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Bats and Mines: Evaluating Townsend's Big-Eared Bat Maternity Colony Response to Reclamation

Gabrielle F. Diamond
Utah State University

BATS AND MINES: EVALUATING TOWNSEND'S BIG-EARED BAT MATERNITY COLONY RESPONSE TO RECLAMATION

by

Gabrielle F. Diamond

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ABSTRACT

Bats and Mines: Evaluating Townsend's Big-eared Bat

Maternity Colony Response to Reclamation

by

Gabrielle F. Diamond, Master of Science

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Major Professor: Dr. Michael L. Wolfe
Department: Wildland Resources

With the loss or modification of natural roosting habitat afforded by caves, abandoned mines have assumed increased importance as surrogate roosting sites for Townsend's big-eared bats (*Corynorhinus townsendii*) and other chiropteran species. However, increasing concerns for human safety have led to accelerated programs for mine closure. In efforts to protect roosting sites in mines showing significant bat activity, "bat compatible" gates are installed, thus allowing continued access to mine workings. Aside from ensuring public safety, these structures afford protection from disturbance to roosting bats. To date few posting-gating studies have been conducted to obtain information on the effects of these structures on bat behavior and roost suitability. I evaluated the effects of gating on bat flight patterns at maternity colonies in two previously gated (reference) and two ungated mines, the latter (treatment) being gated with roundbar Manganal steel gates in the second year of the study. I also monitored four gated and three treatment mines to determine the potential effects of reclamation on internal microclimate. Overall circling activity increased ≥ 6-fold at the portals of treatment mines following gating. Indices of crowding and frequency of bat-gate collisions were significantly higher in previously gated and increased substantially in treatment mines following reclamation. Gates appeared especially hazardous to subadults during initial-volancy periods. Increased activity of bats and collisions with gates at mine portals may amplify vulnerability to potential predators. Changes in internal mine microclimates, specifically increased ranges between minima and maxima in temperature and vapor pressure deficits following reclamation varied among treatment mines as a function of the number of mine openings. Generally, gated mines with multiple openings experienced greater changes in these parameters than those with single openings. Additional studies of bat-compatible gates are needed to elucidate possible long-term effects of these structures on Townsend's big-eared bats.

(69 pages)

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Gabrielle F. Diamond

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CHAPTER I

INTRODUCTION

Loss and modification of historical roosting habitat is a major factor contributing to the putative declines in many bat populations (Tuttle and Taylor 1994, Adams 2003). In response to increased disturbance of historical cave roosting sites, bats are progressively more dependent on abandoned mines as alternative roosts (Pierson 1989, Brown and Berry 1991, Pierson and Brown 1992, Brown et al. 1993, Sherwin et al. 2000). Abandoned mines serve similar functions as caves by providing suitable and stable roosting microclimates necessary for the survival of many bat species (Tuttle and Taylor 1994, Altenbach and Sherwin 1997). More than half of bat species found in the United States (U.S.) regularly use abandoned mines as roosts (Tuttle and Taylor 1994, Bogan 2000, Adams 2003). Of 18 bat species known to occur in Utah, 14 species regularly occur in abandoned mines including 8 former Category II (increased sensitivity and heightened protection status) species that utilize abandoned mines at some point in the year (Hall 1981, Zeveloff 1988, Adams 2003). Townsend's big-eared bat (*Corynorhinus townsendii*), a Utah state sensitive and former Category II species, is found to roost almost exclusively in abandoned mines (Brown and Berry 1997, Oliver 2000).

Abandoned mines provide a variety of roost types for many bat species (Keeley and Tuttle 1999). These primary roost types include: day roosts that are places of rest used during the day, night roosts that are used for digestion, socialization, and resting between nightly foraging bouts, maternity roosts used for rearing of young, and hibernation roosts used as torpor sites during winter months (Tuttle and Taylor 1994).

Specific roost requirements, particularly internal roost microclimate, are necessary for bat recruitment and each species has a specific range of appropriate roosting temperatures that is advantageous to different life phases and thus survival (Kunz 1982).

There are more than 19,000 abandoned mines in Utah (M. Mesch, Utah Abandoned Mine Reclamation, personal communication). Up to 70% of underground abandoned mines exhibit some sign of bat use (Tuttle and Taylor 1994). Increasing concerns over human safety around historical mine excavations has resulted in a need for closure of abandoned mines to protect public safety. Accordingly, the Utah Abandoned Mine Reclamation Program (UAMRP) has begun closing these abandoned mines to address these concerns (Adams 2003). In concordance with these closure actions, the National Environmental Policy Act (NEPA) requires that all management activities be evaluated for their effects on wildlife. Consequently, abandoned mines are surveyed for any signs of wildlife use before reclamation.

Mine engineers and biologists conduct internal biological surveys of abandoned mines in Utah in an attempt to protect bat roosting habitat in compliance with NEPA. Internal surveys are performed during the warm and cold seasons to achieve a more accurate picture of bat use within the mine throughout the year (Altenbach and Sherwin 1997). Mines exhibiting little or no bat sign are excluded and completely sealed to future bat use. A "bat compatible" gate is installed on mines that show significant bat use and/or are utilized by sensitive or endangered bat species (White and Seginak 1987, Tuttle and Taylor 1994, Adams 2003). These gates are designed to allow continued access for roosting bats to mine workings while excluding the public (White and Seginak 1987, Tuttle and Taylor 1994, Adams 2003). Bat compatible gates come in varying designs and are created for specific mine openings (White and Seginak 1987, Tuttle and Taylor 1994). The gate style utilized in Utah is constructed of round Manganal® steel bars with horizontal bars spaced 10 cm apart on the bottom two-thirds and 14 cm at the top third of the gate (Amodt and Mesch 2002). The average gate cost is approximately $3,000, with prices dependent on size and complexity of the mine opening (Amodt and Mesch 2002). Because these gates are expensive and are in widespread use throughout Utah, and the U.S., it is vital to monitor these projects to quantify the effects of mine gating on bat colonies utilizing the abandoned mines. It is essential that reclamation effects on roosting bat populations be quantified, because management activities are eliminating significant portions of future roosting habitat by reclaiming mines that currently show little or no bat activity. Typically, gates are installed on only 15-25% of the mines in a given project area depending on bat use detected (M. Mesch pers. comm.).

Few studies have addressed the effects of abandoned mine reclamation on resident bats, principally bat compatible gate installation and microclimate changes after reclamation (White and Seginak 1987, Ludlow and Gore 2000, Spanjer and Fenton 2005, Martin et al. 2006). Putative effects of reclamation of abandoned mines on bat ecology include: (1) increased energy expenditures; (2) potentially higher predation rates, and (3) modification of microclimatic variables within mine workings. No systematic studies have been conducted that address possible reclamation effects on microclimate within bat roosting areas. Southern Utah University, Utah Division of Oil, Gas and Mining, Utah Division of Wildlife Resources, and the Bureau of Land Management are collaborators in an 8-year research project that focuses on bat-compatible gates in the Silver Reef mining district of southwestern Utah and in the Tushar Mountain mining district in Beaver

County, Utah (K. W. Grandison, Southern Utah University, unpublished report). In an attempt to address possible gate effects on resident bat maternity colonies, this study is monitoring bat colony emergence behaviors from abandoned mines with and without bat compatible gates (Grandison). This study has shown that circling behaviors, defined as a repeated approach to the gate before moving through the gate, are significantly more frequent (> 6X) on a colony scale at gated mines compared to ungated mines (Grandison). The potential energetic costs to bats exhibiting these circling behaviors in the presence of bat compatible gates remain unclear both in terms of its individual and/or colony-level effects.

A more recent study by Spajner and Fenton (2005) monitored the response of several bat species in pre-hibernation swarming roosts to real and mock gates. This study also found elevated levels of circling and avoidance behaviors during emergence activity. However, increased circling they observed may be a response to "novel" gates because most were short-term installations. Furthermore, these roosts might not experience the impacts as greatly as maternity colonies with more discrete age classes.

Increased circling by Townsend's big-eared bats before emergence from behind the bat compatible gates has been observed by Grandison, R. E. Sherwin, and P. E. Brown (personal communication). However, several factors may account for this circling during emergence activity, thus confounding the interpretation of the precise causal mechanism. Some researchers have suggested that this species circle to "sample" ambient light and other environmental conditions before emerging from their roosts, and this increase in circling is sampling behavior rather than a response to gate presence (Twente 1955, Kunz and Martin 1982). Circling behavior observed before emergence may also be due to bats possibly feeding within the mine portal. The behavior may also be attributed to crowding pressure as bats emerge as groups through a constricted area (Twente 1955, Lacki et al. 1993, Speakman and Tallach 1998, Ludlow and Gore 2000). Thus the question remains, are the observed circling events due to species-specific behaviors, such as feeding, sampling or crowding within the mine portal or a response to gating?

Alteration of existing mine roosting habitat is another concern with abandoned mine reclamation. Studies that have quantified roosting microclimates (e.g., air temperatures and desiccation potential) in abandoned mines during pre- and post-reclamation conditions have not been conducted. Richter et al. (1993) indirectly evaluated hibernacula temperature responses to block wall removal, but only measured conditions following removal. In some reclamation cases, alterations to mine complexes are made to improve the effectiveness of reclamation techniques (M. Mesch, Utah Abandoned Mine Reclamation, personal communication). For example, in the cases of mines with multiple openings, one or more openings may be backfilled and/or modified to facilitate gate installation during the reclamation processes (M. Mesch, Utah Abandoned Mine Reclamation, personal communication). Not only may these mines be structurally modified, but the simple addition of bat compatible gates may be altering the airflow, turnover, and consequently the microclimatic conditions within the mine complex.

A more recent study by Martin et al. (2006) monitored mine ambient and substrate temperature and airflow response at three locations to gate installation of an unknown design. This study found slight alterations to winter temperatures while detecting no response to summer conditions. No changes to airflow were observed in either.

In sum, these uncertainties underscore the need for further clarification of observed circling behaviors and microclimate response to abandoned mine reclamation. The central questions include: (1) Do bat compatible mine gates lead to increases in circling behaviors as observed through bat entrance peak behaviors? (2) Does mine reclamation and bat compatible gate installation change roost microclimates within abandoned mines? I hypothesize that bats increase circling activity in response to gate presence and that internal roosting microclimates will change in response to major mine modifications as airflow is altered through reclamation.

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CHAPTER II

BEHAVIORAL RESPONSE TO RECLAMATION

Introduction

Increased flight time caused by greater circling behavior as bats negotiate a gate may be detrimental during certain life cycle stages, primarily during lactation, by straining an already stressed energy budget. Studies of other bat species show that energy demands are 2 – 2.5 times greater for lactating animals than for non-reproductive individuals (McLean and Speakman 1999). These investigators found an increase of 45% food consumption by little brown myotis (*Myotis lucifugus*) during reproductive stages. Increased food consumption requires greater foraging time. A study of brown long-eared bats (*Plecotis auritus*) (often grouped in the same genus as Townsend's big-eared bats) estimated that lactating females must catch one moth every 9 minutes, whereas non-reproductive females would be required to catch one moth every 11 minutes to obtain the necessary energy requirements (McLean and Speakman 1999). Assuming a 40% foraging success rate for that species, lactating females would need to attack a moth every 4 minutes (McLean and Speakman 1999). This increased need for energy intake during periods of gestation and lactation may be exacerbated by increased energy expenditure due to circling in response to a bat gate. Accordingly, whether gates are the root cause of increased circling behaviors and thus higher energy expenditure remains unclear. In addition, increased time spent circling in mine portals may also lead to increased exposure to terrestrial bat predators.

