

# A review of ghost bat ecology, threats and survey requirements

**Prepared for the Department of Agriculture, Water and Environment**

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We acknowledge the Traditional Custodians of Australia and their continuing connection to land and sea, waters, environment and community. We pay our respects to the Traditional Custodians of the lands we live and work on, their culture, and their Elders past and present.

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# 1 Objective

The Department of Agriculture, Water and the Environment (DAWE) has identified gaps in information relating to the ghost bat (*Macroderma gigas*) listed as Vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). This bat is extant across the tropical north of Australia including Queensland, Northern Territory, Kimberley and the semi-desert Pilbara region of Western Australia.

This document addresses the following information gaps:

- roosting habitat descriptions, both natural, artificial, and critical habitat definitions
- guidance on mitigation measures for roost under threat
- information on population dynamics of the species
- guidance on foraging requirements and range.

This study is to provide (where available) current information, data and advice based on publicly available information, Bat Call client information (with the approval of the client) and the author's experience and personal observations on:

- characteristics of diurnal roosting and breeding sites
- usage of seasonal caves and associated seasonal movements
- guidelines for the development of artificial habitat/roosts for the species – key features such as structure, materials, location
- minimum survey technique requirements - minimum effort, minimum number of nights, etc.
- confirmation of spectrum of visible light that could minimise light impacts to this species (within the limits of available data)
- confirmation or update of the range of humidity and temperature conditions for diurnal roosting and breeding sites necessary for survival, and variation with season
- maximum levels of noise and vibration from mining-related activities that species can tolerate (this information would be used to determine buffer zones around known roost and breeding sites)
- impact of public access to roosting and breeding sites, and recommendations for controlling public access to known and suspected breeding and roosting sites (that is, buffer zones, timing, etc)
- description of habitat critical to the survival of the species in particular regarding the information gaps in the table below (within the limits of available data)
- species-specific gaps
  - improved habitat descriptions and critical habitat definition, including clearer description of microclimates utilised by the species

- importance of water sources (including surface water if applicable) close to their roosting and breeding sites, including distance from roosting and breeding sites
- foraging requirements and range
  - confirmation/update of existing advice of average foraging area size of 61 ha and that they return to the same foraging areas each night (Tidemann et al. 1985)
- guidance on mitigation measures (for example, buffer zones)
  - confirmation of breeding season.

It should be noted that there remain information gaps on this species (for example, regarding the importance of permanent water sources for ghost bats).

## 2 Ghost bat ecology

The ghost bat (*Macroderma gigas*) is a monotypic species endemic to northern Australia. It comprises isolated populations extant in the semi-desert Pilbara region of Western Australia, the mesic Kimberley and Top End of the Northern Territory, north-western Queensland south of the Gulf of Carpentaria, Cape York peninsular, wet and dry tropics and the central Queensland coastal and hinterland regions. Its conservation status is Vulnerable under Commonwealth (EPBC Act), and Western Australian state legislation and Endangered under Queensland and South Australian state legislation.

It is a large 130 to 175 g, apex night-time zoophagic predator (for example, Churchill 2008 and Start et al. 2020) with white, pale grey or light brown fur. There is no clear geographic pattern in morphological variation in the ghost bat although there is some evidence for clinal variation, with the northern populations being slightly smaller on average (N. Hanrahan pers. comm.). Females may be slightly larger than males although sexual dimorphism appears to be low (Hand and York 1990). Ghost bats have a surface foraging strategy with 2 modes. It perches in vegetation to ambush passing prey (either on the ground or in the air), and it also gleanes surfaces such as the ground while in flight. It also flies directly into the path of other smaller bats to catch them while in flight (see [section 5.2](#)). The morphology of its wings (span of 700 to 850 mm), body, tail and large ears are understood in the context of its foraging ecology (for example, Bullen and McKenzie 2008a). In this context, its wingbeat frequency in flight, the ecomorphology of its flight muscles, its basal and resting metabolic rates and its musculo-skeletal mechanical efficiency are also understood (Bullen and McKenzie 2002, 2004, Bullen et al. 2014). It has an aerodynamically clean airframe, including pelage, that is optimised for a minimum skin friction drag and for silent flight when approaching prey (Bullen and McKenzie 2008b). Its characteristic flight speeds are published. Its minimum level flight speed is 3.1 m/s, its aerobic foraging speed is 7.2 m/s and its sustainable anerobic speed for commuting is 9.1 m/s (Bullen and McKenzie 2016). Some research in a captive environment (Leitner and Nelson 1967) indicated that the species did not enter torpor; however, other research found that captive individuals did demonstrate fluctuating body temperatures (unpublished data in Geiser and Stawski 2011). The physiology of wild individuals in relation to torpor is poorly understood, however, they do not appear to enter torpor as an energy saving strategy based on high numbers of field observations.

Ghost bats use a variety of echolocation and social calls ranging between 1 kHz and 60 kHz. The usual echolocation call within roosts and while foraging is a series of low intensity brief and steep frequency modulated (fm) pulses from ~60 to ~15 kHz (McKenzie and Bullen 2009; 2012). It also extensively uses a variety of audible social vocalisations between 1 and 15 kHz that are currently poorly understood. Recent work by Hanrahan (2020) has begun to identify a number of these calls. Extreme care should be taken to correctly identify ghost bat echolocation and social calls during field surveys as, while they are unique, there is potential to confuse them with some similar *Taphozous* spp. call types and also some cave-insect sounds. Note, formal identifications should be confirmed only by experienced bat call practitioners familiar with ghost bat calls.

Ghost bats mate during the dry season and females give birth to single young. Parturition appears to vary with latitude with the Northern Territory Top End colonies giving birth as early

as July to August (Churchill 2008; N. Hanrahan pers. comm.), and a bit later in the Gulf country (N. Hanrahan pers. comm.). It is delayed in the southern colonies to the late spring months of mid-October to late-November in central Queensland (for example, Toop 1985 and Hoyle et al 2001) and the Pilbara (Bullen 2021).

### 3 Ghost bat distribution

Sub-fossil data show that the ghost bat was once distributed widely over much of Australia except Victoria and Tasmania, including the arid zone, but contracted northwards during the Holocene period (Molnar et al., 1984; Churchill and Helman 1990). A study that combined information from ancient DNA obtained from remains in extinct southern populations, newly generated and existing genetic data from extant northern populations, and ecological niche modelling based on past and present climatic conditions (Thomson et al. 2012), suggested that the ghost bat expanded southwards during periods of higher humidity (interglacials) and contracted northwards in response to increasing aridity (for example, preceding the last glacial maximum). The combined analyses support previous statements that the ghost bat is a geographically relict species in southern, arid landscapes, present only because caves provide suitable roost microclimates.

At the time of European settlement, arid zone subpopulations remained. Since the arrival of Europeans, ghost bats have contracted further northwards, with much of their arid zone distribution disappearing in the past few decades (Molnar et al., 1984; Churchill and Helman 1990). Burbidge et al. (1988) reported that western desert Aboriginal people stated that ghost bats only ever occurred in a few favourable areas and that they were still present. However, searches of several central Australian sites where they once occurred have failed to locate any (Churchill and Helman 1990). The last central desert specimen was collected in 1961 (Butler 1962).

The species' current range comprises geographically discontinuous populations in the Pilbara (Armstrong and Anstee 2000; McKenzie and Bullen 2009), Kimberley (including several islands; McKenzie and Bullen 2012), Northern Territory Top End including Groote Eylandt (Milne and Pavey 2011), the Gulf of Carpentaria (Australian Wildlife Conservancy 2010), coastal and near coastal Queensland from Cape York to near Rockhampton (Richards et al., 2008), and western Queensland (Mt Isa, Cloncurry and Camooweal districts; J. Augusteyn pers. comm.). Burbidge et al. (2009), using modern, historical and subfossil data, found that the ghost bat occurred in 37 of Australia's 85 bioregions, and that it was extinct in 12. Worthington Wilmer (2012) noted that only 14 breeding sites were then known. Currently, the species 'extent of occurrence' (EOO) is 2.5 million km squared (stable), and its 'area of occupancy' (AOO) is less than 10 km squared (reducing) (Woinarski 2014).

Populations are highly structured, being genetically distinct at both regional and local scales (Worthington Wilmer et al., 1994, 1999). Populations at the southern limits of the species' range, that is Pilbara and southern Queensland, are geographically isolated and separated by a minimum distance of 300 km. This geographic isolation is reflected in the genetic data, with populations at Mt Etna, Cape Hillsborough, and Camooweal in Queensland, and the Pilbara in Western Australia, being highly divergent genetically, implying virtually no movement of individuals between these sites (Worthington Wilmer et al., 1999, Augusteyn et al. 2018). Populations within the Northern Territory and far north Queensland are also highly distinct from each other and other population centres (Worthington Wilmer et al. 1999), while the Kimberley bats are distinct from all other Australian populations with genetic structure evident in the Kimberley populations (Worthington Wilmer 1996).



Early population genetic studies at natal roosts based on mitochondrial DNA markers indicate a high degree of female philopatry (remaining in, or returning to, an individual's birthplace). From nuclear microsatellite markers (Worthington Wilmer et al. 1994, 1999) suggested that gene flow within regions was mediated by male movements and that northern populations had higher heterozygosity and less marked phylogeographic structure than southern groups, which was interpreted to be a consequence of the limited availability and greater separation of roost sites with suitable microclimates in more arid areas. Follow-on studies, that have built on the work by Worthington Wilmer et al. by adding individuals from the Pilbara and Kimberley regions, have also highlighted the distinctness of these 2 subpopulations, high female philopatry, and gene flow within regions arising from male movements (see Woinarski et al. 2014). Further, the genetic separation between the Cape Hillsborough and Mt Etna populations in Queensland has been reaffirmed (Augusteyn et al. 2018). Losses of breeding females from northern regions therefore have the potential to significantly reduce the area of occupancy and population-size.

