Journal of the Royal Society of Western Australia, 93: 165–174, 2010

Assessing the short-term effect of minerals exploration drilling on colonies of bats of conservation significance: a case study near Marble Bar, Western Australia

K N Armstrong

Previously: Biota Environmental Sciences Pty Ltd; Currently: Specialised Zoological
✉ kyle.armstrong@graduate.uwa.edu.au.

Manuscript received March 2006; accepted September 2010

Abstract

Bats are most vulnerable whilst in their roost, and activities that result in roost destruction or disturbance have the potential to cause declines in species of conservation significance. However, conservation efforts for bat colonies can be limited by a lack of understanding of the effect of certain disturbances. An evaluation drilling programme conducted in close proximity to historical underground gold workings near Marble Bar provided an opportunity to examine the short-term effect of this type of activity on colonies of the bats *Macroderma gigas* and *Rhinonicteris aurantia*. A non-invasive approach to assessing the impact of the associated activity was developed, which simultaneously realised the best economy of moving a drill rig. Bats were subject to several types of potential disturbance (from noise and vibration) from earthmoving equipment, the drill rig and the booster compressor. Monitoring involved continuous acoustic and visual observations of mine entrances during drilling, direct counts of emerging bats each evening after drilling, and surveys of other mines in the local area throughout the study. *R. aurantia* was present throughout the drilling programme, but actual numbers could not be determined accurately. A marked increase in the number of *M. gigas* was observed, thought to be independent of the activities associated with the drilling programme and possibly due to concurrent human activities in other local mines or natural factors. It was concluded that short-term activities associated with drilling that are not within 25 m of a mine entrance or 85 m of the roost site within the structure, and that do not intersect workings, might not constitute a significant disturbance to these bats. However, the long term cumulative effects of this and other disturbances, and in the context of contemporaneous activities at other roosts in the district, are unknown.

Keywords: bats; conservation significance; Marble Bar; minerals exploration, drilling; roost destruction

Introduction

The diurnal refuge, or roost, of bats is a major influence in their ecology, offering protection from exposure to daytime ambient conditions and predators, promoting energy conservation, and facilitating social interactions (Kunz & Lumsden 2003). Bats are vulnerable to the destruction of their roosts, as well as disturbances while in them, which are issues for many species worldwide (Hutson *et al.* 2001; Mickleburgh *et al.* 2002). Cave roosting bats will readily move into disused underground mines and form colonies ranging in size from a few individuals to aggregations of thousands (Tuttle & Taylor 1998). The importance of mines to bats is exemplified by past actions in the USA, where the closure or destruction of thousands of mines led to the estimated loss of millions of bats before they were considered as habitat by land managers (Ducummon 2001; Altenbach & Sherwin 2002). In Australia, disused mines provide alternative habitat for more than 20 species of cave roosting bat, some of which are listed in a Threatened category by Australian State and Commonwealth authorities (Hall *et al.* 1997; QPWS 1999; ABS 2000; NSW National Parks and Wildlife Service 2001; Mickleburgh *et al.* 2002; Thomson 2002). The creation of underground mines has allowed some species to add breeding sites and expand their population size. The corollary is that now some mines are critical to the survival of numerous species because most of the known population is aggregated within them, (Duncan *et al.* 1999; Armstrong & Anstee 2000; Armstrong 2001; DEWHA 2010a).

The Pilbara, one of Australia's most heavily exploited mining provinces, contains isolated populations of two bat species of conservation significance that occupy caves and underground mines, and whose presence often coincides with the interests of gold, copper and iron ore mining. The Pilbara leaf-nosed bat *Rhinonicteris aurantia* (Hipposideridae) is listed as Schedule 1 under Western Australia (WA) State legislation, and as Vulnerable under Commonwealth legislation. The ghost bat *Macroderma gigas* (Megadermatidae) is listed on the WA Department of Environment and Conservation's (DEC) Priority Fauna List under "taxa in need of monitoring". Both species are widespread in the Pilbara region, however the majority of their number is concentrated in relatively few underground structures that meet their physiological and breeding requirements (Hall *et al.* 1997; Armstrong & Anstee 2000; Armstrong 2001; DEWHA 2010a). Most of these structures are disused mines that are still subject to interest for their undeveloped minerals potential (McKenzie *et al.* 1999; DEWHA 2010a). Both *M. gigas* and *R. aurantia* are also particularly sensitive to disturbance, and have an observed tendency to vacate roosts in response (Armstrong 2001; K.N. Armstrong unpub. obs.).

In the past decade, the mining boom experienced by WA has expanded our knowledge of their area of occupancy in the Pilbara through increased surveys as part of environmental assessments (K.N. Armstrong unpublished data), as well as baseline surveys conducted by the DEC (McKenzie & Bullen 2009). When a new record of presence occurs in an area planned for development, the proponent then has an obligation to address this as an issue for their project. In general, the success of conservation and management efforts for Threatened-listed species is dependent not only on a comprehensive understanding of their taxonomy and ecology, but also empirical knowledge of how they react to human disturbances and habitat modification. It might be possible to make predictions about such reactions based on knowledge of a species' ecology, but often the questions most relevant for development proposals are very specific and require past experience to answer. There are studies that have investigated how bats respond to disturbance following human entry of roosts, and also to solutions such as the placement of 'bat friendly' gates across cave and mine entrances (Johnson *et al.* 1991; Speakman *et al*. 1991; Richter *et al.* 1993; Thomas 1995; Lackie 2000, Mann *et al.* 2002; Pugh & Altringham 2005; Slade & Law 2008), but in the case of Pilbara mining projects the most common issues that arise when these species are discovered in areas planned for development do not have much similar published experience to draw upon. If plans do not involve the actual destruction of roosts, then a common consideration is the minimum proximity of mining infrastructure, pits and waste dumps to roosts before the combined impacts from noise, blasting, lights, and vehicular traffic cause the colonies to decline in size or reduce the frequency with which roosts are occupied (K.N. Armstrong unpubl.).

Before mining actually begins, the effects of exploration drilling in close proximity to caves or mines occupied by the bats sometimes needs to be considered. Making an assessment of effects such as noise and vibration on bats of conservation significance is difficult because there is no prior published information, and such applied studies require the cooperation and resources of mining companies to complete. An evaluation drilling programme (where the size and value of known ore bodies is determined by intensive drilling) conducted in the vicinity of the historical underground gold workings of the Klondyke Queen near Marble Bar provided the opportunity to examine the short term influence of this type of activity on *M. gigas* and *R. aurantia*. The two species have established colonies of regional importance in the workings, and the mine represents one of the few known roost sites for *R. aurantia* in the region (Churchill *et al*. 1988; Hall *et al.* 1997; Armstrong & Anstee 2000; Armstrong 2001; DEWHA 2010a). The evaluation drilling programme at the Klondyke Queen was used as a case study to determine whether such activities in close proximity to roosts would have a detectable effect on bat presence and abundance. The study was structured to examine bat presence before and during drilling, while simultaneously 1. introducing no confounding factor through the methods used to assess presence, colony size and nightly exodus; and 2. introducing no significantly disruptive or costly measure to the drilling programme.