No systematic studies have evaluated potential predation rates in response to bat-compatible closures. Predation rates increase during subadult initial-volancy periods but definitive connections with gating are lacking (O'Shea and Vaughan 1977). It has been suggested that bats may alter roost exiting behavior as an anti-predation mechanism, but restricted gated openings may impede these behavioral responses (Swift 1980, Brigham and Fenton 1985, Speakman et al. 1995). Predators impact population growth and the behavior of bat colonies; therefore, any roost study must incorporate its possible effects on movement patterns.

In addressing these questions, I used Townsend's big-eared bats as a case study. I contend that clarification of the observed circling behaviors can be made through monitoring bats as they return to the roost near sunrise based on the following assumptions: (1) returning bats have completed their nightly foraging bouts during entrance-peak activity and thus will not feed within the portal area; (2) the animals are not under crowding pressure to move through a constricted area because bats will be moving into mine hallways; and (3) returning bats will have no need to sample environmental conditions because it is the end of the nightly activity period.

Methods

Overall design.-The study employed a before-after-control-intervention (BACI) type design, with 2 previously gated mines serving as controls and 2 mines gated during the study serving as treatment. I selected 4 study mines known to contain Townsend's big-eared bat maternity roosts. This sample represents 44% of all such colonies known to exist in Utah (Oliver 2000). Based on internal mine survey information, these 4 study roosts provide a representative sample size of Townsend's big-eared bat maternity roosts in the state. Two of the above mines were gated prior to my study, while 2 were gated during the study. This allowed for a gating effect comparison using the gated mines as a control. I collected behavioral data at each mine colony during both entrance and emergence peaks for 2 consecutive years through the maternity roosting period; which comprised pregnancy, lactation and subadult initial-volancy. This method allowed me to evaluate colony response to gates across life phases and time.

Study sites.- Study mines were located in the western portions of Utah (Figure 1). Mist netting and internal surveys confirmed that Townsend's big-eared bats use all of these mines as maternity roosts. The 2 gated mines are located in the Tushar Mountain mining district, 32 km west of Marysvale, Utah and the West Dip mining district 3 km south of Ophir, Utah. The "Marysvale mine" was reclaimed with a bat compatible gate in 2000 while the "West Dip Complex" was reclaimed in 1998 (Table 1). The Marysvale and West Dip Complex mines are located in the Colorado Plateau and Great Basin eco-regions respectively (MacMahon 1997). These mines remained gated during both field seasons to serve as controls. The 2 ungated mines were located in the Cherry Creek mining district, 64 km southwest of Vernon, Utah; also located in the Great Basin eco-region and were gated in summer 2004 (Table 1). The Cherry Creek ungated mines, "Cherry Creek HO Complex" and "Cherry Creek IO Complex" served as the treatment: ungated during the first field season and then gated during the second field season.

Bat compatible gates were installed on the two treatment mine complexes in the second field season. Cherry Creek HO Complex was gated beginning 5 August 2004. All three openings of this mine were gated: HO4 on 1 September, VO9 on 16 and 17 August, and VO10 on 5 August 2004. The Cherry Creek IO Complex had bat compatible gates placed on all three of its openings beginning on 21 July 2005: IO3 on 4 August, IO5 and VO6 on 21 July, 2004. The Marysvale mine and West Dip complex, respectively, gated in the fall of 2001 and 1998, remained gated throughout the study.

Data collection.- To address the question of possible behavioral effects of abandoned mine reclamation on Townsend's big-eared bat maternity colonies, I conducted observational surveys May-July 2003 and May, July-September 2004, a span that encompassed the primary maternity roosting period. To collect behavioral data on bat emergence and entrance, I utilized a Sony Nightshot® infrared video camera for 2 consecutive mornings and a single night each month, at each of the four study mines. Morning and evening surveys comprised 3 consecutive hours. Video analysis allowed accurate representation of bat behavior around bat gates in the absence of observers. I began recording 15 minutes pre-sunset for evening surveys and 2 hours pre-sunrise for morning. I placed video cameras at inconspicuous locations within 20 m of the mine portal for full view of the opening and a 1-m buffer zone on either side. Surrounding vegetation was used to conceal equipment where possible to minimize equipment disturbance (Figure 2). Additional infrared light sources were placed near the mine portal for further illumination. This provided shadow elimination and full infrared lighting of 10 m both within and outside of mine portal. Such lighting allowed for an unimpaired observation of all bat activity near the mine portal and thus a view of the entire survey area.

Morning survey periods allowed for observation of the peak entrance activity, when bats were returning from nightly foraging bouts. Observation of the portal during morning hours (entrance peaks) minimized the confounding influences of other factors that might inherently increase circling as described above. I conducted video surveys during the new moon phase of the lunar cycle to maintain similar ambient lighting conditions and thereby provide consistent environmental conditions at each site. Mine survey order was randomized per-month to eliminate possible bias. I collected night video surveys once a month between the two consecutive morning surveys at each of the four mine sites. These post-sunset survey periods allowed for observation of peak emergence activity. The emergence peak video camera sets were in the same location as used in entrance peak observations. I recorded and analyzed a total of 83 video hours (69 entrance and 14 emergence) for the first field season and 123 video hours, 24 of which included newly gated activity, for the second field season (87 entrance and 36 emergence). In total, I analyzed approximately 206 video hours of bat behavior around mine portals.

Analysis.- I cataloged behaviors at gated and ungated mines, classifying each observed behavior into one of three categories while the bat was within 1 m of the gate or mine opening. Any bat observed at distances greater than 1 m was assumed to be indifferent to mine presence and not of relevance to the study. The behavioral categories consisted of: Enter (In), Exit (Out), and Circling. I defined an Enter (In) behavior as a bat proceeding directly through the bat compatible gate and/or mine portal to go into the mine. An Exit (Out) behavior was when a bat proceeded directly through the bat compatible gate and/or mine portal to leave the mine. Circling behavior was defined as a bat approaching within 1 m, on either side of the bat compatible gate and/or mine portal, but not proceeding through the gate. The Circling behavior can occur on either side of the gate or portal and was noted for clarification.

To evaluate the possible effects of crowding pressure that may influence bat portal behavior, I recorded the maximum number of bats observed within 1 m of the mine opening simultaneously. Townsend's big-eared bats are known to minimize use of echolocation when several individuals are present (Twente 1955), presumably to avoid echolocation bounce. Evaluation of cluster formation is necessary because of its potential influence on gate negotiation and bat movement through the portal. I also noted the number of bat collisions with the gate. Awkward movement through the mine portal may provide evidence of reduced echolocation.

To evaluate potential gate effects on predation rates around the roost, I noted any sign or actual presence of possible predators within the mine portal. Potential predators were identified and the observation date and location were recorded for assessment.

Analysis of bat behaviors consisted of comparisons of relative bat activity, "Enter," "Exit," and "Circle" events, between mines with and without bat compatible gates during both field seasons. I also compared bat activity between emergence peak and entrance behavior to evaluate gate effects on the primary types of bat mine portal use. All three behavioral categories were totaled per survey period to obtain a broad picture of seasonal behavioral patterns. In addition, I compared "Circling" event totals with combined "Enter-and-Exit" event totals ("circling ratio") at gated and ungated mines to determine if bat behaviors are skewed towards any treatment. I then evaluated "Circling inside" to "Exits" and "Circling outside" to "Enters" to evaluate circling details for each discrete event to determine which measure best captures colony movement patterns. I conducted a detailed comparison of peak entrance behaviors at gated and ungated mine conditions over the entire season to evaluate possible differences between mines and seasonal life stages. Student's t-tests were used to compare these circling ratios in pre- and post-reclamation conditions as well as across life stages (gravid, lactating and initial-volancy). ANOVA tests were used to compare peaks in activity, reclamation conditions, age effects and individual mine influences on circling ratios. Statistical computations were conducted using SAS® software.

Evaluations of potential crowding pressure consisted of comparisons between mines under all conditions during both field seasons. Analysis consisted of t-tests of the time (minutes) that ≥ 2 and ≥ 3 bats were present within 1 m of the mine portal during both emergence and entrance peak activity. The percent of time that ≥ 2 and ≥ 3 bats were within or near the mine portal was evaluated with total activity ranging from observation of first bat and observation of the last bat during peak activity. The presence of two or more bats was used to evaluate grouping effects but this parameter may be biased by paired "coaxing" events observed within maternity colonies (O'Shea and Vaughan 1977). To reduce this possible bias, I also analyzed the presence of ≥ 3 bats within the portal to assess potential crowding pressure. This was compared across gated and ungated mines.

Results

Circling behavior.- The amount of "Circling" behavior observed differed significantly between gated and ungated mines ($P < 0.001$, Tables 2 and 3). Variations in the overall amount of bat activity were found between gated and ungated study mines, although all showed consistent use through the reproductive period. The Marysvale mine showed the greatest "Enter" and "Exit" activity (Table 2). West Dip Complex was second highest, followed by the Cherry Creek IO Complex and Cherry Creek HO Complex (Tables 2 and 3). Detailed analysis of "Circling" events showed that older gated mines showed significantly higher circling rates inside before exiting than outside per enter ($P < 0.001$, Table 4). This was not true for newly gated and ungated mine conditions ($P = 0.145$ and 0.243, Table 4). As a result, further evaluation of "Circling" to "Exit-and-Enter" event ratios provides a reliable evaluation of activity by minimizing variation observed between discrete circling events.

The "circling ratio" showed a distinct difference in bat activity types for gated versus ungated study mines both within treatment mines and between years. Differences were detected between emergence and entrance peak bat activity although not consistently for all mines (Table 5). Gated mines showed differences in the circling ratio between peaks of emergence and entrance activity, whereas ungated mines exhibited no such difference (Table 5). Gated mines showed greater "Circling" events during emergence peaks when compared to entrance activity (Figure 3). Considering these differences, further circling analyses included only entrance bat behavior to reduce effects that may mask gate impacts, i.e. feeding, crowding or sampling.

Bats were observed circling much more frequently in gated mines than in ungated mines (Figure 3, Table 2). In fact, circling behaviors in newly gated treatment mines exceeded the levels observed in older gated reference mines post-reclamation. The circling ratio ranged below 1:1 in ungated mines but frequently exceeded 6:1 in gated mines. The persistence of these ratios throughout the summer showed that increases in circling were not associated with life stage. Circling did increase during sub-adult initial-volancy but not significantly ($P = 0.069$). Ungated treatment mines showed greater variability in the ratio of circling while gated mines remained relatively constant. Variation was also observed at the individual level with a minimum of 0 and a maximum of 27 Circles per single Enter or Exit.

Comparisons of circling ratios between ungated treatment mines, Cherry Creek HO and Cherry Creek IO Complexes, yielded noticeable differences. Circling behaviors increased after reclamation, at least initially, although not uniformly ($P = 0.001$, Table 5). The circling ratio in Cherry Creek HO fluctuated around 4:1 following gate installation, whereas Cherry Creek IO exceeded 25:1. These mines, when ungated, showed no statistical difference in circling activity ($P = 0.393$, Table 6) with ratios of 0.3:1 and 0.5:1. Gated reference mines Marysvale and West Dip Complex also showed no difference in circling behaviors throughout the study exhibiting ratios of 7:1 and 6:1 respectively ($P = 0.250$).

Crowding and collisions.- Crowding pressures were detected directly and indirectly within these mines. The maximum number of bats observed within the portal at the same time increased dramatically after reclamation (Table 7). Circling increased most during emergence peak bat activity, suggesting differential gate effects on mine portal use ($P = 0.023$). In gated reference mines, ≥ 2 bats occurred more frequently (30-42%) than ≥ 3 bats (10-44%) over the total activity period. Newly gated treatment mines showed similar trends with ≥ 2 bats observed most frequently. Cherry Creek HO Complex when ungated, exhibited ≥ 2 bats 8% of the time but a 0% frequency of ≥ 3 bats. After reclamation, it increased considerably ≥ 2 bats 20% of the time and 2% of the time with ≥ 3 bats in the portal. Cherry Creek IO Complex while ungated, had 3-7% jumping to 22-32% after gate installation.