More recent observations in the most arid of the regions, the Pilbara region of Western Australia, have shown that reproducing females are able to access a variety of caves, moving from roost to roost in response to local prey availability and disturbance (authors unpublished data and other relevant observations [see [section 5.1](#)]). In the Pilbara's Hamersley subregion, ghost bats are most often encountered as groups of 1 and 15 individuals roosting in caves in ironstone strata (author's unpublished observations). In the wet season, these groupings have been observed to include reproducing females, both heavily pregnant and also carrying pups. Examples are reports of females pregnant or with pups near Caves Creek (22.30S 117.30E) and near Mount Robinson (23.00S 118.90E). Larger groupings of up to 100 individuals are rarely encountered. In the Pilbara's Chichester subregion, most of the population roosts in large colonies, comprising 100 to 600 individuals, in abandoned underground mines. However, natural roost caves with similar characteristics to the Hamersley cave roosts do occur in ironstone strata. Because of the ghost bat's dependence on a vagrant foraging strategy, virtually all high-quality caves in the Pilbara that offer appropriate microhabitat conditions must be assumed to be maternal roost candidates, especially in the Hamersley subregion. Due to pressure from development, losses of sites suitable for breeding females have the potential to significantly reduce the extent of occurrence (EOO) and population-size, particular in the Hamersley Range between the Ashburton and Fortescue Rivers, east of Karijini National Park (TSSC 2016).

## 4 Population information

There are no robust measures of abundance across the species entire geographic range. Because of their large size and pale colour, colonies can be counted as members leave cave and mine roosts after dusk on moon-lit nights. Counts have been made from time to time over the past 3 decades at certain large colonies, and some have count data over several consecutive years. Currently, the largest colonies counted are: Pine Creek in the Northern Territory (800 to 1,250 individuals in 2018: N. Hanrahan, 2020), Klondyke Queen mine (>500 in 2018: authors unpublished data), and Lalla Rookh mine (>500 in 2020: C. Knuckey pers. comm.), but such regional maxima are atypical of most colony-sizes (Richards et al. 2008). McKenzie and Hall (2008) estimated the global population size at between 7,000 and 9,000 individuals, with differences amongst the regional subpopulations. In a more recent assessment, Worthington Wilmer (2012) suggested that the total Australian population was between 4,000 and 6,000 individuals (comprising 750 to 850 in Queensland, 2,500 to 3,500 in the Northern Territory and about 1,500 in Western Australia), but did not provide calculations on which the suggestions were based. However, this assessment predated the latest information from the Pilbara, Kimberley and Mount Etna. The Queensland subpopulations are located in only 4 to 5 highly disjunct localities and have been re-estimated at fewer than 1,000 individuals; the major colonies at Mount Etna (79% reduction reported by Augusteyn et al. 2018), Riversleigh (possibly now locally extinct), Camooweal and Cape Hillsborough has declined greatly since the late 1990s (J. Augusteyn pers. comm.).

The Northern Territory subpopulations are distributed among 5 broad regions (Gulf of Carpentaria, Groote Eylandt, Litchfield, Katherine/Pine Creek, Kakadu) with a total population of approximately 2,500 to 3,500 individuals (see Woinarski et al. 2014). Following the passing of the Cane Toad front, recent reports suggest a decline (White et al. 2016; Shine et al. 2016). Individual colonies, however, show significant variability. For example, Kohinoor Adit at Pine Creek had 1,100 to 1,500 ghost bats in the late 1980s (Woinarski et al. 2014), about 560 individuals in 2010 (Grant et al. 2010), 300 to 800 in 2016, and 775 to 1,235 in 2018, depending on the season (Hanrahan 2020). Other Northern Territory sites with large permanent colonies are at Claravale Station, Pungalina Station and Tolmer Falls in Litchfield National Park (N. Hanrahan pers. comm. 2021).

Ghost bats occur in 2 separate regions in Western Australia. In the Pilbara, Armstrong and Anstee (2000) estimated 1,200 individuals. McKenzie and Bullen (2009) found the ghost bat to be more common in the Pilbara than previously thought. They found it at 21 of 24 survey areas, and in all 4 Pilbara sub-regions. In the past decade, surveys for environmental impact assessments (Bullen 2021) have indicated a slightly larger Pilbara population of approximately 1,850 (350 across the Hamersley Range and 1,500 across the eastern Pilbara). In the Kimberley c. 3,000 to 4,000 individuals have been inferred (McKenzie and Hall 2008). McKenzie et al. (2020) also found the ghost bat to be widespread and common at mainland sites (detected at 13 of 38 sites) and on islands along the north-western Kimberley coast (McKenzie and Bullen 2012), observing it on 5 of the islands surveyed and detecting its calls on 6 others. However, recent informal observations by the author have suggested that there may have been a decline in abundance behind the Cane Toad front over the last few years, with the species not found at several previously populated Central and East Kimberley sites around the Devonian Reef.

Abandoned mine adit colonies comprise a significant portion of the population at known roost sites; indeed, the presence of mines may have allowed the species to extend its range and expand its population-size (Worthington Wilmer et al. 1999). Those with large permanent colonies have become refuge and source populations for the surrounding areas. Early colony counts from Hall et al. (1997) in the major mines have recently been supplemented by accurate census data:

- Comet (Pilbara; 21.23OS 119.72OE): 35 (1981); 37+ (1993); 100+ (1996); between 100 and 270 (recent counts between 2017 and 2021, Bullen 2017b and unpublished data)
- Klondyke Queen colony (Pilbara; 21.34OS 119.89OE): 40 (1981); 98+ (1994); 20+ (1994); 40+ (1995); varied between 107 and 366 in the period 12 June to 5 July 2001 (Armstrong 2010); between 70 and 475 (recent counts between 2017 and 2021, Bullen unpublished data)
- Lalla Rookh (Pilbara; 21.05OS 119.27OE): between 200 and 500+ (recent counts between 2017 and 2020, C. Knuckey pers. comm.)
- Bulletin adit (Pilbara; 20.95OS 120.24OE): 406 (1994); 200+ (1995); this roost was subsequently destroyed by open cutting in 2003, but ghost bats persist in unknown numbers in nearby abandoned mines including the Kitchener (Bullen unpublished data)
- Kohinoor adit (Northern Territory; 13.83OS 131.85OE): 300 (in 1981); 780 (in 1984); 1,500 (in 1990); 564 (2010: Grant et al. 2010); 300 to 800 (in 2016: Hanrahan 2020); 775 to 1,235 (in 2018: Hanrahan 2020).

In central Queensland, ghost bats are continuing to decline at the Mount Etna Caves National Park and the surrounding karst system with an effective population size of only 25 in 2012 (Augusteyn et al. 2018) capturing just over one per trap night on average, whereas Worthington Wilmer (1996) caught 25 individual bats over 2 nights in 1993 at a similar time of year, at the same site and using the same methodology. On Cape York Peninsula, maternity sites are known at Mitchell-Palmer limestone and Kings Plains station, with a suspected site near the Iron Range (Reardon et al. 2010). Other available Queensland estimates are 150 at Girringun-Gugu Badhun west of Ingham/Cardwell and 500 at Kuku Nyungkul-Kuku Bubogun, south of Cooktown (Woinarski et al. 2014). Trapping in the early 2000s of the Cape Hillsborough roost also indicates that the wintering population is declining when compared with the numbers caught and recorded from these caves from mid 1970s to early 1990s (M. Cali pers. comm. cited in Woinarski et al. 2014).

A global population size of <10,000 individuals has been estimated. This total is based on counts of colony size at some roosts in combination with calculations based on 'area of occupancy'. The size of each of the various subpopulations have been estimated at between 1,000 and 4,000 individuals.

# 5 Habitat

## 5.1 Roosting habitat

Ghost bats move between a number of caves seasonally or as dictated by weather conditions and/or foraging opportunities, so they require a range of cave sites (Richards et al. 2008). They disperse widely when not breeding but may concentrate in a relatively few roost sites when breeding. Few of these sites are known (Richards et al. 2008; Worthington Wilmer 2012), and most are not protected or managed. In the Pilbara, except for the large, abandoned mine colonies, ghost bats are often present either singly or in small groups (usually less than 15). These have been shown to move periodically, either seasonally or as dictated by prey availability (author's unpublished data). Their vagrant foraging strategy relates to patchy, locally unreliable rainfall events (and prey biomass) across much of its foraging habitat in the Pilbara and elsewhere in other semi-arid parts of its broader Australian range. Hence the relatively small groups that have to move from roost to roost to access their ephemeral patchy food resource.

Roost sites include caves, rock crevices and disused mine adits. In the Northern Territory, major colonies of over 100 are reported in caves in sandstone and limestone strata (Hanrahan 2020). In the Kimberley, ghost bats are widespread across ecosystems associated with rocky landscapes, both sandstone and limestone, including offshore islands with well-developed riparian zones (McKenzie et al. 2020). In the Hamersley Range in the arid Pilbara, preferred roosting habitat is in caves in Brockman and Marra Mamba banded iron formation (BIF) and Robe Pisolite channel iron deposit (CID) geology (Armstrong and Anstee 2000; Bullen unpublished data). In the eastern Pilbara, ghost bats are most often found in abandoned underground mines (see [section 4](#)), and in caves in ironstone geology and granite rockpiles (Hall et al., 1997; Armstrong and Anstee 2000; Bullen unpublished data). The species' persistence in the Pilbara depends on the physiologically benign day roosts found deep underground in temperature-stable caves (Leitner and Nelson 1967; Hall et al., 1997; Armstrong and Anstee 2000; McKenzie and Bullen 2009) with chambers and/or cavities that trap humidity.

### 5.1.1 Roost categorisation

Extensive survey activity in the last decade has led to the proposal of 4 categories of roosting habitat used by ghost bats in the Pilbara region (Bullen 2021). These categories are currently based on characteristics identified for the Pilbara and Kimberley and published data from the Northern Territory and Queensland, though they may also be applicable to other roost sites in the Northern Territory and Queensland.

