Continued use of artificial roosts by the Eastern Horseshoe Bat *Rhinolophus megaphyllus* Grey, 1834 (*Chiroptera: Rhinolophidae*) in Brisbane Forest Park, south-east Queensland

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ABSTRACT

Abandoned mines and other artificial roosts in Brisbane Forest Park ('BFP') were investigated between 2007-2009 and 2021-2023 to determine their potential as microbat roosts, particularly relating to the Eastern Horseshoe Bat *Rhinolophus megaphyllus*. Thirteen structures were identified as diurnal roosting sites used by *R. megaphyllus*, with the Little Bent-wing Bat *Miniopterus australis* and the Large Bent-wing Bat *Miniopterus orianae oceanensis* also found in one adit. Data derived from diurnal counts of roosting bats are presented here, as well as data on the depth and/or microclimate of structures. Specifically, adits were between 6 and 60 m in total depth with bats generally occupying the darkest portions. The maximum colony size noted during diurnal counts was 45 bats. A tunnel was also investigated for use by microbats in 2021-2023, with 89 *R. megaphyllus* counted during emergence. No maternity roosts were detected, although mating was observed incidentally in one adit in June. Trapping in late December in the two largest structures only recorded male *R. megaphyllus*, with one post-lactating and one juvenile female captured in January. The Brisbane area is generally devoid of cave-forming geology, so the population of *R. megaphyllus* in BFP is considered to be strongly dependent on these artificial underground features.

Key words: conservation, *Miniopterus orianae oceanensis*, *Miniopterus australis*, mine

Published: 03 March 2025 DOI: https://doi.org/10.7882/AZ.2025.009

Introduction

Abandoned mines and other artificial structures provide habitat for several species of cave-dwelling bats. Horizontal drives (adits) can vary in complexity from short drives of several metres to complex workings with connected underground passageways (Hall *et al.* 2003). Bat diversity and abundance in abandoned mines are variable. Some species require specific microhabitats and microclimates, while other species display flexibility in roosting requirements and any shelter that is lightless and climatically buffered could be a potential roost site (Meierhofer *et al.* 2023). The closure, collapse or re-working of abandoned mines has been identified as a threat to the viability of bat populations in Australia (Duncan *et al.* 1999).

The Eastern Horseshoe Bat *Rhinolophus megaphyllus* Gray, 1834 (Rhinolophidae) is a widespread species, known to roost in caves, mines and other subterranean surrogates with relatively high humidity and temperature (Young 2001; Hall *et al.* 2003; Slade and Law 2007). The species is known to occupy a range of roost types with varying light levels, and due to low wing loading, is able to use roosts with restricted entrances (e.g. Williams 2019) and narrow vertical drops. Captured prey is usually taken to temporary night roosts to be consumed (Hutson *et al.* 2019). The species has variability in pelage colour from grey to rufous, which may be related to humidity and ammonia levels in the roost (e.g. McFarlane *et al.* 1995), individual genetics (Young 1975) or subspecies phenotype (Young 1975; Cooper *et al.* 1998). In other bat species more predictors of colour were suggested (e.g. Beilke *et al.* 2024). There are no records of the rufous phase south of Black Duck Creek abandoned mine (Young 1975), approximately 80 km south-west from our study site.

Sexually active males have high roost-site fidelity and are more sedentary than adult females, which move to a maternity roost in September or October each year. Females return to their non-maternity roost sites between February and April, forming mixed-sex colonies through the winter months. In the southern portion of their distribution, they also hibernate in these mixed-sex colonies (Hutson *et al.* 2019).

The species is known to roost with other *Rhinolophus* or *Miniopterus* species (Hutson *et al.* 2019). In south-east Queensland, it has been recorded sharing roost sites with both *M. australis* and *M. orianae oceanensis*, although in different chambers (Young 2001). Both Dwyer (1966) and Hall *et al.* (1975) also noted the segregation of adult *R. megaphyllus* from *Miniopterus* species in shared roosts in south-east Queensland and northern New South Wales.

Roosts of *R. megaphyllus* and *Miniopterus* species in abandoned mines in BFP have been confirmed by various studies (McKean and Price 1967; Robinson 1985; Krutzsch *et al.* 1992; Pavey 1998). Our aim is to provide an overview of abandoned mines in BFP with a reference to *R. megaphyllus* and *Miniopterus* species and assess their conservation significance to the region.

Study site and methods

The eastern section of BFP (27°24' - 27°29'S, 152°51'-152°58'E), now officially the southern part of D'Aguilar National Park in south-east Queensland, has a large aggregation of abandoned gold mines from the period 1866 to 1952 (Trezise 1989). These historic remnants were targeted to investigate the presence and roost use of cave-dwelling bats in the Brisbane area.

The climate is subtropical with a summer dominant rainfall pattern. Annual rainfall in the general area during the study period was 595 – 1 711 mm, with the monthly average temperatures ranging from a minimum of ~20°C in July and a maximum of 32.4°C in January (Australian Government Bureau of Meteorology 2023).

The study area is dominated by dry sclerophyll forests and woodlands, with moist and wet sclerophyll forests and gully rainforests in sheltered areas. An understorey is dominated by the introduced *Lantana camara*. Entrances to the mines were generally free of vegetation at the time of both inspection periods.

