. *Ecological Management and Restoration* **13,** 297-305.

Kearney, M.R., B.A Wintle and W.P Porter (2010). Correlative and mechanistic models of species distribution provide congruent forecasts under climate change. *Conservation Letters* **3**, 203-213.

Kehl, J. and A. Borsboom (1984). Home range, den tree use and activity patterns in the greater glider (*Petauroides volans*). *Possums and Gliders* **1,** 229-236.

Kemp, J.E. and A.S. Kutt (2020). Vegetation change 10 years after cattle removal in a savanna landscape. *The Rangeland Journal* **42,** 73-84.

Lassau, S.A., B. Ryan, R. Close, C. Moon, P. Geraghty, A. Coyle and J. Pile (2008). Home ranges and mortality of a roadside Koala *Phascolarctos cinereus* population at Bonville, New South Wales. *Too Close for Comfort: Contentious Issues in Human-Wildlife Encounters* Pages 127-136.

Lawler, I.R., W.J. Foley, B.M. Eschler, D.M. Pass and K. Handasyde (1998). Intraspecific variation in *Eucalyptus* secondary metabolites determines food intake by folivorous marsupials. *Oecologia* **116,** 160-169.

Lebbink, G., J.M. Dwyer and R.J. Fensham (2021). Managed livestock grazing for conservation outcomes in a Queensland fragmented landscape. *Ecological Management and Restoration* **22,** 5-9.

Le Brocque, A.F., and P.M. Wagner (2018). Passive brigalow (*Acacia harpophylla*) woodland regeneration fails to recover floristic composition in an agricultural landscape. *Austral Ecology* **43,** 409-423.

Letnic, M., A. Greenville, E. Denny, C.R. Dickman, M. Tischler, C. Gordon and F. Koch (2010). Does a top predator suppress the abundance of an invasive mesopredator at a continental scale? *Global Ecology and Biogeography* **20,** 343-353.

Lindenmayer, D.B., W. Blanchard, L. McBurney, D. Blair, S.C. Banks, D. Driscoll, A.L. Smith and A.M. Gill (2013). Fire severity and landscape context effects on arboreal marsupials. *Biological Conservation* **167,** 137-148.

MacLeod, N.D., J.C. Scanlan and J.R. Brown (2014). Asymmetric ecological and economic responses for rangeland restoration: a case study of tree thickening in Queensland, Australia. *Rangelands* **36,** 37-44.

Marsh, K.J., B.D. Moore, I.R. Wallis and W.J. Foley (2014). Continuous monitoring of feeding by koalas highlights diurnal differences in tree preferences. *Wildlife Research* **40,** 639-646.

Marshall, V.M., M.M. Lewis and B. Ostendorf (2012). Buffel grass (*Cenchrus ciliaris*) as an invader and threat to biodiversity in arid environments: a review. *Journal of Arid Environments* **78,** 1-12.

May-Stubbles, J.C., A. Gracanin and K.M. Mikac (2022). Increasing fire severity negatively affects greater glider density. *Wildlife Research* https://doi.org/10.1071/WR21091.

McAlpine, C.A., J.R. Rhodes, J.G. Callaghan, M.E. Bowen, D. Lunney, D.L. Mitchell, D.V. Pullar and H.P. Possingham (2006). The importance of forest area and configuration relative to local habitat factors for conserving forest mammals: A case study of koalas in Queensland, Australia. *Biological Conservation* **132,** 153-165.

McLean, C.M., R.P. Kavanagh, T. Penman and R. Bradstock (2018). The threatened status of the hollow dependent arboreal marsupial, the Greater Glider (*Petauroides volans*), can be explained by impacts from wildfire and selective logging. *Forest Ecology and Management* **415-416,** 19-25.

McNeill, A.T., L. K.-P. Leung, M.S. Goullet, M.N. Gentle and B.L. Allen (2016). Dingoes at the doorstep: home range sizes and activity patterns of Dingoes and other wild dogs around urban areas of north-eastern Australia. *Animals* **6,** 48.

McGregor, D.C., A. Padovan, A. Georges, A. Krockenberger, H. Yoon and K.N. Youngentob (2020). Genetic evidence supports three previously described species of greater glider, *Petauroides volands, P. minor, and P. armillatus*. *Scientific reports* **10,** 1-11.

Mella, V.S.A., C, McArthur, M.B. Krockenberger, R. Frend and M.S. Crowther (2019). Needing a drink: Rainfall and temperature drive the use of free water by a threatened arboreal folivore. PLoS ONE **14,** e0216964.

Melzer, A., R. Cristescu, W. Ellis, S. Fitzgibbon and G. Manno (2014). The habitat and diet of koalas (*Phascolarctos cinereus*) in Queensland. *Australian Mammalogy* **36,** 189-199.

Metsers, E.M., P.J. Seddon and Y.M. van Heezik (2010). Cat-exclusion zones in rural and urban-fringe landscape: how large would they have to be? *Wildlife Research* **37,** 47-56.