#### **Category 1 maternity/diurnal roost sites with permanent ghost bat occupancy**

There are several documented permanent roost caves and underground mines in northern Australia, for example, Klondyke Queen in the Pilbara, Tunnel Creek in the Kimberley and Kohinoor mine adit in the Northern Territory. These tend to have large but fluctuating populations, for example, Kohinoor and Klondyke Queen colonies (see [section 4](#)). A permanent colony persists at Mt. Etna in Queensland, Kings Plains, Mitchel Palmer, and Camooweal. In the Northern Territory, there are permanent large colonies at Tolmer Falls, Pungalina and Claravale (Hanrahan 2020). In the Pilbara, other than the large colonies (>100 individuals) in a number of historical underground mines for example, Klondyke Queen, Lalla Rookh and Bamboo Creek, very few such roosts in natural caves are documented. Fluctuating colony-sizes have been

observed at those that may be permanently occupied. An example may be a significant cave with a complex surrounding gully in a CID mesa in the Robe Valley south-west of Pannawonica that has had ghost bats present on most survey visits. The colony-size at this cave has varied from a few to over 70 recorded in April 2017 (Bullen 2017). Usually, these caves are deep and dark, with one or more elevated roosting chambers that provide a stable microhabitat. Further detail is provided in [section 5.1.2](#). Caves with proven permanent presence must all be assumed to be maternity caves, a source population for the surrounding district. They are therefore critical habitat for the ongoing presence of ghost bats in the area. There are no currently documented category 1 caves in the Hamersley Ranges.

### **Category 2 maternity/diurnal roost caves with regular occupancy**

There are a number of Pilbara caves and adits where ghost bats have regular, but not continuous, presence over long periods. These caves have similar features as Category 1 caves but are often less complex with only a single inner chamber and are often in less productive areas that the bats only utilise periodically. The longest continuous monitoring programs have been at Rio Tinto's West Angelas project, and at BHPs Mining Area C and South Flank projects. At all 3 locations there are a number of caves with roosting ghost bats records but none of these have had either permanent presence or consistently high numbers present. Numbers have varied between zero and 5 with very occasional counts of 20 or more (for example, Bullen 2017; author's unpublished data). Based on recent monitoring of a number of Hamersley Range caves using ultrasonic call detectors, ghost bats are present for 25 to 75% of nights over periods of up to several months, but then may be abandoned for weeks or even months. At present, there is insufficient data to see if there are any seasonal trends in these occupancy rates. These caves typically have several other caves, shelters and overhangs within a few hundred meters. Together they make up an 'apartment block' grouping (TSSC 2016, Bullen 2017) that supports the ongoing presence of the bats.

A genetic analysis by Ottewell et al. (2018) of samples taken from 5 West Angelas monitored caves in 2015 and 2017 suggests that some ghost bats tend to use one or a small number of caves regularly over a season or year, but others move between caves in the same period. Their analysis identifies 34 unique individuals at caves over those 2 years and indicated that the 'genetic effective population size' was twelve. Long-term observations have shown that 2 of the 5 caves, AA1 and A1, have regular occupancy (Biologic 2018). In all surveys undertaken, the ghost bats have been either roosting in low numbers or there was evidence of recent roosting at the former and, except for one survey, at the latter. The genetic analysis also supports this conclusion, with presence of multiple bats at these caves over the 2 years of that study. Similar occupancy patterns have been recorded at several other Hamersley Range caves (for example, Bullen 2021). There are an increasing number of observations becoming available of pregnant ghost bats, or of ghost bats carrying pups, at some of these caves although, again, there is insufficient data to identify any trends other than to say that any cave that has regular occupancy must be assumed to be capable of supporting one or more reproducing females and their offspring and are therefore critical habitat. In Queensland, the regular occurrence at some sites and their isolation from other nearby colonies >300 km, suggests the presence of Category 2 caves even though the maternity cave is unknown. These include the colonies at Cape Hillsborough, Mt Isa/ Cloncurry, Cape Melville, Iron Range/ McIlwraith Range, Wet Tropics, and Hervey Range/ Girringun-Gugu Badhun.

### **Category 3 diurnal roost caves with occasional occupancy**

There are many caves and adits where one to a few ghost bats roost occasionally, or rarely. Normally less well-developed structures, such places are often used as feeding sites (as evidenced by middens with food scraps) or temporary refuges. Surveys in recent years have identified numerous caves that have ghost bat scats or small food middens present but either no evidence of roosting bats or with rarely repeated presence observations, for example, 5 of the 7 monitored caves at West Angelas (Biologic 2018) show such a pattern. Reproducing females have been reported from at least 2 West Angelas caves that ongoing observations indicate fall into this category. When adjacent to Category 2 caves, these are considered to be a part of an 'apartment block' and are therefore critical habitat important for the ongoing presence of the species in the area. In contrast, isolated Category 3 caves are not considered critical habitat essential to the long-term viability of a local population. However, these caves may enable the long-distance movement of individuals across a landscape, and therefore contribute to genetic exchange between neighbouring colonies.

### **Category 4 nocturnal roost caves with opportunistic usage**

Numerous observations suggest that the majority of shallow caves, shelters and deep overhangs in the Pilbara are used in at least an opportunistic manner by itinerant ghost bats. This may be anything from a single foraging visit to a longer visit, with a resting period or possibly a feeding session. It is expected that ghost bats in other regions will utilise overhangs and shallow caves in a similar way. One observation from Queensland was of 8 ghost bats roosting in a chicken coop (J. Augusteyn pers. comm.). Evidence of such visits is the widespread presence of small numbers of scats and/or food scraps found, or occasional echolocation calls recorded during surveys. These visits may or may not be repeated, depending on whether the bat is passing through a district or is a more permanent resident nearby. These are not considered critical habitat.

### **5.1.2 Characteristics of natural caves used as diurnal roosts by ghost bats**

Category 1 and 2 caves are most often deep, dark and have at least one roosting chamber deep within, behind a reasonably narrow entrance or in-cave constriction. The roosting chamber is normally elevated above the entrance to trap warm moist air. The ceiling of the chamber is often domed or flat and has cracks and a roughed natural rock surface that allows the bats to grip. Some chambers have hollows in the ceiling where the bats back into completely for roosting or refuge. The ceiling heights are over 1.5 m and usually higher than 2 m, thereby providing some protection from terrestrial predators. The depth of the caves is variable ranging from shallow 20 m depth to 250 m (authors unpublished WA data) to over 500 m in the NT (L. Rhykus pers. comm.). 2 such natural Pilbara caves were described by Armstrong and Anstee (2000). However, ghost bats have been observed roosting in daylight sections of caves at Mt Etna and Cape Hillsborough in Queensland and Tunnel Creek in WA (John Augusteyn pers. comm.)

Breeding activities, such as mating and/or the repeated presence of females either pregnant or with pups, should be used to confirm the roost cave's categorisation. Often, ongoing studies or monitoring may be required before Category 1 and 2 roosts can be confirmed; it can rarely be unequivocally confirmed by a single visit. Proposing a cave to have category 2 'maternity' status may entail observing one or more of the following cave characteristics:

- one or more roosting chambers behind a narrow entrance or in-cave constriction that is elevated to reduce the risk of predation, always dark (though not necessarily completely dark), holds a steady microclimate, and contains substantial evidence of historical



occupation (for example, extensive scat pile/s typically comprising >2,000 scats, sometimes but not always mixed with a food midden; obs. by author and C. Knuckey)

- occupation by multiple individuals (preferably females) during the species' late pregnancy or lactating period (see [section 2](#))
- caves used by multiple individuals on a semi-permanent or recurring basis
- the presence of one or more large scat piles/middens where scat analysis shows usage by multiple females with high levels of progesterone.

Category 3 diurnal caves are usually less well developed as underground structures. They may be shallower allowing some light into their deeper areas, have a wide and not constricted entrance or not have a stable microclimate in an elevated roosting chamber. They will, though, have a roosting chamber with a ceiling over 1.5 m high and usually, but not always, have significant scats and food middens.

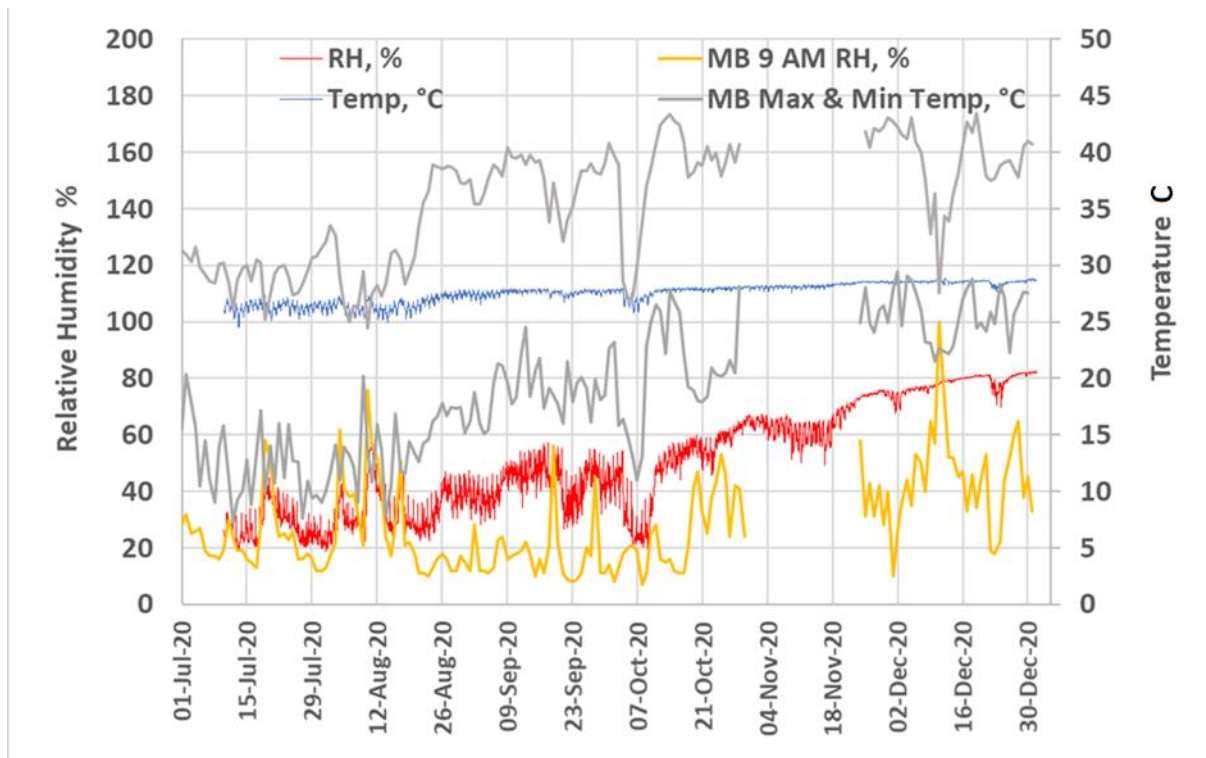
### **5.1.3 Characteristics of ghost bat diurnal roosts in abandoned underground mines**

In the eastern Pilbara region and the Northern Territory, there are a number of historical underground hard rock mines dug in the early and mid-20th century that include permanent ghost bat diurnal roost sites. Known examples that have been visited, characterised, and are currently monitored for ghost bat presence are given in [section 3](#) and [section 4](#). The common characteristics of the permanent Category 1 roosts (Comet, Klondyke Queen, Kohinoor and Lalla Rookh) are that they are deep and have a complex of tunnels and shafts that intersect the water table. The size of the colonies at the 4 roosts varies, but all are large with colonies between 100 and 1,500. A fifth similar Category 1 roost is at Bamboo Creek in the Pilbara, where a large colony of unknown size persists in the complex of underground tunnels centred on the Kitcheners mine. There is also a small, permanent presence of < 20 individuals at the Bow Bells mine in the Pilbara near the Klondyke Queen that has a similar underground complex structure.