Adits and shafts of the investigated mines were driven mostly into metasedimentary rocks of the Bunya Phyllite and Neranleigh-Fernvale beds with fissure-type quartz reefs (Trezise 1989). The terrain on the meta-sediments is typically undulating to rugged in places (Willmott 2004). Mining areas targeted were situated in five locations (Figure 1):

1. Mt Aurum (110 – 120 m above sea level), Enoggera Creek catchment area.
   Adits: Mt Aurum Lower and Mt Aurum Upper

2. Brookfield (70 – 100 m above sea level), Gold Creek catchment area.
   Adits: Acme, Eclipse No. 1, McCulkin's, Surprise United
   Shafts: Centenary, Dr Dixon's, Eclipse No. 1, Eclipse No. 2, Little Wonder No. 1, Little Wonder No. 3

3. Camp Mountain (190 – 250 m above sea level), Dry Creek and Cedar Creek catchment area.
   Adits: Camp Mountain Lower, Camp Mountain Upper, Fitzgerald's, Kitchener's, Unnamed 903691, McLean's, Oliver's

4. Cedar Creek (100 – 110 m above sea level), Cedar Creek catchment area.
   Shafts: Golden Boulder, Never Beat

5. Mt Coot-tha (215 – 255 m above sea level), East Ithaca Creek and Cubberla Creek catchment area.
   Adits: Ghost Hole
   Shafts: Towle's

An additional historic water tunnel at The Gap was located during the 2021-2023 study period, with potential for providing roost opportunities for bats within the study site (Figure 4).

Cave and cavern forming geology is very limited in the Brisbane area, with only one known cave at Mt Gravatt (e.g. Willmott 2005) and further large cavities from Mount Glorious westwards. As such, artificial structures are likely to be important roost resources for the continued occupancy of cave-dwelling microbats in the Brisbane area.

2007-2009 Inspections

All accessible adits exceeding 5 m in the eastern part of BFP according to Trezise (1989) were investigated for the presence of bats over the period 2007-2009. Other mining sites in BFP, being only superficial features according to Trezise (1989), were not investigated due to their likely minor importance for bats. The total number of bats and the presence of other vertebrates (Supplementary data) were recorded simultaneously. Dangerous shafts with the possible presence of bats in their levels were not examined.

The Lower adit of the Mt Aurum mine was subject to roost counts approximately fortnightly between June 2007 and July 2009, with an additional count in December 2009. This 30 m long adit was chosen for regular inspection due to its accessibility, clear profile and ease of counting bats, allowing fast census

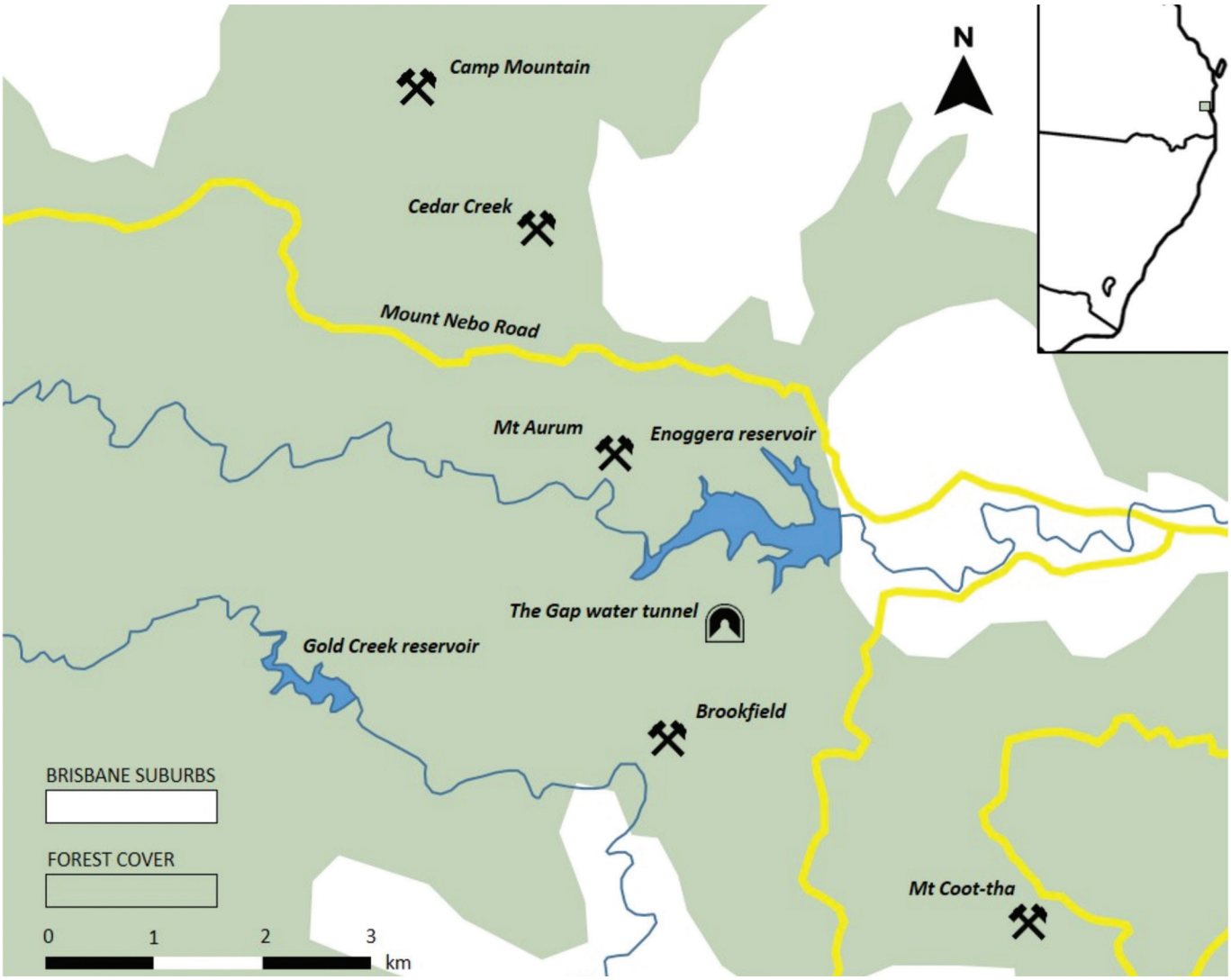

Figure 1. Locations of the main congregations of abandoned mines and the water tunnel surveyed for bat occupancy in the eastern section of Brisbane Forest Park.

without unnecessary disturbance of bats. Counts were performed visually in the shortest possible time using a torch. The other adits with bats were located in 2007 (Brookfield group) and 2008 (Camp Mountain group) and irregularly investigated thereafter.