Actual bat-gate collisions were observed during the latter parts of the reproductive season during subadult initial-volancy periods. The frequency of gate contact varied between mines and survey period (Table 8). I observed gate collisions in all gated reference mines including newly gated treatment mines. The number of collisions was highest in the Marysvale mine with 50 total impacts observed; Cherry Creek IO Complex had 17 total hits, whereas the remaining mines experienced < 5 each (Table 8). The percentage of actual "collisions" per total nightly "Enter-and-Exit" event was significantly higher in Cherry Creek IO Complex after reclamation (7%) (Figure 4). Marysvale, although highest in actual number of impacts, was second with percentage of collisions comprising 3% of its activity, and Cherry Creek HO Complex experienced gate contact making up 2% of its activity (Figure 4). The majority of observed impacts occurred during entrance peak activity (Figure 4). Gate collisions occasionally resulted in bats falling to the ground, 11% of the time (Table 8).

Evidence of increased predation potential due to gating was observed. Single Great Basin Western Rattlesnakes (*Crotalus lutosus*) were observed on 3 separate occasions during the 2003 survey period. All were observed at the base of bat compatible gates later in bat reproductive periods (June 12, July 22 and July 23). This accounts for detection on 10% of all survey dates; however, no direct evidence of snake predation was recorded. No potential predators were observed during the second field season.

Discussion

Townsend's big-eared bats responded immediately to reclamation. The maternity colony inside Cherry Creek IO Complex relocated to a small ungated mine 30 m away during gate installation. This alternative mine appeared to be unsuitable for maternity colony occupation due to its small size and hence limited protection and unstable microclimate. The colony stayed in this surrogate mine for 3 days before returning to the original maternity roost. The primary cause of roost abandonment may be a response to gates themselves or to increased disturbance with construction.

Townsend's big-eared bat maternity colonies appear to show behavioral responses to abandoned mine reclamation as indicated by increases in circling activity around the mine portals. Circling behaviors intensified with the installation of bat compatible gate closures, while existing gated mines showed no difference in the amount of time spent circling during the same period. In fact, circling increased at least 6-fold after mine reclamation. Variations in the amount of circling were apparent at both the individual and colony level. Some individual bats exhibited no circling behavior while others circled 27 times before moving through the portal. The Cherry Creek HO Complex maternity colony showed 0.4 "Circles" per "Enter-and-Exit" events before reclamation quickly reaching 2 circles per combined event following gate installation. The Cherry Creek IO Complex colony exhibited 0.2 "Circles," and 13 "Circles" per "Enter-and-Exit" before and after reclamation, respectively.

Evidence of crowding pressure was also apparent within these maternity colonies. Comparisons of peak emergence and entrance activity yielded significant differences with higher amounts of circling during colony emergence. This suggests that crowding may influence emergence behaviors more strongly than entrance activity. Bats are forced through restricted spaces of underground workings when attempting to exit nightly. These same conditions are not present during entrance activity as bats are moving into the confines of the mine tunnel. Bullock et al. (1987) proposed that emerging colonies experience "bottleneck effects" leading to clustering as individuals move through confined roost openings. Others have suggested that bats naturally cluster during emergence to transfer information between colony members (Twente 1955, Wilkinson 1992, Clark et al. 2002) or as a means of predator avoidance (Speakman et al. 1995). In the case of reclamation, it is likely that gates are imposing bottleneck conditions independent of portal size, because bats must negotiate the bars. Increases in collisions with gates also suggested crowding pressure, because negotiation appeared awkward especially for inexperienced subadults further impaired by the presence of several individuals within confined areas. This too may be a bottleneck response to bat-compatible closures.

Increases in circling appear to be a result of reclamation because no life stage indicated more dramatic changes in comparison to another. Circling increased during volancy periods but the change was not statistically significant. This contradicts Grandison's (unpubl.) findings that circling increased late in the season when subadults reached initial-volancy. This may reflect my analysis of entrance peak activity that indicated different conditions than emergence. Circling increases may be most apparent during emergence peak behaviors resulting from higher crowding pressures as several bats attempt to move through the confines of the mine tunnel.

The frequency of gate collisions increased during subadult initial-volancy periods, suggesting that lack of flight experience present a problem with gate navigation in this species. No collisions with mine workings, walls or ceilings, were observed in the absence of gates. This suggests that collisions are related to reclamation, because the treatment colonies did not exhibit such behavior when ungated. Whether the overall frequency of collisions decreases with experience is unknown. That the impacts occurred at all gated mines suggest this is not the case. Subadults are new each year and therefore must learn to navigate the gate for the first time. This could conceivably have an influence on hibernation survival given that flight time is altered. Subadults must begin to forage immediately to obtain the necessary fat reserves critical to over winter survival. This too could impact subadult survivorship, because they must devote more time learning to negotiate gates hence less time foraging.

The actual frequency of gate collisions varied between colonies. The Cherry Creek IO Complex clearly showed more collisions after reclamation. This suggests that colonies respond to gates differently. Consequently, reclamation may influence colonies in newly gated mines unpredictably. Colonies in older reclaimed mines also responded uniquely to gates. The Marysale mine also exhibited high numbers of collisions. It is not clear whether these collisions are strictly crowding-related or a result of inexperience with flight. The implications are far reaching as bats may be injured in collisions with these metal gates irrespective of the direct cause.

Collisions have been observed in other species during periods of subadult volancy. A study of a pallid bat (*Antrozous pallidus*) maternity roost recorded several occasions in which bats collided with the walls of the roost and falling to the ground

(O'Shea and Vaughan 1977). A recent study of pre-hibernation swarming roosts suggests collisions are not related strictly to maternity roosts and Townsend's big-eared bats. Spajner and Fenton (2005) studied 16 gated and 12 ungated sites used by at least 6 species, including Townsend's big-eared bats. They observed collisions only at real and mock gated roosts. In fact, these collisions comprised 2% of the total activity within swarming roosts. This is similar to my findings with collisions making up 2-7% of the portal activity depending on the mine.

The consequence of bat-gate collisions is likely to vary with bat age, body condition, and impact type. A bat colliding directly with a defined metal closure is more likely to sustain injuries when compared to glacing off a flatter rock wall. What is likely more important is whether the impact is direct or glancing. Bats may experience more direct impacts with defined gate bars while undergoing glancing blows with flattened rock surfaces. No injured bats were observed during the course of this study. Impacts with hard surfaces are dangerous to delicate bones of subadult bats and can cause detrimental injuries. This aspect requires more study for additional clarification in terms of its possible role in subadult mortality.

Increases in circling behaviors related to bat compatible gates may stress an already stretched energy budget that research shows reproductive individuals experience. Each circling event essentially requires twice the energy as an exit or entrance behavior. Bats must approach the portal multiple times to effectively exit or enter a gated mine. This need for multiple approaches to exit or enter increases overall flight time as bats take longer to move through the opening thus altering nightly foraging and resting bout regimes. Because bats must spend more flight time to exit or enter gated mines, the amount of foraging time available to obtain energy is reduced. A study of the Ozark big-eared bat (*C. townsendii ingens*) suggests that during periods of high energetic demand the output may be offset by heightened seasonal prey abundance (Clark et al. 2002). If this is the case, affected colonies may be able to forage more effectively, and thus increased energetic demands incurred through longer roost flight may become negligible.

Increases in colony flight time through circling in gated openings likely makes the roost more conspicuous to predators. As the colony is forced through a crowded opening congested with individuals it is inevitable that overall passage will slow. As a result, predators will be able to cue in on the congestion and may be able to take advantage. Potential predators, Great Basin Western Rattlesnakes, were only seen at gated mines during this study. These predators may not typically prey on bats but it is certainly possible to capture bats colliding with gates and falling to the ground. Predation by the rattlesnakes was not detected directly, although bats were observed dropping to the ground approximately 11% of the time. These potential predators were observed on few occasions, but gates were not installed on treatment mines until late in the reproductive season. This is contrary to Spanjer and Fenton's (2005) study of swarming roosts in which no predators were observed near study mines. This may be due to the presence of researchers stationed near the gates to record activity whereas my study incorporated remote observations through video images. Predation is seen to increase during subadult volancy periods in other species (O'Shea and Vaughan 1977) thus my observations may reflect this amplified pressure. However, potential predators may be able to key on changes in colony movement over a complete reproductive season that may be altered by reclamation. Furthermore, these predators may be simply cleaning up areas thus not changing background death rates. The impact of predators may be great on population growth as many bat species have low reproductive rates (Kunz 1982). Thus this aspect warrants further evaluation.

Townsend's big-eared bats may be altering other aspects of their behavior to compensate for longer flight periods imposed by gate navigation. Several possibilities exist: reduction of night roosting, increased foraging time, and/or use of daily torpor. Townsend's big-eared bats may have the ability to counteract reclamation effects behaviorally as demonstrated in studies of similar species. Whatever the case, affected bats are not immediately abandoning the reclaimed mine roost once the gates are installed. This suggests that this species is able to cope with the bat compatible gate, at least in the short-term.

Management Implications

While there may be some cost of reclamation to roosting maternity colonies, bat compatible gates may be beneficial to bats. It is clear that these bats are responding to gate presence with changes in movement activity. Townsend's big-eared bats are sensitive to human disturbance and, in some cases, will abandon roosts when disturbed (Pearson et al. 1952, Twente 1955). Maternity colonies and hibernation roosts are especially vulnerable to roost disturbance, which can have impacts throughout the entire population. Bat compatible closures undoubtedly reduce direct disturbance to these critical roost types by limiting human access. The exact cost of such disturbance is unclear but can lead to roost abandonment if occurring too frequently. While increases in circling, collisions and potential increases in predation pressures occur after reclamation, roost protection may out weigh these risks. Spanjer and Fenton (2005) suggest that higher energetic expenditures due to increases in flight time are the real cost to bats rather than collisions and predation. Further long-term research is needed to evaluate overall impacts on colony survivorship and reproduction to develop a clearer picture of reclamation influences.

The debate continues about the role of bat compatible gates as a management tool for the protection of sensitive bat species. Townsend's big-eared bat maternity colonies have been shown to respond to gates but current evidence suggests that populations are persisting. This management tool appears to be valuable in maintaining roosting habitat and maximizing human safety. Long-term monitoring of maternity colonies will aid in addressing questions about bat compatibility of gates and their effectiveness in management. Although increases in circling and collisions were observed, variations in response to gates by individuals suggest that that population will persist eventually because of selection for individuals that can cope with gate negotiation, assuming that these traits are heritable. Whether gates have the potential to increase or decrease predation rates remains debatable and requires further examination. These data do suggest that caution should be exercised when employing this management technique. Long-term evaluations of this tool must continue to further improve gate design and interpret its effects on other bat species. Population change may require several generations to become apparent since Townsend's big-eared bats, like many bat species, are long-lived and a slow reproducing species.

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Table 1. Descriptive characteristics of mines used in behavioral analysis.

Mine	Number of openings	Elevation (meters)	Portal height (meters)	Portal width (meters)	Mine depth (meters)	Mine Aspect	Reclamation date	Surrounding vegetation
Cherry Creek HO Complex	3	2300	0.6	1.2	15+	W	9/1/2004	*Artemisia* spp. and *Juniperus* spp mix
Cherry Creek IO Complex	3	2300	0.9	4.3	12+	W	7/21/2004	*Artemisia* spp. and *Juniperus* spp mix
Marysvale	1	2285	1.5	1.2	19.8	SE	Fall 2001	*Artemisia* spp. and *Juniperus* spp mix
West Dip Complex	2	1780	0.9	1.2	39.6+	S	Fall 1998	*Artemisia* spp. and *Juniperus* spp mix

Table 2. Video camera data on bat behavior at previously gated reference mines, Marysvale and West Dip.