There is no consistent layout to these roosts, with combinations of adits, declines, stopes, tunnels and shafts being present. Due to the nature of the hand-dug mining though, all tunnels and shafts have a 2 to 5 m squared cross-section, and all appear to include broader areas where the ghost bats can roost. Diurnal explorations deep into Klondyke Queen (N. McKenzie in 1995, pers. comm.), Comet (author in 2017) and Bow Bells (author in 2018) recorded groups of ghost bats roosting in the tunnels at surface level, well above the water table.

Temperature and humidity data measured in one roosting chamber deep in the Klondyke Queen mine between July and December 2020 gave underground temperatures at a stable 28°C and relative humidity close to ambient levels throughout the dry season. At the Bureau of Meteorology's weather station in Marble Bar, but as high as 80% (well above ambient level) in the wet season (Figure 1).

**Figure 1 Temperature and relative humidity in Klondyke Queen mine inner adit compared to Marble Bar, July to December 2020**



MB: Marble Bar, BOM weather station

## 5.2 Foraging habitat

Ghost bats are carnivores, with a broad diet comprising small mammals including other bats, birds, reptiles, frogs and large insects (Toop 1979, Pettigrew et al. 1986; Schulz 1986; Boles 1999; Johnston et al. 2015; Claramunt et al. 2019; Start et al. 2019). They have a surface foraging strategy with 2 modes. The species perches in vegetation to ambush passing prey (either on the ground or in the air), and it also gleans surfaces such as the ground while in flight. Unlike other zoophagic bats, it does not use its echolocation continuously while foraging (authors unpublished observations). Instead, it appears to scan the area using its sight and hearing, then swoop, often feet first, envelope its prey with its wings then kills with its powerful bite (Richards et al. 2008). There is currently little confirmed data on foraging habitat. An early study found that foraging areas were centred, on average, 1.9 km from the day roost and were small (ca. 61 ha); tagged bats generally returned to the same areas each night (Tidemann et al. 1985). Hunting behaviour within foraging areas consisted of observation at vantage points, with brief sallies to capture prey, mostly insects on the ground, although hawking of flying insects was also observed. Vantage points were changed about every 15 minutes during foraging periods and the mean distance between them was 360 m. Foraging areas were not exclusive; there was overlap between the ranges of several tagged individuals, and in one case an area was used by 20 bats. Ghost bats have also been observed preying air-to-air on larger cave bats (10 g and over) departing their roost, swooping on them from the rear (Churchill 2008; Bullen unpublished obs.) and front on (J. Augusteyn pers. comm.). More recent studies using VHF tracking (for example, Augusteyn et al. 2018; Biologic 2019) and GPS/satellite tracking technologies (Augusteyn et al. 2018, Bullen 2021) show that ghost bats, both male and female, forage over much larger areas up to 12 km from their diurnal roost (Augusteyn 2018; Bullen 2021) with round trip lengths up



to 30 km being recorded (Bullen 2021). Bats transiting to distant sites have also been recorded between 20 and 30 km from their diurnal roost in a night (Biologic 2019; Bullen 2021).

Augusteyn et al. (2018) in one study from Mt Etna in Queensland reported that the bats tended to transit quite rapidly to their foraging areas. Foraging by most of their study bats was above cleared agricultural land and along the edges of a few small remnant thickets of Eucalyptus/Corymbia woodlands on alluvial plains, rather than vine thickets surrounding their cave roost. Sites along an ephemeral watercourse were often used. Small burrows, most likely belonging to rodents, were found in the agricultural areas. Altitude data from the GPS collars suggests that the bats flew close to the ground (1-2 m) and difficulties with obtaining a signal from the VHF collars for all observers except those at higher altitudes suggests the bats were likely to be foraging close to the ground and low hills and structures obscured the signal.

Biologic (2019) and Bullen (2021) also found that most bats tagged in the Pilbara departed the roosting cave vicinity rapidly. The available GPS/sat. data (Bullen unpublished data) suggest that the bats prefer to forage on productive plain areas with thin mature woodland over patchy or clumped tussock or hummock grass (*Triodia* spp.) on sand or stony ground. Isolated trees and trees on the edge of thin thickets on the plains, or trees along the edges of watercourse woodlands, appear to be preferred vantage points. The bats forage at these sites for between 30 and 300 minutes, before moving to a nearby area (Bullen unpublished data).

### 5.3 Artificial subterranean roosts intended for ghost bats

#### Introduction

Destruction of natural roosts should be avoided wherever possible, and creation of artificial habitat should not replace in-situ conservation actions for ghost bats. Furthermore, decision-makers should not sanction the destruction of natural roosts with the expectation that artificial roosts will provide an appropriate, effective or ecologically equivalent offset. Rather, the creation of artificial roosts should be undertaken as a last resort and, as per IUCN guidelines (IUCN/SSC 2014), only if it is a wise application of available resources. Any benefits of artificial roost creation for ghost bats is still to be effectively demonstrated, particularly at scale and duration (that is, number of animals and longevity of use) (L Ruykys).

There are numerous attempts at constructing subterranean roosts for various bat species both in Australia and internationally. The generalised requirements for these have been published (for example, Thompson 2002; Gleeson and Gleeson 2012, sect. 10) and the details of some of these are available in the literature (for example, Crimmins et al. 2014; Tobin and Chambers 2017). The approach is to reproduce the characteristics of a natural cave in terms of depth, dimensions, and surface finish of ceilings and walls, thereby allowing the bats to forage and possibly roost within. In recent years, this approach has been used in 4 Pilbara locations targeting Pilbara leaf-nosed bats (PLNB), a fifth targeting both PLNB and ghost bats, and a sixth targeting ghost bats. Note that in all cases, the artificial roosts were intended to replace category 2 or 3 roosting opportunities. There has been no intention to date to provide an alternative site for a category 1 colony.

The roost targeting both species is at BHP's Cattle Gorge project. It was intended as a diurnal roost for a small permanent or semi-permanent colony of both or either species. Common cave bats (the 22 g *Taphozous* spp. and/or the 5 g *Vespadelus finlaysoni*) colonised these tunnels soon

after construction. Ghost bats began to enter the Cattle Gorge structure soon after its construction, and a diurnally roosting colony has been resident since May 2019 (presentation by S. Wild 2021). It must be said though that development of artificial roosts for the ghost bat is still a 'work-in-progress'.

The artificial ghost bat roosts were constructed to provide an equivalent category 2/3 roost:

- dark conditions
- temperatures maintained between 28 and 32°C
- temperature and humidity buffered from the natural diurnal and seasonal fluctuations outside
- access restrictions: to provide roosting sites for ghost bats (and PLNB) that minimised predation.

The designs were also intended to be maintenance free for the life of the structure.

The first built was a single chamber roost targeting diurnal roosting by ghost bats at BHP's MAC project in 2016. This is a 'cut and cover' modular preform reinforced concrete 'long-life' design, with an adit 15 m long opening into a chamber 3 m long x 3 m wide x 2.4 m ceiling height. Its floor is natural rock and dirt. This roost was not designed to create high internal humidity year-round, and the entrance and adit constriction were sized for ghost bats.

The second built, at BHP's Cattle Gorge project in 2017, was a double chamber structure intended for diurnal roosting by PLNB in the upper chamber and ghost bats in the lower chamber. It was also a preform concrete 'long-life' structure that was buried in the pit during post mining rehabilitation. The adit and lower chamber have dirt floors and are of similar proportions to MAC. There was no attempt to provide increased humidity, other than by rainfall seeping around and through the structure. Above the lower chamber, with access via ceiling holes, is a second chamber originally intended for the PLNB. This roost has been occupied by ghost bats, *Taphozous* spp. and *V. finlaysoni* bats.

The remaining 4 were built at Atlas Iron's Mt Webber project in 2018 and 2019. They are relatively low-cost technology demonstrators with a limited design life, built as replacement foraging caves, that is, for night roosting and other short visits by ghost bats and PLNB. They are constructed of steel, have adits between 12 and 18 m long opening into a chamber of 4.8 × 2.4 × 2.4 m, and are buried either in overburden storage areas or in pit rehabilitation sites. The adit and the chamber have dirt floors. There was no attempt to provide increased humidity other than by rainfall seeping around and through the structure. The entrances are sealed with doors that include holes sized for the small PLNB but restricting entry by ghost bats. Sporadic visits by ghost bats to the entrances have been detected but, to date, no ghost bat have taken up diurnal occupation.

In summary, the current experience with this type of structure has been promising in that there is one successful occupation in a roost designed for ghost bats. It follows then that an updated specification for a ghost bat artificial roost for category 2 and/or 3 caves in the Pilbara should be based on the following requirements:

- 1) Design type – For a replacement permanent roost, the current experience with buried concrete and steel structures, together with the expectation that these will decay and become unusable within several hundred years, indicates that an ‘underground hard rock adit/tunnel/shaft complex in stable strata’ is a preferred solution. A buried prefabricated concrete structure is an acceptable solution where a design life limited to several hundred years is acceptable.
- 2) Design life – The aspirational life of the artificial roost is considered to be unlimited. However, long-term targets for material selection must be in accordance with current best practice mining and/or construction technology. Therefore, a concrete and steel structure would be expected to be viable for up to 300 years in accordance with appropriate construction codes. Further, an underground structure in carefully selected, stable, hard rock strata would be expected to be viable for a considerably longer period.
- 3) Location – Sites that might be considered are:
  - a) Adjacent to a waste overburden dump or in a rehabilitated pit in close proximity to retained caves and remanent foraging habitat, to maximise the likelihood of it being utilised and to retain connectivity of roost habitat in the area.
  - b) At any level in the landscape of an unmined, hard rock stratum that is permanently quarantined from mining, and not subject to future/ongoing project impacts, particularly habitat removal, but also in consideration of noise, light and vibration impacts.
  - c) A geological stable location that will be maintenance free for the life of the roost. Matters such as preventing vegetation growth that might block the entrance must be addressed.
  - d) A gully or a cliff line with an existing series of shallow caves and or deep overhangs, to create an apartment block.