METServe (2020). Terrestrial Ecology Assessment for the Vulcan Complex Project. Report prepared for Vitrinite Pty Ltd by Mining and Energy Technical Services, Brisbane.

METServe (2022). Terrestrial Ecology Assessment for Vulcan South. Report prepared for Vitrinite Pty Ltd by Mining and Energy Technical Services, Brisbane.

Molsher, R., A.E. Newsome, T.M. Newsome and C.R. Dickman (2017). Mesopredator management: effects of Red Fox control on the abundance, diet and use of space by Feral Cats. *PLoS ONE* **12,** e0168460.

Moore, B.D. and W.J. Foley (2000). A review of feeding and diet selection in koalas (*Phascolarctos cinereus*). *Australian Journal of Zoology*. **48,** 317-333.

Moore, B.D., W.J. Foley, I.R. Wallis, A. Cowling and K.A. Handasyde (2005). *Eucalyptus* foliar chemistry explains selective feeding by koalas. *Biology Letters* **1,** 64-67.

Munks, S.A., R. Corkrey and W.J. Foley (1996). Characteristics of arboreal marsupial habitat in the semi-arid woodlands of northern Queensland. *Wildlife Research* **23,** 185-195.

Murphy, B.P., R.A. Bradstock, M.M. Boer, J. Carter, G.J. Cary, M.A. Cochrane, R.J. Fensham, J. Russell-Smith, G.J. Williamson and D.M.J.S. Bowman (2013). Fire regimes of Australia: a pyrogeographic model system. *Journal of Biogeography* **40,** 1048-1058.

Neilly, H. and L. Schwarzkopf (2017). The response of an arboreal mammal to livestock grazing is habitat dependent. *Scientific Reports* **7,** 17382.

Neldner, V.J., B.A. Wilson, H.A Dillewaard, T.S Ryan, D.W Butler, W.J.F. McDonald, E.P. Addicott and C.N. Appelman (2020) *Methodology for survey and mapping of regional ecosystems and vegetation communities in Queensland*. Version 5.1. Updated March 2020. Queensland Herbarium, Queensland Department of Environment and Science, Brisbane.

Ngugi, M.R., R.W. Johnson and W.J.F. McDonald (2011). Restoration of ecosystems for biodiversity and carbon sequestration: Simulating growth dynamics of brigalow vegetation communities in Australia. *Ecological Modelling* **222,** 785-794.

Ngugi, M.R., D. Doley, M. Cant and D.B. Botkin (2015). Growth rates of *Eucalyptus* and other Australia native tree species derived from seven decades of growth monitoring. *Journal of Forestry Research* **26,** 811-826.

Peeters, P. and D. Butler (2014). *Brigalow: Regrowth Benefits Management Guideline*. Queensland Herbarium, Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Phillips, B. (1990). *Koalas. The little Australians we'd all hate to lose*. Canberra, ACT: Australian Government Publishing Service.

Possingham, H.P., D.B Lindenmayer, T.W Norton and I. Davies (1994). Metapopulation viability analysis of the greater glider *Petauroides volans* in a wood production area. *Biological Conservation* **70**, 227-236.

Price, O.F., A.C. Edwards and J. Russell-Smith (2007). Efficacy of permanent firebreaks and aerial prescribed burning in western Arnhem Land, Northern Territory, Australia. *International Journal of Wildland Fire* **16,** 295-307.

Rhind, S.G., M.V. Ellis, M. Smith and D. Lunney (2014). Do Koalas *Phascolarctos cinereus* use trees planted on farms? A case study from north-west New South Wales, Australia. *Pacific Conservation Biology* **20,** 302-312.

Robley, A., A. Gormley, D.M. Forsyth, A.N. Wilton and D. Stephens (2010). Movements and habitat selection by wild dogs in eastern Victoria. *Australian Mammalogy* **32,** 23-32.

Rübsamen, K., I.D. Hume, W.J. Foley and U. Rübsamen (1984). Implications of the large surface area to body mass ratio on the heat balance of the greater glider (*Petauroides volans*: Marsupialia). *Journal of Comparative Physiology B* **154,** 105-111.

Rus, A.I., C. McArthu, V.S.A. Mella and M.S. Crowther (2020). Habitat fragmentation affects movement and space use of a specialist folivore, the koala. *Animal Conservation* **24,** 26-37.

Scanlon, J.C. (1991). Woody overstorey and herbaceous understorey biomass in *Acacia harpophylla* (brigalow) woodlands. *Australian Journal of Ecology* **16,** 521-529.

Scanlon, J.C., and W.H. Burrows (1990). Woody overstorey impact on herbaceous understorey in *Eucalyptus* spp. Communities in central Queensland. *Austral Ecology* **15,** 191-197.