		Event Type							
		Enter		**Exit**		**Circle**		**Circling Ratio**	
Mine	**Date**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Marysvale	May-03	119	6.4	38	17.0	1144	475.9	7.16	2.0
	June-03	51	5.7	26	11.3	320	118.8	4.22	1.9
	July-03	135	15.6	105	48.1	999	88.4	4.92	0.7
	May-04	114	7.8	57	17.7	1246	62.9	7.35	0.8
	July-04	101	9.9	37	7.1	918	93.3	6.66	0.1
	August-04	204	52.3	69	26.2	1647	319.6	6.13	0.6
	September-04	82	9.2	59	6.4	740	23.3	5.31	0.4
West Dip	May-03	66	19.1	48	5.7	431	158.4	3.73	0.6
	June-03	15	2.1	14	2.1	76	3.5	2.70	0.1
	July-03	105	5.0	39	4.2	651	164.8	4.51	0.9
	May-04	55	9.2	41	2.8	458	65.1	4.79	0.1
	July-04	68	6.4	66	21.9	816	135.1	6.38	2.4
	August-04	103	6.4	71	7.8	820	82.7	4.74	0.4
	September-04	88	5.0	38	7.1	680	31.1	5.42	0.2

Circling ratio is the total "Circling" events compared to combined "Enter-and-Exit" events observed at gated and ungated mines.

Table 3. Video camera data on bat behavior at ungated treatment mines, Cherry Creek HO Complex and Cherry Creek IO Complex.

		Event Type							
		Enter		Exit		Circle		Circling Ratio	
Mine	**Date**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Cherry Creek HO Complex	May-03	21	2.1	19	5.7	9	8.5	0.24	0.2
	June-03	24	1.4	24	2.1	14	5.7	0.30	0.1
	July-03	74	21.2	64	25.5	75	55.9	0.50	0.2
	May-04	13	0.0	11	0.0	0	0.0	0.00	0.0
	July-04	13	9.2	12	8.5	8	0.7	0.43	0.3
Gated 8/5-9/1/04	September-04	27	9.9	25	14.1	238	120.2	3.76	1.5
Cherry Creek IO Complex	May-03	10	0.0	11	0.0	8	0.0	0.00	0.0
	June-03	24	7.8	19	5.7	21	5.0	0.49	0.1
	July-03	46	2.1	47	0.7	55	30.4	0.59	0.3
	May-04	9	0.0	4	0.7	0	0.0	0.00	0.0
	July-04	48	0.7	46	5.7	47	0.0	0.50	0.0
Gated 7/21-8/4/04	August-04	11	0.0	11	0.7	858	31.1	45.61	13.3

Table 4. Results of two-tailed t-test comparison of ratios of "Circling inside" to "Exit" and "Circling outside" to "Enter" behaviors of Townsend's big-eared bats at gate, newly gated and ungated mines serving as maternity roosts, 2003 and 2004.

Mine Condition	***t* value**	***p* value**
Gated	0.59	*<0.001
Newly Gated	0.98	0.145
Ungated	0.62	0.243

Table 5. Results of ANOVA of ratios of "Circling" to "Exit-and-Enter" behaviors of Townsend's big-eared bats at gated and ungated mines serving as maternity roosts, 2003 and 2004.

Test	**F value**	***p* value**
Emergence vs. Entrance peaks	7.03	0.023
Gated vs. Ungated mines	145.29	*<0.0001
Seasonal effects (gravid, lactation, volancy)	2.75	*0.069
Volancy effects (gated mines only)	1.70	0.192
Volancy effects (ungated mines only)	1.65	0.213
Circling to Exit-and-Enter (all gated and ungated mines)	11.05	*<0.0001
Circling to Exit-and-Enter (gated IO removed)	5.22	*0.01
Circling to Exit-and-Enter (gated IO and HO removed)	1.37	0.250
Circling to Exit-and-Enter (ungated only)	0.76	0.393
Circling to Exit-and-Enter (newly gated mines)	3.70	*0.063
Circling to Exit-and-Enter (treatment mines)	31.01	*0.001

* $P = \leq 0.001$

Table 6. Results of two tailed t-test comparison of ratios of "Circling" to "Enter-and-Exit" behaviors of Townsend's big-eared bats at gated and ungated mines serving as maternity roosts, 2003 and 2004.

Mine	***t* value**	***p* value**
All Gated and Ungated mines	0.98	*0.023
Marysvale	0.99	*0.005
West Dip	0.99	*0.001
Cherry Creek HO Complex	0.68	0.423
Cherry Creek IO Complex	0.80	0.259

* $P = \leq 0.001$

Table 7. Percentage of time, first bat to last bat, that ≥ 2 and ≥ 3 bats were present at the mine portal as determined by IR video camera sequences.
* $P = \leq 0.001$

"Crowding" category (Number of bats)	**Year**	**Mine**					
		Marysvale	**West Dip Complex**	**Cherry Creek HO Complex**		**Cherry Creek IO Complex**	
≥2	2003	43	38	Ungated	8	Ungated	7
	2004	30	31	Gated	20*	Gated	32*
≥3	2003	44	14	Ungated	0	Ungated	3
	2004	13	10	Gated	2*	Gated	22*

Table 8. Number of bat collisions observed during peak activity (emergence, entrance) at mines serving as maternity roosts. Ground refers to the number of times collisions result in falling or landing on the ground at base of gate.

Year	**Mine**					
	Marysvale	**West Dip Complex**	**Cherry Creek HO Complex**		**Cherry Creek IO Complex**	
2003	20,10	0,4	Ungated	0,0	Ungated	0,0
2004	10,10	0,0	Gated	0,2	Gated	6,9
Ground	4	0	2		2	

Figure 1. Map of study mines used in behavioral and microclimate analyses.

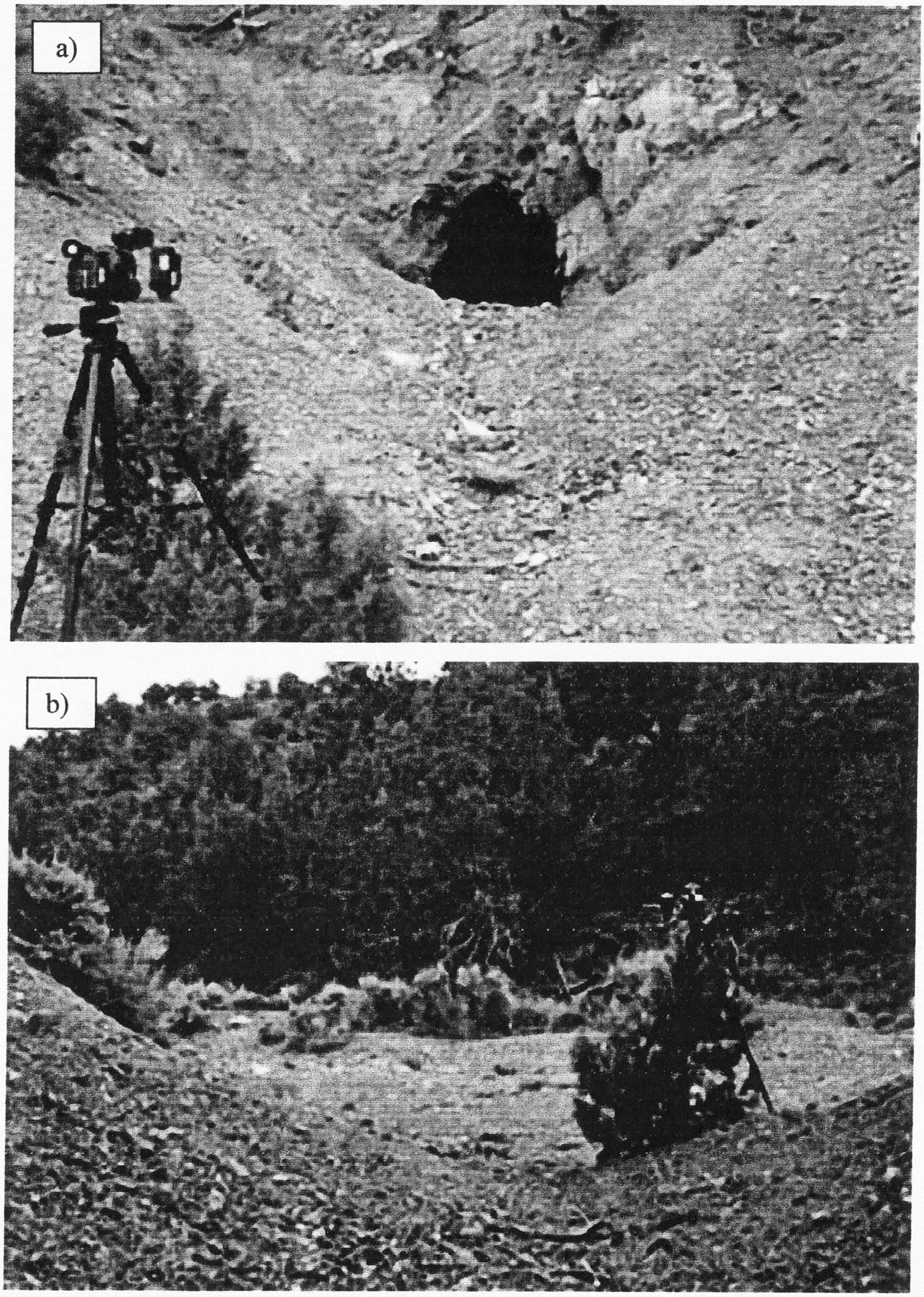

Figure 2. Images of typical video camera set used in behavioral analysis. View from video to mine portal (a) and from portal to video set (b).