Methods

Study species

The bats *M. gigas* and *R. aurantia* have similar distributions over northern Australia, including the Kimberley region, the Top End of the Northern Territory, and isolates in Queensland and the Pilbara region of Western Australia (Churchill 2008). They both rely on relatively deep subterranean roosts with a warm, humid microclimate that enable them to limit energy and water loss (Leitner & Nelson 1967; Kulzer *et al.* 1970; Churchill *et al.* 1988; Churchill 1991; Baudinette *et al.* 2000; Armstrong 2000, 2001), and have established strongholds in the eastern Pilbara where most underground mines occur. The majority of the current known population of *M. gigas* is concentrated in the Comet mine (Marble Bar), Klondyke Queen mine (Marble Bar), Lalla Rookh mine (Panorama Station), Bulletin and Bamboo Creek mines (Bamboo Creek), with smaller colonies (30 individuals or less, and often single individuals) in small mine adits and natural caves throughout the region. *R. aurantia* is found in fewer mines in the eastern Pilbara (Klondyke Queen, Comet, Bamboo Creek, Lalla Rookh, Copper Hills), but there have been numerous records of bats in flight throughout the region, and a record of a cave roost in Barlee Range Nature Reserve (Hall *et al*. 1997; Armstrong & Anstee 2000; Armstrong 2001; McKenzie & Bullen 2009; DEWHA 2010a; K.N. Armstrong, unpubl. data).

Human intrusion into roosting chambers and capture activities have been associated with reduced occupancy of these species at several caves and mines, so non-invasive methods are recommended for determining their presence (DEWHA 2010b). This usually requires electronic bat detectors that can record ultrasonic echolocation calls, but *M. gigas* can also be counted easily under low or red light when emerging from a roost because of their large size and pale colour. It is virtually impossible to make an accurate determination of colony size of *R. aurantia* using remote detection methods because they visit caves and mines after dusk that are not used for roosting during the day, and they will often swarm around a roost entrance after emerging at dusk (K.N. Armstrong, unpubl. data). If capture is not possible, then only presence and activity levels of *R. aurantia* can be determined at caves or mine entrances.

Two other species of bat commonly occupy underground mines in the eastern Pilbara: the common sheath-tailed bat *Taphozous georgianus* and Finlayson's cave bat *Vespadelus finlaysoni*. They are obligate cave roosting bats, and are typically abundant. Their responses to drilling disturbance were not considered in the study.

Study sites and timing

The study area included two main sites: the Klondyke Queen and Klondyke King mining leases, located c. 20 km south-east of Marble Bar, Western Australia (Figure

1). Drilling began at a third lease called Kopcke's Reward, c. 1.9 km east of Klondyke Queen. The observations made on bats were undertaken at the historical workings of the Klondyke Queen mine, which is the only existing underground structure of significant depth and complexity on these leases. A newer adit beneath the old Klondyke Queen is sealed and not known to be occupied by bats of conservation significance. Other historical mine workings in the Marble Bar area where *R. aurantia* had been detected