Adit attributes (location and depth) were initially obtained from Trezise (1989) and complemented by Google Earth layer (HistoricalGoldMinesQLD.kml), with measurements undertaken during this study of the Mt Aurum Lower adit and Upper (aka 'third') adit finding the primary source to be accurate.

The internal temperature and relative humidity of the Mt Aurum Lower adit were recorded during inspections from May 2008 to July 2009 with a digital thermometer data logger (TempTec, Australian Geographic, Terry Hills, New South Wales, Australia). The data logger was positioned near the largest aggregation of bats in the adit, but not close enough to be affected by the heat generated by bats. This adit data was compared to national weather data (minimum and maximum air temperature) collected from the nearest weather station (Australian Government Bureau of Meteorology 2023).

2021-2023 Inspections

The abandoned mines inspected in 2007-2009 were revisited in 2021-2023, excluding those on private property. Direct roost counts and species identification were primarily undertaken in June 2023, although incidental counts or emergence counts during other inspections were also recorded. During these inspections, bat call recorders were used to confirm species identification where required.

Additional adits, shafts and other human-made structures were identified from the Queensland Mineral Resource Site database (Department of Resources 2021) or other published literature and inspected. The only known natural cave in the greater Brisbane region (Willmott 2005) was also visited (Figure 4).

Emergence counts and trapping were undertaken in January-February and December 2023 at two of the deepest voids with unaccessible portions occupied by microbats, to determine approximate numbers and potential use as maternity roosts. A harp trap or adapted mist net was located at the opening of each adit to capture bats emerging for the night. Traps were attended while in operation and captured bats were immediately removed to confirm species, age, sex and reproductive status.

Generalised Linear Models

Generalised linear models (GLMs) were conducted in R 4.4.1 (R Core Team, 2024) with the fortnightly count data from the Mt Aurum Lower adit and explanatory internal and external weather variables. This included minimum and maximum internal adit temperature and relative humidity, as well as external minimum and maximum temperature (as described above). Time of year or breeding season parameters were not included in models as this would greatly influence sample size. To ensure independence in explanatory variables, weather parameters were tested for collinearity with Pearson's correlation coefficients. Paired variables with $r \geq 0.7$ (indicating likely to be linearly dependent) were noted with only one of the variables used per model. GLMs used a quasi-Poisson error structure due to overdispersion. Models were compared using goodness-of-fit tests (to determine which were significantly different to random, with $p<0.05$ considered significant) and ranked using the Akaike Information Criterion corrected for overdispersion (QAICc).

Results

2007-2009 Inspections

Seventeen artificial underground features in the form of abandoned gold mines in the study area were previously verified by Trezise (1989). Fifteen of these were re-located in 2007-2009 and investigated for use by bats (Table 1, Figure 2). Ten of these were used as roosts by *R. megaphyllus* (both grey and/or rufous forms) often in a stage of torpor, with mating observed at the Mt Aurum Lower adit (Figure 3). The only other microchiropteran species recorded was a colony of *M. australis* at the Camp Mountain Fitzgerald's forked adit in June 2009, with estimated hundreds of individuals in a state of torpor. A count the following month recorded only tens of *M. australis* present.

Entry and adit height usually varied between 0.5 m and 1.5 m within each adit, according to the stability of the rock in which they were driven. The span between the furthest underground parts of the mines (Camp Mountain Lower adit in the North and Mt Coot-tha mine in the South) is 10 km.

2021-2023 Inspections

Of the ten structures found to have microbats in 2007-2009, eight were revisited in 2021-2023. Seven of these were found to have continued use by microbats, predominantly *R. megaphyllus*, although *M. australis* and *M. orianeae oceanensis* were recorded on multiple occasions at Fitzgerald's adit.

Additional structures (three adits, six shafts and one water tunnel) in BFP, not inspected in 2007-2009, were also visited to determine their use by microbats, as was the only natural cave in the Brisbane region (Table 1, Figure 4). While microbat scats were found in one additional adit, *R. megaphyllus* (rufous and grey pelage forms) were only observed at The Gap water tunnel.

Trapping at Fitzgerald's adit and The Gap tunnel during February 2023 recorded rufous and grey pelage *R. megaphyllus*, with one post-lactating rufous female captured at the tunnel in late January 2023. Subsequent trapping during the maternity season (December 2023) at both of these structures recorded only male *R. megaphyllus*; of note, almost all males captured at Fitzgerald's adit had golden to rufous pelage.

Roost usage

In 2007-2009, a total of 142 visits to the 10 located *R. megaphyllus* roost sites were conducted. Most of these were undertaken in the Mt Aurum Lower and Upper adits (58 counts each) during the fortnightly roost counts. Mt Aurum Lower adit was used by *R. megaphyllus* continuously between June 2007 and July 2009 (Figure 5). Seasonal patterns in abundance within a mixed-sex roost colony were obvious, with an increase in the number of bats starting in February or March when females arrive and stay in order to mate in June before gradually dispersing in the later months of winter.

Daily use of the other roosts cannot be proved since our visits to those sites were random and sporadic, although similar counts were recorded between the two time periods examined. The shortest adits (Mt Aurum Upper adit and Brookfield Eclipse No. 1 adit) were likely to be transitory or temporary night roosts, with the continued presence of bats unconfirmed. The highest number of bats (45 individuals) was recorded in the Brookfield Surprise United adit in June 2009 and revealed the presence of females at the time of copulation, ovulation and fertilization (Krutzsch *et al.* 1992).