For a replacement roost and considering current experience with concrete structures summarised above, a site that meets either point ‘a’ or ‘b’ (above) and meets ‘c’ and ‘d’ is the recommended alternative solutions.

- 4) Overhead rock thickness – There is no preferred overhead rock thickness other than that it must be stable for the long-term viability of the roost.
- 5) The internal microhabitat requirement for a ghost bat cave is to replicate conditions within natural caves proven to be permanent diurnal roosts. For the hard-rock alternatives, internal temperatures will be self-regulating over 12 months between 25 to 31°C. The required roosting chamber relative humidity is above ambient and reaches 100% seasonally. This is to be achieved by providing an elevated rear chamber to collect warm, moist air and correctly placing the structure in the strata, thereby avoiding the need for any long-term maintenance such as piped in water.
- 6) Entry is to be by an adit-like tunnel – The adit length will be determined by the location of the entrance and the geology of the site chosen. Lengths between 10 and 250 m have been shown to be acceptable to the species. Additional requirements are:
  - a) The tunnel shall have a minimum of 90 degrees of bend to eliminate ingress of light, either natural day light, lightning or nearby artificial lighting.

- b) Minimum cross section shall be at least 2 m wide by 2 m high to allow ghost bats to fly along the tunnel without colliding with the walls, and to pass one another while flying in opposite directions. It may be of any shape.
  - c) Orientation of the adit entrance portal is unrestricted.
  - d) The entry portal to the tunnel shall be gated to prevent unauthorised human access and restrict entry by predators. The gate shall be of a design that allows bats of the size of ghost bat to pass.
  - e) The adit shall contain a constriction point where the adit intersects the inner roost chamber to minimise access to the rear of the structure by predators such as pythons and goannas. The constriction structure may be of any design and is to be permanently fixed in place and have no gaps at the edges. Edge sealing to be in accordance with the target design life. Its opening shall be at least 1.5 m wide by 1 m high if rectangular, or 1.5 m in diameter if circular.
  - f) The constriction and gate structures shall be corrosion-proof, in line with the structure's intended use and life.
  - g) The tunnel shall slope upwards from the portal to the rear chamber to capture hot and humid air within the rear chamber, and to allow any excess water to drain from the structure without ponding. The slope shall be less than 15°.
  - h) As much of the adit floor as practicable is to be graded natural waste rock and topsoil to allow natural humidity to develop from the surrounding rock fill.
  - i) As much of the adit's concrete and steel construction material as practicable should be tinted/darkened to minimise the reflection of light along the entrance tunnel during daylight hours.
- 7) Rear chamber:
- a) Shall have a minimum increased roof height of 500 mm compared to the adit.
  - b) Plan form is optional but proposed minimum size for a cave chamber is 3m wide, 3 m long and 2.5 m high. This is deemed an acceptable size to allow a colony of approximately 10 ghost bats to move freely and fly circular patterns (author's unpublished data). Note that a longer but narrower structure with a footprint of similar area is an acceptable alternative.
  - c) Roof structure shall be domed to replicate ghost bat roosts in natural caves and have a rough and scored surface finish to allow bats to grip that is, similar to the surface finish inside natural caves.
  - d) The chamber shall be shaped to minimise predation by pythons or goannas should they successfully pass the constriction that is, will have effectively vertical walls and square corners. It may have columns to support the roof.
  - e) The ceiling of the entrance tunnel and rear chamber shall be provided with cavities 500 mm deep to allow ghost bat refuge retreats.
  - f) Design and location shall be naturally ventilated by using the characteristics of the strata. It shall not require artificial ventilation.
  - g) Contaminants such as oil or cement dust should be removed from ceiling and walls during construction.

- 8) Monitoring conduit – There shall not be a monitoring conduit to the surface above. Placement of monitoring equipment shall be via the entrance tunnel.
- 9) Construction material for the entrance portal, gate and adit constriction should also be selected in consideration of its geotechnical stability (including load bearing capability given depth of burial), design life/longevity, cost effectiveness, and how readily it can be sourced. These features will also be designed to ensure that the entrance remains free and open for the life of the structure.
- 10) Translocation of ghost bats from permanent natural or underground mine roosts is not considered necessary or actually feasible. The data presented in the previous sections indicate clearly that the species will easily find the roost as soon as it becomes available (see [section 5.3](#)), and, it is clear that the species has a propensity to populate suitable underground structures, as evidenced by the successful colonisation at Cattle Gorge and the number of abandoned underground mines with colonies.

## 6 Anthropogenic threats to ghost bat roosts

Colonies of ghost bats are potentially subject to various broad scale threatening processes for fauna, including events such as loss of foraging habitat due to substantial clearing of native vegetation, over-grazing and/or frequent wildfires, the presence of exotic species that increase predation and competition, changed hydrological regimes, and the expansion of mining, agriculture, and tourism. There are also fine-scale threats such as destruction of individual roosts and disturbance of roosts by humans. These impacts can be permanent or temporary and can result in changes to fauna or faunal habitat beyond an immediate project (EPA, 2016). Impacts from these threats can generally be categorised as either direct or indirect.

Direct impacts reduce the diversity and abundance of species in an area through mortality or displacement of individuals or populations. For a given colony these may include:

- loss of the roost sites including caves and old workings
- loss of foraging habitat
- operational impacts from nearby mine, and low flying helicopters or military or civil aircraft during the maternity season
- importance of water sources and changed water regimes such as flooding or dewatering
- exposure to pollutants such as arsenic and/or cyanide in gold mining areas
- barbed wire fences
- human visitation/ disturbance to caves during the maternity season.

The indirect sources potentially causing impacts to colonies are:

- Introduced predatory species or zoonoses
- sound, vibration, airborne dust and NOx
- increased light
- changed fire regimes.

These impacts can be permanent or temporary, and result in changes to fauna or fauna habitat beyond the immediate project impact development (EPA, 2016).

### 6.1 Direct threats

#### 6.1.1 Loss of roosts

The most direct impact on a colony would be the loss of its critical diurnal roosting habitat. The increase in iron ore and gold mining in the Pilbara and elsewhere in recent years, if left to develop unchecked, has the potential to result in the loss of a significant percentage, possibly the majority, of the natural roost caves in large areas such as the Pilbara. Other examples of roost cave loss are in TSSC (2016). As discussed in [section 6.1.2](#), the majority of the Pilbara caves are in BIF strata that may be of commercial grade. In addition, the abandoned underground mine

roosts are in known gold or copper bearing strata that may be subject to redevelopment. Potential instability and subsequent collapse of historic underground workings is also regarded as a minor-moderate threat contributing to the Vulnerable listing status of ghost bat (TSSC 2016). Pilbara sites such as Bamboo Creek, Lalla Rookh, Klondyke Queen are already subject to nearby mining activities. To date, there are examples of roosts in Pilbara mines that have been lost to development during the years that the ghost bat was not listed as threatened, for example, the Bulletin mine at Bamboo Creek and several mines east of Nullagine. The ongoing listing of the species as Vulnerable in State and Commonwealth legislation is therefore essential for its long-term persistence.

Other than observations of ghost bats abandoning roosts after visitations, there is virtually no data currently available on any impact due to public access. However, current best practice to protect critical habitat roosts including categories 1, 2 and apartment blocks at development projects is to define exclusion/buffer zones surrounding the roost cave. These buffer zones should be of a size that ensures that the cave remains a viable roost throughout any threatening project and should take into account all perceived threats during and after any direct project disturbance including but not limited to in-ground vibrations and repeated accessing by personnel. They must be applied on a case-by-case basis but typically buffer/exclusion zones in place at several Pilbara sites between 200 and 250 m radius from the roost caves are being found to be adequate to limit human visits and interference for category 1 and 2 ghost bat roosts in most cases (author's unpublished data) with smaller zones down to 100 m radius being applicable to isolated category 3 roosts assessed as critical. Buffers that include entire gullies containing apartment blocks of caves are also appropriate. These buffer zones should be clearly delineated and entry by unauthorised public or project personnel should be prohibited. Restrictions on approach and entry protocols should be included in the project's Significant Species Management Plan.

### **6.1.2 Loss of foraging habitat**

Given its typical nightly foraging range of 10 to 15 km and the recent evidence of foraging at the edges of improved agricultural areas (GPS based data in Augusteyn 2018; Bullen unpublished GPS data), broad scale anthropogenic induced changes due to mining or pastoral projects are unlikely to cause significant declines in ghost bat populations. However, broad scale clearing of native vegetation and replacement with other types of development may directly result in declines. There is little research available across northern Australia to base firm conclusions and projects should be evaluated on a case-by-case basis.

To support this, cases have been documented where:

- Large-scale wildfires have had no published impact on a roosting colony, and this is therefore a knowledge gap. However, following an extensive fire east of Marble Bar in October 2020, the Klondyke Queen colony's nightly activity at the roost entrance reduced by approximately 50% for subsequent months (author's unpublished data) suggesting that some bats departed the roost for more productive areas.
- Ghost bats have been recorded foraging in improved agricultural areas within range of their roost caves (Queensland in Augusteyn et al. 2018; Pilbara in author's unpublished data).

### **6.1.3 Typical mine operational impacts**

Currently, factors affecting the persistence of ghost bat roosts adjacent to mining are not well documented. This species is known to be sensitive to disturbances within, or in close proximity to, roost caves and are known to abandon caves where construction or mining activities occur nearby (Jolly 1987). Blasting in the immediately adjacent quarry at Mt Etna forced ghost bats to move and 3 bats were found dead within a week of this incident (Toop 1977a reported in Jolly 1987). Planned expansion of the quarry operations at Mt Etna may also expose the colony to further risks. Nevertheless, there are a number of ghost bat Category 2 and 3 roost caves in reasonably close proximity to active large-scale open cut mining operations at distances ranging from 100 to 500 m. These are at sites such as Atlas Iron's Wodgina and Abydos mines, BHP's Cattle Gorge and MAC mines, and Rio Tinto's Mesa A and West Angelas mines. Ongoing monitoring has confirmed that these have remained viable as diurnal roosts for the species and maternity roost candidates (authors unpublished data).