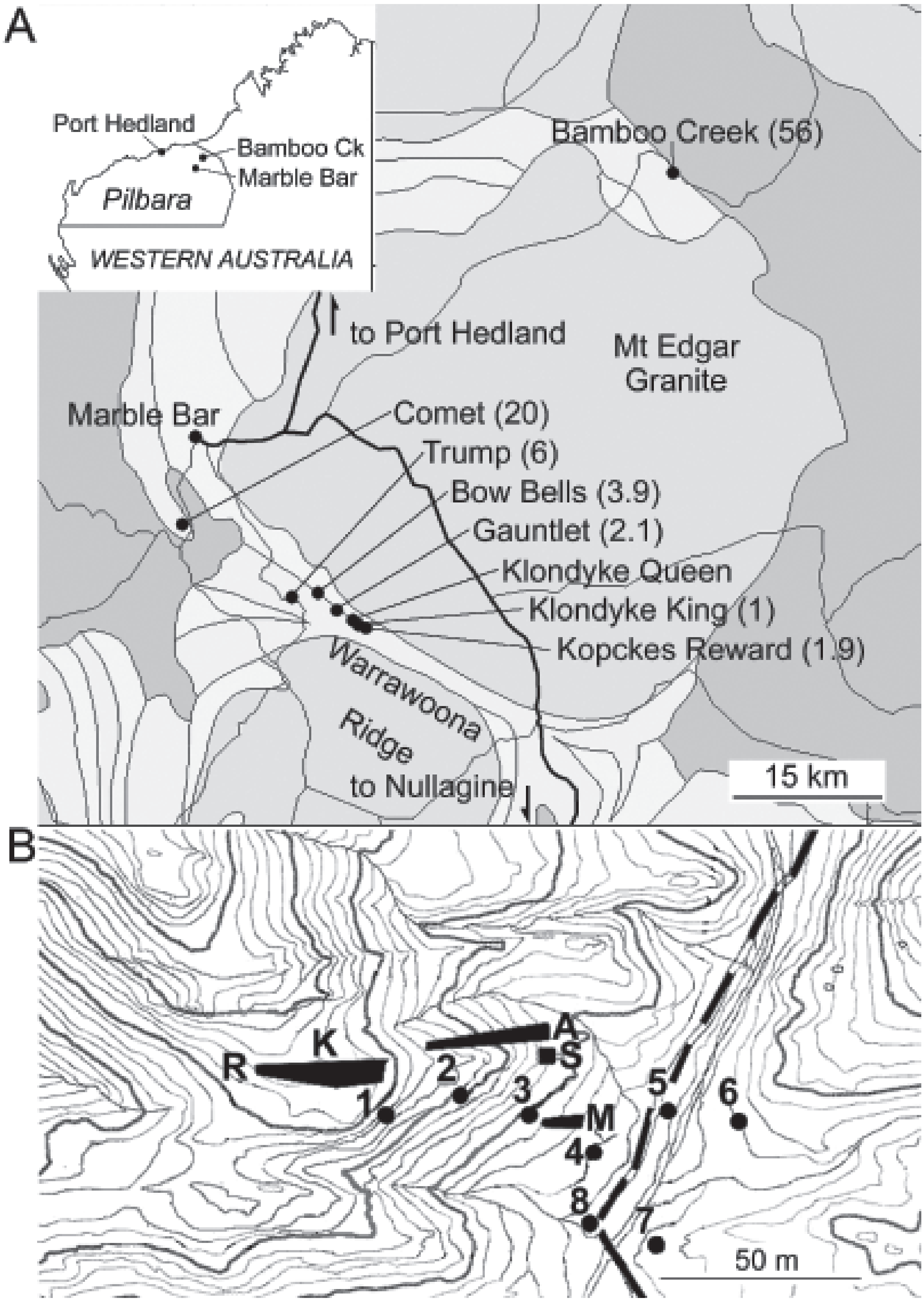

Figure 1. A: Inset: Location of Marble Bar in Western Australia. Main: Location of mines and leases examined for *R. aurantia* and *M. gigas* in the eastern Pilbara during the study, with the distance from the Klondyke Queen mine in parentheses. Shaded regions are major geological units (GSWA 2001). B: Location of drill holes relative to the underground workings in the Klondyke Queen project area (A: adit entrance to the Klondyke Queen; K: black polygons represent Klondyke Queen surface workings; M: entrance to the Mullan workings that extend below the older Klondyke workings; R: approximate location of roost site within the mine; S: small shaft adjacent the main adit entrance; broken line is a vehicle track).

previously (Armstrong 2001) were surveyed as part of the study. All activities were conducted between 12 June and 5 July 2001.

Study design

The study was designed to simultaneously minimise potential disturbance from the drilling programme and the investigators to avoid the exodus of *M. gigas* and *R. aurantia* from the Klondyke Queen mine, while at the same time minimising the cost of moving a drill rig and avoid leaving it idle. Moving a drill rig is costly since it increases the time taken to complete an drilling programme, and was a major inconvenience in the present study area given the steep terrain and low quality of drill pad access tracks. The type of drilling was Reverse Circulation (RC), which results in the extraction of fine, dry dust, and sometimes requires the use of a truck-mounted air compressor ('booster') to provide extra power for deeper holes, and which is relatively noisy compared to the drill rig.

The approach consisted of a logical order to the progression of drilling, and incorporated a set of measurements designed to detect a set of anticipated responses from the two bat species, and which were feasible to be implemented at the site. Observations were made on the bats before drill pad and access track construction with a bulldozer, between pad construction and the commencement of drilling, and throughout the drilling operations (Table 1). The magnitude of the potential disturbance was related to a combination of several factors, including the distance of the rig from the mine entrance, the time taken to drill (dependent on hole depth), whether the booster was used, and what time of the day a particular hole was commenced (early morning or midday). Each hole was then classified in terms of the anticipated level of disturbance, and a schedule was derived that alternated drilling between the Klondyke Queen (eight holes) and Klondyke King areas (12 holes; Table 1; Figure 1). The goal was to gradually increase the level of anticipated disturbance, while determining simultaneously whether an effect could be observed. The schedule could be adjusted based on these responses, and also contingency measures were prepared in case a significant and undesirable effect was observed during drilling.

Table 1

Activities undertaken during the study. Counts of emerging bats were made 17:45 – 20:00 on all nights except 18 – 19/6/01.

12/6/01	Pre-drill pad construction monitoring (14:30 – 17:45); Surveying nearby mines/leases (Kopcke's Reward, Klondyke King, Klondyke Boulder, The Gauntlet, Bow Bells, The Trump).
13/6/01	Surveying nearby mines (Comet, MacKinnons).
18/6/01	Drill pad construction with bulldozer (14:15 – 17:15) (author absent).
19/6/01	Drill pad construction with bulldozer (14:15 – 17:15) (author absent).
29/6/01	Full day drilling at Klondyke King project area; Pre-drill monitoring (14:30 – 17:45).
30/6/01	Morning drilling at Klondyke King project area; Hole 5 drilling (14:00 – 17:15): monitoring (13:20 – 17:45).
1/7/01	Morning drilling at Klondyke King project area; Hole 4 drilling (13:20 – 17:15): monitoring (12:40 – 17:45).
2/7/01	Morning drilling at Klondyke King project area; Hole 3 drilling (13:30 – 16:20): monitoring (13:20 – 17:45).
3/7/01	Hole 7 drilling (08:30 – 17:30): monitoring (07:15 – 17:45).
4/7/01	Hole 8 drilling (07:40 – 17:00): monitoring (07:25 – 17:45).
5/7/01	Hole 6 drilling (07:40 – 13:30): monitoring (07:40 – 17:45).

Drilling commencement time allowed for morning, afternoon, or full-day drilling in the Klondyke Queen area. Drilling was planned initially for mornings in the Klondyke King area (*i.e.* away from the roost in the Klondyke Queen workings) for several reasons: 1. it was predicted that there would be less impact on roosting *R. aurantia* in the afternoon when they become more active before their emergence, than in the morning when their circadian rhythms might dictate that they rest (although it is acknowledged that activity due to social interactions might occur throughout the day); 2. there was a lower likelihood of bats being exposed for the whole day if they vacated the mine due to drilling in the morning; 3. if a response to drilling was detected, the drill rig could be moved to the Klondyke King area, where work could be recommenced in the same afternoon to avoid having the rig idle; and 4. moving the rig to the Klondyke King for morning drilling might alleviate the cumulative effects of drilling a number of holes in succession close to the Klondyke Queen workings.

Drilling at the Klondyke Queen began in the afternoon at Hole 5 (Table 1; Figure 1), which was considered to have a low potential for disturbance given its shallow depth, relatively large distance from the mine entrance, and midday commencement time (Table 2). For the shorter holes, drilling for a slightly longer period with the rig only was considered to comprise less of a disturbance to bats than a shorter period with a greater surface noise level through the use of a booster. Therefore, the booster was not used on the shallow holes (Holes 5 and 3) closest to the Klondyke Queen workings, though its use was unavoidable on one hole of moderate depth (Hole 4) that was commenced at midday. Since there was no detectable effect of drilling the 'afternoon' Holes 5, 4 and 3, it was considered appropriate to commence the deeper Holes 7, 8 and 6 from early morning (the deeper holes required a full day and the use of the booster) (Table 2). The use of the booster was unavoidable on the deeper holes. It would have been expensive and unnecessary to drill the two deeper holes over two afternoons each since the drilling programme would have needed to be extended for a further two days. Holes 1 and 2 were not drilled and no drill pads were constructed for these. Pad construction would have involved blasting with explosives to batter down a steep slope adjacent to the Klondyke Queen workings close to bat roosts. Such activity was deemed highly likely to cause a disturbance to the bats and plans to drill these holes were therefore abandoned. The drill rig was always removed from the project area or shut down at or before 17:30 hours to avoid affecting bats emerging at dusk.