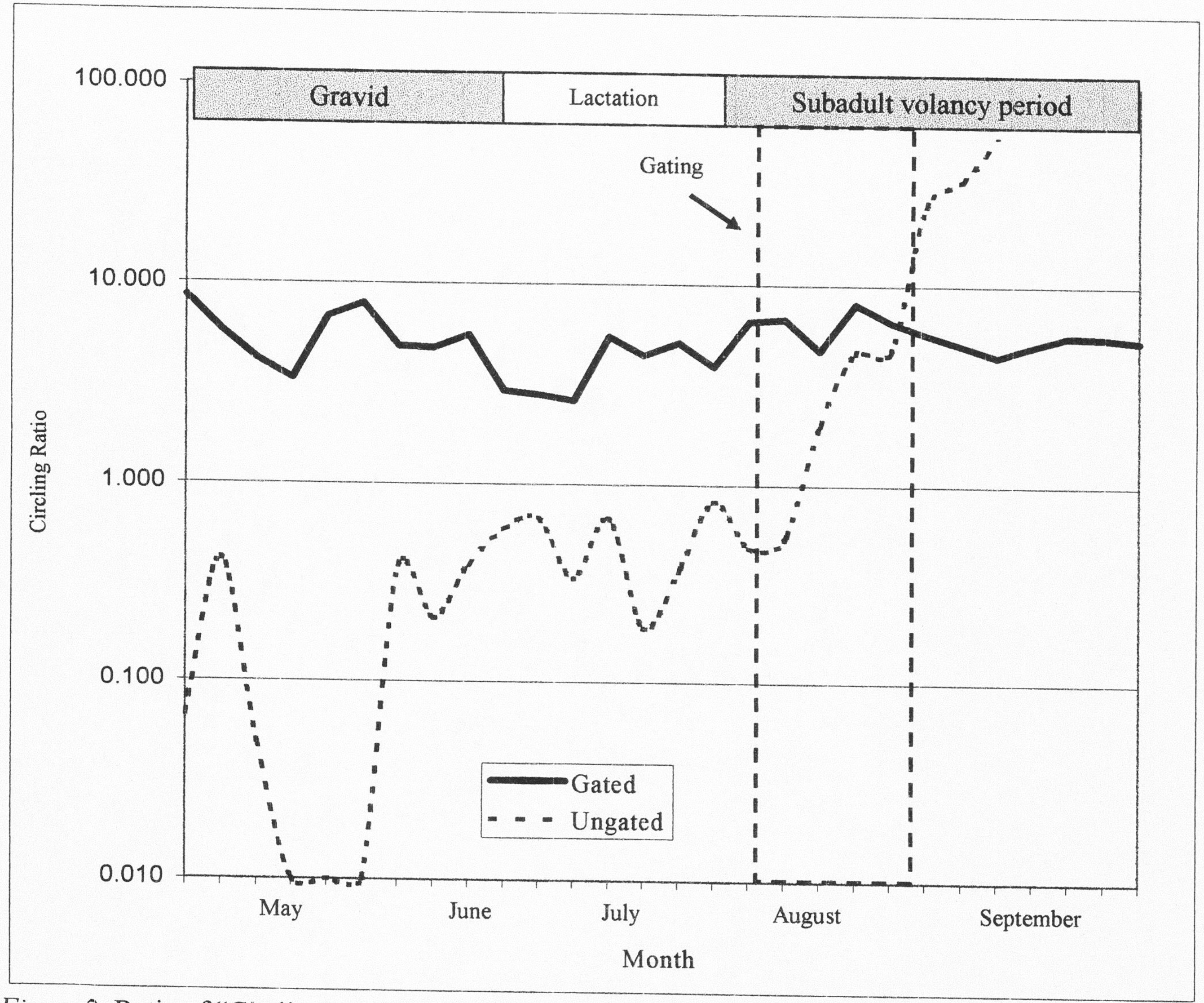

Figure 3. Ratio of "Circling" to "Enter-and-Exit" behaviors of Townsend's big-eared bats in mines serving as maternity roosts, 2003 and 2004. Gates were installed on ungated treatment mines starting 21 July and ending 1 September 2004.

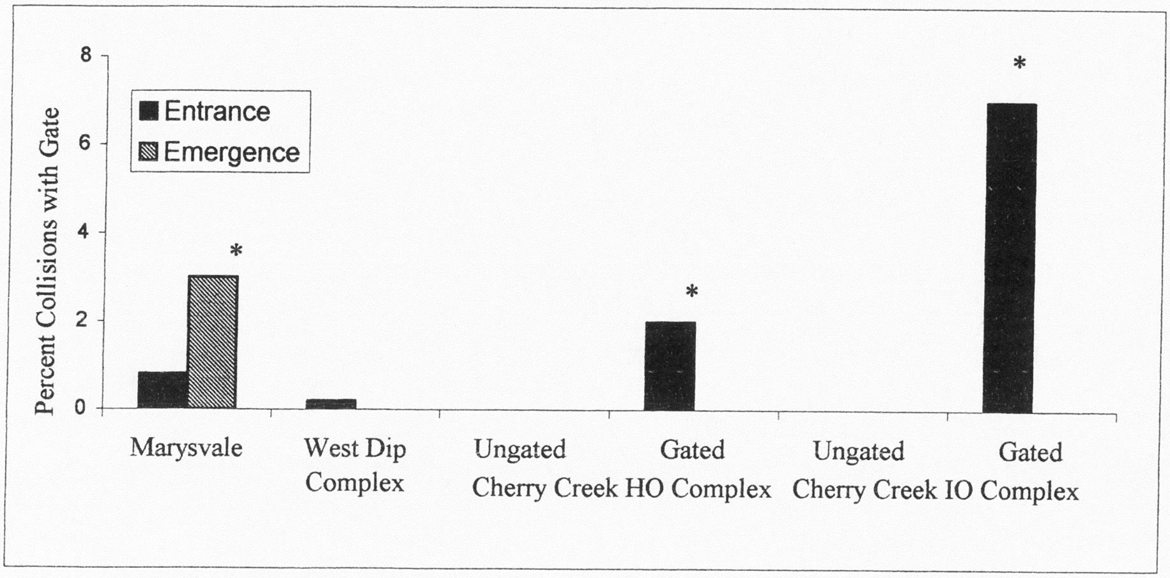

Figure 4. Percent (fraction of total exit and enter events) bat gate collisions during entrance and emergence peak activity as determined by IR video camera sequences. All observed collisions occurred in July during subadult initial-volancy periods. * $P \leq 0.001$.

CHAPTER III

MICROCLIMATE RESPONSE TO RECLAMATION

Introduction

Bats require specific microclimate requirements for different life phases (Kunz 1982, Adams 2003), making this an important variable in assessing post-reclamation roost suitability. Changes in roost temperature patterns may stress an already narrow reproductive energy budget by altering a bat's metabolic rate (Richter et al. 1993) and compromising thermo-regulatory responses. A study of the endangered Indiana bats (*Myotis sodalis*) by Richter et al. (1993) demonstrated changes in hibernating bat numbers following cave entrance modifications, which were ascribed to microclimate alterations. Changes in roost microclimates differentially affect a maternity colony's narrow temperature tolerances and may impact development of young (Twente 1955, Kunz 1982, Humphrey and Kunz 1976). Lower temperatures during the reproductive stages and warmer temperatures during hibernation will increase metabolic demands and can dramatically impact a bat's energy budgets (Tuttle and Stevenson 1982). Combinations of temperature and vapor pressure deficit within the roost will affect transpiration rates because drier air will draw moisture from objects with greater moisture content, in this case a roosting bat.

Roost microclimate modifications, in combination with increases in flight times to negotiate gates, could lead to long-term changes in bat populations using abandoned mines. The long life span and low reproductive rate of Townsend's big-eared bats makes detailed monitoring of reclamation effects on roosting colonies critical (Kunz and Martin 1982).

Recently Martin et al. (2006) attempted to evaluate reclamation impacts by monitoring effects of cave passage manipulations' on internal microclimates. The investigators placed temperature data loggers in 3 specific locations along the mine length regardless of roosting locations. Martin et al. concluded that cave gates did not alter airflow, thus influencing internal conditions as previously suggested. This study found no changes in ambient and rock temperatures in the summer and only slightly altered winter conditions. Unfortunately, the gate design tested was not mentioned in this study therefore its role remains unclear with respect to the round bar type used in Utah.

In addressing similar questions, I use abandoned mines shown to serve as various roosting habitats based on observed bat sign. I submit that elucidation of the mine microclimatic response to reclamation can be made through monitoring roost temperatures and humidity levels based on the following assumptions: (1) bats are selecting specific locations within the mine workings based on temperature and humidity conditions; (2) ranges between maximum and minimum microclimate values influence roost selection; (3) mine microclimate changes reflect potential alteration to current roost ambient factors; and (4) individual species may respond differently to modification levels.

Methods

Study sites.- I collected internal mine microclimate data from 1 May to 30 October in 2003 and 2004 to encompass 2 reproductive seasons, pre-reclamation and post-reclamation, respectively. I installed 10 Onset HOBO® H8 data loggers (Onset Computer Corporation, Bourne, Me) within 10 study mines, 7 to remain unaltered across seasons and 3 to be gated. Three data loggers were installed in the "Cherry Creek" mining district (see Chapter I for area description) and 4 in "Vernon Sheeprocks" mining district (10 km west of Vernon, Utah in the Great Basin region, 2300 m elevation). Three additional loggers were placed in "Ophir" mining district (32 km southwest of Tooele Utah in the Great Basin region (MacMahon 1997) with mines between 2400 and 2700m in elevation) (see Figure 1). The Ophir and Vernon Sheeprocks mining district data loggers acted as "references" and were used to monitor conditions in the absence of reclamation as a comparison to manipulated mines. The data loggers were placed near bat roosting locations as indicated by bat sign or individuals observed during internal mine surveys. Monitored sites reflect similar mine structures to observed roosting areas.

Data collection.- I programmed data loggers to collect relative humidity, dew point (Td) and air temperature (T) at 2.5-hour intervals throughout the 2-year survey period. I then converted air temperature and dew point temperature into current vapor pressure and vapor pressure at saturation to obtain vapor pressure deficit for microclimate analysis. This allowed for more direct analysis of potential water loss from bats within the roost. Determination of vapor pressure deficits (VPD) involved a 3-step calculation using the following formulas and constants.

First, I calculated saturation vapor pressure (e):

$$e = 0.6108 * \text{exponent} [(17.27\ Td) / (Td + 237.3)] \quad (kPa).$$

Secondly, I calculated vapor pressure (es) using T:

$$es = 0.6108 * \text{exponent} [(17.27\ T) / (T + 237.3)] \quad (kPa)$$

Finally, I attained VPD by combining the values obtained above:

$$VPD = es - e \quad (kPa)$$

I evaluated reclamation effects on mine size and complexity by measuring characteristics before and after mine modification. The total number of known mine openings per complex was determined by internal mine surveys and tallied prior to reclamation. Portal height and width were measured at each opening to determine overall portal area, at all mines. Portal area alterations were categorized as "low," "medium," or "high" if overall area changed by $\leq 25\%$, 26-75%, or $\geq 76\%$, respectively. Total opening modifications were considered low if the original portal amount remained, medium if a single portal was closed and high if more than one opening was sealed.

Analysis.- Analysis of roost microclimatic data consisted of comparisons of the overall seasonal trend in average range of daily temperature and vapor pressure deficits collected under pre- and post-reclamation conditions. Because species distributions are likely limited by extreme values not averages, I evaluated maximum and minimum values between study mines and years to assess seasonal influences.

I compared the total range, difference between maximum and minimum values, in temperature and vapor pressure deficit values over 2 reproductive seasons. This allowed quantification of reclamation effect on the seasonal microclimatic fluctuation of within a roosting area. I measured the variability in reference mines over the same time period to quantify the effect of possible annual variation apart from reclamation. Student's t-tests were used to evaluate reclamation effects on mine microclimate within treatments, between treatments within year and between years.

Results

Three mines were reclaimed in 2004. The Cherry Creek HO Complex was closed with gates on all three of its openings beginning 5 August: HO4 on 1 September, VO9 on 16 and 17 August, and VO10 on 5 August. The Cherry Creek IO Complex had bat compatible gates placed on all 3 of its openings beginning 12 July: IO3 on 4 August, IO5 and VO6 on 21 July. Cherry Creek HO2, a single opening, was gated on 4 August. One data logger was stolen (Ophir I HO5) and two malfunctioned (Ophir I HO21 and Vernon Sheeprocks HO1) during the course of this study. The remaining seven mines remained open throughout the study (Table 9).

Reclamation.- Mine portal area changed through reclamation, although not equally. One treatment mine (Cherry Creek HO4, VO9 and VO10 Complex) showed a net increase of 518% in portal area (Table 10). The HO4 complex was modified during reclamation, the horizontal opening, HO4, decreased in area by 58%, vertical opening VO9 increased in portal area by 576% while VO10 showed no change (Table 10).

During the reclamation process, reclamation personnel unintentionally ignited a fire with a welding torch in the portal of Cherry Creek HO Complex VO9 opening. Before the fire, the portal was covered with wooden planks that housed a door in its center (Figure 5). It was also lined with juniper cribbing, or timber supports, along the shaft collar for at least 15 m. These wooden planks and cribbing fell into the vertical shaft and continued to smolder for several days. A BLM fire crew applied water to the smoldering timbers inside the shaft in an attempt to put out the fire. It is unclear whether this smoke or water reached the maternity roost within the workings. The remaining treatment mines (Cherry Creek HO2 and Cherry Creek IO Complex) showed no appreciable change in portal size thus any observed microclimate responses are assumed to be due to bat compatible closures. Treatment mines experienced no alterations to total number of openings. Reference mines experienced no modifications to overall portal area or number of openings during the study.