Operational noise, dust, light, vibration etc. are likely to be the primary impacts, although vehicle collision in heavily travelled areas cannot be ignored. At any ghost bat roost site, mining operations immediately adjacent to the roost that is, within a few hundred meters, will probably result in the temporary abandonment of the cave. However, the species is known to quickly recolonise the roost caves provided that their internal structures remain secure and continue to offer viable internal habitats. Numerous abandoned underground mines attest to this, including the quick reestablishment of the Klondyke Queen colony following the mining operations at the immediately adjacent 'Mullens adit' in the late 20th century (author's unpublished observations).

### **6.1.4 Importance of water sources and changed water regimes**

Currently, factors affecting the usage of water sources by ghost bat roosts adjacent to or nearby their roosts are not well documented. This species is known to forage in productive areas including around waterholes and riparian zones but direct evidence of visits for drinking are rare. Current best practice is to consider semi- and permanent water sources within 5 km of a category 1 or 2 roost to be important but not critical habitat for the species.

Dewatering is the most direct factor likely to impact the ghost bat roosts in abandoned mines connected to the water table. Dewatering is sometimes required to access the ore. Impacts due to dewatering may include a reduction in humidity in the workings. In very dry years, this may lead to the ghost bat abandoning the roost. To date, there are no known roost abandonments documented as a result of artificially lowered water tables.

Flooding of mine lower levels is also a possible future threat to ghost bat roosts. The regulation of disposal of excess water at projects should ensure that this potential threat is addressed. There are known cases in the Northern Territory of ghost bat roosts being abandoned due to flooding; however, whether this is a seasonally recurring cycle is unknown (L. Ruykys pers. comm.).

### **6.1.5 Exposure to pollutants such as arsenic and/or cyanide**

In projects in gold mining areas, cyanide may be used in leaching gold from ore bodies or stockpiles, and in processing gold from crushed ore. The potential for cyanide to impact on the fauna in and around the project area has been identified as an environmental risk (ICMC 2016). Currently at 'no discharge' mine facilities, 50 mg/L weak acid dissociable (WAD) cyanide for



solutions accessible to wildlife (for example, discharge into tailing ponds) is widely recognised by the mining industry as a water quality benchmark for the protection of wildlife (for example, Donato et al. 2007; Griffiths et al. 2014a). This level is derived from observations in both the USA and Australia that bird mortalities tend to occur when the WAD cyanide concentration increases above 50 mg/L (Donato et al. 2007). In recognition of the ghost bat's Vulnerable listing, and the scarcity of data on cyanide lethality to bats, current best practice at gold mines in the Pilbara is to discharge at a peak concentration of WAD cyanide under 30 mg/L, a level consistent with a similar mining operation in New South Wales. It is likely that typical discharges should be much less than this and, following volatilisation of cyanide post discharge, that WAD cyanide in the supernatant pools will be lower still. An additional way of protecting the wildlife at tailings dams is to maintain the salinity above the level that is suitable for drinking (after Griffiths 2013; Griffiths et al. 2014b). Author's unpublished data indicate that bats are unlikely to drink water that is moderately saline (above 3,200 mg/L total dissolved solids but see Laverty and Berger 2020 who report bat activity over desert pools up to 6,000 mg/L).

Concentrated arsenic (As) in gold mining areas is also a potential direct impact on the ghost bats. They forage around, and drink from, various ground water sources that are known to have As concentrations from natural sources. Ground water As levels appear, on limited data, to be higher in the eastern Pilbara than in the ironstones of the Hamersley Ranges. One such eastern Pilbara source is the Copenhagen open cut south of Marble Bar that has been flooded for a number of years and contains water with measured As concentrations of 560 µg/kg in March 2019, after prolonged evapo-concentration. Arsenic is deposited in mammal tissue following exposure from a range of natural sources, including drinking water and food sources, and exists at various levels in all living beings. It remains in some tissues, including hair, for long periods and can build up to levels that can result in chronic and even acute poisoning. Unfortunately, there are no available data directly relating As to bat poisoning or mortality. Ghost bats at the Klondyke Queen colony are exposed to the elevated As-level at Copenhagen due to the short distances between the sites (8 km). To date, no symptoms of chronic As poisoning have been observed at that colony. Arsenic is currently not considered to be a major concern for ghost bat colonies unless a new source of drinking water with high As levels is developed nearby a diurnal roost during a project.

A third type of pollution with a potential effect on ghost bats is the practice (rarely employed) of disposing of waste oils and other liquids down ore body exploration drill holes (Tim Clarke pers. comm.). This practice has the potential to pollute ground water and, if near a diurnal roost, could seep into the roosting chamber, potentially causing the bats to abandon. Best practice demands that this waste disposal method be banned at exploration, mining and related projects.

### **6.1.6 Barbed wire fencing**

Fatal collisions by ghost bats on barbed wire fencing is recognised as a direct threat (Woinarski et al. 2014; TSSC 2016; Figure 2). These collisions are most likely to occur when the bats transit open ground at high speed in ground-effect to achieve maximum energetic efficiency while commuting or foraging. This risk is amplified because fences in pastoral lands are designed to have minimal visual impact; they are virtually invisible at night, (see Figure 3). Recently, best practice in areas close to known ghost bat roosts has been to either replace barbed wire with plain wire strands, or to add bat deflectors to the fence. An early attempt to use empty aluminium cans as deflectors at Lake Robinson in the Pilbara, (see Figure 4), was only partially successful with a low number of collisions still being reported. More recently, higher density

patterns of deflectors have been fitted to fencing in ghost bat sensitive areas, for example, Figure 5. A fence designed to prevent night parrots getting caught could potentially be used to reduce ghost bat collision (Figure 6).

**Figure 2 A ghost bat carcass tangled on a barbed wire fence**



Photograph: © L. Clausen

**Figure 3 A typical barbed wire fence in a Pilbara pastoral area**



Photograph: © B. Bullen

**Figure 4 An early bat deflector design that was partially successful**



Photograph: © Biologic Environmental Survey

**Figure 5 A recent bat deflector design near Hope Downs 1 mine in the Pilbara**



Photograph: © B. Bullen



**Figure 6 A fence designed to prevent night parrots getting caught**



Photograph: © J. Augusteyn

## **6.2 Indirect threats**

### **6.2.1 Introduced species or zoonoses**

Glands in the skin of the cane toad (*Rhinella marina*) secrete a toxic fluid. There has been significant reduction in numbers of ghost bats soon after these toads invaded north-western Queensland and the Northern Territory (White et al. 2016). Author's recent opportunistic observations in the east and central Kimberley also indicate a reduction in numbers behind the expanding toad-front, with several historically occupied roosts appearing to be abandoned. Genetic work indicates that the ghost bat is unable to tolerate bufotoxins (Shine et al. 2016). Evidence of bats preying on toads is given by White et al. (2016) who noted that cave floor samples of droppings revealed that toads were being taken as a very minor component of the vertebrate prey of ghost bats. One dead ghost bat was found with a partly masticated toad in its oesophagus. This, and other indirect evidence, indicates that cane toads are being taken by ghost bats on an occasional basis and that these episodic predation events may be a significant factor in the observed decline in ghost bats populations in areas where cane toads are abundant. However, not all colonies behind the toad front are equally affected as indicated by the counts at Kohinoor adit (see [section 4](#)), other Northern Territory sites (N. Hanrahan pers. comm.) and the author's observations at some eastern Kimberley sites. Little is known about the reasons for the large fluctuations in reported colony sizes (for example, Kohinoor variation quoted above). It may be that toads are only targeted when other preferred prey declines, which could explain why ghost bats and toads coexisted for nearly two decades at Kakadu National Park before recently declining. Woinarski et al. (2014) reported rapid and severe declines in the mammal fauna in Kakadu National Park and ghost bats may have only just started to consume the toads as their preferred food became harder to find. Toad consumption has not been reported from

Cape Hillsborough or Mt Etna where toads and ghost bats have coexisted for the longest period (J. Augusteyn pers. comm.). However, the consumption of toads may have gone unnoticed and occurred at a time that was between researchers. It may also explain the population decline reported during the 1960s (450 ghost bats) (McKean and Price 1967) and the 1970s (150 to 180 ghost bats) (Toop 1985).

Predation by feral cats is cited as a threat to bat colonies (review by Oedin et al. 2021), although direct evidence of predation on ghost bats is sparse. However, the author has a number of observations of ghost bat heads and wings piled-up on the floors of adits containing ghost bat roosts and at tree bases in the Pilbara and Kimberley. While not providing a direct implication, leaving such piles is a known behaviour of cats (Scrimgeour et al. 2012). The author has seen ghost bat wings and heads at one abandoned Pilbara mine adit, Klondyke Queen, that is known to be visited by feral cats. The population at this monitored site also declined (author's unpublished data) prior to the death of one cat (natural causes) and the removal of two. Due to cats' propensity to hunt other species of bats, including large species such as flying-foxes (Tidemann et al. 1994), a precautionary approach should be followed and feral cat populations should be controlled as part of mining operations near Category 1 and 2 diurnal roosts.

Large number of feral pigs (*Sus scrofa*; mobs of >20 individuals have been observed) have been found to shelter inside limestone caves in the Northern Territory during the heat of the day (N. Hanrahan, unpublished data). The pigs emerge from the cave shortly after sunset, coinciding with the fly-out timing of ghost bats. The ghost bat's susceptibility to roost disturbance suggests that they are likely to be negatively impacted by feral pigs using caves through increased noise levels, movement and smell. Separately, wild dogs have been observed resting during daylight hours in an historical adit used by ghost bats as roost (S. Reiffer pers. comm.). When required, feral pig and dog control should be conducted away from the caves to prevent the ghost bats from being further disturbed.