On two occasions (June and July 2009), we counted bats at all located roosts on the same day, with the exception of Brookfield Eclipse No. 2 (both surveys) and Brookfield Acme adit (excluded in June only). These exceptions were due to access difficulty and where few individuals were found previously. The absolute number of bats in visited adits was 92

Table 1. Details of inspections of abandoned mines and other structures for *Rhinolophus megaphyllus* in Brisbane Forest Park and surrounds. The count value given is the maximum number of *R. megaphyllus* observed during June, with the maximum count for the year period in brackets (if different from the June count). The count value with '+' indicates more bats were observed or suspected further in the structure than could be counted. NV = not visited, Miau = *Miniopterus australis*, Mioo = *Miniopterus orianae oceanensis*.

Name	Structure	Approx. length / depth (m)	R. megaphyllus June max. (year max.) count		Notes (incl. other bat species)
			2007-2009	2021-2023	
Containing microbats (Photo No. of Figure 2)					
Mt Aurum Lower (1)	Adit	30	36	33+	
Mt Aurum Upper (2)	Adit	8	0 (1)	0	
Eclipse No. 1 (3)	Adit	6	1 (2)	0	Scats
Eclipse No. 1 (4)	Shaft	5	NV	NV (6)	
Eclipse No. 2 (5)	Shaft	10	NV (2)	NV (5)	
Surprise United (6)	Adit	60	45	NV	
Acme (7)	Adit	30	6	NV	
Camp Mountain Lower (8)	Adit	20	2	2	
Camp Mountain Upper (9)	Adit	50	20	17+	
Oliver's (10)	Adit	30	5	3 (6)	
Fitzgerald's (11)	Adit	50	20	27+	2009: 'Hundreds' Miau 2023: 62 Miau, 3 Mioo
Unnamed 903691 (12)	Adit	15	NV	0	Scats
The Gap (Figure 4)	Tunnel	337	NV	NV (89)	
No microbats recorded					
Kitchener's	Adit	Unknown	0	0	Filled with water
McLean's	Adit	3	NV	0	
Never Beat	Shaft	Unknown	NV	0	With grates, filled with water
Golden Boulder	Shaft	7	NV	0	With grates
Dr Dixon's	Shaft	Unknown	NV	0	Filled with water
Centenary	Shaft	3	NV	0	Collapsed
McCulkin's	Adit	8	NV	0	Collapsed
Towle's	Shafts	2	NV	0	Collapsed
Ghost Hole	Adit	1	0	0	
Mt Gravatt (Figure 4)	Cave	40+	NV	0	
Uninspected					
Little Wonder No. 1	Shaft	Unknown	Located	NV	Unstable/ dangerous
Little Wonder No. 3	Shaft	Unknown	Located	NV	Unstable/ dangerous

Figure 2. The twelve site entrances of located abandoned mines containing microbats in eastern Brisbane Forest Park. Photos taken in 2007-2008 by B. Michálek (1, 2, 3, 7, 10, 11) and P. Šrámek (5), in 2023 by E. R. Williams (4, 8, 9, 12). Photo No. 6 is courtesy of K. Martin from 2021.

Figure 3. Photographs of vertebrates inhabiting the inspected abandoned mines, including mating pair of Rhinolophus megaphyllus at Mt Aurum Lower adit on 24th June 2006 (No. 1), rufous morph *R. megaphyllus* at Camp Mountain Fitzgerald's forked adit on 22nd June 2008 (No. 2), *Miniopterus australis* colony on 18th June 2009 (No. 3) and *Intellagama lesueurii* at Mt Aurum Lower adit on 24th December 2007 (No. 4). All photos by B. Michálek.

Figure 4. The Gap water tunnel southern entrance (No. 1), the northern entrance (No. 2) and Mount Gravatt cave (No. 3). Photos by E. R. Williams in 2023.

individuals in June and 80 in July. The difference in these total counts was due to a significant drop (45 to 22 individuals, 51% reduction) at the Brookfield Surprise United adit.

In general, in both 2007-2009 and 2021-2023, we found the majority of roosting bats in the deepest sections of the adits. However, in the peak mating season (June), we recorded bats distributed along the whole length of adits excluding the sunlit parts near the entrances. At Fitzgerald's mine, where three species were observed roosting in June 2023, *R. megaphyllus* were roosting throughout the length of the adit, either individually or in small groups, and still relatively alert. Whereas both *Miniopterus* species were in a state of torpor, with *M. australis* in small groups and the few *M. orianae oceanensis* roosting individually.

Roost environmental parameters

Temperature and humidity in the Mt Aurum Lower adit showed high stability with a difference of only 1.5°C during the 16 months recorded, especially in comparison with air temperature in the general area (34.4°C difference, Figure 6). Specifically, the minimum recorded temperature within the adit was 17.6 °C in June 2009 and the maximum temperature was 19.1 °C in April 2009.