Measurements to detect anticipated responses of bats

Bats at the Klondyke Queen were potentially exposed to four types of disturbance from noise and vibration: associated with the bulldozer clearing access tracks and pads for the drill rigs; from the drill rig on the surface;

Table 2

The approach to determining drill hole order. Each hole introduced a potentially greater level of disturbance; holes are listed in order of drilling.

Hole	Depth (m)[1]	Distance (m)[2]	Booster[3]	Test rationale
1	—	52 45	—	Pad constructed but not drilled
2	—	31 64	—	Pad constructed but not drilled
5	60	40 122	—	First test of nearby drilling
4	90	38 105	used	Tested for effect of the booster
3	60	25 84	—	Tested for effect of drilling in close proximity to the old workings
7	150	68 129	used [M]	Tested for the effect of morning drilling
8	130	55 108	used [M]	Tested for cumulative and delayed effects of drilling
6	100	59 143	used [M]	Tested for cumulative and delayed effects of drilling

[1] Hole depth;

[2] Distance of the rig from the mine entrance and roost, respectively, see Figure 1;

[3] M: indicates drilling commenced in the morning.

from the booster on the surface; and from the RC drill below the surface. The magnitude of a disturbance from noise or vibration was not measured directly (due to limitations on equipment); rather it was determined indirectly through the response of the bats to the activities. Four types of response were considered possible in both *M. gigas* and *R. aurantia*:

Type 1: Bats emerge from the mine during daylight hours. This response would most likely lead to bat mortality. Subsequently, observations of bats emerging at dusk on the same day would establish whether part of the colony still remained in the mine.

Type 2: Bats become active during daylight hours and fly about within the mine adit, but do not emerge into the open. This type of activity normally occurs before nightly emergence. Pre-drilling observations would establish the time bats normally begin to become active before nightly emergence. This type of response could lead to a *Type 1* response.

Type 3: Bats vacate a roost after dusk emergence and do not return at dawn. This can be assessed from a comparison of counts or presence data before, during and after drilling, and through observations made during drilling.

Type 4: Bats do not enter their normal circadian rhythm after their return at dawn, but also do not fly about within the mine. This type of response was not able to be assessed in the present study.

Five measurements were taken in order to be able to detect both immediate and delayed responses to a disturbance. The measurements were different for *M. gigas* and *R. aurantia*.

Measurement 1: *Presence / absence of R. aurantia at alternative roosts.* The presence of *R. aurantia* at other mines in the local area was assessed prior to drilling. This was done to ensure that mines were present in the local area that were suitable for occupation by *R. aurantia* if drilling caused bats to vacate the Klondyke Queen. Simple presence or absence of *R. aurantia* was assessed after dusk at several disused mine entrances around Marble Bar using electronic bat call detectors: either by placing an Anabat II electronic bat call detector connected to an Anabat delay switch (Titley Electronics) at the entrance to record the period of emergence (two hours following dusk; tapes were later analysed to check for calls of *R. aurantia*), or by visiting the mine with a U30 bat call detector (Ultra Sound Advice; in heterodyne mode, tuned to the frequency of *R. aurantia* at c. 120 kHz; Armstrong 2001; Armstrong & Coles 2007) after counts of *M. gigas* at the Klondyke Queen had concluded (see *Measurement 5*). While electronic bat detectors could not be used to confirm whether *R. aurantia* roosted in a mine, they were the best indicator available of presence given time constraints, and safety issues regarding entry and approach of old mines. Surveys were further complicated by the fact that many of the mines have several entrances.

Measurement 2: *Presence / absence of R. aurantia at the Klondyke Queen mine*. The presence of *R. aurantia* in the Klondyke Queen was assessed using a U30 bat detector in heterodyne mode before pad construction, the period between pad construction and drilling, and at all times during drilling near the mine. All previous surveys at the Klondyke Queen since 1995 (Armstrong 2001) have recorded *R. aurantia* as being present. Therefore, if absence was recorded after pad construction or the commencement of drilling, a disturbance would be assumed. The total number of *R. aurantia* in the mine is difficult to estimate because of the large size of roof exits in the mine, post emergence swarming behaviour, and their propensity to relocate to alternative roosts following their capture. Determining the presence or absence of *R. aurantia* at the mine entrance was undertaken instead. This measurement monitored for a *Type 3* response.

Measurement 3: *Observation of daytime emergence*. The possibility of a *Type 1* response was determined through direct observation during drilling. While the rig was present in the Klondyke Queen project area, an observer was stationed at the adit entrance (Point A; Figure 2) to observe whether bats vacated the mine. These species normally never vacate their roosts during daylight hours due to the risk of exposure, predation and lack of available food.

Measurement 4: Daytime acoustic detection. It was assumed that bats normally exhibit low levels of activity during the day, and only fly about within the structure and approach the entrance not long before their emergence. If calls were detected earlier during drilling compared to the period beforehand, it might indicate a *Type 2* response, or an imminent *Type 1* response. Two pieces of recording equipment were lowered through a hole in the roof to the point where bats emerged from the fully enclosed portion of the adit (Point B; Figure 2):

1. A U30 bat detector, tuned in heterodyne mode to detect the calls *of R. aurantia*, which was monitored with headphones whenever the rig was present in the project area until nightly emergence time of *R. aurantia* (*c.* 17:45). The microphone was connected to the detector via a 10 m extension cord, so the observer could be positioned above Point B (Figure 2). The number of calls of *R. aurantia* was to be tallied over the recording period, but the main function of the U30 was to provide real-time indication of whether this species was approaching the entrance and likely to emerge into daylight, allowing rapid feedback to the drilling crew;

2. An Anabat II detector connected to an Anabat Delay Switch and tape recorder, which was also positioned at Point B prior to and during drilling activity at the Klondyke Queen mine (Figure 2). This detector recorded calls of all four species of bat in the mine using a frequency division system (division ratio 8), and analysis was conducted prior to drilling of the subsequent hole. The number of calls of *R. aurantia* was to be tallied during drilling to quantify the level of bat activity. Calls of *M. gigas* were not quantified because both their echolocation and social calls can be difficult to distinguish from other signals based on their structure.

Measurement 5: *Dusk emergence counts of M. gigas*. Counts of *M. gigas* were used to determine the effect of the drilling program on that species, but they also represented a proxy for the level of disturbance on *R. aurantia*. The number of *M. gigas* emerging from the mine between 17:45 and 20:00 (the period when most of the bats emerged) was recorded both before and during the drilling program. A small head torch was used to illuminate the bats from behind as they flew out of the mine.