Zoonoses are a future risk, specifically the introduction of a disease, possibly fungal, similar to White Nosed Syndrome (WNS) (*Pseudogymnoascus destructans*). WNS is the fungal disease killing bats in their hibernacula in North America. Research indicates the fungus was likely introduced from Europe, possibly by cavers or bat biologists. WNS causes high death rates and fast population declines in the bat species it affects, and scientists predict some regional bat extinction is possible. While studies show that this fungus grows only at cold temperatures (5 - 20°C, Verant et al. 2012), much lower than temperatures within ghost bat roosts, the potential for an equivalent disease to infect ghost bat roosts cannot be ignored. Care regarding hygiene should therefore be taken when working at all roost sites and access and visits to category 1 and 2 roosts should be limited.

### 6.2.2 Sound

Being mammals that emit and hear sounds over a wide range of frequencies it is expected that sound pollution could affect ghost bat colonies. In addition to the sound produced by blasting, levels of sound in an active mining area can be high when equipment is operated at close range. Sound power levels of 120 to 150 dB(Z) may be generated by various types of equipment such as haul trucks, loaders/excavators, dozers, drill rigs and service trucks across the frequency range used by ghost bats (see [section 3](#)). Also, the frequency spectrum of some of this equipment may have high levels in low octave bands below 500 Hz. Sound of this level may be generated between 1 and 10% of the time by mobile equipment, or for longer periods in the case of fixed

equipment. Close to the roost entrance, these levels may generate sound pressures exceeding 100 dB(Z). For instance, a loader operating 200 m away may generate an sound pressure level of 101 dB(Z) for 10% of the time; at 500 m the sound pressure level would be 93 dB(Z). Current best practice is to limit sound pressure levels to below 70 dB(Z) at roost entrances (after Bullen and Creese 2014).

There is a large body of literature on the effects of sound on animals (for example, see Turina and Barber 2011; Shannon et al. 2016). Most researchers agree that noise can affect an animal's physiology and behaviour and, if it becomes chronic, noise induced stress can become injurious to an animal's energy budget, reproductive success and long-term survival. There is also a body of evidence that animals can habituate to sound levels below those given above. Although the potentially chronic sound levels from continuous mining operations near the roost entrance will be greatly attenuated in the underground roost chambers, there is virtually no research on the consequences of bats experiencing high noise levels for brief periods as they emerge from a deep underground roost and transit noisy operational areas. The grey literature from the Pilbara suggests that ghost bats and other bat species may become accustomed to this situation, continuing to depart the roost and transit to foraging areas in a typical manner (for example, ongoing ghost bat presence nearby open cut mines such as Robe Valley Mesa A. Cattle Gorge, Mining Area C and Mt. Whaleback; authors unpublished observations). Very loud continuous noise in excess of 100 dB(Z) may alter this result.

Current experience with the ghost bat at sites such as those listed in 7.1.1, above, where drill and blast mining as well as heavy machinery operate, suggests that ghost bat will habituate to the sound from these types of activities when a buffer of several hundred metres from the entrance is observed (author's unpublished data). But empirical data to fully assess this claim is limited.

Military exercises operating between Rockhampton and Shoalwater Bay often fly directly over the known maternity cave during the maternity season (J. Augusteyn pers. comm.). The impact of these loud low altitude flights is unknown but there are concerns that these frequent but irregular flights may disturb mother bats and cause them to take flight and potentially dislodge non volant pups. Helicopters flying low have also resulted in ghost bats abandoning roost caves for other refuges (authors unpublished data, Figure 7).



**Figure 7 Ghost bats disturbed inadvertently by a passing helicopter**



Photograph: © P. Bolton

### **6.2.3 Inground vibration**

If disturbed during the day, the ghost bat is known to move about within the roost or decamp to a nearby refuge cave (author's unpublished observations), using valuable energy reserves. They may even abandon the roost if the disturbance levels are sufficiently high (Churchill 2008; Woinarski et al. 2014). Production blasting in nearby iron-ore mines, if high blast charges are used at distances between 50 to 400 m, will provide levels of vibration above those that the limited available data suggest may disturb the colony. Bullen (2013) identified an underground vibration limit of 10 to 15 mm/s peak particle velocity (PPV), before roosting ghost bats were disturbed, and noted that this limit is conservative. This is lower than the vibration levels that might be expected to damage and/or cause local collapses in one of the historical mines, a threshold set currently at 25, 50 or 75 mm/s by Geotech assessments in most situations. Relevant international data is limited. An example from Whitecleave Quarry in Devon, UK (URS 2012), is based on impact to human residences. It's possible that vibration levels of 10 mm/s will cause localised collapse within a roost that has unstable strata.

Recent work at various project sites has shown that, if the exact location of the roost within the strata and the vibration transmission characteristics of the rock are both known, routine mine planning can limit the vibration levels within the colony to 10 mm/s or the higher values by combining small blast charges with distances as close as 150 m. Although the relevant

calculations can be based on the equations from Australian Standards, the default equation constants that characterise the rock strata can be highly inaccurate (Martin 2013) and vary the result by as much as +/-100%. Locating the exact colony site and determining the rock vibration transmission characteristics have recently become best practice, but are not common practice yet, and the transmission data are not available for a range of rock types at ghost bat roosts.

The vibration limit of 10 mm/s previously noted is directly applicable to all category 1 ghost bat roosts and category 2 roosts in areas where the bats have no opportunity to easily move to similar roost in the area. For many category 2 roost caves and category 3 caves in nearby apartment blocks outside the females reproducing period, the disturbed ghost bats are able to move to similar roosts elsewhere (for example, bats at Atlas Iron's Miralga Creek and Abydos projects are able to move to the category 1 roost at Lalla Rookh), therefore the relevant in-ground vibration limits are the higher values between 25 and 75 mm/s based on retaining the roost cave undamaged and as a viable underground structure able to be recolonised at a later date.

#### **6.2.4 Airborne dust and NO<sub>x</sub>**

Ghost bats detect prey using audible and ultrasonic sound in combination with their excellent vision. High dust levels may irritate their eyes, reduce their visual acuity and the effectiveness of their ultrasonic calls, thereby effecting their ability to capture prey. There is no current data available regarding these effects on ghost bats. High dust events are likely at locations within mining projects (for example, around the crusher, and after blasting operations), and may also include high Nitrogen oxide (NO<sub>x</sub>) concentrations. The group of gases known as Oxides of Nitrogen (or NO<sub>x</sub>), of which the most common are nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>), are often found as biproducts in nitrate-based explosives. If best practice dust and NO<sub>x</sub> suppression strategies are implemented (for example, AEISG 2011) including using pre-planned limitations for blasting nearby roosts that considers wind direction, it is unlikely that the ghost bat colonies will be affected.

#### **6.2.5 Increased light**

The presence of artificial lighting may have an impact on nearby ghost bats. National light pollution guidelines for wildlife, including marine turtles, seabirds and migratory shorebirds, have recently been published (Commonwealth of Australia 2020) and an appendix for bats is currently being prepared. These guidelines currently recommend best practice lighting designs to minimise impacts on wildlife; they incorporate the following design principles:

- 1) Start with natural darkness and only add light for specific purposes.
- 2) Use adaptive light controls to manage light timing, intensity and colour.
- 3) Light only the object or area intended – keep lights close to the ground, directed and shielded to avoid light spill.
- 4) Use the lowest intensity lighting appropriate for the task.
- 5) Use non-reflective, dark-coloured surfaces.
- 6) Use lights with reduced or filtered blue, violet and ultra-violet wavelengths, that is, with red biased spectra.



The guidelines also state that ‘the way in which light affects a listed species must be considered when developing management strategies as this will vary on a case-by-case basis’. Although the impacts of artificial lighting on ghost bats are currently undocumented, the following points should be considered:

- The species has persisted at Cattle Gorge, 500 metres from mining operations (Biologic 2018) and at other Pilbara projects.
- Excessive light is likely to have an effect on the natural foraging behaviour of ghost bats. Best practice is to locate the mining camp and associated plant behind hills so as to not directly illuminate the diurnal roost entrances
- Red-biased spectra lights may increase predation by ghost bats on orange leaf-nosed bats (including the Vulnerable listed PLNB form), a 10 g species that is common ghost bat prey.

#### **6.2.6 Changed fire regimes**

Due to the species ability to forage over large areas, localised changes in concentrations of insect prey associated with patchy fire-scars are unlikely to reduce the ghost bat population of an entire district. However, data from one site (see [section 6.1.2](#)) suggest that a colony did reduce in size due to the loss of large areas of foraging habitat following an extensive wildfire. As previously discussed, a knowledge gap exists with regard to foraging habitat that is only just beginning to be filled. Much more research is required in this area.

#### **6.2.7 Vehicle strike**

There is no history of mortalities due to vehicle collisions at night. Best practice is to employ appropriate speed limits in sensitive areas thereby minimising collisions with wildlife, including ghost bats.

## 7 Minimum survey requirements

### 7.1 Recommended survey approach

Targeted surveys should incorporate a number of strategies, though in almost all situations, the species can be surveyed without the need for capture. Manual cave assessments are the best method for identifying candidate roost caves. Ultrasonic call detectors and/or scat analysis are currently the best means of non-invasive cave usage characterisation. However, the discovery of all roost sites within a project area will allow the best assessment of whether the species will be affected by a development, given that suitable Category 1, 2 and some 3 roost sites are known to be critical habitat. Other activities can also be used to assess roost occupancy or augment an assessment of presence for example, with video census information. Given the distances that ghost bats can commute, foraging habitat is best assessed using GPS/satellite or VHF tracking technology.

The following points should be noted for this species:

- Ghost bat roost caves and initial characterisations are best identified by inspection during surveying.
- Usage of caves may initially be inferred by the presence of ghost bats, middens or scat piles.
- This species is sensitive to disturbance at their roost. Cave and mine entrances with roosts should not be repeatedly trapped, since capture might cause individuals to vacate to less suitable roosts nearby.
- A seasonal cave entry protocol/prohibition should be employed (see [section 7.1.9](#)).
- Diurnal occupancy of a cave/mine inferred from echolocation data often needs to be confirmed using an alternative non-invasive method such as thermal camera or Infra-lit video or direct observation.
- Because of their tendency to exit entrances in the first 2 to 3 hours after sunset, accurate counts can be obtained using manual or video techniques.
- Using bat detectors placed at cave/mine entrances or within roosting chambers, it is possible to obtain estimates of the size and trends of the change of groups roosting within.
- Ghost bat scats are easily collected from middens and/or carefully placed plastic sheets in natural caves, but often, depending upon an abandoned mine's characteristics, this is not possible due to safe entry restrictions.
- When appropriately collected (Ottewell et al. 2020), genetic analysis of scats can provide information of cave usage, and the number and sex of the ghost bats present in sparsely occupied areas.
- Analysis of scats for progesterone is emerging as a viable technique for confirming the presence of reproducing females.