Analysis with GLMs indicated that a combination of external temperature (minimum or maximum) and adit relative humidity (minimum or maximum) and/or adit maximum temperature models explained abundance of *R. megaphyllus*. In particular, ranking with aQICc indicated the best approximating model was adit minimum temperature, adit maximum

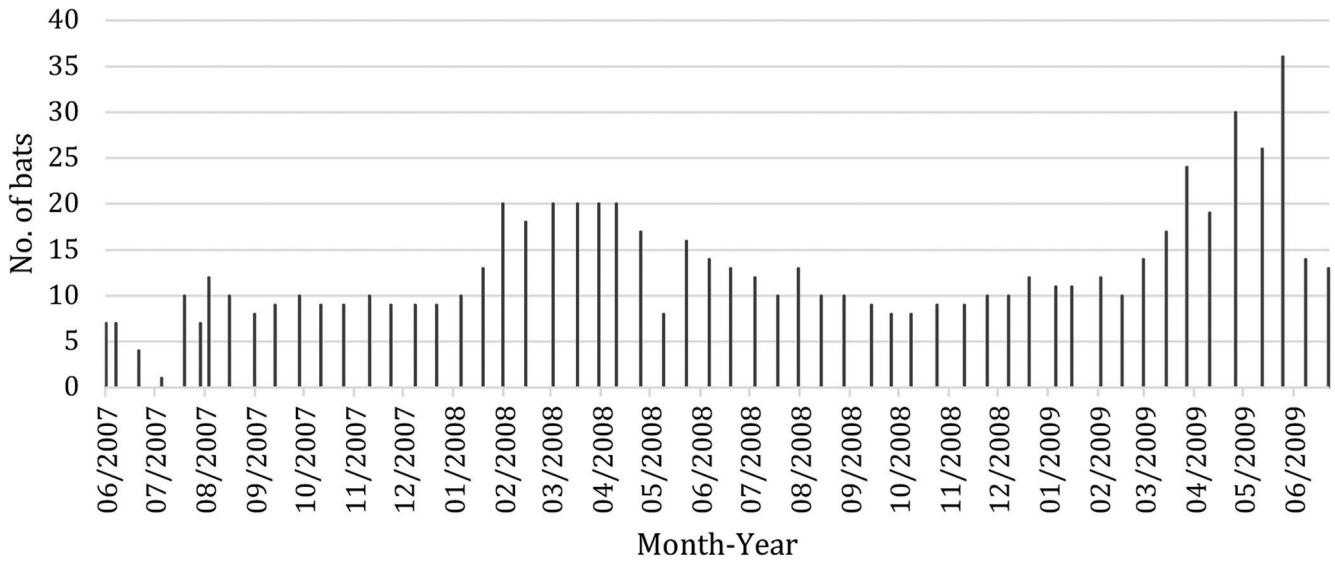

Figure 5. Seasonal patterns of *Rhinolophus megaphyllus* counts during fortnightly adit inspections at Mt Aurum Lower adit.

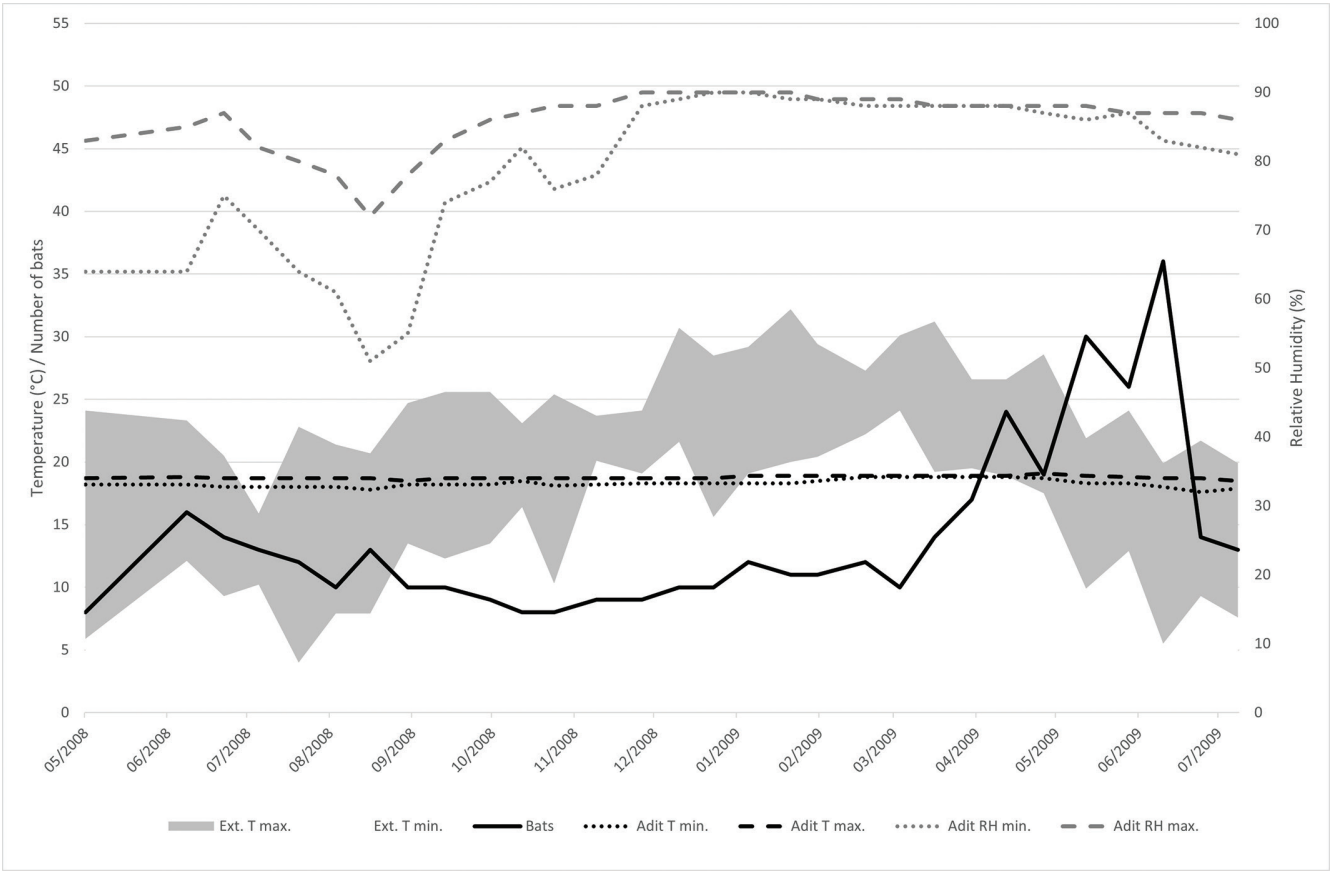

Figure 6. Stability of external and adit roost temperature (T) and humidity (RH) compared to external air temperature at Mt Aurum Lower adit, with the season trend of occupancy by *Rhinolophus megaphyllus*.