Microclimate.- Mine microclimates differed distinctly between treatment and reference mines following reclamation. Treatment mines displayed diverse temperature and vapor pressure deficit ranges in response to installation of bat compatible closures. The Cherry Creek HO Complex showed a pronounced increase in both temperature and vapor-pressure-deficit-range after reclamation, while the Cherry Creek IO complex experienced a slight decline (Figures 6 and 7). Conversely, Cherry Creek HO2 maintained a static range in temperature and vapor pressure deficit with no obvious changes detected after reclamation (Figure 8). The reference mines all showed constancy in the relationships between maximum and minimum temperature and a decline or stasis in vapor-pressure-deficit-range during these same periods (Figures 9 and 10). Overall mine microclimatic conditions did not vary between years. Weekly maximum and minimum temperature and vapor pressure deficits showed no statistical difference between years ($P = 0.540$). As a result, all observed changes in microclimate measures are likely due to reclamation.

A pronounced temperature spike of $\geq$ 10°C from background, and not associated with reclamation was noted in some but not all study mines. Two treatment mines (Cherry Creek HO Complex and Cherry Creek IO Complex) and the two reference mines (Vernon Sheeprocks HO21 Complex and Ophir HO16 Complex) each experienced a dramatic spike in temperature occurred on 18 August, 2004 at 1400 hours. These mines are approximately 48 to 160 km apart and range from 2300 to 2600 m in elevation. This pronounced temperature spike was observed only in mines with multiple openings.

Discussion

Mine microclimates responded differently depending on complexity (number of openings). Microclimatic parameters in mines with multiple openings showed a response to reclamation while those with a single opening did not. This was also apparent with the pronounced temperature spike, not associated with reclamation, recorded only in mine complexes at varying elevation and distances. Internal mine microclimate responses differed widely in trend and magnitude between complexes. This suggests that management efforts must be tailored to individual mines somewhat independently. Those mines possessing more than one opening should maintain original portal size and overall openings when at all possible. Additionally, the array of gated openings should attempt to preserve airflow specifically retaining portals at varying heights on the landscape to encourage air movement between them.

The Cherry Creek HO Complex experienced major portal modification wrought by fire, typically rare in reclamation processes. This Complex showed a clear increase in range of both temperature and vapor pressure deficit, while the range in IO Complex range declined moderately. The change observed in the HO Complex may be attributed to the net increase in overall portal area resulting from reclamation. Its horizontal portal dimensions decreased by 58%, but its vertical opening increased by 576%. Additionally, the Cherry Creek HO Complex's vertical shaft was once lined for 15 m with wooden timbers placed for stabilization that was removed by fire. As a result, wall surface of this shaft changed from irregular logs to a relatively smooth rock surface. Consequently, it may have altered airflow into mine workings thus changing its ability to take in air through the complex of horizontal and vertical workings. The installation of bat compatible closures may also have interrupted airflow within the workings though the extent of which is difficult to determine due to the large change in portal area.

The Cherry Creek IO Complex showed slightly different patterns in response to reclamation with a slight decline in range of temperature and vapor pressure deficit following gate installation. No net change in portal area or number of openings occurred in this complex and the response therefore it is likely due to gate installation. In this case, the gate may be acting as a buffer to the IO Complex.

The microclimate in the simple Cherry Creek HO2 mine, experiencing no portal area change, did not respond to reclamation like the mine complexes. Range in microclimate remained static in both temperature and vapor pressure deficit after reclamation and between survey years. This simple mine's range in temperature reflects the same stable pattern observed in the reference mines. The range in vapor pressure deficit also remained constant between years and reclamation conditions. This suggests that the installation of bat compatible closures had little affect on mines with single openings.

Continuous readings were applied in this study, but greater spatial sampling along entire mine workings would provide insight into the conditions within the entire complex. It is clear that reclamation alters internal microclimate within mine complexes, but this impact may not be uniformly manifested through the entire workings. Data loggers were placed as near as possible bat activity but not within actual roost locations to minimize disturbance to bats. Mines comprise numerous internal structures and shapes that are likely to respond individually to reclamation. Air moving over rough surfaces is more turbulent than that on smooth surfaces. Overhead stopes and domed pockets are likely to experience unique microclimate responses in contrast to those on exposed flattened surfaces because they trap air and heat. The layout of internal workings, specifically straight vs. curving and/or narrow vs. wide tunnels, also affects microclimatic conditions. Bat compatible gates may change airflow into the workings by interrupting air movement. These microclimate measurements reflect one point on a continuum, but indicate that internal mine workings do respond to alteration to opening changes. Sherwin et al. (2000) recommended that microclimatic measurements should incorporate continuous readings within a complex to provide an accurate evaluation of roost conditions.

The bat compatible closure may alter air movement into or out of mine workings because it forms a "barrier" in each portal that may respond uniquely to seasonal conditions. Fast moving warm air may be blocked or further slowed through increased turbulence brought about by the gate obstruction thus reducing the amount traveling through the workings. Slow moving cold air may be minimally impacted by a gate since it retains the ability to creep through regardless of impedance. Colder air is heavier as it becomes dense while warm air is lighter and rises. These differences in air density may impact roost types uniquely when exposed to reclamation as air movement may respond uniquely to the gate barrier.

Hibernacula.- Reclamation effects on the hibernation environment remain unclear, because they were not measured under post-reclamation condition. Studies suggest that hibernacula microclimates may be affected by reclamation. A study of the endangered Indiana bat (*Myotis sodalis*) by Richter et al. (1993) showed increases in roosting bat numbers after the removal of a block wall near the cave opening. These researchers argued that the wall insulated roost temperatures from external temperatures. The study, while not directly measuring the original condition or humidity levels, suggests that hibernacula might be affected by portal modification.

This concept is further emphasized by Martin et al.'s (2006) study of an unspecified gate design affect on temperature and airflow. They observed temperatures responding in colder conditions but showed no change in warm situations. These investigators suggest the biological implications of the detected winter microclimate modification through gating are minimal. Their study did not address humidity issues that may react differently in colder conditions.

Fluctuations in air temperature and vapor pressure deficit will likely impact hibernating bats because they remain in the roost for extended periods. In the absence of insect prey, bats rely on stored fat reserves through winter (Humphrey and Kunz 1976, Adams 2003). Townsend's big-eared bats loose 55% in body weight during hibernation while other species loose only 25% winter (Humphrey and Kunz 1976, Adams 2003). Accordingly, the subject of reclamation affects on hibernacula microclimates merits further investigation to determine possible differences between impacts at hibernacula and warm season roosts.

Potential mitigation measures.- Bats select specific roost structures that provide suitable microclimatic conditions (Humphrey and Kunz 1976, Bell et al. 1986, Kerth et al. 2001, Adams 2003) varying with roost type and seasonality. Often roost features are selected that allow them to modify microclimatic conditions with their own body heat (Humphrey 1975, Sherwin et al. 2000). This ability may allow bats to cope with minor changes in microclimate that occur through reclamation. Maternity colonies are routinely found in stoped areas that form pockets to trap metabolic heat. Bats roosting within these pockets modify microclimatic conditions simply by exhaling air and radiating body heat (Humphrey 1975). Hibernating bats are typically found in colder areas to minimize energy output during torpor (Adams 2003). While reclamation has been shown to alter internal conditions inside portions of mine workings, bats have the ability to select suitable conditions within which may mitigate minor modifications as seen in Cherry Creek IO Complex.

An alternative energy conservation strategy with fewer reproductive consequences may be that of tracking barometric pressure from within the roost to evaluate prey availability. A study of the Eastern Pipistrelle (*Pipistrellus subflavus*) by Paige (1995) indicated that bats may use barometric pressure to evaluate prey availability during roosting, thereby reducing flight time dedicated to assessing prey numbers. The researchers proposed that bats can reduce reliance on daily torpor by predicting insect levels with lower energy out put. Daily torpor use and possibility of tracking prey structure from within the roosts demonstrate bat ability to manage energetic output during critical periods some of which may mitigate minor or moderate reclamation effects.

Bats may counteract increased energetic demands caused by potential reclamation microclimatic modification through various means. Many species enter daily torpor as a means of reducing energetic output during demanding periods. Microclimates within mine workings have now been shown to respond to reclamation techniques, at least in instrumented portions. Individuals decrease body temperatures in relation to surrounding conditions when possible to lessen metabolic energy needed to maintain higher body temperatures (Grinevitch et al. 1995, Adams 2003). Maternity colonies require relatively high temperatures within the roost to accelerate development of young (Humphrey and Kunz 1976, Kunz 1982, Grinevitch et al. 1995, Adams 2003). Some investigators have suggested that the short-term benefits of daily torpor use for reproductive females may be outweighed by long-term fitness costs with extended gestation and slowing of neonatal development (Grinevitch et al. 1995). As a result, daily torpor use will likely be applied only in extreme cases by reproductive females therefore its role in reclamation mitigation is debatable.

Management Implications

Bat compatible closures serve a dual role in management namely: (1) protection of roosting bats and (2) providing public safety by restricting entry into hazardous abandoned mines. The role of mine reclamations influence on roosting microclimates remains vague but it is clear that it can impact internal conditions, at least in areas, with major portal modification. Clearly, gate installation in simple mine workings appears to have little impact on potential roosting areas within. Conversely, complex mines respond variously to reclamation thus its impacts are unique to each mine. Reclamation has been shown to influence fluctuation in summer microclimate within mine complexes, and studies suggest hibernation habitat may also respond, at least in the case of block wall removal and slight temperature changes with gate installation.

Management efforts must reduce changes to existing conditions because mines have shown a response to reclamation. When closing portals, those mines possessing more than one opening should maintain original portal size and overall openings when at all possible. Additionally, the array of gated openings should attempt to preserve airflow specifically retaining portals at varying heights on the landscape to encourage air movement between them. Simple mines with one opening require less caution since internal microclimatic conditions remain stable due to lack of air movement shown to respond.

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Table 9. Descriptive characteristics of mines used in microclimate analysis.

Mine	Number of openings	Elevation (meters)	Portal height (meters)	Portal width (meters)	Mine depth (meters)	Depth of data logger (meters)	Nearest bat sign	Aspect
Cherry Creek HO002	1	2300	1.4	1.2	30.5+	30.5	bat	E
Cherry Creek HO004 Complex	3	2300	0.6	1.2	15.3+	13.7	guano	W
Cherry Creek IO005 Complex	3	2300	0.9	4.3	9.1+	9.1	guano	W
Vernon Sheeprocks HO002	1	2300	2.1	2.4	38.1+	36.6	bat	W
Vernon Sheeprocks HO003	1	2300	1.8	1.5	61+	45.9	insect parts	N
Vernon Sheeprocks HO021 Complex	4	2300	1.5	2.4	15.3+	7.6	guano	W
Ophir HO016 Complex	2+	2600	2.1	1.2	70.1+	30.5	guano	NW

Table 9. Continued.

Mine	Reclamation date	Surrounding vegetation	Known roosting acitivty	Bat species observed
Cherry Creek HO002	8/4/2004	*Artemisia* spp	Hibernaculum, day and night	*Corynorhinus townsendii, Myotis ciliolabrum*
Cherry Creek HO Complex	9/1/2004	*Artemisia* spp and *Juniperus* spp	Maternity	*Corynorhinus townsendii*
Cherry Creek IO Complex	7/21/2004	*Artemisia* spp and *Juniperus* spp	Maternity	*Corynorhinus townsendii*
Vernon Sheeprocks HO002	None	Mountain brush	Hibernaculum	*Corynorhinus townsendii*
Vernon Sheeprocks HO003	None	Mixed conifer forest	Night	*Myotis volans, M. evotis, M. ciliolabrum*
Vernon Sheeprocks HO Complex	None	Mountain brush	Maternity	*Myotis volans*
Ophir HO016 Complex	None	Mixed conifer and *Artemisia* spp	Maternity	*Myoris volans*

Table 10. Portal area (m^2) of mines serving as Townsend's big-eared bat maternity colonies before and after reclamation. Reference mines remained untouched during study.