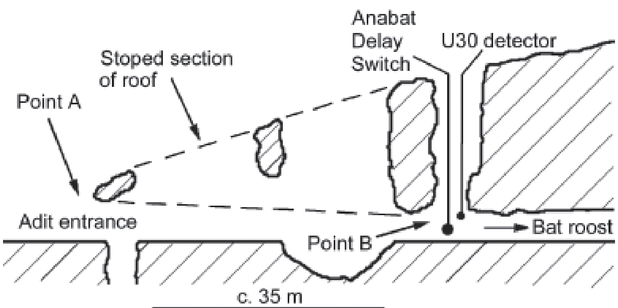

Figure 2. Cut-away section of the Klondyke Queen mine showing the adit entrance, the large gaps in the roof of the mine ('stopes') and where equipment was placed.

Table 3

Emergence times of *R. aurantia* at the Klondyke Queen mine.

Phase	Date	Time	Detection[1]
Pre-bulldozer	12/6/01	17:21	Delay switch
Pre-bulldozer	13/6/01	Prior to 18:30[2]	U30 Point A
Pre-drilling	29/6/01	18:06	U30 Point A
Hole 5	30/6/01	18:04	U30 Point A
Hole 4	1/7/01	17:28	U30 Point B
Hole 3	2/7/01	18:22	U30 Point A
Hole 7	3/7/01	17:28	U30 Point B
Hole 8	4/7/01	17:47	Delay switch
Hole 6	5/7/01	17:53	U30 Point A

[1] The equipment used, and point where observation was made. See Figure 2 for the location of Points A and B;

[2] Equipment problems.

Results

Presence / absence of *R. aurantia* at alternative roosts *(Measurement 1)*

R. aurantia was detected at two other mines near Marble Bar prior to drill pad construction and drilling: Bow Bells (22:30 on 12/6/01) and MacKinnons (within 1 km of the Comet mine; 21:30 on 13/6/01; Figure 1). This species has been observed at the Bow Bells mine on several occasions previously (Armstrong 2001), however, the observation at MacKinnons mine represented a new record. The records suggested that suitable mines were present within the nightly flight range (Bow Bells: 3.9 km; MacKinnons: 20 km) of individuals roosting in the Klondyke Queen mine for relocation if the drilling program caused a disturbance. *R. aurantia* was not detected at the Comet, Golden Gauntlet, Klondyke King, Kopcke's Reward or the Trump mines prior to drill pad construction or drilling.

Presence / absence of *R. aurantia* at the Klondyke Queen mine *(Measurement 2)*

R. aurantia was observed at the Klondyke Queen mine at every nightly emergence prior to and during drilling. Individuals exhibited swarming behaviour between dusk and 20:00, emerging at approximately the same time every evening (*c.* 18:00; Table 3) suggesting that drilling did not cause them to 'hurriedly' vacate the mine after dusk in response to a disturbance (*Type 3* response). Unfortunately, determining whether drilling caused some individuals to relocate during the program was not possible due to the difficulty of obtaining accurate counts of *R. aurantia*. Thus, drilling and pad construction did not cause *R. aurantia* to abandon the mine completely.

Observation of daytime emergence *(Measurement 3)*

An observer stationed at Point A when the drill rig was present did not observe any bat vacating the mine prior to dusk (*Type 1* response). Several *T. georgianus* were observed on walls within the first 40 m of the entrance where the roof is open, however this species normally occupies the semi-dark areas of mines (Jolly 1990), they were observed in this area before drilling, and they did not vacate the mine in daylight.

Table 4

Counts of *M. gigas* between 17:45 and 20:00 at the Klondyke Queen mine. Data on moon position and phase (both in degrees at 18:00) is included for comparison with the progress of the drilling project.

Phase[1]	Date	Number *M. gigas*[2]	Moon Altitude[3]	Moon Azimuth[3]	Moon fraction illuminated
Pre-bulldozer	12/6/01	254	< 0	–	–
Pre-bulldozer	13/6/01	338	< 0	–	–
Pre-drill	29/6/01	108	66.4	47.0	0.64
Hole 5 (60 m)	30/6/01	127	60.0	71.6	0.74
Hole 4 (90 m) [B]	1/7/01	107	50.9	86.5	0.83
Hole 3 (60 m)	2/7/01	121	40.6	95.9	0.90
Hole 7 (150 m) [BM]	3/7/01	128	29.9	102.4	0.95
Hole 8 (130 m) [BM]	4/7/01	106	19.2	107.5	0.99
Hole 6 (100 m) [BM]	5/7/01	366	8.5	111.6	1.0 (full)

[1] B: indicates booster used; M: indicates drilling commenced in the morning;

[2] Total number counted between 17:45 – 20:00 hours;

[3] Moon position in degrees.

Daytime acoustic monitoring *(Measurement 4)*

The Anabat II – delay switch unit was used to obtain data on the normal emergence time of *R. aurantia*. Before pad construction, *R. aurantia* were heard at Point B (Figure 2) at 17:21. No *R. aurantia* were ever observed or heard before this time during drilling (Table 3) indicating that drilling did not cause a *Type 2* response. No calls of *R. aurantia* were heard on the U30 bat detector during drilling activity, however, *R. aurantia* was heard at 17:28 on two occasions (Table 3). On both occasions, the drill rig had left the project area or had shut down earlier, so their activity was interpreted to be unrelated to drilling activity. Social 'chirp' calls of *M. gigas* were heard frequently between 07:00 and 17:45 at Point B on both the U30 and Anabat detectors, and both before and during the drilling programme, but were not quantified.

Dusk emergence counts of *M. gigas* (*Measurement 5*)

The number of *M. gigas* varied during the monitoring period but this did not seem to be correlated with drilling activity (Table 4; Figure 3). There was a drop of c. 200 individuals after pad construction (consistent with a *Type 3* response). However, by the end of the drilling programme the number of *M. gigas* was greater than prior to pad construction. Colony size fluctuation did not appear to be correlated with obvious natural factors such as moonlight (Table 4).