relative humidity and external minimum temperature (Table 2). No other models had ΔqAICc <2 units (indicating competitive models with empirical support; Burnham and Anderson 2002), although a similar model with adit minimum relative humidity had ΔqAICc = 2.22. All models with ΔqAICc <10 (showing some level of empirical support) required the inclusion of external temperature (minimum or maximum) and did not include adit minimum temperature. Adit maximum temperature, in contrast, was in the six top-ranked models.

Discussion

Based on the data gathered and presented in this paper, we conclude that long abandoned mines in BFP are important for the continued occupancy of the *R. megaphyllus* population in the Brisbane area. In particular, for the individual mines where counts were undertaken during June in both time periods discussed in this paper (2007-2009 and 2021-2023), the numbers of *R. megaphyllus* recorded are comparable. This indicates the structures are still important roosts 16 years after the first inspections.

The daily census counts in June and July 2009 from the majority of investigated abandoned mines recorded 80-92 individuals in the 8 structures, while a summer emergence count in 2023 recorded 92 *R. megaphyllus* at the tunnel alone. While these numbers are less than large colonies of the species in deep structures, e.g. 54-999 individuals in Slade and Law (2007), they are comparable to several other studies in both natural caves or abandoned mines in Queensland and New South Wales; max. 100 individuals in Pavey (1998), max. 70 individuals in Young (2001) and max. 9 individuals in Murphy (2014).

Such artificial roosts for cave-dwelling bats are particularly important in the Brisbane area, as natural caves are almost non-existent. It should be noted that there are more artificial underground roosts in the area suitable for bats that have not been described in this work. For example, in addition to other abandoned gold mine sites in BFP, an abandoned railway tunnel (in Samford Village) or other historic mine adits and shafts are known in the greater Brisbane area and south-east Queensland (e.g. abandoned coal mines at Blackstone, Ipswich).

Various studies indicate that *R. megaphyllus* prefers to roost in mine adits with a minimum depth of 15 m (Hall *et al.* 1975; Young 2001; Slade and Law 2007). Whilst our research found the largest colonies in the deepest adits (30-60 m) or at the tunnel (337 m),

Table 2. Candidate GLM models explaining the abundance of *Rhinolophus megaphyllus* at Mt Aurum Lower adit between 2008-2009, with Akaike's information criterion for small samples and corrected for overdispersion (QAICc) and difference between the highest ranked model and the most parsimonious models (Δ) reported.

Model	Adit		External			K	qAICc	ΔqAICc
	RH min	RH max	T max	T min	T max			
1	+		+	+		4	122.95	0
2	+		+		+	4	125.18	2.22
3			+		+	3	127.60	4.65
4		+	+		+	4	128.28	5.33
5		+	+	+		4	128.34	5.38
6			+	+		3	129.36	6.40
7	+			+		3	129.38	6.42
8	+				+	3	132.75	9.79

although short adits (e.g. Mt Aurum Upper adit – 8 m and Brookfield Eclipse No. 1 adit – 6 m) also served as day roosts for individuals.

Maternity roosts

The located abandoned mines investigated in this study indicate that they provide mating and non-maternity roosts for *R. megaphyllus*, with the trends of roost counts during 2007-2009 comparable to the seasonality of non-breeding roost occupancy revealed in other studies. For example, mating was documented in the Mt Aurum Lower adit (Figure 3) in late June 2009, whereafter *R. megaphyllus* formed mixed-sex colonies that persisted through the winter months. There was a slight decrease in bats towards the end of winter, possibly indicating the gradual departure of females from this mating roost.

Additionally, we have found neither a maternity colony of *R. megaphyllus* nor roosting bats carrying young. The presence of females was visually confirmed in the Mt Aurum Lower adit, Surprise United adit, Fitzgerald's adit and the water tunnel between January and July. However, there was a complete absence of females during trapping in December 2023 at the two largest roosts.

A single post-lactating female with rufous pelage was captured at the water tunnel in mid February, with only one other sub-adult female trapped during part of the emergence event. However, this small number of females and single post-lactating individual during the 'shoulder' season suggests that this structure is more likely a staging or non-breeding roost. Specifically, following the summer breeding season, female *R. megaphyllus* typically return to their non-breeding area and roosts between February and April (Young 2001; Churchill 2008).

The microclimatic conditions of the structures investigated in this study also suggest that they are unlikely maternity sites since females require very high temperatures (exceeding 30 °C) and humidity (reaching 100 %) for deliveries and nursing their young (Hall *et al.* 1975). While no maternity roost was located in this study, it is possible one exists within the study area or adjacent forested habitats. Due to the very limited occurrence of natural roosts in the Brisbane area, it is proposed that these maternity roosts occur in unexplored mines with restricted access, insufficiently monitored adits or another type of artificial underground roost. In particular, while there are records of *R. megaphyllus* roosting inside rock piles, buildings, tree roots in undercut creek banks (Churchill 2008), shallow caves (≤ 3 m deep; Dwyer 1966) or concave places originating after uprooted trees (Michálek pers. obs.), these are typically temporary night roosts or casual diurnal roosts for individuals. One exception is the recurring occupancy over a 10-year period of a very large (180 cm diameter at breast height over bark) hollow tree in New South Wales (Slade and Power 2023); however, the size and internal cavity of this tree is unlikely to be common in BFP.