### **7.1.1 Prior to a survey**

An important initial step is to determine whether there are known caves and mines in the project area. Information can be sourced from topographical and geological maps, aerial photography, and various state government departments (for example, the WA Department of Mines, Industry Regulation and Safety [Minedex and Tengraph], Department of Biodiversity, Conservation and Attractions) and experienced bat researchers. Where appropriate, on-site information on the location of caves and mines can be sourced from local residents and from the heritage survey records of particular mining companies. A review of available records from the Atlas of Living Australia, Nature Map, state government department data bases and the proponent's available fauna database is also warranted, however these sources often have few applicable records.

### **7.1.2 Passive ultrasonic detection**

Ghost bats seldom use echolocation when away from caves, so passive ultrasonic detection is best used at cave entrances or within roost chambers where possible. Unattended detectors should be left overnight, because the bats do not always call when either exiting or re-entering; it depends upon moon-phase and ambient light levels at the entrance (author's unpublished data). This is believed to be due to the bats ability to navigate safely through the entrance using eyesight alone when the entrance is well lit. Evening flyout counts are often the most accurate however pre-dawn fly in counts are sometimes more reliable, particularly at entrances well lit by moonlight or artificial lighting (author's unpublished data).

### **7.1.3 Active acoustic detection**

This technique is not suited to ghost bat detection as the species seldom uses its echolocation away from caves. However, detecting social calls may be possible in some circumstances and therefore it may be possible to confirm presence in an area, for example, at a water hole or pond in a suspected foraging location.

### **7.1.4 Recommended acoustic detection devices**

There are a range of ultrasonic bat detectors currently available. The current industry standard for ghost bat surveying in the Pilbara is to use a full spectrum device recording at a sample rate of at least 128k BPS (or kHz) to ensure that calls at the high end of the range (>50 kHz) are not clipped by the recorder. Advice on particular systems should be sought from an experienced researcher who is familiar with the system. Alternatively, a new system to be introduced into survey work should be tested against the current industry standard to ensure its suitability. Some systems also offer a range of microphones for surveys. Common options are omnidirectional and directional mics. Omnidirectional microphones are commonly used in general surveys, including at cave entrances, whereas directional microphones are commonly used inside caves. For general survey work away from caves, the microphone should be oriented upwards or towards the feature being surveyed, for example, a water pool, and preferable at least 1 m off the ground. For targeted work in caves the microphone should be oriented towards the feature being recorded, that is, across the entrance for general surveys or directly into the cave or its constriction for targeted surveys.

### **7.1.5 Trapping**

If traps are to be used it should only be for a specific purpose such as morphometric data collection, tracking studies or tissue sample collection. Harp traps are unlikely to be useful, as

the mass and flight speed of the ghost bat allows them to punch through the banks of arrayed lines. Mist nets are useful in cave entrances but are unlikely to be useful elsewhere because the ghost bat can detect their presence (author's observations). In most cases, unambiguous detection from echolocation recordings and/or video can replace the need for capture, thus avoiding disturbance to the species. Traps should be continuously monitored, and bats released at the site of capture, and only at night; they can be taken by raptors if released during the day.

#### **7.1.6 Exploration for caves (potential roosts)**

Searches can be conducted for relatively deep caves along mesa outcrops, in gorges, deep gullies flanked by rocky outcrop, and beneath ephemeral waterfalls, in the Pilbara focusing on landscapes composed primarily of Brockman and Marra Mamba banded iron formations. For large project areas in gorge and mesa country, searches could be expected to take several days. It may be economical to use a helicopter to identify the most promising caves and follow these observations up on foot.

#### **7.1.7 Roost occupancy determination**

If call-detection surveys have identified a possible daytime roost, if middens are found, or if a relatively deep cave looks suitable as a roost for this species, their emergence at dusk can be observed without entering the cave/mine. To determine if the species is present, an Infra-red lit video, thermal camera video or a high-quality motion camera, accompanied by a detector to record the bats calls, can be placed at the entrance. Accurate manual counts can often be made from the entrance of the cave or mine depending on the entry portal characteristics. Colonies must not be estimated by entering the roost.

#### **7.1.8 Diet analysis and genetic studies using scats**

When appropriately collected (Ottewell et al. 2020), genetic analysis of scats can provide information of cave usage, and the number and sex of the ghost bats present in sparsely occupied areas. Scats can also be examined for diet composition. The scat collection should be done by one ecologist working quietly with torch light always pointing towards the ground and if possible, done at night when the bats have departed to forage. If individuals are found to still be in the roost after entry, the ecologist should complete the scat collection/equipment placement as quickly and quietly as possible and exit the roost. If a ghost bat is disturbed and flushed out of the roost, the caves and their entrance areas should be vacated to allow the bat to return and settle.

#### **7.1.9 Cave entry/prohibition protocol**

Best practice is to apply a conservative protocol when surveying for ghost bats to protect the reproducing females and their young during the most important part of their reproductive cycle. This covers the periods when:

- capture and handling or repeated flushing the bats from their diurnal roost caves, can cause premature birth by gravid females
- capture or disturbance can cause females to drop newborns they are carrying
- repeated disturbance of the mothers can cause them to abandon non-volant young in nurseries

- if repeatedly disturbed, mothers can prematurely abandon newly volant young during the early adolescent period.

For ghost bat category 1, 2, and 3 roost caves that are part of an important cave grouping to protect heavily pregnant and lactating females and young in the roost, it is recommended that tighter restrictions be enforced than governmental licencing limitations:

- 1) No trapping or scat collection should be carried out from one month prior to 2 months subsequent to parturition, that is October to December, inclusive, in central Queensland and Western Australia (where parturition occurs in late October or early November), and from July to September in the Top-End (ie the northernmost part of the Northern Territory).
- 2) Outside step 1, successful trapping sessions, that is when ghost bats are captured or are present and disturbed, should be limited to once per cave from 3 months prior to 3 months post parturition that is during August, September and January in central Queensland and Western Australia and earlier in the Top-End and Gulf Country (see [section 2](#)).
- 3) Where no ghost bats are present, multiple scat collection entries per cave are allowed in August, September and January in central Queensland and Western Australia, and earlier in the Top-End. The scat collection should be done by one ecologist working quietly to minimise stressing any bats present, hopefully not flushing them. If any ghost bats are disturbed and flushed, the caves and their entrance areas need to be vacated to allow the ghost bats to return and settle. Restrictions per step 2 then apply.
- 4) Trapping and collection in accordance with governmental licencing limitations be allowed outside these periods.

For ghost bat category 3 caves that are isolated and not part of an important grouping, and category 4 caves, it is recommended that normal survey activity in accordance with governmental licencing limitations be allowed year-round including both trapping and scat collection entries as appropriate.

## 7.2 Survey effort guide

Depending upon the size of the survey area, a number of days may be required to conduct ground-based inspections of caves and mines. Examination of geological maps and aerial photography can be used to focus the survey on the most likely areas, that is, with gullies, gorges and rocky outcrop. Surveys should be repeated twice, approximately 6 months apart since the species has the potential to be present in some or all seasons. Caves inspected should be listed, and their internal characteristics described along with a proposed roost classification where applicable (see [section 4](#)).

Once identified as a potential category 1, 2 or 3 caves with possible maternity use, echolocation detectors should be placed at the entrance for a minimum of 3 nights to confirm the presence of ghost bats and the potential usage of the cave. For large baseline or 'level-2' surveys in areas where ghost bats are known to be present, the probability of detecting them with ultrasonic detectors is high, particularly at 'apartment block' caves in cave forming strata. The number of detector sites required will be determined by the number of candidate caves present. As guideline, complete an initial study area wide, or 'level-1' survey, to determine the cave density before scoping and attempting a more detailed survey.

### **7.3 Recommended approach to roost monitoring**

Once potentially or confirmed critical ghost bat roosting habitat is defined, monitoring programmes are recommended to be implemented (TSSC 2016). Monitoring can be either continuous where the roost is under immediate threat from a project or periodic where the roost is distant and not directly under threat. Best practice for threatened roosts is to monitor the presence/usage of category 1 and 2 roosts continuously with echolocation or video methods or quarterly where indirect methods such as scat analysis are used. Annual or semi-annual monitoring is appropriate where a roost is distant from any immediate or approaching threat. Echolocation systems supplemented by video census methods are recommended where there are a large number of bats present in a small number of caves. Genetic analysis of scats is recommended where there are a small number of bats using a larger number of caves.

## 8 Glossary

Term	Definition
adit	A horizontal access tunnel into an underground mine.
AOO	Area of occupancy
As	Arsenic
BIF	Banded iron formation
BOM	Australian Bureau of Meteorology
Category 1 and 2 roost caves	Ghost bat roost caves with permanent or regular occupancy and with specific characteristics. All are proven or assumed to be maternity sites and are critical habitat.
Cat 3 and Cat 4 roost caves	Ghost bat roost caves with occasional or opportunistic usage and with less specific characteristics. Cat 3 are potentially critical habitat and Cat 4 are not.
CID	Channel iron deposit
dB(A)	A weighted sound measurement that is modified to approximate human hearing.
dB(Z)	Unmodified, Z weighted or linear sound measurement that represents ghost bat hearing across their full range of frequencies utilised.
EOO	Extent of occurrence
NO <sub>x</sub>	Oxides of nitrogen
PLNB	Pilbara leaf-nosed bat ( <i>Rhinonictis aurantia</i> , Pilbara form)
TSSC	Threatened Species Scientific Committee
ultrasonic call	A sequence of ultrasonic pulses emitted by the bat and recorded during a pass.
ultrasonic pulse	A single ultrasonic pulse emitted by a bat for foraging or navigation purposes.
WAD	Weak Acid Dissociable cyanide bound to the metals Zn, Cd, Cu, Hg, Ni and Ag. It is liberated at a moderate pH of 4.5 and is potentially toxic to humans and animals.

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