Discussion

Short term effects of RC drilling

None of the five measurements made during drilling suggested that bats of conservation significance were affected by an RC drilling programme in relatively close proximity to their roost, with both species present throughout the study. The study was designed to detect a range of possible response types, despite a limitation that actual levels of the disturbance from noise and sub-surface vibration could not be measured directly either at the roost or the mine entrance. Rather, the level of potential disturbance was inferred to be dependent on factors such as proximity of the drill rig from the mine entrance, drilling commencement time, and hole depth. The drill rig produced relatively low and steady levels of noise, with surface noise levels increasing during drilling and rod extraction, and decreasing during down-hole inspections of geology. No bat of any species was seen to exit the mine during the day, and audio monitoring did not detect increased levels of diurnal activity. Furthermore, emergence times appeared unchanged and colony size did not show a pattern of gradual or sudden reduction with sustained low numbers. Therefore, there was no evidence to suggest that this particular drilling programme adversely affected mine occupancy or colony size of either *R. aurantia* or *M. gigas* in the Klondyke Queen mine.

A relatively small colony (thought to number approximately ten) of *R. aurantia* appeared to occupy the mine during the program. Obtaining accurate counts of this species without an invasive approach involving trapping or roost entry is not possible, but it was obvious that, for example, a colony an order of magnitude larger in size was not present. Given the small estimated low number of *R. aurantia* present, the Klondyke Queen might initially be regarded as being of little importance to their conservation. However, only around six other sites or localities have been confirmed as supporting significant numbers of this species, which comprises the majority of the known abundance (*e.g.* Armstrong 2001; DEWHA 2010a). There have been numerous new records of bats throughout the region, but no survey has confirmed roosting or established the presence of colonies of significant size (McKenzie & Bullen 2009; K.N. Armstrong unpubl. data). Given the physiological constraints of the species, the security of the regional population is essentially correlated with the number of known roosts rather than the number of records of bats in flight. It is also possible that the Klondyke Queen is used by breeding individuals, though very little is known about their breeding activity in the Pilbara (Armstrong 2001).

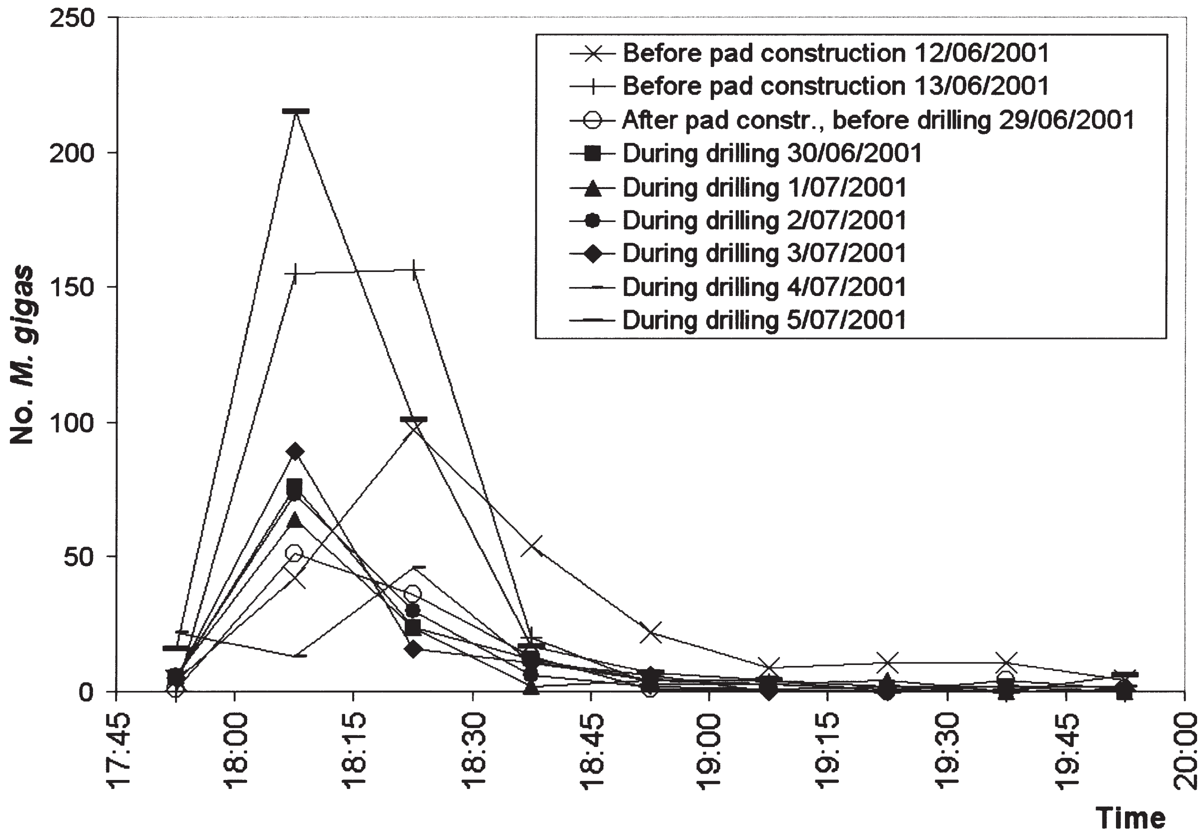

Figure 3. Counts of *M. gigas* at emergence at the Klondyke Queen mine, totalled in 15 minute intervals.

Confounding factors

The counts of *M. gigas* were significantly lower at the Klondyke Queen mine following pad construction, suggesting that the use of a bulldozer might represent a greater disturbance than a drill rig, especially within 50 m of an adit entrance (Hole 3). The bulldozer was operated in close proximity to the old workings to construct a pad for Hole 3. Pad construction for Holes 1 and 2 (not undertaken) closer to the mine entrance might have had greater potential for detrimental effect. However, during the drilling program numbers of *M. gigas* returned to and even exceeded values recorded prior to pad construction. Interpreting the variation in the number of *M. gigas* during the monitoring program is confounded by four possible factors: the activities at the Klondyke Queen mine, including both pad construction by the bulldozer and the operation of drill rig equipment; the (undocumented) concurrent activities at other local mines, in particular the nearest large colony at the Comet mine; moonlight caused bats to stay in the mine during at least part of the night; and any natural patterns of movement that might usually occur. Previous counts of *M. gigas* at the Klondyke Queen recorded 98+ (Hall *et al.* 1997) and 30+ (20/6/96; Armstrong unpublished data in Armstrong & Anstee 2000), suggesting that the number of *M. gigas* has fluctuated previously at the Klondyke Queen. If the short term use of a bulldozer used in pad construction caused some degree of disturbance to *M. gigas*, this was clearly temporary, but it should be highlighted that not every situation might result in a 'recovery' of numbers in the short term. The entrance of the mine did not face the pad for Hole 3, and the result might have been different with a different level of noise. Other disturbances such as roost entry and capture might represent greater levels of disturbance.