Mine	**Portal Area**		
Treatment	**Pre-reclamation**	**Post-reclamation**	**Change (%)**
Cherry Creek HO2	1.7	1.7	0
Cherry Creek HO4 Complex	2.4	1.4	-58
VO9	4.3	24.8	576
VO10	8.9	8.9	0
Cherry Creek IO5 Complex	3.9	3.9	0
IO3	1.9	1.9	0
IO4	1.9	1.9	0
Reference			
Vernon Sheeprocks HO2	5.2	N/A	N/A
Vernon Sheeprocks HO3	2.8	N/A	N/A
Vernon Sheeprocks HO21 Complex	3.7	N/A	N/A
HO2	2.3	N/A	N/A
VO1	9.7	N/A	N/A
Ophir HO16	2.6	N/A	N/A

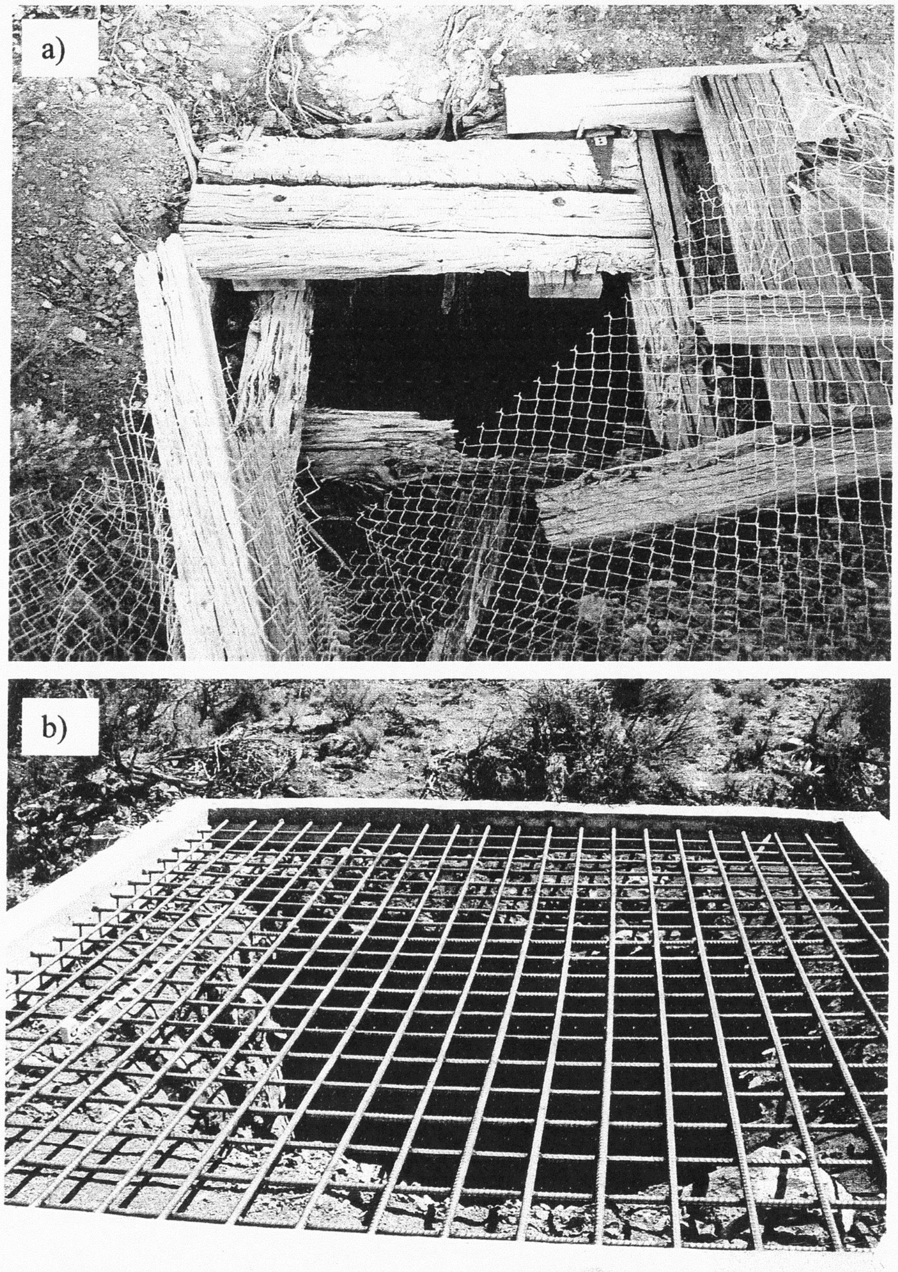
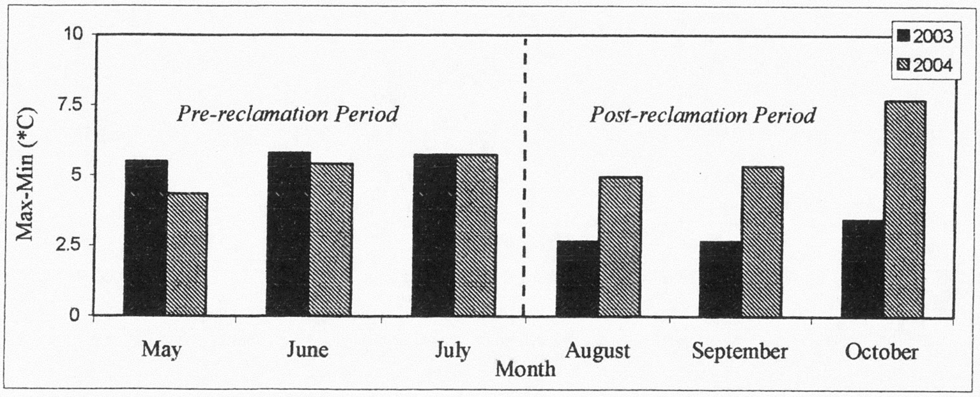


Figure 5. Images of Cherry Creek HO Complex VO09 opening before reclamation (a) and after gate installation (b). Unintentional fire set by a welding torch increased portal area from 2.4 m^2 to 24.8 m^2.



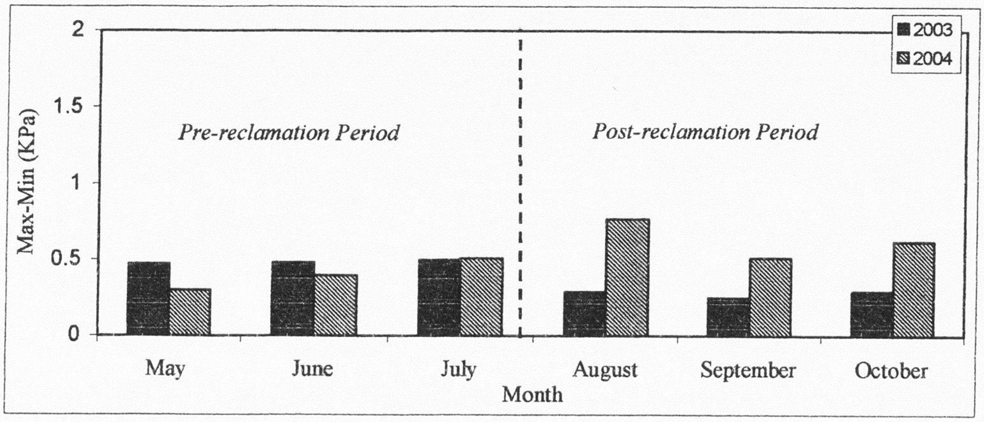


Figure 6. Range in mine temperature (°C) (top) and vapor pressure deficit (kPa) (bottom) in Cherry Creek HO Complex. Gates were installed 5, 17 August and 1 September 2004.

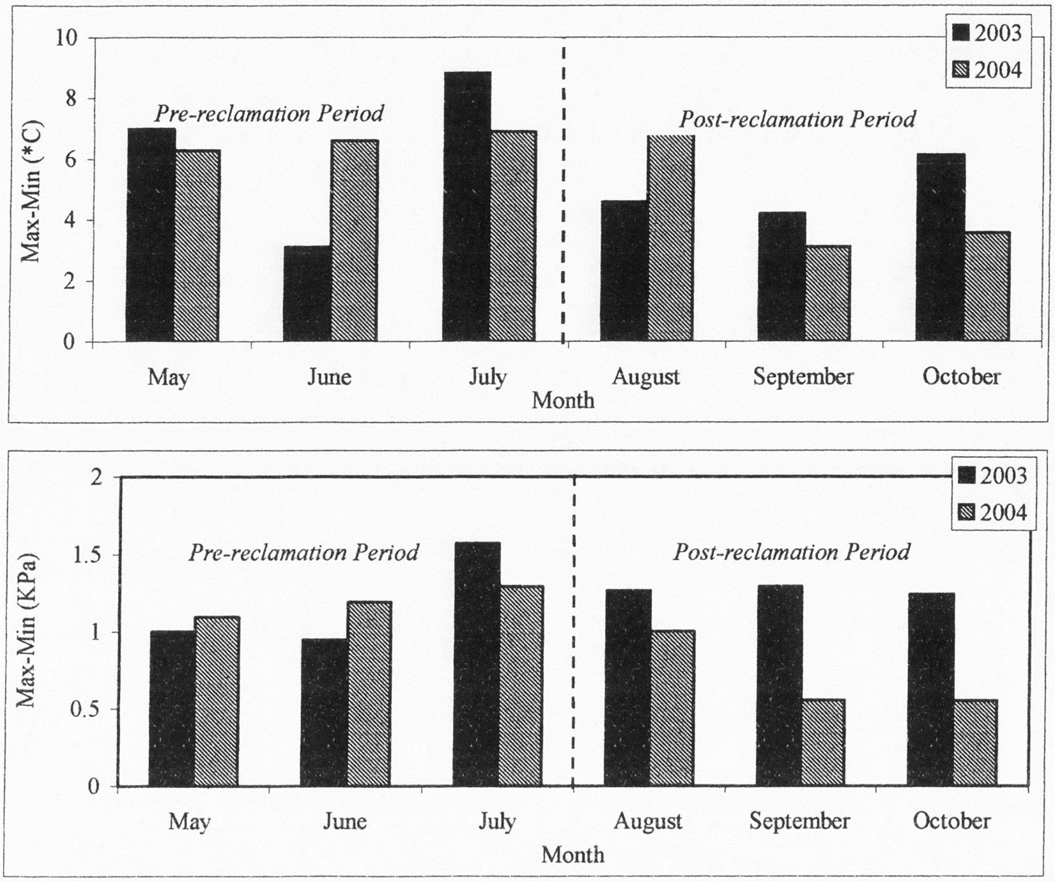
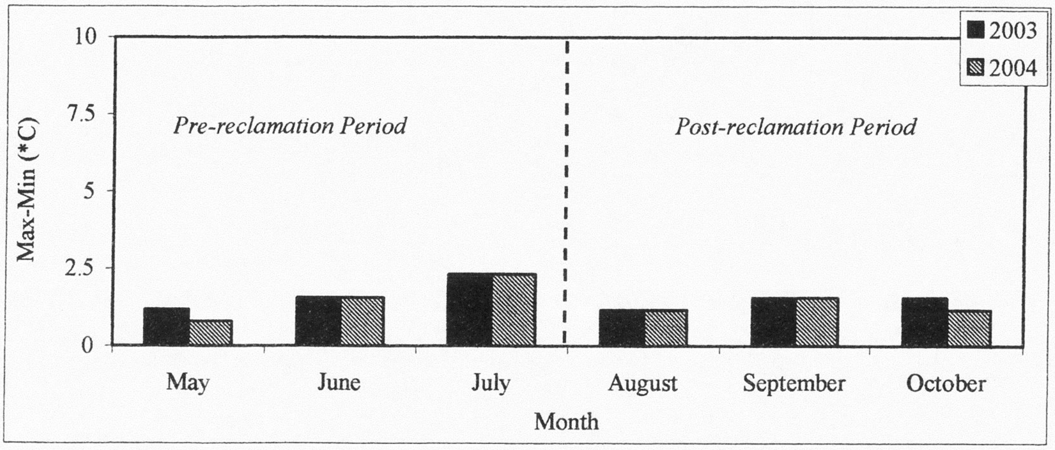


Figure 7. Range in mine temperature (°C) (top) and vapor pressure deficit (kPa) (bottom) in Cherry Creek IO Complex. Gates were installed 21 July and 4 August 2004.