The presence of the rufous form of *R. megaphyllus* in both 2008 and 2023 also supports our proposal that a maternity colony exists in the area. The rufous form of several species of Australian microbats is considered to be due to bleaching of the fur when the animal spends a considerable part of their life in high ammonia environments, which is typically in high humidity roosts where urea and/or guano breaks down anaerobically to produce ammonia (McFarlane *et al.* 1995, Thomson pers. comm. 2023), although there is some conjecture that genetics is also a predeterminant (Young 1975). Specifically, we observed rufous-coloured individuals in the Mt

Aurum Lower adit each month between March and June 2008, when females move to mixed colony sites from the maternity roost. Additionally, golden or rufous individuals were recorded in the Camp Mountain Fitzgerald's forked adit in mid-late June 2008 (Figure 3) and February and December 2023.

Female *R. megaphyllus* have been recorded travelling up to 23 km to their traditional maternity roost (Dwyer 1966). Large maternity sites of this species in Queensland remain largely unknown apart from a suspected maternity site at Larynx Labyrinth Cave in the Mt Etna area suggested by Dwyer (1970) and at Riverton mine on the New South Wales border (Bruce Thomson pers. comm. 2023), both in areas of high temperatures and humidity.

Roost parameters

The long-term temperature measurements and stability at the Mt Aurum Lower adit was comparable to the non-maternity roost at Anjuramba mine in southern Queensland, 84 km north-west of our study area (Hall *et al.* 1975). Specifically, at Anjuramba, the maximum-minimum temperature difference was 2.2 °C over 28 months on 14 occasions in 1970-1972, whilst we recorded a 1.5 °C difference over 14 months on 32 occasions over the period 2008-2009. However, humidity was more variable between the two sites, with a minimum of 51 % in the winter of 2008 and repeatedly a recorded maximum of 90 % in the summer of 2008 at BFP, whilst Anjuramba humidity varied from only 85.5 % to 95.5 %.

Analysis with GLMs indicated that adit maximum temperature and external temperature (minimum or maximum) resulted in the best-fitting models for *R. megaphyllus* abundance at the Mt Aurum Lower adit, particularly if adit relative humidity (minimum or maximum) was included. This may indicate that stability in temperature and/or humidity at this adit, compared to fluctuating external temperatures, provides a more suitable diurnal roost than other roosts in the area.

Only two other species of bat – *M. australis* and *M. orianae oceanensis* – were found in the Fitzgerald's forked adit during this study. In the 2007-2009 study period, *M. australis* were only recorded twice out of the four inspections but were present at all six inspections in 2023. In contrast, *M. orianae oceanensis* was only found in low numbers inside the adit at one inspection in 2023, with many individuals (5-31) captured entering the adit during trapping events, indicating they are likely roosting elsewhere and using the adit as a nocturnal or social roost. The forked shape of this adit may allow characteristic inclination to roost apart from *R. megaphyllus*.

Conclusion

This article provided a review of abandoned mines in BFP regarding the presence of *R. megaphyllus* and other bat species. As a result of the aggregation of those mines, the lack of natural caves and the continued presence of *R. megaphyllus* over a 16 year period, we consider that the eastern portion of BFP and the subterranean artificial structures present are important for the survival of the species in the region.

Further search for a maternity site is needed to better understand the status and conservation management requirements of this species in BFP. Moreover, inaccessible shafts should be subjected to counts of bats so that a comprehensive network of roosts can be determined.

Regardless, the conservation value of the investigated derelict structures for *R. megaphyllus* is obvious. Entrances to these underground places should be managed to prevent disturbance by humans, as well as entrance collapse, to ensure their sustained use as bat roosts. Access for research purposes should be permitted since the complex of adits in BFP is, compared to natural caves, more suitable for ecological studies of this species.

Acknowledgements

We would like to thank Jiří Flousek (in memoriam) and Emil Tkadlec for their support. ERW is grateful to Adam Wood and Cath Walsh for field support, as well as Bruce Thomson for discussions on the project. We are indebted to Sue Churchill for introducing the authors to each other.

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SUPPLEMENTARY DATA

Supplementary data

Other vertebrate species recorded

During inspections, we recorded five other vertebrate species (Table 3) which complement an overview of vertebral fauna of the mines. Two amphibians – the Striped Marsh Frog *Limnodynastes peronii* and the introduced Cane Toad *Rhinella marina*, were recorded at the Mt Aurum Lower adit and the Brookfield Acme adit. Each structure was significantly wet and had semi-permanent puddles of water. Recurring visits to Mt Aurum Lower adit indicated use by both amphibian species mostly in the driest and hottest months of the year. Southern Boobook *Ninox boobook* was encountered in the Mt Aurum Upper adit on two occasions – in November 2008 and October 2009. An Australian Water Dragon *Intellagama lesueurii* (Figure 3) was also recorded in the Mt Aurum Lower adit during December 2007. The Common Dunnart *Sminthopsis murina* was incidentally recorded during trapping in December 2023 at The Gap water tunnel.

These occasional findings indicate the use of the abandoned mines as a refuge for moisture-dependent species; specifically, two species of amphibians: *Rhinella marina* and *Limnodynastes peronii* and one species of reptile: *Intellagama lesueurii*. *Ninox boobook* used the entrance of the Mt Aurum Upper adit as a diurnal hideout. Unlike a similar study of *R. megaphyllus* roost sites in the Pilliga natural caves of New South Wales (Murphy 2014), the use of the mines in BFP by vertebrates other than bats indicates rather low significance. Presumably, the frequency of finds is influenced by the density of vertebrates in the area, search effort, detectability of the species and the number of hiding opportunities. As such, it is possible this study did not match the recorded diversity of vertebrates in the Pilliga caves due to fewer hideouts within the short adits compared to natural cave systems.