Previous observations at the Klondyke Queen mine (K.N. Armstrong unpubl. obs.) suggested that the emergence of *M. gigas* could be delayed by several hours during periods of bright moonlight. This was also noted previously at Mt. Etna, Queensland where *M. gigas* remained in their roost for four nights during the full moon (J. Toop pers. comm. to P. Helman and S. Churchill). No similar observations were made during the present study, despite the presence of bright moonlight. The adit actually faced the direction of moon rise so that the moonlight was shining directly into the mine, and the majority of *M. gigas* exited the mine within a 45 minute period after dusk (Figure 3). Furthermore, a similar number emerged from the mine during periods of both no and full moon. Thus, neither drilling nor phase of the moon had any detectable effect on emergence time, and therefore delayed emergence during periods of bright moonlight might not always occur.

It is suggested that activities occurring at other mines might have had an influence on the number of *M. gigas* at the Klondyke Queen mine. Natural patterns of movement must also be considered, though little is known about their breeding activities and short term or seasonal movements in the Pilbara. It was not possible in this study to determine which other local mine *M. gigas* were moving to, though the Comet mine is the most likely candidate because it is the nearest large permanent colony of this species (Hall *et al.* 1997). The increased numbers at the end of the drilling programme might have resulted from disturbance at a nearby roost such as the Comet. Mine tours were conducted for tourists several times per day at the Comet in 2001, especially in winter. If tours are not conducted appropriately, disturbance to *M. gigas* cause roosting bats to take flight within the mine (K.N. Armstrong pers. obs.), so daytime disturbance in the Comet has the potential to result in higher rates of movement amongst local mines. Concurrent disturbances at nearby major roosts might multiply the effects of individual events.

Possibility of long term cumulative effects

Cumulative effects are a typical cause of an extinction vortex (Gilpin & Soulé 1986). The present study was short-term in duration, however the disturbances associated with drilling, though minor and not detectable by the monitoring approach undertaken, might have the potential to contribute in combination with other factors to longer term effects. Such considerations are relevant in the context of conservation assessments (*e.g.* IUCN Red List criteria A and C; IUCN 2001). Gradual declines in occupancy and colony size might result from a greater frequency of roost switching from a range of factors at multiple local roosts, forced relocation to suboptimal roosts, and interruption of breeding activity. There is some evidence to suggest that *R. aurantia* has moved in the eastern Pilbara more than once in response to a range of disturbances (Armstrong 2001). It is obvious that both past and present (*i.e.* this study) levels of disturbance have not affected usage of the Klondyke Queen mine by *M. gigas*, but numbers of *R. aurantia* do appear much lower than the estimated 350 recorded in 1981 by Churchill *et al.* (1988) (from a capture of 72 individuals). Relatively few individuals have been observed since, though accurate numbers could not be obtained (Armstrong 2001). This is correlated with a range of past activities, including drilling by CRA Exploration Pty Ltd in 1994–1995; the capture of individuals as part of scientific surveys on several occasions; and blasting associated with construction of the Mullan adit (below the old Klondyke Queen workings) sometime in the 1980's. There is also evidence that disturbances in other workings in the district has caused *R. aurantia* to relocate. After a large colony of *R. aurantia* was observed in the Comet mine in 1991 (J.N. Dunlop pers. comm. to N.L. McKenzie; Armstrong 2001), an exodus may have occurred for unknown reasons, and again in 1997 when a pump broke and the lower levels of the mine filled with water. A large proportion of the eastern Pilbara subpopulation now appears to have moved to the Bamboo Creek mine. They were not known from this structure prior to 1996 when it was still operational, however there is no survey data prior to this time. Unfortunately there is only a small amount of data on colony size and mine occupancy in the district (Hall *et al.* 1997; Armstrong 2001), and no information on whether past disturbances have decreased survivorship each time the colony was forced to move.

Conclusions

The present study observed no significant effect of the drilling programme. Furthermore, the drilling programme introduced a level of disturbance that was smaller than that from other activities that have occurred in the past in the Klondyke Queen and nearby eastern Pilbara mines. The present study is detailed so that similar programmes can be designed if drilling or similar activities are considered to have a potentially detrimental effect on colonies of these species. Since this study was undertaken, there is now a greater range of electronic equipment that can be used to monitor bat presence and colony size remotely, including those based on acoustic, video and thermal image recordings. The potential to implement comprehensive and well designed studies using non-invasive approaches (or those that limit disturbance) is much greater, and should be within the capacity of environmental consultants.

If any future drilling (full day, with a booster present) at the Klondyke Queen were to take place further than 25 m from the roost entrance, equivalent to 85 m from the roosting location within the mine, and old workings are not intersected, no significant effect would be anticipated. However, the use of a bulldozer in close proximity of a mine entrance and roost location would need to be considered carefully. These figures might be relevant at other mines, but local conditions would need to be considered.

It is clear that the combined effect of various disturbances will not be known unless there is an organised way of tracking mining related activities and bat occupancy. The creation of a regional plan that can provide guidelines for making assessments of potential disturbance and provide a strategy and recording system for monitoring of contemporaneous impacts would be a first step. Also, when similar issues arise at the Klondyke Queen mine or others in the eastern Pilbara, it might be more intelligent to direct limited resources to actions other than simple monitoring, given the information resulting from the experience of the present study. In the case of the Klondyke Queen mine, it has been known since 1995 when CRA Exploration undertook evaluation drilling, that there were significant reserves of economically viable ore deposit beneath the historical workings. If there was sufficient lead time before the commencement of mining, a more satisfactory result could be achieved for both the miner and the bats, if the proponent, consultant or land manager were able to use the available information to develop a more long term solution. A carefully designed exclusion programme coupled with the preservation, augmentation and / or repair of nearby alternative sites might have a better long term outcome. This is an excellent example of a more broad-scale view that could be gained from a regional plan for management of *M. gigas* and *R. aurantia*.

Acknowledgements: Thank you to Lynas Corporation Ltd, the geologists of Cardinal Minerals Ltd, and the drilling company, Drillex Pty Ltd, who gave friendly cooperation throughout as well as permission to present this information; to Piers Higgs and Roy Teale of Biota Environmental Sciences Pty Ltd who assisted with the management plan and fieldwork.

References

ABS 2000 Bats in Mines – a draft report from the ABS sub-committee. The Australasian Bat Society Newsletter 15: 17–20.

Altenbach J S & Sherwin R E 2002 Importance of protecting mines. *In*: Proceedings of bat gate design: A technical interactive forum (eds K Vories & D Throgmorton). Office of Surface Mining, US Department of the Interior, Alton, Illinois and Coal Research Center, Southern Illinois University, Carbondale, Illinois.