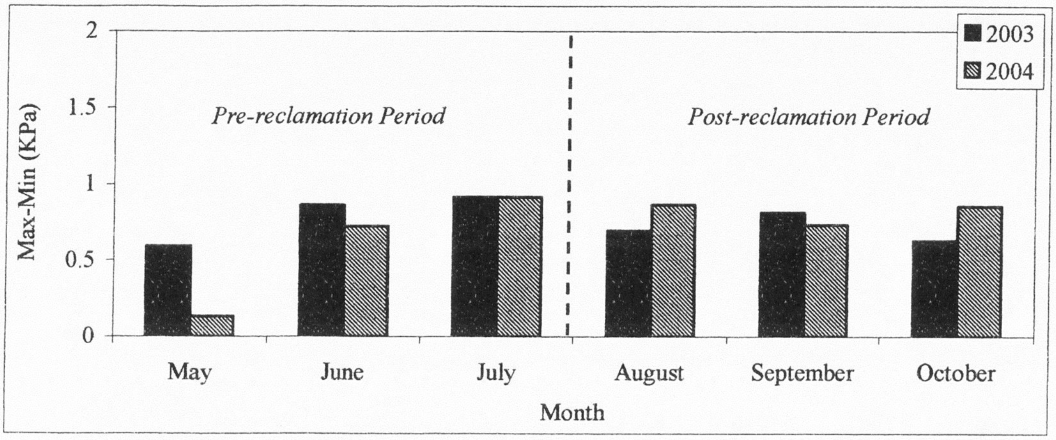


Figure 8. Range in mine temperature (°C) (top) and vapor pressure deficit (kPa) (bottom) in Cherry Creek HO2. Gate was installed 4 August 2004.

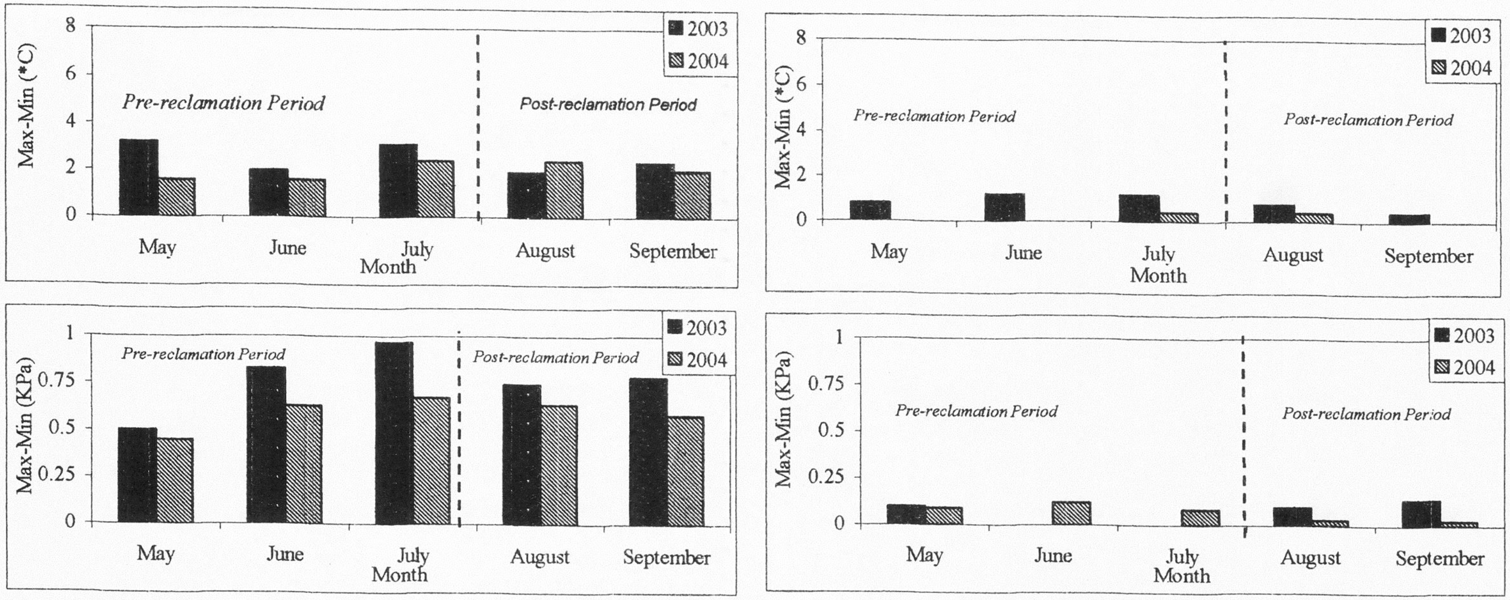


Figure 9. Range in mine temperature (°C) (top) and vapor pressure deficit (kPa) (bottom) in reference mines Vernon Sheeprocks HO2 (left) and HO3 (right). No gates were installed during study.

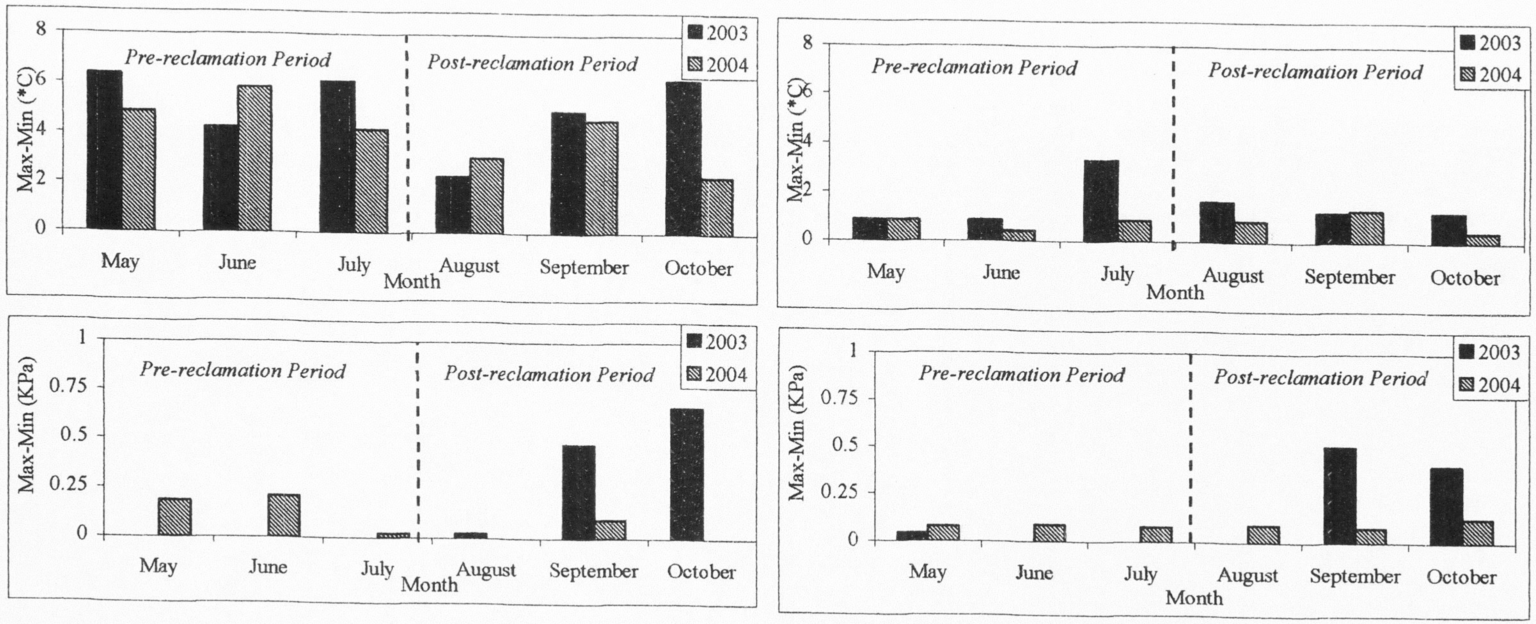


Figure 10. Range in mine temperature (°C) (top) and vapor pressure deficit (kPa)(bottom) in reference mines Vernon Sheeprocks HO21 (left) and Ophir HO16 (right). No gates were installed during study.

CHAPTER IV

CONCLUSION

This study demonstrated behavioral responses of Townsend's big-eared bats to mine reclamation as indicated by increased activity around the mine portal. The amount of circling behavior increased at least 6-fold as bats negotiated bat compatible gates. Bat collisions also rose after reclamation. The long-term impact of this increased activity remains debatable. Predation potential may also increase post-gating, but was not measured specifically. Regardless of behavioral alterations, imposed by reclamation, Townsend's big-eared bats continued using these abandoned mines as maternity roosts.

Mine microclimates, specifically ranges between maxima to minima of temperature and vapor pressure deficits, also changed in response to reclamation especially in cases with pronounced increases in portal size. The variability in range fluctuations was amplified after an increase in overall mine portal area and appeared to be a function of mine complexity. Mines with single opening showed no response to gate installation, while substantial fluctuations in complexes with multiple openings were observed. However, larger workings likely provide alternative structures that bats may use to modify their environments, thereby allowing partial mitigation of reclamation impacts on internal microclimate conditions.

Only one gate design was evaluated in this study, whereas several types and variations are being used worldwide. A study by White and Seginak (1987) comparing major gate types indicated highest use through round bar gates in contrast to angle-iron or funnel type gate designs. Big-eared bats were shown to prefer round bar designs over others suggesting a species-specific response to closures. The round bar gate design employed in Utah incorporates characteristics that facilitate bat movement, specifically greater spacing between bars near the top third of the gate. I observed Townsend's big-eared bats exiting and entering through the top half most frequently (85-100%). It is unknown if this top half preference is species specific and future studies should evaluate this phenomenon to further improve bat compatible gates.

Future studies must assess the effects each gate design has on behavioral responses to determine which one produces fewest impacts to roosting bats. Bat compatible gates are an effective tool for protecting the public from the hazards associated with abandoned mines but must be implemented with caution because the extent of their impacts on roosting bats remains largely unknown. It may be necessary to test gates with varying design to address issues of crowding pressure and complexities of navigation. A typical design used is the "angle iron" style constructed of 6–7 cm wide flattened steel strips welded at 90-degree angles. Assuming circling is a response of echolocation bounce from gate bars, this behavior may increase more dramatically with other gate designs. Angle iron bars will likely focus echolocation waves up as it hits the angled bars while round rails may diffuse them in all directions.

Future mine closures should minimize alteration to portal area to maintain historical roost conditions. The angle-iron design has the potential alter air movement to a greater extent. The modest effects of round bar gates on microclimates found in this study may be the same as with the angle-iron construction. To improve reclamation, further research is needed to evaluate microclimatic response on both the large scale, closure of one or more portals within a complex, and on the small scale, measurement of several locations within the mine workings.

Although this study suggests that reclamation may negatively impact targeted populations, these impacts may be outweighed by positive effects such as prevention of roost disturbance to breeding females. The extent of reclamation influences on roosting colonies may vary with location and human disturbance levels thus evaluation on a broader scale is essential to understanding its impacts.

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