Table 3. Overview of bats and other vertebrates recorded in the studied adits and shafts.

Site	Date	Number of *Rhinolophus megaphyllus*	Other vertebrate species recorded
Mt Aurum Lower adit	17. 06. 2007	7	
	23. 06. 2007	7	
	07. 07. 2007	4	
	21. 07. 2007	1	
	04. 08. 2007	10	
	14. 08. 2007	7	
	19. 08. 2007	12	
	01. 09. 2007	10	
	16. 09. 2007	8	
	29. 09. 2007	9	
	14. 10. 2007	10	
	27. 10 .2007	9	
	10. 11. 2007	9	
	26. 11. 2007	10	
	09. 12. 2007	9	1× *Limnodynastes peronii*
	24. 12. 2007	9	1× *Limnodynastes peronii*, 1× *Intellagama lesueurii*
	06. 01. 2008	9	
	21. 01. 2008	10	

SUPPLEMENTARY DATA

Site	Date	Number of *Rhinolophus megaphyllus*	Other vertebrate species recorded
	04. 02. 2008	13	
	16. 02. 2008	20	
	01. 03. 2008	18	1× *Rhinella marina*
	18. 03. 2008	20	1× *Rhinella marina*
	02. 04. 2008	20	
	15. 04. 2008	20	1× *Rhinella marina*
	26. 04. 2008	20	
	11. 05. 2008	19	
	25. 05. 2008	8	
	08. 06. 2008	16	
	22. 06. 2008	14	
	05. 07. 2008	13	
	20. 07. 2008	12	
	03. 08. 2008	10	
	16. 08. 2008	13	
	30. 08. 2008	10	
	13. 09. 2008	10	
	30. 09. 2008	9	
	12. 10. 2008	8	
	24. 10. 2008	8	1× *Limnodynastes peronii*
	09. 11. 2008	9	1× *Limnodynastes peronii*
	26. 11. 2008	9	
	10. 12. 2008	10	
	23. 12. 2008	10	
	05. 01. 2009	12	
	21. 01. 2009	11	2× *Limnodynastes peronii*, 1× *Rhinella marina*
	31. 01. 2009	11	1× *Limnodynastes peronii*
	18. 02. 2009	12	1× *Limnodynastes peronii*, 1× *Rhinella marina*
	03. 03. 2009	10	2× *Limnodynastes peronii*, 1× *Rhinella marina*
	16. 03. 2009	14	1× *Rhinella marina*
	30. 03. 2009	17	3× *Limnodynastes peronii*, 1× *Rhinella marina*

SUPPLEMENTARY DATA

Site	Date	Number of *Rhinolophus megaphyllus*	Other vertebrate species recorded
	12. 04. 2009	24	1x *Limnodynastes peronii*
	26. 04. 2009	19	
	12. 05. 2009	30	1x *Limnodynastes peronii*
	28. 05. 2009	26	
	10. 06. 2009	36	
	24. 06. 2009	14	
	08. 07. 2009	13	
	04. 12. 2009	12	
	10. 06. 2023	33 min.	
Mt Aurum Upper adit	12. 10. 2008	* see note below	1x *Ninox boobook*
	09. 11. 2008		1x *Ninox boobook*
	10. 06. 2023	0	
Brookfield Eclipse No. 1 adit	03. 03. 2007	2	
	12. 08. 2007	0	
	18. 06. 2009	1	
	02. 07. 2009	1	
	02. 07. 2023	0* (Microbat scat piles present)	
Brookfield Eclipse No. 2 level between 10 m deep shafts	31. 03. 2007	0	
	12. 08. 2007	2	
	14. 08. 2021	3 (Emergence count)	
	11. 04. 2022	5 (Emergence count)	
Brookfield Surprise United adit	12. 08. 2007	25	
	04. 05. 2008	*R. megaphyllus* present, not counted	
	18. 06. 2009	45	
	02. 07. 2009	22	
Brookfield Acme adit	31. 03. 2007	*R.megaphyllus* present, not counted	

SUPPLEMENTARY DATA

Site	Date	Number of *Rhinolophus megaphyllus*	Other vertebrate species recorded
	02. 07. 2009	6	min 5x *Limnodynastes peronii*, min 5x *Rhinella marina*, 1x *Intellagama lesueurii*
Camp Mountain Lower adit	22. 06. 2008	2	
	18. 06. 2009	1	
	02. 07. 2009	1	
	24. 06. 2023	2	
Camp Mountain Upper forked adit	22. 06. 2008	9	
	18. 06. 2009	20	
	02. 07. 2009	20	
	24. 06. 2023	17 min.	
Camp Mountain Fitzgerald's forked adit	22. 06. 2008	20	
	27. 09. 2008	10	
	18. 06. 2009	8	*M. australis* (hundreds)
	02. 07. 2009	13	*M. australis* (tens)
	24. 06. 2023	6 min.	12 *M. australis*, 3 *M. orianae oceanensis* plus 21 unidentified
Camp Mountain Oliver's adit	22. 06. 2008	5	
	27. 09. 2008	4	
	18. 06. 2009	3	
	02. 07. 2009	4	
	24. 06. 2023	3	

*The Upper adit in Mt Aurum area was inspected on the same days as the Lower Adit. No bats were found in the Upper adit except for a single R. megaphyllus found during the following counts: 4. 8. 2007, 24. 12. 2007, 21. 1. 2008, 4. 2. 2008 (inspected after the Lower Adit), 31. 1. 2009 and 18. 2. 2009 (inspected before the Lower adit).

Counts with minimum ('min.') values are conservative estimates; likely more individuals were present further into the roost, but bats were becoming aware and disturbed so counts were ceased.