Armstrong K N 2000 Roost microclimates of the bat *Rhinonicteris aurantius* in a limestone cave in Geikie Gorge, Western Australia. Australian Mammalogy 22: 69–70.

Armstrong K N 2001 The distribution and roost habitat of the orange leaf-nosed bat *Rhinonicteris aurantius*, in the Pilbara region of Western Australia. Wildlife Research 28: 95–104.

Armstrong K N & Coles R B 2007 Echolocation call frequency differences between geographic isolates of *Rhinonicteris aurantia* (Chiroptera: Hipposideridae): implications of nasal chamber size. Journal of Mammalogy 88: 94–104.

Armstrong K N & Anstee S D 2000 The ghost bat in the Pilbara: 100 years on. Australian Mammalogy 22: 93–101.

Baudinette R V, Churchill S K, Christian K A, Nelson J E & Hudson P J 2000 Energy, water balance and the roost microenvironment in three Australian cave-dwelling bats (Microchiroptera). Journal of Comparative Physiology B 170: 439–446.

Churchill S K 1991 Distribution, abundance and roost selection of the Orange Horseshoe–bat, *Rhinonycteris aurantius*, a tropical cave dweller. Wildlife Research 18: 343–353.

Churchill S K 2008 Australian Bats 2nd edition. Allen & Unwin, Crows Nest, NSW.

Churchill S K, Helman P M & Hall L S 1988 Distribution, populations and status of the Orange Horseshoe Bat, *Rhinonicteris aurantius* (Chiroptera: Hipposideridae). Australian Mammalogy 11: 27–33.

DEWHA 2010a *Rhinonicteris aurantia* (Pilbara form) in Species Profile and Threats Database, Department of the Environment, Water, Heritage and the Arts, Canberra. URL: http://www.environment.gov.au/sprat Accessed: 1 September 2010.

DEWHA 2010b Survey Guidelines for Australia's Threatened Bats. Department of the Environment, Water, Heritage and the Arts, Canberra.

Ducummon S L 2001 Ecological and economic importance of bats. In: Bat Conservation and Mining: A technical interactive forum. (eds K Vories & D Throgmorton). Office of Surface Mining, US Department of the Interior, Alton, Illinois and Coal Research Center, Southern Illinois University, Carbondale, Illinois, 7–16.

Duncan A, Baker G B & Montgomery N (eds) 1999 The Action Plan for Australian Bats. Environment Australia, Canberra.

Gilpin M E & Soulé M E 1986 Minimum viable populations: processes of species extinction. *In*: Conservation biology: the science of scarcity and diversity (ed M E Soulé). Sinauer Associates, Sunderland, Massachusetts, 19–34.

GSWA 2001 1:2 500 000 Atlas of Mineral Deposits and Petroleum Fields 2001. Geological Survey of Western Australia, Perth.

Hall L, Richards G, McKenzie N & Dunlop N 1997 The importance of abandoned mines as habitat for bats. *In*: Conservation outside nature reserves (eds P Hales & D Lamb). Centre for Conservation Biology, The University of Queensland, Brisbane, 326–333.

Hutson A M, Mickleburgh S P & Racey P A (comp.) 2001 Microchiropteran Bats: Global Status Survey and Conservation Action Plan. IUCN/SSC Chiroptera Specialist Group. IUCN, Gland, Switzerland, Cambridge, UK.

IUCN 2001 IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge,UK, 30 pp.

Johnson S A, Brack Jr, V & Rolley R E 1991 Overwinter weight loss of Indiana bats (*Myotis sodalis*) from hibernacula subject to human visitation. American Midland Naturalist 139: 255–261.

Kulzer E, Nelson J E, McKean J L & Möhres F P 1970 Untersuchungen über die Temperaturregulation australischer Fledermäuse (Microchiroptera). Zeitschrift fuer Vergleichende Physiologie 69: 426–438.

Kunz T H & Lumsden L F 2003 Ecology of cavity and foliage roosting bats. *In*: Bat Ecology. (eds T H Kunz & M B Fenton). University of Chicago Press, Chicago, 3–89.

Lackie M J 2000 Effect of trail users at a maternity roost of Rafinesque's big-eared bats. Journal of Cave and Karst Studies 62: 163–168.

Leitner P & Nelson J E 1967 Body temperature, oxygen consumption and heart rate in the Australian False Vampire Bat, *Macroderma gigas*. Comparative Biochemistry and Physiology 21:65–74.

Mann S L, Steidl R J & Dalton V M 2002 Effects of cave tours on breeding *Myotis velifer*. Journal of Wildlife Management 66: 618–624.

McKenzie N L & Bullen R D 2009 The echolocation calls, habitat relationships, foraging niches and communities of Pilbara microbats. Records of the Western Australian Museum Supplement 78: 123–155.

McKenzie N, Armstrong K & Kendrick P 1999 Pilbara leaf-nosed bat. *In*: The Action Plan for Australian Bats (eds A Duncan, G B Baker & N Montgomery). Environment Australia, Canberra, 36–38.

Mickleburgh S P, Hutson A M & Racey P A 2002 A review of the global conservation status of bats. Oryx 36: 18–34.

NSW National Parks and Wildlife Service 2001 Strategy for the conservation of bats in derelict mines. New South Wales National Parks and Wildlife Service and New South Wales Department of Mineral Resources, Hurstville NSW, 18 pp.

Pugh M & Altringham J D 2005 The effect of gates on cave entry by swarming bats. Acta Chiropterologica 7 :293–299.

QPWS 1999 State strategy for the protection of cave bat roosting and maternity sites. Queensland Parks & Wildlife Service, Brisbane.

Richter A R, Humphrey S R, Cope J B & Brack Jr, V 1993 Modified cave entrances: thermal effect on body mass and resulting decline of endangered Indiana bats (*Myotis sodalis*). Conservation Biology 7: 407–415.

Slade C P & Law B S 2008 An experimental test of gating derelict mines to conserve bat roost habitat in southeastern Australia. Acta Chiropterologica 10:367–376.

Speakman J R, Webb P I & Racy P R 1991 Effects of disturbance on the energy expenditure of hibernating bats. Journal of Applied Ecology 28: 1087–1104.

Thomas D W 1995 Hibernating bats are sensitive to nontactile human disturbance. Journal of Mammalogy 76:940–946.

Thomson B 2002 Australian handbook for the conservation of bats in mines and artificial cave-bat habitats. Australian Centre for Mining Environmental Research, Ameef Paper No. 15, Melbourne.

Tuttle M D & Taylor D A R 1998 Bats and Mines. Bat Conservation International Resources Publication No. 3, Austin, Texas.