Smith, P. and J. Smith (2018). Decline of the greater glider (*Petauroides volans*) in the lower Blue Mountains, New South Wales. *Australian Journal of Zoology* **66**, 103–114.

Smith, G. C., M. Mathieson and L. Hogan (2007). Home range and habitat use of a low-density population of Greater Glider, Petauroides volans (Pseudocheiridae: Marsupialia), in a hollow-limiting environment. *Wildlife Research* **34**, 472-483.

Smith, A.G., C. McAlpine, J.R. Rhodes, L. Seabrook, G. Baxter, D. Lunney and A. Bradley (2013). At what spatial scales does resource selection vary? A case study of koalas in a semi-arid region. *Austral Ecology* **38,** 230-240.

Starks, J. (2015). The use of on-farm water points and artificial wildlife ponds in providing habitat for fauna in the Wimmera and South Mallee, Victoria, Australia. Masters Thesis, Faculty of Science and Technology, Federation University, Australia.

Sullivan, B.J., G.S. Baxter and A.T. Lisle (2003). Low-density koala (*Phascolarctos cinereus*) populations in the mulga lands of south-west Queensland. III. Broad-scale patterns of habitat use. *Wildlife Research* **30,** 583-591.

Taylor, B.D. and R.L. Goldingay (2009). Can road-crossing structures improve population viability of an urban gliding mammal? *Ecology and Society* **14,** 13.

Taylor, A.C., H. Tyndale-Biscoe and D.B. Lindenmayer (2007). Unexpected persistence on habitat islands: genetic signatures reveal dispersal of a eucalypt-dependent marsupial through a hostile pine matrix. *Molecular Ecology* **16,** 2655-2666.

Thornton, C.M., and A.E. Elledge (2021). Heavy grazing of buffel grass pasture in the Brigalow Belt bioregion of Queensland, Australia, more than tripled runoff and exports of total suspended solids compared to conservative grazing. *Marine Pollution Bulletin* **171,** 112704.

Threatened Species Scientific Committee (2012). Listing advice for *Phascolarctos cinereus* (Koala). Available from: http://www.environment.gov.au/biodiversity/threatened/species/pubs/197-listing-advice.pdf. In effect under the EPBC Act from 2 May 2012.

Threatened Species Scientific Committee (2015a). Conservation Advice *Geophaps scripta scripta* squatter pigeon (southern). Department of the Environment, Canberra. Available from: http://www.environment.gov.au/ biodiversity/threatened/species/pubs/64440-conservation-advice-31102015.pdf. In effect under the EPBC Act from 27 October 2015.

Volkova, L. and C.J. Weston (2019). Effect of thinning and burning fuel reduction treatments on forest carbon and bushfire fuel hazard in *Eucalyptus sieberi* forests of South-Eastern Australia. *Science of the Total Environment* **694,** 133708.

Wakefield, N.A. (1970). Notes on the glider-possum, *Petaurus australis* (Phalangeridae, Marsupialia). *Victorian Naturalist* **87,** 221–236

Wagner, B., P.J. Baker, S.B. Stewart, L.F. Lumsden, J.L. Nelson, J.K. Cripps, L.K. Durkin, M.P. Scroggie and C.R. Nitschke (2020). Climate change drives habitat contraction of a nocturnal arboreal marsupial at its physiological limits. *Ecosphere* **11,** e03262.

Weston, C.J., J. Di Stefano, S. Hislop and L. Volkova (2022). Effect of recent fuel reduction treatments on wildfire severity in southeast Australian *Eucalyptus sieberi* forests. *Forest Ecology and Management* **505,** 119924.

White, N.A. (1999). Ecology of the koala (*Phascolarctos cinereus*) in rural south-east Queensland, Australia. *Wildlife Research* **26,** 731-744.

Williams, P.R., R.A. Congdon, A.C. Grice and P.J. Clarke (2003). Effect of fire regime on plant abundance in a tropical eucalypt savanna of north-eastern Australia. *Austral Ecology* **28,** 327-338.

Woinarski, J.C.Z. and A.J. Ash (2002). Responses of vertebrates to pastoralism, military land use and landscape position in an Australian tropical savanna. *Austral Ecology* **27,** 311-323.

Woinarski, J.C.Z. and C.P. Catterall (2004). Historical changes in bird fauna at Coomooboolaroo, northeastern Australia, from the early years of pastoral settlement (1873) to 1999. *Biological Conservation* **116,** 379-401.

Wright, B.R., P.K. Latz, D.E. Albrecht and R.J. Fensham (2020). Buffel grass (*Cenchrus ciliaris*) eradication in arid central Australia enhances native plant diversity and increases seed resources for granivores. *Applied Vegetation Science* **24,** e12533.

Ximenes, F., M. Stephens, M. Brown, B. Law, M. Mylek, J. Schirmer, A. Sullivan and T. McGuffog (2017). Mechanical fuel load reduction in Australia: a potential tool for bushfire mitigation. *Australian Forestry* **80,** 88-98.